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Ionized and Molecular Gas in IC 860: Evidence for an Outflow
Carson Adams
Mentors: Katherine Alatalo and Anne M. Medling

Galaxies at present-day fall predominantly in two distinct populations, as either blue, star-forming spirals or red, quiescent early-type galaxies. Blue galaxies appear to evolve onto the red sequence as star formation is quenched. The absence of a significant population falling in the intermediate 'green valley' implies that these transitions must occur rapidly. Identifying the initial properties of and pathways taken by these 'dying galaxies' is essential to building a complete understanding of galactic evolution. In this work, we investigate these phenomena in action within IC 860 — a nearby, early-type spiral in the initial stages of undergoing a rapid transition in the presence of a powerful AGN-driven molecular outflow. As a shocked, post-starburst galaxy with an intermediate-age stellar population which lies on the blue end of the green valley, IC 860 provides a window into the early stages of galaxy transition and AGN feedback. We present Hubble Space Telescope imaging of IC 860 showing a violent, dusty outflow originating from a compact core. We find that the mean velocity map of the CO(1-0) from CARMA suggests a dynamically excited bar funneling molecular gas into the galactic center. Finally, we present kinematic maps of ionized gas emission lines as well as sodium D absorption tracing neutral winds obtained by the Wide-Field Spectrograph.

Moving Mass and Mechanical Clutch Mechanisms for One-Dimensional Hopping Robots
Sara Adams
Mentors: Aaron Ames and Eric Ambrose

There are a number of potential mechanisms to create a hopping motion in robots, but not many are energy efficient. By developing energy efficient mechanisms for hopping robots, we allow future robots to have more flexibility doing work in the field, as they can be powered by batteries rather than a tether to an external power supply. Using a spring for hopping allows us to take advantage of restorative spring forces, but deformation and friction still cause energy losses that necessitate the use of an actuator to maintain a consistent hop height. Thus, we compared the functionality and efficiency of a moving mass mechanism and a mechanical clutch for compressing the hopper's spring in order to maintain a hop height of six feet.

Use of Antibiotics as Synthetic Modules for Regulating Bacterial Growth
Swati Agrawal
Mentors: Richard Murray and Reed McCardell

The intricate network of interdependencies driving the operation of biological ecosystems yields capabilities which are largely realised through coordinated community behaviour. It is some of these competitive interactions that we wish to investigate using synthetic growth regulators such as secreted antibiotics and quorum sensing modules. We conducted experiments to assess the dynamic range and kinetics with which antibiotics inhibit cell growth and how tetracyclin (aTC) inducible resistance genes subvert the effects of this toxicity. In an antibiotic gradient experiment with cells lacking resistance genes, the cells showed, albeit with varying profiles depending upon the antibiotic used, complete inhibition of growth on a 24-hour time scale. To explore the phenomenon of rescue, cells transformed with inducible resistance were incubated with a constant antibiotic concentration and an increasing gradient of aTC (0 – 200 ng/µL) was applied. This was performed with a series of antibiotic concentrations. Results indicated that these potentially resistant cells apart from responding to the rescue operation at appreciable aTC levels surprisingly escaped growth arrest even without induction. As the copy number of the plasmid carrying the resistance gene grew larger, effects of this escape became more pronounced and were noticed in antibiotic concentrations as high as 300%. From these observations, we hypothesised the existence of a basal level of resistance accruing from leak of expression from our plasmid compounded by the effect of copy number. In another setup, a pulsed addition of aTC over a time interval of 24 hours to cells already incubated with a constant antibiotic concentration was also successful in reviving cell growth. The antibiotics used in this study were Carbenicilin, Chloramphenicol and Kanamycin, and DH5αZ1 cells provided the cellular chassis.

Probing the Dynamics of SGTA/2, a Chaperone Protein Involved in Membrane Insertion of Tail-Anchored Proteins
Rita Aksenfeld
Mentors: William Clemons and Michelle Fry

The chaperone protein SGTA (and its archaeal homolog, Sgt2) dimer is an integral part of the guided entry of tail anchored proteins (GET) pathway that protects the transmembrane domain of tail-anchored (TA) proteins from the aqueous cellular environment. While it is known that the C-terminal domain of SGTA is the binding site for TA proteins, a structure of this region has not been obtained. Based on data previously collected in the Clemons group, we hypothesize that the C-terminal domain of SGTA has a disordered structure that becomes ordered upon binding. To demonstrate this, a construct containing the C-domain of SGTA was created and expressed in E. coli The SGTA C-domain was purified by nickel column and size exclusion chromatography, and mass spectrometry will be used to confirm its presence. This will be repeated in the presence of TA protein so that a complex forms. We will perform ^{1}H - ^{15}N HSQC NMR spectroscopy to measure the relative disorder of SGTA alone and in complex with a TA protein. If that yields inconclusive results, differential scanning calorimetry will be performed to measure the difference in enthalpy between SGTA alone and in complex with a TA protein.

Inducing Habits in Humans Through Overtraining
Mladena Aleksic
Mentors: John P. O'Doherty and Eva R. Pool

In contrast to goal-directed behaviors, which are driven by the representation of their consequences, habits are outcome insensitive behaviors elicited solely by situational cues. This study aims at inducing habits in humans during a free operant task through an overtraining procedure. Sixty participants pressed keys to accumulate food outcomes during the presentation of outcome-associated stimuli. The task was administered to two groups: one group was trained moderately whereas the other group was trained extensively (i.e., six times more). Following the training, both groups underwent a devaluation procedure, in which the outcome value was reduced through selective satiation. The pressing frequency before and after the devaluation procedure was measured to reflect behavioral sensitivity to the outcome value and compared between the two groups. We expect the moderately trained group to flexibly adapt their behavior to the outcome value by diminishing key pressing for the devalued outcome after satiation; and we expect a reduction of this behavioral sensitivity to outcome value in the overtrained group. This study will enable us to determine the extent to which an overtraining procedure can induce habitual behavior in humans.

Integrating and Testing Simulations Designed for the Dark Energy Spectroscopic Instrument
Thomas Alford
Mentors: Klaus Honscheid and Tim Eifler

The DESI (Dark Energy Spectroscopic Instrument) project is an endeavor to measure dark energy and its effect upon the expanding universe. DESI mainly looks at baryonic acoustic oscillations and redshift-space distortions and uses these to measure the effect of dark energy on the universe. DESI is scheduled to begin measurements in 2018 at the Mayall 4-meter telescope at Kitt Peak National Observatory.

The DESI control system ensures that DESI aligns itself correctly after each image it receives from the telescope in preparation for the next. My project focused on creating simulations of images for the control system. Initially, these image simulations were simple NumPy arrays filled with random values. I created a program that simulated actual images of stars, donuts (out of focus images of stars), and spectra, which I then integrated with the rest of the code running the control system. This control code can then be tested with the simulations to ensure that each part of the system runs smoothly before it takes real data in 2018.

Approximating Feedback Vertex Sets in Tournaments
Ayya Alieva
Mentors: Virginia Williams and Adam Sheffer

The Feedback Vertex Set problem is a well-known problem in discrete mathematics. In a directed graph, a feedback vertex set is a subset of vertices S such that the graph obtained by removing S has no directed cycles. The problem of finding a polynomial-time algorithm for extracting a minimum feedback vertex set from a graph is called the Feedback Vertex Set (FVS) problem. It is one of Karp's 21 NP-complete problems. A graph T=(V,E) is a tournament graph if it is a complete directed graph (such that for any two vertices v, u in V, there is exactly one edge either from u to v or from v to u). The FVS problem remains NP-complete in such graphs. In 2016, Matthias Mnich, Virginia Vassilevska Williams, and Laszlo A. Vegh showed a 7/3 approximation algorithm for the Feedback Vertex Set problem generalized to allow for nonnegative vertex weights. This was an improvement on the previously known 5/2 ratio. My research concerns the above problem. If successful, my research will lead to a (2+epsilon)-approximation algorithm for all epsilon > 0, which is optimal under the Unique Games Conjecture.

Robust Control Synthesis From Temporal Logic Specifications
Rijad Alisic
Mentors: Richard M. Murray and Sumanth Dathathri

Synthesizing correct-by-construction policies from a given Temporal Logic Specification for an autonomous system requires knowledge of the high-level environment behavior. These synthesis algorithms often produce only one policy out of a set of possible ones, without a way of comparing them to each other. By bringing this framework out into the physical world one would need to consider noise and unpredictability as well. The impact of these uncertainties could be dealt with by identifying abstractions that could improve the robustness of control policies during the synthesis or by identifying which policies will be less affected by them. This project focuses on solving and implementing an autonomous valet car parking problem using high-level policies synthesized from Linear

Temporal Logic for various settings of dynamical behavior from the environment. These policies are carried out by subsequent lower level controllers in a F1/10 car that only receive a goal position and orientation and can move safely between the allowed states. Uncertainties in sensing and the environment behavior enter this experimental test bed in a similar fashion as it would if a full-scale car was used.

Bioabsorbable Vascular Scaffold Stent Strut Detection in Intracoronary Optical Coherence Tomography Images
Junedh M. Amrute
Mentors: Elazer Edelman and Antonio Rangel

Bioabsorbable vascular scaffolds (BVS) are the next step in the continuum of minimally invasive vascular interventions and present both new opportunities and challenges for patients and clinicians. They consist of polymeric materials and many standard intracoronary imaging methods, such as intravascular ultrasound imaging (IVUS) fail to efficiently depict them. On the contrary, optical coherence tomography (OCT) is a light-based intracoronary imaging technique which provides high resolution cross-sectional images of plaque, luminal morphology, and implanted BVS stents struts. Until recently segmentation and measurements of OCT images for BVS struts was performed manually by experts. However, this process is laborious and not tractable for large amounts of patient data. Given this current limitation coupled with the emerging popularity of the BVS technology, it is crucial to develop an automated methodology to segment BVS struts in OCT images. The objective of this paper is to develop a novel BVS strut detection method in intracoronary OCT images. The proposed method consists of the following steps: first, the image is pre-processed and imaging artifacts are removed, then K-means algorithm is applied and the image is automatically segmented. Finally, the silhouettes of stent struts are extracted from the rest of the image. The accuracy of the proposed method was evaluated using expert estimations on 1140 annotated images acquired from 15 patients at the time of coronary arterial interventions. Our proposed methodology has a positive predictive value of 0.93, a Pearson Correlation coefficient of 0.88, and a F1 score of 0.90 for BVS stent strut detection. The proposed methodology allows for accurate, rapid and fully automated segmentation of the BVS stent struts and lumen outline in OCT images.

The Fraïssé Limit of Finite Dimensional Matrix Algebras With the Rank Metric
Aaron Anderson
Mentor: Martino Lupini

We show that a certain ring, constructed by von Neumann and realized as the coordinatization of a continuous geometry, can also be realized as the metric Fraïssé limit of the class of finite-dimensional matrix algebras over a field of scalars, equipped with the rank metric. We show that the automorphism group of this metric structure is extremely amenable, implying (by the metric Kechris-Pestov-Todorcevic correspondence) an approximate Ramsey Property, which is also proved directly.

Characterization of Multiferroic Thin Films Produced With Molecular Beam Epitaxy
Margaret Anderson
Mentors: Darrell Schlom, Rachel Steinhardt, and Katherine Faber

Magnetoelectric multiferroic thin films exhibit coupled ferromagnetism and ferroelectricity. Interest in these multiferroics stems from their potential applications in spin-based computing and novel information storage methods. Through characterization with x-ray diffraction (XRD), atomic force microscopy (AFM), and vibrating sample magnetometry (VSM); the growth of multiferroic films with Molecular Beam Epitaxy (MBE) was optimized. Both strain-coupled FeGa composites and rare earth ferrite superlattices were studied. Additionally, this study searched for compatible bottom electrodes that facilitate the measurement of the ferroelectric properties of the films. Because the electrodes are necessarily located between the substrate and the film, all three must have compatible lattice parameters in order to grow successfully with MBE. Characterization of the electrodes with XRD omega rocking curves and AFM revealed that PIN-PMN-PT produced slightly better Iridium electrodes and FeGa films than PMN-PT.

NSmase2 Is Required for Neural Crest Cell Migration
Cecelia Andrews
Mentors: Marianne Bronner and Michael Piacentino

The neural crest (NC) is a group of multipotent cells that develop to form much of the peripheral nervous system, melanocytes, and the craniofacial skeleton. In order to perform their proper function, NC cells must migrate extensively throughout the embryo to reach their final destination in a process that requires extensive membrane lipid regulation. One such metabolic pathway required for cell migration and differentiation in immune cells is the production of ceramide from sphingomyelin by neutral sphingomyelinase (NSmase) enzymes. Previous experiments have shown that the gene encoding NSmase2 is enriched in the migrating cranial neural crest, suggesting that NSmase2 and thereby ceramide production plays an important role in NC cell migration. We examined the role of NSmase2 through gain- and loss-of-function experiments. We performed gain-of-function analysis using an overexpression vector containing a strong promoter, the SMPD3 gene, and an H2B-RFP reporter. We electroporated

Hamburger-Hamilton stage HH4 chicken embryos and allowed them to grow to HH10 to observe the migrating neural crest. We found that SMPD3 overexpression did not have an effect on NC migration, suggesting that endogenous NSmase2 levels are sufficient to cleave existing sphingomyelin and drive NC cells to their maximum migration potential. Additionally, we performed loss-of-function analysis by electroporation of a translation-blocking morpholino (MO). We found the loss of NSmase2 resulted in reduced cranial NC migration, suggesting that ceramide production promotes cranial NC cell migration. Finally, NSmase2 perturbation did not alter proliferation or cell survival. Together these results highlight the importance of NSmase2-mediated lipid metabolism in NC cell migration.

Investigating the Effects of Functionalized Nanoparticles on the Properties of Artificial Wood
Sarah Antilla
Mentors: Chiara Daraio and Eleftheria Roumeli

Artificial wood fabrication is an exciting new research field that is currently being pioneered in Prof. Daraio's group. Currently, the group has developed a method to fabricate artificial wood derived solely from undifferentiated plant cells, and significant progress has been achieved on incorporating nanoparticles in the plant cells in order to selectively tune the mechanical, electrical and thermal properties of the resulting composite material. With this project we have investigated how selected nanoparticles (cellulose, carboxylated nanotubes, halloysite nanoclay, and montmorillonite nanoclay) influence the mechanical and electrical performance of the composite artificial wood materials. Therefore, the nanofillers were mixed with the plant cells once they reached maturity. An alteration in the mixing method and the surface modifications of the nanofillers led to improved dispersion and adhesion between the synthetic nanoparticles and the plant cells. We are currently characterizing the mechancial and electrical properties of the produced composites. The tested samples have a conductivity ranging between 10^{-3} and 10^{-4} S/m, specific strengths of about 10^{-3} MPa m^3/kg, Young's modulus ranging between 100 and 300 MPa, and specific moduli of about 10^{-1} MPa m^3/kg.

Synaptically Targeting the Ligand of the Synthetic System TRACT, for Tracing Neuronal Connections
Deepshika Arasu
Mentors: Carlos Lois and Ting-Hao Huang

The synapse is a specialized type of cell-cell interaction that neuronal cells form which transmits information through brain circuits. We are focusing on the olfactory systems in the *Drosophila* brain which have Olfactory Sensory Neurons (OSNs) expressing the same olfactory receptor gene projecting their axons to a specific glomerulus in each antennal lobe, where the OSN axons form synapses with projection neuros (PNs) and local interneurons (LNs). A synthetic and genetically-encoded system, TRanscellular ACtivation of Transcription (TRACT) uses the Notch signalling pathway to monitor cell-cell contact. The interaction of ligand and receptor results in the proteolysis of the intracellular domain, which activates the expression of a marker in the receptor-cell. Here, the ligand and receptor are targeted to the pre-synaptic and post-synaptic sites of the contacting neurons respectively by fusing with different pre-synaptic and post synaptic markers. Here, we characterized three different pre-synaptic markers for the ligand (CD19), namely Syndecan (Sdc), Defective proboscis extension response-10 (Dpr 10) and Dpr-interacting protein γ (Dip γ). *Drosophila* adult brains were immunostained and confocal microscopy was performed to analyse the results.

Efficient Multiple Description Coding Using Sparse Linear Regression
Oliver Åstrand
Mentor: Michelle Effros

With standard network communication protocols, if a packet is lost in transmission it needs to be resent, and the data can only be reconstructed once every packet is received. This becomes tedious when a large portion of the packets are lost due to disturbances. A possible solution to this problem is Multiple Description Coding (MDC), where each of the packets ("descriptions") on their own allow the receiver to partially reconstruct the transmitted data. In this paper, we suggest the use of Sparse Linear Regression Codes (SPARC) as a way of creating an MDC. The SPARC naturally splits each codeword into multiple sections, and the encoder can then minimize the expected distortion for scenarios when different subsets of these sections are received. Since it is unknown to the encoder how many descriptions will be received, our code minimizes expected distortion with respect to the packet loss distribution. Further research is needed to establish its theoretical relationship with, and possible convergence to the rate-distortion function. Our simulations suggest that the proposed encoding algorithm achieves minimal distortion both when a large and a small portion of the descriptions are received.

SlipChip for Transcriptomics in Single *Salmonella typhimurium* Cells
Beatriz Atsavapranee
Mentors: Rustem Ismagilov and Dmitriy Zhukov

Currently, little is known about genome-wide, single-cell RNA expression levels and heterogeneity in bacteria. In this study, we combine innovative microfluidic technologies with new bioinformatics capabilities to study the transcriptomes of single bacterial cells. Specifically, we focus on analyzing the transcriptomes of *Salmonella* *typhimurium* cells. This biological model is an attractive choice for optimization and quantitative validation of the method because *Salmonella* is both clinically relevant and well-characterized. Individual *S. typhimurium* bacteria are known to be heterogeneous in the expression of SPI1 virulence genes, but it is not known how this heterogeneity relates to changes in RNA expression. We use several strains of *S. typhimurium* bacteria that have been engineered with SPI1-linked GFP reporters. With either imaging or flow cytometry, we use the GFP fluorescence to quantify the virulent and non-virulent sub-populations in a given *S. typhimurium* culture. This allows us to verify the ratios determined from transcriptome analysis and proceed to study expression patterns of specific genes. Once demonstrated on the *S. typhimurium* model, these capabilities will be invaluable to other scientific fields and enable us to answer fundamental questions about the physiology and behavior of bacteria, even in heterogeneous populations.

The Role of MicroRNAs in Modulating HIV Infection
Caroline Atyeo
Mentors: David Baltimore and Alok Joglekar

Cellular microRNAs (miRNAs) are a class of small, noncoding RNAs that regulate gene expression by binding to mRNA, resulting in the inhibition of the translation or the degradation of these mRNA. Recently, miRNAs have been found to play a vital role in antiviral defense, including defense against HIV infection. The miRNAs that influence HIV infection have not been studied comprehensively. In this project, we used a genetic approach to identify potential roles of miRNAs in modulating HIV infection. To study HIV infection, we engineered a replication competent HIV strain with two reporter genes: an extracellular myc tag driven by the HIV promoter and an extracellular V5 tag driven by a constitutive promoter. This reporter allows us to differentiate uninfected, productively infected, and latently infected cells. We also used a CRISPR/Cas9 library that is designed to target only miRNA genes to generate a library of miRNA-knockout cells. Using these two reagents, we identified several individual miRNAs that modulate HIV infection. These results are encouraging as they have the potential to uncover novel roles for miRNAs in HIV infection.

Neural Correlates of Interpersonal Interaction During Flow Experience
Mia Austria
Mentors: Shinsuke Shimojo and Mohammad Shehata

Flow is defined as the mental state of operation in which someone is completely immersed in a feeling of energized focus, full involvement, and enjoyment in the process of an activity. Flow is characterized by specific neural activation patterns, and content factors that contribute to flow's emergence include balance between ability and challenge; concentration; direct feedback of action results; clear goals; and control (Klasen et al., 2012). Moreover, intrinsic reward, loss of self-consciousness, distorted sense of time, and merging of action and awareness are also associated with flow. In this project, the goal is to show that the flow status is often facilitated by social interactions. We will enhance brain activity and flow experience in participants using beeps and by increasing interpersonal interaction. Currently, I am developing a code that calculates the neurofeedback of the interpersonal interactions using the phase locking value. In our particular experiment, participants play a game of O2Jam, and then they discuss goals and strategies. They play again, and their brain activity before and after the training session is compared using EEG. Regarding expected results and conclusions, because communication and familiarity positively relate to flow experience and subsequently influence performance in the game, we expect that increased interpersonal interaction between participants leads to more immersion in the game and thus enhanced flow experience.

Modelling the Magnetite-Based Transduction Hypothesis for a Radio Wave Detector in Migrating and Homing Animals for a Single Magnetite Crystal
Yovan Badal
Mentor: Joseph L. Kirschvink

Migratory and homing animals apparently become unable to use their biomagnetic compass when exposed to radiowave noise in the 0.2-9 MHz range. If true, this indicates the presence of a biophysical mechanism for the sensory transduction of such radio waves in biological cells. Kellenberger et al. (2016) have demonstrated the transduction of radio waves to acoustic waves at twice the carrier frequency in a suspension of magnetite crystals of the appropriate dimensions to be single-domain magnets. We hypothesize that such transduction could be occurring in biological magnetite in cells, allowing ultrasound-activated transmembrane ion channels such as those reported by Kubanek et al. (2016) to act as detectors for radiofrequency noise. We have constructed a variety of biophysical models that might account for this transduction by considering possible interaction mechanisms at the level of a single magnetite crystal. Further experimental work is needed to test these ideas.

The Realization Problem for Prism Manifolds II
William H. Ballinger
Mentor: Yi Ni

A prism manifold is a quotient of the three-sphere by the action of a central extension of a dihedral group. These form a two-parameter family indexed by coprime integers $p > 0$ and q. We determine which prism manifolds are the result of integer surgery on knots in the three-sphere when $q > p$, complementing our work from last summer on the case $q < 0$. We also restrict the possible results of surgery in the case $0 < q < p$. We approach the problem primarily using a lattice-theoretic technique developed by Greene in his work on this problem for lens spaces. This is based on joint work with Ty Ochse, Yi Ni, and Faramarz Vafaee.

Searching for Dark-Photon Production via Higgs-Boson Decay Using a Data-Scouting Trigger
Jamie Bamber
Mentor: Maria Spiropulu

A new model suggests the Higgs Boson could decay into a photon and a dark photon ($\bar{\gamma}$), the boson of a hidden dark-sector equivalent of electromagnetism, giving a single photon + MET signal at the CMS. I repeat the work of those authors by simulating the decay signal. I then investigate the feasibility of a data-scouting trigger to detect the dark photon, and look at the optimum decay channel and trigger settings to use. The signal is generated using a Standard Model $H \rightarrow \gamma\gamma$ file generated with MadGraph5, re-labeling the ID of one of the photons to an invisible particle, then completing the simulation using PYTHIA8 and Delphes. Comparable distributions to those the original study are obtained. Using all channels was found to give too low a signal/background ratio for detection. The VBF channel gives an even worse ratio. However the ZH channel shows promise, using cuts described in a previous paper the Z+gamma background is almost eliminated.

Tools for Visualization and Analysis of Behavioral and Neuroimaging Data
Ayan Bandyopadhyay
Mentors: Vinod Menon and Dean Mobbs

The objective of this project was to provide tools to supplement the Stanford MET study, which tested the effectiveness of in-person and tablet-based cognitive tutoring in increasing the brain plasticity of children with Mathematical Learning Disorders. I developed a web application to be used by experiment administrators to view the behavioral data of each student enrolled in the study as they complete a set of tablet tasks each week. This web application will be used to ensure that the students are completing their tasks, and to monitor changes in response time and accuracy in real-time. Furthermore I adapted a neuroimaging pipeline to the fMRI data in this study by incorporating a watershed skull-stripping workflow. By testing this adapted pipeline against existing pipelines, I determined the efficacy of watershed skull-stripping in improving fMRI preprocessing.

Generalizing the Infinitary Gowers' Theorem and the Carlson-Simpson Theorem
Sam Bardwell-Evans
Mentor: Martino Lupini

Ramsey theory deals with generalizations and analogues of Ramsey's Theorem: for any finite coloring of the set of k-element subsets of the natural numbers, there exists some infinite subset of the natural numbers such that all k-element subsets of that set have the same color. The Carlson-Simpson Theorem and Infinitary Gowers' Theorem are analogous: the former concerns finite colorings of partitions of the natural numbers and monochromatic coarsenings of partitions, and the latter concerns finite colorings of sets of finitely supported functions from the natural numbers to finite sets and monochromatic sets of finite sums of particular functions. In this project, we have worked towards finding a common generalization of these two theorems by representing partitions of the natural numbers with sequences of functions and considering a variant of the Infinitary Gowers' Theorem in which particular infinite sums of functions are monochromatic.

The Petrology and Geochemistry of Adak Island Plutonic Xenoliths: Implications for Crustal Differentiation in the Aleutian Island Arc
Mattison H. Barickman
Mentor: Claire Bucholz

Plutonic xenoliths from Adak Island (central Aleutian Island Arc) provide a rare opportunity to study the lower crust of an active island arc. Previous studies have documented in detail the petrologic and chemical characteristics of a handful of xenoliths – here, we expand these studies to a much larger xenolith suite from Adak Island. We investigate the suite's petrology & mineral chemistry to explore the full lithologic variation of the xenoliths and to lay the groundwork for future geochemical studies. The expanded sample suite is comprised of dunite, wehrlite, amphibole clinopyroxenite, amphibolite, & amphibole gabbro cumulates, similar to previously documented lithologies. Mg#s and modal abundances of different minerals obtained from EMPA suggest that dunites and wehrlites are most primitive, whereas amphibolites and amphibole gabbros are most evolved; however, scattered sample data also suggests that not all xenoliths come from the same batch of melt. Thermobarometry places dunite crystallization at 950-970ºC, 0.79-0.95 GPa, and +2.2-2.4 ΔQFM, indicating lower crustal, relatively oxidizing conditions. Plagioclase-amphibole thermometry for the amphibole gabbros suggest formation at 940-1000ºC. These updated constraints on chemistry & conditions of crystallization are in agreement with original interpretations that the xenoliths represent crystallization products of near primary magmas at the base of the Aleutian Arc crust.

Comparing Simulation and Experiment of a Soft, Planar Rolling Robot
Amarbold Batzorig
Mentors: Carmel Majidi and Michael Mello

Robots composed of compliant materials have the potential to operate in environments unfit for rigid robots: close human contact, confined spaces, and uneven terrain. However, new simulation tools are needed to account for the large deformations that "soft" robots undergo. Dr. Mohammad Khalid Jawed developed a simulation of a soft, planar rolling robot by using discrete elastic rod theory (DER). This simulation could significantly streamline the design and analysis of soft robots similar to the rolling robot. We investigated how well the DER simulation agrees with experiment by fabricating soft rolling robots. Although the two approaches qualitatively resemble each other in motion, the simulation idealizes features that do not hold in reality – planar motion, point ground contact, actuator elastic modulus, etc. Further improvements can be implemented in the simulation and the experimental design in order to quantitatively compare the two.

Optical and X-ray Observation of High-Energy Transients
Victor Baules
Mentors: Nobuyuki Kawai, Ryosuke Itoh, Taketoshi Yoshii, and Yoichi Yatsu

Black hole binary (BHB) systems are transients consisting of a black hole accretor and a donor star. BHBs occasionally undergo outbursts in which radiation from infalling matter increases radio and x-ray luminosity drastically, but they can also express variability in the quiescent state in the form of orphan optical flares. As most BHBs are located in crowded parts of the galaxy, acquiring accurate photometric data requires Point Spread Function (PSF) photometry, in which the PSF of the telescope system is approximated and used to resolve individual objects in an image. At the Kawai Laboratory, the iraf and pyraf programs were used in conjunction with python scripts to perform image reduction and extract photometric data from images of the BHB candidate MAXI J1836-194 taken by the MITSuME telescope in Akeno, Japan. Using this data, a light curve of the object was constructed which was used to search for an orphan optical flare. Thorough investigation of light curves of MAXI J1836-194 and similar objects will hopefully lead to increased understanding and more accurate models of BHBs and other x-ray transients.

Finding the Length Limit of DNA Charge Transport
Sebastian Bedoya
Mentors: Jacqueline K. Barton and Edmund C. M. Tse

DNA's structure allows for charge transport down its length, as the bases stack well allowing for conductivity. DNA repair proteins containing [4Fe4S] clusters take advantage of this capability in order to more efficiently scan the genome, as DNA lesions decrease the yield of charge transport through DNA. To improve our understanding of this model, we used EndoIII, an *E. coli* glycosylase, and different lengths of DNA to examine any significant change in a trend of proteins bound vs. length of DNA. We obtained these different lengths by restricting plasmids and by creating PCR products of desired lengths. Atomic force microscopy (AFM) was used to analyze samples of proteins mixed with DNA. A change in trend was observed at about 3880 base pairs, or about 1.3 μm, meaning this may be a limit for this capability of DNA. Further work will look at the effect of temperature and salt concentration on this critical length and will also look at the speed with which the charge is transported.

The Effect of Oncogenic APC Truncations on β-Catenin Levels
David M. Berger Maneiro
Mentor: Lea Goentoro

Adenomatous Polyposis Coli (APC) is a prominent tumor-suppressor gene involved in cell-cycle inhibition and WNT signaling. It has been well known for several years now that truncations in APC are highly correlated with colorectal cancer formation, especially in hotspots that remove β-Catenin binding sites and aid in destruction complex formation; over 60% of colorectal cancers present one of these truncations. Increased levels of β-Catenin have also been shown to increase the risk of colorectal cancer, indicating a close interplay between APC and β-Catenin in oncogenesis. We induced some of these truncations in APC to quantify how they change β-Catenin levels from the normal in an effort to better understand β-Catenin signaling changes in these cancers.

Tight-Binding Simulations of Nano-Devices Based on Two-Dimensional Materials
Frederick Berl
Mentor: Stevan Nadj-Perge

The goal of the project is to simulate electronic transport properties and electronic local density of states in nanoscale devices based on two-dimensional (2D) materials that can take into account spin related effects as well as superconductivity. We first focused on simulating graphene's properties to test the validity of the simulations. Starting from a tight binding model with parameters obtained through density functional theory (DFT) calculations involving the overlap of p_z orbitals, we reproduced the band-structure of graphene in agreement with previous results in literature. In the future, ours goals are to apply the simulations to different materials, including transition metal dichalcogenides, when coupled to superconductors and placed in a magnetic field. The long term goal of this project is to develop a platform for simulating advanced devices based on on 2D materials, such as topological field effect transistors, which would take realistic material properties into consideration.

Economic Impact Analysis of Immigrant Entrepreneurs Across America
Damien Bérubé
Mentor: Craig Montuori

At the intersection of immigration policy and economics sits immigrant entrepreneurship research, an emerging study of the origins, motivations, activities, outcomes, and impacts of foreign-born individuals who need to navigate an immigration system to start a business. Desiring to provide insight to a facts-based discussion about the impact of these entrepreneurs, we generated a set of economic projections and policy papers at the regional and state level with the end-result being the nationalization of a model of economic impact specific to foreign-born startup founders across the United States of America. We further developed new methods to make use of national entrepreneurship datasets and specific case studies to feature noteworthy examples of founders who often begin as undergraduate students. Together, these tools contribute to the body of knowledge in economic impact analysis and economic development research, help advance immigrant entrepreneurship study and better inform sensible policy decisions.

Finding Effective Radial Thermal Conductivities of 18650 and 26650 Lithium-Ion Cells
Harsh Bhundiya
Mentor: Melany Hunt

Harmful incidents caused by lithium-ion batteries in the past decade have inspired research on the thermal management of these batteries; several recent studies have developed thermal models of lithium-ion cells. A key consideration in the models is the effective radial thermal conductivity of the cell. In a recent paper, the radial thermal conductivities of 18650 and 26650 lithium-ion cells were theoretically determined to be around 0.20 ± 0.01 and 0.15 ± 0.01 W m^{-1} K^{-1}, respectively. While many researchers have used these values in their papers, no accurate experimental values are found in the literature. After disassembling and modelling the cells, we were able to heat the center of the cells with nichrome wire and a power supply, and experimentally measure their radial thermal conductivities. For the 18650 cell, we calculated a thermal conductivity of around 0.10 W m^{-1} K^{-1}, while for the 22650 cell, we calculated a thermal conductivity of around 0.08 W m^{-1} K^{-1}. Both our values are less than the theoretical values, which suggests that the cells are worse at conducting heat than previously thought. We hope our research will help make better thermal models and prevent more harmful incidents from happening.

Quantum Gases and Exceptional Lattices
Marcus Bintz
Mentor: Gil Refael

Different lattice structures in solids can give rise to wildly different physical properties, even when the chemical composition remains the same, as in the famous example of diamond and graphene. Mathematically, the *ADE* classification of root lattices distinguishes two infinite families *An* and *Dn* as well as three exceptional lattices *E6*, *E7*, and *E8*. While the *A* and *D* families include familiar representatives such as the hexagonal and face-centered-cubic, the exceptional lattices have no low-dimensional analogues. This presents the possibility that the exceptional lattices, regarded as physical crystals, could be host to novel features. Here we present a Markov-chain Monte-Carlo analysis of a tight-binding model on *E6*, *E7*, and *E8*, commenting on their thermodynamics and Van Hove singularities.

3D Printing of Temperature Sensing Flexible Films
Alexandra Bodrova
Mentors: Chiara Daraio, Luca Bonanomi, and Vincenzo Costanza

Low ester pectin cross-linked by calcium ions possess a giant responsivity to temperature. In particular, since the crosslinkings between pectin molecules decrease exponentially with temperature, increasing the temperature of a Ca2+-crosslinked pectin increases ionic conduction. Films of dehydrated cross-linked pectin have been shown to outperform the state-of-the-art thin layers for temperature sensing. Until now, pectin films have been produced only via solution casting or spin-coating. However, these methods are not suitable to realize patterned depositions for multi-pixel measurement and spatial mapping. In these project, we established a method to fabricate flexible sensing layers incorporating together the sensing material and electrodes. We realized a setup to deposit electrodes on PDMS substrates via laser-nanowelding of copper (or silver) nanowires. We implemented a volumetric controlled dispensing system in a commercially available 3D printer in order to locally deposit pectin. The described approach represents a decisive step towards the production of fully integrated temperature sensing pectin-based flexible films.

Investigation of Penetrator Impacts on Thermal and Mechanical Granular Properties With Martian Regolith Simulant
Lyndon Boone
Mentors: José E. Andrade and Jason Marshall

The InSight Mission coordinated by JPL launches in 2018 with the goal of characterizing geophysical properties on Mars, including heat flow from the planetary interior. This information will lead to a better understanding of the formation of Mars, radioisotope inventory, crustal thickness and mantle evolution as well as climate history. Heat flux will be calculated using measurements of thermal conductivity and temperature gradient down to five meters below the surface. The Mole is an impact driven penetrator which will be used to hammer into the Martian regolith, dragging a science tether behind it to collect data. The penetrating action of the Mole changes the density of soil around it, affecting thermal conductivity. In this work we used Digital Image Correlation to analyze the changes in density and thermal conductivity of Martian regolith simulant with a model penetrator system. We observed large amounts of densification in regions close to the penetrator which could have a pronounced effect on thermal conductivity measurements and heat flux calculations.

Embeddings of p-ADIC ADS/CFT Holography
Eitan Borgnia
Mentor: Matilde Marcolli

The correspondence between anti-de Sitter space and conformal field theories (AdS/CFT) is of interest in string theory, as it elucidates the relationship between QFT and gravity. In mathematics, it is a common technique to use a simplified "toy model" of a mechanism to more easily conjecture properties of the complex mechanism as a whole. This has been done in the study of the Ads/CFT duality by considering the bulk AdS space discretely, using the field of p-adic numbers. Among other things, the Bruhat-Tits tree (graphical representation of possible p-adic expansions) has been a central object of interest for the toy model. In this project, we attempt to gain new insight on the properties of the Bruhat-Tits tree by studying maps between the tree and hyperbolic space. We explicitly construct a Delaunnay embedding of any finite subtree into the hyperbolic plane, and construct a global embedding by dynamically distorting the curvature of the target space, while keeping it as close to hyperbolic as possible. Finally, we attempt to construct a map in the other direction that has Dirac-Harmonic energy minimizing properties.

Probing Exciton States in Hybrid Perovskite Semiconductors
Nadine Bradbury
Mentors: Geoffrey Blake, Griffin Mead, and Xiaolin Xu

Hybrid Organic-Inorganic Perovskites are a new generation of photovoltaic semiconductors that do not use scarce metals. Study of the viability of these materials involves detailed understanding of the various states an electron may go through in the material. Exciton states are bound excited electronic states just below the conduction band where the electron is essentially orbiting the “hole,” or positive charge, left behind by the promotion of an electron to the conduction band. These exciton states guard the transition between free and lattice electron, but their dynamics and timescales are not yet well understood. Proper characterization of the electron lifetime in the material involves understanding the timescales, and vibrational dynamics of these loosely bound states. We report an optically pumped, time resolved terahertz spectrum of $MAPbBr_3$, a well-studied hybrid perovskite. Transitions between exciton states are resonant in the far-IR, or terahertz region of the electromagnetic spectrum, an area that has been difficult to study until relatively recent advances in generation and detection of this light. Obtaining details of the internal exciton dynamics between hydrogen-atom like states of electron-hole pairs provides an important piece of information for the directed evolution of this promising family of materials.

Mathematical and Computational Modelling of Cell-Cell Interactions in the Notch Pathway
Jacob Bradley
Mentors: Michael Elowitz, Yaron Antebi, and Christina Su

We define formally a model for promiscuous notch pathway interactions between two cells, incorporating tunable cis-inhibition, multiplicity of ligand/receptor variants and the probabilistic decomposition of ligand-receptor complexes to produce signal in each cell. While conceptually intuitive, this is analytically and computationally cumbersome, and so we prove a method of bijectively mapping steady-state solutions of this system with solutions to a far simpler binding-unbinding problem, which we will define. We can then produce code capable of efficiently generating large simulation samples of notch interactions which would otherwise be infeasible. Previous work has focussed on a scheme of total cis-inhibition: we examine behaviour as this assumption is weakened and pictures become more ‘fuzzy’. We investigate how best to categorise and quantify communication between two cells in this case, and then attempt to classify modes of communication possible in simple cases using a variable binary signal threshold. The aim is to find some collection of representative cells expressing the maximum variability in communication profiles for a given model complexity.

KOI-367b: A Dense Sub-Saturn With an Extreme Eccentricity
Madison Brady
Mentors: Heather Knutson and Erik Petigura

The evolution of planets is an important topic in the field of planetary science. Sub-Saturns, exoplanets with radii four to eight times the size of Earth’s, have compositional properties that make them ideal laboratories to study planetary evolution. In order to further our understanding on the statistical properties of these objects, we examine HIRES radial velocity data and Kepler transit data on the sub-Saturn candidate KOI-367b. We use Markov Chain Monte Carlo methods to produce mathematical models to describe the collected data and then use these models to derive system parameters such as mass and orbital eccentricity. Next, we examine these parameters in the context of other exoplanets to draw conclusions about the KOI-367 system. Our analysis shows that KOI-367b has an unusually eccentric orbit for a solitary sub-Saturn at an intermediate distance from its host star. Moving forward, we hope to evaluate possible explanations as to how this strange system formed.

Identifying Orthogonal Nuclear Inclusion A Proteases in the *Potyvirus* Genus
Tatiana Brailovskaya
Mentors: Bil Clemons and Shyam Saladi

A large set of orthogonal proteases (i.e. proteases having highly distinct substrate specificities) that are easy to manipulate experimentally constitute a desirable toolkit for synthetic biology. Nuclear Inclusion A Proteases and their target sequences from the *Potyvirus* genus of (+)ssRNA viruses form an attractive group from which to find such proteases. We develop bioinformatics techniques for finding sets of mutually orthogonal proteases based on analysis of target cleavage site sequences. We devise a motif distance metric that can be used to compare cleavage sites from different proteases and a subsequent clustering procedure for identifying maximally distant sets of sites. Additionally, we propose a Markov Chain Monte Carlo simulation scheme to find proteases with maximally distinct cleavage sites, as quantified by the silhouette score. We further verify our bioinformatics predictions with free energy calculations that estimate binding affinities between protease and cleavage sites. Finally, we will experimentally test pairs of proteases in our final prediction for orthogonality. Next, these proteases will be used to build *in vivo* genetic circuits, however the methods developed here can have implications in other problems in computational biology such as identifying leucine zipper and other dimerization domain specificities.

Development of a Method to Map Higher-Order Protein-DNA Interactions in the Nucleus
Karanbir Brar
Mentors: Mitchell Guttman and Sofia Quinodoz

DNA is highly organized in the nucleus. Specifically, chromatin organization varies greatly depending on chromatin state and transcriptional activity. Further, long intergenic non-coding RNAs (lncRNA) play an important role in regulating gene expression and regulating three-dimensional chromatin structure. To better understand how lncRNAs can play a role in shaping chromatin structure, the Guttman lab has developed a method to identify higher-order interactions of DNA and RNA, termed Split-Pool Recognition of Interactions by Tag Extension (SPRITE). In the present study, we aim to integrate protein maps into the SPRITE protocol. We have identified protein-compatible SPRITE buffers, determined optimal antibody signal:noise ratios, and have obtained a set of protein tags appropriate for multiplexing protein-interaction mapping. Future work entails optimizing multiplex protein-SPRITE with a pool of antibodies for proteins of interest and ensuring that there is no cross-reactivity between antibodies. Once optimized, the addition of protein data into SPRITE will allow for the identification of higher-order protein-DNA structures, providing important insight into how specific nuclear proteins shape DNA structure and play a role in lncRNA function during varying cellular states.

Minimizing Environmental Magnetic Field Sources for nEDM
Alex Brinson
Mentors: Bradley Filippone and Simon Slutsky

Measurement of the neutron’s Electric Dipole Moment (nEDM) could potentially explain why there is more matter than antimatter in the universe, and it would suggest plausible extensions to the Standard Model. We will attempt to detect the nEDM by measuring the electric-field-dependent neutron precession frequency, which is highly sensitive to magnetic field gradients. In order to produce fields with sufficiently low gradients for our experiment, we eliminate environmental effects by offsetting the ambient field with a Field Compensation System (FCS), then magnetically shielding the reduced field with a Mu-Metal cylinder. We discovered that the strongest environmental effect in our lab came from iron rebar embedded in the floor beneath the proposed experiment location. The large extent and strength of the floor's magnetization made the effect too large to offset with the FCS, forcing us to relocate our apparatus. The floor's magnetic field was mapped with a Hall probe in order to determine the most viable experiment locations. A 3-axis Fluxgate magnetometer was then used to determine the floor field's drop-off and shape at these locations, and a final apparatus position was determined which minimized the floor's effect such that it could be effectively offset and shielded by our experiment.

Experimentally Determining the Dynamics of Jupiter's Polar Vortices
Jackson Briones
Mentors: Andrew P. Ingersoll and Cheng Li

On the Cassini space mission, two vortex configurations were observed at Jupiter's poles; on the south pole, a central vortex is surrounded by a pentagon of other vortices, and on the north pole, a central vortex is surrounded by an octagon of other vortices. By recreating the environment in a rotating shallow water model simulation, the properties of these vortices could be examined. In this simulation, 4 main variables were changed: vortex radius, outer vortex latitude, vortex strength, and gravity wave speed. In general, the vortices will drift to the pole until they touch, at which point they begin to merge into one large central vortex. Results showed that while the radius and latitude variables determined the length of time required to start touching, the vortex strength and gravity wave speed variables determined how quick the merging process was; smaller strength and speed variables were associated with slower merging. Because a configuration in which the vortices never merged was never found, we can deduce that the simulation needs to account for more factors, such as jet streams, if it will ever recreate the observed phenomena.

Investigating the Distribution of Anaerobic Methanotrophic Archaea in Sediment From Monterey Canyon, CA Using Hybridization Chain Reaction-Fluorescence In Situ Hybridization
Camille Brzechffa
Mentors: Victoria J. Orphan and Ranjani Murali

Methane, an abundant hydrocarbon, plays a significant role in both post-industrial global warming as well as many of the earth's biogeochemical processes. The microorganisms such as anaerobic methanotrophic archaea (ANME) and its associated sulfate-reducing bacterial partner (SRB) contribute to the anaerobic oxidation of methane in environments like cold seeps and serve as a methane sink in oceans. Due to the difficulty of working with organisms in sediment, these organisms have yet to be fully understood. Studying the distribution and localization of ANME, as well as the spatial association of ANME and SRB in environmental samples can provide insight into their niche differentiation and broaden our understanding of seep ecosystem structure and function. In this work, we use sediment samples from Monterey Canyon, California to visualize ANME and SRB by Hybridization Chain Reaction- Fluorescence In Situ Hybridization (HCR-FISH). Using the results produced from HCR-FISH, I am able to both characterize and identify free living cells and aggregates found in the environmental samples as well as identify possible correlations between the spatial associations and localizations of ANME and SRB, and geochemistry data from the environmental samples.

Investigation, Characterization, and Correction of Image Centroid Motion at JPL's Precision Projector Laboratory
Iván Mauricio Burbano Aldana
Mentors: Roger M. Smith and Andrés A. Plazas

Due to the precision needed in measurements for Weak Gravitational Lensing, it is important that the Precision Projector Laboratory is able to emulate stationary images on sensors. However, motions on the order of microns have been found. To be able to detect the source of this motion it was probed through the investigation of images of lattices of spots with different physical conditions projected onto an H2RG sensor. Characterization of the power spectrum of the motion in search for resonances, the correlation between motions in different sectors of the sensor, and the affine behavior of the motion in the whole sensor was done. The hypothesis of air pressure changes through the optical path was proposed as possible source for the motion. A method for replacing the air with helium is designed to test the hypothesis. In the future, this method will be implemented.

Laser Ablation Inductively Coupled Plasma Mass Spectrometry: Instrumental Procedure Development and Analysis of Egyptian Magmatic Ilmenite Ore
Mark Burleson
Mentors: Paul Asimow and Nathan Dalleska

Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) is an analytical technique used to determine precise elemental composition profiles for solid state materials. Maurice et al. have proposed that the Abu Ghalaga Ilmenite Deposit represents late magmatic melt. Major and trace elemental profiles of different ilmenite ores and rare-earth element profiling of minerals in the surrounding rock using LA-ICP-MS are used to construct evidence for the origin of this titanium-iron oxide ore deposit. Electron microprobe analysis, scanning electron microscopy, and whole-rock analysis were used to produce data and images of the mineralogical profiles of the samples prior to LA-ICP-MS. We present novel methodology for precise elemental profiling in minerals containing little or no silicon or calcium, elements normally used as an internal standard in LA-ICP-MS analysis.

Engineering Hemoproteins for the Biocatalytic Synthesis of Simeprevir Precursor
Lazarina Butkovich
Mentors: Frances Arnold and Kari Hernandez

In recent years, biocatalysis has played an increasingly important role in catalyzing novel reactions and synthesizing important molecules that are difficult to synthesize via traditional methods. This growth in biocatalysis has been made possible by directed evolution, or the iterative mutagenesis and screening of protein biocatalysts to catalyze a specific reaction with high turnover and selectivity. In this specific project, the target molecule was a precursor to simeprevir, a drug used to treat hepatitis c. Biocatalytic synthesis of the precursor involves cyclopropanation of ethyl nitro diazoacetate (NEDA) with 1,3-butadiene, which has a more electron-poor olefin than olefins previously cyclopropanated in the Arnold Lab, such as styrene. Hence a substrate-walk approach was used to evolve the parent protein Rma cytochrome c by starting with cyclopropanation of NEDA with styrene rather than NEDA with 1,3-butadiene. Site saturation libraries of several sites were obtained and screened for beneficial mutations, and the results of these tests served as a basis for combining beneficial mutations to observe epistatic effects. The end goal was to engineer Rma cytochrome c to catalyze the cyclopropanation of NEDA and 1,3-butadiene with high turnover and selectivity.

Codes for Restricted Noise
Jesse Cai
Mentors: John Preskill and Evgeny Mozgonuv

Quantum Error Correction Codes which protect against decoherence are critical for preserving states in quantum computation. Independent and identically distributed noise has been well-studied, but in many physical settings noise is expected to be better modeled by non-traditional restricted models. In this paper we use machine learning to make quick predictions on the performance of both classical and quantum codes where noise models obey symmetries. We find that a linear regression model is able to predict out of sample and bigger system sizes relatively well.

A Biochemical Basis for mRNA Export Regulation by the Nuclear Pore Complex
Sarah Cai
Mentor: André Hoelz

The nuclear pore complex (NPC) is one of the largest and most complex protein assemblies in eukaryotic cells, and it facilitates and regulates the bidirectional transfer of molecules between the nucleus and the cytoplasm. One of the essential functions of the NPC is to directly regulate the export of mature mRNAs, but the mechanism is not well understood, especially in humans. Export of mRNA is completed at the cytoplasmic face of the NPC, where the ATPase activity of the DEAD-box helicase DDX19 is specifically activated by Gle1, Nup42, and Nup214. Dysfunction of the essential mRNA export factor Gle1 has been linked to several human diseases. We show that the thermostability of Gle1 is highly dependent on Nup42, and we find that disease-linked mutants of Gle1 show strongly altered thermostability. Analysis of DDX19 steady-state ATPase activity reveals a novel mode of activation by Gle1 in humans that is independent of the small molecule inositol hexaphosphate (IP_6) in contrast to in fungi. Together with structural data of the DDX19-activating complexes, these results provide a detailed biochemical description of mRNA export regulation by the NPC and a framework for understanding the molecular basis of human disease linked to Gle1.

Investigating Phase Transitions of $LiHoF_4$ to Attempt to Observe a Quantum Quench
Jack N. Caldwell
Mentor: Thomas Rosenbaum

A quantum quench, the process by which order grows quantum mechanically after a rapid transition from the disordered state, is an experimentally uncharacterized phenomenon. We chose the dipolar magnet, $LiHoF_4$, and its transition between disordered paramagnet and ordered, Ising ferromagnet to test theoretical predictions. A quench, by definition, must happen quickly, but changing temperature or magnetic field rapidly is practically impossible for the magnetic field strengths and temperatures involved. Hence we used microwaves to shift the phase transition line by saturating the nuclear levels and thereby changing the effective magnetic moment of the intertwined nuclear/electronic hyperfine energy levels. Multiple loop-gap resonator designs using high-purity copper were manufactured and benchmarked, achieving much higher quality factors than those used in previous attempts to drive this transition. A novel, superconducting design was designed and quantified, but complications with magnetic field penetration made it a secondary choice. As the research came to conclusion, we began to map out the phase change space at milliKelvin temperatures, with attempts to observe the quench planned for the coming weeks.

Creating Mock Images for the JWST
Ben Calvin
Mentor: Philip Hopkins

We were tasked with creating an image processor for the James Webb Space Telescope. The telescope does not have an image processing algorithm because there is no sample data to use to test their routines. We used existing realistic simulation snapshots to create the data in bands that the James Webb will be operating in, and we were then able to create various viable representations. As one of the positive aspects of using infrared astronomy is its visibility through dust and gas, our visualizations tend to emphasize the dust hidden to visible observations. We also created a temperature mapping, as infrared is also traditionally used to detect temperature. The visualization methods and routines created will help translate data from countless infrared exposures, as well as simulations, into meaningful results and images.

Development of a T Tauri Star Spectral Analysis Infrastructure
Philip Carr
Mentor: Lynne Hillenbrand

The question of how planets form is one of the most fundamental of astronomy. Young star systems, especially T Tauri systems, offer a crucial view of the early formation of planetary systems. Circumstellar disks, which provide the raw material for planet formation, frequently form along with T Tauri stars and have been observed to accrete onto the central star. Both the stellar properties of T Tauri stars and the kinematics of circumstellar disk accretion can be analyzed by studying the high-resolution spectra of these young star systems. Absorption lines in the spectra mostly indicate properties about the star, while emission lines mostly indicate accretion properties of the star system. A software infrastructure developed using an IPython Notebook has been developed to help automate the analysis of HIRES spectroscopy data of T Tauri systems recorded using the Keck Telescope. When complete, the notebook will enable users to determine stellar properties such as radial velocity, absorption line equivalent widths, spectral type, and rotational velocity, and accretion properties such as emission line equivalent widths, velocity profiles, and continuum veiling.

Blind Short-Message Communication Scheme Over Wireless Channel Using Huffman Autocorrelation Codebooks
Mattia Carrera
Mentors: Babak Hassibi and Philipp Walk

The fast-paced growth in the use of smart devices and appliances which require to exchange data amongst themselves or with mobile applications has caused the communications network to become more akin to a Machine-to-Machine (M2M) platform. Such data transmissions necessitate fast round-trip times and typically occur over fast fading channels, both of which invalidate the use of traditional communication strategies. In this work, we develop a novel signaling scheme which estimates the transmitted data sequence by assuming no channel knowledge and relies on an encoding rule based on what is preserved (in the noiseless setting) after transmission, namely the zero structure of the data sequence z-transform. A theoretical analysis of the decoding heuristics is supported with several simulations that aim at better understanding the performance of the scheme. Several strategies for improving the Bit Error Rate (BER) while preserving its computational efficiency are also explored. The overall performance of the scheme appears to be especially impactful for real-time applications.

Using Supernovae to Estimate Galaxy Catalog Completeness
Benjamin Cassese
Mentor: Shri Kulkarni

In the new age of gravitational wave astronomy, it is the aim of many researchers to detect the electromagnetic counterpart emission from a neutron star merger. Unfortunately, these short-lived bursts are expected to be embedded within regions containing numerous other similar looking transients, such as supernovae. To account for this, a triage system is used to dismiss events beyond the LIGO detection range and determine which candidates merit spectroscopic follow-up. However, the catalogs of galaxies this system depends on are far from complete; the redshifts of many galaxies are unknown, and consequently improper dismissal of a transient is a concern. To assess this fraction of galaxies with unknown redshifts within the NASA Extragalactic Database, we used $z < 0.05$ supernovae from the last two years to gather a random sample of galaxies, taking advantage of the association between supernovae rates, total stellar mass, and star formation rates. As of writing, the host galaxies of 639 supernovae have been identified, of which 448 have known redshifts, and 191 do not. However, the host galaxies of an additional 227 supernovae in our sample have yet to be identified, and so a completeness estimate cannot be declared until identification has concluded.

Predicting the Effects of Curvature on Laminar Flame Speed
Anuj Chadha
Mentor: Guillaume Blanquart

The principle objective of this project is to obtain how flame speed is related to flame curvature. In order to achieve this, I first simulate flames using 1D Cartesian coordinates. After this, I manipulate the source code to cylindrical and spherical coordinates, and then simulate the flames. With the data garnered from these simulations, I plot graphs which enable me to understand how flame speed changes as a function of curvature for all these three cases. Then, I conduct a literature review where I identify the experimental data to compare against. Finally, I compare the experimental results to the ones achieved via simulation.

Extended Late-Cretaceous Magnetostratigraphy of the James Ross Basin Island, Antarctica
Thom Chaffee
Mentor: Joseph L. Kirschvink

Sediments in the James Ross Island Basin (JRB) in the West Antarctic Peninsula contain one of the world's highest-resolution records of the late Cretaceous period, including the end-Cretaceous (K-Pg) mass extinction event. However, the geological record of this region has been poorly studied, limited in the past only to the relative dating of local fossils. Recent studies of this region have provided only low-resolution data, with gaps of greater than 0.5 million years between samples where no data was collected. A high-resolution magnetostratigraphic sampling and analysis is necessary in order to accurately determine the age of the JRB sediments and connect them to the global time record. During the 2016 field season in Antarctica, our team collected nearly 1,300 sample cores from JRB sediments using a diamond-tipped, gasoline powered coring drill. Drill sites were densely clustered across bedding in order to obtain a high-resolution record of magnetostratigraphy, permitting the recognition of distinct, high-resolution units of time (<50 thousand years) present in local stratigraphy. Our current results come from thermal demagnetization of the characteristic remanance (ChRM) of a group of over 300 of these samples from the Brandy Bay area which constrain the end of the Cretaceous Superchron (C34N) and the C34N/C34R reversal and allow us to investigate the presence of geomagnetic excursions before the end of superchron. These samples span in age from the top of C34N to the mid-Maastrichtian. We also test the Late Cretaceous True Polar Wander (TPW) hypothesis. Current theories on the global extent of TPW are not substantiated by any data sets that confirm the presence and similarity of the effect across multiple continents. Evidence of a rapid TPW oscillation in Antarctica can be correlated with other samples from the North American continent currently under study to provide evidence for the theory of global, short-timescale TPW.

Pyridinium Additives for Carbon Dioxide Reduction
Gabriella Chan
Mentor: Theodor Agapie

Renewable energy can be stored in hydrocarbon fuels via electrochemical carbon dioxide reduction. Currently, this method of hydrocarbon production competes with the hydrogen evolution reaction (HER), has high overpotentials, and experiences difficulty in selectively producing the desired hydrocarbons. To address these challenges, we developed pyridinium co-catalysts to be used with a copper electrode. The prevalence of hydrocarbon production from carbon dioxide reduction on copper electrodes was, for a significant period of time, believed to be a property unique to copper and remains as one of the highest product yield electrodes studied in carbon dioxide reduction research. Previously, pyridine increased methanol production when added to an electrolyte because aromatic N-heterocyclenes (ANH) lower the energy of the lowest unoccupied energy orbital (LUMO) making multi-electron/multi-proton transfer processes, such as carbon dioxide reduction, more energy efficient. To further investigate this phenomenon, we synthesized myriad pyridinium molecules as organic co-catalysts for carbon dioxide reduction. We expect these pyridinium compounds to increase carbon dioxide reduction's Faraday efficiency and methanol production while decreasing its hydrogen gas and methane production.

Dewetting Carbon Nanotube and Superhydrophobic Surfaces for Solar Desalination Applications
Jonathan Chan
Mentors: Morteza Gharib and Jinglin Huang

A major problem in the solar desalination process is the buildup of corrosive salts in the seawater channel. To clean up the channel, its operation must be discontinued, incurring high maintenance costs. Superhydrophobic (SHPo) properties of vertically aligned carbon nanotube (CNT) arrays and other surfaces have potential to repel salt buildup in the channel because their surface structures support a layer of air between the surface-seawater interface. Over time, however, this air layer is unavoidably wetted due to turbulent pressures in the channel, reducing the surface's ability to repel salt. In this study, we address this problem by identifying a family of non-uniform, irregular structures that upon being wetted, can regenerate an air layer under conditions similar to those in a real desalination channel and while fully immersed underwater. We integrate these SHPo structures into a simple electrolytic gas decomposition setup to achieve a reasonably successful air layer restoration scheme. Thus, we demonstrate that geometrically irregular structures capable of regenerating air layers can potentially serve as corrosion-resistant surfaces in the solar desalination channel.

Property HT
Zachary H. Chase
Mentor: Omer Tamuz

We investigate the representation theoretic properties of topological groups with a certain fixed point property. Precisely, a strongly amenable group G acts continuously on a real, separable Hilbert space H such that there exists a nonzero harmonic cocycle, namely a nonzero, continuous map b: G --> H such that b(gh) = b(g)+gb(h) for all g,h in G and the sum of μ(h)b(h) over all h in some finite, symmetric generating set S of the group G, where μ(h) is some symmetric, probability measure on S, is equal to 0. We attempt to prove that the action has a fixed point, and discover some interesting properties of the extended action of G to the Bohr compactification of H.

Characterization and Dispersion Compensation of Femtosecond Pulses With Prism Pairs
Jingjing Chen
Mentors: David Hsieh and Junyi Shan

It's known that when a pulse passes through a dispersive media, the temporal profile of the pulse will change. A prism pair is a set of optical components used to compress the time duration of a positively chirped ultrashort laser pulse by giving different wavelength components different time delays, i.e., compensating the optical path difference generated by previous optical components. It typically consists of two prisms and a mirror. Frequency-resolved optical gating (FROG) is a method to measure the pulse width and the spectrum of an ultrafast laser pulse. We can use FROG to measure the pulse duration of the beam before and after the prism pair to assess the compression of the time duration. It is essential for ultrafast and nonlinear optical spectroscopy measurements since a shorter time duration of a pulse yields a better temporal resolution. What's more, with the knowledge of the temporal profile of a pulse, one can carefully shape the pulse to pump an electronic system to some exotic states.

Automation of Cobra Test Cube for the Subaru Prime Focus Spectrograph
Sharon Chen
Mentors: Evan Kirby and Daniel Reiley

The Prime Focus Spectrograph (PFS) to be incorporated in the Subaru telescope will allow astronomers to obtain spectroscopy of 2400 targets within a wide field of view, providing data about stellar and galactic composition. PFS is equipped with 2400 65-meter optical fibers, each with a "Cobra" fiber positioner, which relay light collected from the telescope to the spectrographs. To ensure the quality of the spectra and correct for imperfections, we need to test the fibers and positioners. This project describes the automation of the existing test cube setup to make the system a useful tool for running tilt and focus tests on the fibers. Communications were established between Matlab and the three hardware components of the test cube: the Andor metrology camera, the linear stages, and the angle and focus gauges. These components were then integrated with existing data analysis programs to provide a single program to run the test cube.

Graphical User Interface Development for Intraocular-Pressure-Sensing Handheld Detector
Shuoqi Chen
Mentors: Hyuck Choo and Jeong Oen Lee

Glaucoma is a condition that causes damage to optic nerves in human eyes, and keeping track of intraocular pressure (IOP) is an essential step to keep and glaucoma-caused vision impairment at bay. At the Choo Lab, we have developed a comprehensive yet user-friendly Graphical User Interface that works in conjunction with the micro scale IOP-monitoring implant, a sensor that would produce a characteristic, pressure-dependent optical spectrum when illuminated by broadband VIS-NIR light. The software interface utilizes advanced data mapping and Artificial Neural Network (ANN) algorithms to capture the real-time optical spectrum, enabling high-frequency sampling that updates IOP readings at a maximum rate of 35 Hz. With multiple optimized calibration tools, the software combines clinical imaging and spectrum analysis techniques and provides fast, accurate, and convenient IOP measurements that pave the way for portable home-based IOP monitoring technologies.

Semi-Supervised Learning Using Bayesian Hierarchical Methods
Victor Chen
Mentors: Andrew M. Stuart and Matthew M. Dunlop

In semi-supervised machine learning, the task of clustering is to divide the data into groups using a labeled subset. Our Bayesian approach to graph-based clustering views the classifying function as a random variable with a distribution that combines the label model with prior beliefs about the classification. In Bayesian hierarchical methods, hyperparameters governing the prior distribution are introduced and can be sampled as well, with the goals of both deriving a classification and learning the distribution of the hyperparameters. We apply Markov Chain Monte Carlo methods for indirectly sampling the posterior distribution of these random variables, as direct sampling is generally challenging. We focus on priors derived from the graph Laplacian, a matrix whose eigenvectors are known to contain cluster information. We implemented Bayesian hierarchical models that learn different sets of hyperparameters, including ones that govern the scale of the eigenvectors or the number of eigenvectors used. We tested these models on real and synthetic data sets. Our results indicate that there is information to be learned about the distribution of these hyperparameters, which could be used to improve classification accuracy.

Analysis of Human Sensorimotor Performance in Challenging Multitasking Control
Sunghoon Choi
Mentor: John Doyle

Effective layered control architectures such as the brain seamlessly integrate high level planning with fast lower level sensing, reflex, and action and facilitate decision, learning, adaptation, augmentation, and teamwork. Despite being implemented in highly energy efficient hardware that has sparse, quantized, noisy, delayed and saturating sensing, communications, computing, and actuation, covering time scales from milliseconds to minutes to days. Prof. Doyle's group have for the first time developed a mathematical framework that systematically treats control design with all of these features and constraints in coherent and rigorous way. Prof. Doyle's group have also developed a video game platform which is both safe and arbitrarily challenging in use of both planning and reflexes. Now that we have the theory and experimental platforms, we add new auditory and visual tasks to the existing experimental platform so that we can safely push the limits of human performance. We give a rich set of variations to the game to manipulate the quantization and delay the subjects experience, compare the result with the theory, and examine how players learn in complex environments. We look forward to transforming the theory of sensorimotor control, which is one of the primary function of the human brain.

Design and Construction of Unmanned Flying Ambulance
Yunsang Choi
Mentors: Soon-Jo Chung and Xichen Shi

This project's goal is to design and construct a vertical takeoff and landing (VTOL) flying ambulance that can be used in both ground and air autonomously. The vehicle uses both rotors and wings to generate lift and thrust, and the aerodynamic interaction between the wing and the propellers are not well understood. The project seeks to use both theoretical and experimental results in order to design the vehicle, and the early stage testing of the small-scale model suggests that though there are optimizations that can be done, it is possible to use both the wings and rotors effectively in the same vehicle. Further construction and optimization is planned for larger-scale prototype that is currently being built.

Liquid to Solid Transition in Powder Flow
Ya Lun Chuan
Mentor: Melany L. Hunt

When powder flows, it can demonstrate both liquid and solid characteristics depending on the material properties and bed density. This complex transitional flow can be examined with Anton Paar's powder rheometer, which can measure torque and normal force while varying the fluidizing airflow and the rotational speed. Using different sized glass beads, the experiments showed that the torque decreased significantly as the fluidizing flow was increased at lower rotational speed. Beyond the minimum required fluidization flow, the torque does not change much at the same rotational speed, but as the rotational speed was increased the torque increases significantly, approaching the values obtained at much lower fluidization flow rate. As the flow rate decreases, the average torque increases, and the powder transitions from solid-like to fluid-like. Learning more about this transition phase can contribute to production improvements in food industry and enhanced understanding about natural phenomena such as sand storms.

Computational Modeling of Social Learning in Humans: How Implicit Race Bias Influences Trustworthiness Judgments
Bo-Ryehn Chung
Mentors: Ralph Adolphs and Damian Stanley

In today's increasingly heterogenous world of diverse races and social groups, it is computationally efficient for humans, in situations of uncertainty, to make social categorizations and behavioral predictions of others. Implicit racial bias has been shown to influence economic trust and monetary reciprocity judgments. However, it is not known what role racial bias assumes when we learn about other people. We constructed computational models leveraging reinforcement learning paradigms in order to investigate how implicit race attitudes influence learning about other people's monetary reciprocity. We modelled specifically whether race bias affects only our initial estimate of a stranger's trustworthiness – akin to a Bayesian prior, or our learning rate dependent on the target race being learnt about. We additionally studied whether race bias scales learning rate dependent on the behavior of the target group relative to one's bias. A modified economic trust game was conducted on subjects recruited online, with implicit race bias assessed using the evaluative priming task and race implicit associative task (IAT). Model selection analyses will be used to determine which of these models, or hybrids thereof, best explains the influence of implicit race bias on social trust learning.

Investigation of Piwi-Like Protein 2 mRNA Sequence and Spatiotemporal Expression Pattern of piRNA Pathway Components Within Chicken Development
Hong (Amy) Chung
Mentors: Marianne Bronner and Riley Galton

P-element Induced Wimpy Testis (Piwi) proteins, present in all metazoans, interact with a class of small RNAs known as Piwi-interacting RNAs (piRNAs), and perform crucial functions in germline cells including germ cell defense and germline stem cell maintenance by silencing transposable elements. Apart from their role in germ cells, Piwi proteins have also been implicated in somatic and cancer cells. There has been one Piwi protein identified in chicken, chicken Piwi-like protein (cPiwil) 1, and a partial sequence for cPiwil2 has been uploaded to GenBank. However, the majority of the sequence for cPiwil2 remains unknown and the expression patterns of the protein have yet to be investigated. Thus, we have been performing 5' Rapid Amplification of cDNA Ends (RACE) to attain the full mRNA sequence of cPiwil2. Furthermore, we have used whole mount *in situ* hybridization to show spatiotemporal expression patterns of three transposable elements, namely LTR7, LTR10C, and Mariner1, and a protein coding gene, Ddx4, that are involved in the piRNA pathway. We will continue our study using hybridized embryos and Ddx4 knockouts to validate our results and elucidate components of piRNA pathway in chicken.

Effectively Transparent Electrical Contacts for Perovskite Solar Cells
Sophia Coplin
Mentors: Harry Atwater and Rebecca Saive

Solar cells are needed to meet rising worldwide energy demand, to reduce greenhouse gasses, and to replace our diminishing non-renewable resources. To be a viable option, solar cells must become less expensive, which can be accomplished by reducing losses and increasing efficiency. Thin film cells use a transparent conductive oxide (TCO) layer to contact a cell electrically. This layer creates parasitic absorption and has low conductivity, which is especially detrimental for larger cells. Triangular cross-sectional front metal contacts are highly conductive, effectively transparent and allow for an ultra-thin TCO layer. Perovskites are a class of thin film solar cells with the potential for ultra-lightweight, radiation resistant cells created by a simple process and with promise for space applications. This project aimed to make transparent and conductive superstrates with triangular effectively transparent contacts for perovskite solar cells. Superstrates were made on glass with both PDMS, a flexible polymer, and silica sol gel, a porous glass, as well as a standalone ultra-thin (30-80 µm) sol gel membrane. The PDMS superstrates can protect perovskite cells from humidity and membranes' weight and thickness is ideal for mobile or space applications. Furthermore, we demonstrated high transparency over a broad wavelength regime.

High Performance Computing Level Set Discrete Element Method Software Development
Robert A. Corado
Mentors: José E. Andrade and Jason Marshall

The Discrete Element Method (DEM) was developed 35 years ago to model the interaction of discrete particles of granular materials. DEM is valuable for scientists investigating thermal diffusion physics and engineers designing simulations of such phenomena. However, the inherent difficulty in physically accurately and computationally efficiently representing particle morphologies, structures, and interactions is evident through the thirty or so different implementations of DEM, none of which are currently the principal choice among researchers or engineers. The Level Set Discrete Element Method (LS-DEM) was developed to accurately represent particle geometry in classical DEM. The key advantage of LS-DEM is the use of level sets, grid representations with values representing the distance to a surface, to represent particle morphology. Level sets are advantageous because they are efficient with particle interaction calculations due to the signed distances to the surface. However, one drawback of level sets is the large quantity of computational memory allocated per particle. Nevertheless, innovations in computational power have enabled advancements in discrete particle modeling that were previously not possible. Thus, this research project improves existing LS-DEM code to utilize high performance computing techniques, with the end goal of LS-DEM becoming a transformational engineering tool in a range of fields.

Reversible Diels-Alder Addition of N-Substituted Maleimides to Furan Functionalized Polymer Systems
Jonathan Cotler
Mentors: Julia Greer and Daryl Yee

Diels-Alder chemistry is a versatile, mild, and reversible method by which two substituent groups may be added to each other. By using polymer systems with furan groups attached, maleimides substituted at the N-position may be added on using this chemistry. Hexyl and decyl substituted maleimides have been synthesized using a zinc chloride and hexamethyl disilazane dehydration. Hexyl, decyl and fluorescein groups have been added to the surface of polymer pucks using this system, causing changes to the hydrophilicity and fluorescence of the puck, respectively.

Magnetoreception: Interpreting the Human Magnetic Sense
Sarah J. Crucilla
Mentor: Joseph L. Kirschvink

Magnetoreception, the perception of the geomagnetic field via the central nervous system, has been shown to exist in humans. This sense is visible through alpha event-related desynchronization (alpha-ERD) in EEG data taken when an earth-strength magnetic field was rotated around the subjects. However, many subjects do not display an alpha-ERD response, and those that do have varying levels of response signal strength. Our work analyzes various contributing factors to these phenomena. First, we report that when exposed to earth-strength magnetic fields, subjects who have previously been exposed to large magnetic fields (i.e. MRI, TMS, etc.) do not exhibit a response. Additionally, when a subject with an alpha-ERD response to earth-strength magnetic fields was exposed to a 70mT magnetic field with a bias opposite of earth's ambient northern hemisphere bias, his responses became inconsistent. These results support the theory that the magnetic sense is based on biological magnetite while also implying that there are other receptors involved within the sensory transduction process. Also, we looked at new analysis methods including phase synchronization, Granger causality, and lateralized readiness potential. The former two expose a signal pathway for the magnetic sense while the latter shows the brain's subconscious response to magnetism when subjects were asked to indicate magnetic field movement. Finally, we created a visual saccade experiment to test whether the magnetic and visual systems influence each other.

Design and Control of a 1-Dimensional Hopping Robot
Noel Csomay-Shanklin
Mentors: Aaron Ames, Eric Ambrose, and Wen-Loong Ma

One dimensional and planar hopping robots have been researched in the past; however, the majority of these investigations have assumed a Spring Loaded Inverted Pendulum (SLIP) model, usually with minimal control input. Hopping is a challenging problem because it involves the analysis of switching hybrid dynamical systems, where both discrete and continuous elements are present. My SURF project was to explore the capabilities and limitations of a one-dimensional hopper, and evaluate the effectiveness of various methods of actuation and control. One aspect of my project was to aid with the design and manufacture of a hopping robot which implements an electromagnetic style clutch system to store and quickly release potential energy built up in the spring between each of the robot's hops. Concomitantly, I investigated two types of controllers to compress the spring in the flight phase: a Bang-Bang style controller, and a Trajectory based controller. Finally, I solved for the hybrid dynamics analytically, allowing for the robot to calculate the amount of pre-compression needed in the spring in 0.25 seconds. We hope to have a fully built hopping robot able to implement state based control in real time and hop to the same or different heights stably.

A Wearable and Flexible Electronic Sensor for Measuring Arterial Waveforms
Can (Sunny) Cui
Mentors: Morteza Gharib and Azin Fahimi

There is growing interest in wearable mechanical strain sensing systems based on metallic nanowire, graphene, carbon nanotube (CNT), polymer nanofibres and nanoparticles. They have sensing abilities beyond that of human skin, and can be incorporated into artificial systems for advanced sensing capabilities with applications in health monitoring, soft robotics and more. We report the fabrication and characterization of novel stretchable strain sensors based on Vertically Aligned Carbon Nanotubes (VACNTs) embedded in a polymer mix of Ecoflex and silicone rubber. We grew VACNTs on various substrates such as stainless steel mesh in a variety of pore sizes, silicon, and nickel foam. We characterized our samples with Scanning Electron Microscopy (SEM) and tensile testing to relate their electromechanical properties to their physical characteristics. We calculated their gauge factors and measured their sheet resistances to compare the sensitivity of the different samples. We found that VACNTs grown on porous stainless steel mesh perform better than existing strain sensors in stability, sensitivity, hysteresis and relaxation. We will be using our sensors to detect both large and small human motions, from joint movement to arterial waveforms.

Simulating Observations on FIRE
Daniel Cushey
Mentor: Phillip Hopkins

Recent FIRE (Feedback In Realistic Environments) and Latte Project cosmological simulations explicitly treat stellar feedback at resolutions on the order of ~100pc, allowing constraints on fundamental ΛCDM parameters with unprecedented accuracy. However, analysis of simulation data must incorporate effects that are essential to the observation process before an accurate comparison against observational data can proceed. Here we implement the radiative transfer code SKIRT which simulates light propagation in the dusty interstellar medium of simulated galaxies and acts as a virtual observing instrument. We present simulated observations of selected objects generated using raw FIRE-2 data and justify observational parameters which were calibrated via comparison with a real dataset. Future observations may be used to verify parameters vital to cosmological simulations, visualize galaxy formation with high spatio-temporal resolution, and further constrain fundamental parameters of ΛCDM.

Microimaging Spectroscopy of Martian Meteorites
Elise Cutts
Mentor: Bethany Ehlmann

Imaging spectroscopy is a proven tool for remote sensing of planetary surfaces. Until recently, it has been primarily implemented on orbiters and flyby probes to collect data on the scale of tens of kilometers per pixel. However, when applied on the micro-scale, imaging spectroscopy promises to be a powerful non-destructive technique for mineralogical analysis of small samples. The approximately 130 known meteorites of Martian origin represent an inherently precious sample set which would benefit from non-destructive analysis. Additionally, because microimaging spectroscopy requires little to no sample preparation, it is ideally suited for implementation on robotic surface probes. Using the Caltech Imaging Spectrometer, we perform a survey of ~50 Martian meteorites to investigate the diversity of rock and mineral types from Mars and compare their spectral properties to Mars data from Mars orbiting and landed missions. Using manual and custom-designed semi-automatic techniques, we identified key mineral phases related to the geologic history of the rocks such as olivines, pyroxenes of multiple chemistries, igneous minerals occurring at minor abundances, and secondary alteration phases formed in situ on Mars or via terrestrial alteration. The technique also distinguishes rapidly between the three major classes of Martian meteorites (chassignites, nahklites, and shergottites), differentiates groupings within the shergottite class, and is a useful tool for identifying regions of interest for subsequent study with destructive techniques. Future work will require confirmation of the results from spectral analysis with standard techniques such as electron microprobe chemical mapping and development of a method for rapid classification of new Martian samples using principal components analysis of spectral data.

Characterization of Blood and Lymphatic Vasculature During Embryonic Development
George Daghlian
Mentors: Young-Kwon Hong, Viviana Gradinaru, and Carol Readhead

One in seven women is infertile due to the failure of blastocyst implantation to the uterine wall. While such conditions as Recurrent Implantation Failure (RIF) are poorly understood, successful embryonic attachment is contingent upon the bi-directional embryo-uterine molecular crosstalk. Namely, the maternal immune system plays a fundamental role in permitting blastocyst attachment and trophoblast invasion into the uterine endometrium. Although it has been shown that lymphatic and blood vasculature (components of the immune system) are crucial to establishing a placenta and a healthy embryo, little is known about their possible role in blastocyst attachment, invasion, and maturation. In this study, we sought to characterize lymphangiogenesis in the uterus during the development of the embryo by using Prox1:EGFP and Prox1:tdTomato report mouse models (Young-Kwon Hong) with fluorescently-tagged lymphatics. A 3D structure of the uterus and its blood and lymph vessels was obtained by clarifying the pregnant uterus using Passive CLARITY (PACT). Lymph vessels are observed to run alongside the major uterine artery, and blood and lymph vessels are noted to branch off the main vessels at regular intervals in both the pregnant and non-pregnant mouse. The implantation sites occur between these side branches. These blood and lymph structures are established prior to pregnancy and appear to define the optimal area for embryo attachment and invasion. Further work is needed to establish whether further lymphogenesis occurs during placentation and embryo development. The molecular components of these events will be identified using hybridizing chain reaction on the cleared samples.

Polar Grid Phased Arrays
Artsroun Darbinian
Mentors: Ali Hajimiri and Aroutin Khachaturian

The performance of an electro-optical imaging system relies heavily on its ability to concentrate its receiving power in a single desired direction so that signals from undesired directions are rejected. This is accomplished by electrically altering the relative phase between radiators in an array, allowing the peak power to be steered over different angles. If these arrays are not carefully designed, undesired peaks in the array's receiving pattern can appear at different directions, limiting the span of directions over which the array can be used. Unfortunately, size constraints do not allow for these arrays to be used in optical chips without the eventual presence of these unwanted peaks. Currently, this limitation is accepted and optical imaging chips have a limited span of usable angles. In this paper, it is found that placing the array's receivers in a circular lattice greatly reduces the magnitude of these unwanted peaks to the point that a full field of view is possible. These arrays have a number of other benefits over arrays arranged on a rectangular lattice that make circular arrays particularly attractive for use in optical imaging applications. A full mathematical treatment of these arrays is given, followed by general and optics-specific application examples.

Free Energy Barriers for Mechanisms of Electrochemical Dihydrogen Evolution on MoS_2: Progress Towards *ab initio* Metadynamics With Explicit Solvation
Collin Davda
Mentors: William A. Goddard III and Yufeng Huang

We report density functional theory (PBE) optimizations of two 3x5x1 Mo scheme single layer MoS_2 supercells exposed to vacuum. The $Mo_{15}S_{33}$ and $Mo_{15}S_{32}$ supercells were each optimized in VASP with a plane wave basis set extending to 300 eV including van der Waals corrections (DFT-D3). The $Mo_{15}S_{32}$ supercell, with one fewer sulfur atom on the S-edge, was chosen for further use because the conduction band is localized to the Mo-edge rather than the S-edge in the alternative structure. From this optimized supercell a solvated supercell with 59 water molecules above the Mo-edge of the slab was created. The water molecules in this supercell were equilibrated over the slab using classical molecular dynamics in preparation for further *ab initio* metadynamics calculations to determine the free energy barriers of the Volmer-Tafel and Volmer-Heyrovsky mechanisms of hydrogen evolution on MoS_2.

Exploring Thermal Transport in 2D Amorphous Solids
Sowill Dave
Mentors: Austin Minnich and Jaeyun Moon

Silicene has been extensively researched recently due to its high electrical conductivity comparable to that of graphene while the thermal conductivity is one order of magnitude smaller than that of crystalline silicon, which makes it an ideal candidate for thermoelectric power generators. We have studied the thermal transport phenomena in 2D c-Silicene and a-Silicene with optimized SW and Tersoff potential. Unlike crystalline materials where vibrations are scattered by anharmonicity, it is showed recently that anharmonicity does not play a role in scattering propagating elastic waves in amorphous silicon (a-Si). This means that the physics of thermal transport in amorphous 2D materials should not strongly depend on the potential we use, which motivates investigations into thermal transport of amorphous silicene. In this study, we utilize lattice dynamics and equilibrium molecular dynamics using GK formalism to characterize thermal transport in amorphous silicene.

Building a Charged Aerosol Detection Device for Trace Analysis on Mars
Noelle Davis
Mentors: Purnendu Dasgupta, Charles Shelor, and Geoffrey A. Blake

Of the billions of planets in the galaxy, only one we know to host life. However, several of the signature compounds and ions associated with living organisms have been detected beyond Earth, and more have yet to be discovered. We are building a compact charged aerosol detection (CAD) device to function as a sensitive universal detector at the end of a capillary chromatography system that will enable trace analysis on Mars and here on this planet. The device converts the sample to an aerosol, charges the aerosol particles, and collects the resulting current in order to quantify each analyte in the sample.

Testing the Efficacy of the Chemotherapeutic Drug, $[Rh(chrysi)(PPO)(phen)]^{2+}$, on Cancer Cell Lines
Catherine Day
Mentors: Jacqueline Barton and Kelsey Boyle

The Barton lab has been developing rhodium complexes as chemotherapeutic drugs to target DNA mismatches. The most potent complex thus far is $[Rh(chrysi)(PPO)(phen)]^{2+}$, which has been tested against HCT116N, a mismatch repair (MMR) proficient cell line, and HCT116O, a MMR deficient cell line. It has been shown that $[Rh(chrysi)(PPO)(phen)]^{2+}$ has a higher efficacy against the HCT116O cell line in comparison to the HCT116N cell line. To confirm that this drug targets MMR deficient cell lines in general, multiple different cell lines must be tested with $[Rh(chrysi)(PPO)(phen)]^{2+}$. Previously, the complex has been tested on other cancer cell lines using the MTT Cytotoxicity Assay, but the viability of the cells levels off at 20 – 40% even at high concentrations. We suspect that this incomplete cytotoxicity may be because $[Rh(chrysi)(PPO)(phen)]^{2+}$ does not kill all cells immediately, resulting in cells that are metabolically active but unable to proliferate, a feature the MTT Cytotoxicity Assay cannot distinguish. To measure both the cell viability and cell proliferation, we are using the Nuclear Count Assay, which looks at the size and structure of the cell nuclei to determine whether or not the cell is viable. Various cell lines, including both MMR proficient and deficient colorectal cancer cell lines, have been assessed with the Nuclear Count Assay to determine the general toxicity of $[Rh(chrysi)(PPO)(phen)]^{2+}$ towards the MMR deficient phenotype.

Reducing Scattering Loss of Rare-Earth Ion Coupled Photonic Devices
Maximilien Debbas
Mentor: Andrei Faraon

Nanophotonic optical structures constructed on rare earth doped YSO (yttrium orthosilicate) substrates are currently being used to study light-matter interactions on the quantum level. In order to increase the efficiency of these quantum interactions, the optical devices must have minimal optical scattering loss which is achieved by reducing their sidewall roughness. In this project, we test the effects of various wet and dry treatments on reducing the surface roughness of YSO, which is a material relatively new to nanofabrication. Dry treatments tested include plasmas of argon and oxygen, while wet treatments include various acids as well different treatments known to work on silicon. Along with varying sample exposure times, the power of the plasmas and the concentration of the wet chemical treatments were varied. In addition to trying to develop a treatment to explicitly smoothen YSO samples, we are testing existing cleans intended for other materials to make sure exposure to them will not ruin a YSO sample. Ultimately, creating higher efficiency photonic devices will have applications in areas such a solid state quantum memory.

Development of a Comprehensive Database for the WIRC+Pol Survey of Cool Brown Dwarfs
Cayla Dedrick
Mentors: Dimitri Mawet, Ricky Nilsson, and Max Millar-Blanchaer

The Wide-field InfraRed Camera (WIRC) on the 200-inch Hale Telescope at Palomar Observatory was recently upgraded with a new observing mode (WIRC+Pol) to enable high-precision spectro-polarimetric near-IR measurements. A large WIRC+Pol survey of brown dwarfs, that will allow characterization of their cloudy atmospheres, is ongoing. Target selection has, until now, been performed manually from a simple database of brown dwarfs compiled from the literature. The purpose of this project is to create a comprehensive survey database, encompassing current target data, observation telemetry, and eventually archiving of new data products, using MongoDB for the creation of the database itself and Flask for the online interface. This web interface displays the database in a user-defined format, and allows for straightforward, multi-parameter querying and creation of finder charts for any object. It is designed to be a tool for semi-automatic scheduling, a resource during actual observing runs, and ultimately a catalogue of survey results from which statistical inferences on the observed population of cool brown dwarfs can be drawn.

Determining Independence Relations in Cyclic Graphs
Alex Denko
Mentor: Frederick Eberhardt

In a structural equation model, each member of some set of variables is equated to a function of the other variables, as well as some randomly distributed error term. There is a natural correspondence between SEMs and graphs, in which graph vertices correspond to variables, and an edge exists from A to B if and only if A is a term in the equation for B. The conditional independence relationships between variables which hold in every SEM corresponding to a given acyclic graph are known to correspond exactly to certain graphical properties. Natural processes are frequently modelled with systems of equations which correspond to cyclic graphs. We demonstrate a necessary and sufficient condition, depending only on the graph structure, given which a conditional independence relation holds in every SEM associated with a cyclic graph, subject to loose constraints.

Characterizing CTCF Binding in X-Chromosome Inactivation
Ramya Deshpande
Mentors: Mitchell Guttman and Noah Ollikainen

CTCF is a zinc-finger transcriptional protein implicated in the formation of chromatin loops and involved in the regulation of X-chromosome inactivation. Elucidating the mechanism through which CTCF binding is reduced on the inactive chromosome is vital in understanding how topologically-associated domains (TADs) disappear and how three-dimensional genomic structure is altered during inactivation. ATAC-seq data in neuronal progenitor mouse cells for the active and inactive chromosome was overlapped with CTCF ChIP-seq data for mouse whole brain cells to analyze the impact of DNA accessibility upon CTCF binding; although the general trend pointed to lowered accessibility from the active (X_a) to inactive (X_i) chromosome where CTCF binding changed, with 75% of regions with a change in CTCF binding showing reduced ATAC-seq signal in the X_i, there were still a surprising number of regions which displayed little change in accessibility, although CTCF binding had changed. Subsequent motif analysis showed no significant enrichment in the set of regions with unchanging ATAC-seq signal in X_i. Further analysis was conducted to determine the contribution of a characteristic upstream and downstream flanking motif upon CTCF binding strength. Unravelling the mechanics of CTCF binding will ultimately reveal insight into how genomic structure is determined.

Computing Band Structure and Phonons for Tin Sulphide, and Use the Wannier Interpolation to Interpolate the Band Structure
Deepak Dhariwal
Mentor: Marco Bernardi

Tin Sulphide is a material of interest for thin-film photovoltaics technologies because of its abundance and non-toxic nature. We use first-principles calculations based on density functional theory to study bulk/layered structures of SnS in order to plot and interpret the electronic structure. SnS meets all the requirements of optical and electronic properties to obtain high conversion efficiency. However, far lower efficiency values have been reported. We use Quantum ESPRESSO code to perform the band structure calculations, and its PHonon package to obtain phonon dispersion relations.

Design Study of Two Stage Shape Memory Alloy Actuator
Somayajulu Dhulipala
Mentors: Kaushik Bhattacharya and Noy Cohen

Shape memory alloys (SMAs) are most suited for actuator applications due to their high power-to-weight ratio; they find use in weight-critical applications such as satellites for deployment of solar panels, MEMS and Surgical Instruments. This research aims to develop a two-stage SMA actuator using a 4-bar mechanism with SMA Springs on the diagonals. A theoretical study is done on MATLAB to understand the influence of various physical parameters on the bi-stable nature of the system. Further, models are generated to understand the transitioning of the system from one state to another upon heating. Subsequently, a theoretical design procedure is developed to manufacture a two-stage SMA actuator. Finally, a proof-of-concept of the 2-stage actuator is done to verify the theoretical models.

Deducing the Impact of DosR on the Three-Dimensional Community Development of *Mycobacterium smegmatis*
Amanda Hazel Dilmore
Mentors: Dianne Newman and Will DePas

Nearly two billion people are living with *Mycobacterium tuberculosis,* but most harbor no symptoms thanks to an adaptive immune response. Once *M. tuberculosis* growth is confined to granulomas, the transcription factor DosR aids in community survival until the immune system is weak enough for *M. tuberculosis* to escape and proliferate. DosR likewise mediates dormancy in several other mycobacteria, including the non-tuberculous *Mycobacterium smegmatis.* The Newman lab is interested in how non-tuberculous mycobacteria (NTM), which are emerging pathogens in cystic fibrosis (CF) patients, are able to survive and cause infection in chemically dynamic CF lungs. When oxygen starved, *M. smegmatis* strains lacking *dosR* (*ΔdosR*) grow much less effectively than wild type *M. smegmatis* (WT), which suggests that the DosR-controlled dormancy regulon is responsible for mediating NTM growth in the hypoxic conditions often present in CF lungs. To test this, we fused GFP to a DosR-regulated promoter in both WT and *ΔdosR* and monitored each community's fluorescence over time using confocal microscopy in an agar-block biofilm assay (ABBA). We found that over time, *dosR* is increasingly expressed in WT in oxygen-deprived regions of the ABBA. Furthermore, WT grows better in lower oxygen environments and overall forms larger aggregates than Δ*dosR.* We conclude that DosR mediates growth of extensive mycobacterial communities, especially in regions deprived of oxygen. This supports our hypothesis that the DosR-controlled dormancy regulon aids in NTM growth in hypoxic regions of CF lungs.

Machine Learning for Cybersecurity: Botnet Detection Using Network Flows Over Limited Time Intervals
Stephanie Ding
Mentor: Julian Bunn

Botnets are collections of connected, malware-infected hosts that can be controlled by a remote attacker, and are one of the most prominent threats in cybersecurity as they can be used for a wide variety of purposes, such as denial-of-service attacks, spam or bitcoin mining. We aim to develop a real-time detection system that utilises machine learning to distinguish between botnet and non-botnet network traffic. Using existing datasets, we investigate the effectiveness of detecting botnets using network flow records, which provide a concise, but partial summary of the complete network traffic profile. We extract a set of statistical features associated with each flow and train classification models to predict whether a flow is malicious or benign based on these features. We also examine the effect of varying the feature set on classifier performance and compare several popular learning algorithms to select optimal models. Finally, we demonstrate the feasibility of botnet flow detection on flows generated over limited time intervals, and implement a proof-of-concept system that aggregates the results of multiple machine learning models to detect infected hosts.

Electrochemical Cell With Ti-Based Electrodes for Human Wastewater Treatment and Hydrogen Recovery
Heng Dong
Mentor: Michael Hoffmann

Electrochemical oxidation (EO) is proved to a highly efficient decentralized water treatment technique to address sanitation challenges in developing countries and rural areas. However, EO was usually recognized as energy intensive process that could produce disinfection byproducts. It is also incapable of recover ammonia as fertilizer, as ammonia could be unselectively oxidized by electrochemically generated free chlorine via breakpoint chlorination. Herein we propose a dual-chambered electrochemical cell to overcome the above drawbacks. A triple layer $SnO_2/CoTiO_2/Ir_{0.7}Ta_{0.3}O_2$ anode was installed in anodic chamber. It has a chlorine evolution rate of 0.920 mg/(L·s), with a current efficiency of 41.7%. In cathodic chamber, we installed a newly developed black nanotube cathode that is more active for electrochemical chlorate reduction compared with the previously reported blue nanotube. Anodic chamber and cathodic chamber were separated by a piece of cation exchange membrane. Wastewater is first treated in anodic chamber then transferred to cathodic chamber, in which the disinfection byproducts and residual free chlorine will be reduced. Meanwhile, a stream of high purity hydrogen could be produced as fuel at cathodic chamber to partially compensate the energy consumption of EO process. Interestingly, it is found that NH_4^+ selectively passed through the CEM from anodic chamber to cathodic chamber during electrolysis. This approach not only enables the recovery of NH_4^+ as liquid fertilizer but also drastically facilitates the anodic wastewater treatment as more free chlorine can be utilized to oxidize organics instead of being consumed by NH_4^+ to form less oxidative chloramines. The energy consumption is significantly reduced from 166 kWh/kg COD for one-chambered cell to 90 kWh/kg COD for dual-chambered cell.

Translating Chemical Reaction Networks Into DNA Strand Displacement Networks
Harel Dor
Mentors: Erik Winfree, Chris Thachuk, and James Parkin

Chemical Reaction Networks (CRNs) provide a succinct notation able to describe complex dynamical systems. In the field of DNA Nanotechnology, various translation schemes have been developed for converting CRNs into DNA Strand Displacement (DSD) networks, sets of DNA molecules that, through the displacement of single-stranded components of double-stranded DNA helices, carry out series of reactions. Several schemes for translating CRNs into DSD networks that exhibit the same behavior have been proposed and demonstrated on simple CRNs such as oscillators and consensus networks. We modify Piperine, an existing CRN-to-DSD compiler, such that it is able to easily translate the same CRN into multiple different DSD schemes. Our aim is to then demonstrate that the compiler produces functional sequences by using the new schemes on simple CRNs, such as one that calculates max(X, Y). Further work will focus on adding support for a wider variety of CRN-to-DSD translation schemes, as well as streamlining the process of adding this support.

Design and Fabrication of a Wafer-Scale Thermionic Energy Converter
Rohan Doshi
Mentors: Roger Howe and Hyuck Choo

A thermionic energy converter (TEC) uses the phenomenon of thermionic emission to convert heat energy into electrical energy. Electrons are emitted by a heated cathode and are caught by a cooler anode. When the two are connected there is a potential difference between anode and the cathode and there is a current flowing due to thermionic emission, thus creating electrical power. A large challenge with achieving high-efficiency TECs is minimizing the space-charge effect, a phenomenon in which electrons collect in the gap between the cathode and the anode, drastically reducing the output current. Breakthroughs in MEMS fabrication techniques over the past decade have made curbing this effect possible. By shrinking the gap between the anode and cathode to several microns, and by placing the TEC in a vacuum with cesium vapor, one can minimize the space-charge effect and achieve peak efficiency. This work focuses on both using MEMS techniques to build a vacuum-sealed device with a ~3-5 micron electrode gap and on building a large-scale vacuum chamber with measurement, heating, and cesium-control setups to test the performance of different electrode materials and device configurations.

The Analysis of Asteroid Light Curves
Alison Dugas
Mentor: Chan-Kao Chang

Super-fast rotators are a class of small asteroids that rotate faster than the usual limit for asteroids of their size. Because the number of known super-fast rotators is small, they are not very well-understood as a group. In order to gain further insight into the physics behind these asteroids, it is necessary to have an accurate estimate of their population size relative to other small asteroids. Here we used data from the Palomar Transient Factory (PTF) to compile light curves for 2,694 asteroids. A period analysis was performed in order to identify possible super-fast rotators and find their rate of occurrence in our data. This analysis was repeated on a simulated set of similar light curves, and machine learning was used to calculate the recovery rate for periods of varying length. From this we are able to produce an accurate estimate of the relative size of the super-fast rotator population.

Determining Thresholds for Quantum Error-Correction Codes via Ising Spin Glass Simulations
Megan Durney
Mentors: John Preskill, Tomas Jochym O'Connor, and Aleksander Kubica

Stabilizer codes, a form of quantum error-correction code used to combat information decoherence, share a topological connection to classical many-body models. An example of such is the thermodynamic Ising model, which allows for the study of rich physics through simulating localized interactions of magnetic moments across a lattice of spins. These interactions are described by the Hamiltonian function for the system, and, through negating the coupling for random interactions given by the Hamiltonian, noise can be introduced into the model. By studying how noise perturbs the system, we can abstract insight on the nature and effectiveness of error-correcting codes. To detect the stability of a quantum error-correction code, we run Monte Carlo simulations of Ising spin glasses set on a torus. We are looking for continuous phase transitions where the system shifts from an ordered to a disordered state at a critical temperature. By plotting the correlation function against temperature for differently sized lattices of the same qubit error rate below the system's error threshold, we can find the critical temperature at the point of intersection. For 0% and 5% error rates, we initially observe the critical temperatures to be between 2.26-2.27 K and 2.06-2.09 K, respectively.

Optimisation and Characterisation of Ultrathin Nanoabsorbers for Photocatalysis
Eoin Elliott
Mentors: Harry A. Atwater and Giulia Tagliabue

Rising levels of atmospheric CO_2 due to humanity's reliance on fossil fuel energy sources are affecting the earth's climate and mandating a global shift towards renewable energy sources. Solar powered photocatalytic reduction of CO_2 could provide storable renewable energy in the form of combustible hydrocarbons. Metals have shown high selectivity in electrochemical CO_2 reduction and can demonstrate increased efficiency by the photonic generation of e^-/h^+ hot carriers. Engineered photonic nanostructures made from catalytic metals have been shown to efficiently absorb light across the entire solar spectrum, and serve as reaction sites for selective CO_2 reduction. A Salisbury screen type absorber consisting of metal films separated by a transparent dielectric is shown to have tuneable absorption, directly altering the hot carrier prompt distribution in the absorbing metal and paving the way for precise selectivity in complex photoelectrochemical devices. Optimised Pd and Pt absorbing nanostructures were fabricated and optically characterised, showing agreement with transfer matrix method theory, demonstrating broad applicability to photoenhancement of reactions with metal catalysts. As this design is lithography free, using only e-beam deposition they show potential as a cheap, selective, efficient, and scalable photocatalytic nanostructure for CO_2 reduction.

Neural Correlates of Interpersonal Flow Experience: Eye-Tracking Measurements
Salma Elnagar
Mentors: Shinsuke Shimojo and Mohammad Shehata

Flow is achieved when a person is said to be “in the zone” as he/she achieves a fit between skills and challenge level in a certain activity. Many of those activities, like video games, playing music or athletic competitions, involve the participation or company of other people. Thus, interpersonal communication could potentially be related to reaching the mental state of flow. Previous research has identified brain areas like the inferior frontal gyrus to be related to individual flow. However, no experiments were yet conducted on interpersonal flow. The purpose of this project is to identify the neural correlates of interpersonal flow experience using EEG and eye tracking measurements in a two-players game paradigm. Pupil diameter and blink rate are measured as an objective indication of when a person is in flow. Ten pilot subjects have been asked to play the game individually and eye measurements were collected using Eyelink 1000. Preliminary analysis of the data collected from 10 participants suggests that pupil diameter and blink rate could be an objective measure of flow experience.

Searching for Variable Stars and Dropouts in the Galactic Plane
Brodi Elwood
Mentors: Thomas A. Prince and Thomas Kupfer

The galactic plane is full of interesting objects, many of which have yet to be identified. A search was performed of the high cadence Galactic Plane Survey collected from the Mosaic instrument on Palomar 48. Objects were cross-matched across frames, for a total of 63 observations per object over a two-hour timespan. Numerous variability indices were calculated from the resultant light curves, which were then filtered based on higher variability and probability of dropout. Frequency analysis was then performed on the filtered light curves. Further research would study these interesting objects for more detailed identification and classification.

Simulation of Nanostructured Metal Surfaces for Intraocular Pressure Sensor Development
Nicole Feng
Mentors: Hyuck Choo and Haeri Park

The Choo lab has been developing an implantable intraocular pressure (IOP) sensor that relies on mechanical deformation to produce a detectable shift in reflectance when light is shined on the sensor. However, the mechanism is dependent on the light's angle of incidence, hindering convenient use by glaucoma patients. As proof-of-concept of an alternative, angle-independent mechanism, simulations of nanopores on an underwater metal surface were implemented in COMSOL Multiphysics and Surface Evolver software. The investigation focuses on the movement and stability of the air-water interface within the pores in response to pressure. Simulations of cylindrical, spherical, and other curved-wall pores ranging from 45 – 300 nm in radius and up to 900 nm deep were implemented. Pore dimensions and hydrophobicity were also varied to achieve pressure sensitivity within human IOP range. Evolver simulations were developed in tandem with those in COMSOL to further understand the wetting mechanism through energy analysis. The simulations provide insight into developing a practical pore-based IOP-sensing mechanism.

Synthetic Spectra for Testing Spectroscopic Exoplanet Detection
Luke M. Finnerty
Mentors: Geoff Blake, Cam Buzard, and Danielle Piskorz

Using high-resolution near-infrared spectroscopy, exoplanet systems may be treated as spectroscopic binaries. Compared with methods that look only at the radial velocity of the host star, this approach gives additional information on the orbital velocity, and therefore mass, of the exoplanet, as well as information about the contents of the exoplanet's atmosphere. However, the precision and limits of these techniques are still uncertain. In order to better determine the limitations of a spectroscopic approach, we develop synthetic spectra to simulate different stellar and planetary spectra, relative velocities, star/exoplanet contrast ratios, telluric spectra, and instrumental effects. By varying these parameters as well as the number and distribution of observations, we can simulate a wide range of observations for a variety of exoplanet systems. The results of these simulations will give a better sense of the constraints the spectroscopic approach is subject to and assist in target selection and observation planning in the future.

SkyPlotter: Displaying Source Candidates Close to High-Energy Neutrino Events
William Fiore
Mentor: Anna Franckowiak

The IceCube neutrino observatory has detected a flux of high-energy neutrinos. However, the origin of those high-energy astrophysical neutrinos is currently unknown. Possible source class candidates are supernovae (SNe), active galactic nuclei (AGN), gamma-ray bursts (GRBs), and other sources of gamma rays. I have developed a visualization tool, called SkyPlotter, to display sources of those classes in the vicinity of a given direction. SkyPlotter draws on catalogs of gamma ray, X-ray, and optical sources of both steady and transient nature. Skyplotter displays sources within the neutrino error circle and provides relevant information, such as flux and redshift. I have applied the tool to IceCube's public neutrino candidates and compared the results to sources found in random directions in the sky.

Characterizing the Mechanical and Conductive Properties of Micro-Architected Materials
Zoey Flynn
Mentors: Chiara Daraio and Eleftheria Roumeli

Recently, micro-architected materials have garnered a great deal of attention. Micro-architected materials have a designed internal structure that can alter the strength, density, and other critical properties of the material by orders of magnitude. The Daraio group at Caltech has been studying the mechanical behavior of nano-reinforced micro lattices with various architectures. The preliminary findings demonstrate that the presence of exceedingly low amounts of nanofillers (<0.01 wt%) leads to a significant increase in the stiffness and strength of the micro-architected composite material. We used stereolithographic (SLA) 3D-printing to fabricate CNT-reinforced structures which were subsequently carbonized through pyrolysis. We will present the measured mechanical and electrical properties of several CNT-reinforced lattices.

Classification of Hyperluminous X-ray Source Candidates
Maya Fuller
Mentors: Fiona Harrison, Marianne Heida, and Daniel Stern

Hyperluminous X-ray sources (HLXs) are extragalactic sources with bolometric luminosities $>10^{41}$ erg/s that are located in a galaxy, but outside of its nucleus and they are candidates for intermediate mass black holes (midsize black holes with masses between 10^2 - 10^6 $M_\odot$). Intermediate mass black holes would serve as the bridge between stellar-mass black holes and supermassive black holes and should, in theory, exist, but there is little evidence of them.

The goal of this project was to classify spectra of HLX candidates and measure their redshifts to ensure that they are in the galaxy they appear to be in. To do this, I reduced spectroscopic data of a sample of potential HLXs that were selected using the 3XMM-DR5 catalog of X-ray sources and the Sloan Digital Sky Survey Data Release 12 and observed with Keck/DEIMOS. The next step will be to identify the most promising HLX candidates for follow-up studies, including Palomar and Keck spectroscopy.

Design of Experimental Flow Battery System for Testing of Ferro/Ferricyanide-Based Complexes
Devi Ganapathi - Caltech
Mentors: Simon Jones - JPL, Harry Gray, Brendon McNicholas, Emmanuelle Despagnet-Ayoub - Caltech

Redox flow batteries have been proposed as a system to store electricity generated from solar energy during the day and dissipate it at night. Electrochemically active complexes that undergo highly reversible redox reactions are currently being investigated for use in these batteries. In this study, the species $[Fe(CN)_6]^{3-/4-}$, $[Fe(CN\text{-}BPh_3)_6]^{3-/4-}$, and $[Fe(CN\text{-}B(C_6F_5)_3)_6]^{3-/4-}$ were characterized through UV-Vis spectroscopy and basic electrochemical testing. A flow battery created from these compounds was theorized to produce a voltage of ≥ 3 V, higher than most commercial systems currently in use. Two systems were designed to test the practicality of using these compounds in flow batteries. The first was a fuel cell modified to have flow cell functionality. The second system was an H-cell with two active compartments separated by a membrane. The modified fuel cell resulted in high crossover of active species across the membrane, making it a poor system for flow cell testing. With modification of commercially available Nafion membranes, the H-cell was optimized for flow cell testing, laying a foundation for future experiments.

Auditory-Visual Crossmodal Interactions in Perception: The Spatial Double Flash Illusion
Ishani Ganguly
Mentor: Shinsuke Shimojo

Multimodal illusions, such as the double flash experiment initially carried out in the Shimojo Laboratory, allow us to understand how humans prioritize and organize sensory stimuli when perceiving their surroundings. This classic experiment overturned predominating concepts by demonstrating that in some cases audition can be prioritized over vision, and showed that the brain can postdictively alter future perceptions based on already perceived stimuli. My project deals with a recently discovered variation of the original double flash illusion called the spatial double flash illusion. In this experiment, a central visual flash is initially depicted in conjunction with an auditory stimulus that is displaced to one side. Then, a second auditory stimulus displaced to the opposite side generates an illusory visual flash in that direction. My objective was to optimize the robustness of the illusion by noting how altering various factors influence the postdictive perception observed. To achieve this, specific experiments were coded in MATLAB and subsequently run on human subjects. Pilot results suggest that the addition of a static fiducial bar extending into central vision, in addition to the original visual flash set in the periphery, strengthens the illusion by making it easier for subjects to perceive a sense of movement.

Manipulation of Silicon Nanoparticle Size via *in situ* Incorporation of Surface Functional Groups
Paige Gannon
Mentors: Theodor Agapie and Heui Beom Lee

Silicon nanoparticles with alkyl and amide surface functionalization have been synthesized via the reduction of silicon tetrachloride with alkyl trichlorosilanes and lithium dioctylamide respectively. These reactions were completed at room temperature in an air and water free environment, with sodium naphthalenide used as a reductant. Elemental analysis via SEM and EDS has confirmed the presence of silicon and carbon in the products. Further supporting characterization as nanoparticles, fluorescence spectroscopy has revealed emission near 400 nm, as well as in the near IR region, both of which are consistent with literature reports of silicon nanoparticles. Through varying the quantity of surface functional groups present in the reaction mixture, as well as other reaction conditions, the possibility of size control has been explored.

Investigating Sulfur Mass-Independent Fractionation (S-MIF) in the Archean Atmosphere
Amanda Gao
Mentors: Yuk Yung and Pin Chen

In 2000, sulfur mass-independent fractionation (S-MIF) was first discovered in Archean rocks; today, researchers still struggle to explain observed S-MIF and its implications for the composition of early Earth's atmosphere. Though most studies have focused on SO_2 photolysis as the key process causing mass-independent fractionation of sulfur isotopes, recent work suggests that sulfur recombination reactions may have also played a defining role in generating observed S-MIF. Using KINETICS, an atmospheric modeling program developed at JPL and Caltech, we have been able to approximately reproduce recent modeling results that posit sulfur recombination as a major mechanism in S-MIF formation. Our completed atmospheric model, acting in tandem with other current efforts to explain S-MIF, will hopefully provide needed insight on the precise nature of the Archean atmosphere.

Label-Free Detection of Pancreatic Islet Secretions for Diabetes Management
Ian Garcia
Mentors: Hyuck Choo and Shailabh Kumar

Pancreatic cell transplantation has proven to be a potential cure for patients with type 1 diabetes, where healthy cells from donors are transplanted into patients. However, current methods for testing whether pancreatic cell clusters (islets) obtained from donors are healthy enough to produce insulin under high blood glucose conditions requires the use of molecular labels. This process is inefficient and often leads to damage to the cells being tested. The Choo lab seeks to eliminate the use of molecular labels by using Raman spectroscopy to determine the secretion profile of the islets. To find these signatures we soak gold nanoparticle cluster-based surface-enhanced Raman scattering (SERS) substrates in various kinds of islet secretion for about twelve hours and use a 785 nm Raman laser to record the Raman signal from the islet secretions. We have found several spectral differences between samples secreted by the islets under low glucose and high glucose conditions, including a small peak at 810 cm-1 that could be of viable use to a label free detection system.

Timing Studies for CMS ECAL Calibration Using Z Boson Decays to Electron-Positron Pairs
Daniel Gawerc
Mentor: Maria Spiropulu

The Compact Muon Solenoid (CMS) experiment records data from proton-proton collisions at the Large Hadron Collider (LHC) to measure properties of, and probe physics beyond, the Standard Model. The CMS electromagnetic calorimeter (ECAL) is a cylindrical layer of lead tungstate crystals that detect the energies of electrons and photons. To best utilize the ECAL timing capabilities to find new physics, the clocks in every crystal must be synchronized. Z boson decays to electron-positron pairs are used to ascertain and to eventually improve the current ECAL time resolution. Z boson decay data from 2016 yields an ECAL time resolution of 420 picoseconds, much worse than the LHC Run 1 ECAL time resolution of 70 ps. Even after applying two crystal transparency corrections for time resolution, it did not noticeably improve. Investigating the time-of-flight of a single electron/positron through multiple crystals, a time resolution of 140 ps was achieved. In addition to plots of time resolution against ECAL geometry, this local time resolution suggests that the algorithm for combining crystal timestamps on a global level can be refined.

Determining the Wrong-Sign Component of a NOvA Beam in Anti-Neutrino Mode
Monika Getsova
Mentors: Ryan Patterson and Kirk Bays

In order for the NOvA experiment to be able to accurately study and compare neutrino and anti-neutrino oscillations, the wrong-sign component of a beam must be able to be determined with great accuracy. However, there is currently no way to directly measure the wrong-sign of an anti-neutrino beam. Using ROOT, I tested several proposed handles for determining the wrong-sign of the anti-neutrino beam using a Monte Carlo simulated data set as well as real detector data and statistical methods such as chi-squared analysis to determine each handle's efficacy. If, through further research, a method is developed that can measure the wrong-sign component of an anti-neutrino beam, then exciting new information can be gained about the neutrino mass hierarchy as well as CP violation in neutrinos.

An Investigation of a Semidefinite-Analogue of Dictionary Learning
Nikhil Ghosh
Mentors: Venkat Chandrasekaran and Yong-Sheng Soh

The theory of sparse representations plays an important role in many areas of engineering and statistics. The utility of sparse representations comes from the notion that data can often be modeled using relatively few degrees of freedom compared to its ambient dimensionality. For example, natural images are often well-approximated by a small number of wavelet coefficients, financial time series may be characterized by low-complexity factor models, and a small number of genetic markers may constitute a signature for disease. In each case, the datapoints can be concisely represented by linear combinations of a set of atoms. An interesting question arises when an appropriate set of atoms is not known a priori. This leads to the problem of "dictionary learning". Given a dataset, how do we identify a set of atoms such that the data permits succinct representations? This is the main question of dictionary learning. In our project, we consider an operator analogue of this problem. Namely, the goal is to find a linear map such that the data can be expressed as the image a low-rank matrix.

Risk-Aware Motion Planning for Mars Rovers
Sourish Ghosh
Mentors: Richard Murray and Masahiro Ono

Accurate kinematic state estimation for Mars Rovers is computationally expensive since they have two rocker-bogie suspensions on each side and a common differential mechanism summing up to 10 degrees of freedom. Therefore we introduce a faster and approximate state estimation algorithm that works on a 3-dimensional configuration space and estimates probability distributions of the 7 other internal state parameters. We use these distributions to perform collision checking by computing the total probability of failure of the internal parameters over an edge in a planning graph. Traversability of an edge is checked using a threshold on the probability of failure, which we term as the risk-factor. We use a simple arc-based path planning algorithm to demonstrate this probabilistic approach. The algorithm is tested on the Athena Rover at the Mars Yard, JPL.

Identifying Periodicity Due to Close-Binary Stars in Planetary Nebulae
John Gilhooley
Mentor: Nadejda Blagorodnova

Planetary nebulae (PNe) are expanding clouds of dust and gas that have been ejected from their progenitor stars. Their complex morphologies have been attributed to rotational/magnetic effects and most recently, binary interactions in a common envelope (CE) during the later stages of binary evolution. CE interactions are currently poorly understood due to a dearth of observed objects, so it is important to increase the sample size by finding more close-binary (CB) stars in PNe. PNe are extremely short lived on astronomical timescales, so the state of the

CB in this phase is representative of how the system would be immediately after the ejection of the CE. Finding such objects can be achieved by selecting objects close to the centre of PN that are blue in colour and performing a time series analysis on their light curves to search for indicators of periodicity. In doing so, we have identified 5 possible candidates in archival data from the intermediate Palomar Transient Factory.

Magnetohydrodynamics Simulation With Formal Lagrangians
Mark Gillespie
Mentor: Peter Schröder

Electrically conducting fluids appear throughout nature, from the center of the Earth to the surface of the Sun. Simulations of magnetohydrodynamics (MHD) in the earth's core have provided key insight into the earth's changing magnetic field. And understanding the interplay between magnetic fields and fluid flow in the Sun is essential to understanding solar phenomena such as sun spots and coronal mass ejection. We present a fully-variational integrator for ideal MHD in a two-dimensional domain with boundary and prove that the integrator preserves total energy, magnetic helicity and cross helicity.

Modeling the Relation Between Curli Fibrils and Mutant Huntingtin Oligomerization
Matthew Gladstone
Mentor: Ali Khoshnan

Curli fibrils are a group of functional amyloid proteins produced by the bacteria of the order enterobacteriales some of which are common gut bacteria. This amyloidogenic property is relevant to huntingtin aggregation in the progress of Huntington's disease also caused by an amyloidogenic protein. By transfecting HEK 293 cells with mutant huntingtin exon 1 and then adding curli fibrils to the medium the ability of the fibrils to promote huntingtin oligomerization may be tested. Huntingtin-GFP fusions are utilized to allow fluorescence imaging study of the oligomerization in combination with a program to identify the aggregates in the image and determine the proportion of the brightness in the image that is within these aggregates. Results thus far seem to indicate that this addition of curli fibrils does promote the oligomerization of Huntingtin. Further study of this relation may show that this is a major environmental factor in the course of Huntington's disease.

Exploring a Pockels Cell's Use as a High Frequency Voltage Controlled Waveplate
Juan (Felipe) Gomez
Mentors: David Hsieh and Alon Ron

The Pockels Effect creates a birefringence on a crystal induced by an applied electric field. By carefully timing an applied voltage with the pulses of a pulsed laser going through the crystal, and by choosing the applied voltage to yield a specific phase shift between two perpendicular polarization components of the pulses, an effective voltage-controlled waveplate is created. Such a device, the Pockels Cell, can modulate between a half-wave plate, which shifts the polarization components by π, and adding no new phase shift. Here, we exploit this feature to turn the Pockels Cell into an effective high frequency optical chopper to improve the signal-noise ratio of a pump-probe setup. Ultimately, this approach fails due to the piezo-electric ringing of the KD*P crystal at high frequencies. We consider other setups that require lower frequencies where the Pockels Cell could still be used, such as the optical Kerr setup, where the Pockels cell will divert different polarization components to a photo detector.

Creating Cobalt Phosphide Catalyst Films via Pulse Electrodeposition for the Hydrogen Evolution Reaction in Acidic Conditions
Miguel Angel González
Mentors: Nate S. Lewis and Paul A. Kempler

Platinum-based catalyst are widely considered to be the most effective electrocatalysts for the hydrogen evolution reaction (HER), but their high costs and scarcity makes them impractical for use in economically- competitive energy conversion devices. As result, earth-abundant metals have widely been studied as cost-effective alternatives despite having significantly lower catalytic activity and stability under operating conditions. In this work, cobalt phosphide films were created via short-pulsed electrodeposition to alter the elemental composition and morphology of created films to improve catalytic activity and film stability under acidic conditions. Created films were studied via scanning electron microscopy and their activity assessed via cyclic voltammetry and chronopotentiometry. Electrochemical impedance spectroscopy was utilized to in order to understand the charge-transfer limitations of the electrode system. Preliminary results demonstrate pulse-electrodepositions creating uniform phosphorus-rich films with better catalytic activity than traditional constant-voltage electrodeposited films.

Modeling the Atmosphere in the Era of Big Data From Extremely Wide Field-of-View Telescopes

Junellie Gonzalez Quiles
Mentor: Jakob Nordin

Surveys like the Sloan Digital Sky Survey (SDSS), Pan-STARRS and the Palomar Transient Factory Survey (PTF) receive large amounts of data, which need to be processed and calibrated in order to correct for various factors. One of the limiting factors in obtaining high quality data is the atmosphere, and it is therefore essential to find the appropriate calibration for the atmospheric extinction. It is to be expected that a physical atmospheric model, compared to a photometric calibration used currently by PTF, is more effective in calibrating for the atmospheric extinction due to its ability to account for rapid atmospheric fluctuation and objects of different colors. We focused on creating tools to model the atmospheric extinction for the upcoming Zwicky Transient Factory Survey (ZTF). In order to model the atmosphere, we created a program that combines input data and catalogue values, and efficiently handles them. Then, using PTF data and the SDSS catalogue, we created several models to fit the data, and tested the quality of the fits by chi-square minimization. This will allow us to optimize atmospheric extinction for the upcoming ZTF in the near future.

Increasing Incorporation of Non-Canonical Proline in Proinsulin

Kristen Goodfriend
Mentors: David Tirrell and Alex Chapman

Non-canonical amino acids (ncAAs) are produced by modifying the side chains of standard amino acids. When incorporated into therapeutic proteins, ncAAs could allow researchers to exert a medicinal chemistry-like control over the protein's structure and function. Insulin, a well-known therapeutic protein used to treat diabetes, is a model case for the applications of ncAAs. Insulin contains one proline residue at position B28, which can be replaced with proline derivatives in a residue-specific manner. While this method of ncAA mutagenesis sometimes results in high incorporation of certain ncAAs onto the peptide chain simply using the biosynthetic machinery of the host cells, some ncAAs cannot be properly charged onto the tRNA by the natural tRNA synthetase, resulting in minimal or no incorporation of the desired amino acid derivative. To address this issue, we have mutated the prolyl-tRNA synthetase to alter the binding pocket with the goal of accommodating (3R)-hydroxy-L-proline and (4S)-carboxy-L-proline. We have determined the qualitative extent of proinsulin expression and ncAA incorporation using gel electrophoresis. While we have observed no significant incorporation of (4S)-carboxy-L-proline using the mutated prolyl-tRNA synthetases, we are continuing to explore how these mutated synthetases affect the incorporation of other proline derivatives, including (3R)-hydroxy-L-proline.

Modeling the Role of Thermally-Activated Viscous Flow in Subduction Zone Slow-Slip Events

Arjun Goswami
Mentors: Sylvain Barbot and Jean-Philippe Avouac

Slow-slip events (SSEs) are earthquake-like events characterized by low slip rates. While peak coseismic velocities can reach tens of meters per second, SSEs can be as slow as on the order of 10^-7 m/s, with slip lasting for days or weeks. Under the widely-used rate-and-state model of fault friction, only a narrow range of frictional parameters can produce SSEs. However, SSEs are common in subduction zones worldwide, which presents a conundrum. It is unlikely that subduction zones across a wide range of international sites embody the same narrow range of parameters. The ubiquitous phenomenon of SSEs on subduction zones can alternatively be explained by thermal effects. Shear heating and high temperatures at depth induce melting and thermally-activated viscous flow. This velocity-strengthening mechanism inhibits fast ruptures. To investigate, a dynamic, semi-brittle model of a fault is implemented, which incorporates both friction and flow as constitutive properties. Exploration of the parameter space, and observation of the thermal behaviors accompanying slip events, can lend insight into the fundamental nature of subduction zone SSEs.

Design and Initial Experimental Characterization of a DNA-Based Neural Network With Learning Capabilities

Gokul S. Gowri
Mentors: Lulu Qian and Kevin Cherry

Biomolecular circuits to carry out neural network computations have been successfully implemented via DNA strand displacement cascades. However, these computations are not adaptable, and neuron weights must be determined *in silico* prior to chemical implementation. Consequently, learning systems are not possible in existing frameworks. Here, we explore the possibility of using an activatable seesaw gate motif to allow *in vitro* manipulation of weights in a winner-take-all neural network. We explored several molecular designs, and identified two designs to be the most feasible. Because these designs each have distinct advantages and potential issues, we look to experimental characterization to gain a better understanding of both designs. The first step in demonstrating an activatable seesaw gate requires plugging it into the previously developed winner-take-all neural network. To directly read the output signal of the activatable seesaw gate while keeping the other components of the winner-take-all circuit unchanged, and to save the cost and turnaround time for purchasing new fluorophore and quencher labeled strands as required in traditional reporters, we adapted and experimentally characterized a modular reporter design. Using this modular reporter complex, we explore the viability of the two activatable seesaw gate designs for implementation of molecular learning in a DNA winner-take-all system.

2-BIT Demonstration of Bimolecular Processes in Multiphoton Lithography
Muskaan Goyal
Mentors: John Fourkas and Julia A. Kornfield

The order of nonlinear processes involved in multiphoton lithography is investigated via 2-Beam Initiation Threshold (2-BIT) characterization. The order of nonlinear polymerization is expected to be consistent only with two-photon absorption. However, at very high and very low repetition rates of laser pulses, the order is higher, indicating additional processes occurring simultaneously. The most likely explanation is the presence of triplet-triplet annihilation (TTA), a bimolecular process in which two triplet-state molecules collide to produce one molecule in an excited singlet state. This process would account for the higher effective order of the polymerization process. To test this hypothesis, first, a Matlab simulation of the two-photon absorption process is carried out with and without the presence of TTA over long exposure times to give an idea of the expected order of polymerization. Second, 2-BIT experiments are performed on biacetyl and on 7-diethylamino-3-thenoylcoumarin (DETC) with varying wavelengths of deactivation to determine the experimental order of the process.

Development of a 10 Picosecond Time-of-Flight Detector
Marcel Griffioen
Mentors: Maria Spiropulu and Cristián Peña

The Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC) records data from proton-proton collisions to search for new physics beyond the Standard Model. The High Luminosity upgrade to the LHC will increase the number of proton-proton collisions per bunch crossing (pileup) by a factor of ten, making it very difficult to reconstruct the collision vertices. The electromagnetic calorimeter (ECAL) is used to determine the energy of particles leaving the collision site. One solution to the problem of collision pileup is giving the ECAL precision timing capabilities. If the timing resolution of the ECAL is increased to roughly 20 picoseconds, the pileup of collisions can be reduced drastically. One instrument proposed for use in this timing layer is the silicon photomultiplier (SiPM), which has been experimentally shown to exhibit a time resolution of as low as about 5 picoseconds.

Investigating Structure of *Sc*Get3 in Complex With Tail-Anchored Protein Cargo Utilized in GET Pathway
Reeti Gulati
Mentors: Bil Clemons and Michelle Fry

Tail-anchored (TA) proteins in eukaryotes must be targeted to the endoplasmic reticulum and mitochondrial membranes post-translationally through specialized pathways. In fungi, this transport is conducted by the Guided Entry of Tail-anchored proteins (GET pathway), which involves 6 different proteins, Get1-5 and Sgt2. Currently, two models of the GET pathway exist due to various evidence suggesting that the Get3 protein linked to the TA protein in this pathway exists both as a homodimer and a homotetramer. This project aimed to determine whether the tetrameric form of Get3 when transporting TA proteins in the GET pathway is of biological significance. The goal of this project was to obtain an atomic reconstruction of the tetrameric form of Get3 in complex with TA protein. To obtain this, we created constructs containing a TA protein (Bos1, Pep12, Sbh1) without its N-terminal domain. This was done to minimize aggregation of the protein. These constructs were expressed along with Get3 protein in *E. coli* and purified thoroughly via affinity and size exclusion chromatography. The obtained tetrameric form of Get3 in complex with TA protein will be observed under negative-stain imaging to determine if the expected features such as a tubular shape and 15 nm length are seen. If the protein appears homogenous and representative of the tetrameric Get3, we will continue on to cryo-EM to obtain high resolution reconstructions.

Implementation of Randomized Algorithms With Stochastic Chemical Reaction Networks
Evan Gunter
Mentors: Erik Winfree, Robert Johnson, and Andrés Ortiz-Muñoz

In the stochastic chemical reaction network (SCRN) model of computation, an algorithm is described by (1) a set of reactions with their stochastic rate constants and (2) a set of initial counts of molecules. The randomness and parallelism inherent in this model allows for efficient implementations of randomized algorithms. I demonstrate an SCRN that implements a probabilistic algorithm for problems in complexity classes PP and BPP and examine the time efficiency of this SCRN. I also investigate the possibility of simulating probabilistic Turing machines with SCRNs. This research is conducted with the goal of better describing the powers and limitations of SCRNs as a model of computation.

Investigating MORC-1 Phosphorylation in the *C. elegans* Germline
Gloria Ha
Mentors: John Kim, Nicita Mehta, and Rob B. Phillips

Endogenous small interfering RNAs (endo-siRNAs) in the nematode *Caehnorhabditis elegans* are deposited from the maternal germline into the embryo. This transgenerational inheritance of endo-siRNAs is critical for both germline maintenance and for heterochromatin formation at target genes. We previously found that *morc-1*, the *C. elegans* homolog of the highly conserved Microrchidia family of chromatin-binding proteins, is a crucial link between endo-siRNAs and multigenerational chromatin organization. MORC-1 is comprised of an ATPase domain and a zinc finger domain. Based on conservation analysis, an "E39A" mutation in the ATPase domain of MORC-1 was found to exhibit much higher levels of phosphorylation than wild type MORC-1. Mass spectrometry yielded two putative phosphorylation sites of MORC-1, both serines. A "WWAA" mutation in the zinc finger domain of MORC-1 has been implicated in preventing recombination. Additionally, co-immunoprecipitation showed that MORC-1 directly interacts with CSR-1, the only *C. elegans* Argonaute that is essential to fertility and embryo viability. The interesting phosphorylation behavior of MORC-1, in addition to its role in recombination and its interactions with a critical Argonaute, led us to further investigate these qualities. We verified two putative sites of MORC-1 phosphorylation through immunoblotting, and sought to identify the kinase that phosphorylate MORC-1 through a targeted screen of 58 germline kinases. Through genetic crosses, we found that knocking down *csr-1* through RNAi rescues the WWAA recombination defect. We also imaged CSR-1 localization in the absence of MORC-1 through immunofluorescence, and investigated the interaction between CSR-1 and MORC-1 in different RNAi backgrounds through co-IP. Our results have identified putative kinases responsible for MORC-1 phosphorylation and further clarified the relationship between MORC-1 and the Argonaute CSR-1.

Encapsulation Methods for Thermosensitive Pectin Films
Richard T. Hamel
Mentor: Chiara Daraio

As autonomous robotic systems grow more advanced, the need for more sophisticated sensors grows more apparent. One of the more difficult sensory devices needed is a robotic skin since such a sensor must be flexible to function. Dried pectin treated with calcium ions forms a flexible film whose conductivity is highly dependent on its temperature, making it an excellent thermosensitive skin for applications where it must conform to mobile architectures like robotic arms and joints. While these skins are quite sensitive to temperature, they are also hygroscopic, making them very sensitive to humidity as well, diminishing its usefulness for accurately sensing temperature. This study examines several encapsulation methods to protect thermosensitive pectin films from humidity changes and make them viable as useful thermosensitive devices.

Inhibiting DNA Repair by DNA2
Keira Hamilton
Mentors: Judith L. Campbell and Piotr J. Polaczek

DNA dependent replicative nuclease/helicase 2 (DNA2) is an enzyme involved in DNA replication and repair. It plays key roles in removing flaps during Okazaki fragment maturation and in degrading stalled replication forks in order to stabilise them, as well as in 5' end resection preceding homologous recombination repair. Previously, it was found that DNA2 is upregulated in some cancers, and that upregulation correlates with poor prognosis in breast and ovarian cancer. We have been performing *in vivo* tests on the DNA2 inhibitor 4-hydroxy-8-nitroquinoline-3-carboxylic acid (C5), and analysing data from a similar screen of sixty cell lines, which show that different cells have different sensitivities to this drug. From this we have seen that the potential of this DNA2 inhibitor to be used in therapy depends on the specific cancer in question. However, cellular inhibition occurs only at high drug concentrations. In order to identify a more potent inhibitor, an *in silico* screen was used to identify possible nuclease active site inhibitors. To validate these inhibitors, I set up a nuclease assay to determine which compounds selectively inhibit DNA2.

Optical Aberration Measurements of *ex vivo* Rabbit Eyes
Samuel Han
Mentors: Hyuck Choo and Haeri Park

Elevated intraocular pressure (IOP) is a major risk factor of glaucoma, a leading cause of blindness. For frequent, accurate measurement of IOP, the Choo lab has developed a nanophotonics-based implantable IOP sensor for the management and study of glaucoma. A potential concern for the implantable photonics based sensor is the influence of optical aberrations intrinsic to the eye on the sensor performance. Because the compact sensor is implanted behind the cornea in front of the periphery of the iris, the reflected spectrum that composes the sensor's signal is influenced by the aberrations of the cornea and anterior chamber of the eye before reaching the spectrometer. In order to determine how these aberrations influence the sensor's signal, the aberration of *ex vivo* rabbit eyes was characterized using a Shack-Hartmann sensor, an accepted device for objective wavefront aberration measurements. Then a spectrometer along the same optical axis was used to acquire the reflection spectra obtainable from the IOP sensor implanted in the eye. By measuring the aberration and signal prominence of the same region of the eye, the influence of aberration on the sensor's performance was observed.

Reliability of Power Grids Under Cascading Failures
Ashwin Hari
Mentor: Konstantin Zuev

Critical infrastructure networks form a technological skeleton of our modern society. As urban conglomerations are growing, our dependence on critical infrastructures that provide energy, water, electric power, and other essential utilities and services is constantly increasing. This makes *1) enhancing the resilience* of and *2) estimating the extent of failure in* such infrastructures some of the most fundamental problems of applied science and engineering. We focus on tasks 1) and 2) in 3 networks (US Power Grid, North American Power Grid, and European Power Grid), and use the Motter-Lai Model (MLM) for cascading failures. In examining 1), we investigate a strategy involving identifying cascade-critical nodes based on their topological properties. We analyze the relationship between cascade-criticality and various centrality metrics from an attacking and defending perspective using techniques such as correlation analysis. Our analysis indicates that a node's closeness, in addition to its betweenness, is an important topological feature for predicting its cascade-criticality. Similar results are obtained for EPG, in spite of significant topological differences between the former and USPG. In examining 2), we specifically study the effects of Natural Disaster attacks (NDAs), such us a hurricanes, earthquakes, and floods. A distinguishing property of the triggering failure caused by a natural disaster is that it may consist of several failed nodes. To accommodate for this, we extend the original MLM, where cascades are triggered by a single node, to multiple nodes. Our analysis indicates that NDAs can be as much as 300 times as destructive random-single-node-attacks, and that cascading can double network damage in moderately resilient and resilient networks

Maximizing Physisorption of Hydrogen Into Metal-Doped Graphene Derived Carbon
Ariel Hasse
Mentors: Brent Fultz, Hillary Smith, and Channing Ahn

Hydrogen, as a vehicular fuel, is limited by storage capabilities where it is difficult to pack densely as lower pressures are approached. Material based storage using graphene as an adsorption substrate is a promising alternative to mechanical storage of hydrogen. Hydrogen is adsorbed on the graphene through physisorption, the enrichment of a substrate with a gas or liquid, where the gas interacts weakly with Van der Waals on the graphene planes. Graphene is a monolayer carbon that is lightweight and has a surface area of 2630 m^2/g, potentially allowing an increase in volumetric hydrogen density.

This research seeks to further maximize hydrogen adsorption in graphene substrate without an increase in surface area, an approach contrary to the widely-accepted Chahine's rule, which requires an increase in surface area for an increase in hydrogen adsorption. Through synthesis and characterization of several graphene activated metallic samples, subsequent surface area and adsorption testing, and frontier analysis of enthalpy and compound structure, this work shows an exception to Chahine's rule with a 15 to 30 percent increase in hydrogen adsorption over pristine material for a copper-functionalized material with 2600 m^2/g surface area in the room temperature regime.

Entanglement Entropy for Spectral Triples
Erik Emmanuel Herrera
Mentor: *Matilde Marcolli*

We study the Rényi entropy of free fermions defined in terms of a regularized Tr $\log|D|$, with D the Dirac operator. Given a spectral triple $(\mathcal{A},\mathcal{H},D)$, we relate the entropy to the zeta function of the spectral triple. We also compute the resulting entropy for various examples of spectral triples, including a flat torus, and analyze what information they give in terms of the relation between entanglement and geometry. Furthermore, we consider possible refinements to the given notion of Rényi entropy.

Debris Flow Initiation by Flash Floods in Flume Experiments
Erich Herzig
Mentors: Michael P. Lamb and Tom Ulizio

Debris flows are destructive events which can quickly alter a landscape and pose a threat to people and property. Debris flows can be initiated by *en masse* failure of river-bed sediment during a sudden increase in water flow, such as a flash flood; however, the necessary conditions to trigger a debris flow by this mechanism are unclear. To investigate debris flow initiation by flash floods, we conducted a series of experiments in the large tilting flume at the California Institute of Technology. A gate was designed to release a known volume of water as a surge that flowed over a saturated gravel bed. We explored debris flow initiation over a wide range of conditions including different gate heights, bed saturation, and bed slopes. Preliminary results include measurements of surge shape, particle motion, pore water pressure, and ground shaking, and will be used to inform models for flash flood induced debris flows.

High Resolution Label and Label-Free Imaging of Atherosclerosis Plaques, and Building of a Multimodal Non-Linear Multiphoton Microscope
Meva Himmetoglu
Mentors: Hyuck Choo and Blaise Ndjamen

Atherosclerosis is a chronic lethal disease associated with a slow and progressive plaque building up inside the arteries and causes heart attacks or strokes. The early detection or prevention of the disease and prediction of instable plaque buildup become principal objectives for our research. Molecular changes in extracellular matrix through different ages of Watanabe heritable hyperlipidemic rabbit (WHHLMI) animal model are imaged both with fluorescent antibody labels on optically cleared samples and with homemade multimodal non-linear microscope system without labeling. The system uses minimalized number of components in order to obtain four different signals (SHG, THG, CARS and FWM) simultaneously and hyperspectral unmixing analysis of these signals leads individual images of the structures. This comprehensive method of using ex vivo images for characterization of the plaque burden and defining an index ultimately will help us build a minimally invasive in vivo imaging system for the disease progression.

Genetic Regulation of Vertebrate Sleep Homeostasis
Sarah Hou
Mentors: David Prober, Daniel Lee, and Andrew Hill

Even though a third of our lives is spent asleep and a tenth of Americans are affected by sleep disorders, very little is known about how and why we sleep. The Prober lab and other groups have shown that zebrafish can be used as an alternative model to study sleep. Studies in models, like *Drosophila* and rodents, have used sleep deprivation assays to help identify the mechanics of sleep. The Prober lab has developed a sleep deprivation assay using a mechanoacoustic stimuli. We have tested several conditions involving sleep deprivation durations and light schedules as well as with reverse cycled animals, sleep deprived during their relative night, and normal cycled animals, sleep deprived during their relative day. After the six hour sleep deprivation, there is a robust and significant increase in sleep for sleep deprived animals compared to their control siblings with around a 50% recovery made in sleep within the first 18 hours post sleep deprivation. Furthermore, after recovery sleep, the sleep deprived animals have the same levels of sleep as their control siblings. These results are encouraging for the future usage of the sleep deprivation assay.

The Role of TGFβ Signaling and Thrombospondin-1 During Angiogenesis of Cancer
Jenny Hsin
Mentor: Gudrun Valdimarsdottir

The Transforming Growth Factor beta (TGFβ) super family are cytokines which regulate important functions often disrupted or uncontrolled in cancer, such as cell growth and migration. TGFβ also regulates angiogenesis in cancer by activating, remodeling, and expanding a pre-existing vascular network in normal systems. Mechanistically, TGFβ signals through the endothelial specific ALK1 and the general ALK5 receptors. ALK1 stimulates endothelial cell proliferation and migration. Meanwhile, ALK5 mediates inhibition of vessel growth, like another naturally occurring inhibitor of blood vessel formation called thrombospondin-1 (TSP-1). The role of TSP-1 in cancer metastasis is controversial but it is known that TSP-1 is a major physiological activator of latent TGFβ and that its expression is repressed by a TGFβ/ALK1 target gene called Id1 in fibroblasts. Thus, we studied the network of TGFβ, TSP-1, ALK1, ALK5, and Id1 to elucidate the mechanism by which TGFβ and TSP-1 regulate the interplay between the endothelium and tumor cells. We cultured human umbilical vein endothelial cells (HUVECs) and two breast tumor cell lines, MCF7 and MDA-MB-231. Protein expression was analyzed with Western Blots and gene expression with PCR. Tumor cell growth was quantified by proliferation assays and observation of tube-like formation. Knock down and overexpression of genes in the TGFβ pathway using viral infection and RNA interference showed that TGFβ/ALK5 induces TSP-1.

Sorting Algorithms Using Stochastic Chemical Reaction Networks
Adrian Huang
Mentors: Erik Winfree and William Poole

One of the constantly studied problems in computer science is designing sorting algorithms, a study not notorious for its difficulty but for providing examples of algorithms with bases in different algorithmic strategies. Stochastic chemical reaction networks (SCRNs) are a formal model of well mixed chemical reactions useful in understanding biochemical computing. SCRNs have been shown to perform computations such as addition, solving sudoku puzzles, and the Approximate Majority algorithm, a stochastic process that occurs in living cells. This begs the question: Could we use SCRNs as another basis for designing sorting algorithms as they would happen within a synthetic chemical computer? In fact, we can. Three different SCRN sorting algorithms were designed and simulated in-silico, each of which encode a list of numbers into different chemical species and return a list of input ranks. We begin with a simple SCRN that sorts by randomly decrementing species. From this pilot design, we improved the SCRN across many different metrics: accuracy, runtime, complexity, and reaction firings. The evolution of this SCRN resulted in a design with small error rates and linearly scaling species and reaction complexity with respect to input size.

Architecting Materials for Intelligent Deployment
Cindy Huang
Mentors: Jordan Raney, Avi Sooriyarachchi, and Jason Marshall

Just as phase transformations in materials involve the storage or release of energy, novel architected materials can be produced that absorb or release strain energy. One way to do this is through the use of bistable beam structures, which snap between two stable, but different, energy configurations. By making such structures from anisotropic materials, bistable structures that are able to release their stored energy autonomously in response to a particular solvent can be created as a result of anisotropic swelling and a concomitant change in critical geometric parameters that define the mechanical response of the system. This research looks at the development of a new anisotropic ink formulated from PDMS, glass fibers, and alumina fibers. The new ink was characterized through tensile tests and compared to an anisotropic hydrogel ink from literature. Finally, bistable structures were printed with the new ink.

Design and Production of an Automated Microscope for Sequential Fluorescent In-Situ Hybridization
Zhong Qian Huang
Mentor: Long Cai

Sequential fluorescence imaging preserves information about the spatial orientation of a cell within its tissue system, while still providing a significant amount of data on its gene and protein expression. However, these experiments often involve a substantial number of repetitive hybridization cycles, and can last up to weeks for a single run. In the Cai Lab we have programmed a system that is able to automate this experimental method by sequentially pumping reagent solutions through cell samples in a laminated fluidics assembly, and then taking high-resolution laser-illuminated images at the conclusion of each cycle. This eliminates the need for human intervention during the experiment and significantly reduces time inefficiencies. We aim to engineer the system into a robust stand-alone module that is reliable and easily replicated.

Investigating Proteomic Changes in nAChR Subunit Expression
Stephanie Huard
Mentors: Henry Lester and Matthew Mulcahy

Nicotinic acetylcholine receptors (nAChRs) are pentameric ion channels activated by the endogenous neurotransmitter acetylcholine and exogenous agonists, such as nicotine. Nicotinic receptors are expressed in mammalian skeletal muscle (muscle-type nAChRs), and the mammalian central and peripheral nervous systems (neuronal-type nAChRs). Chronic exposure to nicotine has been shown to increase total and region-specific expression of the α4 and β2 neuronal nAChR subunits. Menthol, a tobacco product additive, has also been demonstrated to upregulate α4 and β2 expression, both when administered alone and when co-administered with nicotine. These data suggest that changes in α4 or β2 nAChR subunit expression could be used as a biomarker for neuronal nicotine and/or menthol exposure. In this study, we examine potential methods for the quantification of β2 subunit expression. We investigate the expression of β2 in the murine brain, comparing tissue from mice exposed to treatments of either vehicle, nicotine, (-)-menthol, or &(-)-menthol. We find that β2 expression is upregulated in a region-specific manner under nicotine, (-)-menthol, and nicotine & (-)-menthol treatment conditions. These data further support the potential use of β2 as a biomarker for neuronal nicotine and/or menthol exposure, which may enable a better understanding of the effects of nicotine and menthol on protein expression, as well as their role in addiction.

Large-Scale Automated Imaging of Quantum Dots With Nanoscale Precision
Noah Huffman
Mentors: Nir Rotenberg and Keith C. Schwab

The fabrication of nanophotonic structures over quantum dots allows for precise control of the local optical environment and enhancement of desired quantum photonic properties, such as efficiency and directionality of emission. However, this control is dependent on how precisely the quantum dots can be placed within the structures. Quantum dots epitaxially grown to have favorable coherence and stability randomly self-assemble in the growth plane, meaning nanophotonic structures cannot be fabricated precisely around quantum dots until their position is determined. Here we present an automated procedure for the localization of quantum dots over a large area (1 mm^2) relative to reference marks with uncertainties <5 nm. A MATLAB algorithm was written to integrate image/spectra acquisition, sample movement, and optical lens adjustment into a cohesive suite so that collections of quantum dots can be localized relative to multiple reference marks automatically. The algorithm sequentially images bordering regions of interest, ranging from 40-60 μm^2, containing reference marks and quantum dots, then analyzes the images to determine the quantum dots' relative locations. This allows for the subsequent fabrication of nanophotonic structures containing quantum dots at predetermined positions, as required for cutting-edge quantum technology applications.

Investigating the Formation of Planet Nine
Oriel Humes
Mentor: Mike Brown

Planet Nine is a recently hypothesized giant planet in the outer solar system with a distant and eccentric orbit. Planet Nine's proposed distance and eccentricity pose challenges to the currently accepted model of Solar System formation. This project investigates a formation mechanism for a distant, eccentric Planet Nine that involves interactions between six giant planets in the early solar system. Using the computer modeling, the dynamics of six-planet solar systems were explored, using orbital resonances to trigger instability in the evolving early solar system. Though so far, no configuration of six initial giant planets has reproduced a solar system with a Planet Nine-like configuration in the outer solar system, this work does not necessarily rule out this formation scenario due to the large size of parameter space of the problem. However, based on current results, producing Planet Nine via a six-giant planet interaction mechanism appears to be unlikely.

Application of Advanced Deep Learning Techniques to Charged Particle Tracking in High Energy Physics
Yikai Huo
Mentors: Maria Spiropulu and Jean-Roch Vlimant

In experimental collider particle physics, as done at the Large Hadron Collider one of the most computing intensive task in processing the data is the reconstruction of the trajectory of particles. With the upgrades in the LHC, the amount of data will reach a higher level, the traditional algorithms like Kalman Filter and Hough-like Transformation scale worse than quadratically, so the computing resource cannot match the demand anymore. In order to explore the application of deep learning algorithm in tracking, we build several Deep Recurrent Neural Networks of different models with Keras python library. We make prediction of target tracks and track candidates. At last, we evaluate the performance of different models and suggest improvements for the modification of DNN in the future.

Reprogramming a Bacterial Repressor as a Sensor for Neurotransmitters
Nicholas Hutchins
Mentors: Viviana Gradinaru and Xiaozhe Ding

We have previously identified and evolved a multi-drug binding repressor protein to detect a neurotransmitter *in vivo* at low micromolar concentrations. However, high nanomolar sensitivity is required to monitor physiology concentrations of neurotransmitters in typical model organisms. As such, we combined high-throughput screening with error prone mutagenesis in order to identify improved variants of the protein. Here, we show that two subsequent rounds of directed evolution in a plate-based fluorescence assay are able to decrease the detection limit of this repressor protein to closer to physiological concentrations in *E. coli*. We also present a selection method which helps improve the ability to transfer our protein to mammalian cells and will improve the efficiency of future rounds of evolution.

Stability and Structure of Fields in a Flow With a Hydrodynamic Discontinuity
Daniil V. Ilyin
Mentor: William Goddard

We consider from a far field the evolution of a hydrodynamic discontinuity separating incompressible ideal fluids of different densities, with mass flow across this interface. By solving the boundary value problem and finding fundamental solutions of linearized dynamics, we directly link interface stability to structure of the flow fields. We find that the classic Landau system of equations for the Landau-Darrieus instability has a degenerate and singular character. Eliminating this degeneracy leads to appearance of a neutrally stable solution whose vortical field can seed the instability. We further find that the interface is stable if the flux of energy fluctuations produced by the perturbed interface is small compared to the flux of specific kinetic energy across the planar interface. The interface is unstable if the energy fluctuations flux is large compared to the kinetic energy flux. Landau's solution is consistent with the latter case.

Significance of Environmental Density in Shocked Poststarburst Galaxy Survey Object Evolution
Laura G. Jaliff
Mentors: Katherine Alatalo and Mansi Kasliwal

The Shocked POststarburst Galaxy Survey (SPOGS) comprises 1,066 galaxies undergoing the transformation from blue cloud late-type spirals to red sequence non-star-forming early-type ellipticals and lenticulars. They are selected via spectral analysis of ionized gas line ratios, which indicate shocked objects, and Balmer H-δ equivalent width, which select recently formed stars, but not active star formation. E+A galaxies (Zabludoff et al. 1996), like SPOGs, contain young stars but no emission lines consistent with star formation. They differ in that the quality used to discern SPOGs, their shocks, produces H-α lines that prevent them from being found via the same criteria as E+As. Thus, SPOGs can be found before being entirely stripped of their gas, and, while E+As are largely red and dead, found leaving the green valley, SPOGS are mostly entering it. The environmental density data for SPOGs was retrieved via the NASA Extragalactic Database (NED) radial velocity constrained cone tool, which provides counts and densities within spheres of radii 1, 5, and 10 Mpc from the center of search as well as relative positions and redshifts of objects. The kinematic morphology-density relation (Cappellari et al. 2011) is employed as a point of comparison for how SPOGs' environmental densities might relate to morphological and spectroscopic factors, including tidal features, asymmetry, and color, in order to fully understand the role of environmental factors in SPOGS object evolution.

Four-Electron CO_2 Reduction by Modified Bis Vinylterpyridine Catalysts
Gyu Bin Jang
Mentors: Harry Gray and Wes Kramer

Electropolymerized films of poly-[M(v-trpy)$_2$] (M = Cr, Fe, Co; v-trpy = 4"-vinyl-terpyridine) have been shown to perform the electrocatalytic four-electron reduction of CO_2 to formaldehyde in aqueous media. We will present an investigation into the production and Faradaic efficiency of formaldehyde by the electropolymerized poly-[M(v-trpy)$_2$] catalysts. Additionally, we hypothesize that the high degree of cross-linking in films of poly-[M(v-trpy)$_2$] will cause much strain and lead to an open coordination site where the four-electron reduction can occur. Thus, we have prepared a series of [M(v-trpy)(trpy)]$^{n=}$ complexes (M = Cr, Co, Fe), which are expected to form less-strained linear polymer films, to compare their CO_2 reduction activity with the poly-[M(v-trpy)$_2$] catalyst films. We will analyze liquid products with chromotropic acid test, NMR, and HPLC and gaseous product with gas chromatography.

Simulating the Pharmacokinetics and Pharmacodynamics of Nicotine
Janice Jeon
Mentors: Henry Lester and Amol Shivange

Chronic exposure to nicotine results in the upregulation of nicotinic acetylcholine receptors (nAChRs), a process at the basis of nicotine addiction. It was believed that nicotine follows an "outside-in" signal transduction pathway by activating nAChRs on the cell surface, which leads to events within the cell that upregulate nAChRs. However, it is now becoming evident that nicotine can pass through the cell membrane, enter the endoplasmic reticulum (ER), and stabilize nAChRs that are not completely folded. As a pharmacological chaperone, nicotine also alters the ER by reducing ER stress levels and the unfolded protein response. Because nicotine induces changes to the cell from inside the ER, the study of the mechanism of action of nicotine and subsequent processes are referred as "inside-out pharmacology." We used MATLAB SimBiology to develop a model that incorporated both the inside-out and the outside-in pathways, then simulated the pharmacokinetics and pharmacodynamics of nicotine. After comparing the pathways, we found that both processes were necessary to explain aspects of nicotine addiction. Through our work, we gained new insight into the neuropharmacology of nicotine addiction, which is of great importance considering that the FDA now plans to lower nicotine levels in cigarettes to decrease likelihood of nicotine addiction.

Identifying the Roles of Schwann Cell Precursors in Peripheral Nervous System Development
Aya Jishi
Mentors: Marianne Bronner and Stephen Green

The neural crest is a transient cell population that gives rise to many cell types important to vertebrate development. In mouse, derivatives of the neural crest called Schwann Cell Precursors (SCPs) give rise to peripheral neurons, placodes, and melanocytes. Recent work in the lab has shown that lamprey, a kind of jawless fish, also possess these SCPs. Lamprey SCPs contribute to enteric neurons, but it is unknown what proportion of enteric neurons they produce, and whether they also contribute to other cell types. We seek to identify the relative contributions of vagal neural crest cells, trunk neural crest cells, and SCPs to enteric nervous system development, and to identify any contributions to other cell types. We cloned constructs that allow us to genetically label neural crest cells, and to track their migration at vagal and trunk levels. Characterizing the roles of these SCPs in organogenesis is essential for understanding vertebrate evolution and may have impacts on regenerative medicine.

Forming Controllable, Self-Assembling, Multi-Species Bacterial Aggregates
Christopher Johnstone
Mentors: David Tirrell and Mark Kozlowski

Inspired by biofilms and other natural consortia, there is increasing interest in the use of artificial multi species bacterial aggregates for a variety of applications, such as pharmaceutical synthesis and environmental remediation. Recently, the Tirrell lab has shown that surface display of recombinant aggregation proteins in *E. coli* can cause self-assembly of single-species aggregates on the 20 to 200 micron scale. Here, we attempt to make a multi-species aggregate between E. coli and Bacterioides thetaiomicron, a model anaerobic gram-negative bacterium. We have worked to clone the aggregation system, which consists of a translational fusion of the autotransporter protein (a membrane protein responsible for exporting macromolecules) and pairs of self-associating proteins, into a pNBU2-based integrase vector that integrates the gene into the B. theta chromosome. Additionally, we demonstrated the ability to modulate cellular behavior in aggregates through the activation of a LuxI-LuxR quorum-sensing circuit, providing a mechanism by which gene expression can be turned on after the consortium is formed.

Engineering Communication Circuits for Synthetic Cells
Malin Jönsson
Mentors: Richard M. Murray and Shaobin Guo

In natural biological systems, compartmentalization is a commonly used way to support chemical reactions which could not be executed without the isolation from one another. Such an example is the mammalian transcriptional and translational machinery which are incompatible with each other unless separated in space. Several research groups are already exploiting transcriptional/translational (TX/TL) machinery in the absence of living cells for the production of biochemical products from genetic codes and the encapsulation of these machineries into vesicles could be the verdict of creation of artificial cells. Although, in order to get there, several subsystems would still be needed, one of them being the sensing and signaling between the artificial cells but also towards their environment. This project utilizes components with abilities to sense external conditions and signaling cascades that amplifies and processes environmental signals through the encapsulation of TX/TL machinery inside lipid vesicles. This enables a more modular design by the use of controlled compartments holding genetic circuits, managed both through external signals as well as through vesicle to vesicle communication, and could act as a stepping stone towards programmable artificial cells.

Using Fast Enumeration Algorithm and the Lattice Boltzmann Method to Re-Discover Electrodynamic and Hydrodynamic Laws
Chao Ju
Mentor: Mark Stalzer

In this project, we devise a robust scheme to re-discover smooth, differential theories, which can be represented by a set of alphabet having different complexities according to the number of derivatives taken. After enumerating the alphabet set to form novel theories of a given complexity, we can validate the theories by using the output data from the virtual experiment and singular value decomposition of the data matrix. Using the far-field approximation of an oscillating dipole as the virtual experiment, Maxwell's equations and the equations of light can be re-discovered within 2 seconds. To test the robustness of this method in other realms of physics, we use the Lattice Boltzmann Method to simulate the random motion of a gas in a 2D box and low Reynolds number 2D flow past a cylinder. We are in the progress of re-discovering the ideal gas law and the Navier-Stokes equations.

Quantum Borel Chromatic Number
Luke W. Juusola
Mentor: Martino Lupini

Given a graph, we can color its vertices such that if two vertices are adjacent in the graph then their colors are different. This idea has proven very useful in many aspects of combinatorics and far removed fields such as information theory. This led to the study of graph colorings in a variety of contexts. Of these, the first we are concerned with is descriptive set theory, where the Borel coloring was introduced by Kechris, Solecki, and Todorcevic in 1998. The second context is "quantum mathematics," where the notion of quantum graph coloring was introduced by Cameron et al. in 2007. We marry these two notions into one and attempt to prove several properties about it, focusing on separation.

The Spectral Action on Multifractal Robertson-Walker Cosmologies and Apollonian Circle Packing
Yeorgia Kafkoulis
Mentor: Matilde Marcolli

We study the spectral action for Apollonian Circle Packings for two different Dirac operators, to understand a more simple case of Apollonian Sphere Packing, which is the basis of the Swiss-Cheese Cosmology Model. We study the residual set of an Apollonian circle packing P to determine the zeta function of the length spectrum of our packing, and take the multiplicities of the eigenvalues of our Dirac operator on the circle to be constant. Then, we find the zeta function of the Dirac operator on a single circle, and then of a packing of circles P, which we find is the product of some constants, the Riemann zeta function, and a series of radii terms from our circle in P. We study the series of radii in terms of a geometric zeta function, and try to find its poles and complex dimensions introduced by Lapidus. Moreover, we attempt to find a pattern in the spectral action coefficients for the Robertson-Walker metric via methods in linear algebra and pseudodifferential calculus, specifically a dependence between the coefficients and exponents of scaling factor terms in the spectral action.

Optimizing Superconducting Qubit Design for Fast Readout Times
Anant Kale
Mentors: Oskar Painter, Michael Fang, and Andrew Keller

One of the prerequisites for implementing a scalable quantum computer is being able to perform many gate or readout operations on qubits within their decoherence times. In order to maximize the number of operations that can be performed, we wish to minimize the time required for the readout of the qubit state. We have found that increasing the qubit frequency to 11.5 GHz and coupling the qubit dispersively to a Purcell-filtered 7.8 GHz readout resonator can yield a fast and high fidelity readout (above 95% state-separation fidelity in 80ns). In the transmon qubit design a higher qubit frequency is achieved by decreasing the shunt capacitance while also increasing the Josephson energy. The anharmonicity of the qubit is increased to $\eta = 600\text{MHz}$ to maintain it at the 5% level. The electromagnetic simulation software Sonnet was used to model the frequency response of the qubit and to design the appropriate capacitive couplings between components. With this substantial increase in frequency compared to current designs, we consider the effects of higher frequency on various loss and decoherence mechanisms.

Computational Analysis of Massively Parallel Sequencing Data to Identify Low Frequency Mutations and Rearrangements
Karthik Karnik
Mentors: David Kwiatkowski and Paul W. Sternberg

Massively parallel sequencing (MPS) is a form of sequencing technology for high-throughput DNA sequencing projects, including the analysis of human genetic variants. In the Kwiatkowski Lab, MPS is used to detect sequence variants and mutations in patients who have the genetic disorder Tuberous Sclerosis Complex, and in several types of tumors and cancers. Using MPS, the output received in the lab is a binary alignment map (BAM) file containing reference genome-aligned sequencing data, as well as a collection of reads which do not align correctly. However, BAM files alone are not feasible for identifying variation found in the input DNA. Rather, they must be interpreted and analyzed by other programs to obtain data that indicates DNA sequence variants. We have developed a robust, user-friendly program written in the Unix command line, Python, and MATLAB that specifically searches the BAM file data for sequence variants across a given gene at a user-specified allele frequency and determines potential sites of large-scale deletions. This program has been tested with various projects and will be used on the lab's entire collection of BAM files from various genomic and cell-free DNA samples.

The Evolution of Candidates in the Face of California's Top-Two Primary System
Nivetha Karthikeyan
Mentors: D. Roderick Kiewiet and J. Andrew Sinclair

The adoption and enforcement of the top-two primary in California has given rise to a flurry of questions and criticisms regarding the structure's suspected impact. Debate has primarily centered around the presumed negative effects upon political party representation in the state, as parties are no longer permitted to run closed primaries solely amongst their registered members. By looking at the types of candidates running pre- and post-implementation of the primary system, however, we can determine whether top-two has truly altered the political landscape. Specifically, we have conducted statistical analyses on the presence and performance of incumbents in races for the lower house of the state legislature. This allows us to conclude that there is effectively no change in the types of candidates vying for election - rather, the same people stay within the political system, generally repeatedly running for the same seat, regardless of the structure of the primary. As such, the foundational nature of candidacy has remained the same.

Copper-Catalyzed Enantioselective C–N Coupling of a Carbamate With a Racemic Halide
William Kayitare
Mentors: Gregory C. Fu and Jun Myun Ahn

More than half of the pharmaceutical drugs currently in use are chiral and often possess C–N bonds. Due to the varying biological activity governed by the molecular chirality, a strategy to synthesize molecules with high degrees of enantioenrichment is of critical importance. Although several methods to construct C–N bonds exist, recently, the Fu and Peters groups have reported C–N bond formation using visible light in copper-catalyzed cross-couplings under thermally mild conditions. Of particular interest is the use of carbamates as nitrogen nucleophiles for their versatility in subsequent derivatization. Using a carbazole-based ligand as a photosensitizer, a variety of electrophiles were evaluated in couplings with methyl carbamate to optimize the enantiomeric excess (ee) and yield of the product. Preliminary studies have indicated formation of the desired coupling product in moderate yield and low ee. We intend to continue to optimize the reaction conditions by varying reaction parameters such as temperature.

Reinforcing Porous Ceramics With Silicon Carbide Whiskers
Carl Heinrich Christian Keck
Mentors: Katherine T. Faber and Claire T. Kuo

Solution-based freeze casting is a ceramic fabrication technique in which a preceramic polymer solution is directionally chilled to a temperature below the freezing point of the solvent. As the solution is cooled, phase segregation occurs as the solvent crystallizes, resulting in an interconnected crystal network. The solvent is then sublimed to produce the pore network. In porous ceramics, pores often serve as crack initiators, which limits the strength of ceramic materials. This limitation restricts the use of porous material. Therefore, the goal of this study is to increase the compressive strength of freeze-cast porous structures by creating solid bridges between pore walls. In the current experiment, SiC whiskers are added to the polymer solution. It is hypothesized that if the whiskers are sufficiently long, they will be engulfed by the freezing front of the solvent. With the engulfment of silicon carbide whiskers by the freezing front, the SiC whiskers would bridge pore walls. Varying loads of SiC whiskers were added to preceramic polymer solutions to produce freeze-cast porous silicon oxycarbide composites. The effect of SiC whiskers on microstructures and compressive strength of the freeze-cast structures were characterized with scanning electron microscopy, permeability tests, and uniaxial compression tests.

Understanding the Propagation Mechanisms of Vocal Fold Vibrations in the Human Head for Implantable Vibration-Driven Energy Harvesters
Yeokyoung Kil
Mentors: Hyuck Choo and Hyunjun Cho

Advances in medical engineering have led to a trend of surgically implanted medical devices. Despite their many advantages, these medical implants pose major risks because they need their batteries surgically changed periodically. The Choo Lab has designed an implantable piezoelectric energy harvester that uses vocal fold vibrations to power these medical implants. This project seeks to find the optimal site for implanting the energy harvester. In order to do so, a finite-element model of the head was created with the 3D image processing software ScanIP, using publicly available CT scans. Simulations on vibration propagation were run on this model using the acoustic-structure interface of COMSOL Multiphysics®. An anatomical model of the human head was also used to map the vibration measurements on the human head. Combining these results will hopefully help determine the optimal implant location of the energy harvester.

Effect of Indium Tin Oxide (ITO) Thickness on Perovskite Solar Cell Performance
Hyunseong Kim
Mentor: Harry Atwater

Conductive and transparent top layers are pivotal for efficient solar cells. As a transparent conducting oxide (TCO), indium tin oxide (ITO) excels in both aspects. However, while conductivity increases with ITO thickness due to lower resistance, transparency decreases due to parasitic absorption, indicating a trade-off. This study aims to find the optimal ITO thickness for perovskite solar cells through simulations and cell fabrication. When computationally simulated using PV Lighthouse's Module Ray Tracer, the cells absorbed the most incoming light of 50.35% at a thickness of 55nm. This indicates there is also an optical trade-off between parasitic absorption and antireflection that depends on the ITO thickness. When actual perovskite cells were fabricated under different thicknesses, the best efficiency of 13.5% occurred at a thickness of 125nm. Under spectral response measurements, the fabricated cells demonstrated similar external quantum efficiency (EQE) trends as expected from the simulations.

Coordinated Policy Gradient
Kun Ho Kim
Mentors: Oussama Khatib and Joel W. Burdick

We propose a coordinated policy gradient method for training multiple agents to discover distinct strategies for accomplishing tasks. To encourage coordination between agents we use a jointly trained state value function baseline. To encourage deviation we enforce a soft KL divergence constraint which creates repulsion between the agents in similar regions of the state action space. Preliminary results of the algorithm on a 2D maze navigation domain show that the proposed method has potential for generalization to a higher dimensional space.

Data Analysis of Laminar Flame Speeds
Minjae Kim
Mentor: Guillaume Blanquart

This research seeks to unify our current model for laminar flame speeds of carbon based fuels by analyzing pre-existing data with a more holistic approach. Most of the data currently attempts to compare the laminar flame speeds of only one type of fuel in various experiments. There is a distinct lack of data in this method. However, there is an abundance of data if the various types of carbon-hydrogen based fuels are compared together in one plot within the same system. Through these comparisons,we will try to verify that our fuels exhibit identical SL variations between the experimental model and simulated model at variousφ, T, and P. In order to do this we are optimizing the various analytical functions that result from graphing all the flame-speed data of the different fuels together and comparing them to that of simulation data to find an overarching algebraic model. We seek to quantify the fit of our experimental data with an all encompassing function.

Linear Systems Over Join-Blank Algebras
Suna Kim
Mentors: Alan Edelman, Jeremy Kepner, and Xinwen Zhu

Linear algebra can be extended to more general algebraic structures like semiring. Specifically, we are interested in the solution set X(A, w) in semirings induced by complete lattice that also satisfy the infinite distributive law: these semirings are called Join-Blank algebras. As the Structure Theorem suggests that the solution set will be a union of intervals with same terminal points, we investigate different Join-Blank algebras to determine exact form of the solution set that can be calculated systematically from given A and w. We also introduce concepts like quasi-intervals along the way, which can be further studied.

Carbonate Mud Production From Abrasion of Ooids and Skeletal Grains
Lydia Kivrak
Mentors: Woodward Fischer and Lizzy Trower

The production of carbonate mud is still a largely unsolved problem in carbonate oceanic chemistry, with the sources and rates of production unclear. As calcium carbonate is a large component of marine sediments, the study of carbonate mud holds large implications for constraining environmental conditions in the past and present. Under high magnification, carbonate mud consists of distinct aragonite needles. We examine the formation of carbonate mud as a process of abrasion from carbonate sand grains, studying results from both ooids and skeletal grains. The experimental process consists of placing sand in abrasion mills for 1-3 weeks and measuring the amount of mud produced by measuring both centrifuged samples of the mud and the average size change in the sand grains. As predicted, larger grains and a faster propeller speed consistently result in larger mud production rates.

Access Control in Online Marketplaces: A Search Cost Model
Jack Kleeman
Mentor: Adam Wierman

This project considers optimal network design in online marketplaces. Uber and Amazon severely restrict who may sell a given product at a time, often to a single vendor, but existing models of networked marketplaces do not suggest this is particularly beneficial, especially given that the choice of optimal vendors is often computationally intractable. In contrast, eBay makes no such restrictions. In seeking to understand why, I propose a generalisation of the linear cost networked Cournot model to consider the costs of search to consumer welfare, and show that this makes the inclusion of less firms better for the welfare of the market, even in markets with very symmetric cost profiles. Furthermore, this can simplify the computational problem of optimal network design.

Search for SUSY With Delayed Photons at CMS
Gillian Kopp
Mentor: Maria Spiropulu

The Large Hadron Collider (LHC) collects data from proton-proton collisions to search for physics beyond the standard model and test supersymmetery theories (SUSY), as well as measuring properties of known particles more precisely. A dark matter search with LHC data requires an understanding of how signal and background events can be separated, and the phase space that is useful to search. This work presents an analysis of simulated Compact Muon Solenoid (CMS) collision events where two $\widetilde{\chi}_1^0$, dark matter neutralinos, are produced, and the event signature is two time delayed photons and missing transverse energy (MET). The simulated events are produced with the CMSSW framework, and the time measurements for the reconstruction is validated against the generator (truth) information in the electromagnetic calorimeter (ECAL).

Maximizing Coherence in an Ising Spin Liquid
Giacomo Koszegi
Mentors: Thomas F. Rosenbaum and Daniel M. Silevitch

In an Ising magnet, quantum spins are constrained to point up or down along a single direction, known as the Ising axis. The Ising magnet $LiHo_{0.045}Y_{0.955}F_4$ forms a spin liquid at ultra-low temperatures, in which the spins do not freeze but fluctuate together. The goal of this research was to cool a single macroscopic crystal of $LiHo_{0.045}Y_{0.955}F_4$ in a helium dilution refrigerator with weak coupling to the thermal bath, to determine the points in phase space that maximize quantum mechanical coherence. The parameters varied were DC magnetic field applied transverse to the Ising axis, which adjusts the spin tunneling probability by mixing up and down states, and AC magnetic field along the Ising axis. The nonlinear complex AC magnetic susceptibility probes coherence via a pump-probe technique and a Fano resonance analysis. When the Fano parameter crosses zero, excited spin clusters locally decouple from their environment, indicating minimum dissipation and, hence, maximum coherence. Once the maximum coherence conditions are known for this simple model system, this knowledge can be applied to more complex quantum computing systems.

Assessing the Accuracy of Using Sea Surface Height Anomalies as a Proxy for Atlantic Meridional Overturning Circulation Variability
Maximilian Kotz
Mentors: Andrew Thompson and Felix Landerer

The Atlantic Meridional Overturning Circulation (AMOC) is a key component in the global climate system responsible for 25% of global heat flux. Accurate observation of AMOC under a changing climate is key to predicting climate change in Northern Europe. Sea surface height anomalies (SSHA) have been used as a proxy for estimating AMOC variability. This method was extended to include recent data and the proxy relationship found to be inaccurate over 2014-2016 period due to a spatially extensive (10-40˚N, 90-50˚W) growth of SSHA in the Western Atlantic which was uncorrelated to AMOC variability. The coincidence of this event with one of the strongest eastern El-Nino events on record is argued to be indicative of a link between the two; analysis of wind stress data is used to provide an explanatory mechanism for this event and wind stress curl is shown to be significantly correlated to changes in SSHA in this region. This is compared to previous strong El-Nino events (1997/1998) which did not cause significant growth of SSHA in the western Atlantic and other discrepancies between the SSHA proxy and AMOC variability are explained using wind stress data.

Investigation of Mechanical Interaction of the InSight HP^3 Mole With Martian Soil Simulant
Jonah Krop
Mentor: José Andrade

The Mars InSight mission launches in 2018 in order to measure various geophysical data on the planet. A significant portion of the data, specifically heat flow from the planet's interior, is measured using the Mole, which hammers into the surface of Mars up to 5 meters deep. The penetrating action of the Mole can affect the thermal and mechanical properties of Martian regolith as it compacts under the load of penetration. In this research, we investigate the forces felt by the penetrator through the use of force sensors in various soil particle distributions and densities under dynamic loading. Forces captured can help estimate the resistance felt around the Mole at certain depths. The forces captured can help the accuracy of thermal measurements, which are related to the side-wall forces on the penetrator, and help optimize the Mole's penetrating action for certain depths and soil densities.

Redox Activated Oxidative Addition of Strongly Polar Alcohols to the Si(111) Surface
Alex Krotz
Mentors: Nathan Lewis and Miguel Caban-Acevedo

A necessary characteristic for efficient solar hydrogen production using silicon photocathodes is the formation of an optimal Schottky junction between *p*-Si and the hydrogen evolution reaction (HER) catalyst. Passivation of the *p*-Si surface with polar organic monolayer introduces an interfacial dipoles that can be utilized to optimize the barrier height when in contact with high workfunction HER catalyst. Polar alcohols including 4-methoxyphenol, 4-fluorophenol, ethanol, and 2,2,2-trifluoroethanol were reacted with H-Si(111) substrates in the presence of a one electron oxidant (ferrocenium, acetylferrocenium, or 1,1'-diacetylferrocenium). The substrate surfaces were then analyzed with transmission infrared spectroscopy (TIRS) and X-ray photoelectron spectroscopy (XPS) to determine the fractional monolayer coverage. The surface recombination velocity (SRV) was obtained using microwave-detected photoconductance decay, and the barrier height measured using a mercury drop cell. Theoretical calculations were also conducted to estimate the relative strengths of the surface dipoles created by each alcohol and the expected effect on band position. Functionalization with 2,2,2-trifluoroethanol yielded a high fractional coverage and resulted in a positive surface dipole. Further investigation is necessary to decrease the density of defect states and identify pathways to deposit metal catalysts layers.

First-Principles Calculations of Ground State Structures of III-Nitride Semiconductors
Anita Kulkarni
Mentors: Marco Bernardi and Vatsal Jhalani

In recent decades, materials scientists have become increasingly interested in performing first-principles calculations of scattering mechanisms that govern dynamics of electrons, phonons, and electron-phonon interactions in semiconductors. These mechanisms regulate properties of semiconductor devices, but are difficult to probe experimentally as they occur on ultrafast (pico- to femtosecond) timescales and nanometer length scales. The Bernardi group employs cutting-edge first principles methods based on density functional theory (DFT), a formalism for calculating the ground-state electron density and energy of a many-body system, to perform these calculations on systems with no empirical parameters as input. One system is the III-Nitride (Al/In/Ga)N family of semiconductors, which is critical for efficient light emission technology (LEDs). While studying DFT, I used the Quantum ESPRESSO DFT code package to perform calculations of various ground-state properties of these IIInitrides, including ground-state energy, equilibrium lattice parameters, and electronic bandstructure. Furthermore, I calculated various equilibrium unit cell structures of InGaN and AlGaN alloy systems, which comprise the active layers in LED devices. In the future, I will combine these calculations with electron-phonon scattering calculations to compute carrier dynamics and transport in these systems, with the ultimate aim to study the microscopic mechanisms that regulate LED device efficiencies.

Investigating the Thermalization of Spin Systems Using the Lindblad Master Equation
Varoon Kumar
Mentors: John P. Preskill and Evgeny Mozgunov

Master equations have been proven to correctly approximate the time evolution of a quantum system that is weakly coupled to its environment. We investigate the accuracy of this approximation by considering the thermalization of a state of a transverse-field Ising spin chain. Using the Lindblad master equation, with a Lindblad term which we derive from the evolution of the isolated environment, we numerically simulate the thermalization of the chain. By comparing the results with those of the exact evolution, where we model the environment exactly, we observe a decay in the expectation value of the magnetization of the first spin, the rate of which depends on the coupling between the system and its environment. Furthermore, by converting the spin chain to a system of free fermions, we examine the applicability of master equations to larger system sizes.

Search for Supersymmetry With Razor Variables in Higgs to Diphoton Decays Produced in Association With Leptons and Jets in Proton-Proton Collisions at $\sqrt{s}$ = 13 TeV
Stephanie Kwan
Mentors: Maria Spiropulu, Cristián H. Peña, and Si Xie

Supersymmetry (SUSY) is one of the most promising extensions of the standard model of particle physics. In SUSY models that conserve R-parity, the Lightest SUSY Particle (LSP) is stable and is a viable dark matter candidate. We present a search for SUSY with 13 TeV proton-proton collision data recorded in 2016 by the CMS experiment at the CERN LHC and corresponding to an integrated luminosity of 35.9 fb^{-1}. The final states under study include Higgs to diphoton decays produced in association with jets and leptons. SUSY scenarios are studied, in which the lightest neutralino has Higgsino-, bino-, or wino-like components, resulting in decays to photons and gravitinos, where the gravitinos escape undetected. We are currently pursuing a more inclusive approach by integrating the lepton categories into the existing search and thus increasing the sensitivity of CMS for electroweak SUSY production. Preliminary results show that the lepton search produces more stringent limits compared to the existing search.

Atmospheric Energy Balance and Its Effect on the Intertropical Convergence Zone (ITCZ)
Karim Q. Lakhani
Mentor: Tapio Schneider

The ITCZ is the region of largest rainfall on Earth, and subtle shifts in its position can have a severe impact on the majority of the world's population. Its dynamics are not fully understood, and current models have biases in simulating it. We are investigating how mechanisms that cause the ITCZ may have varied in the past using simulations of a wide range of past climates. Specifically, we are testing recently developed theories for the ITCZ position to see if they correspond to model responses in different climate regimes in order to pinpoint causes of model biases. Using compiled data from the Climate Model Intercomparison Project (CMIP5) and the Paleoclimate Modelling Intercomparison Project (PMIP3), we compared the variations in ITCZ shifts to two quantities related to the atmospheric energy balance, the energy flux equator and the net average energy input at the equator. We found that these variables do not correlate very well, with some correlation coefficients less than .02. The largest correlations were between the net average energy input with the ITCZ during the boreal spring to fall. Further studies involve using modified definitions of the quantities to determine how robust these results are and looking at the precipitation and energy balance over specific areas of interest such as oceans as opposed to globally averaged values.

Developing Methodologies for Mass Analyzing $^{13}C/^{12}C$ Ratios of PAHs via Gas Chromatography and Fourier Transform Mass Spectrometry
Christopher Lamartina
Mentor: John Eiler

Polycyclic aromatic hydrocarbons (PAHs) are organic compounds that are byproducts of incomplete combustion reactions and can be found naturally in meteorites as well. To analytically measure precise $^{13}C/^{12}C$ ratios of pyrene, a PAH of interest, a Fourier transform mass spectrometer called the orbitrap is being implemented. The focus of this summer was to develop gas chromatography methods which involve trapping gas elution peaks in a steel reservoir, so that we could examine one sample continuously for an hour. We have successfully created a method to examine the 202 m/z molecular ion fragment peak of pyrene, as well as the single ^{13}C substituted 203 m/z peak and double ^{13}C substituted 204 m/z peak. The methodology obtains $^{13}C/^{12}C$ ratios that are accurate within 2 permil standard error and 1 permil shot noise limitations, and can be used to analyze pyrene in combustion samples and Murchison meteorite samples.

Covalent Immobilization and Purification of CRISPR Tagged lncRNA Binding Proteins
David A. Larios Colorado
Mentor: Mitchell Guttman

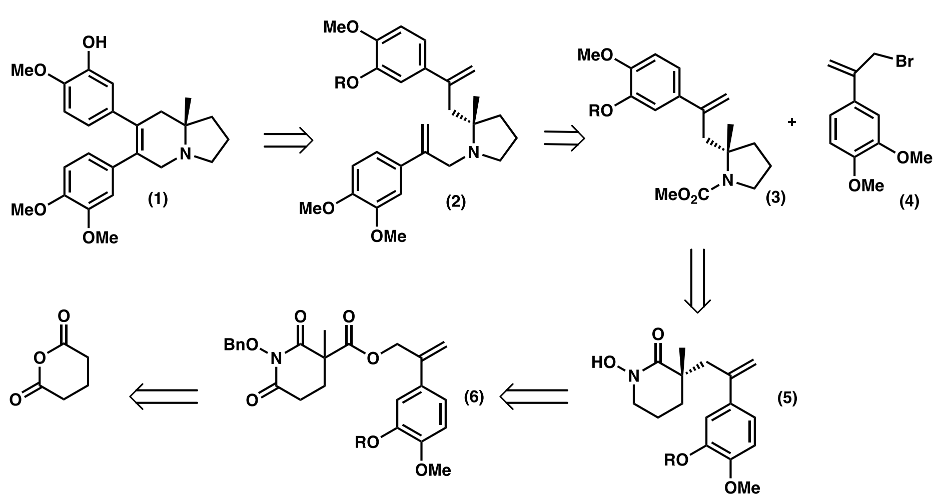
Long noncoding RNAs (lncRNAs) play an essential role in nuclear architecture and regulation of gene expression by their interactions with nuclear proteins. For example, during X Chromosome Inactivation (XCI), Xist lncRNA binds to specific nuclear proteins to recruit repressive enzymatic complexes to silence the whole chromosome and attach it to nuclear lamina. The method these phenomena have been studied with is Crosslinking and Immunoprecipitation (CLIP), which can report RNA-protein interactions that occur *in vivo,* through the isolation of a protein of interested using antibodies. CLIP is limited in stringency because the purification method relies on maintaining antibody-protein interaction leading to background from *in vitro* associations. Here, we report a method that replaces immunoprecipitation of proteins with covalent immobilization, which allows for the purification of protein-RNA complexes with fully denaturing wash steps minimizing background *in vitro* associations. Using the CRISPR/Cas9 system we inserted a low molecular weight tag (Spytag) into proteins of interest (specifically LBR, PTBP1, SAF-A and RBM15) at their genomic locus allowing us to covalently purify them and their associated RNAs. With this study, we will be able to re-evaluate the already reported protein-RNA interactions and reveal the real functional role of each lncRNA-chromatin interaction.

Development of Cpf1 as an Alternative Tool for Genome Editing in Chick Embryos
Alexa Lauinger
Mentors: Marianne Bronner and Shashank Gandhi

Genome editing has been essential in the modern study of genes and their functions. Recently, Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) coupled with Cas9, an RNA-guided endonuclease, has allowed for specific genome editing in a variety of model systems ranging from vertebrates such as mouse and zebrafish to invertebrates such as *Ciona intestinalis*.. Cas9, in complex with with a small RNA molecule called 'guide RNA' (gRNA) can cleave DNA in a sequence-specific manner, using Watson-Crick base pairing between the gRNA and the target site to achieve high specificity. The CRISPR/Cas9 has become the most widely used technique to knock out genes of interest. There is the possibility that another CRISPR endonuclease, Cpf1 will allow for similar genome editing. Cpf1 is different from Cas9 in their size, recognition motifs in the genome, and deletion mechanisms. The primary focus of this project is to develop the CRISPR/Cpf1 system as a tool for genome editing in chick embryos. We will establish proof of principle by knocking out Pax7, an important transcription factor in the neural crest, a vertebrate-specific multipotent population of cells. By means of a simple electroporation-based transfection technique, we expect to produce results comparable to the knockout of Pax7 using Cas9. If the results are as expected, the CRISPR/Cpf1 system could be an easier method for genome editing.

Toward the Total Synthesis of Tylohirsuticine
Dat Le
Mentors: Brian Stoltz and Elizabeth Goldstein

Tylohirsuticine, a compound in the alkaloid family, has both an interesting structure with its stereocenter and potentially useful biological activity[1]. The synthesis of this compound would allow further research on Tylohirsuticine's application in the pharmaceutical industry and beyond. Based on the group's developed means to synthesize quaternary carbon stereocenters, a retrosynthesis of the compound was devived. We have successfully created a highly enantioselective approach for the synthesis of the pyrrolidine core of the natural product from readily available achiral starting material.



Investigation of Ring-Opening Metathesis Polymerization With Ruthenium Catalysts Bearing Cyclic(Alkyl)(Amino)Carbene Ligands
Dylan Leary
Mentors: Robert Grubbs and Tonia Ahmed

Synthesizing polymers with ring-opening metathesis polymerization (ROMP) has been studied extensively in the literature. This method implements typical olefin metathesis, i.e. metal-centered alkene substituent exchange, and takes advantage of ring strain relief of cyclic olefins (typically norbornene derivatives) as a driving force for the reaction. Our interest was in a subclass of metathesis catalysts, namely those based on ruthenium complexes bound to cyclic(alkyl)(amino)carbene (CAAC) ligands. Preliminary studies with catalysts have shown mixed results, as they've proven to be exceptionally slow initiating towards ROMP. In agreement with slow catalyst initiation, it appears the successfully synthesized polymers are high molecular weight, making their macrostructural properties difficult to characterize by standard methods. Fast initiating, open coordination site catalysts are being synthesized and could be used for more effective ROMP, or ultimately any other type of metathesis reaction, e.g. ethenolysis.

Developing Next-Generation 3D Microbatteries, via Two-Photon Lithography
Nima Leclerc
Mentors: Julia Greer and Mike Citrin

Solid state batteries (SSBs) have attracted much attention in recent years for their applications in transportation and biomedical devices. However current SSBs are made from thin-film materials, which restrict the cells to relatively small mass loadings. This limits the thin-film devices from achieving high energy density over a small footprint area. Here, we introduce a 3D micobattery design which aims to eliminate this issue due to utilizing the battery's height, allowing for larger mass loading. We develop 3D primary lithium-iodine (Li-I) batteries with nanolattice scaffolds created using two-photon lithography, for implementation in small biomedical devices, such as wearable sensors. Historically, the Li-I chemistry has proven to be practical in pacemakers for its safety and relatively high energy density. The iodine cathode material was selected for its self-forming electrolyte, allowing us to demonstrate the high energy density of the 3D microbattery relative to its thin-film counterpart. In our fabrication, the Li anode was deposited via electroplating. Efforts were made to increase conformality of electroplated Li, including the use of an ionic cesium additive in the electrolyte solution to reduce dendrite formation and minimizing the electrolyte volume.

Functional Dissection of Neuron Types in the Mammalian Thirst Circuit System
Christian Lee
Mentors: Yuki Oka and Allan Hermann-Pool

Previous work identified genetically distinct populations of Thirst-ON and Thirst-OFF neurons in the mouse subfornical organ (SFO) which modulate water consumption to balance internal osmolality and fluid homeostasis. Further investigation revealed that Thirst-ON neurons project to downstream regions of the brain, including the median pre-optic nucleus (MnPO) and vascular organ of lamina terminalis (OVLT). The aim of this research is to determine whether these signals from the SFO are decoded into distinct cell-type subprograms in the MnPO and OVLT. Using computational analyses to process RNA sequencing data, unique markers are extracted based on localization amongst principal component analyses-derived clusters. We are currently employing histological approaches to determine the validity of these markers. For example, we have visualized indistinct expression patterns for both the Penk and Brs3 antibody, indicating these may not be critical markers of the thirst circuit. Future experiments will map the remaining MnPO, SFO and OVLT markers and functionally dissect the encoding neurons using optogenetics. These experiments will quantify the effect of these neuronal-types on drinking behavior and reveal the logic underpinning neural circuits mediating basic drive behaviors.

Optimizing the *in vitro* Splicing of IRF7 pre-mRNA
Wen-Hua Lee
Mentors: David Baltimore and Luke Frankiw

Post-transcriptional processing of premature messenger ribonucleic acids (pre-mRNA) is an important step to attaining functional protein in eukaryotic cells. Specifically, the excision of non-coding sequences (introns) and the linkage of coding sequences (exons), collectively known as splicing, can form mature, full-length mRNA transcripts that exit from the nucleus to the cytoplasm for translation. The splicing reaction is thus the key to understanding gene expression and its time regulation. In the canonical mechanism for splicing, the proposed rate-limiting step involves the ability of the branch point adenine in the middle of the target intron to "recognize" and migrate to the 5' end of the intronic sequence. Some RNAs like the one coding for interferon regulatory factor 7 (IRF7) exhibit weak 5' splice sites – junctions with slowly migrating branch points – such that the intron is retained. Mass spectrometry has been used to identify proteins cross-linked to nascent IRF7 mRNA. Bud13, a member of the retention and splicing complex in yeast and humans, was found to be six-fold more enriched on the transcripts compared to actin control. It is hypothesized that Bud13 binds to the spliceosome and potentially "safeguards" pre-mRNAs with weak 5' splice sites from disassembly. To assess this claim, *in vitro* splicing reactions at various time points were performed with homemade wild-type and modified nuclear extracts with and without Bud13 from the human kidney 293t cell line and phosphorus-32 radiolabeled pre-mRNAs: IRF7 and hemoglobin, a normally spliced control product. The samples were visualized on polyacrylamide and agarose gels to investigate the role of Bud13 in the splicing reaction and its interaction with various splicing factors. Understanding the kinetics and mechanism of Bud13 and the spliceosome helps in the optimization of the splicing reaction.

Lower Bounds and Obstructions for Constant Depth Arithmetic Circuits
Gideon Leeper
Mentor: Chris Umans

A series of recent results have provided efficient depth reductions for general arithmetic circuits to depth three or four. This would suggest a path for proving general circuit lower bounds via lower bounds for shallow (constant depth) circuits, as they are intuitively much more structured, but no sufficiently strong lower bounds have been shown. Some strong lower bounds were recently established in specific cases, particularly the homogeneous case, with the use of complexity measures related to the rank of the "shifted partial derivatives" of a polynomial. However, such measures appear ineffective against gates of high degree; without restrictions on degree, the best known lower bound for depth-three circuits is only about $\Omega(n^3)$, despite the seeming weakness of the model. We investigate the known lower bounds for constant depth circuits, and the limitations of current methods (in particular, shifted partial derivatives) in proving stronger bounds.

Measuring Time Resolution of Silicon Photomultipliers Used in the Mu2e Experiment
Alex Lettenberger
Mentors: David Hitlin and Jason Trevor

The Mu2e experiment aims to observe a muon to electron decay via a charged lepton flavor violation, and it utilizes an experimental limit not reached yet by other experiments. To get the experimental limit to this level, the data taken must be as accurate as possible, so the time resolution of each Silicon Photomultiplier (SiPM) is important to know. This is because to get an accurate measurement for the wavelength of the photon hitting the photomultiplier, and thus the initial energy of the electron inciting the photon, it is important to know the instant the photon hits the SiPM. For this reason, the time resolution must be measured accurately for each SiPM, which is done by using ^{22}Na, in which the expelled electrons cause the scintillators to emit photons registered by a SiPM and a phototube. Using the standard deviation of the time difference between the two pulses, the time resolution of the SiPM is found and can be accounted for in calculations. The project is still ongoing; currently work is being done to make the sensors as accurate as possible.

Isolation and Identification of Autotrophic Thiosulfate-Oxidizing Microbes From a Low-pH Freshwater System
Jessica D. Li
Mentor: Jared R. Leadbetter

The sulfur cycle is a global collection of processes that cycles sulfur between mineral forms and living organisms. It involves many changes in redox states, several of which are catalyzed by microorganisms, so understanding the species and metabolisms involved may help mitigate imbalances caused by human activity. Thiosulfate is of particular interest as it contains two sulfur atoms at the redox extremes and thus may be oxidized and reduced simultaneously. Here we enriched for autotrophic thiosulfate-oxidizing microbes from Cedar Swamp, a low-pH freshwater system in Woods Hole, Falmouth, Massachusetts. From the enrichment cultures, we isolated several microbes by repeated passage of colonies onto solid medium. We then used a combination of light microscopy and 16S rRNA gene sequencing to identify the isolates. We observed members of *Thiomicrospira*, *Pseudomonas*, *Methylobacterium*, and *Aeromonas*. Further work will need to be done to more accurately identify isolates at the species level and determine if any new species were discovered.

A Computational Tool for Determining Thermodynamic Isotopic Factors
Jieni Li
Mentor: John M. Eiler

In a sample of molecules of a single compound, the relative abundance of different isotopologues contains important information about the natural processes the sample has been through. The study of these processes, or isotopic fractionations, is the basis of geochemistry tools that are widely applied in earth sciences, chemistry, biology, and many other disciplines. One key value that describes how isotopes affect chemical equilibrium constants is the thermodynamic isotopic factor (β). It indicates the likelihood of a heavy isotope being favored at a specific site within a molecule. This project aims to create a computational tool which can be used to calculate the β factor for every site in any of a wide range of compounds. It provides visualization and computes the thermodynamic isotopic factor dynamically based on the structure of the molecule. It can be used to test current methods of estimating the β factor as well as future hypotheses that are aimed to improve the accuracy of the estimation.

A Comparison of Quasar Variability for Different Types of Quasars
Jiguang Li
Mentors: George Djorgovski and Eilat Glikman

Variability is an effective way to select quasars from huge amount of astronomical data. A study of quasar variability can help us better understand the physics of accretion discs in quasars and the growth of supermassive black holes. To characterize the variability of a large sample of quasars, we use imaging data from the Catalina Sky Survey (CSS) which provides magnitude repeatedly over 8 years. The input data enables the computation of variability indices for each quasar's specific light-curve. The first part of this research involved determining whether there is a significant difference in the statistical distributions of variability indices between radio-loud and radio-quiet quasars. We built overlapping histograms to emphasize the visual difference in the variability distribution between these two populations. Two-sample Kolmogorov-Smirnov test and Anderson-Darling test have also been run to confirm that we could reject the null hypothesis with very high level of significance. Further research is needed to compare the variability indices among type1, type2, BAL, and red quasars. We expect to see there would be a compelling difference in variability indices among these populations as well, which may point to physical differences in accretion behavior.

Searching Exoplanet in Binary Systems and Validation 1 in a Close Binary System, EPIC 201920032
Yangyang Li
Mentors: Dimitri Mawet and Ji Wang

The extended Kepler mission, K2, is now providing photometry of bright star and the precision allows detections of small planets on short-period orbits in binary stars. We select out four K2 candidates with known stellar companion from our physical binary systems. We combine ground-based seeing-limited survey data, photometry results and adaptive optics imaging with a transit analysis pipeline to validate one candidate as planet and identify one candidate as likely false positive. The host, EPIC 201920032, a bright (K=11.364) G star hosting a 2.39907R_E planet with a period of 28 days orbited by a faint star in a distance of 6546 AU. We use Monte Carlo to get planet parameters with giving stellar properties and VESPA to calculate each candidates false positive probability and statistically and photometrically validate transiting exoplanet.

The Role of Small-Scale Convection in the Thermal Evolution of Oceanic Lithosphere
Yida Li
Mentors: Michael Gurnis and Christopher Grose

Small scale convection beneath old oceanic lithosphere is believed to be the reason for topographic flattening of old seafloor. To investigate the role of small scale convection, we have used a ridge-parallel 2D finite-difference model equipped with marker-in-cell Eulerian-Lagrangian method and treat topography with the sticky-air technique. Two benchmarks of our model have been done to test model accuracy. We also investigate the influence of mantle viscosity, sticky air viscosity and sticky air thickness. Experiments of isostatic relaxation time in our model configuration with a ridge axis column and lithosphere show the correlation between mantle viscosity and isostatic relaxation time. We have also attempted to improve the accuracy of the thermal problem by better resolving the constant temperature condition at the surface of the lithosphere. The influence of radiogenic heat will also be addressed, although preliminary result show that the effects on subsidence are negligible. To investigate small scale convection we are presently performing a grid search for the parameters in the viscosity equations. We constrain the viscosity structure of the upper mantle which best fits the geophysical observations. Results show that small-scale convection is required to fit the observations, which requires a relatively low viscosity of the asthenosphere.

A Formal Language-Based C*-Algebra for the Brillouin Zone of Quasicrystals
Crystal Liang
Mentor: Matilde Marcolli

Quasicrystals are materials that exhibit an ordered but aperiodic arrangement of atoms with symmetries forbidden by the crystallographic restriction theorem. An important feature of the structure of quasicrystals is the Brillouin zone, which has been modeled by a noncommutative space. The relevant C*-algebras have been constructed in terms of a dynamical system encoding the substitution rules of the aperiodic tiling of the space. It has been shown that the aperiodic tiling of a quasicrystal can be expressed as a formal language of type D0L. We seek to combine these noncommutative geometry and formal language approaches to studying quasicrystals by finding a noncommutative C*-algebra of the Brillouin zone of a quasicrystal, in terms of generators and relations of the D0L formal language associated with the substitution rules of the tiling. Given such a C*-algebra, we will try to compute its K-theory, the range of the trace, and index theorems and understand what meanings they have in terms of the spectral theory of associated physical systems.

The Whole Atmosphere Community Climate Model and the Polar Vortex
Ty Limpasuvan
Mentors: Yuk Yung and King-Fai Li

Holton and Tan introduced the idea that the quasi-biennial oscillation (QBO) of wind and the 11-year solar cycle have significant effects on the polar vortex of our planet. We define the polar region of the planet as the regions above 65 degrees north latitude. This happens when planetary waves collide at high altitudes above sea level, causing the temperature to rise in the stratosphere and the concentration of ozone to change in the polar vortex. We use data from the Whole Atmosphere Community Climate Model 4 (WACCM4), along with QBO and 11-year solar cycle data to model these effects. The final step involves comparing our models to actual observation data in order to gain understanding as to what the limitations of our data could be. The models could contain data that observations failed to pick up on, and it is also possible that the models are inaccurate. Having accurate models of our planet is important in that it will allow us to predict future trends in temperature and chemical species concentrations, and this data will help their robustness.

Characterization of Microelectrodes and Their Durability for Retinal Implants
David Lin
Mentors: Yu-Chong Tai and Tzu-Chieh Chou

The purpose of this project is to construct character profiles for different electrodes under various environmental conditions. I focused on their durability by running the electrodes through potentiostatic electrochemical impedance spectroscopy (EIS) and repeated chronopotentiometry. Data such as impedance over time, resistivity, and capacitance per area can be obtained to distinguish the electrodes.

The gold electrode under 1mA pulses of 1ms showed a significant considerable increase in capacitance per area (6.592uF/cm^2 to 2486uF/cm^2) and a significant decrease in impedance (234.9kΩ to 498.4Ω) after 9 days. Its continued functionality over this period in these conditions suggests a durability much longer than this. A new gold electrode is currently being run under 5mA conditions, which will force a much shorter durability. Platinum electrodes will also be tested through this method and are currently being fabricated through different processes such as electroplating and electron beam evaporation. Ultimately, these profiles can be used to determine what material is in terms of performance and durability for the implant.

An Implementation of Formally Accurate Higher Order Schemes in Large Eddy Simulations
Zach Lipel
Mentors: Tapio Schneider and Kyle Pressel

Pressel et al. (2017) have shown that the interaction between the numerical schemes and the sub-grid scale (SGS) model is important in determining the quality of large eddy simulations (LES). Previously, the numerics implemented in PyCLES, a python based infrastructure for cloud large eddy simulations, have been at most second order accurate regardless of the formal order of the polynomial reconstructions used to solve the governing equations. However, novel numeric schemes that are both formally higher order and higher order accurate have been developed and implemented in PyCLES. The dry convective boundary layer discussed in Sullivan and Patton (2011) was simulated with both these newly developed schemes and previously implemented lower order accurate schemes. It was found that the higher order accurate schemes, while converging faster than their predecessors, seemed to perform poorly than the lower order accurate schemes. Both schemes converged to the same solution, but the lower order accurate schemes converged regardless of resolution whereas the higher order accurate schemes were sensitive to grid resolution, with coarse resolutions resulting in poor performance, which we attribute to problems with the scalar reconstruction scheme and possible non-conservation in the novel numeric schemes.

Stimulus Independency of SFO Function in Thirst
Mengyu Liu
Mentor: Yuki Oka

Thirst is a hard-wired motivational state essential for survival. The subfornical organ (SFO) has been demonstrated to be necessary for thirst control, because it is proposed to respond to osmolality and hormonal changes. The excitatory neurons of the SFO, marked by neuronal nitric oxide synthase (nNOS) are activated by thirst and, when naturally or artificially stimulated, they potently induce intense thirst and subsequent drinking behavior. However, under certain conditions, the dependency of thirst control on the SFO can be changed. Here, we aimed to use natural and artificial stimuli to change the dependency of SFO on thirst control. To naturally stimulate the SFO, naïve mice were put on a five-day water restriction paradigm followed by ad lib water access to form thirst experiences. Blood osmolality, activity of SFO^{nNOS} neurons and drinking patterns were studied after a second round of water restriction. The results show that although the experienced mice displayed overdrinking behaviors, it was hard to observe the differences in blood osmolality and the $SFOn^{NOS}$ activity pattern. Artificially, optogenetics was used to repeatedly inhibit the SFO excitatory neurons in thirsty mice for a few days. Drinking behavior was then recorded every day to explore the effect of SFO^{nNOS} inhibition on thirst. These results potentially show that natural stimuli have negligible effects on the dependency of the SFO functions on thirst. However, further experiments are needed to demonstrate the influence by artificial stimulus.

Single Cell Integrated Proteomics and Transcriptomics on a Microfluidic Based Barcode Chip
Qianhe Liu
Mentors: James R. Heath and Alex Xu

Quantification of proteomics and transcriptomics is often done using an average of a large collection of cells. However, cancer cells' heterogeneous nature in a tumor can cause this averaging of information to be false and misleading, while inaccurately describing any individual cells. The Heath Lab uses a microfluidic device that integrates DNA barcode chip and barcoded beads for simultaneous quantification of single cell proteomics and transcriptomics. For each cell channel, individual stripes on the barcode corresponds to unique protein assays, while a barcoded bead in the channel traces transcripts back to their individual cells. The goal of this project is to optimize both the design and operation of the microfluidic device through separate testing of each performance step, and gradually incorporating the results into the existing procedure. The process by which the mRNA on barcoded beads are collected and purified was improved through testing of the manual PCR procedure and adjusting AMPure XP bead purification methods. The device with which the unique column barcodes are loaded was redesigned to optimize usage of a new microchannel flow apparatus. Ultimately, this combined platform can provide integrated mRNA and protein expression information to improve accuracy of targeted cancer treatment.

Selective Suppression of Out of Network Events for Earthquake Early Warning
Timothy Liu
Mentors: Egill Hauksson, Jennifer Andrews, and Men-Andrin Meier

Earthquake early warning (EEW) systems are designed to deliver a warning that shaking from an earthquake is imminent. EEW uses a network of seismometers that monitor ground motion and a collection of algorithms that characterize earthquakes shortly after they begin. Events that occur outside of the sensor network pose a challenge for EEW; these events are often mistaken for local earthquakes and can lead to false alerts. The hyperbola method is a technique for locating events using the difference in p-wave arrival times at stations. Originally meant for local events, the hyperbola method can be combined with the Gutenberg Algorithm and the frequency content of events to better locate regional, out of network events. The accuracy of this technique also improves as more stations trigger, and the algorithm regularly updates its estimates as more stations come online. Improved out of network location estimates can reduce the number of false alerts and improve the reliability of EEW.

Querying for Generality and Upstream Regulators of Two Unbalanced Processes in Melanoma
Victoria Liu
Mentors: James R. Heath and Yapeng Su

$BRAF^{V600E}$ is a common mutation in melanoma. When the M397 melanoma cell line is treated with Vemurafenib, a $BRAF^{V600E}$ inhibitor, the cells initially respond. However, the cells eventually undergo a whole transcriptomic change to become resistant. Surprisal analysis was used on this refined, kinetic transcriptomic data to determine two constraints—lambda 1 and lambda 2—that can govern all of these gene expression changes. Each lambda is a list of gene sets that are regulated together, and the biological meanings of the two constraints were discovered using GSEA and Cytosacpe. Lambda 1 represents cell adhesion, epithelial-mesenchymal-transition, and oxidative phosphorylation; lambda 2 represents cell proliferation and epigenetics. To query the generality of the two constraints, GSVA analysis was conducted on the transcriptomic data for thousands of other samples. These samples included melanoma cell lines, different cancer cell lines, melanoma patient samples, and different cancer patient samples. Generality, as defined by co-occurrence, was discovered across all of the samples. These promising results led to a deeper, ongoing investigation of upstream molecular regulators of lambda 1 and lambda 2. This research may pave the way for easier classification of patient tumors based on lambda 1 and lambda 2.

Calibration of the Calorimeter Crystals by Stochastic Gradient Descent Program on GPU for Mu2e
Xiaoling Liu
Mentors: David Hitlin and Bertrand Echenard

The Mu2e experiment at Fermilab is looking for muon-to-electron conversion without the production of neutrinos, which is a sign of Charged Lepton Flavor Violation (CLFV). Using simulated data from ROOT, we know the total energy of an event from the track part of the experiment and the energies detected on each crystal of the calorimeter. We want to estimate the calibration constants (energy deposited/energy detected) with uncertainties for the 684 crystals on the first disk of the calorimeter, so that the chi-square error between the track energy and the total energy deposited in the calorimeter is minimized. Then we can use these calibration constants to infer the energy of the production particles in the actual experiment. In order to do the chi-square minimization, we code a

Stochastic Gradient Descent program, which achieves the minimum of a function by moving along its negative gradient, on **Graphics Processing Unit** (GPU), because parallel processing on GPU enables the update of all the calibration constants simultaneously and is much faster than coding on CPU.

Analysis of Aerobic and Anaerobic Growth of *Pseudomonas aeruginosa* in Cystic Fibrosis Sputum Using MiPACT and HCR Microscopy
Jared Livingston
Mentors: Dianne Newman and Peter Jorth

Understanding how bacteria grow in the lungs in cystic fibrosis (CF) is essential for the development of effective treatments, and recent studies have shown that the mucus in CF lungs is anoxic, suggesting that bacteria may grow anaerobically *in vivo*. We use the recently developed MiPACT (*M*icrobial *i*dentification after the *PA*ssive *C*larity *T*echnique), a tissue-clearing technique that allows bacteria to be visualized in sputum *in situ*, coupled with hybridization chain reaction (HCR), a technique that provides *in situ* molecular signal magnification enabling simultaneous mapping of multiple target RNAs, to visualize bacterial gene expression and infer the growing conditions. We hypothesized that expression of *narG*, a nitrate-reductase encoding gene, would be a proxy for anaerobic growth and could be visualized using HCR. We measured *narG* expression in *in vitro* samples grown anaerobically and aerobically using qRT-PCR (*q*uantitative *R*everse *T*ranscription *P*olymerase *C*hain *R*eaction) and visualized expression using MiPACT and HCR. *narG* was expressed more highly in the anaerobic condition and *narG* probes were found to colocalize with *P. aeruginosa* during microscopy, indicating that these probes may be good proxies for visualizing anaerobic growth of *P. aeruginosa* in sputum samples.

Searching for Echoes of Gravitational Waves From the Coalescence of Exotic Compact Objects: A Bayesian Approach
Ka Lok Lo
Mentor: Alan Weinstein

The ringdown part of the gravitational wave from the merger of two black holes was suggested as a probe of the internal structure of the remnant compact object, which may be more exotic than a black hole. Cardoso et al. pointed out that there would be a train of echoes in the late-time ringdown phase for different types of exotic compact objects (ECOs). Abedi et al. claimed that they have found evidence of echoes in binary black hole mergers detected by LIGO. In this project, we aim to search for echoes of gravitational waves in the three detections LIGO had, and verify their results using their phenomenological model with Bayesian analysis instead. We perform a Bayesian parameter estimation on the parameters related to echoes and Bayesian model selection of presence of echoes versus their absence, to provide stronger evidence for the presence or absence of echoes in these detections. The analysis technique developed in this project could be repeated with different models to provide even more robust evidence of the existence of echoes from ECOs.

The Search for Dwarf Carbon Binary Stars in Palomar Transient Factory Data
Jackie Lodman
Mentors: Tom Prince, Bruce Margon, Ashish Mahabal, Thomas Kupfer, and Kevin Burdge

Carbon stars are a class of stars with significant molecular carbon absorption lines in their spectra. The carbon itself is thought to originate from the cores of massive stars. However, most known carbon stars are dwarf stars that could not produce carbon themselves, thus it is believed that these stars accreted their carbon from a massive companion. Therefore, it is believed that most, if not all, carbon dwarfs should be found in binary systems. To date, only three dwarf carbon binary stars have been identified. Using the color information from the Sloan Digital Sky Survey (SDSS) and PanSTARRS, potential carbon stars in the Palomar Transient Factory (PTF) database were identified, then a period finding script was run on the light curves. To confirm a periodic candidate is in fact a carbon star, a spectrum will need to be taken when the candidate becomes visible from Palomar Observatory, then the radial velocity measured to confirm it is a dwarf star. Overall, more than five candidates have been identified as periodic stars with the correct colors, and there are plans to take spectra/radial velocities of them when they become visible.

Validation of Fracture Methods for Stable Crack Growth in Brittle Solids
Christopher Long
Mentors: Katherine T. Faber and Neal Brodnik

Stable fracture in brittle materials of arbitrary geometry is difficult to achieve. Recently, a method for stable fracture was developed where the opening displacement travels with the crack tip, which is referred to as a surfing load condition. This new method is promising but requires empirical validation. For this purpose, well-established but geometrically restricted configurations—double cleavage drilled compression (DCDC), diametral compression (Brazilian disk), and tapered double-cantilever beam (TDCB)—were analyzed as follows. Stereolithographically printed specimens were subject to compressive loading and displacement maps recorded with a high-resolution imaging camera. These images were evaluated using the J-integral method to calculate strain energy release rate and K_{Ic} fracture toughness. The values were compared to empirical calculations for homogeneous specimens and the same analysis method was used to calculate toughness for heterogeneous specimens. In homogeneous specimens, the J-integral is expected to yield a discrete value intrinsic to the material, whereas in heterogeneous specimens, and toughness depends on the size and location of the introduced heterogeneities. The J-integral and K_{Ic} values obtained in these geometrically constrained tests can then be compared to those obtained from the surfing load condition.

Investigating a Functional Signature of V2 in Higher Order Areas of the Mouse Visual System
Alejandro López
Mentors: Doris Tsao and Francisco Luongo

One fundamental function of the brain is to extract meaningful information from sensory input. The mechanisms by which this occurs remain a mystery. The visual system processes information along a hierarchy of visual areas, extracting increasingly complex information. This hierarchy is well characterised in primates and to a lesser extent in mice. Understanding this organization in mice would enable the use of molecular and genetic tools to understand underlying mechanisms. A recent study found a functional signature of V2, the secondary visual area, in primates; it responds more to natural image statistics than V1, the primary visual area. In mice, there are several extrastriate visual areas, but the order of processing beyond V1 has not been established. This project establishes visual areas analogous to V2 in mice by looking for this signature. I presented visual stimuli containing naturalistic textures and a control of spectrally matched noise to GCaMP transgenic fluorescent mice with surgically clear skulls and compared the response of known visual cortex areas to naturalistic textures to the response of the same areas to control images. Understanding the organisation of the mouse visual system will allow future studies to dissect how neural circuits efficiently extract information from the senses.

Path Planning and Navigation on the Cassie Biped
Filippos Lymperopoulos-Bountalis
Mentors: Aaron Ames, Jake Reher, and Wenlong Ma

Bipedal robots are especially useful for navigating semi-unstructured environments as well as interacting with humans. One of the primary challenges to navigation on bipedal robots is planning feasible walking paths for which the robot can select stable footstep locations. The main goal of this work is to facilitate the implementation of path planning algorithms which can generate efficient walking routes for the bipedal robot Cassie around the Caltech campus. After creating a Digital Elevation Model to locate walkway grades for reference in navigation and an occupancy grid to mark allowable walkways, the remaining goal of this project is to create the necessary software for Cassie to walk on this simulated uneven terrain using the Robot Operating System (ROS).

Exploring the Structure of the Distant Universe With MUSE Data Cubes
Mason MacDougall
Mentors: Lise Christensen, Charles Steinhardt, and Dimitri P. Mawet

Only the most advanced instrumentation is capable of exploring the structure of the early universe and identifying distant objects to be used for further analysis. An ideal tool for surveying such objects is the Multi-Unit Spectroscopic Explorer (MUSE) of the Very Large Telescope array which employs a wide field-of-view and a large spectral range to produce high-spatial-resolution datasets. Here we exploit the 1 spectral and 2 spatial dimensions of a particular MUSE “datacube” to identify and characterize emission line sources near the line-of-sight to quasar PKS1937-101, which lies around z=3.787. In particular, we search for galaxy companions to a z=3.572 Lyman-limit system measured in the quasar spectrum and find an associated Lyman-alpha emitter at z=3.556 with a projected distance of 30.2 kpc from the quasar line-of-sight. Through a combination of automated source extraction and by-eye investigation, we also identify 25 emission line galaxies and another Lyman-alpha emitter in our field. The proximity of several of these objects to the quasar line-of-sight allows us to reliably identify emission lines and fluxes and tie these to absorption lines in the quasar spectrum. This will help characterize metal lines and kinematics of galaxy halos and circumgalactic media in the early universe.

Towards a Glucose Powered, Electro-Osmotically Propelled, Externally Controlled Microbot for Targeted Drug Delivery
Daniel Magley
Mentor: Hyuck Choo

Implantable intravenous transport systems for propelling a load to a target site holds promising applications for targeted drug delivery and non-invasive surgery. In prior work, we have developed a micro-fluidic thruster capable of propelling its own weight at 135 Bodylengths/s while consuming 10^3 times lower power than any prior propulsion method. This low power consumption allowed for it to be the first method capable of sustained propulsion from a glucose biofuel cell. In this work we develop a glucose bio-fuel cell capable of powering this device, a microscale implantable antenna to receive instructions, and a 100um x 100um Integrated Circuit Chip to process the received signal and control the power from the fuel cell put out to the thrusters. In future work all of these components will be integrated together to form a Microbot capable of being navigated through a three dimensional microfluidic terrain such as the blood stream or lymphatic vessels to a target site and deliver an on-board drug payload.

Growth, Spectral Categorization, and Conductivity Testing of PECVD Produced GNRs Under Different Conditions
Omar Mahfouz
Mentors: Nai-Chang Yeh and Chen Chih Hsu

Using the novel technique of plasma enhanced chemical vapor deposition (PECVD), graphene nanoribbons (GNRs) were grown on copper foils at low temperatures. Varying partial pressures of methane, hydrogen, nitrogen, and the carbon precursor, dichlorobenzene, were tested in the growth chambers. They were categorized using Raman spectroscopy to indicate the presence of GNRs and their edge defects. These samples are then sonicated from their copper foils and transferred onto silicon wafers. Using electron beam lithography, metal contacts with the GNRs are patterned onto these silicon wafers. Finally 4-point resistance measurement is applied to measure the sheet resistance of the GNRs.

Modeling Water and Carbon Monoxide Condensation Fronts in Protoplanetary Disks
Morgaine Mandigo-Stoba
Mentors: Geoff Blake, Dana Anderson, and Masha Kleshcheva

The location of certain critical condensation fronts in protoplanetary disks can have profound impacts on planet formation, especially those of water and carbon monoxide. In this project, we attempt to accurately model these condensation fronts in a total of seven protoplanetary disks from the five disk systems (two of which are binaries): RNO90, WaOph6, VSSG1, GSS31, and AS205. Spectroscopic data for several isotopes of carbon monoxide have been collected for all of the disks using the Atacama Large Millimeter/Submillimeter Array (ALMA) in Chile. We have derived estimated inclination and position angles of the disks using the dust continuum data and have made spectral line images of the disks in order to estimate the local standard of rest velocity. We then use these estimates, along with those found in previous literature, as the basis for a series of Markov Chain Monte Carlo (MCMC) simulations. In total we aim to fit the most probable values for 12 parameters, including the temperature at the condensation front, the radius at which the condensation front occurs, and several parameters related to the column density at or beyond the snowline(s), as well as inclination, position angle, and V_LSR (mentioned above). After all parameters have been adequately fit, we will de-project the disk images to make radial trends more easily observable and perform matched filtering to improve the signal-to-noise. From this work, conclusions may be drawn about the placement of these critical snowlines in protoplanetary disks, with applications to much of planetary science.

CIBER2 Automated Optical Focus Calibration System
Animesh Mangu
Mentors: Jamie Bock and Phil Korngut

The Cosmic Infrared Background Experiment (CIBER1) was a sounding-rocket probe experiment created to study infrared background light from above the Earth's atmosphere. A vital aspect of this experiment was assuring that the detectors were placed accurately at the correct focal position of the instruments. In the CIBER1 focusing procedure, a knob and a micrometer turned by hand was used to adjust the focus position, an incredibly tedious and tiring process once repeated multiple times. This is the functionality I have been assigned to upgrade for CIBER2 measurements, automating the previously manual task and decreasing the time for the measurement from approximately 2 days to barely 2 hours. To implement this function, a precise, remotely controlled stepper motor to scan a pinhole through a collimator's focus was purchased, along with a relay device used to communicate with the CIBER2 data acquisition system. A Python program and GUI was written to control the Moonlite Mini Controller stepper motor and relay device, thus automating the movement for a scanner given a set of input parameters. While the scanning functionality is completed, my goal is to complete the data analysis module of the program by the end of the summer.

Electrified Flow in Slender V-Groove Microchannels: Generalized Stability of Steady State Configurations
Vilda K. Markeviciute
Mentors: Sandra M. Troian and Nicholas C. White

Although spontaneous capillary flow can be an especially rapid process in slender open microchannels resembling V-grooves, enhanced flow control is possible through application of an electric field which generates an opposing electrohydrodynamic pressure along the air/liquid interface, which tempers the capillary pressure. Earlier work by Romero and Yost (1996) and Weislogel (1996) elucidated the dynamics of Newtonian films in slender V-grooves driven solely by capillary forces. Here we examine a modified Romero and Yost model which includes the contribution of Maxwell stresses for the case of conducting wetting films. We first identify allowable steady state film shapes for various inlet and outlet boundary conditions. Using a generalized stability analysis, we show that shapes generated by field distributions which scale as $\sqrt{z}$, where z is axial distance in the groove, are super-stable to small perturbations obeying Dirichlet boundary conditions. These results reveal how the ratio of Maxwell to capillary stresses influences the degree of linearized transient growth or decay for thin film flows. We will be extending this study to more general boundary conditions and field distributions in the future.

Image Recognition of Two-Dimensional Materials on Viscoelastic Substrates
Avery M. Marshall
Mentor: Stevan Nadj-Perge

Transition metal dichalcogenides (TMDCs) are a class of materials that can be easily mechanically cleaved into few layer two dimensional crystals. Many of these can be tuned into a topological phase (through electrostatic gating) to create 2D topological insulators that permit helical dissipationless currents to run along their perimeters. These spin-polarized currents provide a foundation for the study of Majorana bound states as well as other spintronic applications. However, an inconvenience that arises with research on these material comes from the transparency of thinner layers. Mechanical exfoliation of TMDCs produces flakes of varying thickness, and finding desirable few-layer flakes scattered among thicker ones can prove to be quite frustrating. This research aims to streamline this process through development of software that can identify flakes deposited on transparent viscoelastic substrates. By determining the thickness of photographed flakes with Raman spectroscopy, the relation between optical contrast and layer number can be characterized for a variety of TMDCs. This allows the software to not only recognize finer flakes during exfoliation, but to also estimate their thickness from a microscope image alone.

Using Neural Networks for Quantum Error Correction on Topological Stabilizer Codes
Nishad Maskara
Mentors: John P. Preskill and Tomas Jochym-O'Connor

In this work, we apply fully connected feedforward neural networks to assist in decoding the toric, surface, and color code. In order to decode a given error syndrome, first a simple correction procedure is applied. We then ask the neural network to categorize the logical effect of the correction procedure. Logical operators can then be applied as necessary to recover the original state. We found that multi-layered neural networks with batch normalization were able to match the performance of minimum weight perfect matching (MWPM) on the toric and surface code. For the independent error model MWPM is optimal, and we our method demonstrated the same error threshold. When applied to the color code, we were able to recover a similar error threshold compared to the current best known decoders for this code.

Stereoselectivity in Reactions Catalyzed by Six-Membered *N*-Heterocyclic Carbene-Supported Ruthenium-Based Metathesis Catalysts Containing Dithiolate Ligands
Alexander H. Mason
Mentors: Robert H. Grubbs and Tonia S. Ahmed

Recently, dithiolate-containing metathesis catalysts have been shown to be highly stereoretentive in cross-metathesis; *E*-olefins give *E*-products and *Z*-olefins give *Z*-products. Recent work by the Bielawski group has shown that the ruthenium-carbon bond length seen with six-membered *N*-heterocyclic carbene (NHC) ligands is shorter than that seen in typical imidazole-type NHC ligands. This property of six-membered NHCs was the basis for this project, with the hypothesis that this shorter carbon-metal bond distance would affect the steric influence of the NHC on the ruthenacyclobutane intermediate. Thus far, a stereoretentive dithiolate-bearing catalyst supporting a six-membered NHC ligand has been synthesized and isolated. Other six-membered NHC ligand precursors have been synthesized which will soon be incorporated into new catalysts and their activity, along with their stereoretentive properties, will be examined.

Gravitational and Topographical Signals of Ocean Dynamics Inside Europa
Surya Mathialagan
Mentors: David J. Stevenson and Hao Cao

Europa is one of the four Galilean satellites of Jupiter which has an icy surface and a radius comparable to that of the Earth's moon. During the multiple flybys of Europa, the magnetometer of the Galileo spacecraft detected perturbations in the external magnetic fields (Jupiter's tilted dipole magnetic field) near Europa that requires a near surface electrically-conducting layer. This electromagnetic induction measurement, when combined with the inferred composition and density of the outer layer of Europa, suggests a near surface internal ocean, making Europa a popular destination for the search of extra-terrestrial life. In this project, we forward calculated the gravitational and topographical signals of the subsurface ocean dynamics of Europa. We first performed a Monte Carlo survey of the static interior structure to match the observed mass, equatorial radius, and the inferred moment of inertia of Europa. A Concentric Maclaurin Spheroid (CMS) calculation was then performed to derive the gravitational moments and surface shape of a uniformly rotating Europa with no ocean dynamics. We then carried out a quantitative analysis of the gravitational and topographical signals from the subsurface ocean dynamics of Europa using the dynamical height approximation for several assumed ocean dynamics profiles. The gravitational response of the ice shell to the ocean dynamics were further assessed using the CMS method. The observable gravitational and topographical signals from the ocean dynamics and the ice shell response were then calculated iteratively. We assessed their detectability by the Europa Clipper mission, which is scheduled for launch in 2020s. These calculations have strong implications on the interpretation of the gravitational and topographical data from the Clipper mission, given that ocean dynamics could have a significant impact.

Temporal Logic Control With Integrated Experiment Design
Hubert Ménou
Mentors: Richard Murray and Sofie Haesaert

Overall actions imposed on dynamic systems required by tomorrow's technologies – such as driverless cars – are particularly well described with Linear Temporal Logic (LTL) specifications. Recent work that enables us to automatically synthesize hybrid controllers satisfying these tasks requires accurate models. Data from experiments can be used to get more accurate models. It is of interest to do these experiments online, to gather data while satisfying the high level operational LTL-specifications. This SURF project aims to newly introduce experiment design into temporal logic control. Architecturally, the controller is split up in two layers: one abstract finite-state layer for high level decision making and trajectory planning, and one continuous-space layer implementing the continuous low level control. The design of this continuous control is generally solved as a model predictive control (MPC) problem. In this work, an Experiment Design constraint is integrated into this MPC problem, such that, while controller still enforces the LTL-specifications, it also allows for efficient online data gathering. More precisely, we use the Fischer Information Matrix, which is a function of the continuous state trajectories. As this matrix expresses the information content of the data, the experiment design constraint integrated in the MPC is chosen as its lower bound.

Directed Evolution of an Iron-Containing Biocatalyst for C–H Amination
Emily Miaou
Mentors: Frances Arnold and Ruijie (Kelly) Zhang

All organic molecules contain a myriad of C-H bonds, which are typically considered to be chemically inert. Development of catalytic methods to reliably and selectively transform C-H bonds will transform the way chemical synthesis is performed. Existing methods for C-H bond functionalization suffer from several limitations, including their reliance on catalysts that are commonly complexes of precious metals with complex ligands. Furthermore, developing methods that achieve high stereocontrol in intermolecular transformations, which offer the greatest potential for streamlining synthesis, has been particularly challenging. This project seeks to develop hemoprotein catalysts for selective C-H functionalization, contributing to goals for conducting sustainable chemical production. Given that amines are found in many biologically active compounds and are highly versatile intermediates, they are considered extremely valuable products and targets for catalysis. Previous work in the Arnold lab has demonstrated that hemoproteins are competent catalysts for performing enantioselective intermolecular C-H amination using tosyl azide as the nitrene precursor. Given this finding, we hypothesize that hemoprotein-catalyzed intermolecular C-H amination chemistry can be extended to other nitrene precursors. In this project we design non-azide nitrene precursors and use directed evolution to create variants of hemoproteins capable of performing catalysis with these substrates. Ultimately, we aim to expand the scope of non-natural biocatalytic C-H amination chemistry.

Plasma-Etched Nanoporous Graphene for Reverse Osmosis Desalinization
Rebecca Mikofsky
Mentors: Konstantinos P. Giapis and Ben Kanevsky

Nanoporous graphene is a valuable membrane for reverse osmosis desalinization, due to its increased theoretical performance over current polymer membranes. Graphene is a single layer of carbon atoms and nanoporous graphene (graphene with carbons knocked out) has properties of high permeability, tensile strength, and hydrophobicity. This allows water to pass through it well while salt is rejected. Chemical vapor deposition is used to grow the graphene on copper foil at 1000C in the presence of hydrogen and methane gasses. The nanopores are introduced via plasma bombardment, then analyzed through Raman spectroscopy which depicts the defects of graphene. Helium plasma destroyed the samples within six seconds, so pretreatment cleaning time was increased and the gas was switched to argon, which is more capable of removing contaminants from the chamber. Argon plasma destroyed all the graphene within 40 seconds, allowing for more control. This increased accuracy allowed for samples of the same time to have more consistent defects. Further research can be done testing the membranes within a micro-fluidic setup in order to test salt rejection.

Alaska: A Framework for Automated, Complete RNA-Seq Analysis
Kyung Hoi (Joseph) Min
Mentors: Paul W. Sternberg and David Angeles-Albores

A typical RNA-sequencing (RNA-seq) workflow consists of generating libraries to obtain reads, aligning them, and identifying the genes that are differentially expressed in response to a perturbation. At the end of the workflow, the reads are submitted to the Gene Expression Omnibus (GEO). Although the molecular biology behind RNA-seq is well understood, the computational analysis remains challenging because researchers must learn how to operate complex software correctly. Moreover, GEO metadata do not use controlled ontology—this decreases the reusability of the dataset and prevents its incorporation into databases such as WormBase, decreasing its impact. These difficulties prevent labs without dedicated experts from incorporating RNA-seq into their day-to-day workflow. We introduce a fully automated RNA-seq framework, which we call Alaska. Alaska automatically infers the correct way to analyze an experiment from user input and performs all downstream analyses. The data are automatically submitted to GEO along with the appropriate metadata, which is written using a controlled ontological language. This allows databases to automatically perform powerful meta-analyses, and enhances indexing and searching of experiments, maximizing the impact of each dataset on the scientific community. The entire process from input to output is performed in minutes and requires no technical expertise.

Characterizing the Role of Various Cytokines in the Pathogenesis of Inflammation in Restenosis
Anvita Mishra
Mentors: Tejal Desai, Yiqi Cao, and Henry A. Lester

Cardiovascular disease is the leading cause of death globally, estimated to cost over $320 billion in annual healthcare costs in 2017 alone. Many cases of cardiovascular disease have been treated with angioplasty; however, nearly 40% of angioplasty patients suffer from restenosis within a year of treatment. Previous studies have indicated that restenosis is characterized by arterial wall remodeling and neointimal hyperplasia, which is the uncontrolled proliferation of vascular smooth muscle cells and endothelial cells after injury. Preliminary research in the Desai lab has shown that nanostructured TiO_2 surfaces may attenuate this proliferative response. However, the mechanism of attenuation in the experimental model of Human Coronary Artery Endothelial Cells (HCAEC) and Human Coronary Artery Smooth Muscle Cells (HCASMC) is not yet understood. We believe that inflammatory cytokines such as Tumor Necrosis Factor α (TNFα) and Platelet-Derived Growth Factor (PDGF) may play an important role in mediating vascular inflammation, In this project, we developed a model of vascular inflammation by comparing the vascular response to various cytokines with quantitative PCR. Further studies will utilize this model to evaluate the potential mitigating effects of nanostructured TiO_2 surfaces on restenosis.

Controlling a UR10 Robotic Arm to Enhance Spacecraft Simulation
Prinesh Mistry
Mentors: Soon-Jo Chung and Yashwanth Nakka

The Universal Robots UR10 robot is a six degree-of-freedom robotic arm with an integrated controller. This research investigates different methods of controlling the arm pursues the implementation of a custom controller. Newer versions of the UR10 have very different hardware and firmware, limiting the number of preexisting resources. The methods of control explored are via the included “teach pendant,” a touchpad connected to the controller with a Universal Robots GUI and via an external computer using a socket connection. Both methods require use of UR’s proprietary programming language “URScript.” Control from a computer was chosen to allow for basic motion planning. The second stage of this research was to make the robot track a marker in 3D space using cameras and inverse kinematics. In the scope of spacecraft simulation the arm will carry a one meter scale asteroid along a predefined trajectory such that a “spacecraft” robot can interact with the asteroid intelligently.

Mean Field Analysis of Recurrent Neural Networks
Sarang Mittal
Mentors: Maria Spiropulu, Stephan Zheng, and Jean-Roch Vlimant

We analyze the dynamics of recurrent neural networks whose initial weights and biases are randomly distributed. Utilizing mean field theory and making some mean field approximations, we develop a theoretical basis for length scales which limit the depth of signal propagation in a one layer recurrent network with long input or prediction sequences. For specific hyperparameter choices, these length scales diverge. Building on the conclusions of Schoenholz et. al. (1), we argue that random recurrent networks can only be trained if the input signal can propagate through them. This suggests that recurrent networks can be trained with arbitrarily long sequences provided they are initialized sufficiently close to criticality. We begin searching for empirical evidence in support of our conclusions, and provide some preliminary results.

Investigating Legislation Intended to Curtail Minority Vote Dilution
Connor Moffatt
Mentor: J. Morgan Kousser

Throughout American history, various racial, ethnic and socio-economic minorities have been underrepresented at all levels of government. Structures such as at-large elections enable vote dilution; this dilution, whether intentional or not, can limit a group’s ability to elect a preferred candidate. Disproportionate representation may lead to a government that only acts for a subset of its electorate. Two of the most contentious attempts to inhibit vote dilution are the federal Voting Rights Act of 1965 and the California Voting Rights Act of 2001; both laws intend to ensure governmental bodies are reflective of their constituencies. By using databases on violations of these laws and changes in elected officials, we can analyze the strengths and weaknesses of both acts. For example, by using the number of Latino officials elected onto city councils and school boards as a marker, we can assess the effectiveness of the legislation. This analysis may assist drafting similar legislation at the state and federal levels.

Manganese Oxidation as a Gateway Mechanism to Modern Oxidative Photosynthesis
Kabir A. Mohammed
Mentors: Woodward Fischer and Usha Lingappa

The origin of oxygenic photosynthesis is one of the most significant metabolic events in the history of life. It enabled autotrophs to vastly increase their productivity, and the resulting increase in biomass flux energetically allowed for the evolution of eukaryotic and multicellular life. We believe that modern photosynthesis was preceded by a metabolic process involving the oxidation of reduced manganese species. The manganese composition of the water oxidising complex in photosystem II, and the Mn(II)-rich composition of the paleoocean make this hypothesis plausible. We test environmental samples of cyanobacteria and algae from various locations for the presence of manganese oxides. We also aim to characterise the manganese chemistry of the model organism *Chlamydomonas reinhardtii*. The project is ongoing.

Effects of a PID Control System on Electromagnetic Fields in an nEDM Experiment
Daniel Molina
Mentors: Bradley Filippone and Simon Slutsky

The Kellogg Radiation Laboratory is currently testing a prototype for an experiment that hopes to identify the electric dipole moment of the neutron. As part of this testing, we have developed a PID (proportional, integral, derivative) feedback system that uses large coils to fix the value of local external magnetic fields, up to linear gradients. PID algorithms compare the current value to a set-point and use the integral and derivative of the field with respect to the set-point to maintain constant fields. We have also developed a method for zeroing linear gradients within the experimental apparatus. In order to determine the performance of the PID algorithm, measurements of both the internal and external fields were obtained with and without the algorithm running, and these results were compared for noise and time stability. We have seen that the PID algorithm can reduce the effect of disturbances to the field by a factor of 10.

Automated System for Electrochemical Activation of Neural Probe Microelectrodes Used for Recording and Stimulating Brain Activity
Antonio Monreal
Mentors: Thanos Siapas and Gustavo Rios

The underlying neural mechanisms governing brain functions such as perception, emotion, learning, and memory currently remain poorly understood. What is known is that these functions emerge from the coordinated interactions of billions of neurons distributed throughout the brain. These interactions are in the form of electrical pulses which can be monitored using microelectrodes. Until recently, neural probes were limited to have about 100 recording microelectrodes and, thus, can sample neuronal activity only very sparsely. The Siapas Lab has developed nanofabricated neural probe arrays that drastically increase the number of recording microelectrodes into the thousands. While these microelectrode arrays are an improvement over previous electrophysiological systems, the tissue-electrode interface requires further modification to maximize their performance. Electrodeposition of conductive polymers has been shown to drastically reduce the electrical impedance of microelectrodes, thus, reducing noise, and even allow for safe electrical brain stimulations. Implementing this across thousands of microelectrodes is a challenge since the depositions are hard to replicate and time-consuming. To systematically apply this technique, we developed a fully automated, microfluidic-based system that allows for sequential electrodeposition of conductive polymers onto hundreds of microelectrodes along with electrochemical characterization of their electrode-electrolyte interface.

The Age of Non-Model Organisms: Making Multinuclear Macroalgae Genetically Tractable
Mie Monti
Mentors: Elliot Meyerowitz and William T. Gibson

Biology has traditionally focused on established model organisms, benefitting from community effort to provide a vast array of molecular tools for experimentation. However, this approach limits our knowledge as information about the diversity and ingenuity of biological systems is missed. We have undertaken the study of the green macroalga *Caulerpa,* which defies the paradigm of cellular developmental biology as it shows complex patterns across a giant multinuclear single cell. Moreover, it possesses promising downstream applications due to its lipidomic profile and abundance of bioactive molecules. In order to investigate this organism thoroughly, *de novo* transcriptome sequencing combined with multiple bioinformatic analyses have been used to isolate genetic regulatory elements. Their assembly into synthetic constructs containing fluorescent reporter proteins allows for optimization of transformation protocols for this alga to visualize and study its intriguing cellular biology. The potential to label the cellular ultrastructure will help elucidate *Caulerpa's* as yet poorly understood developmental model. Ultimately, these tools and protocols have the potential to revolutionize the field of algal biotechnology, opening the field to a new model system with numerous advantages over those currently used.

An Elementary Proof of the Landsberg-Schaar Relation and its Generalization
Christopher Moon
Mentor: Zavosh Amir-Khosravi

The Landsberg-Schaar Relation is a relation that only involves finite sums, yet the only known proof relies on limits of infinite sums. This project was to show an "elementary" proof to the relation that did not rely on complex analysis as well as for its generalization, the generalized quadratic reciprocity law for Gauss sums. We have successfully demonstrated a proof that relies solely on finite methods using a direct application of a discrete analog of the Poisson summation formula. The same method can be used to prove its generalization. Furthermore, by translating our method, we hope to generalize proofs of the relation even further to say finite abelian groups.

Simulating Instabilities in Dusty Fluids
Stefania L. Moroianu
Mentors: Philip Hopkins and Jonathan Squire

In a variety of astrophysical systems, radiation pressure on dust grains can cause strong "dust-driven winds". However, this system, where the wind is driven by the drag between the dust and the gas, is generically linearly unstable to a spectrum of "resonant drag instabilities" (RDI). These instabilities drive exponentially-growing dust-to-gas ratio fluctuations, and eventually the non-linear terms lead to turbulence in gas and dust. We numerically study the statistical properties of a coupled dust-gas system where the dust is distributed over a broad spectrum of sizes. The dust grains are subject to external accelerations from incident radiation and stream through the gas at supersonic speeds. We study a variety of grain size spectra and prescriptions for the radiative accelerations, corresponding to different astrophysical environments. The clustering properties of different dust species depend strongly on these choices. We discuss how this affects dust collision velocities and the implications for grain growth in astrophysical systems.

The Dynamics of Dust and Gas in Radiation
Eric Roger Moseley
Mentor: Philip Hopkins

When a dust-gas mixture is placed in a radiation field, the two components will experience unequal forces. The dust being opaque, it will feel an acceleration that the gas does not. This leads to a new type of fluid instability known as a dust streaming instability. The source of the instability is imperfect coupling of dust and gas that leads to exponentially growing density perturbations in both the gas and dust. The linear regime of the instability has been understood analytically up to this point, but in order to understand the non-linear regime, computational methods are required. Using the hydrodynamical code GIZMO, I have investigated the effects of dust-gas coupling while the dust is experiencing a uniform force and Epstein drag. I have run a suite of simulations with varying parameters (e.g. grain size, force on the dust, dust-to gas mass ratio, etc.) to understand the character of the instability on different length and velocity scales, as the behavior of the instability can vary wildly depending upon the parameters used. These instabilities have implications for planet formation (by concentrating dust), star formation (by influencing local metallicity), and other astrophysical problems involving dust-gas coupling and a force that drives only one of the two components.

Using Tensor Networks to Simulate Topological Phase Transitions
Marc E. Muhleisen
Mentor: Xie Chen

Typical phase transitions in condensed matter systems exhibit a certain type of symmetry which is broken at a critical point. These systems can be well understood using Landau's symmetry-breaking theory. Other types of phase transitions, in contrast, are not nearly as well understood. In this study, we use numerical methods implementing tensor networks to simulate transitions between topological phases. Tensor networks are a way of representing a many-body system's wave functions without causing a conventional computer to run out of memory. Recent work in our research group has improved the tensor network approach by identifying which parameters and mechanisms are responsible for driving the phase transitions. Here, we calculate the variational ground states of some elementary models throughout several phase transitions in order to determine their orders and the universal scaling properties around any critical points. This approach has the advantage that it can be applied equally well to the simplest topological models as well as to more complicated ones without conventional analogues. The wide applicability of our tensor network algorithms will allow future studies to simulate phase transitions for all locally interacting models and thereby potentially to formulate a general theory of topological phase transitions.

Task Programming for Generalization in Robotic Assembly
Suraj Nair
Mentors: Silvio Savarese, Animesh Garg, and Pietro Perona

The challenge of developing artificial intelligence and robots that can learn complex tasks in realistic environments have been a prominent research topic for many years. The recent work of Neural Task Programming shows that using neural programing and meta-learning generalizes well to hierarchical tasks and can learn new tasks with only one demonstration. The primary drawback of this work is that it uses hand crafted state representations, in turn limiting the algorithm to simple, simulated tasks. In this project we take these advancements and expand on them such that they can be used in real world settings on physical robots. Specifically, by incorporating end to end visual learning as well as domain transfer, we will show that our algorithm can complete complex tasks in the real world, such as assembly, organization, and cleaning. From preliminary results, we suspect this work will be the first to successfully learn complex, hierarchical manipulation tasks on a physical robot from a single demonstration.

Understanding the Limits of Bootstrapping in Quantum State Tomography
Sasha Nanda
Mentors: John P. Preskill and Philippe Faist

Being able to determine quantum states using tomography is crucial to advance quantum computing. The error analysis of the reconstructed state is usually carried out using statistical methods like bootstrapping. While bootstrapping has worked well in practice, it fails in some extreme cases. We try to find other such cases by simulating data from a true state, performing a Maximum Likelihood Estimation, running a bootstrap procedure to generate an estimated error bar on the figure of merit (fidelity to a target state), and comparing them to the true error. We characterize the reliability of the bootstrap by considering the probability that the error bar is a particular fraction of the true error. We perform the bootstrap for a qubit, Bell pair, Greenberger-Horne-Zeilinger state, and W-state, varying the purity of the state, amount of noise in the measurements, and number of measurements. We find that the bootstrap is reliable, as the error bars generated from the bootstrap are spread evenly around the true error bar even with the addition of noise to the measurements. This is a step towards understanding the reliability of the bootstrap. The techniques and code we have developed are expected to facilitate future extensions of our work.

The Cassini Mission Activity on Titan
Maya Nasr
Mentor: Charles Elachi

Titan is one of the most interesting satellites in the Solar System. It is particularly unique for the thickness and density of its atmosphere, in addition to its surface composition that has many indications of water, silicates or even large amounts of organic compounds. One of the intriguing features of Titan's surface, however, is its large number of surface lakes surrounded by raised rims. The Cassini-Huygens spacecraft is equipped with eighteen instruments that help in investigating and gathering as much data as possible about Saturn and Titan. This research particularly works on registering the data from Cassini's VIMS: Visual and Infrared Mapping Spectrometer and from RADAR's SAR: Synthetic Aperture Radar Imager found in NASA's Planetary Data System (PDS) in order to investigate the cause of Titan's lake rims formation in details. We use the Integrated Software for Imagers and Spectrometers (ISIS3) in order to overlay the VIMS data images over the highest resolution images from the Cassini Radar Basic Image Data Record (BIDR). This combined data registered helps in mapping out Titan's surface and in extracting the information that could determine the main cause of the formation of the rims around Titan's surface lakes.

Building a Web Portal for Biochemists to Predict Protein Expression
Charles Nelson
Mentors: Bil Clemons and Shyam Saladi

Integral membrane proteins (IMPs) present a challenging target for current research. Comprising a majority of key drug targets, they have proven difficult to cultivate through overexpression, with less than 10% of proteins of interest able to be expressed in the lab. The net result is a field lagging years behind comparable research into soluble proteins. However, novel research by the Clemons lab has shown that modeling IMP expression using machine learning techniques including support-vector machines (SVMs) and artificial neural networks (ANNs) can generate empirical predictions of expression before any attempts at synthesis are performed. Given this existing research, we expect to produce a web app that will allow researchers to access our results in an intuitive and easy way, and use our predictive tools to accelerate the pace of their own research.

Optimization of Single-Cell Microfluidics System With CRISPR/Cas13 Technology for HPV Detection
Laura (Maria) Newport
Mentors: Kam Leong and John H. Seinfeld

Cervical carcinoma is primarily caused by the persistent infection of the human papillomavirus (HPV) in the cervix. Early detection of HPV can be critical to preventing cervical cancer from forming. Recently, a new CRISPR associated RNA endonuclease was discovered, namely Cas13a, which originates from the viral defense mechanism of bacterial adaptive immune systems. Under the guidance of a specific guide RNA (gRNA), Cas13a can recognize the specific RNA sequence of HPV and trigger a "collateral damage" effect, which amplifies the signal of detection. In order to mimic the low concentrations of HPV RNA in the early stages of cancer, the Cas13a/gRNA complex is utilized within a microfluidic chip detection system (MCDS) that can isolate a singular cervical cancer cell within a double emulsion droplet. In this research paper, we construct and optimize these two systems together to detect HPV RNA at a low limit of detection which rivals other methods, such as the golden standard RT-PCR, at a fraction of the price.

Altered Immune System Response in Zebrafish With Disrupted Sleep
Cat Ngo
Mentors: David Prober and Audrey Chen

Over 30 million Americans suffer from chronic sleep disorders such as narcolepsy and insomnia. However, despite the medical impact of sleep disorders, relatively little is known of the genetic and neuronal mechanisms that regulate sleep and wakefulness. Zebrafish larvae serve as a simple and cost-effective model to study neural circuits that regulate sleep. In David Prober's laboratory, new sleep regulators in zebrafish have been discovered and well-studied; yet, not much is known how immune system affects the sleep-wake behavior of zebrafish. Therefore, we quantified cytokine expression in zebrafish mutant in order to determine whether the immune system is altered in fish with abnormal sleep behavior. We designed primers that targeted cytokines Interleukin 1 β, Interleukin 6 and NF-κB, then quantified their expression using qPCR. In our examination of zebrafish larvae with overexpression of hypocretin (*hsp:hcrt*), overexpression of neuropeptide VF (*hsp:NPVF*), deletion of neuropeptide VF (*npvf -/-*), deficiency of histamine production (*hdc -/-*), and pharmacologically inhibited histamine receptor 1 (*Hrh1*) signaling, we found altered immune system markers in zebrafish with disrupted sleep.

Octacyanomolybdate- and Hexacyanoferrate-Borane Adducts for Next-Generation Redox Flow Batteries
Danh X. Ngo
Mentors: Harry B. Gray and Brendon J. McNicholas

Redox flow batteries (RFB) are a renewable form of energy storage with great longevity, yet their energy density leaves much to be desired. In order to access higher potential reversible redox couples as redox flow battery electrolytes, octacyanomolybdate- and hexacyanoferrate-borane adducts were synthesized. The borane employed in coordination displayed a direct relation between its Lewis acidity and the redox potential shift per borane. In some cases, borane coordination eliminated electrochemical reversibility from the parent redox couple of the cyanometallate. In others, wildly different electrochemical behavior was observed due to the formation of a rare borane-linked cyanomolybdate(IV) dimer. However, redox potential control was established for the monomeric cyanometallates, revealing a promising platform for further investigation of cyanometallate-borane adducts.

High Voltage Hexacyanometallates for Non-Aqueous Flow Batteries
Cherish Nie
Mentors: Harry Gray and Brendon McNicholas

We investigate the coordination complex $[Mn(CN)_6^{3-}]$ and characterize its behavior with and without outer-sphere borane adducts, specifically BPh_3 and $(C_6F_5)_3B$, to determine its viability in flow battery technology. Binding of highly soluble Lewis acids 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. These benefits allow for increased energy densities while preserving cost-efficiency and adaptability in flow batteries. Characterization was accomplished by UV-Vis spectroscopy, cyclic voltammetry, X-ray crystallography, EPR spectroscopy, and spectroelectrochemistry. The addition of borane adducts was found to anodically shift the redox couples by consistent intervals per borane, and reversible and quasireversible peaks were observed for the Mn(III/II) and Mn(II/I) couples of the six-coordinate complex respectively in acetonitrile and DCM. Electrochemical reversibility and cyclic stability indicate that $[Mn(CN)_6^{3-}]$ is a promising complex, and it will be useful to test its behavior in model flow battery systems. We will expand our library of low-cost metal organic complexes by characterizing hexacyanochromate in a similar fashion.

The Prism Manifold Realization Problem, Part II
Tynan Ochse
Mentor: Yi Ni

We continue our investigation of the prism manifold realization problem and deduce a complete list of all prism manifolds $P(p; q)$ with $1 < p < q$ that arise as integral surgery along a knot in S3. This is done by classifying all C-type changemaker lattices, which extends and generalizes the methods used in the $q < 0$ case.

Assay Development for Point of Care Detection of *Chlamydia trachomatis* and *Neisseria gonorrhoeae*
Pedro Ojeda
Mentors: Rustem F. Ismagilov, Daan Witters, and Erik Jue

Nucleic acid amplification testing (NAAT) is a medical tool that is now available to most medical centers and is applied to diagnose over 1.4-1.8 million patients with Chlamydia (CT) and Gonorrhea (NG) every year in the United States alone. Currently, NAAT technologies are not amenable to point of care (POC) or limited-resource settings (LRS). NAAT requires a trained professional since it is a multistep procedure involving lysis, nucleic acid purification, amplification, and detection and final diagnosis could take place hours to days after the original patient's visit. The purpose of this project is to develop an assay that can be executed on an automated sample-to-answer device that incorporates all of the steps of the NAAT and can be used in LRS and POC settings. To be successful, a POC NAAT device must meet the ASSURED criteria set by the World Health Organization: affordable, sensitive, user-friendly, rapid, equipment-free, and deliverable. The design that the Ismagilov group proposes will use loop-mediated isothermal amplification (LAMP) to detect CT and NG RNA. Here we explore ways to bring LAMP to an automated device by validating and improving extractions methods, lyophilization of LAMP reagents, and design of LAMP primers.

Boundary Region Embedding: A New Approach to Quantum Mechanics/Molecular Mechanics Simulations
Willis O'Leary
Mentor: William A. Goddard III

Quantum Mechanics/Molecular Mechanics (QM/MM) atomic-scale simulations can efficiently describe large systems with high accuracy. QM/MM accomplishes this feat by only treating small regions of interest with QM; less-important regions are described with classical MM. Conventionally, interactions between QM and MM regions are accounted for using force fields. However, since accurate reactive force fields are difficult to develop, we propose a new methodology: boundary region embedding (BRE). BRE introduces a boundary region through which the QM and MM regions can influence one another. For testing purposes, we will use BRE to model water at the Pt(111)/H_2O interface and compare our results to those derived with full QM simulations. In the future, we hope to use BRE to study the oxygen reduction reaction at the Pt(111) surface.

Optimization and Testing of Multi-Agent Systems
Suzanne Oliver
Mentors: Soon-Jo Chung, Rebecca Foust, and Salar Rahili

The purpose of this project is to explore the benefits of multi-agent systems by solving the "Uber problem" and establishing a multi-agent testbed. The "Uber problem" is defined as optimizing a transportation company's profits by determining the most valuable trips to make and assigning agents to those tasks. Taxi data from Chicago was analyzed at various times of day to determine the most profitable customers for the company based on their location, intended destination, and the time of day. This study produced an algorithm which determines the best customer for each agent in a city to pick-up, based on the city's traffic history and the other agents in the area, and suggests optimal routes for fixed-path buses. This algorithm uses a Markov Decision Process, a SARSA Reinforcement learning algorithm and some elements of game theory. Additionally, robots were set-up for testing multi-agent guidance and control algorithms like the one above. These robots were fitted with communications modules, their motions were characterized using Vicon cameras, and a motor controller was implemented using motor encoders and an Arduino. The robots can now be fully controlled remotely as needed for the algorithm testing. Now that the set-up is complete, these tests can begin.

Toward the New Generation of Universal Force Fields for Molecular Simulations of Materials
Julius Oppenheim
Mentors: William A. Goddard III and Saber Naserifar

Electrostatic and van der Waals (vdW) interactions dominate in determining the properties, structures, and dynamics of chemical, biochemical, and material systems. While described well at the quantum mechanics (QM) level, these interactions flounder in the various force field simulations models. We recently developed the Polarizable Charge Equilibration (PQEq) model to predict accurate electrostatic interactions and validated the model by comparing polarization energies computed by PQEq with that of QM, of which there is excellent agreement. In addition, we are developing a universal vdW curve, based on high quality QM calculations with dispersion forces of crystalline systems, to capture accurate vdW interactions. All of these vdW curves are identical in the scaled space, which means there is a possibility of introducing a universal curve to define the vdW interactions. To describe the valence terms, we use and optimize well-established valence functional terms of different force fields, such as Dreiding and OPLS. The PQEq model combined with this universal vdW curve provide a new universal force field, which is based on accurate electrostatics and high quality QM calculations. We expect that the new universal force field will be useful for a large range of applications and development of new generations of materials.

Exploring the Physics of Galaxies in the Early Universe Using Photometric Template Fitting
Camilla Ora
Mentors: Charles Steinhardt, Mikkel Stockmann, and Peter L. Capak

Astronomical instrumentation has allowed cosmologists to probe neighboring galaxies to extract their various properties, such as their spectral energy distributions (SEDs), and thereby infer the physical laws that govern galactic assembly and evolution. However, when these physical relations are scaled to galaxies beyond our nearest localities, we reach bizarre conclusions: the derived masses of these galaxies at high-redshift are so large, our current cosmological paradigm could not forecast the capability of gravity assembling their constituents. While this disconnect may suggest error in our observational methods, it has potential for implying the laws that govern the oldest of the cosmos are more eccentric than previously believed. Using photometric template fitting, by which we fit the observed galactic photometry with derived SEDs and calculations, we take steps in understanding what properties, and consequently laws, would have permitted the birth and existence of more than three hundred of some of the oldest galaxies in the observable Universe.

Investigating the Synthetic Scope of Chiral Heterocycles by a Tandem Sakurai Allylation / Intramolecular Cyclization
Ciara M. Ordner
Mentors: Sarah E. Reisman and Julie L. Hofstra

We recently developed a one-pot tandem reaction that converts chiral allyl silanes into chiral heterocycles with high stereospecificity under Lewis acid catalyzed conditions. These chiral heterocycles are common motifs found in bioactive natural products, many of which have may find use as potential drug targets. We report on the optimization of this cascade reaction to benchtop-scale chemistry, as well as an initial expansion of the synthetic scope. In our studies, we were successful in varying the cyclization ring size, investigating cyclization preference in the presence of multiple electrophilic leaving groups, and altering the functional groups present on the aldehyde starting material. Ultimately, we envision this method will be useful in the synthesis of a variety of chiral heterocycles.

Geometric Models of Syntax
Andrew Ortegaray
Mentor: Matilde Marcolli

In the syntactic parameter formulation of languages, we analyze the structure present in high-dimensional syntactic parameter space. Through the laplacian eigenmap method of Belkin and Niyogi, we generate network graphs for both languages and parameters at varying neighborhood distances and connectivity values. We explore the space of these graphs though different graph parameters to identify graphs with locally high clustering and with eigenmaps that produce large variance in the coordinates of the syntactic parameter space. We anticipate that this will produce transformed parameters that can more efficiently describe individual languages. We further apply clustering information from the network graphs for phylogenetic reconstruction of several language families from the syntactic parameters. Further work will have the syntactic parameters mapped in a sparsely distributed memory known as a Kanerva network. Recoverability information for each parameter from the Kanerva network will be applied for similar phylogenetic reconstruction. This information will allow for the removal of the assumption that languages evolve independently in the construction of language phylogenies.

The Polynomial Freiman-Ruzsa Conjecture for Shift-Minimal Downsets
Will Overman
Mentor: Nets Katz

The Polynomial Freiman-Ruzsa conjecture would allow one to switch between combinatorial and algebraic information with only polynomial losses in the information and is a central open question in additive combinatorics. We have attempted to expand on the work of Ben Green and Terence Tao in which they proved this conjecture for certain sets known as shift-minimal downsets using a 30^{th} degree polynomial. Our effort has been to decrease the degree of this polynomial in order to obtain a tighter result. We have attempted to take a significantly different approach than the original authors by studying sets we named “primitive” shift-minimal downsets and how their sumsets behave. It is our hope that information about these sets can be used to obtain a lower degree for general shift-minimal downsets.

Utilizing Sentinel-1 Radar Amplitude Data to Model Larsen C Rift Propagation
Kayla Owens
Mentors: Mark Simons and James Dickson

The Larsen C ice shelf in Antarctica has been rifting since 2010, and the rift propagation began significantly accelerating in 2016. The Sentinel-1 satellites use interferometric synthetic aperture radar (InSAR) to image the rift, returning both amplitude and phase data. The amplitude data from these satellites was processed and filtered in order to track rift propagation. The data sets were georeferenced using Sentinel-1 orbit data and projected in order to visualize the relative rift movement. After the data showed a few weeks of very little rift development in June, we observed the ice shelf calve between July 6^{th} and 12^{th}. Radar data at the rift tip was processed back to late 2015 with the intention of creating a time series of the propagation. Subsequent work would begin by creating this time series, then more accurately coregistering the images into a stack and using phase data to observe the mechanics behind the rifting.

Resolving Mechanisms for Mass-Independent Fractionation of Sulfur Isotopes in Earth's Archean Atmosphere
Aimee Oz
Mentors: Yuk Yung and Pin Chen

On Earth today the abundances of stable sulfur isotopes are ^{32}S (94.9%), ^{33}S (0.76%), ^{34}S (4.29%) and ^{36}S (0.02%). Mass-independent fractionation of sulfur isotopes (MIF-S), preserved in early Earth's geological rock record (between 3.8 and 2.4 Ga), coincides with an anoxic atmosphere. A careful examination of previous work describing plausible atmospheric conditions and reaction mechanisms prior to the Great Oxidation Event circa 2.4 Ga was done in order to constrain an atmospheric model. Our KINETICS model incorporates possible sulfur recombination and photochemical reactions under a simulated Archean atmosphere. This model needs to be adjusted to reproduce the MIF-S seen in the Archean rock record.

Deep Neural Networks for Imaging Calorimetry
Vitória Barin Pacela
Mentor: Maria Spiropulu

One of the greatest challenges at the LHC at CERN is to collect and analyse data efficiently. In this project, we use deep neural networks (DNN) to recognize images produced by jets originated by the collisions in the Linear Collider Detector (LCD) calorimeter, designed to operate at the Compact Linear Collider (CLIC). Jets are cone-like showers of hadrons that originate from high-energy quarks and gluons, or from decays of W/Z bosons, Higgs bosons and top quarks. We can determine the particle that originated the jet as a machine learning classification problem, and reconstruct the energy of this particle by using regression. We reconstruct particles from calorimetric deposits using image recognition techniques based on convolutional neural networks; the dataset consists of calorimetric showers produced by pions, electrons or photons hitting the surface of an electromagnetic calorimeter and eventually showering within the electromagnetic and hadronic calorimeters. When testing the performance of our model, the predicted and true energy values were approximated as in an identity function, and the mean of the normalized difference between true and predicted energy was centered at (-0.120.07)10-3 GeV, with a standard deviation of 0.04 GeV.

Design and Construction of an Extended Cavity Diode Laser for Spin Initialization in Rare-Earth Quantum Memories
Anusha Pai Asnodkar
Mentors: Andrei Faraon and Jonathan Kindem

Rare earth ions (REIs) in crystals are a leading technology for ensemble-based quantum memories and transducers due to their long coherence times at cryogenic temperatures and intrinsic inhomogeneous broadening. The inhomogeneous broadening of these ensembles enables quantum interfaces with an inherently large bandwidth and multimode capacity. Harnessing the advantageous properties of REIs for use in memories requires precise preparation of the ensemble via optical pumping. Towards this goal, we designed, constructed, and characterized an extended cavity diode laser (ECDL) to enable greater precision and flexibility in the optical pumping required for quantum memory studies involving Ytterbium-doped crystal hosts. Additionally, we worked towards building a frequency offset lock with another laser already in operation in our lab to expand experimental possibilities for preparation and optical storage. After construction and characterization, we used the laser for initial demonstrations of spectral hole-burning and spin initialization in Yb-doped YSO crystals as a first step towards efficient optical memories in these crystals.

Computational Tools for Image Analysis for Spatial Genomics in Brains and Embryos
Jeffrey Pak
Mentor: Long Cai

Using a method called Sequential barcoding FISH (seqFISH) in order to try to combine the two techniques and attempt single-cell in situ RNA profiling by sequential hybridization, it is possible to image transcriptomes directly at single-cell resolution. The final goal of this project is to create a 3D map between barcoded protein sequences and cell images using DAPI and Nissl stained mouse cortex images. DAPI stained images had a segmentation and watershed algorithm run on them to create a binary mask, which were then used to run a marker-controlled watershed algorithm on the Nissl stained images. The cortex project is still underway; however, future plans include extending this mapping to cover stem cell data or development brain data.

Sensorimotor Control of the Human Brain
Angelina Pan
Mentor: John Doyle

Control and dynamical systems is central to modern technology and science. One case study, the layered architecture of the human brain, is particularly interesting in both the robustness and efficiency of sensorimotor control and the fragilities that are possible. Ideally, an effective control architecture like the brain can integrate high level planning with fast lower level reflexes, in addition to learning and making decisions. In the past years, we have developed a mathematical theory that treats control design in a coherent but rigorous way. This project aims to enhance a low-cost, accessible video game that explores how well the theory predicts how humans multiplex planning and reflex tasks. The game consists of a basic driving simulation that models after the process of riding a mountain bike down a twisting bumpy trail. It captures the planning plus reflex, as well as learning and multitasking of the process of following the path simulated. We enhance the game to include a setting for changing the advanced warning, as well as settings for adding audio and visual tasks. After running the new version of this video game, we hope to test the game on more subjects to get larger and more complete data sets.

Identifying Transcription Factors Supporting CVM Cell Migration in *Drosophila*
Hee Won (Michelle) Park
Mentors: Angelike Stathopoulos and Frank Macabenta

Cell migration allows the growth and maturation of organisms, and is required for a variety of mechanisms, including wound repair, tissue homeostasis, and organogenesis. The Stathopoulos lab uses *Drosophila* as a model for studying gene regulation and cell migration, and recently identified several transcription factors expressed in a subset of longitudinal muscle precursors called the caudal visceral mesoderm (CVM). The objective of this project is to characterize the relative contributions of transcription factors Doc1, Doc2, Doc3, HLH54F, Mef2, and Biniou in mediating migration of CVM cells. We used AP *in situ* hybridization and antibody staining to visualize the morphology of *Drosophila* embryos. By then live imaging the embryos with RNAi via confocal microscopy, we were able to visualize the effect knockdown of various transcription factors had on CVM cell migration pathways. We anticipate that the lack of these transcription factors in embryos will hinder proper cell migration, for their functions are all related to differentiation or organogenesis. Ultimately, this will help contribute information to form a robust gene regulatory network for the CVM. Developing a comprehensive understanding of cell migration would be beneficial, as this has potential applications in understanding invasive cancer cell behavior and possible therapeutic avenues.

Implementing a System Level Approach for Distributed Controller Synthesis
Vandan Parmar
Mentors: Steven Low and James Anderson

As sensors and actuators have become increasingly small and cheap to build, their numbers have increased rapidly. Combined with ubiquitous communication networks, this has resulted in many large scale distributed networks, such as, Internet of Things, the smart grid and automated motorway systems. Designing robust and optimal distributed controllers for these large networks is theoretically challenging as the problem is non-convex and scales poorly with system size. Many traditional (centralized) control methods assume that all information about a system is available immediately, the control action can be computed quickly and calculated actions can be communicated to the system without delay. Clearly this is not the case in many of the large networks described above. Decentralised controllers are designed to act using delayed and incomplete information meaning however, few scalable methods exist to construct decentralised controllers.

The System Level Approach is a new framework for control of networks that decomposes the global optimization problem into locally solvable subproblems, in such a way that the resulting synthesis method is O(1) with respect to the size of the networked system. In this project, this approach is integrated into a toolbox written in Python with the aim of analyzing networked power systems.

Deep Learning Methods for Characterization of Individuals Using Parcellation of the Human Cerebral Cortex
Vaishnavi Sunil Patil
Mentors: Ashish Mahabal and Julien Dubois

Spontaneous fluctuations in brain activity measured with functional Magnetic Resonance Imaging (fMRI) during the resting-state can be used to study brain networks, which yield refined functional parcellations of the human brain. Characterizing the variability of individual parcellations has potential clinical value, providing sensitive markers of various diseases. We used the time series activations of the parcellations obtained using the fMRI to predict various characteristics of the individuals like their gender, IQ, etc. Statistical features were obtained from the time-series and were used as input to a feed-forward neural network which predicted a binary label indicating the gender. Recurrent Neural Networks using Long-Short-Term-Memory blocks was used to process the time series to predict the IQ values of the individual. The architecture of the networks was varied for different hyper-parameters and was optimized using the Bayesian Optimisation process. The hypothesis of using the Pearson correlation matrices between the different parcellations along with using transfer learning methods to get a better accuracy at predicting the characteristics using the time-series of the parcellations remains to be tested.

Understanding Catalyst/Ionomer Interactions by Studying Polyimidazolium Coatings on Transition Metals
Tillie H. Pederson
Mentors: Robert H. Grubbs and Aidan Fenwick

Electrochemical reduction of carbon dioxide (CO_2) to useful products, such as carbon monoxide or methane, could allow researchers to better understand the interactions between reduction catalysts and ionomer electrode coatings. Imidazolium salts studied for this purpose have demonstrated correlations between efficiency of reduction and substitution at the C2 and C4,5 positions of the imidazolium ring. A series of imidazolium-based monomers has been synthesized with intentions of utilizing ring-opening metathesis polymerization (ROMP) and spin-coating techniques in order to coat CO_2 reducing electrodes. Finally, these electrodes' reduction efficiency will be tested to further our understanding of these materials' interactions.

Continuous Unitary Transformation Flows of the Anderson Localization Hamiltonian on Maximally Tree-Like Cubic Graphs
Changnan Peng
Mentors: Gil Refael, Evert van Nieuwenburg, and Samuel Savitz

The Anderson transition on a Bethe lattice was first solved in 1973, but an extended non-ergodic intermediate phase was reported about forty years later. It was suggested that this non-ergodicity, i.e. high interactions only with a few branches in the tree graph, might be related to the absence of thermalization in the many-body systems and might be further related to metal-insulator transitions. However, the details of this intermediate phase are still under discussion. Here we use the technique of continuous unitary transformation flows to provide insight into the Anderson transition and the extended non-ergodic phase. We consider a non-interacting disordered tight-binding model on large girth cubic graphs which have maximally tree-like local structure. We focus on the cages, which have largest girth with fewest nodes, and vertex-transitive graphs, which have maximum symmetry. Then we run a third-order continuous unitary transformation flow on the Hamiltonians on the GPU. The level repulsions during the flow indicate the interactions between the nodes in the graph. By analyzing the distribution of the repulsions and how they decay with the distance between the nodes, we find a new indication of the Anderson transition and the extended non-ergodic phase.

A Synchrotron Mössbauer Spectroscopy Study of a Hydrated Iron-Sulfate at High Pressures
Tyler Perez
Mentor: Jennifer Jackson

Szomolnokite is a monohydrated ferrous iron sulfate mineral, $FeSO_4*H_2O$, where the ferrous iron atoms are in octahedral coordination with four corners shared with SO_4 and two with H_2O. While somewhat rare on Earth, szomolnokite has been detected on the surface of Mars along with several other hydrated sulfates and suggested to occur near the surface of Venus. It is not clear if these sulfates are a result of reactions occurring at depth driven by changes in the behavior of iron in the sulfate. To date, only a few high-pressure studies have been conducted on hydrated iron sulfates using Mössbauer spectroscopy. Our study represents a first step towards understanding of the electronic environment of iron in a mono hydrated sulfate at pressure. Using a hydrostatic helium pressure-transmitting medium, the pressure dependence of iron's site-specific behavior in a synthetic szomolnokite powdered sample was explored up to about 100 GPa with time-resolved synchrotron Mössbauer spectroscopy at the Advanced Photon Source of Argonne National Laboratory. At 1 bar, the Mössbauer spectrum is well described by three Fe^{2+}-like sites, consistent with conventional Mössbauer spectra reported in Dyar et al. At pressures up to 20 GPa, changes in the hyperfine parameters are most likely due to a structural phase transition. Above this pressure, a fourth site is required to explain the time-spectra. Changes in the electronic configuration of iron, such as those due to a phase transition and/or a spin crossover, will affect the material's compressibility and transport properties. We will compare our high-pressure trends with those of other iron-bearing phases and discuss the relative influence on the dynamics of terrestrial planetary interiors.

Jet Classification With Interaction Networks
Avikar Periwal
Mentors: Maria Spiropulu and Jean-Roch Vlimant

We develop techniques to tag particle jets in simulated data from the Large Hadron Collider (LHC). We run simulations to simulate particle behavior in an LHC detector, process the resultant data to classify each jet, and set up data to be an input to a variety of deep learning techniques, which tag jets based on information from their constituents. We modify previous research done by Google DeepMind to infer dynamics of interacting systems, interaction networks, to infer the structure of a jet before classifying. We also train classifiers based using recurrent neural networks, which infer jet structure less explicitly than the interaction networks. We find that the interaction network based classification out-performs the recurrent neural network, and that both networks perform better than jet-based decision trees.

An Objective Definition for Onset and Withdrawal of the Western African Monsoon
Karen Pham
Mentor: Simona Bordoni

Accurate definition of the onset and withdrawal of the seasonal monsoon in West Africa is important for agriculture and water management in the region. Though several methods exist for defining the onset and withdrawal, they are threshold-based methods that may result in a false onset when weather anomalies occur even before the real monsoon onset. This project utilizes a method for more objective definition of the monsoon using change point detection (CHP). This method used has previously been shown to correctly characterize the South Asian summer monsoon (SASM) and may be useful for defining onset and withdrawal of other monsoons as well. Using this change-point detection method, we also study seasonal variations in climatological factors of the West African monsoon to aid in future monsoon forecasting.

Quantifying Immune Response to Tph2 and Aanat2 Mutations in *Danio rerio* During the Sleep Wake Cycle
Andrew Phillips
Mentors: David Prober and Audrey Chen

Sleep is a necessary biological process that is prevalent throughout the animal kingdom. While this rest phenomena takes up almost a third of each human day, little is known of the biological regulation and effects of sleep. In order to give insight into the biological implications of sleep, the immune response of *Danio rerio*, commonly zebrafish, was quantified through qPCR in serotonin and melatonin sleep mutants. Three cytokines, interleukin 1b, interleukin 6, and nuclear factor kB, were used as immune system markers. Tph 2 (serotonin) and Aanat 2 (melatonin) mutant and wild type fish were then sacrificed at different time points in the sleep/wake cycle.

A series of qPCR analyses were then run after completing cDNA synthesis. Relative Expression values were then calculated for each cytokine using *PRISM.* In addition to low sample size, collected data yielded insignificant results leading us to believe more data sets are required to fully understand the impact of serotonin, melatonin, and sleep on the immune system.

Developing a Soft X-Ray Charger for Aerosol Particles
Sophie Piao
Mentors: Richard Flagan and Changhyuk Kim

Soft x-rays can be used to charge or neutralize aerosol particles for a variety of applications, including classification of said particles using a differential mobility analyzer (DMA). In order to improve the charging efficiency of the charger, we use SOLIDWORKS to model charging chambers with designs that attempt to minimize diffusion losses and COMSOL to simulate the aerosol flow through them. A charger design with the elements that best eliminate backflow and particle loss was then fabricated, characterized, and compared to the charger currently in use. The final model included a seven degree inlet angle and a removable static mixer and showed improved performance over the original design.

Analyzation of Unusual Variable Stars With the SPitzer InfraRed Intensive Transients Search
Samuel Piascik
Mentors: Mansi Kasliwal and Jacob Jencson

The *Spitzer Space Telescope* was launched in 2003 as the final mission of NASA's Great Observatories Program, and is currently taking measurements in the 3.6 and 4.4 μm imaging bands. The SPitzer InfraRed Intensive Transients Search (SPIRITS) searches for infrared transients and variables in repeated observations of a sample of

194 galaxies within 20 Mpc. In order to study the spectra of variables, red supergiants and asymptotic giant branch star in the nearby dwarf-irregular galaxy NGC 6822, we worked with SPIRITS follow-up data from the MOSFIRE instrument on the 10 m Keck I telescope. This data was first cleaned of cosmic rays using a custom script, then fed through the MOSFIRE data reduction pipeline before the final spectral extraction and examination of the corresponding data.

Comparing Clustering Algorithms for Graphs
Olivia Pomerenk
Mentors: Leila de Floriani, Federico Iuricich, Riccardo Fellegara, and Michael C. Vanier

We are considering a new data structure for encoding a network based only on its k-cliques and vertices to provide greater efficiency in extracting substructures from a graph (a process which is generally computationally intensive, especially with large networks). The purpose of this summer's research is to compare various graph clustering algorithms to find the best candidate to be a basis for this new data structure. The ideal algorithm has to work solely based on the community structure of the graph, without any extraneous vertex or edge attributes. The project relies heavily on preexisting literature and algorithms—specifically, algorithms written in the R iGraph library. The algorithms are tested on publicly available networks of increasing size (from hundreds to millions of nodes) and compared based on their space and time complexity, scalability, requisite parameters, homogeneity of the clustering they produce, and the number of edges within and without a cluster. The anticipated outcome of this research is the selection of one algorithm which will provide an ideal decomposition for new data structure.

***Ex vivo* Biosensor Data Transmission and Analysis Via Bluetooth Low Energy and Near Field Communication**
Nikhil Poole
Mentors: Azita Emami and Abhinav Agarwal

In the past year, the Mixed-mode Integrated Circuits and Systems group developed a low-power, implantable biosensor chip capable of monitoring levels of oxidase-based analytes, such as glucose and lactate, and ionophores in subcutaneous, interstitial bodily fluid. Gravitating towards an *ex vivo* rendition of this biosensor, the lab is currently developing a low-energy external wearable device to measure such biochemical markers using non-invasive analysis of sweat, thereby eliminating the size, power, and host-biocompatibility constraints associated with its *in vivo* counterpart. This project investigates the transmission and analysis of sensor data directly to the user's smart phone, through an integrated Bluetooth Low Energy (BLE) and potentiostat system. In particular, we develop an Android application interface capable of reading and parsing transmitted data and displaying it and relative statistical properties real-time. To test the functionality of the application, we utilize an nRF52-Development-Kit, a BLE-compatible, ultra-low-power multiprotocol SoC ideal for experimentally transmitting simulated data via BLE. In implementing the Continuous-Glucose-Monitoring and GATT service/profile, the application successfully receives, displays, and analyzes metabolite data real-time. Following completion of the BLE application, the interface will be tested with the actual patch sensor, while subsequent research will analyze data via a Near-Field Communication (NFC) Android application.

A Functional Screen of Pre-Committed T Cell Genes Using CRISPR-Cas9
Nikhita Poole
Mentors: Ellen Rothenberg and Xun Wang

T cells are a critical component of the human body's adaptive immune system, which is designed to recognize and target specific pathogens. The presence of T cells is necessary in order to mount a full immune response, so any problems with them, such as T cell leukemias, are extremely damaging. Thus, understanding the mechanisms of T cell development from hematopoietic stem cell precursors is crucial because it offers insight into both the process of stem cell differentiation and the origins of T cell leukemias. Several genes have been found to be heavily influential in the early stages of T cell development, particularly one known as PU.1. PU.1 is a regulator of a number of other genes, but the functions of these targets are currently unclear. To elucidate their roles, we will use the CRISPR-Cas9 system to disrupt these target genes in cells prior to T cell commitment, and examine the resulting effects on the cells' developmental progression. This initial screen will allow us to identify particularly significant genes that merit deeper exploration, and thus may pave the way for further studies that will provide new insight into the control of progression through T cell development.

Eye-Tracking Shows How People With ASD Differ in Collecting Visual Information for Social Inferences on Daily Scenes
Ziyi Pu
Mentors: Lawrence Jin, Ralph Adolphs, and Brooks Fu

People with ASD pay reduced amount of spontaneous attention captured by social stimuli, such as human eyes and gestures. However, previous studies were controversial on whether people with ASD can make normal inference on other people's intention or not. One of the major sources as the input for cognition is through vision, so people's eye-movement can be especially revealing for the knowledge of how people process information and interact with the world and other people. By presenting daily scene photos with and without humans in it, we ask participants to view them to answer a social or nonsocial inferential question. And their eye-movement data (fixation cascades, etc.) are recorded and quantified. We aim to answer whether the neurotypical group with intact social cognition have more expertise and a prior attention to socially salient stimuli in social situations compared to people with ASD.

Automation of WIRC+Pol's Data Reduction Pipeline
Michael Randolph
Mentors: Dimitri Mawet, Ricky Nilsson, and Max Millar-Blanchaer

A new polarimetry mode has recently been commissioned to the Wide field Infrared Camera (WIRC) at Palomar Observatory's 200" telescope. The new configuration, WIRC+Pol, will be used for a several yearlong survey of brown dwarfs, using polarimetry data to characterize the heterogeneity of clouds in their atmospheres. An observing night will have approximately 10GB of data. Due to the large amount of data, building and using a robust, automated data reduction pipeline is necessary. Automating the sorting, calibration and processing of data, provides timely feedback to observers.

A critical step in an automated pipeline is the sorting of data. I have been working on a program in python that sorts images into groups of observation types, using metadata and clustering algorithms, which has been successful, excepting fringe cases. The next step is adding code that associates science images with appropriate calibration images of identical exposure times, a necessary step for the pipeline's integration. The automated pipeline will make it possible to rapidly process large samples of brown dwarfs in order to answer fundamental questions about the nature of the structure of their atmospheres.

Application of RPMDrate to Rate Calculation for OH+CO
Gregory Rassolov
Mentor: Mitchio Okumura

OH and CO both play an important role in atmospheric chemistry, especially radical reactions, and their reaction with each other to produce H and CO_2 is one of the most important processes occurring in the atmosphere. The potential energy surface for this reaction is complex, and there are multiple product channels and several stable intermediates. These intermediates have sufficient lifetimes to participate in collisions with bath gases. One relatively new method for studying such reactions in a way that fully captures most quantum effects is ring polymer molecular dynamics, and the program RPMDrate was recently written to use this method to study bimolecular gas-phase reactions. To evaluate the suitability of RPMDrate for studying OH+CO, we performed a large number of test calculations on the $H+H_2$ system and some calculations on OH+CO itself, and we report a comparison of the experimentally measured rates with the unmodified RPMDrate result. Future research will focus on modifying and expanding RPMDrate to better account for interaction with bath gases, non-equilibrium reactant state distribution, and non-adiabatic behavior, as well as a determination of the kinetic isotope effect and a comparison with the measured kinetic isotope effect.

The Study of the Individual Contributions of Elastic and Adhesive Heterogeneities on Fracture Loads and Peel Front Characteristics in Thin Polymer Adhesive Materials
Tucker Reese
Mentors: Kaushik Bhattacharya and Louisa Avellar

In order to toughen materials against fracture, heterogeneities can be introduced so as to impede the propagation of cracks. The simplest way to study this phenomenon is in one dimension, through the analog of tape peeling, which has long been used as an easy way to repeatably study crack propagation. It is known that both elastic and adhesive heterogeneities (layering tape and patterning its substrate, in the tape analog) cause significant fracture toughening, but little is known about the way these heterogeneities interact when combined. The goal of this study is to determine the relationship that heterogeneity stacking has on the force required to peel tape from a surface. Secondarily, this study aims to characterize the shape of peel fronts resulting from different heterogeneity geometries. Understanding fracture and discovering new ways to prevent cracks from growing would free engineers to design the previously impossible without fear of failure.

The Effect of the Inhibition of Hypocretin Neurons in Zebrafish on Locomotor Activity and Neuronal Activation
Alison Ren
Mentors: David Prober and Chanpreet Singh

Sleep is a phenomenon universal to nearly all organisms, yet there is little known about the mechanisms that govern the transitions between different states of arousal. These mechanisms play a role in not only sleep regulation but also metabolic regulation, immune function, and several neurological disorders. Therefore it is important to continue to expand upon the current research available in this field. To better understand these mechanisms, the Prober lab uses zebrafish as an animal model since they are diurnal, produce large clutches of embryos, and can easily be used for optogenetic studies. This project focuses on the effects of inhibiting hypocretin (hcrt) neurons using the activation of halorhodopsin (eNpHR). Using the larvae from a hcrt-eNpHR transgenic line, we have done many behavioral studies, monitoring the locomotor activity of zebrafish larvae after activating eNpHR using amber light. The results from these experiments show that the inhibition of hcrt neurons promotes sleep and reduces activity in zebrafish. We have also studied the activity of neurons throughout the entire brain when hcrt is inhibited using cfos in situ staining techniques. The results from this staining have yet to be conclusive and will be further investigated.

The Role of *hif1a* During Zebrafish Sympathetic Nervous System Development
XinYi Ren
Mentors: Marianne Bronner and Megan Martik

Neuroblastoma is a type of cancer that commonly affects children and arises from improper differentiation of sympathetic neuronal precursors. The sympathetic nervous system arises from an embryonic population of cells called the neural crest shortly after formation of the central nervous system, and it is known that dysregulation of the neural crest leads to the onset of neuroblastoma. Understanding the regulatory events within a gene regulatory network (GRN) will provide important information towards understanding the development of neural crest-derived cancers. This research project focuses on how the gene *hif1a* is integrated into a gene regulatory network controlling sympathoadrenal development. *hif1ab* has been shown to be implemented in neuroblastoma. This project will focus specifically on what activates the transcription of this gene, and what this gene transcriptionally controls during normal zebrafish development is being investigated. Our analysis of downstream targets of Hif1a included the creation of a *hif1a* knock-out line using CRISPR/Cas9, and *in situ* hybridization to analyze downstream targets on the *hif1ab*-KO. Mutations of the *hif1a* gene were validated using T7 endonuclease digestion and sanger sequencing. Results from our knock-out regulatory analysis will inform upon how Hif1a is working within a gene network controlling sympathetic nervous system development.

Stochastic Estimation of Delta-Hyperbolicity of Complex Networks
Zhi Ren
Mentor: Kostia Zuev

Delta-hyperbolicity is an important parameter in complex networks that captures the tree-likeness of graphs. Though many combinatorial techniques exist that can compute its exact value, they are very inefficient on real complex networks where the number of nodes n is large. In the paper, we propose two stochastic estimation methods for computing delta-hyperbolicity that run in time O(n), which is much faster than the existing deterministic methods.

Rapid, Isothermal Nucleic Acid Amplification for Detection of Antimicrobial Resistance
Amrita E. Rhoads
Mentor: Rustem F. Ismagilov

Antimicrobial resistance (AMR) has become a growing threat in the past decades, due in part to overprescription of antibiotics to treat minor infections, failure of patients to take an entire course of antibiotics, and development and transmission of colonies of resistant infections in hospitals. Under current models of prediction, antibiotic resistant diseases will be poised to kill 10 million people a year by 2050, far exceeding the current death toll of cancer (O'Neill 2016). Ongoing work focuses on rapid and isothermal phenotypic tests for antibiotic susceptibility, in a way such that these tests may be carried out in point-of-care settings and do not depend on the presence of specific resistance genes. Currently, nucleic acid amplification remains a promising avenue of research -- by quantifying DNA content in samples in the presence and absence of antibiotic treatment, one could determine whether antibiotic presence inhibited bacterial growth (Schoepp et al. 2016). LAMP, or loop-mediated isothermal amplification, functions as a single-step method of amplification with highly specific results. A variety of other methods for rapid and/or isothermal amplification, such as RCA, SDA, or HDA present themselves as viable alternative methods of amplification as well. This project examined the viability of these methods in comparison to LAMP in terms of primer design, robustness, and speed, first by designing protocols for low-volume DNA amplification with real-time measurement and then by optimizing conditions for rapid nucleic acid detection.

Control Over Gaussian Channels With and Without Source–Channel Separation
Elias Riedel Gårding
Mentors: Victoria Kostina and Anatoly Khina

We consider the problem of controlling an unstable system over an additive Gaussian noise channel. To that end, much effort has been put into extending the tandem communications strategy, where the message is quantized into a stream of bits which are subsequently mapped into coded channel inputs. This is a conceptually attractive technique that was shown to be optimal in the limit of long messages. However, the real-time nature of networked control necessitates transmitting very short messages, for which the tandem strategy is not optimal. An alternative paradigm is that of analog joint source–channel coding (JSCC), where the message is mapped directly to an analog channel input, thereby bypassing the digital domain altogether. In this work, we develop schemes that follow both approaches and compare their control performance using numerical simulations. Specifically, we construct a tandem scheme using recently developed techniques for optimal quantization and anytime reliable codes in the context of control, and compare it to analog JSCC schemes employing Shannon–Kotel'nikov maps. We find that the JSCC schemes provide performance gains in both control cost and computational efficiency.

Effects of Supernovae Explosions on Ultra-Faint Galaxies
Milan S. Roberson
Mentors: Andrew J. Benson and Shrinivas R. Kulkarni

Semi-analytic models of galactic evolution treat supernovae (SNe) as continuous sources of energy that provide a negative feedback on star formation. While this continuum approximation is valid for large galaxies, SNe are in fact discrete events; the energy output from just one can completely disrupt the star forming regions of the smallest galaxies. We present modifications to GALACTICUS, a semi-analytic model of galaxy formation, that implement discrete SNe in low mass regimes where the continuum approximation breaks down. To ensure convergence between the discrete and continuous approaches, the mass of gas ejected by SNe is determined by the continuous approximation's rate of mass outflow. We find that the discrete SN approach agrees more closely with the mean star formation history of a sample of dwarf galaxies in the Local Group at mass cuts of $\log M_*/M_\odot \leq 6$ and $\log M_*/M_\odot \leq 7$.

IBOs and IAOs in the Solid State With Applications to Model Hamiltonians
Paul J. Robinson
Mentor: Garnet Chan

Solid-state electronic structure calculations are lacking in all-purpose atomic charge determination and bond localization tools. Though many methods exist for this in the gas phase, relatively few of them have made it to periodic systems, and those that have are not suited for all systems. In this work we explore the possibility of migrating a well-tested gas phase tool into the solid state. The Intrinsic Bonding Orbital (IBO) method has proven itself in the gas phase by naturally arriving at different bonding motifs in molecules (lone pairs, two-center and multi-center) rather than enforcing them. We show that this benefit is not compromised when applied to periodic systems. Additionally, we examine the possibility of using an Intrinsic Atomic Orbital (IAO) basis to create model Hamiltonians. IAOs are a minimal basis that also encodes polarization from a larger basis; this makes them ideal for deriving more accurate model Hamiltonians. We demonstrate the usefulness of this technique on systems in both the gas phase and solid state.

Near Field Radiative Heat Transfer in Thermophotovoltaic Solar Cells
Charles Ross
Mentor: Axel Scherer

Near field radiative heat transfer occurs between bodies brought within distances less than the characteristic wavelength given by blackbody radiation between two surfaces. This potentially exceeds heat transfer that occurs due to blackbody radiation by orders of magnitude. To demonstrate this phenomena, we will fabricate a thermophotovoltaic(TPV) solar cell which will have a metamaterial with a novel geometry design so that the emission and absorption peaks are below 2.5 microns, corresponding to the bandgap energy of the cell. Previous TPV solar cells covert solar power into thermal emissions tuned to energies above the bandgap and rely on the less efficient blackbody radiative process.

Transmission of Aluminum Oxide at 200-300GHz for Studies of the Early Universe
Jack C. Roth
Mentor: James Bock

Large-area focal planes for modern studies of the early Universe require large focusing and filtering components, which can pose a fabrication challenge. Aluminum oxide, often called alumina, presents a possible solution to this challenge, as it can be manufactured to the required sizes of these components. Before alumina can be used in telescopes tuned to the highest observing frequencies, which are needed to characterize Galactic foregrounds, its transmission in the 200GHz to 300GHz range must be investigated. The setup in this experiment includes an RF source tuned to a single frequency, which outputs a chopped microwave beam that is passed through a collimating lens and then a second lens focused on a detector. The RF source steps through a set of frequencies once without and once with the alumina sample in the collimated beam. The ratio of these sweeps yields the sample's transmission spectrum as a function of frequency. The transmission spectrum is then fit using a lossy Fabry-Perot cavity model, enabling absorption and in turn transmission to be determined as a function of frequency.

Investigating Nanocomposites of Polylactide and Tungsten Disulfide for Thinner, Radio-Opaque Bioresorbable Vascular Scaffolds (BVS)

Edgar E. Ruiz Bello
Mentors: Julia A. Kornfield and Karthik Ramachandran

Coronary Heart Disease is the leading cause of death in the world. A promising alternative to permanent metal stents are Bioresorbable Vascular Scaffolds (BVSs) – transient implants made from poly-L-lactide that support the occluded artery for 3-6 months, but are completely resorbed in 2-3 years. Unlike metal stents, BVSs restore arterial vasomotion and eliminate the risk of Late Stent Thrombosis. However, current BVSs are nearly twice as thick (~150µm) as metal stents (~80µm) and cannot treat smaller arteries. Furthermore, the poor radio-opacity of polylactide makes it challenging to implant BVSs under X-rays. We hypothesize that a nanocomposite of polylactide (PLA, 98% L-content) and Tungsten Disulfide (WS_2) nanotubes offers a viable solution for a thinner, radio-opaque BVS. We select WS_2 as it is well tolerated *in vitro* and offers radio-opacity similar to platinum, the standard for radio-opaque markers. We probe the impact of a flow-field on the crystallization behavior of PLA and PLA-WS_2 and use an *in situ* optical technique to characterize changes in their microstructure. We discovered that even a relatively low concentration of WS_2 (0.05 wt%) induces a highly-oriented morphology in PLA that has the potential to enhance strength in a thinner profile, thereby enabling a new generation of BVSs.

Developing and Improving Space Solar Power Technology

Philipp Saive
Mentors: Harry A. Atwater and Mike Kelzenberg

Technological progress is leading us to a more and more energy consuming society. As a result, we need improved energy sources. In particular, we desire to replace fossil fuels with renewable energy sources (e.g., solar power) that provide an unlimited, clean energy supply. However, one of the major disadvantages of conventional solar energy is that it is not continuously available (e.g., at night time). The **SSPI** (**S**pace **S**olar **P**ower **I**nitiative) seeks to make possible the continuous delivery of solar power for terrestrial needs from solar cells which are placed in space. This requires development of ultra-lightweight, high efficiency solar panels that can operate in space. Our project seeks to reduce the weight of solar panels by using lightweight reflectors that focus light on small, efficient solar cells. We are fabricating reflectors from carbon fiber and studying their shape accuracy with laser scans and light simulation tools. We expect this to lead to an improved fabrication process for future reflectors. The ultimate goal is to use this concentrator design for real application in space in a few years.

A Deep Structured Learning Approach for Image Segmentation

Seyed Sajjadi
Mentor: Alexandre Cunha

There is a great difficulty of creating robust image segmentation algorithms to automate the delineation of objects of interest present in images. While humans can seemingly do this without much effort, computers have a hard time to distinguish even simple objects. This is the case of biological images where cells might not be uniformly marked with fluorescent proteins leading to gaps and spurious data and consequently to poor segmentation results (Cunha, 2010). Deep Convolutional Neural Networks (CNN) have shown promises in learning the abstract features of images given a one-to-one correlation from input (image/pixel) to output (label) during a single training iteration. Structured Prediction(SP) on the other hand takes advantage of a many-to-many correlation of inputs and their corresponding outputs during a single training phase. We combine CNN and Structured Prediction to provide a learned joined pipeline that can segment plant stem cells from the *Arabidopsis thaliana* model organism.

Development of Two-Photon Lithography-Compatible Resins for Architected Shape Memory Polymer Materials

Erika Salzman
Mentors: Julia Greer and Luizetta Navrazhnykh

Shape memory polymers (SMPs) are highly elastic materials that are able to store "memory" of the shapes in which they were synthesized, undergo temporary mechanical deformation, and then return to their original shapes in response to a specific thermal, electrical, or other stimulus. Functional groups have been added to pentaerythitol pentaacrylate-based SMPs via the thiol-Michael reaction, allowing for greater control of the chemical properties of these materials. Manufacturing 3D architected, high-functional group density SMP nanostructures using two-photon lithography allows for the fabrication of nearly any imaginable structure, suggesting promising applications in biomedicine. A method to quickly measure the ability of SMPs to maintain their deformed shapes (shape fixity) was developed, allowing for the comparison of shape memory characteristics of polymers with different chemical compositions. Promising candidates will be developed into TPL-compatible resins, and their mechanical properties will be tested and compared on the macro and nano scales.

Development and Testing of a Two-Locus Cleavage Drive for Gene Replacement in *Drosophila melanogaster*
Alexander Sampson
Mentor: Bruce Hay

The use of gene drives for gene replacement in different populations has widespread potential in the treatment of infectious disease – for example, a gene drive could be used to drive a gene conferring resistance against the malarial parasite to fixation in a susceptible mosquito population to prevent this species acting as a disease vector. The Hay Lab has proposed a novel gene drive system known as a two-locus cleavage drive utilising CRISPR-Cas9 technology and based on the Medea gene drive project. The proposed drive uses a construct containing genes encoding the Cas9 restriction enzyme and gRNAs designed against a recessive lethal target gene, alongside a gRNA insensitive rescue version of the same gene derived from a related species. This project identified Spt5 and Xpd as potential target genes; gRNAs designed against these genes were then incorporated into a construct backbone alongside the Cas9 gene and rescue genes amplified from *Drosophila* suzukii genomic DNA to generate the two-locus cleavage drive constructs. These constructs were then injected into *Drosophila melanogaster* in order to study population dynamics of the drive.

3D Multi-Contact Gait Design for Prosthesis Using FROST
Elin Samuelsson
Mentors: Aaron D. Ames and Rachel Gehlhar

Walking with an energetically passive prosthetic leg constrains the user in many ways. Powered prostheses are under development and hold potential to give an amputee full mobility in various terrains. The goal of this project is to simulate stable gait trajectories for the powered prosthetic leg AMPRO. It should walk as human-like as possible. This includes the multi-contact behavior of respectively putting pressure on the heel and toe throughout one step.

The human lower body is modeled as a chain of links and joints and the gait as a hybrid system with continuous domains and discrete transitions in between. Using optimization to minimize energy while fulfilling specific constraints, appropriate movements for each joint are found. In simulation, a feedback controller then drives the joints to follow these desired paths, generating the actual trajectories. The MATLAB toolkit FROST, developed by the AMBER lab for this kind of problem, is used as the control development framework. A natural next step is to implement the simulated trajectories on the actual prosthesis and perform experiments. The code is also easy to modify to generate gaits for other walking behaviors, such as walking on slopes and stair walking.

Computational Approaches to Individual Differences in Altruistic Decision-Making
Dasha A. Sandra
Mentors: Ralph Adolphs and Anita Tusche

Choices often require us to weigh competing considerations. Should the needs of another person trump our own selfish needs? Our study used a computerized altruistic choice task together with mouse-tracking to examine whether differences in the temporal dynamics of computing benefits for others and for yourself underlie the remarkable differences in people’s altruistic behavior. Mouse-tracking refers to the continuous monitoring of the trajectory of a computer mouse during the decision process, which has proven to be an powerful methodological tool to study the temporal dynamics of decision-making. Mouse-tracking data are analyzed using logistic regressions, which allows estimating the precise time at which monetary benefits to oneself and benefits to another person start guiding their choice. We hypothesize that people that represent others benefits later chose self-selfishly more often. We also hypothesize that emotional facial expressions of the other player presented prior to the choice can speed up the representations of other’s payoffs, leading to more generous behavior. After extensive optimization of the task-battery, we are now in the position to launch extensive data collection to test these hypotheses.

Selection of High-Redshift Quiescent Galaxies Using Machine Learning
Madeline Schemel
Mentors: Sune Toft, Charles Steinhardt, and Peter L. Capak

A recent discovery in astronomy has been that galaxies seem to die, or cease star formation, surprisingly early in the universe’s history. In order to learn more about this population, we want to be able to identify large numbers of these high-redshift, quiescent galaxies. However, at higher redshifts the cost of obtaining full galaxy spectra makes it increasingly difficult to select for quiescent galaxies, namely due to the presence of a few known contaminants, such as dusty, but star-forming, galaxies. We apply machine-learning algorithms such as the self-organizing map (SOM) and T-SNE to this problem. Both the SOM and T-SNE are clustering algorithms with the capability of mapping n-dimensional, photometric data (taken across a range of color filters) to a two-dimensional grid. We demonstrate that these clustering algorithms are capable of picking out various galactic properties, and then use them to select for possible high-redshift, quiescent galaxies.

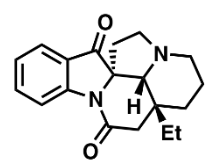
Enantioconvergent, Photoinduced Copper Catalyzed Cross Coupling of Alkyl Halides With Primary Amines
Joseph E. Schneider
Mentor: Gregory C. Fu

Progress was made on the development of an enantioconvergent method for the photoinduced, copper-catalyzed cross-coupling of primary amines with racemic alkyl iodides. Investigations have found that product with an enantiomeric excess (ee) above 30% could be obtained contingent on the presence of an ethereal directing group on the electrophile, a hindered P_1 phosphazene base, a temperature of −30 ºC, and catalytic copper(I) iodide and enantiopure BINOL. Further changes to the reaction parameters (e.g. ligand development, changes to the directing group, additive effects) will hopefully optimize this transformation and allow us access chiral amines with high enantiopurity.

Investigating the Ferromagnetism-Induced Energy Gap in the Surface States of Magnetic Topological Insulators
Benjamin Seddon
Mentors: Nai-Chang Yeh and Chien-Chang Chen

Topological insulators are insulating in the bulk but have massless Dirac surface states protected by a topological invariant. For time reversal invariant topological insulators these states are protected by time reversal symmetry, which can be broken by ferromagnetism-induced proximity effects. The binary topological insulators to be investigated in this work consist of a layer of Cr-doped topological insulator below a layer of pure topological insulator. This Cr-doped layer becomes ferromagnetic and breaks the time reversal symmetry below the Curie temperature, which induces ferromagnetism in the adjacent pure topological insulator by proximity. We assembled a scanning tunnelling microscope (STM) head, specifically building the z part of the coarse approach, and the probe tips. We then tested and calibrated the STM at high and low temperatures using gold, HOPG and calibration samples. We will use this STM head to make spatially resolved spectroscopic measurements of the bilayer sample of $(Bi,Sb)_2Te_3$/Cr-doped $(Bi,Sb)_2Te_3$. The change in tunnelling current with respect to bias voltage is proportional to the density of states at the surface, which will be used to find and compare the strength, spatial homogeneity and temperature dependence of the ferromagnetism-induced proximity effects on the surface states of the binary topological insulators.

Studies Toward the Total Synthesis of Melokhanine E
Zachary Sercel
Mentors: Brian Stoltz, Gerit Pototschnig, and Alexander Sun



Melokhanine E

The natural product Melokhanine E was recently isolated from *Melodinus khasianus* and represents a desirable synthetic target due to its interesting structural motif and its inhibitory activity against *Pseudomonas aeruginosa* and *Enterococcus faecalis*. We report our synthetic studies toward the compound, utilizing palladium-catalyzed decarboxylative asymmetric allylic alkylation for the key formation of the all-carbon quaternary stereocenter in Melokhanine E, the sole enantiodetermining step. The molecule's two other stereocenters are set by chiral induction. The endgame will employ a novel radical cyclization pathway for the construction of the 2-spirocyclo-3-oxindole moiety and complete the concise total synthesis of this complex natural product.

Reducing Leak in DNA Seesaw Circuits
Mrinank Sharma
Mentors: Erik Winfree, Frits Dannenberg, Lulu Qian, and Chris Thachuk

The emergence of DNA as a new material of choice for the construction of synthetic, cell-free dynamic nanotechnology can be attributed to predictable secondary structure and well understood thermodynamics. The seesaw circuit architecture, utilizing a reversible DNA strand displacement reaction, has been demonstrated to be highly composable whilst allowing the implementation of systems with complex behaviour including but not limited to digital logic circuit gates as well as analogue circuits. However, both the reliability and robustness of these circuits (and other strand displacement systems) have been plagued by the presence of leak reactions: unwanted reactions which lead to spurious outputs through alternative reaction pathways. It is desired to reduce the rate at which these leak reactions occur. Here several strategies are suggested for the reduction of these leak rates and through the modification of existing DNA kinetic simulation software, these proposals are quantitatively evaluated in terms of not only the extent to which undesired reactions are impeded but also the extent to which intended reactions are affected.

Element-Wise Electromagnetic Modulation of Phononic Metamaterials
Shivam Sharma
Mentors: Chiara Daraio and Osama R. Bilal

Reciprocity or time reversal symmetry is a fundamental principle in the wave propagation phenomena which states that waves can symmetrically travel from one point to another in reversal manner. This is applicable in electromagnetic waves, optics, acoustic and mechanical waves. However, a growing area of interest is concerned with the breaking of the reciprocity principle for unidirectional elastic wave propagation, which can lead to the realization of acoustic systems analogous to electronic devices such as diodes. In this project, an acoustic diode is designed and experimentally tested. Geometric nonlinearities controlled by electromagnets are utilized at the unit cell level. Geometric nonlinearities allow the unit cell to change the shape significantly while electromagnets allow dynamic tuning of the unit cell. This tuning allows for periodically modulating elastic properties of the structure in space and time. This spatiotemporal modulation of elastic modulus breaks mechanical reciprocity and induces one-way transmission of the waves, thus, enabling the structure to behave like an acoustic diode, which is analogous to electronic diodes.

How Does Cooperation Gain Scale With the Number of Nodes in a Network
Ruoqi Shen
Mentor: Michelle Effros

A network consists of senders and receivers where senders send encoded messages to receivers to decode. The capacity of the network describes the maximal rates at which the senders can simultaneously and reliably transmit information across the network. Using network cooperation strategies, network nodes can work together to achieve a higher capacity. In this project, we derived upper bounds on the additive and multiplicative cooperation gains as a function of the number of cooperating nodes. Channel models considered include both Gaussian channels and finite-alphabet channels.

Investigating the Relationship Between Leader and Follower Cells During Collective Cell Migration Through the Use of Zebrafish Trunk Neural Crest Cells
Max Shen Molesky
Mentors: Marianne Bronner and Ezgi Kunttas-Tatli

The neural crest (NC) is a multipotent embryonic cell population present in vertebrates that migrate collectively throughout the body during embryonic development and differentiate into several cell types including bone and cartilage of the face, neurons and glia in the peripheral nervous system. Improper development of the NC is the cause of one third of all congenital birth defects and cancers such as neuroblastoma and melanoma; thus, the study of these unique cells is pertinent to medical research. In this study, we used advanced imaging technology combined with genetic tags in zebrafish embryos to better understand the collective migration behavior of trunk NC cells. First, we used a *Sox10Gal4-UASlifeactGFP* line to label the actin cytoskeleton in migrating NC cells and analyzed the cellular behavior between leader cells and the follower cells. We then used a *Ct122a-Sox10mRFP* line to label the environment that NC migrate through and analyzed the relationship between NC cells and surrounding cells as well as the speed and directionality of multiple streams during migration. In the future, we will also label the nuclei of these cells to be able to track each cell to further analyze the relationship between cells during collective migration.

Cationic Rhenium and Manganese Complexes for Carbon Dioxide Reduction Catalysis
Tom Sheridan
Mentors: Harry Gray and Brian Sanders

A series of catalysts for carbon dioxide reduction have been synthesized and fully characterized by NMR, mass spectrometry, UV-vis spectroscopy, and single-crystal x-ray crystallography. These catalysts use a ligand functionalized with a cationic methyl trimethylamine group (TMAM) which means that catalytic properties like solubility can be changed based on the anion paired to the positive complex. Rhenium and manganese were explored as catalytic centers, and two different anions were used, giving Re-TMAM-Cl and Mn-TMAM-Cl as potential water-soluble catalysts with Re-TMAM-PF_6 and Re-TMAM-PF_6 as organic-soluble catalysts. Ion-pairing studies were also conducted via NMR with a sulfonate phenol anion in solution to see if it could act as a proton shuttle to increase catalytic activity. Cyclic voltammetry in a variety of solvents revealed that while the catalysts deposited onto the electrode in pure water, Re-TMAM-Cl was an effective catalyst in a mixture of 9:1 propylene carbonate and water. Furthermore, Re-TMAM-PF_6 and Mn-TMAM-PF_6 proved highly active in organic solvents like acetonitrile. Further research will explore other functionalized ions for catalysis, potential photocatalytic activity, and electrochemistry in other solvent systems.

Deep Learnt Classification of Light-Curves
Kshiteej Sheth
Mentors: Ashish Mahabal and Fabian Gieseke

We tackle the problem of automatically classifying astronomical transients captured by the Catalina Real-Time Transient Survey (CRTS) in the form of light curves using state of the art Machine Learning algorithms. Each light curve is a time series having the negative logarithm of flux on the y axis and mean julian date on the x axis. The pipeline proposed by us first includes a novel pre-processing step involving encoding each light curve into a 2-D image and then classifying the object using a Convolutional neural network (CNN). We also conduct further experiments in which we separate objects of each class in the training set into foregrounds and backgrounds and then train the CNN on only the foregrounds. Results suggest that the former strategy with the backgrounds gives a better testing accuracy than baselines using other classifiers and removing the backgrounds further boosts the testing accuracy. It can be concluded that a CNN classifier is a much better choice compared to other classifiers and removing the backgrounds from objects makes the 2D representation quite discriminative and training on this data gives a more accurate CNN classifier. Further research plans objectives evaluating and improving performance of these classifiers on other datasets.

Towards a 3D Nano-Architected Solid-State Battery: POSS-PEG Elastomer Electrolyte and Airtight Transfer Chamber
Aaron Shih
Mentors: Julia Greer and Xiaoxing Xia

In the effort to create a 3D nano-architected solid-state battery, a solid-state electrolyte must be chosen that can suppress lithium dendrite growth as well as resist volume changes in the cell over multiple charge/discharge cycles. An elastomer of polyhedral oligomeric silsesquioxane (POSS), a cubic organosilicon compound, cross-linked with chains of poly(ethylene glycol) (PEG) exhibits greater storage modulus than that of poly(ethylene glycol) alone. POSS-PEG elastomer films were synthesized using a 1:4 molar ratio of POSS:PEG and a 16:1 ratio of ethylene glycol monomers to lithium ions. Symmetric coin cell cycling tests at 90 °C and current density 0.3 mA/cm^2 demonstrate correspondence to literature values. POSS-PEG elastomer electrolyte films are a good candidate for further testing in the application of a 3D nano-architected solid-state battery. An airtight transfer chamber was designed and fabricated from aluminum and resin for use in hermetically sealed transport of the coin cell for imaging after cycling tests. The airtight seal will prevent any damage to the cell during transport as well as provide a method of sample transport for air-sensitive materials. Imaging of the cell will provide valuable information about the mechanics of lithium nucleation in the cell.

Various Filters of the Guided Entry of Tailed-Anchored Proteins Pathway Reject the Translocation of Signal Recognition Particle-Independent Pathway Substrates
Woo Jun Shim
Mentors: Shu-ou Shan and Hyunju Cho

As one-third of proteins is translocated into the endoplasmic reticulum (ER), an efficient mechanism to translocate nascent protein to the ER is essential for a properly-maintained homeostasis in *Saccharomyces cerevisiae* yeast cells. A major group of protein translocated to the ER called tailed-anchored proteins (TAs) has their transmembrane domain (TMD) in the C-terminus. It is known that TAs follow post-translational targeting of the guided-entry of TAs (GET) pathway to the ER; however, the filters with which and the mechanism by which the GET pathway rejects non-GET pathway substrates is poorly described. We use glucose-signaling factor 2 (GSF2) that contains a central TMD as the model substrate of the signal recognition particle-independent (SND) pathway to delineate such selection filters of the GET pathway. By measuring the translocation efficiency of GSF2 in various SND mutants through immunoblotting, we will confirm that GSF2 is indeed a substrate of the SND pathway. Subsequently, turbidity assay *in vitro* and pulse-chase experiments *in vivo* will determine the binding of GSF2 to Hsp70 (Ssa1), a promiscuous hub in the upstream of the GET pathway. Pulldown assay and fluorescence resonance energy transfer (FRET) assay will show that Sgt2 (adjacent GET pathway downstream of Ssa1) rejects the transfer of GSF2 from Ssa1.

Classic Geomechanical Tests Using Level Set Discrete Element Method (LS-DEM)
Pranavkumar Shivakumar
Mentors: Jose Andrade and Jason Marshall

The study focuses on creating routines for simulating classic geomechanical test including triaxial test, bi-axial test etc. using the recently developed level set discrete element methods or LS-DEM. Introduction of level sets into classic discrete element mechanics technique was done to solve the challenge of capturing the exact grain morphology to identify complex particle shape with precision. The approach for writing a generic routine is based on abstracting out things common across different geomechanical tests like: grains, material properties, sample preparation, input parameters, boundary conditions etc. and writing templates for each of them. The first test looked at in this study is the triaxial test which is an important test to find the shear strength parameters of soil. The routines created will allow the user to input the level sets of the grains, the desired initial conditions like void ratio or porosity and confining stresses. Based on these inputs and the boundary conditions incorporated by a flexible cylindrical membrane the program could calculate and update both the local and global stresses and strains based on LS-DEM and output the results desired by the user.

Modulation of Double-Flash Illusion Using tACS
Naomi Shroff-Mehta
Mentors: Shinsuke Shimojo, Kyongsik Yun, and Mohammad Shehata

The double-flash illusion is a well-known behavioral paradigm for studying multi-modal interaction, which has been used to suggest that the perception of an illusory second flash may be influenced by an auditory stimulus. In order to better understand the information flow between auditory and visual cortices that underlies this illusion, this project uses transcranial alternating current stimulation (tACS) to see if the illusory perception can be modulated. We hypothesize that the alternating current stimulation on the auditory (T7/T8) and visual (O1/O2) cortices in the gamma band frequency may increase or disrupt the illusory perception based on the phase of the stimulation. The study consists of 3 experiments: 1) in-phase stimulation between the auditory and visual cortices to increase synchrony and enhance the illusion; 2) anti-phase stimulation between the auditory and visual cortices to disrupt the illusion; 3) sham stimulation as a control. We collected 5 participants for the experiment 2 and 3 participants for the experiment 3. Our preliminary results showed that with 2 beeps, the number of perceived flashes decreased after stimulation; with 1 beep, the number of perceived flashes increased after stimulation. These results show that tACS could play a role in inducing the illusory flash.

X-ray Spectral Analysis of NGC 1386
Tawny Sit
Mentors: Fiona Harrison and Murray Brightman

Active galactic nuclei (AGN) are supermassive black holes in the center of galaxies that emit radiation including x-rays. The growth rate of AGN can be parameterized by the Eddington ratio λ_{Edd}, the ratio of AGN luminosity to the Eddington luminosity, the theoretical luminosity where pressure from gravity and radiation are balanced. A correlation between the x-ray spectral index Γ and λ_{Edd}, which is particularly useful for estimating the growth rate of heavily obscured AGN where λ_{Edd} is difficult to estimate. In previous analysis, NGC 1386 does not conform to this correlation, possibly due to low count data. We analyze data from a second observation of NGC 1386 from NuSTAR in conjunction with previous observations from NuSTAR, Chandra, and XMM-Newton using two toroidal models of heavily obscured AGN to constrain Γ and λ_{Edd}. This will help determine if NGC 1386 fits into the Γ-λ_{Edd} correlation, providing evidence for AGN unification (between obscured and unobscured AGN) if it does and warranting further investigation into another type of object if it does not.

Redefining the Habitable Zone
Tomas Soltinsky
Mentor: David J. Stevenson

Search for life in the universe and celestial objects is one of the great scientific questions of our time. The habitable zone is usually defined as the zone around a star where liquid water is stable at the surface of a planetary body. This definition has proved to be insufficient by the existence of subsurface oceans at moons such as Europa, Ganymede and Enceladus, supported by data collected by Galileo and Cassini spacecrafts. The fact that liquid water can be found beyond the Asteroid belt implies that habitability does not depend only on the distance from a star. We are developing a model of a planet heated by an internal source such as radioactive decay, which is blanketed by Hydrogen-Helium atmosphere providing sufficient Greenhouse effect. The results show that planets of similar mass to Earth with adiabatic atmosphere arising from a pressure-induced opacity can provide a steady-state system with temperature suitable for liquid water, even if they are located where the solar flux from a star is negligible. The goal of this project is to emphasize the importance of interstellar planets and their conceivable habitability.

Characterization and Improvement of the Thermal Stability of Antennae-Coupled TES Bolometers
Rita Sonka
Mentors: Jamie Bock and Bryan Steinbach

The successful detection and characterization of the B-modes in the Cosmic Microwave Background (CMB) would dramatically illuminate the physics of the inflationary era. The Observational Cosmology Group is iterating on bolometers in an attempt to detect this signal. The previous detector design became unstable in parts of its transition when adjusted for 220/270 GHz frequencies, limiting its use. This is believed to be due to the increased thermal coupling with the bath necessary to vent the increased power from the higher frequency. Based on this, 7 new PdAu mask designs were installed alongside the original design, and were tested for instability with a bias-step response procedure. Design types C, D, F, and H were more thermally stable than the original design. Designs D and F both coat the titanium TES cage but do not directly interface with either TES, and they were found to have 93%+ detector yields, no signs of the characteristic instability in their power-resistance curves, and simultaneously-biased zones over 650% of that of the original design.

Exploring the Soft-State of the Black Hole GX 339-4 Using X-Ray Reflection Spectroscopy
Navin Sridhar
Mentors: Fiona Harrison and Javier García

One of the unsettled issues pertaining to Black Hole x-ray binaries is the evolution of the inner radius (R_{in}) of the accretion disc during an outburst. In this project, we analyzed the RXTE spectra of GX 339-4 in the luminous hard to soft state, comprising millions of counts collected over several kiloseconds from four outbursts. The source spectra was ordered by hardness, and using the pcacorr tool, the data was re-caliberated to a precision of 0.1%. Several simulations were performed with *gaussian* and *relativistic reflection (relxill)* models to test the capability of RXTE/PCA in detecting narrow gaussian lines and large inner radius (R_{in}) for different cases of black hole spin (a_*) and reflection fraction. An extensive analysis of ~200 observations across the luminous hard to soft states were performed with absorbed *thermal comptonization* and *gaussian* models to understand the evolution of associated parameters. Data/Model ratios revealed no evident relativistic broadening in the reflection features with decrease in hardness ratio values. We will further this study by including the advanced reflection model *relxillCp*, to particularly target the strong features in the relativistically broadened Fe-K emission line, Fe-K edge, and the Compton hump in selected observations, to better constrain R_{in}.

Understanding the Impact of Sea-Level Rise on Channel Avulsion Locations on River Deltas
Sarah Steele
Mentors: Michael Lamb and Austin Chadwick

Many river deltas grow through the process of channel avulsion, abrupt shifts in the channel that combat land-loss due to sea-level rise and also pose a flood hazard to coastal populations. Previous work suggests that avulsions occur at a relatively consistent distance upstream from the shoreline for a given delta, corresponding to where flow begins to decelerate due to standing water downstream. However, it remains unclear how rising sea-levels may influence avulsion location through shoreline retreat and hydraulic effects.

To isolate the impact of sea-level rise rate on avulsion location we performed physical experiments at the Caltech River-Ocean Facility, where laboratory-scale deltas grew over many avulsion events and under varying sea-level rise conditions. For each avulsion event, we identified avulsion locations and delta shorelines using overhead photography, and measured water-surface velocities using image-processing techniques. Channel avulsions on our experimental deltas occur at a fixed distance from the shoreline set by the zone of flow deceleration regardless of sea-level rise-rate, consistent with field observations. However, avulsion locations are shifted upstream when sea-level rise causes intermittent retreat of the shoreline. Ongoing work using flow-velocity maps explores the relationship between river hydraulics and avulsion location at different rates of sea-level rise.

Multipoint Evaluation of Arithmetic Circuits and Related Implications of SAT Algorithms
Jesse Stern
Mentor: Chris Umans

Multipoint evaluation is a term for a method that computes a polynomial on multiple settings of the variables faster than the trivial method of computing a single evaluation, then starting the computation over on the new setting of the variables. In general, computing multiple settings for the variables in the trivial manner would take $s \times n$ steps where n is the number of settings of the variable. Professors Kedlaya and Umans proved that polynomials that are sums of products can actually be computed at n points in close to $s+n$ steps, turning the multiplicative factor into an additive one and yielding a significant improvement. We investigated the still open question as whether or not this sort of improvement exists for evaluating polynomials that are not of this convenient form (such as polynomials represented as the product of other polynomials). We also considered the implications of multipoint evaluation algorithms with respects to SAT algorithms which could yield new circuit lower bounds against NEXP.

Bayesian Optimization for Hyper-Parameter Tuning of the XOR Neural Network
Lawrence Stewart
Mentor: Mark Stalzer

When applying Machine Learning techniques to problems, one must select model parameters to ensure that the system converges but also does not become stuck at the objective function's local minimum. Tuning these parameters becomes a non-trivial task for large models and it is not always apparent if the user has found the optimal parameters. We aim to automate the process of tuning hyper-parameters by utilizing Bayesian Optimization. We will apply this technique to tune an Artificial Neural Network used to model the XOR function, optimizing prediction accuracy with less parameter tests than manual tuning. Finally, we demonstrate the same technique on a temporal example, by optimizing the tuning of a Recurrent Neural Network.

Creating a Compressible Dielectric for Micro-Capacitors in Pressure Sensing
Ariel Stiber
Mentors: Julia Greer and Amanda Bouman

Micro-capacitor pressure sensors have promising applications in areas such as robotics and medicine. For the capacitor to work at very small pressures an easily compressible dielectric structure must designed between the capacitor's parallel plates. Using Matlab, a concentric spring design was created. This design was modeled on Solidworks to test its compressibility. Previous code was adapted to convert the Matlab design to a GWL file so it could be written with IP-Dip resin on a Nanoscribe. Laser power and scan speed were optimized for this design to create an optimal spring. Further steps will be to test the Young's Modulus and percent strain for the individual and concentric springs under a relevant pressure and to compare this to previously made nanolattice designs. This will confirm whether this spring design will prove a better dielectric.

Kalman Filter Estimation for Multiple Sensor Fusion
Hyung Ju Suh
Mentor: Soon-Jo Chung

Kalman filters have been used extensively in the field of sensor fusion and estimation. The problem statement of this research is to provide a well performing localization filter given three sensors: Snapdragon Flight (a visual-inertial localization sensor), an IMU (inertial-measurement unit), and a downwards-facing lidar. Due to attitude dynamics, we deal with a non-linear case with an EKF (extended-Kalman Filter) formulation. Additional techniques such as frequent-rate propagation, and decoupling of linear and angular state is used. We compare the results of the implemented Kalman filter with the ground-truth path obtained using Vicon motion capture system, against the localization results of Snapdragon Flight.

Magnetic Sensor Circuit Utilizing an Inductive Bridge
Garret Sullivan
Mentors: Ali Hajimiri and Matan Gal-Katziri

Development of point-of-care diagnostics allows for important medical results to be obtained quickly and conveniently instead of requiring samples to be sent to centralized laboratories for testing. One key technology for point-of-care systems is the magnetic biosensor, capable of detecting the presence of various molecules by attaching small magnetic beads to said molecules and measuring the effect of those beads on the local magnetic field. An inductive bridge circuit provides an effective way to detect changes in the magnetic field through the field's effect on inductance. By utilizing an external cancellation scheme to handle manufacturing tolerances and to ensure the accuracy of measurements, a low-cost sensor can be produced and widely deployed, allowing effective diagnosis of various conditions in any location.

Assay of Peptidase Function in *Drosophila* Cell Migration
Hsuan-Te Sun
Mentors: Angela Stathopoulos and Heather Curtis

Peptidases are enzymes that play various roles in developmental processes including cell migration, where errors can have serious consequences such as mental disability, vascular disease, or tumor formation. Our goal is to provide mechanistic support for the function of four conserved peptidases (Mmp2, Tasp1, Tok1, CG9416) using the easily observable *Drosophila* caudal visceral mesoderm (CVM) cell migration as our experimental system. Tasp1 and Tok1 are primarily expressed in migrating CVM cells, while Mmp2 and CG9416 are expressed in several tissues including CVM. Although the human orthologues of these peptidases have been connected to overexpression in cancers and roles in various tissue development, little is known about their specific biological mechanisms. We analyzed tissue-specific RNAi mutants and published genetic knockout mutants of the peptidases via immunohistochemistry against CVM markers, then assayed the RNAi mutants with live imaging movies. So far, we have observed pronounced stalling, asymmetry, and other abnormal migration phenotypes in the Mmp2 mutants specifically, and are waiting on more results to confirm their statistical significance. We hope to see phenotypes in the other mutant peptidase lines, which may ultimately lay the foundation for future treatments of developmental diseases or cancer.

Thruster Control and Characterization for a 6 Degrees of Freedom Spacecraft Simulator Testbed
Jui Hung (Ray) Sun
Mentors: Soon-Jo Chung, Yashwanth K. Nakka, and Rebecca Foust

Spaceflight involving small satellites, particularly large numbers in spacecraft "swarms", has attracted interest from commercial aerospace and current research. The Aerospace Robotics and Control Group at Caltech investigates highly agile flight, aerospace robotics, and the application of estimation, nonlinear control, and vision-based navigation in autonomous aerial and space vehicles. We are developing a 6 degrees of freedom (DOF) testbed for experimental validation of guidance, navigation, and control algorithms for small spacecraft. A linear actuator and 16 cold-gas thrusters permit the attitude stage to mimic the 6-DOF motion of a satellite in microgravity within the 1 g environment of Earth. My project concentrates on the selection and design of low-level control hardware for the testbed thrusters in addition to the design and conduct of thruster characterization testing for subsequent thruster controller design. Future work after SURF includes integration of electronics, final assembly, and verification testing. We intend to utilize multiple testbeds in experiments involving vision-based navigation, autonomous rendezvous and docking, and distributed multi-agent control for swarm applications.

Optimization of Methods to Find Extreme Galaxies in the CLU 3π Galaxy Survey
Bethany Suter
Mentors: Mansi Kasliwal and David Cook

In the past decade, galaxies with extreme properties called green peas and blueberries have been found at low redshift which are likely analogs for galaxies that formed shortly after the Big Bang. Originally found through visual inspection, the number of blueberries and green peas grew slowly. To automate the selection process, we use colors from multiple imaging surveys (i.e. SDSS, WISE, and GALEX) that span a broad range of wavelengths to more cleanly separate these galaxies from a random sample of galaxies and QSOs. Our color cuts found 92% of the targeted extreme galaxies, while previous studies using optical-only color cuts found 30%. Furthermore, out method is missing about 9% of the extreme galaxies and has a contamination percentage of 3-4%. We applied these color cuts to an area of the sky that overlaps with the CLU (Census of the Local Universe) survey which can provide confirmation of their extreme properties by measuring the star formation rate via imaging. We found about 17,000 blueberries and green pea candidates. We present the physical properties (star formation rate, metallicity, and stellar mass) of a subset which have been spectroscopically confirmed and investigate whether these extreme galaxies follow the trends of regular galaxies.

Characterization of the Genetic Pathway Responsible for Orange Pigment in a Marine *Pseudoalteromonas sp.*
Gemma R. Takahashi
Mentors: Dianne K. Newman, Kyle C. Costa, and Jared R. Leadbetter

The *Pseudoalteromonas* genus is filled with organisms that produce pigmented, often bioactive compounds in a range of environments. Some of these compounds have been shown to have antibiotic, antifungal, and antifouling properties. This project focused on elucidating the genetic pathway behind pigment production in two strains of *Pseudoalteromonas piscicida*, an orange marine species known to kill fish under laboratory conditions. Pigment production in this organism has been loosely correlated with its bioactivity, so understanding one may shed light on the other. We used transposon mutagenesis to generate mutants, which ranged from having a lack of to an overproduction of pigment; sixteen of these were chosen for further sequencing, and have yet to be processed. In addition, we described a protocol for the successful conjugation of marine *P. piscicida* with fresh water *Escherichia coli*, as well as preliminary steps in characterizing the orange pigment.

Preparation for the Integration of Single-Cell Proteomics and Transcriptomics
Kaitlyn L. Takata
Mentors: James R. Heath and Alex Xu

Single-cell analysis eliminates the bias which a few cells can cause when one analyzes a large population, such as a tumor. The cellular heterogeneity of tumors can be further studied by combining proteomics and transcriptomics at the unicellular level. Microfluidics provides a platform for isolating and analyzing mRNA and proteins from single cells. Each microfluidic device is made of two layers of polydimethylsiloxand (PDMS) polymer on a glass slide and has a 6x6 grid of chambers, each of which ideally traps one cell and a few microbeads. Each chamber contains unique DNA barcodes which bind to the beads, allowing mRNA molecules to be paired with their respective cells. Once the mRNA is collected, it undergoes reverse transcription, PCR, purification, and sequencing. The collected beads are transferred to a tube which is incompatible with automatic thermocyclers; thus, the first PCR is performed manually. The manual PCR conditions have been optimized to increase the quality of the final sequencing material. More work must be done to optimize the purification protocol in order to select for the correct cDNA lengths. Once mRNA capture and analysis are perfected, they will be combined with a protein-capturing antibody array to create the final integrated platform.

Investigating the Mechanism Behind Biocatalytic Carbon-Silicon Bond Formation
Allison Tang
Mentors: Frances Arnold and Russell Lewis

Enzymes can efficiently and sustainably catalyze highly selective reactions, but their catalytic range is limited. In recent years, directed evolution has allowed us to engineer enzymes that can conduct reactions outside their natural repertoire. Specifically, the Arnold lab has evolved *Rhodothermus marinus* cytochrome *c* to form carbon-silicon bonds, introducing a myriad of possibilities of bringing silicon into biology. However, the details of the carbon-silicon bond-forming reaction mechanism are unknown. In order to study the mechanism, we conducted several kinetics experiments to determine a primary kinetic isotope effect (KIE) for our reaction. We substituted the hydrogen atom on the silicon substrate for a deuterium and compared initial rates between the substrates. To investigate how the reaction mechanism may have changed through evolution, we performed these experiments with both the wild-type protein and the current best protein variant. We calculated the KIEs, and discovered that both KIEs suggest the Si-H bond is broken during the rate-limiting step. The KIEs also imply that our evolution changed the relative energies of the rate-limiting step, an interesting result that may inform future protein engineering.

Design of a Sensorless Field Oriented Motor Controller Circuit Board
Aditya Telikicherla
Mentors: Soon-Jo Chung and Xichen Shi

Although brushless direct current motors exhibit greater reliability, increased longevity, and quieter operation than their alternating current and brushed counterparts, they require control circuitry to operate. Nearly all commercial speed controllers use inefficient, open loop algorithms, while others are either not programmable or too large in size. The purpose of this project is to create a small circuit board that powers motors for implementation in a flying car design. We expanded upon a Texas Instruments reference design for ease of soldering, while still satisfying the flying car's motor speed and power supply needs. After testing an evaluation board with a tachometer, we obtained that a typical drone motor spun to within 0.15 Hz of various input speeds. Once the board was assembled, we found that it spun the target motor to within 0.25 Hz of the desired speed. The maximum frequency with which the input speed could change while still accurately controlling the motor speed was about 50 Hz. Lastly, we compared the board's performance to those of a few other commercial field oriented speed controllers. Future work would include using the board on a prototype of the flying car and evaluating its control capabilities.

Developing a Complete Binding Signature of the α4β4 Nicotinic Acetylcholine Receptor
Gabrielle Tender
Mentor: Dennis Dougherty

Nicotinic acetylcholine receptors (nAChRs) are part of a larger class of ligand gated ion channels, which play a fundamental role in neurological signaling. These proteins are of particular interest, because they are pharmacological targets for nicotine addiction, Alzheimer's disease, autism spectrum disorder, and schizophrenia. nAChRs are comprised of five subunits and are activated by the binding of a ligand, either a neurotransmitter or drug, at the interface of two subunits. One of the primary issues with their drug discovery is that twelve known subunits can combine to form distinct receptor subtypes. It is important that we understand how agonists bind to and activate different subtypes to develop subtype-specific pharmaceuticals. The objective of this study is to test the hypothesis that the complementary subunit (the β-subunit) is the key to subtype specificity with respect to agonist binding in α/β receptors. Using unnatural amino acid mutagenesis, the binding of two drugs to α4β4 was probed and compared to a previous binding model of the same drugs to α4β2. By only altering the identity of the β-subunit, we are able to test this hypothesis. This is an ongoing project, and more experimentation is required.

Multiply-Substituted Isotopologues Distribution on Hydrocarbons Synthesized via Fischer-Tropsch Type (FTT) Reaction
Laura I. Tenelanda Osorio
Mentor: John Eiler

Measurement of the bulk isotopic composition of carbon materials found in meteorites have been carried out to better understand the environment and the mechanism of formation of heavy hydrocarbons and its origin in the solar system. As the Fischer Tropsch reaction is a potential route to form these species, we performed the reaction at 800 torr of pressure and at different temperatures between 100 and 150°C to make up hydrocarbons, using iron oxide (Fe_2O_3) and silica (SiO_2) as catalyst on a steel vessel. We compare the different isotopic composition of the hydrocarbons produced and expect to have heavier hydrocarbons at low temperatures and lighter at high temperatures. With this project we expect to provide more information about the conditions of formation of those species.

Using Hidden Markov Models for Classification of Astronomical Time Series
Joseph Tilahun
Mentors: Matthew Graham and Mathieu Desbrun

We investigate the classification of datasets encoding the brightness of heavenly bodies in time. Astronomical time series of this nature are often large, noisy, and irregularly sampled, thus calling for machine learning techniques to properly analyze them. In this project, we focus on examining the feasibility of using hidden Markov models (HMMs) to perform this classification. We first investigate whether HMMs have sufficient discriminatory power to differentiate periodic variable stars, whose brightness variability is the result of a deterministic process, based on their location in the HMM parameter space. We then test HMMs for the classification of quasars, whose brightness variability is the result of a stochastic process. We also discuss the most appropriate choice of software library and the computational power required for these massive datasets.

Understanding Detector Sensitivity to Features in the Spectrum of Supernova Neutrinos
Alicia Tirone
Mentor: Ryan Patterson

Neutrinos are theorized to play a role in the explosion of core-collapse supernova; theories about the role of neutrinos in restarting the stalled accretion shock in a supernova predict certain features in the spectrum of neutrinos from a supernova. This project is focused on determining time resolution necessary to see the neutrino trapping notch and standing accretion shock instability (SASI) in the proposed DUNE detector, a 40 kiloton liquid argon detector which will be deep underground. By generating artificial data sets as seen in the detector with different time resolutions, the significance of the trapping notch can be determined using the chi squared statistic. An analysis of the SASI oscillations was done using Fourier transforms to understand how well the DUNE detector would be able to see the oscillations.

Analysis of Parameterization of Boundary Layer Turbulence and Clouds for Climate Modeling
Nicholas Trank
Mentors: Tapio Schneider and Colleen Kaul

For reasons of computational cost, global climate models use spatial resolutions that are too coarse to directly represent turbulent mixing and clouds. Approximate relationships, called parameterizations, are used to represent the effects of these unresolved processes on large-scale atmospheric flow. One such parameterization is called the Eddy-Diffusivity/Mass-Flux approach, which assumes that all air movement can be either categorized as a turbulent environment that has an eddy diffusivity behavior, or as coherent updrafts that satisfy mass-flux equations. To inform parameterization development, limited-area models called large-eddy simulations (LES) are used. In this work, we investigate a novel approach to EDMF parameterizations that includes updraft "memory" terms and a systematic derivation of the budget of turbulent kinetic energy. Simulations of shallow cumulus convection were run to determine whether some of the assumptions made in the current model are supported by LES data. Important variables, such as the entrainment and detrainment rates of the updrafts, were also investigated to attempt to identify useful parameterizations. We found that even though the parameterization is able to capture many features of shallow cumulus convection, there are some assumptions that are not supported by LES data, suggesting areas in which the parameterization could be improved.

Validation and Application of Coarse-Grained Kinetic Algorithms for the Simulation of Nucleic Acid Reaction Pathways
Bergthor Traustason
Mentors: Niles A. Pierce and Mark Fornace

To complement the utility of thermodynamic calculations for designing and analyzing nucleic acid reaction pathways, it is desirable to be able to also simulate the kinetics of the interacting nucleic acid strands. The Pierce Lab has been developing computationally efficient and scalable algorithms for the analysis of secondary structure kinetics for the past decade. The algorithms identify dominant species and kinetic rates between them using coarse-graining over the ensemble of a small box containing several strands or a large box containing a dilute solution of strands. The objective of this study is to validate and apply these algorithms to simulate nucleic acid reaction pathways that play important roles in the emerging fields of molecular programming and synthetic biology. For small cases, rigorous comparisons are made to fined-grained, fully-enumerated solutions as well as to analytic coarse-grained solutions. We will validate the forced-join move of the large-box algorithm against the small-box algorithm. Furthermore, we will outline future research into the methodologies for efficient simulations of the coarse-grained kinetics of nucleic acid secondary structures.

Investigating Thermal Transport in Amorphous Graphene
Ayushman Tripathi
Mentor: Austin J. Minnich

Past works have investigated heat transfer in amorphous graphene using equilibrium molecular dynamics and non-equilibrium molecular dynamics. Given the discrepancies in thermal conductivity magnitude and temperature dependence of thermal conductivity that have been reported in previous works, there is a need for clarity in understanding thermal transport in amorphous Graphene. To gain more insight into the heat transport in a-Graphene, we will first calculate the thermal conductivity of a-Graphene at various temperatures using the Green Kubo formalism. We will also compute dynamical structure factors at 0 and 300 K to investigate the effect of anharmonicity and local elastic modulus variations on scattering propagons in this work.

A Novel Tumour Ablation System Using Low Frequency Ultrasound
Leyre Troyas Martinez
Mentors: Morteza Gharib, Mikhail Shapiro, and David Mittelstein

Oncotripsy investigates a method to selectively target cancer cells by means of ultrasound harmonic excitation at their resonant frequency. Due to their differences in mechanical properties, modal analysis has revealed a spectral gap in the natural frequencies and, most importantly, in the resonant growth rates of cancer and healthy cells. Experiments now focus on investigating its applicability to biological tissue and identifying the most effective parameters that can be used to selectively target cancer cells using low frequency ultrasound radiation. Additional experiments have also been done to investigate whether the changes in mechanical properties occurring throughout the cell cycle affect and can be used to increase vulnerability of the cell when exposed to ultrasound. Experimental results so far have shown agreement with predictions from the computationally resonant model, where level of cell death for both, cancer and healthy cells, appear to be frequency dependent. But perhaps most significantly, sharp cut-off voltage and pulse duration values have been identified, thus appearing to be minimum parameter values of stimulation for each cell type determined by its mechanical properties. Computational and experimental data suggest that the optimum treatment could be achieved at the frequency where the difference in critical pulse duration is largest between the cancer and healthy cells.

Laser-Control Interface Upgrades and Measurement Automation in Quantum Optomechanics Experiments
Ásgeir Tryggvason
Mentors: Oskar J. Painter, Gregory MacCabe, Szilard Szoke, and Hengjiang Ren

We present various improvements to laser control software in the Painter Lab involving user interfaces, control scripts and device compatibility to central control software. We also present the experimental setup used in various experiments in quantum optomechanics. Our measurement automation upgrades to the experimental setup involve modification of the routing of light through optical system components as well as real-time execution of experimental protocols and data collection. The optical setup and hardware systems are used to perform optical measurements of a quasi-1D “nanobeam” optomechanical crystal cavity as well as a quasi-2D “snowflake” design, which are designed for co-localization of acoustic and optical modes and large optomechanical coupling. Previous designs have been used to generate non-classical states of light and prepare the mechanical vibrational mode near the quantum ground state. There is great promise in such optomechanical systems for tasks in quantum-information processing, computation, and potentially storage and communication. These systems show also promise in conversion of microwave and optical signals. Studying such devices at low temperature requires sophisticated optical measurement setups and protocols. The improvements will result in greater efficiency and general control in experiments.

Numerical Implementation of the Electron-Phonon Interaction Coefficients in PERTURBO Software Platform
P. R. Vaidyanathan
Mentors: Marco Bernardi and Luis Agapito

The interaction between electrons and phonons is highly important in predicting many fundamental opto-electronic properties of materials. This interaction is quantified through scalar coefficients that can be directly computed from first principles, that is, using only the basic information for the atoms that constitute the material and the standard numerical solutions to the equations of quantum mechanics. With the current state of computation, it is not possible to calculate these coefficients entirely from first principles to a resolution high enough to make converged predictions. Hence, these coefficients are calculated for a coarse grid and the remaining values are obtained using accurate interpolation techniques. PERTURBO, a Python/Fortran software platform under development in the Bernardi group, can perform this interpolation. Currently, it builds on the coarse-grid coefficients computed using Quantum Espresso (QE), which is the standard quantum-mechanical software package used in the field of computational materials science. My project is to implement the computation of the coarse-grid coefficients in Python so as to extend the flexibility of PERTURBO by reducing its dependency on QE. This involves computing the electron-phonon interaction coefficients $g_{mn}^{\kappa\alpha}(\mathbf{q},\mathbf{k}) = \langle\psi_{m\mathbf{k}+\mathbf{q}}(\mathbf{r})|\partial_{\mathbf{q},\kappa\alpha}V(\mathbf{r})|\psi_{n\mathbf{k}}(\mathbf{r})\rangle$, which in turn requires me to obtain the wave function of the electrons $\psi_{n\mathbf{k}}(\mathbf{r})$ at any given $\mathbf{k}$-point and band n as well as the perturbation of the crystal potential $\partial_{\mathbf{q},\kappa\alpha}V(\mathbf{r})$ due to the vibrations of the atoms associated with a phonon of wave vector $\mathbf{q}$. The perturbation potential can be divided into contributions arising from the electronic cloud ($\partial_{\mathbf{q},\kappa\alpha}V_{\mathrm{SCF}}(\mathbf{r})$) and from the ionic movement ($\partial_{\mathbf{q},\kappa\alpha}V_{\mathrm{ion}}(\mathbf{r},\mathbf{r}')$) which require different integration techniques in order to maximize efficiency. I will be using the routines provided in the Python DFT code - GPAW and also the Python Numeric Computation Package - NumPy.

Terahertz Spectroscopy of Lead Halide Perovskites
Miha Valencic
Mentors: Geoff Blake, Xiaolin Xu, and Griffin Mead

Lead halide perovskites have grown in prominence over the last ten years due to their high energy conversion efficiency and low cost to produce. However, despite this increase attention, the reasons for the high conversion efficiency is largely unknown and the optoelectronic properties of lead halide perovskites are not well known. We have created an experiment to study the charge carrier dynamics in the lead halide perovskites $CH_3NH_3PbBr_3$ and $CH_3NH_3PbI_3$ using terahertz pump-probe spectroscopy. The perovskites are excited both above and below the band gap with the terahertz light sources and the charge carrier dynamics are monitored on a femtosecond time-scale. With the data taken from these experiments we can gain a greater understanding of the optoelectronic properties of lead halide perovskites and thus create more efficient and cost-effective solar cells.

Improvements in Cryogenic Design of the TIME-Pilot Experiment
Tine Valencic
Mentors: Jamie Bock and Abigail Crites

Observations of the redshifted 157.7 µm line of singly ionized carbon [CII] may enable us to better understand the epoch of reionization, when the first stars and galaxies formed. The TIME-Pilot intensity mapping experiment will make such measurements using a linear array of spectrometers cooled to a temperature of 250 mK. The goal of this project was to develop the cold trap for the cryogenic system, which is necessary for the He-4 coolant to remain pure. In turn, the purity of the liquid helium is critical to keeping the spectrometers cold and able to register data. After extensive modeling in SolidWorks, the cold trap was fabricated and tested for leaks. Additionally, various simulations of the cryostat as a whole were made in order to analyze the deformation of the system in response to thermal stresses. These tests provided guidelines regarding the tolerances required in the experiment to counter distortions when the system is cooled to operating temperatures.

Studying the Resonant Effect of Carrier-Envelope Phase (CEP) Current in Response to Changing Intensities
Praful Vasireddy
Mentors: Franz Kaertner, Phillip Donald Keathley, and Manuel E. Endres

In response to a very short-pulse, high-intensity laser field, electrons can be emitted from a metal through Fowler-Nordheim tunneling rather than multiphoton emission. Mathematically, the laser field can be represented by a Gaussian envelope that is amplitude modulated by a carrier wave. The current generated via tunneling emission depends on the phase difference between the envelope and carrier, referred to as the carrier-envelope phase (CEP). For certain pulse intensities, theoretical predictions show that the magnitude of the current generated by this tunneling emission drops off suddenly and the CEP-dependent current switches phase by 180 degrees. We have developed a system to precisely vary the input optical intensity while performing CEP-dependent current measurements. Using this system, we have confirmed this theoretical model and observe a resonance-like effect of the CEP-dependent current in response to a varying input optical intensity.

Morphological Variation Between Island Populations of the Tree Skink *Emoia sanfordi*
Gene Vaughan
Mentors: Jonathan Losos, Alison Hamilton, Melissa Kemp, Anthony Geneva, and Rob B. Phillips

Emoia sanfordi is an arboreal skink distributed broadly in the Vanuatu archipelago. We investigated morphological characters in over 200 *E. sanfordi* specimens from 13 islands in Vanuatu. These characters include a suite of length measurements, scale counts, and coloration. Dorsal coloration varied noticeably between populations on different islands. Other characters indicative of adaptive evolution, like jaw width and toe lamellae counts, varied between populations but only to a small degree. Most characters showed little variation across islands, as could be expected given the probable recent origin of the species (the archipelago may only have been emergent in the Pacific for the last 2 million years). Given the consistent nature of *E. sanfordi*'s niche throughout its range, adaptive evolution would perhaps not be expected, and the degree to which it has been observed may be due to an insufficiently large data pool. However, the variation in color is more puzzling, with most populations being predominantly green and a few populations consisting almost entirely of dark individuals. It is possible that color evolution has been driven by population-specific selective pressures, but what these may be and whether or not they have caused concurrent evolution in other characters is an open-ended question.

Studying the Effect of Chromatin Context on hnRNP Binding Sites
Akshay Vegesna
Mentors: Alexei Aravin and Jae Hyoung Cho

Heterogeneous nuclear ribonucleoproteins (hnRNPs), a class of RNA-binding proteins, have long since been known to regulate transcriptional processing, mRNA splicing events and mRNA stability. With the development of a novel technique termed TRIP (thousands of reporters integrated parallel), researchers have been now able to multiplex reporter assays, with proof of concept studies assaying transcriptional activity for as many as 27000 reporters. We extend this technique to find the RNA-binding sites of hnRNP molecules using parCLIP, CLIP, and next-generation sequencing. Work in this lab has already found the sites of integration of the reporters, but what is left is to find the RNA-binding sites using CLIP and high-throughput sequencing. By looking for these reporters in the sequences of RNA bound to hnRNP, we can find a relationship between hnRNP binding sites and chromatin position effects.

Modification of Electronic Properties in Bilayer Graphene via Twist Angle
Lucas Venta Viñuela
Mentors: Michael Ortiz and Juan Pedro Méndez Granado

Bidimensional layered materials have electronic properties that depend upon their twist angle. The asymmetry caused by rotating one of the graphene layers with respect to the (0 0 1) crystallographic direction allows us to study twist-dependent features in bilayer graphene: electronic Density of States (DoS) and conductivity. Rotating the layers, weakly bonded by Van der Waals forces, lead to distinct Moiré patterns, which result in different electronic spectra. In the present work, Molecular Dynamics simulator LAMMPS is used to study equilibrium configurations of bilayer graphene, while the calculation of the electronic DoS, derived from density-functional theory, is carried out by SIESTA (Spanish Initiative for Electronic Simulations with Thousands of Atoms). Engineering electronic properties in bilayer graphene, through the above-mentioned twists and by doping or inducing a perpendicular electric field to the layers, would offer promising unique features to the field of nanoelectronics, improving transport and optical properties from conventional semiconductors.

Investigation of Ferroelectric Properties of Oxide Superlattices at Low Temperatures
Vibha Vijayakumar
Mentors: Darrell Schlom, Natalie Dawley, and David Hsieh

The oxide superlattice $(SrTiO_3)_nSrO$ has been identified as a promising tunable dielectric for modulating frequency signals, especially at 5G gigahertz frequencies, due to its epitaxial strain to enhance tunability and defect mitigating structure that reduces charged point defects. The next generation of this material, $(SrTiO_3)_n(BaTiO_3)_1SrO$ thin films, combines two ferroelectric materials, $SrTiO_3$ and $BaTiO_3$, in a superlattice broken up with non-ferroelectric SrO layers. This study explored the in-plane and out-of-plane ferroelectric and dielectric properties of the $(SrTiO_3)_n(BaTiO_3)_1SrO$ thin films at temperatures 80 K – 340 K for n=1, 3, and 5. Understanding the competing $SrTiO_3$'s and $BaTiO_3$'s polarizations' interactions can be useful for optimizing the material for planar and vertical devices. Measurements involved the use of Cr/Au interdigitated electrodes for in-plane characterization and a $SrRuO_3$ bottom electrode with Cr/Au circular top electrodes for out-of-plane characterization. The data was collected by combining ferroelectric and dielectric measurement software with a low temperature probe setup. By investigating dielectric constants with temperature and measuring ferroelectric hysteresis loops at 80 K, we found that in-plane shows a clear ferroelectric transition around 170-180 K and clearly shows ferroelectric properties at 80 K. Out-of-plane measurements show high leakage and did not clearly indicate ferroelectric properties.

Effect of Lithographic Texturizing on Semi-Conductive Materials for Anti-Reflective Use in Photovoltaic Cells
Eleanor Walker
Mentors: Julia Greer and Alessandro Maggi

We explored the optical properties of three dimensional nano-architected solids, for ostensible use in such applications like the anti-reflective layer of photovoltaic cells. The nano-architected structures were fabricated in titania through three dimensional laser lithography using the Nanoscribe Photonic Professional GT, which is more accurate and can make more detailed designs than current texturizing methods like wet etching. Simulation of the structures over layering evocative of a photovoltaic cell, with silicon and a silver backing, suggested that the overall transmittance of more detailed structures, such as an "inverted arrowhead" shape, could surpass that of the current optimal geometry for anti-reflective coatings, an inverted-pyramid. Importantly, this technique could be used to create more effective anti-reflective coatings, resulting in higher efficiency solar cells and, on a wider scale this suggests the subsequent use of lithographic texturizing to alter of a substance's optical properties.

A Forward Genetic Screen for Novel Genes Necessary for Stress Induced Sleep in *Caenorhabditis elegans*
Sophie Walton
Mentors: Paul Sternberg and Han Wang

Sleep, as characterized by a reversible state of increased arousal threshold along with behavioral quiescence, is a process necessary for development and recovery from stress in many organisms. However, many of the genetic pathways of sleep remain uncharacterized. In order to discover potential genes that are necessary for stress induced sleep we conducted a forward genetic screen on the model organism *C. elegans* to identify sleep defective mutants. In a pilot screen, we examined about 21600 mutagenized genomes, and recovered 11 suppressor lines. We are currently working on characterizing the mutants through complementation tests and chromosomal mapping. We also plan on sequencing the genomes of our suppressors in order to find what genes are responsible for mutant phenotypes in our mutant worms. We believed that we did not find all genes essential for sleep in *C. elegans* in this initial screen, so we are conducting a second screen to obtain more suppressors. Through our efforts we hope to find and characterize novel genetic pathways involved in sleep.

Targeting Heterogeneous InP From Well-Defined Molecular Precursors Under Mild Conditions
Ruomeng Wan
Mentors: Theodor Agapie and Joshua A. Buss

Indium phosphide (InP) is emerging as an important semiconductor material due to its unique optoelectronic properties. However, the broader application of InP is hindered by its challenging synthesis, which traditionally involves expensive precursors and harsh reaction conditions. Herein we propose a reductive pathway for the preparation of InP materials from well-defined molecular precursors. Using a molecular phosphorus transfer reagent and indium (III) salt as starting materials, we synthesized crystalline InP thin films *via* electrodeposition.

This strategy was extended to the synthesis of InP quantum dots from P^{3+} phosphorous precursors *via* chemical reduction. SEM (scanning electron microscope), EDS (energy dispersive X-ray spectroscopy), XPS (X-ray photoelectron spectroscopy) and PXRD (powder X-ray diffraction) were applied to characterize the products obtained from these methods. Measurements of photovoltaic behavior as well as optical spectroscopy were also carried out to further probe the properties of the InP materials prepared by this strategy.

On the Prouhet-Tarry-Escott Problem
Allison Wang
Mentor: Zavosh Amir-Khosravi

The Prouhet-Tarry-Escott problem of degree n asks for two disjoint sets of integers $\{a_1, a_2,..., a_k\}$ and $\{b_1, b_2,..., b_k\}$ such that $a_1^m + a_2^m +...+ a_k^m = b_1^m + b_2^m +...+ b_k^m$ for all integers m between 1 and n, inclusive. An ideal solution is a solution in which $k = n + 1$. Solutions are called equivalent if one can be obtained by an affine transformation of the other. We consider the Prouhet-Tarry-Escott problem of degree 8, which has only two known inequivalent solutions, and attempt to generalize the method used to find one of these solutions. In addition, we consider the Prouhet-Tarry-Escott problem over number rings other than the integers.

Postdictive Movement: Perception of Static Gradients in the Double Flash Illusion
Christine Wang
Mentors: Shinsuke Shimojo, Armand R. Tanguay, Jr., and Noelle R. B. Stiles

The double flash illusion is a multimodal perceptual phenomenon in which a visual flash accompanied by two auditory beeps results in a second illusory flash. We investigate the blurry double flash illusion, a variation in which the visually flashed object contains a static spatial gradient (black at the center fading to white at the edges) perceived to expand then contract during both the real and illusory flashes. We explore the possible gradient stimulus parameters, such as luminance and gradient function, that influence the perceived dynamics of expansion then contraction, as well as the perceptual outcomes of presenting it simultaneously with a solid-edged flash. Experiments were coded in MATLAB using the Psychophysics Toolbox package. Pilot results indicate that certain gradient functions result in greater perceived expansion and contraction than other gradient functions. Gradient stimuli scaled to a larger size also result in greater perceived dynamics. Luminance and gradient function may also determine whether flashing a solid-edged and gradient edged stimulus simultaneously with two auditory beeps results in a second illusory flash of one of the stimuli. This illusory phenomenon shows that a dynamic visual stimulus can be replayed when triggered by an auditory beep, thereby broadening our understanding of visual-auditory interactions.

Establishing a Specific and Efficient T-cell Activation Reporting System for Identifying Antigen and T-Cell Receptor Interaction
Jessica Wang
Mentors: David Baltimore and Guideng Li

T-cell receptors (TCRs) are cell surface receptors that help T-cells recognize invading microbes and infected or cancerous cells in the body. TCRs bind specifically to antigens expressed on diseased cells and activate gene transcription in the T-cell in order to initiate an immune response. Since TCR specificity and response depend on TCR-antigen pairing, a method called T-cell receptor gene therapy has been used to enhance the immune system's response to cancer cells. In this method, T-cells from a patient are genetically altered to express TCRs targeting antigens specific to, or associated with, the patient's tumor cells. Thus, identifying the TCR that can recognize a specific antigen and identifying the antigen that can be recognized by a specific TCR are both very important for TCR-based gene therapy. We have established two reporting systems for verifying antigen-TCR pairs. The first reporting system is a TCR reporting system that uses NFAT-controlled expression of ZsGreen. The second reporting system is a synthetic Notch (synNotch) receptor reporting system using Gal4-VP64-controlled expression of ZsGreen. Response and specificity of these systems will be compared to determine which method is more efficient. In the future, this reporting system can be used as a tool for TCR-based gene therapy.

The Evolution of the Accretion Disk in the Low/Hard State in GX 339-4 Seen by NuSTAR and Swift
Jingyi Wang
Mentors: Fiona Harrison, Javier García, and Jack Steiner

We analyze eleven *NuSTAR* and *Swift* observations of the black hole X-ray binary GX 339-4 in the hard state, six of which were taken during the end of the 2015 outburst, five during a failed outburst in 2013. These observations cover luminosities from 0.46%-4.64% of the Eddington luminosity. Implementing the most advanced reflection model *relxill*, we perform simultaneous spectral fits on both datasets to track the evolution of the properties in the accretion disk including the ionization, the disk emission and the photon index. We find the disk becomes more truncated when the luminosity decreases, and no evidence shows a truncation radius larger than $50R_g$. We also explore a self-consistent model under the framework of coronal Comptonization, and find consistent results regarding the disk truncation.

Investigation of Neuronal Populations Controlling Salt Satiation in Mice
Maple (Leanne) Wang
Mentors: Yuki Oka and Sangjun Lee

Fluid homeostasis, an important process for regulating the necessary fluids in the body, maintains internal water and salt balance. A long-term goal of this project is to understand how the brain controls sodium appetite. Our preliminary data has indicated that the pre-locus coeruleus (PreLC) is critical for sodium appetite and connects downstream to inhibitory neurons of the bed nucleus of stria terminalis (BNST) and central amygdala (CeA). To determine whether these inhibitory connections are involved in sodium appetite, mice were sodium deprived, given sodium, and then stained with cfos, an indicator of neural activity. These results were compared to that of two other control groups, in which mice were sodium deprived but not given sodium before perfusion and in which mice were sodium deprived and given water before perfusion, in order to screen for regions potentially involved in salt satiation. We found minimal overlap between cfos-expressing neurons and the inhibitory neurons in the BNST and CeA. These results can be further confirmed using different behavioral paradigms and imaging techniques.

Implementation of Multi-Agent Controlling Architecture for Micro-Quadrotors
Qifan Wang
Mentors: Soon-Jo Chung and Kyunam Kim

With the introduction of commercially available micro-quadrotors, efficient algorithm for controlling and guiding swarms of such quadrotors have become a major area of interest. An architecture of control system, with a powerful controlling algorithm, has been developed as a legacy of previous researchers, but its implementation lack robustness and versatility. A new way of implementing such architecture is proposed by using the Robotic Operating System (ROS), which allows easy development and experimentation of controlling algorism, while preserving the virtue of the existing architecture. It is hoped that such system will efficiently and accurately control a mass swarm of micro-quadrotors with complex trajectories.

Towards Adaptive Deep Brain Stimulation in Parkinson's Disease: LFP-Based Feature Analysis and Classification
Taige Wang
Mentor: Azita Emami

Deep Brain Stimulation (DBS) is a well-established therapy for advanced Parkinson's Disease (PD). To improve the battery life and minimize side-effects of DBS, recent studies have applied the closed-loop control (adaptive DBS) using feedback from biomarkers of local field potential (LFP) signals. However, current aDBS practices focus on simple feedback signals like beta band power of LFP, without optimized control algorithms like threshold trigger. In this work, we study the capacity of several classifiers including XGBoost, support vector machine (SVM) and Multi-Layer Perceptron (MLP) Neural Network with 66 features extracted from 4 channels of LFP to predict the binarized tremor frequency power in the accelerometer recording among 12 PD patients. With typical settings, MLP Neural Network achieves the best F1 score 83.5 %, SVM and XGBoost follow with 81.6% and 69.4%, respectively, for randomly selected data, all of which improve by 15% at a risk of overfitting. Besides, entropy and phase coherence across contacts outperform beta band power in both single feature correlation analysis and XGBoost feature importance analysis. These results suggest a great potential to improve current aDBS system by implementing a classifier with multiple features. More data is required to study optimal labeling techniques and tune the classifier parameters to improve the performance.

Searching for R Coronae Borealis Stars in the Andromeda Galaxy
Tianshu Wang
Mentor: Shrinivas Kulkarni

R Coronae Borealis (RCB) stars are carbon-rich, hydrogen-poor super-giants with irregular declines in their optical light curves which are attributed to dust formation episodes. They are possibly produced by mergers of two white dwarfs, and hence are likely to be the low-mass analogs of Type Ia supernovae. In this study, we use light curves from the Palomar Transient Factory (PTF) survey to search for RCB candidates in the Andromeda galaxy. With the spectra taken by the Hale/200-inch (P200) Telescope in Palomar Observatory and the Keck Telescope in Hawaii, we are able to confirm or reject these candidate RCBs.

Using Network Methods to Identify Sexually Dimorphic Regulatory Pathways in Non-Small Cell Lung Cancer
Tina Wang
Mentors: John Quackenbush and Matt Thomson

Non-small cell lung carcinoma (NSCLC), the most common subtype of lung cancer, has differing natural history, progression, and response to therapy in men and women. To explore whether this sexual dimorphism was due to complex gene regulatory interactions involving sex chromosomes and hormones reflected in the action of disease-associated transcription factors, we used two gene regulatory network inference algorithms, PANDA (Passing

Attributes between Networks for Data Assimilation) and LIONESS (Linear Interpolation to Obtain Network Estimates for Single Samples), developed at the Quackenbush Lab at Dana-Farber Cancer Institute and the Harvard T.H. Chan School of Public Health, to analyze squamous cell carcinoma and lung adenocarcinoma data from The Cancer Genome Atlas. We found substantial differences in the overall network topology implicating distinct roles for transcription factor regulatory processes in men and women from comparing gene regulatory networks. Among the most differentially targeting transcription factors between the sexes were ARID3a and FOXL1, which play critical roles in colorectal cancer and ovarian cancer, respectively. We also found many other transcription factors that have not been previously studied in NSCLC but are involved in processes relevant to the disease and its progression. Preliminary results provide potential avenues for further research and clinical drug development.

Frequency Dependence of Critical Spin Dressing and Its Effect on the Search for the Neutron Electric Dipole Moment
Ezra Webb
Mentors: Bradley Filippone and Christopher Swank

Investigation of the neutron electric dipole moment (nEDM) which will take place at the Spallation Neutron Source at Oak Ridge National Laboratory involves measurement of the precession of neutron spins in electric and magnetic fields. Spin precession measurement uses Ultracold neutrons (UCN) diluted in a Helium super fluid, where the ^{3}He acts as a detector to spin polarisation. Using a technique called critical spin dressing the effective gyromagnetic ratios of the UCN and ^{3}He can be matched in order to eliminate systematic effects associated with field fluctuations. Using Monte Carlo simulations of the experiment, the frequency dependence of this technique and its effect on measured value of the nEDM were investigated. Frequency modulation of the dressing field using Gaussian pulses was of particular interest and has been demonstrated to display high stability over time scales on the order of 10^3 seconds. Using this technique, a systematic correction to the measured value of the nEDM at low dressing frequencies was characterised. Additionally, π/2 pulses used to initialise the experiment were investigated, yielding positive results.

Towards Fast Encoding of Garcia-Stichtenoth Algebraic Geometry Codes
Matthew Weidner
Mentors: Chris Umans and Anand Narayanan

Error-correcting codes are ways to “encode” a block of bits as a longer, redundant series of bits, such one that can decode the original message even if the encoded message has suffered some errors. Garcia-Stichtenoth algebraic geometry codes encode messages by interpreting them as functions in Riemann-Roch spaces of curves in the Garcia-Stichtenoth tower, then evaluating those functions at many rational points on their curve. They improve upon Reed-Solomon codes, which are used frequently in everyday life, by having arbitrarily long blocks while still allowing one to correct a constant proportion of errors. However, the current best encoding algorithm is slow, outputting encoded messages of length *N* in time *O*((*N*log(*N*))^3). In this project, we make progress towards a faster algorithm, by attempting to construct “explicit” bases for Riemann-Roch spaces of curves in the Garcia-Stichtenoth tower. We succeed in extending existing explicit bases to the third level of the tower. We also construct explicit bases for related but weaker codes over the field with four elements. Additionally, we propose several pathways towards solving the general problem.

Cyclic Sections and Reciprocity
Felix Weilacher
Mentor: Zavosh Amir-Khosravi

An n-th power reciprocity law in a number ring O relates, for two primes p and q in O, the question of whether p is an n^th power modulo q to the question of whether q is an n^th power modulo p. Here, basic group theoretic techniques are used to reduce proofs of such reciprocity laws to questions about the existence of subsets of O/p, O/q, and O/pq satisfying certain properties. For the case O = Z, the integers, and n = 2, it is found that such subsets are easy to construct, and so a proof the classical law of quadratic reciprocity is obtained. It is shown that these techniques can also prove special cases of quadratic laws in rings larger than Z. The question of the existence of these subsets is investigated for n > 2. It is found that they can be constructed if the corresponding reciprocity law is assumed, and so their existence and the corresponding law are equivalent.

Optical Gyroscope on a Chip
Alexander White
Mentors: Ali Hajimiri and Parham Porsandeh Khial

Optical gyroscopes take advantage of the Sagnac effect to calculate their angular velocity. When two light beams traverse a rotating system in opposite directions, their inertial reference points change, due to the angular velocity of the system, and a phase shift between the waves can be measured with an interferometer. This phase shift is directly proportional to the angular velocity in the plane of the system, and thus velocity can be measured directly. However, because the effect is very small, the instrumentation that measures it must be extremely robust to noise. Using optical waveguides that guide two beams in a circle and interferometers to read the phase shifts, both of which can be fabricated on silicon, we can construct an optical gyroscope on a chip. Here we develop systems to test a prototype of an optical gyroscope chip, evaluate its performance, and use the knowledge generated by this study to contribute to the design of the next iteration of these chips.

Towards the Synthesis of Clusters Containing Redox-Inactive Metals to Reveal the Effect of Iron's High Redox Activity in Biological Clusters and the Synthesis of GaN Nanomaterials From a Well-Defined Molecular Precursor
Sophie Rebecca Whitmeyer
Mentors: Theodor Agapie and Christopher Reed

Complexes containing iron and nitrogen can be used to study the interactions that take place at the organometallic active site of the Nitrogenase enzyme, which biological systems use to produce ammonia from dinitrogen. Studying these interactions is part of a series of studies being conducted by the Agapie lab on iron cluster chemistry featuring varied metals in order to understand the role played by the iron, especially the role of its high redox activity, in small molecule interactions with these clusters. This research presents the synthesis and characterizations of analogous gallium, a redox inactive metal with a similar ionic radius to Fe(III), clusters, which have been studied via X-ray crystallography, mass spectrometry, gallium NMR and proton NMR. Additionally, via previously synthesized gallium complexes with 2, 3:5,6-Dibenzo-7-aza bicyclo[2.2.1]hepta-2,5-diene, this research also presents the synthesis of GaN nanomaterials, which shows potential for use in efficient high-speed, high-power devices that are both radiation resistant and capable of operation at elevated temperatures.

Improving the Efficiency of Machine Learning Algorithms With Error-Correcting Codes
Anna Winnicki
Mentors: Babak Hassibi and Navid Azizan Ruhi

Efforts to develop distributed algorithms, or algorithms designed to run on computer hardware constructed from interconnected processors, have enabled analysis of very large data sets in a timely manner. Lack of perfect synchronization of computing clusters can potentially diminish the benefits of parallel algorithms, calling for schemes that mitigate the effect of slow machines. One potential scheme involves the use of error-correcting codes, in particular, Reed-Solomon codes, where replication in the computation is introduced in order to recover all the computation from only some machines that return data in a timely fashion. The technique is used to speed up distributed reinforcement machine learning algorithms.

Microfabricated Thermionic Energy Converter Utilizing Atomically-Modified Alkali-Earth Metal Oxide Films
Kelly Woo
Mentors: Roger Howe, Heather Chiamori, Eric Wu, and Hyuck Choo

Thermionic energy converters (TECs) serve as a means to increase efficiency in energy harvesting by utilizing readily available heat as its source. A TEC typically consists of an emitter electrode and a collector electrode. The emitter is heated to high temperatures to emit high-energy electrons, which are then received by a much cooler collector. The objective is to create a commercialized wafer scale TEC device. With the technology relying on maintaining large temperature differences, maintaining vacuum, and exposing to extreme heat, the fabrication process requires careful consideration of thermal properties, structural integrity, and experimentation with current microfabrication techniques to produce the designed structures. We are currently designing processes and characterizing the fabrication of the structures needed for the device. Additionally, we are producing a testing chamber with automated data acquisition for electrical characterization of the device. This will provide a more accessible method to test the device and will aid in developing a more efficient TEC.

Fabrication and Qualification of High Inductance Nano Coils
Steven Wood
Mentors: Oskar Painter and Matthew Hunt

In the field of quantum information processing, interconversion between disparate photon wavelengths is an important part of connecting distant systems operating at different frequencies. Electro-opto-mechanical quantum superconducting LC (inductor-capacitor) circuits provide one such means of conversion, from microwave to optical frequencies. The aim of this project is to improve upon the inductor component of the circuit by creating a more tightly wound aluminum wire with smaller pitches than those achievable by traditional electron beam lithography and reactive ion etch techniques. The state of the art inductor, previously achieved by the Painter group at Caltech, is a three millimeter long coil with a pitch of 500 nanometers. An improvement in the pitch was sought by utilizing a He/Ne/Ga focused ion beam (FIB) instrument in the Kavli Nanoscience Institute (KNI). By operating the neon ion beam at an energy of 10 keV and optimizing the beam current, beam dose, and beam step parameters, a spiral pattern was directly etched into a 60 nanometer pad of aluminum on a silicon substrate. This allowed for the fabrication of a three millimeter long coil with a pitch of 150 nanometers, an improvement of more than three times the previous benchmark. This inductor will be incorporated into an LC circuit and tested at milliKelvin temperatures to determine the quality factor of the device. A high impedance device is an important test case for quantum electronics and will provide useful insight for future opto-mechanical experiments.

Inducing Ferromagnetism on Transition Metal Dichalcogenide Thin Films
Mackenzie Wooten
Mentors: Nai-Chang Yeh, Wei-Hsiang Lin, and Robert Polski

We attempt to induce ferromagnetism in Transition Metal Dichalcogenide (TMDC) thin films by stacking a monolayer of aligned magnetic nanoparticles onto the surface of the two dimensional TMDCs. The TMDC thin films of thicknesses varying from monolayer to multilayers were synthesized by chemical vapor deposition (CVD). We created solutions of magnetic nanoparticles using a mixture toluene, alpha-terpineol, and oleic acid as solvents. These solutions were spin coated onto as-doped Si (100) silicon wafers and were heat treated and placed under a magnetic field to observe possible self-assembly of the nanoparticles. The TMDCs have been characterized using Raman Spectroscopy, and the nanoparticles have been imaged using Scanning Electron Microscopy (SEM). The magnetization of the TMDC-nanoparticle stacks will be measured using a Superconducting Quantum Interference Device (SQUID) magnetometer. These stacks will be further patterned into a Hall Bar geometry for magneto-electrical transport-based measurements with a Physical Property Measurement System (PPMS).

Intraocular Pressure (IOP) Sensor Testing Chamber Design
Asta Wu
Mentors: Hyuck Choo and Haeri Park

Elevated intraocular pressure (IOP) has been linked to the development of glaucoma. A method of measuring IOP utilizes the IOP sensor, and part of the testing process of the IOP sensor involves placing the sensor into a testing chamber. Light is shown into the chamber and the reflected beam is analyzed with a spectrometer. The current testing chamber restricts freedoms in measurements performed on the IOP sensor. The setup only allows for measurements to be performed directly above the chamber, and the chamber lid is too thick, limiting the angles of light projection into the chamber. Our goal is to redesign the testing chamber and testing setup. The resulting chamber will be able to stand upright such that light can be shone horizontally into the chamber, and the lid thickness will allow for greater degrees of freedom in light projection. Furthermore, the testing system – a pressure gauge and pressure regulator – attached to the chamber will be compatible with the new chamber. The testing system will function under hydraulic conditions and allow for precise measurements between 0 and 350 mmHg. This device will be put into practical testing in the future.

Understanding DNA CT-Mediated Damage Detection in Bacterial DNA Repair Through Iron-Sulfur DNA Repair Proteins
Brenda Wu
Mentors: Jacqueline K. Barton and Andy Zhou

The exact mechanism by which DNA repair proteins are able to locate lesions in the genome is unknown. Many of these DNA processing enzymes contain redox-active [4Fe4S] clusters, which can participate in DNA-mediated charge transfer (CT) when bound to DNA. One of these proteins is E. coli EndoIII (nth), a base excision repair (BER) glycosylase. Here, we use UV irradiation to investigate EndoIII mutants and their ability to signal via DNA CT to UvrC, the [4Fe-4S] containing endonuclease in nucleotide excision repair (NER). However, we find the UV irradiation assay to be inconclusive, as it cannot distinguish repair between the BER and NER pathways. To continue probing DNA-mediated CT within the cell, we are taking advantage of the E. coli InvA strain where the repair of R-loops by DinG, another [4Fe4S]-containing DNA repair protein, is essential for survival. We are integrating mutant EndoIII sequences into InvA Δnth E. coli strains, to study the ability of the EndoIII mutants to signal via DNA CT to DinG, and rescue the InvA growth defect.

Precision Placement of Quantum Dots on SiO_2 With DNA Origami
Emily Wu
Mentors: Paul Rothemund and Ashwin Gopinath

Precise placement of nanostructures is a powerful tool in nanofabrication. Precision placement of quantum dots on silicon-based wafers is of particular interest in quantum computing and quantum cryptography. Our approach to achieve this is to first precisely place DNA origami with biotin linkers at lithographically-patterned binding sites on silicon dioxide. Streptavidin-conjugated quantum dots are then bound to the origami by taking advantage of the streptavidin-biotin link, thus precisely placing the quantum dots. One major challenge is that this process suffers from background binding of quantum dots. However, the formation of a polyethylene glycol passivation layer outside of the binding sites is a promising solution to this problem. Since the streptavidin-biotin interaction need not be used to precisely place quantum dots, the process we are developing may generalize to other linker chemistries. A second problem is that lithographic patterning of binding sites is extremely expensive. Inexpensive benchtop methods for patterning create binding sites which are too large (200 nanometers in diameter) for standard origami (just 100 nanometers). Thus to make our method accessible to other fields and applications, we have designed a large 200 nm diameter circular DNA origami composed of four quarter-circle DNA origami.

Constraining Vp/Vs of Subducted Slabs With Earthquake Clusters
Fan Wu
Mentor: Zhongwen Zhan

Vp/Vs provides a valuable way to probe the composition and proprieties of subducted slabs. Spatial variations of Vp/Vs may indicate thermal or chemical heterogeneities in those regions. We apply a method using differential travel times for P and S wave to estimate Vp/Vs in source region. The differential travel times are obtained from arrival times that are aligned from seismic records. We then conduct a robust fitting procedure to measure Vp/Vs using demeaned differential travel times. Since deep earthquakes are rare, the fitting is likely to have large uncertainties. We use several approaches to control the quality of the data. To reduce bias caused by differences in P and S takeoff angles, we make corrections based on 1-D reference model. To test the applicability of the corrections, we use different models and measure their Vp/Vs using theoretical arrival times. We further apply the method in several subduction zones, compare the Vp/Vs with 1-D model and find the spatial variations of Vp/Vs.

Characterizing a Soft X-Ray Charger
Jennifer Wu
Mentors: Richard Flagan and Changhyuk Kim

The atmospheric aerosol is a suspension of small particles distributed over a wide range of sizes. The impact of those particles on the environment and human health is a strong function of the particle size distribution, which is measured by differential mobility analysis. The inference of particle size distributions from differential mobility analyzer (DMA) data requires knowledge of the charge distribution on the particles being measured. To obtain a known charge distribution, the particles pass through a bipolar diffusion charger in which they are exposed to an electrically neutral cloud of positive and negative ions produced by radioactive decay, soft X-rays, or other sources, and ultimately attain a steady-state charge distribution. We aim to characterize a soft X-ray charger, previously built by the Flagan group, by finding the fraction of positively charged particles over a range of particle sizes with diameters smaller than about 10 nm. To find these charge fractions, particles were generated by a hot wire source, charged by the soft X-ray charger, then passed through a nano-radial differential mobility analyzer (nRDMA) to separate the positively charged particles from the uncharged ones. Particle counts were measured upstream and downstream of the nRDMA to determine the charge fraction.

Influence of Activity on the Dynamics and Phase Behavior of Colloidal Gels
Yanze Wu
Mentors: John F. Brady and Ahmad Omar

Colloidal gels are a class of gels consisting of attractive particles that form an interconnected percolating network. They are ubiquitous in nature, such as cytoskeleton in living cells and biofilms. In biological systems, some colloidal particles can be active (such as bacteria with flagella) in the sense that they can convert chemical energy into mechanical motion. Previous studies have shown that these active particles (swimmers) exhibit their own unique 'swim' pressure on their surroundings, which makes it harder to confine them than their passive counterparts. However, the impacts of this pressure when active particles are embedded in other materials remain to be explored. Here we report computer simulations of colloidal gels in the presence of a small amount of active particles. We find that activity can have a significant influence on the structure and dynamics of colloidal gels, reflected in the time-evolution of the structure factor. Our findings indicate that activity helps gel demix in the early stage of formation but can also break up large clusters, the overall effect depending on both the level of activity of the swimmers and the attraction magnitude. Ultimately, our results can help understand how active materials such as motile cells influence their environment.

Development and Implementation of Captive Trajectories in the NOAH Laboratory
Alex Wuschner
Mentors: Beverley McKeon and Maysam Shamai

The NOAH Laboratory water tunnel is currently used to statically test airfoils. This project aims to enhance its capabilities by allowing for the implementation of dynamic models using the recently installed Captive Trajectory System (CTS). Capable of actuating translational and rotational motion about three axes, the CTS provides a means by which dynamic behavior can be simulated in an accurate and precise manner. Accounting for both applied forces and simulated "virtual" forces (based on an appropriate model), the CTS is able to effectively replicate the motion of various captive trajectories, such as a mass-spring-damper system as well as a gravitational orbit model. In the latter case, the CTS can implement circular, elliptical, and hyperbolic orbits based on appropriate initial conditions, and successfully integrate the magnitude and direction of applied forces into the trajectory. The ability of the CTS to accurately replicate free response behavior will be evaluated by comparing a captive trajectory to an experiment studying an airfoil in the wake of a cylinder with vortex shedding. The comparison with the free-response experimental observations will indicate the accuracy with which the CTS predicts free response motion and will be used to guide future improvements.

Degradation of Common Pharmaceuticals Using Carbon Monolith 3D Electrode With 3D Printed Electrochemical Reactor
Siyuan Xiao
Mentors: Michael R. Hoffmann and Kai Liu

Pharmaceuticals are considered as emerging pollutants that are prevalent even at low concentration. Due to their continuous introduction into the aqueous environment, they significantly affect ecosystem and human health. Electrochemical oxidation is one of the most promising methods for degrading aqueous pharmaceuticals. Direct heterogeneous and indirect homogeneous oxidations are two of the most common mechanisms in electrochemical oxidation. The former involves the direct adsorption of contaminants onto the electrode surface and the latter involves the generation of reactive oxidizing species (ROS) at electrode. Rare metal doped electrode arrays are typically employed and both strategies are limited by the mass transfer on the electrode. Therefore, it is necessary to develop inexpensive 3D porous electrode with large surface area, large voidage, low tortuosity, and interconnected macropores for electrochemical wastewater treatment.In this study, we have constructed an electro-peroxone system for the continuous degradation of aqueous pharmaceuticals. Within this system, H_2O_2 are generated in situ by the carbon monolith cathode via oxygen reduction reaction. Subsequently H_2O_2 reacts with ozone to produce hydroxyl radicals.

Demonstration of a Fiber Injection Unit With Polychromatic Light for Observing Exoplanets With High-Dispersion Coronagraphy
Yeyuan Xin
Mentors: Dimitri Mawet, Jacques-Robert Delorme, Nikita Klimovich, and Reed Riddle

High-dispersion coronagraphy (HDC) combines high contrast imaging techniques with high spectral resolution spectroscopy to observe exoplanets and determine characteristics such as chemical composition, temperature, and rotational velocities. It has been demonstrated in lab that with monochromatic light, a fiber injection unit (FIU), in which an optical fiber is used to couple to light from the exoplanet, could be used to direct exoplanet light to a high-resolution spectrograph, with robust performance and speckle suppression that exceeds conventional image-based speckle nulling by at least two orders of magnitude. We now demonstrate this technique in lab with polychromatic light, which is necessary for spectroscopy, and have obtained a similar suppression as in the monochromatic case, along with more robust and efficient speckle nulling algorithms. We conclude that we have successfully tested and improved upon the performance of the fiber injection unit design using polychromatic light.

Optimization of a Low-Band Gap Perovskite Material for Higher Efficiency Perovskite-Perovskite Tandem Cells
Grace Xiong
Mentors: Michael D. McGehee, Rohit Prasanna, Tomas Leijtens, and John Seinfeld

Perovskite solar cells have become a promising alternative to silicon solar cells, having While single junction solar cells are limited by a maximum theoretical efficiency of 33.16%, tandem or stacked solar cells have a much greater efficiency near 86.8%. In perovskite-perovskite tandem cells, which was the focus of this research, a low band gap cell and a high band gap cell are used. Traditionally, the limiting factor for efficiency has been the low band gap cell due to a historic difficulty in fabricatince g perovskite films thick enough to absorb the necessary wavelengths from light. A new fabrication technique using NMP instead of the traditional solvent of DMSO in $MAFAPbSnI_3$ solutions has shown to have efficiencies that exceed 14%. Unlike previous $MAFAPbSnI_3$ solutions, the new NMP based solution have resulted in films of 750 nm and are more compatible in perovskite-perovskite tandem cells.

Automatic Image Processing Pipelines for the Keck-NIRC2 Vortex Coronagraph
Wenhao Xuan
Mentors: Dimitri Mawet and Garreth Ruane

The Keck-NIRC2 camera, equipped with the vortex coronagraph, is an instrument targeted at the high contrast imaging of extrasolar planets. To uncover a faint planet signal from the overwhelming starlight, we utilize the Vortex Image Processing (VIP) library, which carries out principal component analysis (PCA) in two flavors: angular differential imaging (ADI) that takes advantage of the rotation of the field of view, and referential differential imaging (RDI) that uses closely correlated point spread functions from other stars to model light from a target star. To bridge the gap between data acquisition and data reduction, we implement a workflow that downloads, sorts, and processes NIRC2 vortex data with VIP in real-time, displaying the reduced images, contrast curves, and auxiliary information on a website just as new images are being taken. This system allows observers to make educated decisions about distributing observation time on different targets, optimizing the science yield. After the observation, a more thorough reduction is performed, injecting products into a database that is linked to the website. We also aim to systematically re-reduce three years of data, and organize the intermediate and final products in the database where they could be downloaded from the website or through python functions. This infrastructure would serve as the foundation for doing RDI on the hundreds of M stars taken with the vortex, promising new discoveries along the way.

Graphene Membrane Intraocular Pressure Sensor
Kathleen Yang
Mentors: Hyuck Choo and Jeong Lee

A graphene based intraocular pressure sensor was developed to help facilitate and speed up the process of taking pressure measurements. Monolayer graphene has two well defined Raman peaks, the G and the 2D peak. Applying stress or strain causes these two peaks to shift. This pressure sensor will relate the shifting of the Raman peaks to the pressure being measured. To fabricate this device, monolayer graphene was transferred onto a silicon nitride membrane suspended between silicon. Pressure measurements using the device were made in two ways:
(1) Placing a water droplet in the cavity of the device and sealing the cavity to form a capillary bridge, (2) Sealing the cavity of the device and placing it within a pressure chamber. It was found that the Raman peaks of the graphene shifted due to the pressure differential, indicating that the device may be viable as a pressure sensor. The angle dependency of the sensor was also investigated, and preliminary data suggests that the Raman peaks stay constant within a 30° degree angle of rotation. Further data needs to be gathered to relate Raman peak shift with pressure and to investigate the angle independency of the Raman spectra of graphene.

Investigating the Gating Mechanism in Inner Nuclear Membrane Protein Import
Theo Yang
Mentors: Andre Hoelz and Stefan Petrovic

A main challenge in the study of Nuclear Pore Complex function is determining how integral membrane proteins (IMPs) are transported from the outer nuclear membrane to their destination in the inner nuclear membrane. We investigate the structure and interactions of the large adaptor nucleoporin 192 (Nup192) and the linker nucleoporin 53 (Nup53) which are hypothesized to constitute a gate which controls passage of large proteins with hydrophobic and cytosolic domains. To test this theory, we are attempting to crystallize the Nup192• $Nup53^{31-67}$ using techniques such as antibody complexing, seeding, and crystal soaking. Secondly, we are also using a series of *in vivo* yeast assays to examine the effect of structural perturbations to the gating mechanism. Specifically, we will covalently crosslink Nup192 and Nup53 using the Spy and Spycatcher proteins, and observe the effect of gate closure on the import of a florescent transmembrane tag, mCherry-h2NLS-TM. Current crystallization attempts suggest that co-crystallization of Nup53 and Nup192 is inhibited by the size of Nup192 solvent channels. Further characterization of the Nup192• $Nup53^{31-67}$ dimer likely necessitates the use of novel $Nup192^{NTD}$ constructs.

Modeling Ising Spin Chains With a Lindblad Master Equation
Alejandro Yankelevich
Mentors: John Preskill and Evgeny Mozgunov

Master equations in Lindblad form are often used to approximate the thermalization of open quantum systems. However, error becomes considerable as the thermal link between the system and environment increases. To determine the Lindblad equation’s range of validity, we apply this equation to spin-1/2 chains in the presence of an external magnetic field as described by the Ising model, which can be simulated with exact diagonalization. Comparing the exact and approximate time evolutions shows that increased coupling between subsystems of the spin chain results in faster decay for the Lindblad simulation. This relation implies that the Lindblad equation is only applicable to systems that have minimal interactions with the bath. Other forms of master equations with different error bounds may be more suitable for highly coupled systems.

Tsix and Kcnq1ot1 Exploit Local Chromatin Structure to Regulate Mono-Allelic Expression in Development
Julian A. Yano
Mentors: Mitch Guttman and Tony Szempruch

Mammalian genomes encode tens of thousands of long non-coding RNAs (lncRNAs), which play critical roles in diverse biological processes and numerous human diseases. Given they are often located antisense to monoallelically expressed genes, it has been proposed that lncRNAs silence genes by polymerase clashing, and that the transcript itself is a non-functional byproduct of cis-regulation. Monoallelic expression of select genes can be regulated randomly, in the case of X-chromosome inactivation (XCI), and in parent-of-origin specific fashion, as with imprinted genes. Improper maintenance of these expression patterns is associated with birth abnormalities and various cancers. This study aims to characterize the lncRNAs Tsix, the transcript antisense to Xist that prevents XCI, and Kcnq1ot1, a paternally expressed transcript responsible for monoallelic expression of the KCNQ1 locus. Preliminary and published data suggest both lncRNAs are functional: they are shown to localize to genomic sites proximal to their transcription termination sites and destabilizing mutations to Tsix are shown to result in ablated silencing capacity. This study uses gapmer-mediated degradation of Tsix to observe the effect on genetic expression of genes ordinarily repressed by Tsix. Additionally, we optimize existing RNA Antisense Purification (RAP) methods to enable greater reduction of nonspecific interactions and thereby identify essential regulatory factors. Subsequent cell biology studies disrupting these proteins can functionally verify the necessity of specific lncRNA-protein interactions in genetic regulation.

Searching for Quasars Behind the Andromeda Galaxy
Yuhan Yao
Mentors: Shri Kulkarni and Thomas Kupfer

Quasars behind the Andromeda Galaxy (M31) are difficult to be identified due to the high stellar surface density, yet they are great beacons to probe the interstellar medium (ISM) via metal absorption line systems in their spectra. Our goal is to find quasars within and in the close outskirts of M31 with optical variability data from the Palomar Transient Factory (PTF) survey. Based on Machine Learning (ML) algorithms, we used 60 known quasars and 500 known stars as a training set to build our “star-quasar” separation filter, which selected 112 quasar candidates. We obtained spectra for 51 candidates using the Palomar 5-m telescope, and 47 of them were confirmed to be bona fide quasars, including 20 in the most challenging central 3 square degree region around M31. This is an improvement compared with previous results (true positive rate≈8%), and suggests that about 90% of the remaining 61 candidates are likely real quasars.

Neural Connectivity Within Individual During Flow Experience
Shota Yasunaga
Mentors: Shinsuke Shimojo and Mohammad Shehata

Flow is the mental state of operation in which a person performing an activity is fully immersed in a feeling of energized focus, automation, full involvement and enjoyment. Previous studies have shown that appropriate task difficulty is crucial to flow. However, few researches have applied brain imaging techniques. This project investigates the neural connectivity of flow experience with electroencephalography (EEG) within individual. We used music rhythm game as the task. For the flow condition, we used normal game and for a negative control, we used reverse and shuffled music. We used the Adaptive Mixture of Independent Component Analyzers (AMICA) to get independent component of EEG data acquired with 128 channels. We calculated partial directed coherence to those components for the measurement of the neural connectivity with a software called group-SIFT. We observed increase in connectivity around basal area and wide occipital area. Statistical tests are going to be done to obtain the difference in connectivity between conditions.

A New Giant Planet in the HAT-P-11 System
Samuel Yee
Mentors: Heather Knutson and Erik Petigura

HAT-P-11 is an active mid-K dwarf in the constellation Cygnus, and hosts a super-Neptune extrasolar planet, HAT-P-11b, on a 4.9 day orbit. Transit and radial velocity (RV) observations have revealed that HAT-P-11b is on an eccentric and highly inclined orbit relative to the star’s rotation axis, in contrast with the close spin-orbit alignment of other planetary systems like our own. We have analysed a decade of RV data and discovered a second planet in the system, HAT-P-11c. We performed a joint RV-activity analysis to correct for variability from the star’s activity, to pin down the parameters of both planets. We also investigated the dynamical connection between the two planets, finding that the presence of the outer planet can help to explain the high inclination of HAT-P-11b. Finally, we present the prospects for follow-up observations by future high-contrast imaging studies.

At the Molecular Interface: Elucidating Chaperone-Client Interactions With Photo-Inducible Probes
Mansen Yu
Mentors: Shu-ou Shan and Alex Siegel

Membrane proteins are a molecular biologist’s least favourite molecule to work with. They are extremely promiscuous, difficult to extract, and often flexible and unstable outside of their native environment. This makes it all the more frustrating that membrane proteins are essential to understanding physiological and pathological cell behavior. Previous work in the lab of Dr. Shan has created a novel in-vitro translation system in which to synthesize and study membrane proteins. This project took advantage of the system and its ability to incorporate molecular probes into membrane proteins. Specifically, we inserted the synthetic amino acid p-benzoyl-L phenylalanine, a photo-inducible crosslinker, into the membrane protein LHCP to probe its interactions with its chaperone: cpSRP43. By crosslinking LHCP to cpSRP43, we aim to identify the interfaces of this chaperone-client interaction. Ultimately, we will sequence this crosslinked complex via mass spectrometry to determine the individual amino acids in this interaction. Better characterization of protein chaperones like cpSRP43 and more efficient methodologies to study membrane proteins have much greater implications for understanding the fundamental regulation of protein dynamics, as well as the potential for biotechnology and bionanomachines.

Miniature Endoscope for Investigating Effects of Optogenetic Stimulation of Adult-Born Granule Cells on CA1 Place Cells in Transgenic Mice
Hanwen Zhang
Mentors: Carlos Lois and Walter Gonzalez

The hippocampus is known for being responsible for learning, memory and spatial navigation. In addition, the dentate gyrus, the input region of the hippocampus, is one of the two main sites of neurogenesis in adult mice. Recently, the hippocampal circuits and specifically the contribution of neurogenesis, were studied with either ablation or optogenetic stimulation of the dentate gyrus neurons. These studies found that ablation impairs hippocampal memory retrieval and spatial pattern separation, while stimulation triggers fear memory recall. However, these studies focused on the effects at the behavioral level but lacked direct analysis of the downstream neuronal dynamics, a result of the lack of instruments to simultaneously perturb and image large populations of cells in freely moving animals. In this project, we developed a low-cost miniature endoscope to record neuronal dynamics from transgenic mice expressing GCaMP6s. In addition, we generated viral vectors to induce expression of red-activatable channelrhodopsin (ReaChR) in adult-born granule cells in the dentate gyrus. With this setup, we seek to optogenetically activate a subgroup of adult-born granule cells in the dentate gyrus and directly investigate its effects on the activity of hippocampal place cells both during and after optogenetic perturbation.

Gaussian Process Regression on Surrogate Models: Application on Numerical Relativistic Binary Black Hole Merger Waveforms
Hao Zhang
Mentor: Yanbei Chen

Surrogate waveform models are necessary in performing LIGO real-time detection and parameter estimation, since a simulation that involves full numerical relativity (NR) takes incredibly long time and would thus be impractical for fast evaluations. Previous surrogate model uses polynomial regression in the interpolation step, which is potentially limited by its power of representing general functions. Here we propose an alternative regression method called Gaussian Process Regression (GPR), a robust Bayesian method that is powerful in high dimensional fitting. We test our method in the parameter space of 7 dimensions (one mass ratio and three spin components for each black hole), both on individual time nodes and on the full waveforms. We plan to add an option on the original regression code to use GPR regression method. Our final goal is to build an optimized 7d NR Surrogate model, which we evaluate by comparing with the polynomial fitting results - figure 2 in Blackman et al. 2017b.

Characterization of Chrome-on-Glass Apodizer Test Sample
Manxuan (Rebecca) Zhang
Mentors: Dimitri Mawet and 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 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.

Laser Induced Fluorescence and LED Strobe Light for High-Speed Photography on the Caltech Water-Ice Dusty Plasma
Xiaotian (Jim) Zhang
Mentors: Paul Bellan and Ryan Marshall

Strobe light photography has enabled ordinary DSLR cameras to become pseudo high-speed cameras and laser induced fluorescence (LIF) has facilitated improving neutral Argon temperature measurements in the Caltech water-ice dusty plasma. We sought to implement these two techniques in our cold Argon dusty plasma to image the trajectory of water-ice dust grains and to determine the neutral Argon atom temperature. The strobe light solution to trajectory imaging is an inexpensive replacement for costly high-speed cameras and was tested on computer fans as well as soldering fans to confirm the effect. The strobe was measured to have a minimum pulse frequency of 2.07 kHz and a maximum of 6.25 kHz with minimum pulse length at 60 microseconds and maximum at 159 microseconds. The LED beam was focused onto a plane that would encompass the plasma's vertical dimension and has higher power output than the previously used halogen lamp by 14%. We successfully observe LIF photons from Argon neutrals, and have dramatically improved the signal from initial measurements. Going forward, we hope to combat broadening to increase the accuracy of temperature measurements.

Extending Self-Imitation Learning for Solving Mixed Integer Linear Programming Problems
Albert Zhao
Mentors: Yisong Yue, Jialin Song, and Ravi Kiran

Many optimization problems ranging from routing deliveries to task scheduling can be formulated as mixed integer linear programming problems (MILPs). Currently, the standard technique for solving MILPs is branch and bound, where the solver searches a tree-structured space of possible solutions and prunes branches that are unpromising. However, current solvers are inefficient, taking hours to solve large-scale problems with tens of thousands of variables and constraints.

To increase solver efficiency, machine learning approaches, using solutions from training problems of the same scale as target problems, have been used to learn branch and bound heuristics. However, since it is expensive to obtain solutions to large-scale problems, the scalability of these approaches is limited. A novel algorithm, self-imitation learning, surmounts this obstacle as it requires only solutions to smaller-scale problems to train a solver for large problems. In this project, we improve the performance of self-imitation learning to efficiently solve MILPs. We have incorporated using multiple “good” solutions and exploration during training to improve self-imitation learning. We aim to use self-imitation learning to train efficient state of the art solvers on various datasets.

A New Knowledge Base for G-Protein Coupled Receptors
Benjamin F. Zhao
Mentor: Ravinder Abrol

G-protein-coupled receptors (GPCRs) are a large family of transmembrane protein that play important roles in a number of biological systems. GPCR’s profound significance is highlighted by the fact that at least half of the 800 human GPCRs have been identified as potential therapeutic targets. Because of the importance of GPCRs, there is a growing demand to provide scientists and educators with an easy to use and organized knowledge-base on GPCRs. There currently exist some GPCR databases like IUPHAR and GPCRDB. However, these database lacks many qualities that certain biologists and biochemists seek. Finding relevant data on certain GPCRs often requires going through multiple search bars and pages, which can be rather cumbersome. We have begun development on a new integrative knowledge-base on GPCRs that will bring together their sequence, structure, signaling, mutation, and disease-link knowledge in an easy to navigate as well searchable user friendly interface which will facilitate both teaching and research on GPCRs. Our knowledge base will concentrate information from many different databases on a specific GPCR onto a single page for ease of use and analysis. By pulling information from databases like the RCSB Protein Data Bank, IUPHAR Guide to Pharmacology, PubChem, UniProt Knowledge Base, dbSNP, and the Kyoto Encyclopedia of Genes and Genomes, the knowledge base will contain a wide array of relevant data on GPCRs. On each GPCR’s dedicated page, there will be sections for relevant data including the protein’s sequence, structure, various mutations and their frequencies, signaling pathways, as well as other information relevant to GPCR researchers. This single page format will allow users to more quickly and efficiently access the information. Furthermore, we are developing a number of toolboxes to facilitate acquisition of important data and to facilitate structural bioinformatics as well as other analyses. Among these toolboxes is an advanced query tool allowing users to search for proteins based on a Boolean combination of sequence motifs, structural signatures, ligand binding sites, mutations/SNPs, signaling partners, signaling pathways, function, and disease. Additional tools will be available for customized sequence alignment. There will also be structural views showing critical residues based on user defined criteria, such as structural signatures, ligand binding sites, GPCR “hot-spots”, and mutations/SNPs. The GPCR knowledgebase is expected to be useful for accessing all available information on GPCRs as well as to generate specific hypotheses for probing their functional biology.

GPS-Denied Navigation
Michelle D. Zhao
Mentor: Soon-Jo Chung

Computer vision techniques, including feature matching, can be used to match aerial images taken from the UAV with satellite maps of the region. One technique that can be used for image matching is Scale Invariant Feature Transform (SIFT), a method for detecting local features. SIFT is fundamental to many core vision problems and can be applied towards motion-tracking, multi-view geometry, and recognition. We can take SIFT to track the movement of the UAV by repeatedly matching the small images taken from the UAV onto a larger map. SIFT requires some type of key-point detection for the later analyses. I investigated different image processing techniques, including edge detection, corner detection, and road extraction. After processing the images to filter for significant features, we will also use normalized cross-correlation as an effective similarity measure for matching the UAV images to pre-existing maps of the area (from Google Earth for our case).

Electrostatic Fluctuations in Inhomogeneous Macromolecular Systems
Qiyuan Zhao
Mentors: Zhen-Gang Wang and Kevin Shen

Charged polymers and colloids are ubiquitous in biology and industrial problems such as protein solubility, drug delivery, adhesives, and surfactants. Further, many natural processes and applications involve the behavior of such charged objects at interfaces. Despite the prevalence of such large charged objects, theory has either approximated their electrostatic fluctuations as that of simple electrolytes, or treated their macromolecular nature only in the bulk. In this work, we implement the recently developed Renormalized Gaussian Fluctuation theory to study the nature of macromolecular electrostatic fluctuations near interfaces. We present interfacial adsorption and surface tension results and discuss how a macromolecule's spatially extended structure modifies the electrostatic fluctuations.

Deducing Point Spread Functions of Pupil by Multiplexing Method
Ling Zhong
Mentor: Changhuei Yang

Fourier ptychography (FP) is a new computational imaging scheme that requires simple hardware. To acquire the image of retina and eliminate the aberration of pupil which will reduce image quality, an aperture-scanning Fourier ptychographic optical system was built with incoherent light as light source to solve the problem. However, the dim light and environment noisy were still preventing us to acquire satisfactory image. Thus, multiplexing lighting method was employed to eliminate the noise. After some pretreatment to captured image, we can deblur the point spread functions (PSF) form blurry and noisy pairs. Finally, by synthesizing the point spread functions in Fourier domain, we can deduce the PSF of full pupil with high signal-to-noise (SNR). Compared to normal FP method, our strategy can deduce the PSF of unknown object with high SNR and have high application value in biomedical field.

Analysis of KBO Colors to Determine the Velocity Distribution of Haumea Family Objects
Angelica Zhou
Mentor: Mike Brown

The Haumea family is the only known collisional family in the Kuiper Belt. A glancing collision in the early solar system between the progenitor and another object elongated the dwarf planet Haumea and caused it to rotate rapidly. Objects associated with the collision have been observed to orbit only within the 150 m/s velocity dispersion range from Haumea and can be identified through their high albedos and water-ice spectra. A few paradoxes arise from this distribution. To account for the scattering of Haumea's orbital elements, a dispersion rate of 400m/s is required. Furthermore, we expect to find objects at the 900 m/s range, which is the proposed escape velocity of the progenitor based on estimates of its mass. It was originally proposed that Haumea's orbital elements previously resembled those of its family, but evolved to their current values. In this project we explore Kuiper Belt Objects at up to the 1 km/s dispersion velocity and examine their colors through B and I filters to determine if they are associated with Haumea. A refined velocity distribution gives insight to the composition of the progenitor.

Investigation of Antiferromagnetic $YMnO_3$ Using RA-SHG at 2.45eV
Preston Zhou
Mentors: David Hsieh and Alberto de la Torre

$YMnO_3$ has a highly frustrated spin configurarion above TN = 70K. Below the neel temperature $YMnO_3$ freezes into an antiferromagnetic order not yet fully understood. Here, we utilize RA-SHG (Rotation anisotropy second harmonic generation), which is a form of measurement that is extremely sensitive to inversion breaking phases of matter, including antiferromagnetism, to fully resolve the spin configuration in $YMnO_3$. Previous SHG measurements show a maximal sensitivity to the antiferromagnetic order with 2.45 eV light. However, prior to this work, the Hsieh lab lack the capability to perform RA-SHG measurements at this photon energy. Thus, we developed an extension of the previous RA-SHG setup to 2.45 investigate the properties of $YMnO_3$ with the best experimental conditions.

Interaction Between Cardiolipin and Two Mitochondrial Proteins, Drp1 and OPA1
Zikun Zhu
Mentor: David C. Chan

OPA1 and Drp1 are proteins central for mitochondrial fusion and fission, respectively. Cardiolipin, a kind of mitochondrion-specific lipid, plays a key role in mitochondrial fisson and fusion. To figure out the binding of these two proteins and cardiolipin, a protein-lipid overlay assay was performed. I have been optimizing the assay by changing different conditions and got positive results using purified full length Drp1 and shortened versions of OPA1. After that, I tested the Q785R mutant of OPA1, which has been shown to be defective for lipid binding. The results showed that its cardiolipin binding ability was not influenced negatively. As a consequence, I have predicted other mutants that may lead to deficiency and purified them. Liposome floatation assay should be done in the future to quantify their binding. In order to figure out which domain of OPA1 is responsible for cardiolipin binding, we noted that OPA1 has a region similar to dynamin's pleckstrin homology domain which is known to bind lipid. I found that this domain can bind cardiolipin, which triggered our interests to solve its structure. So far, we have got the initial crystals of pH domain and are trying to optimize it.