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Student-Faculty Programs 2018 Student Abstract Book

STUDENT-FACULTY PROGRAMS

2018 Abstract Book

This document contains the abstracts of the research projects conducted by students in all programs coordinated by Caltech's Student-Faculty Programs Office for the summer of 2018.

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SUMMER UNDERGRADUATE RESEARCH FELLOWSHIPS

S U R F

Calibration of Instrument Deployment Arm (IDA) Aboard InSight

Saeed Aamer Mentor: José Andrade

NASA's InSight Mars Lander will land on Mars in November 2018, upon which it will perform an array of tests on Martian regolith. The Instrument Deployment Arm (IDA) aboard InSight will be used to perform various Soil Mechanics experiments including an Indentation Test to determine elastic properties of Martian regolith. Once deployed, the IDA will press into the soil and record force and displacement data, which will then be used to assess elastic properties. In preparation for these Soil Mechanics experiments, a replica rover in the Jet Propulsion Laboratory (JPL) will perform identical experiments. Calibrating the replica IDA will be crucial in ensuring the accuracy of the readings collected by the IDA aboard InSight. My present research is to calibrate the IDA aboard the replica rover of the Mars InSight Lander present at the JPL. To achieve this, an external setup that can independently calculate force and displacement data has been developed. My work primarily involved calibration of analog sensors, manufacturing of components to create an integrated test setup and preparation of soil test beds for the JPL Soil Mechanics experiments. Adjustments to IDA settings can be made or correction factors can be introduced during data logging by comparing the two, independent sets of data collected.

How Fear Impairs Positive Life Choices

Nayla Abney Mentors: Dean Mobbs and Haiyan Wu

To pursue life goals, it requires the courage to make decisions that may have detrimental outcomes but may also have high payoffs. This project will focus on how fear impacts people's pursuit of positive life goals such as vocational and education aspirations, relationships, and extraordinary experiences. We will investigate how fear of making positive life choices is elevated in specific groups. To study how fear impairs life choices, we will conduct two questionnaires through Amazon Mechanical TURK with five hundred participants. The participants will identify a multitude of fears that applies to them, and then address their beliefs about how attainable a range of positive life choices are and how likely they are to pursue them in the future. To further this research after data analysis, brain imaging (i.e. functional MRI) could be utilize to investigate how reactivity in the brain's fear circuits can predict the subject's fear of pursuing positive life choices.

Analysis of Acoustic Instabilities in a Continuously Variable Resonance Combustor

Kasey Adams

Mentors: Guillaume Blanquart and Guillaume Beardsell

In liquid fuel rocket engines, thermoacoustic instabilities are often difficult to predict and very catastrophic in nature resulting in problems such as increased vibration, flame extinguishing, and engine destruction. This project focuses on the analysis of thermoacoustic instabilities in a specific geometry called a Continuously Variable Resonance Combustor (CVRC). The CVRC is a design that allows for a variance in properties of the combustion chamber without altering the geometry of the chamber or properties of the fuel by using a linearly actuated oxidizer post. The CVRC is also useful in thermoacoustic analysis because of the simplicity and universality of it's geometry, allowing for results in the project to be applied widely in the field after completion of the project. To perform the analysis, simulations were performed in ANSYS Fluent using 2-D axisymmetric approximations to model the combustion chamber.

Establishing a Three-Dimensional Trap Assay to Determine Odor Preference in *Drosophila* Ashima Agarwal

Mentors: Elizabeth Hong and Kristina Dylla

The Hong Lab researches in the area of developmental biology and synapse specialization, and specifically studies how early life olfactory experience affects future brain physiology and behavior of organisms. They have found evidence that in *Drosophila melanogaster*, rearing the animal in an odor affects future odor preferences. This project aims to determine if these effects can be seen in an experiment where the flies are released and are free to fly towards their preferred odor, and become trapped for later counting, which we call a three-dimensional trap assay. This experiment was designed to be performed in darkness, and the traps designed to keep the flies from escaping, all in an effort to determine the flies' baseline response when given a choice between odors at different concentrations compared to the pure solvent. In this project, we are not able to conclude that these effects are present, however, we are able to create an experiment that performs reliably with wine, a known attractor. We are also able to create a mechanism and software by which the flies can be recorded and their behavior can be analyzed post-experiment. Future considerations would be to create better controls and starving paradigms and make the video capturing process less disruptive to the experiment. This would pave the way to reliable tests that produce results that can be compared to the lab's previous findings.

The Dynamics, Regulation, and Role of Liprin-a1 O-GlcNAcylation

Rita Aksenfeld

Mentors: Linda Hsieh-Wilson and John Thompson

O-linked β -*N*-acetylglucosamine glycosylation (O-GlcNAcylation) is a dynamic, inducible post-translational modification of thousands of intracellular proteins that is highly enriched in the brain. Interestingly, there are only two enzymes responsible for O-GlcNAc cycling in higher eukaryotes, O-GlcNAc transferase (OGT) and O-GlcNAcase (OGA), which catalyze addition and removal, respectively. Multiple studies have indicated that modulating either OGT or OGA expression/activity in the brain has profound effects on synaptic function, learning, and memory. However, relatively little is known about the specific functional roles of O-GlcNAcylation in these processes. Previously, our laboratory identified liprin-a1, a protein critical for a-amino-3-hydroxy-5-methyl-4- isoxazolepropionic acid receptor (AMAPR) targeting and synaptic plasticity, as being O-GlcNAcylated in a proteome-wide screen of mouse cortical tissue. Here, we further demonstrate that liprin-a1 is highly O-GlcNAcylated in mouse primary cortical neurons. We also show that this modification is dynamic to KCI-mediated neuronal depolarization, indicating that liprin-a1 is dynamically O-GlcNAcylated in neurons, current studies are focused on investigating the regulation and functions of this modification. Taken together, these studies provide key mechanistic insight into the role of O-GlcNAc in regulating liprin-a1 function, AMPAR targeting, and synaptic plasticity.

Characterization of Water Production From Carbon Dioxide Reduction With Re(bpy) Catalysts Alessio Amaolo

Mentors: Harry B. Gray and Jillian Clinton

In preparation for extended Mars missions, JPL has gained interest in the production of oxygen from carbon dioxide (CO₂). One method of doing so is the reduction of CO₂ in the presence of a proton source to form water and carbon monoxide and the subsequent oxidation of the water to form oxygen and recycle the protons. Three catalysts for carbon dioxide reduction are examined, Re(4,4`-R-2,2`-bipyridine)(CO)₃Cl, where R = H, (CH₂)₈CH₃, or CH₂NH₃⁺. Their faradaic efficiencies at 5mM concentration with 0.5M electrolyte (tetrabutylammounium hexafluorophosphate), 1M proton source (2,2,2-trifluoroethanol) in dry acetonitrile are measured, and the amount of water they produce is quantified. It was found that for R = H, (CH₂)₈CH₃, and CH₂NH₃⁺ the catalysts produce 5.12, 5.32, and 4.16 µmol of water per coulomb passed through the cell, respectively. These rates correspond to 99%, 103%, and 80% faradaic efficiencies, respectively. Thus, there must be an external source of water, and the experiments will be repeated with dry CO₂. Future work will include verifying the reproducibility of this data, as well as optimizing the water production to run for longer periods of time and in different conditions.

Genome-Wide CLAP/RAP Analysis of a Barcoded ORF Library

Enrique Amaya

Mentors: Mitchell Guttman, Mario Blanco, and Anthony Szempruch

Recent evidence has shown that ubiquitous transcription of mammalian genomes produces thousands of long noncoding RNAs (IncRNAs). Though several IncRNAs have been associated with diverse biological processes, efforts to precisely establish functional interactions between proteins and IncRNAs, have been hindered by a lack of sensitivity and specificity in current methods. To overcome these limitations, we designed a strategy to adapt Covalent Linkage and Affinity Purification (CLAP) and RNA Antisense Purification (RAP) to be performed with higher sensitivity in a genome-wide scale. Both methods allow for purification of *in vivo* crosslinked RNA-protein complexes: CLAP covalently couples tagged proteins to a resin, while RAP biochemically purifies specific RNAs through hybridization with biotinylated probes. These tools will be implemented in a high-throughput analysis of a library of >10,000 tagged mouse Open Reading Frames (ORFs), each one associated with a Unique Molecular Identifier (UMI). In detail, each protein is fused to two domains: a covalent capture tag and an RNA-binding domain used to barcode the protein of interest. We will investigate a pool of transfected cells containing >10,000 barcoded ORFs by CLAP/RAP. With this approach, we will confirm the RNA binding profile of the mouse proteome, and therefore expand our understanding of IncRNA biology.

Quantum Annealing Methods for Charged Particle Tracking in High Energy Physics

Abhishek Anand

Mentors: Maria Spiropulu and Jean-Roch Vlimant

Track reconstruction is one of the most crucial and computationally intensive steps in the data analysis of collisions in a high-energy particle accelerator. The High Luminosity LHC conditions increase the energy of colliding protons by a factor of 10 over the LHC's design value. Traditional algorithms such as the Kalman Filter and Hough-like Transformation scale worse than quadratically. Hence, it is expected that they will take excessive computing resources. Quantum annealers have been shown to solve quadratic unconstrained binary optimization (QUBO) problems effectively. The energy function of a traditional method for tracking, the geometric Denby-Peterson (Hopfield) network method represents the Hamiltonian of an Ising spin model that can be encoded as a QUBO problem. We prototype a novel approach for track reconstruction by applying quantum annealing to the DP method. Furthermore, to incorporate the physics of the particle detector to the DP network, we design a sequential version of the DP method and implement it on the D-Wave quantum annealer. The sequential method is similar to the classical Kalman filter method and constructs tracks one by one. We evaluate and compare the performances of the two methods across classical and quantum implementations.

Angled Helium Focused Ion Beam Milling of Graphene

Margaret Anderson

Mentors: Nai-Chang Yeh and Matthew S. Hunt

Graphene is a monolayer hexagonal lattice of carbon atoms. This two-dimensional material has drawn much attention for its unique electrical properties and potential application in valleytronic devices. In order to electrically characterize graphene, it must be patterned into the Hall bar geometry. This project optimized parameters to mill graphene with helium focused ion beam milling. After encountering extensive substrate swelling at beam doses required to mill through graphene, the sample was tilted to investigate varying incident beam angles. Oblique incident angles decreased swelling and produced thinner, deeper cuts. Tilt also decreased the required milling dose, reducing milling times. The optimal beam parameters were 20 pA current, 25° substrate tilt, 10 µs beam dwell time, 2 nm pixel spacing, and 30 pC/µm dose. The resulting channels were about 8 nm deep and 200-400 nm wide, electrically isolating the Hall bar from the surrounding graphene. Simulations performed with EnvizION software will elucidate the mechanism behind improved milling efficiency and reduced swelling at oblique angles. Hall bar devices were fabricated in graphene over strain-generating nanostructures and will be electrically characterized with a physical property measurement system (PPMS).

Investigating the Quality of Two-Dimensional Transition-Metal Dichalcogenide Material Transfer

Sara Anjum Mentor: Harry A. Atwater

Previous work has demonstrated absorbances exceeding 90% in ultrathin transition-metal dichalcogenide (TMDC) photovoltaic heterostructures. However, external quantum efficiencies were around 50%, implying carrier generation and collection efficiency (IQE) of only ~70%. In this work, we explored the fabrication of cleaner interfaces by transferring TMDCs at various temperatures using polydimethylsiloxane (PDMS) and with and without pre-treating the PDMS with ultraviolet ozone, both techniques which have been demonstrated in the past to yield smoother transfers with less residue. Qualitatively, we have observed that the temperature of the transfer affects the residue amount much more than the pre-treatment, and that transfers in the 60-90 C temperature range yield the smoothest, most controlled transfers with the least residue.

Real-Time Background Subtraction for Moving Scenes Using Image Focus Thresholding

Logan Apple Mentor: Pietro Perona

Background subtraction algorithms traditionally define the background as parts of a scene that are at rest. Many previous algorithms only assume a stationary camera and do not operate in real-time. In this new, multistage method, we neither assume that the camera nor the objects in the scene are stationary. The method uses only 2D image measurements to construct the foreground-background model. To quickly segment objects in the foreground, the Laplacian and the intensity gradient of the image are computed. A morphological transformation is then applied to thin the edges. The external contours of the resulting image are computed, returning a foreground mask. A sparse model of the foreground is then built by estimating a compact trajectory basis from trajectories of stable points across the possible foreground and background. Contours in the foreground are then classified into definite foreground and possible foreground by approximating the similarity in the velocity of motion in regions of the foreground relative to nearby regions of movement in the background. Testing the algorithm against the LASIESTA dataset and Actions dataset demonstrated that the background subtraction method can run at real-time speeds on mobile devices.

Recurrent Generative Adversarial Networks for Simulating Pileup in Proton-Proton Collisions at the LHC Jesús Ariona Martinez

Mentors: María Spiropulu and Jean-Roch Vlimant

In a typical hard scattering process, other interactions occur that do not correspond to the Primary Vertex. These are referred to as pileup and usually degrade the reconstruction performance. Their simulation is computationally expensive and may become a limiting factor in the proposed High-Luminosity LHC upgrade. We propose a Generative Adversarial Network that is capable of simulating pileup that matches the high-level physical features of more computationally expensive simulations and results in appropriate jet transverse momentum distributions after the pileup mitigation algorithm Softkiller is applied. Through the use of a recurrent architecture, it directly generates particle tracks, unaffected by the detector's geometry and bypasses many of the problems of traditional Convolutional Networks. We also show that the Wasserstein distance for relevant features can be used for monitoring training and comparing model performance.

Characterizing Granular Materials Using a Powder Cell Rheometer

Rahul Arun

Mentors: Melany Hunt and Shahrzad Roshankhah

Granular materials are important in a wide range of fields, from storage in the food industry to foundation analysis in construction. Powder rheology aims to classify the flow and deformation of granular materials using their physical properties. An Anton Paar MCR 302 Rheometer with powder cell is used. Wall friction is determined by shear tests with stainless steel and Teflon (PTFE) plates. Undrained shear strength is determined via shear tests using a Warren Spring geometry. Compression with an air-permeable piston allows for measurements at a variety of solid fractions. These tests are performed at multiple strain rates to classify rheological behavior over many regimes of deformation. Glass beads (120 µm) and sand samples from Kelso Dunes (crest sand and base sand) are tested and compared. The packing, composition, shape, and size of the granular materials are considered in explaining and comparing their rheological behaviors. Stick-slip is observed during shear at low normal stress. An increase in the shear resistance of glass beads over time is observed during Warren Spring shear.

Maximizing the Coherence Time of Diamond SiV Color Centers Through Application of Permanent Strain Daniel Assumpcao

Mentors: Marko Loncar, Michael Burek, and Hyuck Choo

The realization of quantum networks for quantum technology has been hindered by the lack of a quantum bit (qubit) platform that is scalable, stable, and has long coherence times. One promising platform is the siliconvacancy color center in diamond which shows excellent properties. However, it has a poor coherence time, which is limited by phonon mediated thermal decoherence caused by the high susceptibility of the SiV's energy levels to strain. Here, the SiV's high susceptibility to strain was taken advantage of by applying a large permanent strain to the center, thus enlarging the gap in the energy levels and increasing the coherence time. This large strain was created through the patterning of optimally designed high stress thin film of silicon nitride on top of the diamond. The SiV devices showed both a large shift in their energy levels and a correspondingly large increase in their coherence times.

Developing a Computational Pipeline for Cell Segmentation of Serotonergic Neurons

Cory Atwater

Mentors: Viviana Gradinaru and Min Jee Jang

Gathering and analyzing data about the brain is an extremely difficult task, due to the number and density of cells. In order to accelerate and refine the process of gathering information, it is necessary to use computational pipelines. The raw data is gathered through a mixture of the passive CLARITY (PACT) technique and RNA labeling that allows researchers to selectively label individual cell types with fluorophores based on their RNA transcripts. These tagged RNA strands are visible as a 3-dimensional dot matrix under a confocal microscope, stored as a stack of 2 dimensional images. Some regions of the brain have clear signals that very cleanly show the presence of particular neurons, but others, such as the serotonergic region of the brain known as the Dorsal Raphe Nucleus have a very densely packed and spotty RNA signal. Various combinations of approaches for image preprocessing and clustering data points are explored, and compared in effectiveness for different data sets.

Sensory Transduction of Radio Waves: Modeling Energy Conversion From Radio Waves to Ultrasound in Magnetite Crystals and Transduction of Ultrasound at Pressure-Sensitive Ion Channels

Yovan Badal

Mentors: Joseph L. Kirschvink and Isaac Hilburn

Homing animals have been found to become unable to use their biomagnetic compass when exposed to radiofrequency (RF) noise at 0.2 - 9 MHz. In previous work, we have proposed a biophysical mechanism for the sensory transduction of RF waves involving transduction into ultrasound at magnetosomes in cells, followed by propagation of ultrasound to mechanosensitive ion channels, possibly in the magnetosome membranes. We now augment our model for transduction of RF to ultrasound (based on displacement of single-domain (SD) magnetite particle moments from easy axes by magnetic fields, as described by the Stoner-Wohlfarth model). We parameterize the model for distributions of crystal size, shape, and spatial distribution. Current iterations agree with a well-known maximum in the imaginary part of the complex susceptibility (corresponding to energy dissipation in the crystal in varying magnetic fields) of SD particles near the superparamagnetic-SD threshold. Further work will build on this to model complex magnetic susceptibility of magnetite suspensions. Fitting the model to measurements of complex susceptibility in frequency space should provide a test of the model's predictions and indicate any further consistency with the results of Kellnberger et al. (2016), our model being consistent with doubling of carrier wave frequency during transduction to ultrasound.

Development of a Method to Determine Three-Dimensional Genomic Structure

Toby Baker

Mentors: Mitchell Guttman and Sofia Quinodoz

The three-dimensional structure of the genome has been implicated in core biological functions such as transcription and DNA repair. Increased knowledge of its architecture could open avenues for research into new treatments. SPRITE (split pool recognition of interactions by tag extension) was developed by the Guttman lab to help elucidate genomic structure. Here we describe a method to form a three-dimensional model of the genome from SPRITE data using a classical multidimensional scaling algorithm. The model is in good agreement with existing experimental measurements of distance between different genome regions and the active and nucleolar hubs as determined by FISH. Further work is required to test predictions made by the model in order to verify its accuracy.

Reconstructing the Phylogenetic Lineages of Single Cell Derived Subclones Using Patterns of De Novo Mutagenesis and Clonal Heterogeneity

Anthony Bao

Mentors: Cheng-Zhong Zhang, Logan Blaine, and Judith L. Campbell

Single-cell DNA sequencing preserves the heterogeneity found in a tumor cell population, allowing for the construction of high resolution maps of subclonal cells and mutational events. To generate a sufficient quantity of DNA for sequencing library construction, cells must undergo whole genome amplification, a process which invariably introduces artifacts including amplification errors and coverage variability. Because of these complications, high confidence de novo variant detection in single cells requires the variant to be shared in biological replicates: daughters and siblings. This strategy is feasible for passaging cells, but cannot be applied to terminally differentiated cells. The goal of this project is to determine the possibility and potential workflow of using single-cell sequencing data to identify signatures of de novo mutagenesis in the presence of multiple amplification errors. The sequenced cells are daughters of RPE-1 cells with chromatin bridges and their derived subclones. Chromatin bridges can induce catastrophic mutational events such as chromothripsis and kataegis, and are thus of great interest. Once we establish a lineage, we can identify specific mutational events and when they occurred in the tumor cell evolution. After extensive filtering, cluster analysis suggests a potential phylogeny that can be validated by copy number data.

Identification and Classification of Atypical Nuclear Morphologies in Glioblastoma

Richard Bao

Mentors: Cheng Zhong Zhang, Richard Tourdot, and Mathieu Desbrun

Although molecular information, like genetic alterations and gene expression profiles, are becoming widely adopted in cancer diagnosis and classification, changes in nuclear morphology remain the "gold-standard" for pathological analyses of cancer biopsies. Cellular activities relevant to tumorigenesis are dependent on the composition and organization of the nuclear envelope, as well as the chromatin it contains. Through observation, pathologists have discovered several classes of nuclear morphology, some of which are indicative of cancerous cells. However, they remain poorly defined and understood. The primary goal of this project is to apply machine learning techniques to develop a quantitative algorithm that can detect and classify different types of nuclear atypia based on BAF staining. A TensorFlow neural network was constructed and trained on a set of more than 10,000 nuclear images from various scans of glioblastoma cell lines, and was optimized to achieve 95% accuracy. An exploratory, unsupervised machine learning approach was also pursued, involving the implementation of PCA, tSNE, and Isomap. Clustering demonstrates the existence of four distinct groups, and perhaps an additional group as well.

Reinforcement Learning in Partially Observable Environments

Manish Kumar Bera

Mentors: Animashree Anandkumar and Kamyar Azizzadenesheli

Problems in Reinforcement Learning are modeled as MDPs (Markov Decision Processes). But, often in real world scenarios, this is not optimal as MDP makes a strong assumption that the state of the environment is completely known to the agent. So, in general, POMDPs (Partially Observable MDPs) best describe the real world applications. This project aims at exploring various methods of tackling POMDPs. We mostly look into modifications of Trust-Region techniques. We primarily tested our models on the *Roboschool* physics engine environments.

Bulk Optical Properties of Secondary Organic Aerosol Formed From the Oxidation of Aromatic Precursors Under High $NO_{\rm x}$ Conditions

Damien Bérubé

Mentors: John H. Seinfeld and Christopher M. Kenseth

In the last decade, biomass burning in the United States has increased considerably, both in frequency and intensity, leading to a heightened interest in the oxidation chemistry underlying the formation of light-absorbing aerosols (i.e., "brown" carbon) from organic precursors in smoke plumes. In particular, aromatic compounds

emitted during biomass burning have been identified for their potential to form secondary organic aerosol (SOA) largely comprised of nitro derivatives that could act as efficient chromophores. While the oxidation products of these aromatic derivatives have been studied in some detail, the effect of these chromophores on bulk optical properties has yet to be determined. In this project, molecular components of SOA formed from the gas-phase chemistry of guaiacol, a phenol derivative, under high NO_x (NO + NO₂) conditions are sampled in a time-resolved manner. They are characterized using liquid chromatography coupled to electrospray ionization mass spectrometry (LC/ESI-MS), and structures are assigned to the major species. Their properties are compared to known standards, their formation explained via oxidation mechanisms, and their presence is correlated with bulk light absorbance using UV-visible spectrophotometry. Their identification will help constrain the effects of biomass burning aerosol on radiative forcing.

Extension of Continuous Tensor Decomposition Methods to Control Problems

Vivek Bharadwaj

Mentors: Animashree Anandkumar, Rose Yu, Kamyar Azizzadenesheli

Optimal control problems, such as robot motion planning, often require computations that involve high-dimensional state spaces. As the dimension of the state space grows, both the computation time and the storage space necessary to characterize the state space exactly grows exponentially in the dimension, a phenomenon known as the curse of dimensionality. Recent work has shown that high-dimensional tensors (arrays in more than one dimension) can often be approximated using a low-rank tensor train decomposition; likewise, high-dimensional multivariate functions can be compactly expressed using function train (FT) decomposition, and recent work has shown applications of FT-decomposition to stochastic optimal control problems, where the system dynamics are known in advance. The purpose of this project is to demonstrate the application of FT-decomposition to control problems where the system dynamics are learned from exploration of the system environment. Specifically investigate learning the dynamics of systems such as *MountainCar* and *PoleCart* through Gaussian Process (GP) regression models. We then use the dynamics models to learn expected reward functions represented through a high-dimensional function train, which in turn allows planning of the optimal control trajectory. We demonstrate the application of the algorithms by applying our results to control problems and available environments in OpenAI gym.

Characterizing LIGO Environmental Channels

Ayon Biswas

Mentors: Ashish Mahabal and Jessica McIver

Ground-based gravitational wave detectors such as LIGO are required to detect changes in the space-time continuum of less than one thousand times smaller than the diameter of a proton. It is essential for the interferometers to be in optical resonance for collecting scientific data. They are susceptible to ground motion caused due to earthquakes, winds, microseism and anthropogenic activity like snow plows which leads to the loss in observation time. It can take several hours for the detectors to return to operating state. There are a large number of environmental channels which continuously monitor the physical environment around the detector. There is a direct correlation between the ground velocity and lock loss events. The detector operation becomes unstable at higher ground velocities. There are cavity power channels which monitor stability of the Interferometer based on the power in each of the cavities and the cavity length sensing channels which monitors any change in the length of the cavities. These channels can provide an insight into the cause of lock loss. The uptime can be increased by predicting a lockloss to automatically tune the interferometer state to maximize astrophysical reach. We are creating signatures like dmdt features and spectrograms for profiles of various channels and use them in our analysis. The aim is to apply supervised deep learning algorithms to predict lockloss events by characterizing the contribution of elevated ground motion as witnessed by independent environmental channels as well as the behaviour of cavity power and cavity length sensing channels. We have trained a convolutional neural network on the dmdt features of the cavity channels. We obtained around 90% with single channels, around 93.6 % with cavity power channels, 98.2% with cavity length channels and 99.26% with all six cavity channels.

Low-Power Wireless Communication Circuits for Implantable Biosensors

Harpa Ósk Björnsdóttir

Mentors: Azita Emami and Abhinav Agarwal

The development and design of implantable biosensors is a field rapidly growing in the medical industry; as highly miniaturized, low-cost, and low-power devices are created, the capabilities for accurate transmission of body-related data experience a corresponding upward trajectory. Professor's Emami's group is of developing and testing a low-power implantable biosensor chip that can be used to measure and transmit data regarding various vital parameters, including glucose, lactate, and other biologically relevant analytes in the body. This CMOS chip is powered from near-field RF signal at 915 MHz lying in the ISM band of the EM spectrum. The chip has wireless bidirectional data communication (uplink and downlink) capability to transmit the recorded data (uplink) and get reconfigured to change sensor settings (downlink) to adapt itself for measuring several different bioanalytes with the same platform. Since these chips are wirelessly powered and do not operate on a battery, reducing the power consumption of the chip is critical to be able to power these at reasonable depths inside the human body. It is also

critical for the chip's solution to be compatible with the existing standard, EPCglobal Class 1 Gen 2 Specification, which is regarded as the state-of-art communication standard for connecting passive UHF tags and readers. Hence, there is a lot of push to explore novel circuit and system architectures to reduce the overall power consumption of chip Particularly important is the wireless data communication block which consumes a significant portion of the overall system power.

Dirac Harmonic Maps Between Hyperbolic Space and Bruhat-Tis Buildings

Eitan Borgnia Mentor: Sarthak Parikh

The correspondence between theories of gravity in anti-de Sitter space (such as various string theories) and conformal field theories (AdS/CFT) is of great interest in physics. One approach in the study of AdS/CFT is to consider the bulk space discretely using the field of p-adic numbers as a toy model. The Bruhat-Tits tree, which is the graphical representation of possible p-adic expansions, has been central to this approach. In the previous year's SURF project, we constructed Delaunnay embeddings of the tree into the hyperbolic plane using graph theoretic tools. We now attempt to extend this work and gain more insight on the properties of the tree by finding structure preserving maps in the reverse direction. A natural choice would be Dirac harmonic maps. These maps have only been defined between manifolds (and recently pseudo-Riemannian manifolds), but discrete spaces like the Bruhat-Tits tree cannot be given such structure. We can, however, use principles of non-commutative geometry to endow the Bruhat-Tits tree with a spectral triple, which affords similar advantages. In this project, we attempt to make use of the properties of spectral triples to generalize the definition of Dirac harmonic maps to arbitrary discrete spaces.

Design and Control of 1-Dimensional Hopping Robot

Alexander A. Bouman Mentors: Aaron D. Ames

Single legged systems, or monopods, have a single point of contact with the ground and move by hopping. The conditions for hopping of this particular robot, called a hopper, did not allow direct actuation on the world. With the eventual goal of mounting the hopper inside a rubber ball, the hopper had a spring mounted on its base to simulate a rubber ball enclosure. This requirement is a significant restraint on the hopper's design as it ruled out most forms of rapid and forceful actuation. In the hopper's current design, the spring is compressed during the hopper's flight phase and release during the ground phase.

Response of Monolayer WS2 Transport Properties to Circularly Polarized Light

Cole J. Brabec Mentor: Nai-Chang Yeh

Mono-layer transition metal dichalcogenides (TMDCs) serve as very promising materials for use in novel electronic devices. Specifically, their unique optical and conduction band properties make them promising candidates for efficient high-sensitivity photo-detectors. The optical properties of mono-layer TMDC's arise due to their strong spin-orbit coupling. This allows circularly polarized light to better impart energy into electrons. Thus circularly polarized light is able to propel electrons into the TMDC conduction band, decreasing its resistance. In order to better characterize this effect, the effect of circularly polarized light on the electrical transport properties of a particular TMDC, \$WS_2\$, was measured. Using the Van der Pauw method, right circularly polarized light was found to increase carrier mobility in WS2. This confirms that WS2 would serve as an effective photo-detector.

Reconstructing Gene Order in Cancer Cells Using Tree Leaf Permutations

Tatiana Brailovskaya Mentor: Lior Pachter

Recent studies uncovered genomic rearrangements specific to different types of cancers that play a significant role in disease progression. A novel high-speed, low-cost RNA sequencing technique has been proposed for detecting these rearrangements. The method constructs a labeled tree revealing the spatial relationships of those genes. We know what the normal gene order must be and use it as a guideline to determine what the gene order was in the sequenced genome. Here we propose an efficient algorithm for reconstructing gene order by minimizing the number of inversions in leaf labels of the tree. We also found a condition on the tree such that if it is satisfied, then the gene order that corresponds to the minimal inversion leaf ordering is unique. Algorithmic tools developed here can be applied to the analysis of data obtained from the aforementioned sequencing method and aid in cancer diagnosis.

Real-Time Election Analysis: Using NLP to Avoid Bias in Corpora Containing Short Documents

Jackson Briones

Mentors: R. Michael Alvarez and Nicholas J. Adams-Cohen

With all of the social technology available in today's society, it has become possible for many people to discuss events as they occur. By utilizing large datasets from social media websites such as Twitter, political scientists can perform research on specific topics while they remain in the public eye, as opposed to performing research after the fact. Data is often selected based on the presence of specific keywords, but sentimental bias inherent to language can skew results. By iteratively finding new keywords in the original dataset and expanding the set for the next run, a more inclusive set of keywords can be obtained. The attempted extraction algorithms include simple n-gram frequency, selectivity, and term frequency-inverse document frequency (TF-IDF). Results show that results from simple frequency metrics have strong recall but weak precision, selectivity based results contain high precision keywords which have low recall, and TF-IDF based results are often skewed by popular tweets. Before a tool to perform this can be finalized, the extraction algorithms need to be improved; subsequent work should focus on improving results of the base algorithms before attempting to implement the full iterative process.

Structure of the Pom152 Immunoglobulin Domains of the Nuclear Pore Complex

Krystal Brodsky

Mentors: André Hoelz and Taylor Stevens

The nuclear pore complex (NPC) of eukaryotic cells allows for the bidirectional exchange of materials across the nuclear envelope and consists of proteins termed nucleoporins (Nups) associated with nuclear pores. Poms, a category of Nups, are integral membrane proteins with a pore-facing, transmembrane and lumen-facing region; Pom152 in yeast is a type II integral membrane protein widely conserved among fungi. Pom152 contains transmembrane helices that connect a short, soluble unstructured region associated with the rest of the NPC to a chain of repeating immunoglobulin (Ig) domains located in the luminal space of the nuclear envelope. These Ig domains are a distinctive feature of Pom152 and are also found in a similar protein in plants and animals, notably Nup210 in vertebrates. Biochemical approaches involving production and purification of large protein quantities are taken to crystallize the Pom152 Ig domains. The resulting crystallographic data can be used to determine the protein's structure and provide insight into its purpose and potential functions and interactions, which can translate to homologous proteins like Nup210. The structural determination of Pom152 will contribute to ongoing efforts to elucidate the complete structure of the NPC, whose design could provide a basis for mechanistically understanding nucleocytoplasmic transport.

Identifying Roles of P1 Aggression Promoting Neurons in Drosophila

Krystin Brown

Mentors: David Anderson and Eric Hoopfer

Male fruit flies, *Drosophila melanogaster*, engage in social behaviors like aggression and courtship. Previous work in the lab has identified 20 GAL4 driver lines that label neurons that promote aggression when artificially activated. However, it is not known whether activation of these neurons is directly or indirectly promoting aggression. Our first question is whether these neurons cause a fly-autonomous increase in aggression or if they lead to aggression via social interactions and escalation. We tested whether the aggression phenotype displayed by each GAL4 line is the same when paired against a non-aggressive, wild-type male. The flies receive optogenetic neuronal stimulation using Chrimson, a version of Channelrhodopsin that is activated by red light. By quantifying aggression and courtship behaviors, we can segregate these driver lines and gain insight into causes of aggressive behaviors. Our second question is whether activation of these aggression neurons leads to an immediate or time-locked behavior, or if stimulation causes a lasting change in fly behaviors. We placed two flies on opposite sides of a sliding door chamber, activated the neurons, and then removed the barrier. These results will tell us whether neuronal activation causes an intrinsic and persistent change in the aggressive state of the fly.

Determining the Center of Gravity Position of an Irregularly Shaped Robot

Michael Brown

Mentors: Soon-Jo Chung and Alireza Ramezani

In aerial robotics, the position of a robot's center of gravity greatly affects stability during flight. So, it is essential to accurately determine this center of gravity position to enhance the robot's performance. This location can be found by experimentally measuring the robot's mass distribution in different orientations. To conduct these experiments, one could construct a testbed that allows the experimenter to easily identify the orientation of the robot and the robot's mass distribution. The testbed must be easy to assemble and quick to take measurements to minimize the testing time. Since robots have moving parts, the testbed must also keep each part of the robot fixed to prevent the center of gravity position from moving between measurements. The construction of this experimental setup has been completed for Caltech's Leg ON Aerial Robotic DrOne (LEONARDO). Once the robot is ready to begin testing, the testbed will be used.

Investigating the Nucleation Behavior of Diblock Copolymers During an Order-Disorder Transition to Spherical Phases

Dorian Bruch Mentor: Zhen-Gang Wang

Diblock copolymers are polymers consisting of a block of A-type monomers covalently linked to a block of B-type monomers. These polymers are known to microphase separate into spherical phases such as body-centered cubic (BCC) and the Frank-Kasper sigma phase. Several theoretical and experimental studies have examined factors that drive the formation of these phases; however, few studies have examined the kinetic pathway of the order-disorder transition (ODT) to these spherical phases. For this reason, we investigated the nucleation behavior of a diblock copolymer melt as it undergoes a phase transition from a uniform, metastable disordered (DIS) phase to a BCC phase using self-consistent field theory in tandem with the string method. We found that the critical nucleus size and energy barrier grow as the ODT temperature is approached. We also found that, under certain conditions, the nucleus goes through a small energy barrier before the critical nucleus barrier, corresponding to the formation of a single micelle, which is consistent with previous theoretical studies. Lastly, we found that composition fluctuations are significant near the disordered phase spinodal and cannot be ignored. Future studies will account for these fluctuations as well as study nucleation phenomenon of the DIS-sigma transition.

Neurogenetic Dissection of Flight Behavior in Drosophila melanogaster

Lazarina Butkovich

Mentors: Michael Dickinson and Matthew Clark

Our central nervous system has billions of neurons with orders of magnitude more connections between them. To better understand how neural connections generate complex behaviors, we can study more tractable model systems, such as *Drosophila melanogaster*, or fruit flies. With ~100,000 neurons, the fly brain may be studied in greater precision, allowing us to map specific behaviors down to individual neurons and simplified circuits. My project concentrated on the effect of ventral nerve cord interneuron (VNC IN) activation on wing behavior, where small wing beat changes lead to dramatic changes in flight heading. I used the GAL4/UAS system to express the optogenetic effector CsChrimson in VNC IN split-GAL4 drivers selected for specificity and putative targeting of the flight neuropil. Upon optogenetic stimulation during flight, I recorded changes in stroke amplitude and wingbeat frequency. Results showed that VNC INs had a variety of effects on amplitude and frequency compared to controls, suggesting that dedicated interneuron groups govern specific wing motions. Future goals include using neurogenetic mapping techniques to determine neurotransmitter type and whether the VNC INs are directly premotor INs. Similarly, we can record from flight muscle groups directly during optogenetic stimulation to functionally validate downstream targets.

Continued Study of Ring Opening Metathesis Polymerization for Fluorous Block Bottlebrush Copolymer Synthesis

Sabina Cabrera

Mentors: Robert Grubbs and Willie Wolf

Bottlebrush polymers are an interesting class of macromolecule that consist of a polymer backbone that is highly substituted with shorter polymer sidechains. Ring Opening Metathesis Polymerization (ROMP) is used to synthesize bottlebrush copolymers that can potentially self-assemble into photonic crystals. The use of fluorous macromonomers for ROMP has been observed in creating bottlebrush polymers that exhibit unique phase separation and aid in self-assembly of 1D photonic crystals. Currently we are studying the properties of fluorous macromonomer synthesized last summer in order to allow for longer degrees of polymerization to be accessible from ROMP.

Preparation of the High Contrast Testbed for Segmented Telescopes With Transmissive Optics (HCST-T) Ben Calvin

Mentors: Dimitri Mawet, Nemanja Jovanovic, and Jorge Llop

It is of paramount importance for instrumentational astronomy to test and characterize optical equipment before implementing them. This optical equipment typically falls into one of two categories, reflective optics and transmissive optics. Our project was to create a testbed with decent raw contrast to characterize transmissive optics in the context of vortex coronagraphy that can both image the wavefront and accurately measure its power through fiber optics. Primarily, standard alignment techniques were used to guide the beampath along the instrument for an initial alignment. Then, we would observe the beam through both the pupil and focal plane to ensure the proper optics were aligned and conjugated with each other. Finally, the phase aberrations of the beam at the exit of the instrument was measured and corrected for final image sharpening. With the final alignment, the wave front has a Strehl ratio of >80% and an output power efficiency of 54%. With this, HCST-T has a raw contrast of 4% on-axis light compared to off-axis light.

Deep Learning for Single-Cell Biology

Isabella Camplisson Mentors: David Van Valen and Erick Moen

The ability to identify and track cells in microscopy images and videos is integral to many experiments in biology, as well as the diagnosis and treatment of numerous diseases. The heterogeneous, often unpredictable nature of cells and their movement makes this task difficult, currently requiring countless hours of manual curation and resulting in a highly inefficient process. The proposed solution to this problem is to train deep convolutional neural networks, a type of supervised deep neural network, on a series of annotated microscopy images of cells. In order to create the volume of highly accurate, annotated microscopy images required for this task, in-depth instructions and videos were created to direct the contributions from a crowd-sourcing platform. Similarly, a variety of cell types were used, from HeLa to triple-negative breast cancer cells. These annotations were improved upon using both a correction program and human-in-the-loop verification, before being used as the training data for the deep learning program.

Chemoenzymatic Labeling of a Bacterial Transmembrane Protein for Imaging in Live Cells

Siting (Cindy) Cao Mentors: David Tirrell and Samuel Ho

Methods of protein imaging help to visualize protein subcellular localization and are crucial for understanding the functions of bacterial proteins. One method of imaging proteins in live cells utilizes the eukaryotic enzyme *N*-myristoyltransferase (NMT) to append an azido fatty acid to the *N*-terminus of the protein of interest (POI) that is modified with an NMT recognition sequence, followed by strain-promoted azide–alkyne cycloaddition to label the POI with a fluorescent dye. A small molecule fluorophore offers the advantage of being less likely to perturb protein localization than large fluorescent proteins. This method has been demonstrated by the Tirrell Lab with bacterial POIs outfitted with the recognition sequence and NMT co-expressed from separate plasmids. Here, we use the methyl-accepting chemotaxis protein, Tsr, under control of either a synthetic constitutive promoter or the endogenous promoter in *Escherichia coli*, to show that the method can also be applied after integrating the modified gene directly into the bacterial proteins with a genomic insert of the POI.

Application of Supervised Machine Learning to Classification of Variable Young Stars

Philip Carr

Mentor: Lynne Hillenbrand

Young star systems are crucial to the understanding of how planetary systems form, providing a window into the dynamics and short-lived behavior in some of the earliest stages of planetary system development. Young stars are known for the variety of distinct variability patterns in their light curves. Previous research has demonstrated the classification of young stars into eight variability types, largely based on the degree of periodicity and asymmetry in flux of the light curves, that could be used for further studies of specific variability types. As the size and scope of photometric variability surveys increase in the future, classification of these young stars will become highly favorable for computers to automate. A selection of supervised machine learning algorithms has been applied to the classification of young stars, previously-defined features have been tested to be robust for supervised learning, and new features have been developed for the classification of young stars. The random forest algorithm currently performs with the highest overall accuracy of 76 ± 3 % and balanced accuracy of 77 ± 5 %. While not an ideal performance for the direct application to unclassified young stars as of yet, the use of machine learning algorithms for the classification of these objects has been shown to be potentially viable.

Feasibility of In-situ Water Production During Fast-Accreting Super-Earth Formation

Benjamin C. Cassese

Mentor: David J. Stevenson

In recent years, the Kepler mission and subsequent follow up studies have revealed numerous super-earth terrestrial exoplanets. Although these make tempting targets for habitability assessment, it is possible that these worlds form dry in regions too close to their host stars for water to condense in the adjacent nebula. Indeed, Earth's water was likely delivered from elsewhere, a process that may not be universal. We propose a mechanism distinct from our solar system's own icy body bombardment that could lead to the accumulation of substantial quantity of water on these worlds. Central to this mechanism is the presence of a primordial gaseous nebula of mostly hydrogen during this fast formation. As rocky precursor material encounters this atmosphere, it can break up into liquid droplets, whereupon silica can react with molecular hydrogen to produce silane gas and water vapor. A fraction of this vapor could partition into the liquid melt, where it would be trapped and protected from the XUV which will eventually dislodge their gaseous counterpart volatiles. Upon cooling, the planet would be left with a substantial mass of water trapped in the now solid rocky bulk which may even be outgassed via volcanic processes to form a surface ocean. We present an initial review of the parameter space that would enable this process to take place, as well as basic calculations of the state of the atmosphere of an actively accreting planet. We find that under the expected conditions of 3-10 earth mass planets forming within a 200-1000K nebula in < 3Ma that the

mass equivalent of a tens of km ocean of water could be produced and stored via this mechanism. This finding illustrates the need for acknowledging non-traditional modes of water accumulation on terrestrial planets when estimating their total water budget, and potentially increases the population of feasibly watery, or even habitable, worlds.

Fabrication and Experimental Verification of Plasmonically Enhanced Nanoscale Field Emission Devices Dominic H. Catanzaro

Mentors: Axel Scherer and Lucia de Rose

This project is part of an ongoing effort to fabricate plasmonically enhanced nanoscale field effect devices. Deposited onto silicon chips, these devices consist of nanometer scale diffraction gratings, silicon waveguides, and gold electrodes and were fabricated in the Kavli Nanoscience Institute. The diffraction grating couples 1550 nm light into the waveguide where it is focused into the gap between the electrodes. This results in the plasmonic effects that enhance the electric field between the electrodes. The devices were imaged with a scanning electron microscope during multiple steps of the fabrication process. To ensure proper device behavior, four-point probe measurements were conducted on both the substrate and electrode materials. The devices were characterized under vacuum using IV sweeps, and displayed characteristics distinct to field emission. The optical input to the device was modulated using a chopper and the device characteristics were measured using a lock-in amplifier. The optical coupling to the grating and waveguide were simulated to understand the optical power delivered to the device. A strong correlation was found between optical input and device characteristics, suggesting photonically gated of opto-electronic devices can be fabricated with current technology.

Autonomy for Flying Vehicles

Anuj Chadha Mentors: Soon-Jo Chung and Kyunam Kim

Fully autonomous VTOL (vertical take-off and landing) flying ambulances are part of the future. Society will benefit enormously from the improved mobility that results from flying ambulances — in some rural areas, people are left waiting for an unreasonable amount of time for emergency support. A drone ambulance that could carry the necessary packages and aid could drastically cut the wait times and undoubtedly save many lives. This project designs the autonomous system for a flying ambulance via a series of sensors designed to measure the linear acceleration, angular acceleration and altitude in order to measure and control the attitude of the vehicle. Through computational analysis of this data, the ambulance can fly on its pre – determined path. This is performed in combination with multiple camera systems which employ obstacle – avoidance algorithms in order to ensure a successful autonomous flight. Our ambulance aims to fly from Caltech to JPL autonomously. An unhindered, successful will provide the groundwork for research into future vehicles that can easily and quickly provide aid.

Variations in Stable Isotope Composition of Great Salt Lake Carbonate: Is There a Microbial Impact on the Sedimentary Record?

Andrew Chan

Mentors: Kathryn Snell, Miquela Ingalls, Lizzy Trower, and Woodward W. Fischer

Carbon ($\delta^{13}C_c$) and oxygen ($\delta^{18}O_c$) stable isotopes from carbonate minerals formed in ancient lakes are often used to infer about past environmental conditions. To improve the use of lacustrine carbonate in paleoclimatic and paleoenvironmental reconstructions, we test the necessary assumption that carbonate that precipitates at approximately the same time across a single lake basin will record a consistent isotopic signature which can be paired to a particular environmental parameter. We study Great Salt Lake (UT, USA; GSL) as a proxy for the alkaline, hypersaline lakes that were more common in the past to better understand the effects of early diagenesis on the stable isotopes of carbonate precipitated from this unique lake chemistry. We hypothesize that microbial activity mediates the carbonate chemistry in the water column and below the sediment-water interface, thus affecting δ^{13} C_c and δ^{18} O_c. We measured δ^{13} C_c and δ^{18} O_c of microbialites collected at the sediment-water interface and five cores of various depths across the north-south extent of GSL and compared isotopic compositions at the sediment-water interface between sites to see if coeval sediments record comparable isotopic compositions. $\delta^{18}O_{carb}$ from four of the five cores shows down-core and between-site variability of $\sim 3\%$, suggesting that cores with similar carbonate facies are robust paleoenvironmental proxies. However, $\delta^{13}C_c$ varies by ~5% down-core within and between coring sites, perhaps indicating that microbial activity (e.g. respiration) affects the early diagenesis of lacustrine carbonate in GSL. Finally, although we expect a closed basin hydrological system like GSL to have a positive $\delta^{13}C_c - \delta^{18}O_c$ correlation, we find no significant correlation. We believe this is because $\delta^{18}O_c$ is mainly controlled by hydrology; this is not appreciably changed on the timescale of our cores' recorded sedimentation. Therefore, any perturbations from the expected positive correlation result from early diagenesis of $\delta^{13}C_c$. As such, we suggest that the main force controlling the down-core isotopic variability in GSL is a microbial process that mediates carbon cycling between the inorganic and organic carbon pools, changing the pH and alkalinity of the lake/porewater and altering the dissolved inorganic carbon pool from which carbonate precipitates.

Towards the Total Synthesis of Cancer-Inhibiting Enmein-Type Ent-Kauranoids

Jonathan Chan Mentors: Sarah E. Reisman and Jordan C. Beck

Extracts from the *Isodon* plant species have been used for centuries in traditional Chinese medicine due to their antitumor, antibacterial and anti-inflammatory activities. Many of these natural products, including enmein, are *ent*-kauranoids, highly oxygenated diterpenes containing several connected ring systems. An efficient total synthetic strategy to access these natural products could allow for a more thorough investigation of their biological mode of action; however, there have been few successful total syntheses to date. Our convergent retrosynthesis of these *ent*-kauranoids involves an asymmetric coupling between a [3.2.1]-bicyclooctane fragment and a vinyl iodide fragment, the latter of which we have successfully synthesized. We work to develop a chiral radical cyclization reaction to produce the [3.2.1]-bicyclooctane fragment. We aim to expand the scope of this rhodium-photocatalyzed reaction to vary the functionality of other bicyclo-octenyl compounds. This research paves the way for a highly modular, enantioselective total synthesis of bioactive *ent*-kauranoids, and more broadly, advances the fields of synthetic methods development and drug discovery.

Inferring 3-D Structure of Herbig-Haro Objects From Keck Cosmic Web Imager Spectra

Arlindo Chan Borges Mentor: Lynne Hillenbrand

Herbig-Haro (HH) Objects are compact shock-excited nebulae that form as a result of ejected material in a protostellar jet colliding with the interstellar medium. The Keck Cosmic Web Imager team obtained unprecedentedly blue spectra on HH-32 in the form of a data cube, from which new information on the source can be obtained to revise prevailing jet models. The one-dimensional integrated spectrum was used to identify the presence and absence of certain emission lines, providing information on the temperature, chemical composition, and density of the emitting gas. Position channel maps of the emission lines and line ratios are generated to visualize the jet structure and obtain shock diagnostics. From manipulating the data cube, radial velocity channel maps are also created to further probe the kinematics and 3-D structure of the source.

Maximally Monomially Modulated Discrete Hilbert Transform

Zachary H. Chase Mentor: Ben Krause

The number of triangles in a Cayley graph with generating set S is directly proportional to the probability that the sum of two elements of S is in S. A conjecture on the maximum number of triangles that a regular graph of specified size and common degree can have translates into an interesting upper bound for the mentioned probability. We prove this additive combinatorial upper bound using Fourier analysis.

Sample-Efficient Deep Reinforcement Learning With Generative Dynamics Model

Hongjie Chen

Mentors: Anima Anandkumar and Kamyar Azizzadenesheli

The Half Field Offense (HFO) is a subtask of simulated RoboCup where one team of players strive to score, and the other team endeavors to defend. HFO is a very difficult Artificial Intelligence (AI) problem without effective solutions currently, because of its high-dimensional state space and parameterized action space. Traditional methods hand-code each player, which need lots of human efforts and expert knowledge. In this project, we propose a sample-efficient reinforcement learning algorithm which is able to make players effectively learn how to score by themselves just using their own experiences. With our algorithm, while learning how to score, the player also trains a generative model which is a Recurrent Neural Network (RNN) to learn dynamics of the environment. The generative model can not only make long-term predictions on what will happen in the future, and thus help the player make better decisions, but also decrease the number of samples needed for training. Moreover, our algorithm tackles the exploration and exploitation dilemma by encouraging the player to explore space where its generative model cannot predict precisely.

Investigating Effects of Blocking Pumping on Defecation Cycles of C. elegans

Jingxian Chen

Mentors: Paul Sternberg and Han Wang

Pharyngeal pumping and defecation are two conserved behaviors among nematode C. elegans. Previous experiment results show that long enough after worms have been transferred away from food, their pumping ceases, along with a dramatic lengthening of their defecation cycles. However, there is also evidence showing that some mutants continue to defecate in the absence of food. Our principle objective is to investigate whether blocking pumping suppresses defecation or not. We generated four strains, two of which have the same defecation defect and respectively integrate a transgene that blocks pumping in the presence of histamine (PS8050), or that induces sleep upon heat shock (PS7823). The other two strains have another defecation defect, and either of the two transgenes as well (strain name not assigned yet). Feeding on histamine plates, we found defecation of PS8050

also ceases while in control experiment using strain PS7199 defecation cycle lengths before and after feeding on histamine plates are robust and steady. Thus, our principle conclusion is that blocking pumping represses defecation cycle in *C. elegans*. More experiments on the other strains are to be conducted.

Development of Classroom Space and Scientific Labs in Virtual Reality

Lucy Chen

Mentors: Santiago Lombeyda and George Djorgovski

Virtual reality (VR) has showed promising results in creating a sense of immersion that enhances the understanding of perceived visual information, as well as simulating the feeling of social presence. We take advantage of these features to develop a classroom and scientific lab in virtual space in order to improve online and scientific education. There are certain models or environments that can be generated in VR but not in real life due to technological, cost, or safety restraints, so we have developed a platform that allows multiple users to collaboratively interact with models such as 3D data sets, particle simulators, and 3D meshes as if they were directly in front of them. Furthermore, we utilized formal contextual inquiry methods to conduct field research on user experience (UX), via various in-class observations and professor interviews. Using those results, we have designed an ergonomic space that implements surveying and signaling methods to make teacher-student interactions more seamless and meaningful, as well as increasing student privacy to minimize social discomfort that may act as learning barriers in a classroom. Through our UX studies, we combine the benefits of VR, online courses, and real-life classrooms to enhance learning.

Numerical Modeling of Time-Independent Accretion Disc With Instabilities and Self-Irradiation Hverin Cho

Mentor: Sterl Phinney

The most powerful astronomical sources of ultraviolet and X-ray radiation are accretion discs: around white dwarfs, neutron stars, and black holes. Accretion discs are not steady flows but are subject to numerous instabilities. Our goal is to make a general model of accretion disc instabilities that can be used to understand observed transient phenomena. This model can cover all types of accretion discs, from those in quasars around supermassive black holes, to the tiny discs around white dwarfs/neutron stars. I started with accretion discs, assumed to be in equilibrium, geometrically thin, optically thick, and non-self-gravitating. Up-to-date opacity tables and equations of state from Modules for Experiments in Stellar Astrophysics(MESA) were used to generate realistic models. Solutions show the thermal instability where density has multiple values between which a time-dependent disc cycles. Next, convection was considered for regions with high opacity, since in this region, transport of heat via convection dominates over radiation. Finally, self-irradiation was also considered. This matters when the height to radius ratio is increasing with radius. The outer disc can be heated by irradiation from the hot inner disc more than by locally generated heated. This changes the location and timescale of thermal instabilities.

Validation of the COGEF Method as a Tool for Systematic Development of Mechanophores

Nicolas J. Choquette Mentor: Maxwell Robb

Polymer mechanochemistry focuses on force mediated chemistry using polymer chains to transduce mechanical force to mechanically sensitive molecules called mechanophores. Mechanophores undergo transformations varying from the release of small molecules, changes in color, chemiluminescence, and acid generation. The development of new mechanophores is challenging and testing their mechanochemical activity experimentally is a challenging process. The ability to reliably screen new mechanophores via computational methods would be valuable for the development of new mechanochemically active materials. The goal of this research project is to validate the commonly employed 'Constrained Geometries simulate External Force' (CoGEF) computational method for predicting the mechanochemical behavior of molecules. To accomplish this goal, we first assembled a comprehensive collection of molecules from the literature with experimentally studied mechanochemical properties. DFT calculations using the CoGEF method were performed on each molecule in this survey and the predicted behavior was compared to the published experimental results. We focused on the B3LYP/6-31G* level of density functional theory which is used widely in the literature and has an appropriate balance between accuracy and computational cost. Our evaluation of putative mechanophores, as well as molecules previously demonstrated to predicting mechanochemical behavior.

Sample Complexity in Human-Robot Interaction

Rohan C. Choudhury Mentors: Anca Dragan and Yisong Yue

As robots become increasingly capable of complex tasks, training them to collaborate and interact effectively with humans grows more and more important, especially in domains such as self-driving cars. Examples of such collaborative behavior include complicated lane changes, or signaling intent to other drivers at a busy intersection. In this work, we determine the sample complexity of model-based and model free approaches for training

autonomous vehicle agents to interact with humans in a range of scenarios. The model-free approaches we consider are constrained policy gradient methods, such as Trust Region Policy Optimization (TRPO) and Proximal Policy Optimization (PPO). The model-based methods we use are based on predicting the human action either through a neural network or through Continuous Inverse Optimal Control (CIOC) and solving the resulting nested optimization. We find that model-based approaches, while less flexible and more sample dependent, have much lower sample complexity than model-free methods. On the other hand, while model-free deep reinforcement learning methods work across a wider range of scenarios, the sample complexity is significantly higher than with model-based planning approaches.

Parcellation of Human Ventral Occipital Temporal Cortex With Deep-Learning Network

Xingjian Chu

Mentors: Doris Y. Tsao and Pinglei Bao

Ventral Occipital Temporal Cortex (VOTC) is crucial for human object recognition behavior. Although several category-selective areas have been identified in this part of cortex, the unifying functional organization rule is still not clear. To tackle this question, we analyzed a public functional magnetic resonance imaging (fMRI) data set including subjects' data who viewed almost 5,000 distinct images depicting real-world scenes. We passed though these images into AlexNet and built an object space that was computed by performing Principle Component Analysis (PCA) on responses of units in the fully connected layer 1. For each subject, the response of each voxel was modelled as a linear combination of 50 object axes. Applying PCA on the projection of all voxels revealed several principal components (PCs) highly consistent across subjects, which presented the basic functional structure of VOTC. Several areas could be parcellated based on their modulation on these PCs which are consistent with the regions defined before. In addition, the linear model can help us build a linear regression model to decode the image's identity for each subject. Further work will focus on trying different dimensionality reduction methods and different layers of the neural network to improve the decoding accuracy.

Investigation of Interactions Between Multiple Enhancers of *twist* **in Early** *Drosophila* **Development** Hong (Amy) Chung

Mentors: Angelike Stathopoulos and Jihyun Irizarry

Twist (twi) is a basic helix-loop helix transcription factor essential to Drosophila embryonic development that specifies the mesoderm and promotes invagination of the ventral furrow by activating various target genes. These functions are conserved in higher organisms and aberrant twi activity often leads to multiple human diseases. Enhancers act in a coordinate fashion to regulate diverse gene levels. In Drosophila, two twi enhancers are present: proximal element (PE) enhancer and distal enhancer (DE). Previous studies using reporter constructs suspect that PE activates the twi promoter in early-stage embryos; however, no studies have been done regarding the functions of the distal enhancer. To study the roles of these two enhancers, we take a deletion approach. We delete PE and/or DE at the endogenous locus via the CRISPR/Cas9 system and assess twi expression in these mutant lines by in-situ hybridization. Furthermore, to investigate the functionality of each enhancer, we examine the expression levels of downstream genes such as snail, and investigate ventral furrow invagination. Unlike reporter assays done in the past, manipulation of enhancer activities at the endogenous locus may provide mechanistic insight into how multiple enhancers coordinate to support endogenous gene levels. Furthermore, six mesoderm genes including twi were reported to have similar transcriptional trajectories during early Drosophila embryonic development, suggesting that mesodermal genes may share a similar mechanism where multiple enhancers support endogenous gene levels. Thus, this study may elucidate a molecular mechanism where gene level coordination is mediated by multiple enhancers, for not only twi, but also a variety of other mesodermal aenes.

Design and Simulation of an On-chip Silicon Nanophotonic Resonator for Implementing the Digital AFC Protocol

Dimitrie-Calin Cielecki Mentors: Andrei Faraon and Ioana Craiciu

Light-matter interfaces play a vital role in the development of quantum networks. On-chip optical quantum memories for storing photonic qubits are an important application. Rare earth ions doped crystals are promising quantum storage systems when different protocols are used, such as atomic frequency combs (AFC) and controlled reversible inhomogeneous broadening (CRIB). Digital AFC is a new scheme that combines both AFC and CRIB for dynamical control and miniaturization of the on-chip memories. This project aims to design and simulate a silicon optical resonator on erbium-doped yttrium orthosilicate (YSO) with photonic crystal mirrors. A high cavity quality factor and a large mode fraction in YSO to couple the optical mode to the ions are required. The dimensions of the photonic crystal mirrors are optimized for largest ratio of the photonic band-gap to the midgap frequency. A potential increase of the mode fraction in YSO comes from a slotted waveguide design, but it has multiple limitations, which will be discussed. On-chip electrodes at low voltage are used to achieve the necessary electric field gradient to enable the CRIB protocol, part of the Digital AFC scheme. Meep and COMSOL are used for the optimization of the design.

Laser Induced Fluorescence of a Dusty Plasma With an Acousto-Optic Modulator

Robert Clemenson

Mentors: Paul Bellan and Ryan Marshall

The Caltech dusty plasma experiment utilises a weakly ionised Argon RF plasma, an injected supply of water vapour, and two LN_2 cooled electrodes that cause the water vapour to freeze. This experiment is relevant to various astrophysical dusty plasmas, including protoplanetary disks and Saturn's E, F and G rings. By chopping the laser into the plasma, measurements can be made of the Argon neutral velocity distribution using laser induced fluorescence. This is done by considering the relative absorption of different frequencies scanned about the stationary absorption wavelength and considering the Doppler shift of laser light as 'seen' by the Argon neutrals. We modified the method by which the laser is chopped to instead use an acousto-optic modulator (AOM). The AOM essentially acts as a diffraction grating that can be turned on and off electronically very quickly, allowing for the first order deflected beam to be pulsed. Before the AOM, a mechanical chopper was used. This chopper was less reliable, less precise, and could not pulse the laser as fast as the AOM. We took data to explore the signal to noise ratios for different modulation frequencies.

Regulation of DNA2 by Proteins and Small Molecules

Julia Clendenin Mentor: Judith Campbell

During DNA replication, stalled replication forks and DNA double strand breaks arise when blocks, such as lesions introduced by radiation and chemotherapy, are encountered in the DNA template. DNA2 helicase-nuclease processes the damaged DNA, mediating repair and resumption of DNA replication. However, DNA2 repair results in genetic instability if not strictly regulated. Guided by previous genetic experiments, we have used biochemistry to show that RAD51 and FANCD2 proteins are two negative regulators of DNA2 nuclease. We find that RAD51 inhibits DNA2 by forming nuclease-resistant filaments on single-stranded DNA on damaged templates. Similar studies are being performed with FANCD2 and both inhibitors together. C5 is a small-molecule competitive inhibitor of DNA2 nuclease. Twelve analogues of C5 were rationally designed and synthesized for us by the Brian Stolz lab, with the goal of identifying a more potent inhibitor as a lead compound for developing a drug to sensitize cancer cells to radiation therapy. We identified two new, significantly improved and informative inhibitors. We will now test their specificity and ability to kill cancer cells. Drugs based on these compounds might offer groundbreaking impact for cancer treatment.

Improving the Post-Processing Methods Used by the Keck NIRC2 Vortex Pipeline

Therese Cook

Mentors: Dimitri Mawet and Garreth Ruane

The Keck NIRC2 vortex coronagraph is a powerful instrument used to directly photograph extrasolar planets. Performing further processing on NIRC2 vortex images enables us to drastically improve contrast limits and detect fainter planets in small orbits. My project focuses on comparing the effectiveness of different post-processing methods used by our data reduction pipeline, and measuring how the values of certain parameters relate to this. Some of these parameters include frame-to-frame rotation requirements, the number of pixels to mask off of the central region of an image, and whether to divide images into several circular annuli instead of using the full frame. Initial testing on the HR8799 system dataset has shown annular principal component analysis-based methods outperform classical methods, improving the signal-to-noise ratio of the innermost planet by a factor of 5 after fine-tuning the parameter values. Once found, such optimized parameter values can be implemented in the pipeline to improve our reduction results for existing and future observations.

Rapid Isolation and Analysis of Bacteria at Zeptomolar Concentrations

Jonathan A. Cotler Mentor: Julia A. Kornfield

Silicon-oxy-carbine membranes can be freeze cast to have a dendritic pore structure, which is ideal for maximizing residence time while still achieving high flow rates. These membranes can be functionalized with PEG to vary the retention rate of polystyrene beads in the membrane. As the beads can be used as an analogue to platelets in blood, this provides suggest that the membrane itself can be used in a way to allow whole blood to be flown through, while resisting non-specific adsorption of any particles, which allows for further functionalization to promote specific adsorption of a desired particle.

Mathematical Analysis of Precipitate Hardening in Solids

Luca Courte Mentor: Kaushik Bhattacharya

To increase the yield strength of an alloy, it is necessary to prevent the occurrences of plastic deformations. Plastic deformation is caused by the movement of dislocations and twin boundaries. Dislocations are line defects in the crystal structure and twin boundaries are surface-like defects. Contrary to twin boundaries, nature shows us that

the movement of dislocations can be hindered by the presence of precipitates in the crystal. The goal of this project is to understand why dislocations are more likely to get pinned by precipitates than twin boundaries. Therefore, we study mathematical models that describe both types of movements. Assuming a quasi-periodic arrangement of precipitates in the crystal, we are able to show that for small concentrations, the critical force that is required to move a twin boundary through a precipitate is less than the critical force required to move a dislocation. The main reason for this is that twin boundaries are surface-like defects (2D) and dislocations are line defects (1D). The critical forces for both phenomena scale with the radius of precipitates to the second and first power. respectively, which explains their difference.

Control, Guidance, and Navigation Framework for Use With a Six Degree-of-Freedom (6-DOF) Spacecrafts Dynamics Simulator

Irene Crowell

Mentors: Soon-Jo Chung, Rebecca Foust, Yashwanth Nakka, and Sorina Lupu

Autonomous spacecraft simulators provide an important avenue for research into guidance, navigation, and control (GNC) algorithms. This research focuses on designing and implementing a Robot OS (ROS) backed framework to allow for modular swapping of the three GNC components. Along with a communication architecture, the framework includes an implementation of a position and attitude controller designed in the lab for a 6-DOF spacecraft simulator and a Vicon motion capture navigation system. Implemented guidance algorithms include Fast Motion Planning (FMP) and Swarm Assignment and Trajectory Optimization (SATO), for collision avoidance and multi-agent movement respectively. Fault detection software was also implemented to improve the autonomy of the spacecraft by making use of redundant hardware systems in the event of a failure. The modular framework allows for rapid implementation and testing of new algorithms, generalized to autonomous robotic systems beyond spacecraft simulators.

Pyrite Disease: An Analysis of the Causes and Products of Pyrite Oxidation

Sarah Crucilla Mentor: George Rossman

Pyrite is one of the most common sulfide minerals, found on its own in a variety of different habits or as a constituent in many fossils. Its oxidation, also known as "pyrite disease" can be devastating to museums and scientific collections alike, as it destroys the specimen from within and produced sulfuric acid. Interestingly, despite being kept in identical temperature and humidity conditions, only certain pyrites seem to oxidize. Through energy dispersive X-ray fluorescence, we determined a correlation between the presence in the pyrite itself or its host rock of titanium, zinc, silicon, manganese, and aluminum and oxidation. The crystal habit also correlated with presence of the disease. We used Raman spectroscopy and attenuated total reflectance infrared spectroscopy to categorize the various secondary minerals in the weathering products. We determined the presence of many iron-rich and sulfur-rich minerals, as well as aluminum-rich minerals, likely indicating reactions between weathering products and aluminum-rich host rocks.

Measuring Dynamic Strength of Mg and OFHC Cu at High Strain Rates of 10³-10⁴s⁻¹

Jackson S. Crutcher

Mentors: Guruswami Ravichandran and Zev Lovinger

Uncoupling the effects of hydrostatic pressure and high strain rates in the dynamic behavior of materials is an important avenue of investigation in experimental mechanics and for achieving better ability to calibrate material models for numerical modeling. This work is the first stage of a larger research project investigating the nature of the contributions of these effects to the dynamic strength of materials by conducting high strain rate testing at high strain rates with both low and high pressures to decouple the effects of pressure sensitivity from strain rate. Stage one involves the use of a Kolsky Bar to obtain the stress-strain diagrams of cylindrical specimen (CS) and shear-compression specimen (SCS) sample geometries at strain rate sensitive while the latter is not according to the literature. The results of this work will be compared with the literature and will form the reference for the high pressure tests that will be conducted using a powder gun in the future.

Characterization of Protoplanetary Disks Around Late-Type Stars

Douglas Nicholas Currault

Mentors: Dimitri Mawet and Max Millar-Blanchaer

Although astronomers have made recent significant discoveries of Earth-sized exoplanets in habitable zones of their respective stars, details about the evolution of these planets are lacking. Using data from optical telescopes, we can gain many observational details of the protoplanetary disks in which these exoplanets are born, such as the radial profile of dust in the disks. A better understanding of how these radial profiles vary over time in both optical and radio wavelengths will allow us to understand how the size of dust in protoplanetary disk changes over time, a

key aspect of exoplanet evolution. In this project, I attempt to leverage new computational reduction techniques (Karhunen–Loève Image Projection) to analyze existing images of protoplanetary disks from the Space Telescope Imaging Spectrograph on the Hubble Space Telescope. Most of these images are from HST surveys from the early 2000s and have been reduced with classical PSF subtraction (if at all). When used on disks spanning a wide range of ages, re-reduction of these data will allow us to learn new details about the process of exoplanet evolution around late-type stars.

Characterizing a Deep Marine Chitin-Degrading Anaerobic Microbial Community

Elise Cutts

Mentors: Victoria Orphan and Sujung Lim

The most abundant renewable biopolymer in the oceans, chitin is a linear polysaccharide that makes up structural elements in organisms including fungi, algae, and arthropods (e.g. crustaceans, insects, amphipods). Annually, between 10⁹ and 10¹¹ tons of chitin are produced in the ocean. This makes chitin a significant sink for biologically accessible carbon and nitrogen. It is clear that chitin must be processed and returned to the environment since otherwise marine carbon and nitrogen would become rapidly depleted. However, the process by which this occurs remains opaque. This project seeks to identify and isolate microbes which perform the fermentative step of chitin-degradation in a microbial community isolated from sediment collected the Monterey deep marine whalefall site. Techniques such as serial transfers, manipulation of media, and dilution to extinction are used to isolate individual microbes from the community for pure culture, and TAG sequencing allows comparison of the microbial diversity observed in the various cultures and the site samples. Numerous cell morphologies have been observed in culture via microscopy in agreement with sequencing results. Further work should focus on investigating the role of community structure in the chitin-processing behavior of the community and consider implications for global oceanic carbon and nitrogen availability.

Interpolation of Discriminator of a Boundary Equilibrium Generative Adversarial Network for Free Viewpoint Face Generation

Sihui Dai

Mentor: Kin-Choong Yow

Popular entertainment comes mostly in the form of spectatorship; however, the spectator is limited to watch from a specific viewpoint. Free viewpoint television is the idea of creating a system where a spectator and freely control which viewpoint they are watching from. Due to a finite number of cameras being able to record the scene, a system to generate the views inbetween the fixed viewpoints provided by the cameras. In this project, we focus on generating inbetween viewpoints given two images of a face. To achieve this, we trained a Boundary Equilibrium Generative Adversarial Network (BEGAN) on a celebrity face dataset (CelebA) as well as other face images obtained by crawling Google images. To increase the amount of face image data we had, we used data augmentation. We used linear interpolation of the discriminator to generate inbetween views.

Seasonality in Drosophila Sun Navigation

Michelle Dan

Mentors: Michael Dickinson and Ysabel Giraldo

The fruit fly, Drosophila melanogaster, flies across vast distances by means of a navigation system which is visually guided by celestial cues. This project investigates whether seasonal temperature and light conditions affect *Drosophila* flight headings, and will shed light on how *Drosophila* might arrive at seasonally inhospitable habitats, such as the Mojave Desert. We reared wildtype *Drosophila* melanogaster under divergent daylength and temperature conditions to simulate summer, winter and spring. After reaching adulthood, flies were tethered and placed in a flight simulator, which surrounds the fly with a visual panorama in which we display a simulated sun (bright spot) or a landing site (dark, vertical stripe). A machine-vision software tracked the fly's wing strokes, allowing the fly to control the azimuthal angular velocity of the stimulus. An analysis of flight headings suggests that flies reared under winter conditions tend to fixate the sun frontally, thus performing phototaxis, whereas summer and spring flies adopted a variety of non-frontal headings, ie. menotaxis. In conclusion, this data supports the idea that seasonal conditions affect navigation strategy. *Drosophila* reared under winter conditions may develop neural circuitry which predisposes navigation towards a light source, and hence a presumably warmer habitat.

Occlusion Boundary Detection With Motion Cues

Gefei Dang Mentor: Doris Tsao

Detection of occlusion boundaries is an important task for both biological and artificial vision, as it is useful for object detection, segmentation, and motion control. In the past decade, researchers started to use motion cues, in addition to static cues, for occlusion boundary detection, and this increased the accuracy significantly. For my SURF project, I have been trying to replicate and improve the state-of-the-art method for occlusion boundary detection. The method focuses on local contextual information, and makes use of convolutional neural networks (CNNs) and conditional random fields (CRFs). It feeds three static cues and two motion cues of small patches of a picture into a

CNN, aggregates the local outcomes into a probability map on the whole picture, and refines the global outcome with a method based on CRFs. Choices of training data, values of parameters, and design of the main CNN influence the results significantly. I have focused on the tuning of these factors so that the model can reach, or even surpass, the accuracy claimed by the state-of-the-art method.

Liquid Exfoliation of Graphene Nanostripes

Dorte R. Danielsen Mentors: Nai-Chang Yeh, Jacob D. Bagley, and Deepan K. Kumar

Graphene nanostripes (GNSPs) are vertical walls of multilayer graphene with high aspect ratios that are attractive candidates for the electrode material of supercapacitors. It is possible to achieve high yield and high quality growth of GNSPs using single-step plasma enhanced chemical vapor deposition (PECVD) with 1,2-dichlorobenzene as a precursor. This method is scalable and enables fast growth at room temperature, and using low power. In order to study the dimensions and electronic properties of GNSPs, it is necessary to develop a reliable method for separating the GNSPs, and transferring them to an insulating substrate. The aim of this project is to apply liquid exfoliation as a method to separate and transfer GNSPs onto silicon dioxide. The transferred GNSPs are characterized with scanning electron microscopy (SEM), and it is studied how the yield of transferred GNSPs is influenced by several process parameters, including type of solvent, water uptake of the solvent, sonication time, centrifugation speed, GNSP concentration, and centrifugation tube material. Yields of more than 100 transferred GNSPs.

Taking a Stab at Massively Magnetic Cells: Characterization With the FORC Technique

Richard Dargan

Mentors: Joseph Kirschvink and Isaac Hilburn

Recent discoveries have shown that humans have a neural response to earth-strength, weak magnetic field changes. Transduction of magnetic field changes to neural activity is likely mediated by ferromagnetic materials such as single-domain magnetite. The magnetite crystals would be arranged in some ordered fashion in a massively magnetic cell. To learn more about this system, we must learn about the concentrations, particle sizes, and in situ arrangement of the magnetite crystals. Using first-order reversal curves (FORC), we can screen tissue samples for nanophase biological magnetic materials. The FORC technique exposes samples to precisely-controlled, DC peak magnetic fields at various strengths. In order to implement this system, we are developing high precision control of the DC magnetic field pulse to within a precision of around 0.2%.

Detecting Gravitational Wave Sources Given Skymap Probability Data From Detector Localization

Gianfranco De Castro Mentors: Jonatan Selsing and Sterl Phinney

The recent detection of gravitational waves has spurred much interest into discovering where their sources are in the sky. The three detectors worldwide are able to formulate a probability map of the sky of regions where the sources may exist given the angle at which waves are detected by each respective detectors. By analyzing the highest probability regions, we are able to, using spectroscopic data for those regions gathered from galactic catalogs, determine which specific galaxies are most likely to have hosted the gravitational wave event. Since the gravitational wave source signal decays rapidly after initial detection, our code that narrows down possible sources must be rapid and efficient to give us sufficient time to direct our telescope to our highest probability host galaxy before the signal fully decays. There is no single "right" algorithm to do this as some strategies may work for some probability maps more effectively than they would for others. Our goal is to create a program that will work effectively in the greatest amount of events possible. The ability to detect the host of a gravitational wave event is important to our understanding of galactic events, such as binary neutron star mergers, as gravitational waves are not affected as they travel across space to reach us, giving us an unaltered account of what actually occurs at the source.

Microwave Domain Analysis of Multifunctional Optical Devices

Maximilien Debbas

Mentor: Andrei Faraon

Although Metasurfaces are extremely versatile optical devices, their subwavelength thicknesses do not allow them the degrees of freedom necessary to support multiple functionalities at once. A solution currently being studied is to use machine learning to design thicker, high-efficiency devices, but these require complex 3D nanofabrication. Since Maxwell's equations are scale-invariant however, these devices can be scaled up to operate at microwave frequencies, where the complex design can simply be 3D printed much larger (on the order of centimeters). To test the devices, we built a parallel plate waveguide with a separation distance small enough such that only TEM modes can propagate to simulate two dimensional plane waves. We then illuminated the devices with a microwave beam and measured the field profiles of diffracted waves using a scanning antenna. This work allows for the direct validation of a variety of multifunctional devices compared to simulations before fabricating them in the optical

domain. Examples of multifunctional devices being considered include lenses able to focus different wavelengths of incident light to different points. Such devices have applications in cameras as a far more efficient way to direct light to color sensitive photodetectors.

Two Planets Orbiting HD97101

Cayla Dedrick Mentors: Heather Knutson and BJ Fulton

We developed a new method for detecting planets in radial velocity (RV) timeseries. Using the tools for fitting Keplerian orbits from the python package RadVel, we created a Bayesian periodogram for multi-planet systems where we have data from multiple instruments. This method was used in the discovery of two planets orbiting the nearby (38.8 ly) K dwarf HD97101. By analyzing RV data taken with Keck/HIRES and the Automated Planet Finder Telescope (APF), we were able to detect four significant periodic signals. Two were ruled out as planets using photometry and stellar activity indices to link them to the stellar rotation period and long term magnetic activity cycle of the star. We interpret the two remaining signals as planets with masses of approximately 8.8 and 52 Earth masses (a Super Earth and a gas giant about half the size of Saturn) orbiting at 0.23 AU and 1.4 AU away from the host star respectively.

A Technique for Studying Quantum Quenches Using Pulsed Microwaves in LiHoF4

Daniel Delgado Cornejo

Mentors: Thomas F. Rosenbaum and Daniel Silevitch

The magnetism of the Ising magnet LiHoF4 at near absolute zero temperatures, as defined by its quantum phase diagram, varies with magnetic field and temperature. The boundary between ferro and paramagnetism shifts depending on the presence or absence of hyperfine coupling, allowing the study of dynamic transitions in addition to static ones. We generate a pulse sequence comprised of fast chirps around the resonant frequency of a microwave cavity holding the sample to initiate the quench, driving the sample to oscillate across this phase boundary. Dynamically, this allows enthalpy to overcome entropy resulting in spins that exhibit ferromagnetic domain growth. A detailed analysis of such behavior could potentially provide an enhancement to the current quantum mechanical model and address the effects of spin disorder and the universal properties of quantum critical phenomena.

Analyzing the Transcriptional Effects of CRISPR-Targeted Micronucleation

Ramya R. Deshpande

Mentors: Cheng-Zhong Zhang and Mitchell Guttman

During mitosis, lagging chromosomes may become partitioned into rupture-prone micronuclei, defective environments that can spawn a host of genomic rearrangements characteristic of cancer genomes. Here, we overcome the challenge of analyzing the transcriptional consequences of micronucleation by utilizing CRISPR/Cas9 cutting to induce an acentric fragment and subsequently "target" a specific chromosome arm into a micronucleus; cells with micronuclei can then be extracted via laser capture microdissection (LCM) and subjected to single cell sequencing. CRISPR sgRNAs targeting the 5q arm, 1p arm, $X_a q$ arm, $X_i q$ arm and 4q arm of human RPE-1 cells were designed and characterized for micronucleation efficiency, achieving up to 15% micronucleation frequency. CRISPR/Cas9 cutting without synchronization in G₁ still yielded a significant frequency of micronucleation compared to controls, implicating micronucleus formation as a possible side effect of CRISPR editing. p53 silencing increased the frequency of micronucleation, supporting previous evidence of p53 inhibition improving gene editing efficiency. Sequencing reads from captured cells were computationally analyzed for fold-changes in expression to provide insight into transcriptional consequences of isolating chromosomes into micronuclei.

Synthesis of Nitrogen-Rich Graphene Models as a Potential Catalyst for the Oxygen Reduction Reaction in Fuel Cells

Vidhya M. Dev

Mentors: Theodor Agapie and Masanari Hirahara

Nitrogen-doped graphene nanostructures have been intensively studied as catalysts for the oxygen reduction reaction (ORR) in fuel cells. However, heavily doped nanostructures have not been as investigated. Herein, a graphene nanostructure doped with twelve nitrogens has been synthesized from the precursors 5-bromo-2-iodopyrimidine and (3,5-di-t-butylphenyl)boronic acid via a suzuki-miyaura coupling reaction followed by sonogashira coupling and 2+2+2 cycloaddition. The final compound was dehydrogenated via a reduction with sodium and characterized through UV-Vis absorption spectroscopy, single crystal x¬-ray diffraction, mass spectroscopy, and NMR spectroscopy. In future experiments, the nanostructure will be characterized by electrochemical measurements with a potential/pH diagram and elemental analysis. The ORR activity will then be evaluated using either glassy carbon disc electrodes or indium tin oxide electrodes coated with the nanostructure.

Computational Modeling of the Influence of Implicit Bias on Trait Learning

Kiruthika Devasenapathy

Mentors: Ralph Adolphs and Damian Stanley

The national conversation surrounding race has highlighted the fact that we are often unconscious of our own biases and therefore unable to mitigate their potentially harmful effects. Doing so first requires an understanding of how implicit biases interact with our decision-making processes—a task that greatly benefits from the development computational models of social interaction. Existing models only account for the effects of bias on static, one-time decisions, but this provides limited information since human relationships are continuous and interactive. In order to account for this, we used reinforcement learning algorithms instead. These models predict participants' perception of other individuals' trustworthiness and rely upon the error margin between prediction and outcome to update predictions. Thus, they are capable of predicting how the processes of bias and feedback-engaged social learning interact in forming a social representation of an individual in the human mind. Data were collected from participants through Amazon Mechanical Turk as they rated the trustworthiness of agents of different races, and implicit race bias was assessed using the Affect Misattribution Procedure. We determined that the optimal models were initialized using the linear combination of a bias metric and a population-wide fitted parameter, and updated using the product of the error margin and an individually fitted learning rate from the real-time trust feedback; thus, as a subject learns from their interactions, the model accuracy increases as well. In the future, we plan to incorporate hierarchical modeling for the learning rate parameter and determine if the computational modeling corresponds to known neurological mechanisms.

Determining the Location of RF Sensitivity

Jeremiah O. Dibble

Mentor: Joseph L. Kirschvink

Recent, but as yet unpublished research from the Kirschvink & Shimojo groups here at Caltech has demonstrated that humans have a subconscious response to changes in the magnetic field around them, similar to the response present in many migratory and homing animals. Kirschvink's lab is currently using simple loop antennae to expose people to Radio Frequency (RF), but this antenna fills the test chamber with RF. Because the current antenna exposes the entire subjects body to RF, we do not know exactly what part of the body is detecting the RF. I have constructed a smaller antenna that will only expose a small portion (a few cubic CM) of the subject to RF, which will allow me to test people who responded to the change in RF with the large antenna to determine where in the subjects body is the RF being detected. This will help those who are trying to determine what process is used by humans to detect RF, by providing constraints based on location.

Determining DosR's Impact on Non-Tuberculous Mycobacteria's Three-Dimensional Community Development and Viability

Amanda Hazel Dilmore

Mentors: Dianne Newman and William DePas

Non-tuberculous mycobacteria (NTM) *Mycobacterium avium* and *Mycobacterium abcessus* are emerging pathogens in cystic fibrosis (CF) patients. Although NTM are classified as obligate aerobes, previous work in the Newman lab characterized their host environment in CF as largely hypoxic. Another mycobacterium, *Mycobacterium tuberculosis*, possesses a well-characterized dormancy response that is upregulated under low oxygen. Furthermore, there is a significant viability defect in *M. tuberculosis* upon knocking out the response's regulator, DosR. Therefore, we hypothesize that the DosR-regulated dormancy response, which is conserved in NTM, is critical to maintain growth and viability in NTM pathogenesis when oxygen is scarce. To address this hypothesis, we examined the viability of *M. smegmatis* containing combinatorial deletions of two *dosR* genes under varying oxygen concentrations and the relative expression of DosR-regulated genes in *M. smegmatis* grown under hypoxia. We have found that *dosR* deletions dramatically reduce viability under hypoxia. In future studies, genes found to be highly expressed under hypoxia will be used as reporter genes to determine where DosR is expressed spatially in developing mycobacterial communities.

Characterizing a Targeted Protocol for Human Pulse Remagnetization Experiment

Grace Ding

Mentors: Joseph Kirschvink and Isaac Hilburn

Prior research in Kirschvink Lab has uncovered EEG evidence that the human brain reacts to changes in earthstrength, weak magnetic fields. Pulse remagnetization experiments suggest that this stimulus-response is mediated by biogenic, single-domain magnetite crystals. Based on preliminary experiments using a custom-built, whole-head pulse-coil system, an approximately uniform field with peak intensity of 70 mT through the head is enough to change how the brain reacts to different magnetic field changes. This project examines a more targeted stimulation method, using a standard MagStim transcranial magnetic stimulation setup. The system is typically used in basic and clinical neuroscience research, and generates a strong field to modulate brain activity. At larger distances from the coil, field strengths should be suitable for pulse remagnetization. Through systematic measurements of the vertical magnetic field at 1 cm increments above the TMS coil, we see that a field of 70 mT can be reached at 10 cm above the center of the coil. With more minute measurements at the millimeter level, we can get a clearer grasp of the magnetic field that will be produced through the human head and minimize effects of the magnetic field on non targeted areas of the brain.

Cell Image Segmentation With a Discriminative Loss Function

Jing Ding Mentors: David Van Valen and William Graf

A major challenge in cell imaging is the problem of identifying which parts of a microscope image correspond to which individual cells. In this project we tackle the problem with a discriminative loss function first introduced in 2017 for semantic instance segmentation. Based on existing deepcell architecture at the Van Valen Lab, we build a deep convolutional neural network (CNN) to evaluate the performance of the discriminative model on segmenting 2-dimensional nuclear data and 3-dimensional mouse brain data. The network maps each pixel to a vector-space such that pixels belonging to the same cell lie close together. With appropriate embedding dimension and post-processing steps, our final model achieves competitive performance on 2-dimensional cell image segmentation. Further research will generalize the discriminative model to higher dimensional datasets.

Exotic Quantum "Wires" From Topological Phases

Weiyi Sophie Ding Mentors: Jason Alicea and Shenghan Jiang

The study of topological phases has attracted a lot of attention recently, as the rich physics involved in the anyon excitations lays a solid foundation for topological quantum computation, one of the most exciting approaches to construct fault-tolerant quantum computers. The physics of topological phases can be further enriched with symmetry added to the system. In this paper, I will study the properties of the interface between 2 pieces of topological phases sewed together, where one of them is symmetry enriched. The system is shown to exhibit robust metallic edges as a result of the constrains imposed by the symmetry. The transportation schemes of particles across the interface are also found to be fundamentally related to the symmetry, which give rise to interesting properties of the propagating modes and phases on the edge.

Developing a Capacitive Pressure Sensor to Obtain the Center of Pressure of a Person During Walking Alrick Dsouza

Mentors: Chiara Daraio and Luca Bonanomi

The development of robotic prostheses can strongly impact the life of amputees with a significant improvement of the quality of life. In particular, actuated prosthetic legs can allow amputees to walk again and overcome daily obstacles such as stairs without major difficulties. Measuring the center of pressure under the feet is crucial for balance during movement and accurate mapping of pressure can be used in medical treatments to correct human walking pattern. Capacitive sensors are mechanically robust, electrically stable and present a simple architecture and design. These properties make them appealing to be used in a harsh environment such as the interface between a robotic foot and the ground. In this project we tested the mechanical properties of different plastics that can be used as dielectric layers for capacitive sensing. We performed compressive tests simulating the forces applied under the foot during walking. Among the materials we tested, nylon showed the best response in terms of durability and energy absorption. We also designed an electronic circuit to measure the change in capacitance of the sensor under compression and started testing its functionality. The low capacitance of the sensor will probably require improvements of this first circuit we designed to overcome the poor signal to noise ratio we observed.

Calibrating the Absolute Magnitude of RR Lyrae in the ZTF Native Photometric System

Alison Duck Mentor: Chow-Choong Ngeow

RR Lyrae stars are stars that pulse periodically and have well known magnitudes. Thus these stars are vital for estimating distances to astronomical bodies. This project calibrates the absolute magnitude of these stars in the Zwicky Transient Facility's (ZTF) native photometric filters. We selected a sample of well known globular clusters that house RR Lyrae stars that had been observed by ZTF. Then phased light curves were created from the time-series data collected from ZTF. These phased light curves were fit to templates in order to estimate the average magnitude of the RR Lyrae. Next they were corrected for extinction from galactic dust based on the color of the globular cluster and their distance. In order to calibrate ZTF's photometric systems this process will be repeated with RR Lyrae in the field of globular clusters but not members of that cluster, observed during Gaia Data Release 2. Then the results of this process with the Gaia Data Release 2 observations and ZTF observations will be compared to find the necessary calibration factor for ZTF's photometric system.

Analysis of Time Dependent Slip in the Costa Rican Subduction Zone

Joseph Duncan-Duggal Mentors: Jean-Philippe Avouac and Zachary Ross

We explore the kinematics of slip on a subduction megathrust, which lies off the coast of the Nicoya peninsula in Costa Rica, with a focus on distinguishing between coseismic, interseismic and time dependent slip, the latter of which may contain evidence of slow slip events (SSEs). We use time series obtained from a network of 32 continuously recording GPS stations in Costa Rica. The different sources of deformation in the time series are analyzed both spatially and temporally, using both principal component analysis (PCA) and independent component analysis (ICA). An inversion is also carried out for slip on the subduction megathrust at depth. It is found that coseismic slip correlates with the portion of the megathrust that was locked in the period preceding the M = 7.6 earthquake in 2012. Analysis of time dependent slip on the megathrust is ongoing.

Coherent X-Ray Imaging of Electronic Textures

Kenny Duran

Mentors: Riccardo Comin, Abraham Levitan, and Rana Adhikari

The macroscopic emergent properties of quantum matter are largely determined by the nanoscale spatial organization of electronic degrees of freedom. In order to disclose the underpinnings of this macroscopic emergent behavior, one needs to visualize materials on the nanoscale. This work is important to understanding the behavior of materials such as transition metal oxides, which manifest quantum electronic phenomena such as superconductivity, metal-insulator transitions, ferromagnetism, anti-ferromagnetism, and orbital order. The Comin group at MIT uses the NSLS-II at the Brookhaven National Laboratory to probe materials at the tens-of-nanometers scale using Coherent Diffractive Imaging (CDI) methods. CDI is an experimental technique wherein a beam of light, typically x-rays, is incident on some object and the far-field diffraction pattern's intensity is recorded. One can then use algorithms to retrieve the diffraction pattern's phase and the real-space object. We've implemented a GPU-accelerated Python program capable of performing phase retrieval on 2D CDI and transmission ptychography CDI experimental data, and that will also be able to perform phase retrieval on 3D CDI, 2D Bragg ptychography, and 3D Bragg ptychography data. We've been able to use the program on cxidb cxi files. In the future, we'd like to use this program on NdNiO₃ CDI data.

Genetic and Hormone Analysis of Downstream Targets of SUPERMAN in Arabidopsis thaliana

Stefán Eggertsson

Mentors: Elliot Meyerowitz and Nathanäel Prunet

SUPERMAN (*SUP*) encodes a putative transcriptional repressor and plays an important role in maintaining the boundary between whorl 3 stamens and whorl 4 carpels. Additionally, *SUP* plays a role in proper stem cell termination in the floral meristem. The phytohormones auxin and cytokinin have been implicated in *SUP* function and treatment with PCIB, a competitive inhibitor of auxin, rescues the phenotype. Recently it has also been shown that two auxin biosynthesis genes are direct targets of SUP binding. Treatment with BAP, a cytokinin, has also been shown to rescue the phenotype and in collaboration with two groups, a couple of cytokinin related genes have been identified through microarray experiments as potential targets of SUP. We use confocal microscopy to compare the expression of these genes in wildtype and *sup* background, to see how they are expressed together with SUP, and to look at the effects of BAP and PCIB on their expression in *sup* flowers. Preliminary data suggests altered expression in several candidate genes. However, several reporter lines remain to be imaged but primarily a lot of data has been generated and needs to be processed for further conclusions.

Interaction Between Piwi and Aubergine in Phased piRNA Biogenesis

Eleanor Elgood Hunt

Mentors: Alexei Aravin and Xiawei Huang

piRNAs are a class of small non-coding RNA that act, in complex with PIWI proteins, to silence transposable elements during germ line development. The biogenesis of piRNAs is very different from that of other small noncoding RNAs. One pathway leads to the production of phased piRNAs (so named because they have sequences that are directly adjacent in the precursor piRNA). However, the exact biogenesis mechanism is unclear. In *Drosophila*, interactions between the PIWI proteins Aubergine and Piwi, are predicted to be essential for the phased piRNA pathway. Co-immunoprecipitation was therefore utilised to confirm their interaction. Furthermore, as Aubergine and Piwi function in different cellular compartments to silence transposable elements, regulation of their interaction is required. Methylation deficient mutants and methylation inhibitors were utilised to test the effect of methylation on the Aubergine-Piwi interaction. The domains utilised by the proteins to interact were then mapped using truncation constructs and co-immunoprecipitation. Interestingly, whilst methylation decreased the level of interaction between Aubergine and Piwi, the interaction interfaces did not contain the modification sites.

Thruster, Reaction Wheel, and Linear Actuator Integration in Spacecraft Simulators

David Elliott

Mentor: Soon-Jo Chung

Systems of multiple small spacecraft hold much promise for the future of satellite technology and space exploration, but testing these systems in the 1g environment of Earth's surface is difficult. Spacecraft simulators provide a solution to this problem. By mimicking the dynamics of microgravity spaceflight, they facilitate experimental validation of guidance, navigation, and control algorithms. The spacecraft simulators in development at the Aerospace Robotics and Control Lab at Caltech use cold gas thrusters, linear and spherical air bearings, and a linear actuator to achieve realistic movement in six degrees of freedom. To enable this movement, hardware and software was designed to control each simulator's thrusters, reaction wheels, and linear actuator. The cold gas thrusters were characterized, making more precise thruster control possible. Finally, the thruster, reaction wheel, and linear actuator control hardware and software were integrated on the simulators to realize a fully-functional testbed for small spacecraft.

Using JKR Theory and Electrostatics to Model the Adsorption and Desorption of Proteins From the Surface of Nanoelectromechanical Systems Devices

Thomas Else

Mentors: Michael Roukes, Warren Fon, and Jarvis Li

Single particle nanoelectromechanical mass spectrometry (NEMS-MS) has been developed using nanoscale resonators. The inertial mass of adsorbed molecules can be measured, distinguishing it from conventional mass spectrometry. The recent development of soft ionisation techniques such as electrospray ionisation (ESI) mean that NEMS-MS is suitable for the study of large, delicate molecules such as proteins and protein complexes. These molecules often have molecular masses near or above the limit of commercial mass spectrometers. The system is being developed to allow the sorting of molecules in a sample, one by one, by molecular mass. An important process in the realisation of this technology is the desorption of proteins from the NEMS surface. In this project, protein-surface interactions are modelled using JKR theory and electrostatics. The electric field strength for the desorption are determined. To make progress with desorption experiments, a new method for ion beam deflection is required, and a multipole electrostatic deflection component was designed. Theoretical modelling suggests that the electrostatic multipole can deflect the beam by up to a millimetre, and this will be tested experimentally using an electrometer.

Galactic Archaeology: Metal-Poor R-Process-Enhanced Stars and Their Origins

Sergio Escobar

Mentors: Alex Ji and Alan J. Weinstein

Our Milky Way's stellar halo is built from both stars born in our galaxy and stars stripped from accreted dwarf galaxies. In general, we do not know which stars fall into which category. Our stellar halo contains a small number of metal-poor r-process-enhanced stars that trace the nucleosynthetic output of neutron star mergers. It has been hypothesized that such stars only form in accreted dwarf galaxies. Here, I test the hypothesis that r-process-enhanced stars are accreted by comparing the kinematics of normal halo stars to halo stars with various degrees of r-process enhancement. I use a data set of 107 halo stars that is the largest sample with a complete determination of r-process abundances for each star. The sample is of interest because it contains data on both r-process-enhanced and ordinary halo stars. I also use data from the Gaia DR2 release in April. The correlated error in the data sets is accounted for by using a Markov Chain Monte Carlo (MCMC) technique. Preliminary results using MCMC techniques show that the most r-process-enhanced stars have higher galactocentric velocities than other halo stars.

Analysis of a Correlated Random Coefficient Panel Data Model

David Fager

Mentor: Robert P. Sherman

This project will continue the development of a correlated random coefficient panel data model, proposed by Hoderlein and Sherman (2018), which allows all random coefficients to be correlated with all regressors in all time periods. This model differs from previous models in that it allows for regressors to be correlated with random coefficients from previous time periods and in particular, allows for lagged outcomes to be regressors. In this project, we aim to estimate causal effects under this rich model of endogeneity and compare the results to those of previous models. Specifically, we will estimate the first moments of this model and then test the accuracy of our estimates using computer simulations.

Noise Suppression Properties of Simple Biochemical Reaction Networks With Robust Perfect Adaptation

Meichen Fang

Mentors: John Doyle and Fangzhou Xiao

Robust perfect adaptation (RPA), the ability of adapting despite disturbances and uncertainty is essential for a functioning biological system. It has been well studied in control theory that RPA is equivalent to integral feedback control. However, control in chemical reaction networks(CRN) is significantly different from control in other fields like automatics, due to the intrinsic constraints of biochemical reaction networks, which limits possible integral variables for the system. The inherent noisy nature of chemical reaction networks also limits their ability to suppress noise. By associating logarithmic gains proposed by Johan Paulsson with stability and using linear noise approximation, we can study the noise properties of networks that can achieve RPA. Specifically, for two components networks, when the integral variable is a component of networks, which is the case of the famous negative feedback motif, it is hard to suppress intrinsic noise; while when the integral variable is a function of several components, it is possible to suppress noise. It suggests why coupling reactions. To decrease noise, the average lifetime of the controlled component is better to be much greater than those of other components. Coupling reactions can significantly suppress noise. It suggests why coupling is a common phenomenon in biological systems. We can use the method here to systematically study more general and complicated networks further.

Understanding How Artists Sketch Based on Stroke Semantics

Nicole Feng

Mentors: Julie Dorsey, Sherry Qiu, and Mathieu Desbrun

Current computer-aided design and sketching systems suffer from lack of true sketch understanding, while current nonphotorealistic rendering (NPR) techniques depend solely on geometric and image-space properties of a particular object. In reality, how a person draws is the product of many mental processes that are not understood well at all. The goal of this work is to understand *stroke semantics* and *artist intent* by using real artist drawings, collecting them in a database that preserves information about how they were drawn. Using an online tracing interface, we collect artist sketches of a variety of photographs, paintings, and images rendered from 3D models. Preliminary analysis of the order, speed, direction, pressure, inter-stroke relationships, and underlying geometry of strokes provide insight into the human process of drawing. This work represents, to the best of our knowledge, the first rigorous approach to understanding sketch semantics inspired by differential geometry, perceptual psychology, and cognition, and the construction of a sketch database which captures the relevant statistics for reuse in a broad range of future research. Semantic understanding of sketches has applications in NPR; sketch analysis, understanding, and recognition; and sketch-to-3D translation.

Direct Spectroscopic Detection of HD187123b

Luke Finnerty

Mentors: Geoff Blake and Cam Buzard

HD187123b is a hot Jupiter on a 3.1 day orbit around a solar twin. Because the planet is non-transiting, its true mass cannot be determined from radial velocity techniques. We use high-resolution ground-based spectra from Keck-NIRSPEC to directly detect the planet in the K band, using a technique previously used to detect tau Bootes b (Lockwood et al 2014), HD88133b (Piskorz et al 2016), and ups And b (Piskorz et al 2017). This technique breaks the mass-inclination degeneracy of radial velocity measurements and provides information about the contents of the planet's atmosphere, but observations in the K band are complicated by high correlation between the stellar and planetary spectra.

Distinct Distances With Local Properties

Sara Fish

Mentors: Adam Sheffer and Polona Durcik

The objective of this project is to investigate a variant of the Erdős distinct distances problem. Posed in 1946, the original distinct distances problem asks the following deceptively simple question: Given n points in a plane, what is the minimum number $\varphi(n)$ of distinct distances they determine? Erdős was able to prove that $\varphi(n)$ is asymptotically at least $n^{1/2}$ and at most $n/\sqrt{\log(n)}$. Over the decades, mathematicians improved this lower bound. In 2010, Guth and Katz proved that $\varphi(n)$ is asymptotically at least $n/\log(n)$, almost completely settling Erdős' conjecture. The original distinct distances problem spawned many related problems. One of these problems, first posed by Erdős in 1985, asks the following: Given n points in a plane which satisfy the additional local property that every subset of k points determines at least I distinct distances, what is the minimum number $\varphi(n,k,l)$ of distinct distances they determine? Despite the seeming simplicity of this modification, very little is known about the behavior of $\varphi(n,k,l)$ in general. In this project, we attempt to find an upper bound of $\varphi(n,k,l)$ by introducing an explicit construction and a lower bound of $\varphi(n,k,l)$ by considering additive energies.

Characterization of the Lifetime of Synthetic Circuits

Emanuel Flores Mentors: Richard M. Murray and Andrew D. Halleran

Synthetic biology enables engineering of living organisms. Complex genetic circuits can be assembled and 'booted up' inside cells in a rapid and predictable fashion. However, expression of synthetic circuits imposes a cost on cells by siphoning off the host's transcription and translation machinery. This cost, known as burden, is characterized by a decrease in the host's growth rate. Mutants that inactivate the circuit grow faster than engineered cells and therefore will overtake the population, ending the synthetic program. This universal feature of synthetic circuits imposes a limit on the lifetime of programmed cellular functions. We exploit a simple model system of an inducible activation circuit and perform mathematical modeling to better understand the biological principles underlying the stability of genetic circuits.

Comparing Abundance of synGAP Isoforms in the Post Synaptic Density

Scott Fordham

Mentors: Mary Kennedy and Tara Mastro

Comparing the abundance of synGAP isoforms, alpha1 and alpha2 in the postsynaptic density (PSD) allows for analysis of synGAP and its role in long term potentiation of excitatory synapses. The abundances of synGAP isoforms were compared by quantitative western blotting. In brief, a known amount of postsynaptic density protein was loaded onto a 4% stacking and 8% resolving acrylamide gel containing SDS. Once separated the proteins were transferred to PVDF membranes through electrophoretic transfer, blocked, and incubated with primary antibodies overnight. Visualization was achieved through fluorescent secondary antibodies, against the host species of the primary antibody, that are scanned on the LI-COR Odyssey scanner and quantified using the LI-COR Image Studio software. A linear range was established for the antibodies and isoform specificity was confirmed. Initially the abundance of the synGAP isoforms has been compared between *wildtype* mice and mice heterozygous for *synGAP*, in both PSD and homogenate fractionations. Further research will determine the expression and abundance of the two synGAP isoforms of interest in mice that lack the *Tau* gene which is a critical protein in the development of Alzheimer's.

Sculpting of the Outer Kuiper Belt by Planet Nine

Maya Fuller

Mentor: Konstantin Batygin

The presence of Planet Nine, a hypothetical planet whose orbit is far beyond that of Neptune, could explain the odd orbits of a group of trans-Neptunian objects (TNOs). In 2014, it was first noted the arguments of perihelion for distant objects in our solar system clustered about 0°. It was later found that this clustering only had a 0.007% probability of occuring by chance, meaning the clustering was most likely the result of some dynamical processes. This led to the realization that a giant planet in the outer solar system could explain the clustering of some TNOs as well as a few other long-held mysteries of the solar system (e.g. the 6° obliquity of the sun). A critical question that is still struggled with is how much the distant Kuiper Belt is being shaped by Planet Nine and what fraction of distant Kuiper Belt objects have been recently scattered out by Neptune to long-period orbits. By analyzing N-body simulations of the solar system under the influence of Planet Nine using the N-body integrator REBOUND, I gained key insight into the degree to which Planet Nine shepherds objects in the solar system.

Second Harmonic Generation as a Function of Angle of Incidence

Elisabeth Gallmeier Mentors: David Hsieh and Alon Ron

Optical techniques are flexible methods of studying a material's crystallographic, electronic, and magnetic properties. However, researchers often laboriously set up, align, and test experimental setups, which may detract from a researcher' time spent performing the experiment. We present a method of controlling a laser beam's polarization, amplitude, angle of incidence, and azimuthal angle relative to a sample that requires minimal movement of optical components. We directly imaged the laser beam with a webcam to characterize the beam and quantify effects from optical aberrations as a function of angle of incidence. We subsequently tested the setup's capabilities by performing rotational anisotropy measurements on GaAs around its [001] axis using Second Harmonic Generation.

Burden Reduction in Gas Vesicle Producing Cells via Stress-Induced Feedback Regulation

Thomas Gallup

Mentors: Mikhail Shapiro and Avinoam Bar-Zion

Abstract submitted and approved nbut withheld from publication.

Classifying Sparse Light-Curves Using Deep Learning

Meet Bankim Gandhi Mentor: Ashish Mahabal

Astronomy has moved from taking static snapshots of the sky to obtaining high-cadence images. Light curve is time series dataset of magnitude which is negative logarithm of flux measurement as smaller magnitude implies brighter objects. Variables with brightness varying by several standard deviations for a very short period of time are called transients. Light curves obtained from astronomical surveys are mostly irregular as observatories take certain number of images of a specific part of the sky at regular intervals of time and then return to same part of sky after completing imaging of most of the sky. Many times, transients fade faster hence we require novel methods for rapid classification. Recently, two dimensional mapping of light curves was introduced based on changes in magnitude and time differences. These dm-dt mappings which preserve features of light curves were converted into an image format so that they can be used as input to convolutional neural network which was trained on these dm-dt mappings for classification. Main outcome of the work is to classify variables recorded by ZTF using various Deep Learning techniques.

Finding Early-Type Galaxies in the CLU Ho Survey via Absorption Lines

Zhen-Kai Gao Mentor: David Cook

Census of the Local Universe (CLU) Ha survey aims to provide a more complete census of the local Universe. This survey will provide better statistics of normal star-forming galaxies and extreme galaxies which will help us to better understand galaxy evolution and the structure of the local Universe. In addition, the detection of gravitational waves provides a new tool to observe the Universe. However, coupling this new tool to electromagnetic counterparts is required to truly understand the physics. Our CLU survey will help in this search by providing the locations and distances of a more complete list of galaxies from which to perform a targeted search of GW counterparts. In the previous study of CLU Ha survey, star-forming galaxies can be found by the color excess in narrowband filters. However, this method will only find galaxies currently forming stars, and thus missing galaxies with little-to-no star formation (i.e., passive galaxies). Passive galaxies have weak absorption features that would be difficult to be detected from the color excess methods. In this project, we utilize forced photometry to reduce the scatter in narrowband colors to pick out the absorption lines from passive galaxies. We have had limited success using the single exposure images of the CLU survey; however, this method may prove successful after the full survey with deeper imaging has been completed.

Design and Prototyping of a Cable-Based Positioning System for the CAST Drone Lab Alexei Garcia

Mentors: Morteza Gharib, Marcel Veismann, and Christopher J. Dougherty

The drone lab of the Center for Autonomous Systems and Technology (CAST) is used for dynamic flight tests of experimental drones. This project focuses on the design and prototyping of a platform positioning system that uses motor driven cables to control and move an end-effector platform anywhere within a defined workspace. The system is intended to interface with motion capture cameras to act as an autonomous safety harness that mirrors the movement of drones in flight. The system can also be manually controlled to position cameras and calibration equipment anywhere within the lab. Platform position is controlled by four independent cables attached at the upper corners of the workspace and produce linear movement by continually updating motor speeds calculated from desired velocity vectors in a positional feedback loop. The design process followed a series of rapid prototyping where a small test setup was built to test the control structure and interface motion capture feedback. We are currently finalizing the control system and large scale motor system, which will be installed in the drone lab with further research.

Building an Ultrasensitive Response Motif at Post-Translational Level

Xiaofei Ge

Mentors: Michael Elowitz, Ronghui Zhu, and Lucy Chong

Ultrasensitive could be critical in higher-order regulatory systems that produce cascades, oscillation and bistable switch. In order to turn the Michaelis–Menten like input-output relationship to the sigmoidal curve, an ultrasensitive response motif at post-translational level was built. The N_TVMVP-CfaN2 and CfaC-C_TVMVP are input while TVMVP activity is output in our system. The mutN_TVMVP-CfaN(1+2) was set as a thresholding module, which can spliced with CfaC-C_TVMVP to produce an inactive mutant TVMVP. If the input lower than it, the TVMVP enzyme activity will be near zero. Therefore, active TVMVP is reconstituted only when Input level is high enough to overcome the threshold. Different concentration of input was tested for the purpose of titration under constant concentration threshold module. After comparing the result with no threshold module groups, we can see obvious ultrasensitive effect.

Applications of Neural Networks to the Prediction of Tracer Fluxes in Quasi-Geostrophic Turbulence

Tom George

Mentors: Andrew Thompson and Georgy Manucharyan

Realistic simulations of highly turbulent geophysical flows are computationally demanding and in practice impossible to achieve over large spatial or temporal scales because small-scale phenomena affect large-scale circulations via cumulative tracer fluxes. Theoretical parametrisations of turbulent tracer fluxes have been extensively studied, but these theories remain hard to validate due to the lack of simultaneous comprehensive observations of velocity and tracer fields in large-scale ocean flows. In addition, the majority of in situ and satellite observations are concentrated in the upper ocean leaving the deep ocean virtually unobserved. Here, we develop a machine learning framework to demonstrate the potential for reconstructions of turbulent tracer fluxes from a limited set of upper ocean observations. We use an idealised high-resolution numerical model of stratified ocean turbulence as a testbed to train a deep convolutional neural network to predict instantaneous domain-averaged tracer fluxes given snapshots of either the upper ocean tracer field or the sea surface height, but not both. Our framework predicts the fluxes to up to 80% accuracy and is robust against strong amplitudes of observational noise. This technique could be used to test or bypass the need for theoretical parametrisations of eddy tracer fluxes and improve the accuracy of Reynolds-averaged simulations.

Projection for WZZ Production Cross Section Measurements at the HL-LHC

Monika Getsova

Mentors: Maria Spiropulu and Jay Lawhorn

The WZZ triboson coupling is of interest to physicists in the study of anomalous gauge couplings and may be helpful in advancing the search for new physics beyond the Standard Model. The High Luminosity Large Hadron Collider (HL-LHC) struggles with differentiating the WZZ signal from other triboson couplings and quark-antiquark pairs. This project aimed to find a method to increase the WZZ signal to background ratio by first identifying possible WZZ events in Monty Carlo generated signal and background files, reconstructing the bosons, and then applying cuts to variables of the constituent particles which would in theory increase the signal to background ratio. No large increase in the WZZ signal to background ratio was achieved although some interesting observations were made throughout the process.

Active Ordinal Embedding via One-Bit Matrix Completion

Nikhil Ghosh Mentors: Yisong Yue and Yuxin Chen

We consider the problem of ordinal embedding, where the goal is to learn an embedding of a set of objects in Euclidean space such that distances correspond to a useful dissimilarity measure, from a set of noisy relative comparisons of the form "is item j close to item i than item k?". We formulate the problem of learning a distance matrix as a one-bit matrix completion problem, where we view the relative comparison queries as indirect measurements of the pair-wise distances between data points. Using the techniques of ranking from pairwise-comparisons, properties of Euclidean distance matrices, and the Nystrom extension, we are able to develop a computationally feasible algorithm for the setting where we seek to embed large numbers of points or the set of comparisons is sparse.

Analysis of Surface Markers and Proliferation Ability in Tumor Cell Lines Post UV and Riboflavin Treatment With the Mirasol System

Matthew Gladstone

Mentors: Raymond Goodrich and Alison Ondrus

The Mirasol system utilizes a reaction whereby riboflavin, also known as vitamin B2, associated with DNA becomes activated by UV light before reacting with the adjacent DNA to damage it. Though developed for leukoreduction and pathogen reduction of blood while minimizing damage to other components the same qualities may allow it to block the ability of cancer cells to proliferate whilst remaining otherwise intact. The objective of this research is to demonstrate that inactivation occurs while the tumor cell retains its immunological appearance measured by staining of surface markers including MHC complexes. After surgical extraction of a solid tumor and treatment of its cells they would then be safe to inject back into the patient whereupon they would be more immunologically visible than in the original tumor to generate a strong immune response against any remaining cancer.

Investigating the Aggregative Properties of the Fused-In Sarcoma

Mahi Gokuli

Mentors: André Hoelz and Siegfried Musser

Membraneless organelles contain high concentrations of RNA-binding proteins (RBPs) with low complexity (LC) domains, and are thought to form via liquid-liquid phase separation (LLPS). Among these organelles are stress granules (SGs), RNA/protein aggregates arising from exposure to various cell stresses. In vitro, RBPs with LC domains form liquid droplets analogous to SGs, which transition to a solid-like state. The fused in sarcoma (FUS)

protein undergoes an aberrant transition within the cytoplasm, forming fibrous amyloid-like aggregates implicated in neurodegenerative diseases such as ALS and frontotemporal degeneration. Enhanced SG assembly resulting from defective nuclear import of FUS is linked to ALS/FTD development; accordingly, SGs or other ribonucleoprotein granules may act as condensation sites for FUS aggregates. Previous studies use a GFP tag to observe the phase-separative/aggregative properties of FUS; however, in one study done by Sun et al. in 2011, FUS without a GFP tag initially formed circular ring structures, followed by filamentous polymers. This implies that the large folded GFP domain contributes to the formation of droplets. We obtain wild-type FUS and a variant which can be labeled with a dye, allowing us to further investigate the behavior of FUS by monitoring the mobility of the labeled proteins.

Smart Patch and App for Continuous Temperature Monitoring

Cristina Aimée Gómez Peña

Mentors: Chiara Daraio, Vincenzo Costanza, and Luca Bonanomi

The measurement of body's temperature has significant applications for the health diagnosis of a person. An abnormal change in temperature can help to early detect an occurring disease or condition. Temperature measurements can, as well, serve to observe the body's reaction to medical treatments. At the same time, temperature variations or abnormal temperatures can also serve to recognize different biological processes the body goes through. The recent development of flexible electronics opened up the possibility to realize wearable sensor to enable continuous measurement of body temperature. Pectin films cross-linked by divalent ions have been shown to be highly sensitive to temperature changes. Their flexibility and biocompatibility make them a suitable material for wearable devices to monitor body temperature. When an AC voltage is applied to these films, the current measured across the film has a phase shift which depends directly on the temperature. In this project, we developed an electronic circuit to measure this phase shift through an Arduino board. We implemented a 10/12-bit binary counter that counts how many clock pulses of a high frequency reference clock fits inside the output signal of a phase detector. This method allows us to characterize the fabricated pectin films in order to have an accurate temperature sensor and sets the acquisition method for developing wearable devices based on pectin.

Observing an Odd-Parity Angular Dependence on the Magnetoresistance of Rare-Earth Magnets

Juan Felipe Gomez

Mentors: Thomas F. Rosenbaum and Daniel M. Silevitch

Magnetoresistance, a change in a material's electrical resistance under an external magnetic field, generally does not change upon flipping the direction of the applied magnetic field(even-parity). A dependence on the sign of the magnetic field (odd-parity) theoretically arises from the Lorentz force upon fixing the moment of a strong magnet upon along a particular direction. This new theory predicts a dependence of the magnetoresistance on the angle between the magnetic field and magnetization in metals with net magnetic moments. The prediction is tested at room temperature using 3D-printed mounts to rotate samples of the rare-earth magnets $SmCo_5$ and $Nd_2Fe_{14}B$. The magnetic fields applied were between -5,000 to 5,000 Oe, and the observed changes in resistance were on the order of hundreds of pico-Ohms/Oe, and hence have been ignored or overlooked until now. The result is a cosine dependence of the magnetization, as predicted by the theory.

Development and Optimization of ULTRON: A Flow-Through Device for Continuous Disinfection of Domestic Wastewater

Nissim Gore-Datar

Mentors: Michael Hoffmann, Clement Cid, and Kai Liu

The Ultra-portable Three-stage Ozone-assisted Nano-filtration system (ULTRON) is a briefcase-sized water treatment system being developed by the Hoffmann group with the aim of deployment in parts of the developing world lacking access to sanitation and wastewater treatment. After over 9 months of development, the team has built a 3D-printed prototype that allows continuous flow-through wastewater treatment. However, operation parameters still need to be optimized in order to maximize the pathogen and organic contaminant removal efficiency, and design parameters require modification to enable efficient performance and large-scale production. This project aims to optimize design parameters such as size, shape and materials as well as operating parameters such as ozone concentration and flow rate. Additionally, performance of the system is quantified through biological characterization to measure log reduction values (LRV) of different classes of indicator microorganisms (*E. coli* for bacteria, *MS2* coliphage for viruses, and *Ascaris* eggs for helminths) using plate counts and fluorescence microscopy methods. The experiments and design iterations resulted in a new prototype built with readily available materials (primarily ABS and PVC piping) and having improved efficiency (flow rates up to 60 ml min⁻¹), and demonstrated promising LRVs (>5 for bacterial removal). The ULTRON system was eventually integrated into a custom-built urinal for an on-site demo planned for November 2018.

Designing Amplifiable Molecular Gene Expression Classifiers for Disease Diagnostics

Gokul S. Gowri Mentors: Georg Seelig, Lulu Qian, and Randolph Lopez

For many diseases, diagnosis can be performed through *in silico* classification of gene expression data using support vector machines (SVMs). Although many gene expression data sets have been curated to facilitate the training of such SVMs, this diagnostic approach is currently impractical for widespread clinical use due to the cost and complexity of gene expression profiling. Recently, DNA-based computers have been created to classify gene expression on a molecular level without the need for direct gene expression profiling. However, these molecular SVMs require concentrations of RNA higher than those found in biological samples. In the existing scheme, amplification is not viable, as amplification bias significantly distorts computation. Here, we propose and theoretically explore an alternative method of encoding SVM weights that would allow for a calibration process, after which the classifier can be adjusted to counteract amplification bias. We show that this method can theoretically be used to implement arbitrary SVMs regardless of amplification biases, while using fewer oligonucleotides than the existing scheme. Additionally, we developed a web application that largely automates the design and calibration of amplifiable molecular classifiers.

Innovative Methods in Exoplanet Detection

Reggy Granovskiy Mentors: Dimitri Mawet, Elodie Choquet, and Garreth Ruane

High contrast imaging involves investigating objects in close proximity to significantly brighter objects, such as in the case of exoplanets orbiting stars. A major obstacle in this task is residual diffracted light from the nearby star obscuring dimmer light of objects of interest. A combination of specialized instruments and post-processing techniques is used to overcome this by removing the noise and glare from starlight. Current post-processing techniques inevitably create imperfect models, and identification of exoplanets from processed images by examination is slow and prone to human error. Introducing machine learning techniques allows for automation of companion identification and more accurate detection. Supervised learning involves training a model from labeled data, and a large corpus of data combined with a well balanced learning algorithm can yield a highly accurate model. To train a binary classifier for exoplanet detection, I generated positive samples of patches with exoplanets present and negative samples of noise. I trained a unique random forest classifier for a given data cube to classify patches with probabilities of containing a companion. I generated binary and probability maps to show the results of my classifier. Testing this method on Beta Pictoris yielded promising results, successfully identifying Beta Pictoris b at a 99% probability threshold with few false positives. Future work could focus on creating a generalized model and experimenting with different classifiers.

Using Temperature-Sensitive Gal80 to Block GFP Induction in Larval Stage Drosophila

Nora Griffith

Mentors: Carlos Lois, Ting-Hao Huang, and Aubrie De La Cruz

Blocking misleading induction of GFP with temperature-sensitive Gal80 would help optimize our new geneticallyencoded neuronal tracing tool, TRACT, which is based on transneuronal activation of transcription. In *Drosophila*, the Rh5 driver drives ligand expression in the R8 photoreceptor and the HB eyelet. The HB eyelet makes connections with the s-LNv neurons (pdf neurons). With TRACT, we see the ligand expressed in the Bolwig's neuron (the precursor to the HB eyelet) in larva, but not in the adult HB eyelet. However, there is induction of GFP in both the s-LNV and in the I-LNv neurons, suggesting that the induction in the s-LNv is from the larval stage. To determine if this induction can be reduced, flies with the GFP reporter, Rh5 driver, temperature-sensitive Gal80, ligand, and two copies of the receptor were produced through multiple crosses. These flies were kept at 18°C until the adult stage and were separated into 18°C and 30°C for two days. The flies were dissected, immunostained, and imaged with a confocal microscope. We expect that flies kept at 18°C will have reduced GFP induction overall and flies transferred to 30°C will have induction in the I-LNvs, but little to no induction in the s-LNvs.

Bartolomé de Las Casas's *Devastation of the Indies*: The Rise of Human Rights From a Debate Over Spain's Lordship of the Indies

Heather Grotzinger Mentor: Nicholas Wey-Gomez

When Christopher Columbus set out on his initial voyage after receiving funding from Queen Isabella and King Ferdinand, his goal was to reach India and to bring glory and wealth to Spain. In addition to material goods, Columbus anticipated to find a population for Spain to exploit as a labor force. From knowledge accumulated by previous Portuguese expeditions down the West Coast of Africa, Columbus expected to find people with dark, black skin at the latitudes he was sailing to, but this was not the case when he first saw the people on the islands. The controversy over the enslavement of these people would ensue in Spain and turn into a full fledged debate decades later. The violent subjection Indians endured would not go unnoticed by a group of Dominican friars who condemned the encomienda system and the Spaniards actions. Bartolomé de Las Casas, who eventually became a friar himself, heard the Dominican's ideas and fully devoted himself to the cause of abolishing indigenous slavery. Las Casas believed in peaceful evangelization and expressed horror at the violence and war subjected upon the Indians at the hands of conquistadores in his writings. One of Las Casas's most famous works, *A Short Account of the Destruction of the Indies*, shows how Las Casas reworked language that was used by his opponents to justify slavery. Las Casas's turned his opponent's arguments to describe the Indians as inherently good people who embodied Christian values. In 1550, Las Casas would debate Juan Ginés de Sepúlveda in Valladolid over the extent of the Spanish Crown's rights in the New World and their right to enslave the native population. Both men would draw upon a multitude of sources, from Ancient greek philosophers to theologians, in order to build their arguments. This debate would question ancient notions of "natural slavery" and set precedents for the future of colonization and imperialism.

Erythrocyte Conjugation to Increase Gas Vesicle Longevity

Sirisha Gudavalli Mentors: Mikhail Shapiro and Bill Ling

Abstract submitted and approved but withheld from publication.

Data Analysis in Virtual Reality

Sarah Guenov Mentor: S. George Djorgovski

Virtual Reality enables useful visualizations of data sets that are extremely challenging if not impossible to visualize using standard visualization tools such as Excel or Python. In particular, Virtual Reality based visualization excels at allowing users to identify the number of clusters present in a data set, a step that is essential to many clustering algorithms. To identify the types of data sets that benefit most from VR visualization, I crafted sets of varying complexity, with differing numbers of clusters and different levels of overlap and discovered that closely grouped clusters separated by angles rather than distance are extremely challenging to understand in 2D but very intuitive in VR. The next phase of this project involves recruiting subjects to analyze a given data set assigned to use either VR or Excel for visualization and comparing the results so as to quantitatively compare results for each tool.

Investigating Structure of *Sc*Sgt2/A C-domain 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, the first identified pathway for ER-TA proteins is the Guided Entry of Tail-anchored proteins (GET pathway), which involves 6 different proteins, Get1-5 and Sgt2. Despite the essential role of the Sgt2/A's-C domain for binding to TMDs, there is limited structural knowledge of this region and how exactly it binds to the transmembrane domain (TMD). This project aimed to solve the structure of the ScSgt2/A-Ccons bound to the TMD of a TA protein. Multiple structural methods were used to obtain this, including x-ray crystallography and Nuclear Magnetic Resonance (NMR) spectroscopy. Multiple homologs of the Sgt2 Ccons domain were covalently linked to the TMD of the TA protein Bos1 and purified. A protein stability assay will be conducted to determine the most stable proteins and they will be expressed in labelled minimal media for structural determination via NMR spectroscopy. Crystal trays will also be set with the identified stable proteins to gain insight into the structure and binding mechanism of the complex.

Contract-Based Design of Control Systems

Steve Guo Mentors: Richard M. Murray and Tung Phan

Current control systems lack rigorous verification of system specifications, and complexity explosion results in the need for an efficient way to conjoin components. Assume/guarantee contracts prove to be an efficient mathematical framework, as their finite state machine representation allows for composition, conjunction, and refinement of separate components while avoiding the risk of ad-hoc specifications. However, current contract theory is not powerful enough for practical examples, as fixed, finite alphabet automata fail to capture many of the functions needed for systems. Thus, we extend basic contract metatheory to symbolic finite transducers, whose transitions rely on boolean predicates and therefore have a larger possible range of alphabet. We present the use of these contracts by verifying a self-driving car planner in the context of a traffic intersection, with basic features like safety and pedestrian presence, with the hope of extending contract use to more complex examples such as an automated valet parking garage.

Colliding CO₂ and H₂O Ions to Yield H₂ and O₂

Michael B. Guy Mentor: William A. Goddard

The European Space Agency was discovered molecular oxygen (O2) in the comet 67P. This is a truly groundbreaking discovery as O2 is rarely detected outside of our own planet. The original hypothesis for its presence was that it was formed in the early universe. However, Dr. Kostas Giapis has recently put out a paper that explains experimentally that simply by colliding H2O and CO2 ions at various surfaces the interaction yields O2 and H2 ions. We have set out to demonstrate this process computationally by using a silica dioxide structure given to us by Dr. Andres Jaramillo-Botero and through a series of LAMMPS calculations that will allow us to simulate the interaction and demonstrate it as a movie.

Japanese Earthquake Data Manipulation and Sensor Noise Analysis for ShakeAlert

Andrea Hands Arocha Mentor: Monica Kohler

The ShakeAlert project is a joint venture between the USGS and various university partners to develop and test an earthquake early warning system. To model larger scale earthquakes, data collected from the Kumamoto (7.0, 2016) and Tohoku (9.1, 2011) earthquakes were used, and subsets of that data were taken to simulate those same events with modified station densities. Using the Vincenty formulas for distance and various methods of interpolation, station density was calculated for the station lists. In order to model specific scenarios, the station list was edited by removing stations until our specifications were met. Sensors used in ShakeAlert are sensitive to noise that is generated from everyday occurrences, loud levels of noise have the capacity to send out false earthquake alerts to ShakeAlert. STA/LTA analysis and "spikes" are used to determine threshold levels that would categorize stations based on their noise levels. These categorizations would then be run in real time to create a self-correcting list of black-listed stations that would be continually updated in order to prevent stations from sending out false alerts.

Optimizing Transduction Efficiency of the AAV9 Virus for Acoustically Targeted Chemogenetics John Heath

Mentors: Mikhail Shapiro and Jerzy Szablowski

Abstract submitted and approved but withheld from publication.

Effects of Specific Environmental Signals on Differentiation and Proliferation in Early T Cell Development

Michelle Hendriks Mentors: Ellen Rothenberg and Mary Yui

T lymphocytes play a central role in adaptive immunity, particularly in the activation of B cells, cytotoxicity, and the production of cytokines. During development in the thymus, hematopoietic precursors undergo rapid proliferation and become committed to the T cell fate. Disruptions to these developmental processes can result in highly proliferative T cell leukaemias. Several signaling pathways have been found to be crucial to early T cell development, survival, and proliferation, including Notch and IL-7. In addition, microarray data from early thymocytes indicates high expression levels of surface receptors including PDGFRβ and CXCR4 of unknown functions during this stage. To elucidate the roles of these environmental signals in development and proliferation, different signaling conditions were applied to mouse bone marrow cells in an *in vitro* co-culture system. Cell numbers and developmental states were ascertained by flow cytometry with staining for known developmental markers. These initial experiments will allow us to better understand the roles of these signals, as well as their interactions. Furthermore, they offer insight into the relationship between differentiative and proliferative processes in early T cell development to be explored in future experiments.

Lower Limb Exoskeleton for Assisted Walking

Jesus Hernandez

Mentors: Aaron Ames and Claudia Kann

Ankles account for the majority of the required mechanical power used during walking. Thus, lower-limb exoskeletons (LLE) that aid the ankle can ease the strain of walking for non-disabled people. Previous LLEs have not been very successful because of their reliance on external support (crutches, pulley system), their inability to handle quick, precise motions, or their weight, which actually makes walking harder. At AMBER Lab we are creating a LLE that is successful in assisting walking as a result of its light weight as well as its ability to create the large torques required to aid in walking. Our LLE design consists of a shoe insert connected to a moment arm that extends past the back of the heel with a center of rotation about the ankle. Our LLE uses a series elastic actuator to create the moment about the ankle and measure force applied. Using this design and novel nonlinear-control methods we will be able to create an ankle exoskeleton, which significantly reduces the metabolic cost of transport for healthy individuals as they walk.

Effect of Local Charge on Electron Transfer Properties of Tryptophan in Cytochrome P450

Lilian P. Hicks Mentors: Harry Gray and Brian Sanders

Proteins that use molecular oxygen for metabolism and biosynthesis are subject to damage from reactive oxygen species and may have evolved protective mechanisms involving electron transfer (ET) reactions through redox active amino acids. A prime example of this type of protein is cytochrome P450, which generates high-valent iron-oxygen species and performs radical chemistry. It is anticipated that these radical transfer pathways function during uncoupled turnover to deliver strongly oxidizing holes from the fragile active site to the surface of the protein where they can be safely handled. We aim to correlate the effect of local charge on the ET properties of the Trp⁹⁶ residue, which is suspected to play a key role in a protective ET mechanism in cytochrome P450 BM3. This will be accomplished through manipulation of the amino acid residues within and surrounding the ET chain followed by photo-triggered oxidation of P450. Mutations of Trp⁹⁶ to His result in no heme oxidation, demonstrating that the Trp⁹⁶ residue is essential to the ET reaction. The introduction of anionic residues surrounding the heme propionate-Trp⁹⁶ interaction results in dramatic changes in yield and kinetics of heme oxidation. Additional mutations focus on the Arg³⁹⁸ residue, which exhibits a π -cation interaction with Trp⁹⁶.

Medical Diagnostic Applications of Single Cell mRNA Sequencing

Zev Hirt Mentor: Matt Thomson

Implementing single-cell mRNA sequencing (scRNA seq) data to evaluate an individual's health status is a new and uncharted territory. With a single sample of blood, scRNA seq can output a ~10,000 by ~20,000 data matrix which can be analyzed to give a thorough analysis of an individual's health status. By training algorithms on synthetic (and eventually, real) data sets, we are developing a new and affordable method which can help future researchers to diagnose patients at an earlier stage allowing for preventative and more efficient treatment. One such application of this diagnosis is the early detection of metastatic cancer. We are developing a method that can detect metastatic cells in an organ which can provide vital information about the primary site of cancer and how to proceed treatment.

Deploying Neural Networks for Single-Cell Image Segmentation

Andrew Q. Ho Mentor: David A. Van Valen

The identification of individual cells in microscopy images, otherwise known as image segmentation, is an essential technical requirement for many live-cell experiments. In the past, researchers have tackled the image segmentation problem using conventional methods, such as thresholding and other morphological image processing procedures. While these techniques are moderately effective, they prove to be limited in their efficiency as the scale of experiments grow larger. However, DeepCell, an software endeavor spearheaded by the Van Valen lab using Keras/Tensorflow, has shown that the implementation of deep convolutional neural networks and machine learning algorithms is highly successful at accurately identifying the cytoplasms of individual bacterial and mammalian cells. The automation provided by neural networks allows the analysis of thousands of cells, offering more accurate quantification of data and the ability to simultaneously segment and identify different mammalian cell types. While the project has had considerable success, the Van Valen Lab aims to convert the DeepCell neural network into a fully packaged image segmentation tool for the scientific community.

There were three major hurdles to overcome: 1) serving Tensorflow models from a Server, 2) creating the software architecture to properly query the Tensorflow Server, and 3) packaging the architecture using container orchestration.

DeepCell uses Keras and Tensorflow, high-level machine learning package designed by Google to facilitate the creation and training of machine learning softwares. Tensorflow possesses scalable built-in functionalities, a package called Tensorflow Serving, designed specifically for serving Tensorflow machine learning models online. Using Tensorflow Serving, we successfully created a Tensorflow Serving server that hosts and serves multiple versions of different neural networks. Next, the software architecture consists of three moving parts. First, the ReactJS user interface uploads the data for processing. The data is then sent to a Python Flask application which queries Tensorflow Serving and receives the post-processed data and returns it to the ReactJS user interface. Finally, in order to push DeepCell to deployment, we implemented Docker to "containerize" our product and Kubernetes, a portable open-source platform for container orchestration.

While the project is not complete, the underlying software structure is sound and scalable. We hope to deploy DeepCell to the scientific community soon.

Implementation of New Singular Value Decomposition Methods in the Cluster Computing Framework Apache Spark

Ankush Hommerich-Dutt Mentors: Andreas Stathopoulos and Adam Wierman

The Singular Value Decomposition (SVD) is an increasingly important factorization technique for analyzing big datasets. An SVD algorithm based on the subspace iteration eigenvalue method (SI) was previously created by Dr. Stathopoulos, and this project aims to provide a working implementation of this algorithm in the Apache Spark framework, which is a popular easy-to-use engine for performing fault-tolerant data processing across large clusters. The current SVD algorithm in MLlib, Spark's machine learning library, uses the Arnoldi Method, which may converge slower than SI when there are large spectral gaps. The process of implementing SI in Spark required research into Spark's method of representing distributed datasets and their framework for communicating between nodes, creating functions for efficient matrix operations like matrix-vector multiplication, interfacing with the native linear algebra libraries, and providing optimized caching. Once SI is successfully integrated into Spark with reasonable runtime speeds, then it will be published and merged with the official release for Apache Spark. If time permits, a more versatile SVD algorithm based on the Golub-Kahan Davidson method will also implemented in Spark. This method is the main SVD algorithm in an eigensolver software package named PRIMME that Dr. Stathopoulos also created.

Genetic Regulation of Vertebrate Sleep Homeostasis

Sarah L. Hou Mentor: David Prober

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 model organisms, 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 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. Furthermore, after recovery sleep, the sleep deprived animals have the same levels of sleep as their control siblings. We have also tested the sleep deprivation assay after administering an EGFR inhibitor to the larvae to see if sleep homeostasis is in part regulated by the EGFR pathway.

Characterization of Pose Estimation Methods for Unknown Uncooperative Spacecraft Geometry Juliette Hu

Mentors: Soon-Jo Chung, Vincenzo Capuano, and Kyunam Kim

Simultaneous localization and mapping (SLAM) is the computational problem of building a map of an agent's surroundings while simultaneously keeping track of its location in the map as it moves. The goal of our research is to investigate SLAM-based methods for pose determination of uncooperative unknown spacecraft in terms of accuracy and computational burden. With images acquired by a monocular camera, we want to retrieve a rotation matrix and translation vector of the target with respect to the camera. We will compare the performance of an EKF-SLAM-based approach to other methods such as Structure from Motion, as well as image-to-model approaches that can be adopted in case the target geometry is known.

Characterization of the Superhyperfine Interaction and Coherence Properties of ¹⁷¹Yb³⁺:YVO₄

Yan Qi Huan

Mentors: Andrei Faraon and Jonathan Kindem

Rare-earth ions in crystals are a promising platform for quantum memories and quantum information processing. In particular, ${}^{171}Yb^{3+}$ ions are attractive for this application as they have electronic and nuclear spins of 1/2, which allows for coupling to both optical and microwave photons while maintaining a simple energy level structure due to their low spin. In this work, we present a computational characterization of the energy level structure of the ${}^{2}F_{7/2} \leftrightarrow {}^{2}F_{5/2}$ transition of ${}^{171}Yb^{3+}$ in YVO by considering the Zeeman, hyperfine, and superhyperfine interactions with the nearest neighbor spins in the host crystal. We demonstrate the utility of our model by using it to successfully predict experimental spectral holeburning spectra. The superhyperfine interaction was further explored by modeling the magnetic dipole-dipole interaction of phase memory time due to this mechanism and are able to predict the coherence time for both optical and nuclear spin transitions to within a factor of 2 with no fitting parameters. The predictive power of this simulation can potentially aid in discovering accessible superhyperfine levels for future long-lived quantum memories.

Monitoring Protein Intake and Retention With Wearable Chemical Sensors

Adrian Huang Mentor: Wei Gao

Non-invasive chemical sensing techniques have found success in nutritional and medical applications, and the detection, measurement, and transmission of chemical data in sweat is possible with wearable chemical sensor arrays. We have successfully designed and characterized chemical sensors that respond to urea and ammonium. These sensors have been tested for sensitivity of urea and ammonium both in situ and in vitro and can successfully detect natural fluctuations of urea and ammonium concentrations in sweat. We focus on measuring sweat samples of human subjects before and after single meals and over long-term dieting. We have shown that urea and ammonium concentrations rise after a meal and are also higher in those with high-protein diets. Additionally, uremia (retention of urea in the bloodstream) is caused by partial or complete kidney failure; urea in the bloodstream is present at ten times higher concentration in uremic patients compared to healthy subjects. Excretion of urea from the bloodstream into sweat allows for the diagnosis of uremia using urea and ammonium sensors within minutes and without requiring extraction of internal bodily fluids.

Cloning and Expression of Hedgehog Proteins

Christie Huang

Mentors: Alison Ondrus and Rahul Purohit

The Hedgehog signaling pathway is an important developmental pathway for embryogenesis in metazoans. When the Hedgehog pathway is not regulated properly, its activity leads to congenital deformities and various human cancers. The protein I have focused on is the Hedgehog (Hh) protein itself, which is responsible for activating the pathway and undergoes a unique autocatalytic proteolysis. While fragments of Hh proteins have been crystallized, we aim to crystallize the full length Hh proteins from several different species. Using the Ligation Independent Cloning (LIC) method, I have been working to clone seven different Hh proteins (Chicken Sonic Hh (Shh), Fly Shh, Frog Shh, Zebrafish Shh, Human Desert Hh (Dhh), Human Indian Hh (Ihh), and Human Shh) into two backbone vectors with different tags for protein purification (TRX and His). Of the fourteen constructs, I have been able to successfully clone five (His-Chicken Shh, His-Fly Shh, His-Human Dhh, His-Human Ihh and TRX-Human Ihh). I have also performed expression tests on four of the five successful constructs (His-Fly Shh, His-Human Ihh), and TRX-Human Ihh) and verified via western blot that I have obtained the full length protein from each of these constructs.

Modification of a Hopping Robot

Cindy Huang

Mentors: Aaron Ames and Eric Ambrose

Hopping robots that use a clutch mechanism may possess an advantage over hopping robots that use a moving mass mechanism by allowing larger amounts of potential energy to be used in its motion. A 7" by 7" by 17" linear hopping robot with a clutch mechanism is manufactured with aluminum parts. Potential energy in this robot is obtained when a motor compresses an 8.33 N/mm spring and released when a linear solenoid detaches its lower gear system. A Teensy Arduino manages the robot's commands and implements a PID controller to achieve the desired spring compression in accordance with real-time feedback.

Characterising the Morphology of Dopaminergic Neurons in NF1 Knock-Out Mice

George Hudson Mentors: Viviana Gradinaru, Elliott Robinson, and Gerard Coughlin

Neurofibromatosis 1 (NF1) is an autosomal dominant condition affecting 1/2500 people worldwide. Although characterised by skin lesions, some NF1 patients present with cognitive defects thought to be due to undermaturation of dopaminergic neurons in the ventral tegmental area (VTA) of midbrain. Thus, to shed light on the pathophysiology of NF1, we decided to characterise the morphology of these neurons in an NF1 knock-out mouse model by using 3 systemic adeno-associated viruses (AAVs) to deliver fluorescent-protein-encoding transgenes into the VTA. As transduction is stochastic, different cells receive different ratios of the transgenes and each adopts a unique colour hue, allowing differentiation between neurons. In this way, we work towards the tracing of individual dopaminergic projections and quantitative assessment of their morphology using confocal microscopy. We therefore hope our results will build upon the previous work of the Gradinaru lab which has shown functional differences in dopamine release for this mouse model.

Fabrication and Electromechanical Characterization of Ferroelectric Ceramic Barium Titanate

Nerys Huffman

Mentors: Katherine Faber and Wei-Lin Tan

Ferroelectrics are materials with inducible switching of electric polarization through mechanical stress or applied electric fields. Previous studies by Wojnar, le Graverend and Kochmann on lead zirconate titanate (PZT) have shown that electromechanically cycling ferroelectric ceramics can induce high damping characteristics. This is

unusual as ceramics are typically brittle and their damping capabilities are often limited. To better understand this phenomenon, this project aims to study the electromechanical characteristics of polycrystalline barium titanate (BT), which is similar to PZT but has a simpler crystal structure and has been widely studies in its single crystal form. Our objective is to optimize fabrication of dense polycrystalline BT beam specimens which will then be characterized electromechanically via Broadband Electromechanical Spectroscopy (BES). Although BT beams have been successfully fabricated, their high porosity and internal cracking prevent the use of high electric fields for electromechanical testing. Several methods to improve the quality of BT beams such as the use of nanopowders, higher pressure, and different sintering profiles have been explored.

Sulfur Isotope Composition of Organic Matter From the Monterey Formation: Implications for California Margin Redox Conditions in the Late Miocene

Ella Hughes

Mentors: Alex Sessions and Xingchen Wang

This study presents continuous records of the isotopic composition of organic sulfur ($\delta^{34}S_{org}$), a potential recorder of past biogeochemical conditions, from two basins of the organic-rich Miocene Monterey Formation. In the relatively restricted San Joaquin basin, $\delta^{34}S_{org}$ values decreased progressively from ~+5‰ at c. 13 Ma to near -20‰ at c. 6 Ma. These low $\delta^{34}S_{org}$ are similar to the modern Santa Barbara Basin and likely reflect increasing contribution of low- $\delta^{34}S$ sulfide in the sediments or water column with progressive basin isolation and expanding anoxia. In contrast, within the less restricted Santa Maria Basin lower phosphatic shales have average $\delta^{34}S_{org} \sim 17\%$ and upper siliceous shales have average $\delta^{34}S_{org} \sim 24\%$. This latter value is the highest yet reported for marine organic sulfur, and roughly 2-3‰ higher than Miocene seawater sulfate. The abrupt ~7‰ increase in average $\delta^{34}S_{org}$ in the Santa Maria Basin is coincident with a sharp lithostratigraphic contact at c. 11 Ma, but is not clearly reflected in other geochemical parameters. Such a shift in $\delta^{34}S_{org}$ implies a change in sulfurization regime that may in turn reflect a rapid transition in basin conditions. Possible environmental and biotic mechanisms underpinning these records are likely complex and will be further explored.

Integration of the BICEP Array's First Receiver: Assembling and Testing the Sub-K Insert and the Calibration Macrobolometers

Katherine Hughes

Mentors: Jamie Bock and Alessandro Schillaci

The BICEP Array telescope is designed to measure the CMB's polarization in search of primordial gravitational waves originating from inflation. In its cryostat, epoxied carbon fiber truss legs support and thermally isolate the sub-Kelvin cryogenic stages. Other observational cosmology experiments have experienced failures with similar legs, damaging sensitive equipment. After performing FEM simulations on the two leg types, pull tests were designed to screen each leg we built at both room temperature and following a cryogenic cool-down – testing at stress levels more than 5x greater than their maximum operational load. We found that it's difficult to get a uniform gluing process within leg assemblies, but the pull tests provide sufficient verification of the surviving legs' strength. The screened legs were assembled into the sub-K insert for the 30/40GHz BA receiver. For the same project, we are designing, fabricating and testing macrobolometers to measure the cryostat's incoming radiative power to the 4K, 50K, and 250mK stages. We set parameters including estimated incoming power, thermal conductivity of the material, and desired temperature change to correctly design the macrobolometers. After building, they will be calibrated in a test cryostat and later used inside the BICEP Array to ensure the filters are working properly.

Further Computational Optimization of Statistical Inference With Temperature and Magnetic Conditions Zev Imani

Mentor: Matt Thomson

Statistical fluctuations present in Ising Spin Models allow the inference of underlying Coupling Matrix connections through machine learning. Working with a pre-existing inference algorithm I significantly improved the line search methods by applying a conjugate gradient descent function, greatly reducing the computational difficulty of network inference. Recent findings suggest a relationship between network dynamics and learning limits; the intensity of interference and fluctuations varies according to the physical characteristics of the system. The correlation between temperature and interference means that there exists an optimal temperature at which inference is most efficient. Applying this concept, I developed a temperature sweep to determine the optimal temperature at which the Fisher Information is maximized, and inference is most efficient. The magnetic field present in the system also affects the learning efficiently. Therefore, I applied an additional magnetic field sweep, which yields the optimal magnetic conditions for the determined temperature, at which inference is most computationally efficient.

Development and Implementation of Aerodynamic Models for Simulation of Autonomous Air Transports Michael Iovine

Mentors: Soon-Jo Chung and Xichen Shi

The unmanned flying ambulance is a proposed vertical takeoff and landing vehicle that is currently in development. In the interest of testing autonomous features for the flying ambulance without the need for hardware, we have built a virtual simulator that uses the real flight controller firmware for control and a physics engine for feedback. A model for the computation of lift and drag forces was developed to match the experimentally observed properties of the vehicle. Another model was developed for the computation of forces and moments imparted on the vehicle by the rotors. Physics engine plugins were developed to implement these models.

Light Dark Matter eXperiment - Active Target Candidate and Hadronic Calorimeter Research and Development

Maheck Jerez Terceros Mentor: David Hitlin

The Light Dark Matter eXperiment (LDMX) is an accelerator experiment planed for the Stanford Linear Accelerator Center (SLAC). It will be searching for dark matter in the sub GeV energy range, specifically looking for dark force carriers in rare "dark bremsstrahlung" interactions. These interactions are characterized by a deflection of a charged particle after interaction with a nucleus, with no other conventional matter showers produced. In order to differentiate these effects from conventional bremsstrahlung and other interactions, there must be no charged or hadronic matter produced, and there must be no photons present from normal bremsstrahlung. An actively scintillating target must be used in order to detect the production of photons in the target that could normally be lost to photonuclear reactions. There must also be a large and highly efficient hadronic calorimeter veto system that forces neutral reaction products to create an electromagnetic shower that can be detected with polystyrene scintillator bars with high levels of spacial resolution for momentum reconstruction. Here, LYSO is studied as a potential candidate for the active target due to a short interaction length and quick scintillation properties, and the optimal geometry for scintillator bar readout is explored for the hadronic calorimeter.

Learning Lorenz-63 Parameters Using Ensemble Kalman Inversion for Data Assimilation

Rupesh Jeyaram

Mentors: Tapio Schneider and Andrew Stuart

Climate modeling is an essential tool in environmental science, allowing researchers to quantitatively predict earth system processes such as atmospheric, oceanic, and geochemical behavior. To learn the unknown parameters in climate models given simulation data, a data assimilation technique known as Ensemble Kalman Inversion is used. The aim of this project is to develop an online version of this algorithm and determine its performance and accuracy in the Lorenz 63 model setting. The algorithm has been tested with varying frame sizes, noise levels, and ensemble sizes. The online algorithm runs predictably faster than the existing algorithm, and is within tolerable accuracy of the truth values. This online algorithm can now be used to increase efficiency for many climate modeling situations in which simulations are computationally intensive. This will allow tests to run in a fraction of the time as they do now.

Studying Cancer-Relevant Cysteine-to-Tryptophan Mutation at the [Fe₄S₄] Cluster of Endonuclease III Under Nitrosative Stress

Qixuan (Alice) Jin

Mentors: Jacqueline K. Barton and Levi A. Ekanger

In biological systems, DNA repair enzymes correct mutagenic lesions in DNA that may otherwise lead to disease. Base excision repair (BER) enzymes identify base pair mismatches with the aid of their structural [Fe₄S₄] clusters. Recent research in the Barton group discovered that a cysteine-to-tryptophan mutation in the [Fe₄S₄] cluster of the BER enzyme MUTYH is highly associated with colon cancer and polyposis in humans. The mutated enzyme is more susceptible to degradation. Nitric oxide, a biological signaling molecule, has been shown to degrade [Fe₄S₄] clusters. The excess production of nitric oxide is also correlated with colon cancer. We model the MUTYH mutation with the homologous mutation in the BER enzyme Endonuclease III (EndoIII). We induced the cysteine-totryptophan mutation in the *nth* gene of a plasmid, which encodes for EndoIII, with the molecular biology technique of site-directed mutagenesis. We transformed the mutated plasmids into *E.coli* cell cultures engineered for protein overexpression and verified that the mutagenesis was successful with DNA sequencing. We overexpressed the mutant EndoIII protein in incubated cell cultures and optimized our anaerobic protein purification protocol to maximize protein yield. We will measure the reaction rates of nitric oxide with the wildtype and mutant EndoIII enzymes. We will further characterize the reaction products through spectroscopy techniques and electrochemical studies.

Early T-Cell Development: OP9-DL1 and -DL4 in vitro Co-Culture Systems

Suin Jo

Mentors: Ellen Rothenberg and Wen Zhou

T-cell developmental studies have largely benefited from in vitro co-culture system, which facilitates T-cell differentiation from stem cells by providing Notch-Delta signal, one of the principal actors for T-lymphopoiesis. OP9-DL1 system is the widely-used one; generation of T-cells can be achieved by co-culture with OP9-DL1 cells expressing a Notch ligand, Delta-like (DLL) 1. However, while both *in vivo* thymocytes and *in vitro* OP9-DL1- incubated cells can differentiate towards the T-cell path, several discrepancies including its transcriptome have been observed. Indeed, since DLL4, but not DLL1, was critical in the thymus for T lymphopoiesis, a necessity of DLL4 feeder system has arisen. Here, we characterize OP9-DL4 co-culture system in terms of its general features, DLL4 surface expression level, T-cell development from bone marrow cells (BMC), and permissibility for the other lineages in comparison with the OP9-DL1 system. Interestingly, despite 10-fold less DLL surface expression than OP9-DL1, OP9-DL4 also supported T-cell path with distinct developmental pattern but gave rise to more non-T lineages, also note-worthy. To scrutinize the OP9-DL1/DL4 systems, total RNA sequencing on the BMCs at different developmental stages as well as on the OP9-DL1/DL4 cells has been conducted. Lastly, we identified OP9-DL4 clones expressing various levels of DLL4 by FACS.

Implementation of a Simulation Module for Adaptive Charging Algorithms for Electrical Vehicles Daniel Johansson

Mentors: Steven Low, James Anderson, and Zachary Lee

Our energy system is on the brink of change when it comes to making it more sustainable to reduce the system's negative impact on the climate, nature and our societies. Aside from the difficulties with production of the energy, a major part of the vision of a fully sustainable future is to make the transportation system electric. This implies an extensive expansion of charging infrastructure which will put a large load on the future power grid. To limit this stress, adaptive charging algorithms are used on large-scale charging networks to minimize power usage but still supply every electrical vehicle with the energy requested. For evaluating the performance of different charging algorithms, a physical testbed called Adaptive Charging Network (ACN) has been developed at Caltech. In this project, we have implemented a simulation module in the ACN Research Portal that will allow researchers to test and analyze charging algorithms before applying them to the real system. This reduces the risks of accidents and damages to the infrastructure. To further increase its usefulness, the simulation module also implements a data-driven statistical model that is based on real data from the ACN to generate the EV charging sessions used in the simulations.

Studying Minimal Winning Coalitions of Transitive Voting Rules

Maya Josyula

Mentors: Omer Tamuz and Wade Hann-Caruthers

We study "transitive" voting rules, which are election systems that are egalitarian, in the sense that all voters play the same role. In particular, we study the size of minimal winning coalitions in such rules; these are sets of voters who determine the election result when they all agree. While it is well known that under mild conditions all perfectly symmetric voting rules have to be majority rules---and that hence have minimal winning coalitions of size half of the population---we show that transitive voting rules can have much smaller winning coalitions, of size proportional to the square root of the size of the population, but no smaller. For a particular type of transitive voting rules---which we call generalized electoral college rules---we show that the minimal winning coalition is of size that is proportional to the population size to the power of log 2 / log 3, and that this bound is tight. Not coincidentally, this exponent is the Hausdorff dimension of the Cantor set.

The Role of Non-Homologous End Joining in Creating Large-Scale DNA Rearrangements in Chromothripsis

James Jusuf

Mentors: Cheng-Zhong Zhang, Alexander Spektor, and David Van Valen

Chromothripsis is a recently discovered mutational phenomenon that produces massive rearrangement of one or a few chromosomes in a single catastrophic event. The pattern of rearrangements suggests that the affected chromosome(s) are subject to fragmentation followed by random recombination. Experimental studies have shown that chromosome fragmentation can be caused by abnormal nuclear structures called micronuclei, and chromothripsis is generated when damaged DNA from micronuclei is reincorporated into the primary nucleus. However, the exact mechanism by which chromosomal fragments are joined together after reincorporation is unknown. To partially address this question, I tested whether the non-homologous end-joining (NHEJ) pathway is necessary to generate chromosomal rearrangements in chromothripsis. I artificially generated micronuclei in normal cultured cells, identified and picked cells with reincorporated micronuclei, and constructed DNA sequencing libraries of these cells. I then repeated the experiment on cells with knockout of DNA ligase 4 (LIG4), since LIG4

knockout inactivates NHEJ. Surprisingly, micronuclei generated in LIG4 knockout cells never got completely reincorporated into the primary nucleus following cell division. This unexpected result raises interesting questions about how LIG4 knockout may affect DNA damage accumulation and chromosome fragmentation in micronuclei. I will discuss potential mechanisms behind this observation and ways to test them experimentally.

Finite Connected Planar Graphs as a Projective Fraïssé Class

Luke Juusola Mentor: Aristotelis Panagiotopolous

Classical injective Fraïssé Theory has become a powerful tool in bridging model theory and finite combinatorics. In 2006 Irwin and Solecki introduced a dualization of this classical theory --- known as Projective Fraïssé Theory --- that has proven useful in studying the dynamics of various topological spaces in terms of finite combinatoric. Here, after proving the class of finite connected planar graphs is projective Fraïssé and a canonical quotient of its limit is homeomorphic to the Sierpinski Carpet, we use various facts about the combinatorics of the graphs to study the Sierpinski Carpet.

Riemann Surfaces and an Alternative Proof to Teichmüller's Theorem

Yeorgia Kafkoulis Mentor: Vladimir Markovic

A basic question central to most pursuits in topology and geometry is how to properly classify surfaces. Via the Riemann Mapping Theorem, topological and conformal classification is related, but in a very crude way. To refine this classification, the idea of a Teichmüller space is introduced, which partitions the of Riemann surfaces via a specific equivalence relation. Once such a space is defined, the Teichmüller Theorem states that we can find a unique quasiconformal mapping bt any two compact Riemann surfaces. We are concerned with understanding the intricacies of Riemann Surfaces, insofar as their construction and various properties. We attempt to provide an alternate proof to the Teichmüller theorem using techniques developed from the theory of Riemann Surfaces.

Quantum Chaos and System Size Scaling of OTOCs

Anant Kale

Mentors: John Preskill and Nick Hunter-Jones

Chaotic dynamics in many-body quantum systems leads to scrambling of information. A quantitative means of characterizing chaotic systems is by measuring the out-of-time ordered correlator (OTOC) function. The OTOC value is expected to decay to zero with time. However, for finite system sizes, the OTOC saturates at some small non-zero value that is dependent on the system size. In this paper, we study how this residual value scales with system size for systems with locality of interactions (such as the Ising model) and systems that are highly non-local (such as the SYK model). We find that the residual value falls off exponentially with system size for non-local systems. We provide numerical simulations and try to provide analytical reasoning to support our conclusion.

Structured Exploration via Hierarchical Policy Networks in Cooperative Multi-Agent Systems

Aleksandra Kalisz

Mentors: Yisong Yue and Stephan Zheng

In environments with large state-action spaces reinforcement learning becomes challenging because exploration can be highly inefficient in high-dimensional spaces. Even if the environment dynamics are relatively simple, in high-dimensional state-action spaces they might be combinatorially hard to recover. However, if one could exploit a low-dimensional structure in a high-dimensional state-action environment, one could further use such a structure to make the exploration more efficient in the given complex environment. We focus on collaborative multi-agent problems, since state-action spaces in such problems are exponentially large in the number of agents but they often have a low-dimensional coordination structure. We propose a hierarchical approach to structured exploration to improve sample efficiency of on-policy exploration in large state-action spaces. The key idea is to model a stochastic policy as a hierarchical latent variable model, which allows to exploit the low-dimensional latent space. We want to demonstrate this approach is successful in continuous (partially-observable) environments.

Impact of Background Conditions and Diffusivity Model on the Response of Laminar Premixed Flames to Acoustic-Induced Pressure Fluctuations

Andrei Kanavalau

Mentors: Guillaume Blanquart and Guillaume Beardsell

Thermo-acoustic instabilities remain a problem in design of propulsion systems. Modern numerical simulation tools do in theory allow analysis of the whole combustion chamber to be performed. But, the computational costs associated with this are impractical for most applications. This project aimed to build up the understanding of the topic by investigating local response of laminar premixed flames to acoustic pressure fluctuations. Direct numerical simulations with detailed chemistry were performed for a wide range of acoustic frequencies using *n*-heptane as a

fuel. Gain and phase of the unsteady heat release response were extracted, which are directly related to the Rayleigh criterion and thus the stability of the system. A number of different temperatures and pressures have been investigated. It was observed that there are common trends at all conditions and that changes in temperature and pressure impact the system in opposite ways. Three different techniques for evaluating chemical species Lewis number were also investigated. It has been shown that its value is of primary importance only in direct proximity to the flame and does not have to be rigorously evaluated at each time step throughout the whole simulation domain. This should allow for a significant reduction in computational costs when dealing with large chemical models.

The Efficacy of Therapeutic AAV Vectors for Treating Motor Symptoms of Friedrich's Ataxia Jaevoung Kang

Mentors: Viviana Gradinaru and John Elliott Robinson

Friedrich's Ataxia is an autosomal recessive neurodegenerative disorder that typically occurs in children aged 5 to 15, with associated motor symptoms such as decreased muscular coordination and loss of fine motor ability. Friedrich's Ataxia is caused by a mutation of the FXN gene which reduces expression of the mitochondrial protein frataxin. As Friedrich's Ataxia is a genetic disorder, we hypothesized that gene therapy with adeno-associated viral (AAV) vectors could have potential to alleviate motor symptoms in animal models of this disease.

Knock-in / knock-out (KIKO) mice with one allele of the FXN expansion mutation and one allele of the FXN deletion mutation were bred as Friedrich's Ataxia mouse models, alongside wild-type controls. Half of the KIKO model mice were then treated via delivery of an AAV-PHP.eB.-FXN / AAV-PHP.S.-FXN vector cocktail containing the therapeutic transgene. Treated KIKO mouse models, untreated KIKO mouse models, and the wild-type controls were put through a previously established, custom-designed runway behavioral apparatus, and gait analysis was conducted using Mousewalker, a validated MATLAB bioinformatics program. We also utilized novel balance beam setups and video-tracking software to assess these mice for coordination and motor capacity. Further locomotor assays will be conducted to continue searching for potential therapeutic uses for engineered AAV vector designs.

High Luminosity Periodic Variables in the SPIRITS Survey

Viraj Karambelkar

Mentors: Mansi Kasliwal and Scott Adams

SPIRITS : Spitzer InfraRed Intensive Transient Survey is a survey searching for transients using the InfraRed Array Camera (IRAC) aboard the Spitzer Space Telescope. We identify variable sources in this survey in 10 galaxies upto a distance of 1 Mpc and 10 bright galaxies from 1 Mpc to 10 Mpc. From the light curves, we calculate the periods of these variables using Lomb Scargle periodograms. We generate point spread function (psf) catalogs for these galaxies, and use these to estimate the magnitudes of these variables. We present the period-luminosity (PL) diagram and color magnitude diagrams for these variables, and compare them to existing data from the Large Magellanic Cloud (LMC). While some of the variables populate the asymptotic giant branch of the LMC, we identify long and short period variables that occupy previously unexplored regions of the PL diagram, which appear to extend the extreme AGB branch. These variables could be OH/IR stars, which are dust enshrouded stars that exhibit OH maser emission.

Freeze Casting Preceramic Polymers With Different Molecular Weights to Observe Changes in Freezing Microstructure

Carl Heinrich Christian Keck Mentors: Katherine T. Faber and Noriaki Arai

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 sublimated to produce a porous network. In this study, our objective is to observe the changes in freezing microstructure, pore morphology, and mechanical properties in porous silicon oxycarbide caused by freeze casting polysiloxane with different molecular weights. The polysiloxane is partially cross-linked via a thermally induced condensation reaction, causing an increase in the molecular weight of the preceramic polymer. This produces an equivalent increase in the viscosity of the freeze casting solution. By altering the rheology of the solution, the microstructure and consequently mechanical properties of porous ceramic materials can be tailored. This work has developed a powerful tool to increase the level of control over microstructure in porous, freeze-cast ceramics. The effect of solution viscosity on pore morphology and mechanical properties are characterized via rheometry, scanning electron microscopy, permeability testing, and uniaxial compression testing.

Engineering Secreted Antibiotics as a Tool for Growth Regulation

Leah Keiser

Mentors: Richard Murray and Reed McCardell

In synthetic biology, most production and experimentation are done in monocultures; however, bacteria in nature are found in diverse communities consisting of many different phenotypes. Cells in communities are found to make

more robust and productive populations, which has led to an increasing interest in the development of synthetic microbial consortia. In this project, an *E. coli* secreted narrow spectrum antibiotic, called colicin, is developed as a tool for population regulation in a multi-membered microbial community. We have demonstrated that the expression and release of colicin can be tightly controlled using synthetic regulatory elements and used to maintain a stable population density. By examining the effects of colicin-producing strains on bacterial communities, we can prove that colicin limits bacterial populations to different densities based upon level of induction, which reveals its potential for future use in a microbial population control circuit.

Center of Pressure Calculation Used in Prosthetic Control to Stabilize Patient Gait

Hana Keller

Mentors: Aaron Ames and Rachel Gehlhar

Current powered transfemoral prosthetics don't provide patients with a natural looking human gait and the goal of the AMPRO prosthetic is to create a control method that will stabilize the movement. This study uses sensors on the bottom of the prosthetic to calculate pressures under the foot during each step. Center of pressure locations are calculated during each step to produce a pressure trajectory during motion. Distributions of pressure over the foot are calculated as well. Presentation of these data during testing will allow better analysis of different methods of control. Comparison to a normal human foot during a step should allow more data for the control algorithm to use when optimizing the prosthetic's trajectory.

Designing Inertial Microfluidic Channels for Flow Cytometry-on-a-CMOS Platform

Yeokyoung Kil

Mentors: Amin Arbabian, Jun-Chau Chien, and Ali Hajimiri

Flow cytometry is a biophysical technology in which cells suspended in fluids pass through an electronic detection apparatus. This apparatus analyzes cells based on their physical properties, making it a powerful tool for diagnosing illnesses such as cancer. Our flow cytometry-on-a-CMOS platform characterizes cells using their dielectric properties with single-cell dielectric spectroscopy. Integrated into this device is a microfluidic channel that filters and focuses cells, allowing more accurate detection by ensuring that only one cell passes the sensors at a time. This project was focused on building this microfluidic channel using inertial microfluidics, a special case of microfluidics in which inertia affects particle flow in the microchannels. Multiple designs of inertial microfluidic channels were fabricated with polydimethylsiloxane(PDMS), a silicon based organic polymer, and were tested under various flow conditions to determine the optimal channel design that will yield a high throughput for flow cytometry.

Transporters and the Principles Governing Cellular Membrane Crossing

Esther Kim

Mentors: Douglas C. Rees and Naima G. Sharaf

In both *Escherichia coli* (*E. coli*) and *Neisseria meningitides* (*N. meningitidis*), the substrate binding protein MetQ scavenges and delivers methionine from its environment to its cognate membrane embedded transporter MetNI. While structures of both *E. coli* and *N. meningitidis* MetQ are available, a detailed understanding of the structural basis for methionine recognition is lacking. To gain a more thorough understanding of rules that govern methionine binding to MetQ, we conducted protein-ligand binding studies using methionine analogs that contained changes to the amino, carboxyl or side-chain group. To carry out these experiments, *E. coli* and *N. meningitidis* MetQ was first purified by affinity and size exclusion chromatography, and SDS-PAGE (sodium dodecyl sulfate-polyacrylamide gel electrophoresis) was used to access its identity and purity. Next, we used the previously established FAXS (fluorine chemical shift anisotropy and exchange for screening) NMR technique, a competition-based experiment that monitors the displacement of medium affinity fluorine-modified ligand, to study how changes to the methionine backbone influence binding. We found that both *E. coli* and *N. meningitidis* MetQ were able to bind several methionine analogs, including D-methionine, N-acetyl-L-methionine and L-ethionine although at lower affinity in comparison to L-methionine. Surprisingly, binding of L-cysteine was not detected under our experimental conditions. These data suggest that the methyl group attached to the methionine sulfur plays a key role in molecular recognition by MetQ.

Commissioning MIP Timing Detector Prototype Using TOFPET 2 ASIC

Hyunseong Linus Kim

Mentors: Maria Spiropulu, Cristian Pena, and Si Xie

CERN's High Luminosity-Large Hadron Collider upgrade will increase the number of particle collisions by 10 fold to observe rare phenomena, such as the di-Higgs boson production. Current detectors and reconstruction algorithms, however, will not be adept for reconstructing the events due to the high levels of pileup. To mitigate this problem, a timing layer will be inserted which will suppress spurious track-to-vertex association by 3 fold. This timing layer will require thousands of channels, each with a 30 picosecond time resolution for a minimum ionizing particle (MIP). The Time-of-Flight Positron Emission Tomography (TOFPET) is one of several candidate devices for this purpose since it can achieve 30 picosecond time resolution while activating a maximum of 512 channels. We

investigated the circuitry and internal parameters of the TOFPET, and how these affect the radiation spectrum as well as time resolution. We discovered the electric noise between the TOFPET and detector circuit board to be a limiting factor for the time resolution, and are working to reduce this noise.

Phenotypic Analysis of ASD-Associated Missense Variants Using Caenorhabditis elegans

Judy Kim

Mentors: Paul Sternberg and Sandy Wong

In Autism Spectrum Disorder (ASD), a neurodevelopmental disorder with a large genetic component, the linked variants are from rare variant mutations, most prominently missense mutations. The purpose of focusing on missense mutations is not only due to their significance in altering a protein based on a single nucleotide but also due to their abundance and difficulty to study in other organisms. Using C. elegans as the model organism is useful because of these animals' short generation time, small size, transparency, invariant development, and stereotyped behavior. While the human genes BRAF and TRIO are well known as oncogenes, their role in ASD is essentially not recognized. Their corresponding C. elegans orthologs are lin-45 and unc-73, respectively. lin-45 is crucial for larval viability, fertility, and the induction of vulval cell fates; unc-73 is necessary for cell migrations and axon guidance in C. elegans. My project focuses on characterizing phenotypes of ASD-associated missense mutations in C. elegans. Mutant strains were generated using CRISPR-based gene editing. I then analyzed the effects of these ASD-associated alleles using a reduction of function allele of chemotaxis assay to study their neuronal phenotypes. Prior to this study, chemotaxis was reported defective in a *lin-45* mutant. We used a mutant of *odr-10*, the diacetyl receptor as the positive control. Wild type C. elegans are attracted more towards diacetyl than towards ethanol, while the odr-10 mutant strongly favored diacetyl. Double mutant strains are still being generated and analyzed. The findings in this study will help characterize new missense alleles with human disease and ultimately contribute to implications of medical practices and molecular genetics.

On an Identity Regarding Kazhdan-Lusztig Polynomials

Suna Kim Mentor: Xinwen Zhu

In 2011, it was conjectured that certain polynomials, of the form $P^{\sigma}_{y,w}(q)$, give (-q)-analogues of weight multiplicities of the Langlands dual group G. Notably, these are variations of Kazhdan-Lusztig polynomials for twisted involutions in an affine Weyl group. In the following year, George Lusztig and Zhiwei Yun proved the conjecture using affine Grassmannian and the geometric Satake equivalence. In search of a new approach to this idenity without using geometric notions, we investigate Soergel bimoudles, which categorify Hecke algebras.

Evaluating the Ball Ring Transmission System

Yu Jin Kim Mentors: Mark Yim and Joel Burdick

Robotic arms have become increasingly popular in their use as manipulators on various types of robots. A crucial aspect of developing such manipulators involve a transmission system for physically actuating them. Bearing and harmonic drive transmissions are popular in commercially available robot arms, but they often have flaws in transmission friction, compliance, and kinematic error. The cost for manufacturing these is also very high. Thus, a method of transmission that depends on rolling friction between the ball bearings in the system, which we can manufacture with low cost and actuate with low profile, high efficiency, and high (continuously variable) torque ratio, was proposed. The transmission system is currently being tested with a static fixture rig where the system is attached to torque sensors whose signals are amplified by an op-amp circuit and read through an oscilloscope. One notable trend seen in the data is that the transmission ratio of the system increases as the load applied increases. After all the experimental data has been collected, it will be used to calculate the variable transmission ratios and the efficiency of the system.

Subliminal Processing Subserved by Different Classes of Photoreceptors

Lily Kitagawa

Mentors: Shinsuke Shimojo and Shao-Min (Sean) Hung

Visual perception is separated into supraliminal and subliminal visual processing. Supraliminal processing describes what most simply call vision, while subliminal processing refers to "unconscious perception," that is, while an observer receives sensory inputs, the content nonetheless remains inaccessible to our conscious mind. Subliminal processing provides unique opportunities for insight into visual processing, as signals still reach the brain and modulate behavior. For example, when light stimulation is carefully presented in the blind spot and remains subliminal to the observer, the mean luminance of the surrounding area is nevertheless enhanced. This suggests the involvement of ganglion photoreceptors in subliminal processing since no classical photoreceptors (i.e. rods and cones) are present in the blind spot. In the current study, we further examine whether subliminal information in the blind spot can lead to behavioral changes. (describe our hypothesis and task briefly here) Once the involvement of the ipRGC photoreceptors has been established, more complex questions can be asked, including whether or not each photoreceptor specializes in a particular aspect of subliminal visual perception.

Classification and Characterization of Fractures, Gale Crater, Mars

Lydia L. Kivrak Mentors: John P. Grotzinger and Nathan Stein

The Curiosity Rover was sent to Mars to find evidence of a past habitable environment. The presence of desiccation cracks is an important component to this study, indicating periods of wetting and drying in the ancient lacustrine environment. Identifying these and distinguishing them from other fractures in Gale Crater such as hydraulic fractures is helpful to the understanding of the presence and eventual disappearance of water from the surface of early Mars. We have conducted a survey of Curiosity Mastcam images, classifying them based on criteria including the presence or absence of fractures and the potential type of fractures. Other work includes the tracing of potential desiccation cracks to compare their geometry with that of hydraulic and thermal weathering fractures.

Design and Implementation of a Controller to Advance in Multi-Lane Traffic Similar to Human Behavior Using Control Improvisation

Filip Klaesson

Mentors: Richard Murray and Jin Ge

Autonomous vehicles are anticipated to revolutionize the transportation system. An important traffic situation which needs to be considered in the development of autonomous vehicles is multi-lane driving. When developing a control system for autonomous multi-lane driving, it is crucial to consider the human-vehicle interaction. Both human passengers and other traffic participants would most likely appreciate a human-like behavior of the autonomous vehicle instead of a deterministic naive behaviour. Another aspect is whether the overall efficiency actually improves when the majority of cars change lane autonomous. One approach to solve this is to design a improvisation controller to simulation the human behaviour. A improvisation controller can be divided into two problems. The first is to design a randomized lane-changing rule which determines if a possible lane change should be carried through. The second part is to move the car autonomous to the desired position. In this project the second part of the improvisation controller is implemented into an F1/10 unit to demonstrate autonomous lane changes. The F1/10 unit is using SLAM in order to localize and build a map of the environment based on lidar data. With the localization, the unit is able to move between user defined coordinates. Towards the end of the project the path planning will be refined and if time allows, a randomized lane-changing rule will be designed.

Simulating Self-Organized Criticality in Driven Open Rydberg Systems

Kai Klocke

Mentors: Gil Refael and Michael Buchhold

Recent experiments utilizing laser-driven ensembles of Rydberg atoms have discovered aspects of self-organized criticality (SOC) in the dynamics of strongly interacting spins. Although the experimental signatures unambiguously identify SOC as the underlying mechanism, the connection between spin dynamics and the phenomenology of SOC is barely understood. We investigate the dynamics of such Rydberg ensembles in the SOC regime by means of a coarse-grained, effective Langevin equation (LE) describing the evolution of the active state density. Here we present an efficient numerical integration scheme for the LE, yielding precise simulations in 1+1 dimensions. Our results convincingly demonstrate an SOC regime. We further observe that tuning a single experimental parameter yields two non-SOC regimes: one showing periodic excitations spanning the whole system, and another showing a support the three regime picture and evidence clean power-law scaling for high frequencies, most notably in the supercritical regime. We comment on a possible relationship to neural networks, where SOC has been hypothesized to play a role in signal transmission. Finally, we consider a modified noise kernel that better describes off-resonant excitations and demonstrate similarity in the results.

Investigation of Stripped-Envelope Supernovae With ZTF

Ho Ko Mentor: Christoffer Fremling

Supernovae (SNe) are iconic transient events in the sky. Stars form, and stars die. Simple, but difficult to study. When a star dies there is a massive energy release into typically a multi-layered envelope structure. This gives rise to a range of possible spectral features and light curve behaviors depending on the SN type. Here we study one particular event, a Type IIb supernova found by the Zwicky Transient Facility, ZTF18aalrxas. This SN belongs to the stripped-envelope (SE) class of core-collapse SNe — stars that have lost most of their envelopes prior to their explosions. Due to the nightly cadence of ZTF, we were able to detect ZTF18aalrxas almost immediately after it exploded. Interestingly, ZTF18aalrxas shows an early peak in its light curve followed by another peak of longer duration. This is not typically seen in SE SNe, and we believe that this is a sign of a different, more extended, envelope structure at the time of explosion. In such a scenario the first peak is a result of cooling of extended material after the SN shock has passed through. By integrating data in the optical and UV and fitting analytical models to the multi-band and bolometric light curves we will be able to constrain the structure of the extended envelope, and the SN explosion parameters (ejecta mass, kinetic energy, nickel mass).

Using Deep Learning to Track Cells in Single Cell Biology

Nora Koe Mentors: David Van Valen and Erick Moen

Currently, the ability to accurately classify cells through space or time is a resource-intensive task as it requires manual curation of data. However, deep learning models can be trained to annotate raw microscope images much faster. Through time, this classification task refers to tracking individual cells through a series of microscope images. This requires the ability to identify and distinguish cells from one another which is done via a model with a Siamese neural network to classify a pair of cells as the same cell, different cells, or the parent and daughter cells from a division. A tracking algorithm leverages this prediction to produce tracks of cells through time as well as cell lineage information when divisions occur. The developed model will be available as a tool for all laboratories to use for their own data analysis. This ability to track cells allows for better investigation of dynamic cellular interactions, which has implications for the diagnosis of various diseases.

Development of Chemical and Physical Biosensors on Laser Scribed Graphene Electrodes

Adam Kogan Mentor: Wei Gao

Biosensors are essential to accurately observe and learn from the constant processes occurring in the human body. Many biosensors exist today, however they are limited by invasive methods and discontinuous monitoring. We have developed highly sensitive noninvasive physical and chemical sensors to be used to detect small changes in temperature as well as varying concentrations of chemicals in sweat, including sodium and glucose. These sensors were developed using laser scribed graphene electrodes and various techniques were used to create the sensors and respective reference electrodes used for testing. The system uses the electrolytes released from the body in sweat during exercise to monitor physiological state in real-time, which is useful for health analysis and diagnostic applications.

Paraburkholderia nodosa Protects Aspergillus ustus From Phenazine-1-Carboxylic Acid: Genetic Insight

Marko Kojic Mentors: Dianne Newman and Kurt Dahlstrom

Phenazines are redox active molecules produced by soil bacteria and are known to protect plants from fungal pathogens. However, there are some plant promoting fungi that are not natively resistant to phenazines, but still live in the rhizosphere with phenazine-producers. Recently, a soil co-isolation yielded *Aspergillus ustus*, a fungus that withstands phenazine assault when paired with its partner, *Paraburkholderia nodosa*, which forms spherical biofilms within the fungal colony that sequester this toxic molecule. Therefore, we hypothesize that *P.nodosa* offers protection to *A.ustus* from phenazine-1-carboxylic acid assault. Our aim was identifying a genetic basis for this protection by conducting transposon mutagenesis, screening the mutants for loss of protection, and identifying the disrupted gene through arbitrary PCR. We constructed 1000 mutants of *P. nodosa*, screened for loss of protection against PCA. Since phenazine-producers are often found in drier areas, understanding how bacteria-fungi interactions determine which microbes are allowed into the rhizosphere opens the possibility of engineering the community for a given climate.

Optimization of Next Generation Advanced Reacting Turbulent Solver (NGA) Code

Frank Kou

Mentors: Guillaume Blanquart and Nicholas Burali

The latest trend in High-Performance-Computing (HPC) processors is to have more threads on lower power core and more cores per node. NGA, however, is not designed to operate multiple threads per core. For my project, I use the Open Multi-Processing (OpenMP) communication protocol to implement a MPI-OpenMP hybrid approach. The code is ran and tested on Stampede2, a supercomputer composed of two different nodes: 4,200 Knights Landing (KNL) nodes and 1736 Intel Xeon Skylake (SKX) nodes. I perform benchmark tests on the NGA code with solely MPI, solely OpenMP, and MPI-OpenMP hybrid. Then, I quantify the NGA performance differences for model problems with speedup factor graphs.

Validation of the COGEF Method as a Tool for Rational Design of New Mechanophores

David Peter Kovacs Mentor: Maxwell J. Robb

Polymer mechanochemistry is an emerging field of chemistry studying the effect of mechanical force on the molecular level. In the past years several computational methods have been developed to simulate mechanochemical reactions. This project concentrated on validating one of the most widely used approaches called COnstrained Geometries simulate External Force (COGEF). We assembled a comprehensive library of all

mechanically active molecules reported to date and the COGEF procedure was applied to each molecule using the B3LYP/6-31G* level of restricted density functional theory. In 80% of the cases this computationally inexpensive method produces results in agreement with experimental reports in terms of predicting, qualitatively, the products of the reactions. Furthermore in 15% of the cases, the calculations predicted the anticipated mechanochemical reaction, but there were minor differences between the experimentally identified outcome of the reactions. For the small number of cases where the simulations failed to predict the experimentally identified outcome of the reactions, the calculations were repeated using higher levels of theory. We find that the MP2 method gives the most reliable results agreeing well with experimentally reported products.

Ultralight Perovskite Solar Cells for Space Solar Power Applications

Maria Kowalchuk

Mentors: Harry Atwater and Michael Kelzenberg

Perovskite solar cells show great potential for space solar power applications given their low-cost processing methods, high efficiencies, and resistance to radiation. Cells must be developed on ultralight, flexible polymers to obtain high specific power, or power per mass, which is crucial to lower launch costs. A perovskite cell fabrication process of structure ITO/NiO/MAPbI₃/PCBM/Ag using spin-coating and e-beam deposition methods has been developed. This process has been adjusted through troubleshooting methods to regain high efficiencies after a glovebox repair affected cell performance. Perovskite fabrication has been further processed on ultrathin polymers. Polymers were tested for temperature and chemical compatibilities. NiO annealing was adjusted to account for lower temperature capabilities of polymers. Polymer samples have been prepared using ITO sputtering and NiO spin-coating or deposition. Surface properties of polymers must be further examined to allow for uniform perovskite coating. Alternative cell structures will be examined to further improve efficiencies. Fabrication on polymers will continue to reach a goal specific power of 10 W/g.

Integrating Domain Knowledge for Faster Learning in Optimal Control

Meera Krishnamoorthy

Mentors: Yisong Yue, Hoang Le, Victor Dorobantu, and Andrew Taylor

Controllers created solely using control theory methods perform sub-optimally when employed in real situations because they are not sophisticated enough to account for the varying degrees of uncertainty that could exist in a system over time. Furthermore, current machine learning methods can force a system to perform any possible action when searching for the optimal controller, which could be harmful for those systems. This project defines and tests a technique that combines domain knowledge and machine learning approaches to create safer and more accurate controllers to solve optimal control tasks. The first step of this technique is to create a nominal controller for a system based on its drift dynamics, actuation matrix, and control Lyapunov function. The nominal controller is episodically augmented using data aggregation and supervised learning techniques, specifically a 2-layer neural network. This technique has been tested in simulation on the inverted pendulum system. The final augmented controller is able to perform better than the nominal controller at forcing the inverted pendulum to track equilibrium. The next steps involve testing this technique on hardware (namely the bipedal robot Cassie) and in simulation on higher dimensional systems.

Three-Point Bending Fracture of Microscale Silicon Beams and Potential for Understanding Fracture in Bone

Peter Kuetzing

Mentors: Julia Greer and Ottman Tertuliano

Bone exhibits two seemingly mutually exclusive material properties, toughness and strength. At the nanoscale, bone is mainly comprised of hydroxyapatite, a hard mineral, and collagen, a soft organic phase. These constituents form the basis for the complex hierarchical structure of bone: nanoscale fibrils, microscale lamellae, and millimeter sized trabeculae and osteons. The fracture behavior of the nano and microscale fibrils in bone in its hydrated environment remain elusive. This is due to experimental challenges in isolating and performing mechanical experiments at this length scale in any material. Previously, in situ SEM (high vacuum) microscale fracture experiments were performed to measure the fracture toughness, KIC, of silicon. Here, TEM lift-out procedure is utilized to place silicon beams onto supports, creating a microscale three-point bending test with pure mode I crack propagation. We perform ex-situ experiments using a nanoindenter and report similar KIC values as in-situ experiments. These results, coupled with the versatility of the ex-situ experiment, provide a promising approach for an in-vitro (hydrated) study of the fracture behavior of bone at fibril and lamellae length scales.

Implementing MSA-Based Methodology in the Context of Gene Neighborhood Analysis

Anthony Kukavica

Mentors: Grant J. Jensen and Davi R. Ortega

The genes encoding the protein components of macromolecular machines are often arranged in clusters in the genome. These clusters are relatively conserved at the phyla level. Over the course of evolution, mapping rearrangement events provide insights into the functional roles of individual components of the machine, as well as

the whole machine itself. While multiple sequence alignments (MSA) are often used to summarize evolutionary events at the sequence level, a suitable analogue at the gene organization level has not yet been developed. Here, we build an application named GeneHood to visualize organizational changes within conserved gene clusters over the course of evolution. Furthermore, we have created and implemented an analogue of MSA at the gene organization level, which we refer to as multiple gene cluster alignment (MGCA). Finally, GeneHood uses our MGCA formalism to generate gene cluster logos that summarize the aforementioned conservation patterns.

A Model for Interspecies Communication Through Programmed Plasmid Transfer Between Escherichia Coli and Bacillus subtilis

Sanjana Kulkarni

Mentors: Richard Murray and Andrey Shur

Bacteria have increasingly been used to record events by being programmed to output signals or undergo genetic changes in response to specific stimuli. We propose plasmid transfer as a means of relaying information in a targeted manner between two bacterial species, *Escherichia coli* and *Bacillus subtilis*, as a model for the detection and recording of other microbial species in an environment. The ability of *E. coli* to send plasmids was achieved with an inducible circuit that produces the X174E toxin, which lyses the host cells, releasing any DNA in the cells into the environment. After ensuring the function of this circuit, two plasmids were designed and transformed into *E. coli*, constituting the sender strain in the model. A transfer plasmid contained the information to be sent flanked by homology sequences that would allow it to be integrated into the genome of *B. subtilis*, the receiver strain. The other plasmid contained the aforementioned lysis circuit and another inducible circuit to produce the I-SceI restriction endonuclease, which would linearize the transfer plasmid to facilitate transformation into *B. subtilis*. Tunable elements in the system allowed for control of the uptake of foreign DNA by *B. subtilis*, linearization of the transfer plasmid, and lysis of *E. coli*, providing temporal separation of the events. This model demonstrates highly specific interspecies communication able to transfer large quantities of information, an improvement upon the quorum sensing typically employed by bacteria to detect cells in close proximity.

Defining Real Multiplication Fields, Types, and Reflex Fields

Vinayak Kumar Mentor: Zavosh Amir Khosravi

A totally real field is a field such that any embedding of it into C will be contained in R. Based off of complex multiplication (CM) fields, real multiplication (RM) field extensions are defined as a totally real quadratic extension of a totally real field. Some unique properties of CM fields were unable to be carried onto RM extensions. However, we have proposed definitions of the type of tensor product of RM extensions and the tensor product of RM extensions with CM fields, and the corresponding reflex field they produce using an operation called the "box tensor". With these proposed definitions, we hope to formally define RM extensions as a category.

Deep Cell - Deep Learning for Cell Image Segmentation and Tracking

Daniel Kyme

Mentors: David Van Valen and Erick Moen

Live cell imaging is a crucial tool for studying cells, proteins, and tissues that can shed light on cellular structures and processes. While it produces valuable data, cell imaging is limited by the need for many hours of manual curation and the difficulty of sharing data and procedures between labs. Utilizing deep convolutional neural networks, a computer vision system, Deep Cell, was built for cellular image segmentation and tracking that serves as a timely and universal tool for researchers. Using a Siamese network, a neural network architecture that differentiates between two inputs and learns the similarities between them, cells could be tracked through 2-dimensional movies and cell lineages could be outputted. To make this system applicable in all labs, an easy to use pipeline has also been constructed to take raw cell images and process, annotate, and produce training data for Deep Cell. As a result, Deep Cell will provide valuable data on cellular dynamics with implications for diagnosing and curing diseases.

The Synthesis, Isolation, and Characterization of Well-Defined N-Doped Heterosuperbenzene Molecules for Oxygen Reduction Reaction Catalysis

Christopher Lamartina

Mentors: Theodor Agapie and Arnaud Thevenon

The molecular oxygen reduction reaction (ORR) is one of the most important chemical processes for biological systems, allowing for aerobic respiration. It is also key for the function of energy converting systems such as fuel cells. Major challenges for fuel cell design have been creating cost efficient nonprecious metal catalysts, as well as metal-free catalysts, which avoid use of expensive and toxic platinum based compounds. This creates the need for synthesizing new N-doped carbon based ORR catalysts which have well-defined structures and can bind to cost-efficient transition metals where catalysis can occur. The goal of my project is to synthesize N-doped ligands that contain large delocalized carbon π -systems which can bind to various metals. The expectation is that the delocalized electron systems will allow the metal centers to reduce oxygen at voltages close to thermodynamic

potential. The synthetic techniques that are being used to make the ligands are closely based on previously reported well-defined graphitic carbon structures. The project has exciting potential for furthering the efforts of efficient fuel cell production.

Visualizing Turbulence in Pair Plasmas via Numerical Methods

Maggie Lang

Mentors: Nuno Loureiro and Paul Bellan

Plasmas made of electrons and positrons, known as pair plasmas, are hypothesized to experience almost negligible turbulence and extremely slow cross-field transport when exposed to a magnetic field. Theoretical models suggest that with a plasma skin depth, d_e, and a wavenumber of fluctuations perpendicular to the magnetic field, k_{\perp} , at fluid (MHD) scales, as characterized by $k_{\perp}d_{e} \ll 1$, the energy spectrum scales as $k_{\perp}^{-3/2}$, and at kinetic scales, as characterized by $k_{\perp}d_{e} \ll 1$, the energy spectrum scales as $k_{\perp}^{-11/3}$. To validate these models, the Viriato code, which uses the Kinetic Reduced Electron Heating Model (KREHM) to simulate the behavior of plasmas exposed to a magnetic field, is used to conduct numerical investigations of pair plasmas. The energy spectra of simulations with varying d_e and resolution are compared to the model calculations. Our initial results indicate general agreement with the theory, and research is ongoing.

Dynamics of Cell Signaling During Early Human Development

David Larios-Colorado

Mentors: Michael Elowitz and Nicolás Peláez-Restrepo

One of the most remarkable processes in nature is the development of a multicellular organism from a single cell. Embryonic development occurs as a hierarchical process that translates genetic information into temporal and spatial gene expression patterns that provide the positional information and signals necessary for the normal unfolding of the organism. Dynamics of signaling pathways between embryonic cells remain unclear to date due to the lack of tools to study such process. To overcome this limitation, in this project I developed molecular tools to engineer embryonic cells in order to know how they self-arrange to generate all the early embryonic germ layers.

Engineering Metabolic Cross-Feeding Relationships for Robust Microbial Consortia

Elin Larsson

Mentors: Richard Murray and Rory Williams

In many microbial ecosystems, cooperativity plays an important role in the stability and function of the network. One example of this is amino acid auxotrophy, that is common among microbial species. In microbial consortia with auxotrophic members, the metabolic functions can be divided between the species, allowing every species in the community to save energy and become specialized. This project utilizes mathematical models, consisting of simple differential equations that assume Monod kinetics, in an attempt to predict the growth behaviour of multi-strain communities of auxotrophic *E. coli* strains. Parameters, such as growth rate and metabolite export rate, for the models are going to be estimated from experimental data obtained from single strain growth experiments and multi-strain cross-feeding experiments. Multiple auxotroph-strains will be generated by knocking out genes for biosynthetic pathways of an additional amino acid. The hope is to be able to use the models to construct multistrain communities that are stable over a certain range of conditions and can recover from introduced disturbances in one of the community members.

Predicting Signal Peptide Sequences of Proteins Using Machine Learning

Alycia Y. Lee

Mentors: Frances Arnold, Kevin Yang, and Zachary Wu

Industrial production of engineered proteins from cells relies on secretory pathways to function. Signal peptides, short amino-acid sequences at the N-terminus of newly-expressed proteins, provide the cellular signal for these pathways to transport proteins from the intracellular to extracellular space. The current method for identifying signal peptides is inefficient, as it involves screening libraries of signal peptides. This means that high coverage is unattainable for large libraries, whereas non-additive effects are not taken into account for small libraries. Machine Learning (ML) models—useful for predicting and optimizing outcomes of complex biological processes—are effective tools for exploring the innate and learnable cellular language possibly inherent in secretion rules, and potentially for determining functional signal peptides for proteins. We implemented the Transformer encoder-decoder model, trained on filtered datasets from UniProt, to predict signal peptide sequences given proteins of interest. The model achieved a validation accuracy of ~40% after the final epoch. Effectiveness of predicted signal peptides for five classes of enzymes will be tested by expressing these enzymes in *Bacillus subtilis* KO7-S. Current tasks focus on establishing an expression system for testing these predictions and creating signal peptide libraries. Secretion levels for predicted signal peptides will be measured through activity assays.

River Mapping With Autonomous Surface Vehicle

Chi Yen Lee

Mentors: Richard Murray, Chris Clark, Woodward Fischer, and Michael Lamb

River flooding is among one of the most hazardous natural disasters in the world. Over the past ten years, the damage of river floods across the globe had amounted to a staggering 50 billion dollars. It is possible to determine where and when a flooding might occur given an accurate profile of river geometry. Unfortunately, the vast majority of the river bed topography and flow rate profiles are either outdated or unavailable. The current method of surveying river with boat is not fast enough to account for rivers' tendency to self-adjust their courses. This project focuses on the development of an autonomous system capable of mapping rivers. We equipped an Autonomous Surface Vehicle (ASV) with an Acoustic Doppler Current Profiler (ADCP) and programmed it to create high resolution river bed topographies and flow rate profiles. The data collected during each survey expedition was fused using a 1D Kalman filter, and the resulting profiles were further fed into a RRT path planner that planned for a second route optimized for information gain. The results of this project were validated during multiple trips to Kern River, California.

Meta-Analysis of Empirical Estimates of Loss-Aversion

Hye Joon Lee

Mentors: Colin Camerer and Alex Brown

Loss aversion is the phenomena where distress from losing a certain amount exceeds reward from gaining the same amount. The degree of loss aversion is represented through the loss aversion coefficient λ , which represents how much utility one derives from gaining versus losing relative to a reference point. However, studies of loss aversion often lack consistency with respects to definition, methodology and statistical reporting style. Moreover, with the parameter λ having gained a reputation of a benchmark value of 2, publication bias is conceivable. The goal of this research is to investigate how variation in factors like methodology affects the value of the loss aversion coefficient λ , and if publication bias has led to a skewed representation of λ . Encoded data from 132 out of 179 papers, encompassing 446 experimental values of the loss aversion parameter, reveals that the reported values of the mean loss aversion coefficients have a weighted mean of 2.46, standard error of 0.77, and a median value of 1.66. A funnel plot of loss aversion coefficient data from 132 papers suggests potential publication bias, revealing an overrepresentation of higher values of the loss aversion parameter λ , especially in studies that have a smaller sample sizes.

Mounts and Alignments of Optics for an Image Slicer Integral Field Unit on the Magellan IMACS Regina Lee

Mentors: Rosalie McGurk and Alastair Heptonstall

This project will investigate a faster and cheaper alternate method of obtaining spectra covering a whole galaxy – Integral Field Spectroscopy – which uses an image slicer to divide an image of a galaxy into slices. In order to obtain an image of a galaxy in this situation, a series of 92 mirrors and lenses will be mounted and aligned to guide light into 4 spectrograph slits. This project's goal is to create optic mounts for the mirrors that have the ability to be adjustable and accurate. The model will have to isolate tilts in the X and Y-axes as well as be easily constructible. A deflection and strain analysis were done on the different models, and the best performing prototype was used. The prototypes were made on SolidWorks then milled out of aluminum. The most practical design which fulfills these criteria includes two flaps to isolate the tilts and connects to a base that controls the angle. The design chosen has a universal mirror mount with an adaptable base, therefore making it easier to create multiples of these mounts at different angles. The mounts have been fabricated to practice aligning the optics to properly direct the light into the spectrographic slit.

Applications of Virtual Reality in Data Analysis

Su Min Lee Mentor: George Djorgovski

With the advancement of VR/AR technology, data visualization beyond the traditional 2-dimensional projects is a realistic possibility. Based on many studies, there is a possibility that multidimensional data visualization will make data analysis more efficient and accurate by using virtual reality as a data analytics tool. My project aims to objectively evaluate the advantages of data visualization in VR over traditional data analytics tools such as Excel, Matlab, R, and Python. I have been generating data sets with different properties, such as dimensions, clusters, correlations, outliers, etc. Then, I was internally testing the data sets using both a VR/AR data visualization package and the traditional tools. Eventually, the internal testing will expand to a greater sample of people and the results will be analyzed to assess in which categories and by how much the VR/AR data visualization package is more effective and efficient at analyzing multidimensional data sets. The ability to visualize data in virtual reality may be the next technical revolution that reveal new correlations and meaningful outliers across all fields of science.

Investigating the Impact of Gut Microbiota on the Pathogenesis of Huntington's Disease

Yelim Lee

Mentors: Ali Khoshnan and Anjalika Chongtham

Huntington's disease (HD) is an inherited neurodegenerative disorder caused by expansion of CAG repeats in the coding sequence of the huntingtin gene. Expansion of CAG repeats produces a protein with elongated polyglutamine (polyQ), which is amyloidogenic. HD symptoms include uncontrolled movements, cognitive decline, and emotional instability. This project utilizes a Drosophila model to investigate the impact of intestinal microbiota on gut-brain interactions in HD. The Huntington's Disease is characterized by the neuronal accumulation of pathogenic aggregated mutant huntingtin protein. Specifically, I will examine whether elimination of gut microbiota by antibiotics (specifically penicillin-streptomycin and rifaximin) or colonization with inflammatory intestinal bacteria influences the amyloidogenic properties of mHTT. Here we found that the elimination of gut microbiota alleviates the aggregation of N-terminal 586 AA, and that the introduction of bacterial amyloids such as Curli promote the oligomerization of mHTT. These results suggest defects in gut-brain signaling in HD flies and support a role for gut bacteria in the pathogenesis of HD.

Classification and Computability for Nonlocal Games

Gideon Leeper Mentor: Thomas Vidick

Nonlocal games are a convenient reformulation of Bell inequalities in quantum mechanics, and provide a natural setting to investigate advantages provided by access to entanglement. We study two common variants of nonlocal games, namely XOR games and linear system games, which involve players providing (partial) solutions to systems of linear equations. The two types of games have served different purposes: many bounds and structural results have been shown for XOR games, while linear system games have been the setting for undecidability results and have provided separations between classes of quantum correlations. We attempt to relate the two models, by studying the relationships between their strategies and refutations, and try to understand when results for one model can be transferred to the other. We also independently investigate bounds and tractability for XOR games.

Characterization of Fluid Dynamics in CPOT

Lexy LeMar Mentors: John H. Seinfeld and Yuanlong Huang

Flow reactors are one of the methods for studying atmospheric aerosols and their role in climate. Information on how secondary organic aerosols form in the atmosphere is currently incomplete. Before analyzing the kinetics of aerosol formation in a flow tube reactor, a more complete understanding of the type of mixing and particle transmission in a given reactor is necessary. This project focuses on characterizing the fluid dynamics in the Caltech Photochemical oxidation flow tube reactor (CPOT). First, we injected SO₂ into the reactor to better understand the type of mixing through residence time distribution modeling and analysis. The results show that simple axial dispersion plug flow reactor (AD-PFR) modeling is consistent with the CPOT. Later, we analyzed particle transmission efficiency in the CPOT. A customized atomizer was used to generate ammonium sulfate particles, which were then size selected using a differential mobility analyzer before entering the reactor. A scanning differential mobility analyzer was used at the end to measure the particle count of the outlet stream. Preliminary results suggest that charged particles have a higher transmission efficiency than neutral particles in the CPOT.

Test, Interest, and Limits of a Fiber Injection Unit on a High Dispersion Coronography Testbed Nicolas Levraud

Mentors: Dimitri Mawet, Garreth Ruane, Jorge Llop Sayson, and Daniel Echeverri

For years we have been looking for exoplanets through 3 main techniques: radial velocity, photometry of transits and direct imaging. The direct imaging technique is the most difficult to achieve but also the most promising as it allows to characterize directly the exoplanet detected. Among the most recent development is the addition of a Fiber Injection Unit (FIU). It allows improved contrast by its selectivity and also the coupling with a High Contrast Spectrograph to further improve the characterization and the detection of exoplanets through corellation with known planetary models. This year in the Exoplanet Technology Lab, these new methods are tested in a controlled environment to confront their fundamental limits with reality. Here we present the experiments carried out for this test and the problem encountered.

Synthesis of Cholesterol-Derived Probes to Study Hedgehog Protein Cholesteroylation in Signal Transduction

Amanda Li Mentor: Alison Ondrus

The Hedgehog signaling pathway is a biological pathway central to embryonic development. Its dysregulation has been linked to birth defects and multiple cancers, including basal cell carcinoma. Many details of the pathway,

including the precise interaction between cholesterol and the Hedgehog protein, remain unknown. In order to study Hedgehog cholesteroylation, we will incorporate appropriate functional groups into the structure of cholesterol while maintaining its bioactive features. We are synthesizing two chemical probes for this purpose: a fluorescent probe to monitor cholesterol-dependent Hedgehog trafficking, secretion, and reception, as well as the nature of intra- and extracellular forms of active Hedgehog; and a photocrosslinking probe to identify cholesterol-dependent Hedgehog protein-protein interactors in sending and receiving cells and extracellular vesicles. After troubleshooting several possible methods, we have identified promising synthetic routes for both cholesterol derivatives. These probes will provide important understanding of the Hedgehog pathway and ultimately lead to improved therapies for Hedgehog-related cancers.

An Experimental Investigation on Human-Robot Interaction and Its Impact on the Disposition Effect Chenyue (Lyn) Li

Mentors: Elena Asparouhova and Jaksa Cvitanic

The amount of trades placed by algorithmic trading systems (robots) has been increased in recent years. To understand the impact of algorithmic trading on financial markets, it is crucial to gain a deeper understanding of human-robot interaction. In this research, we explore whether the use of algorithms will alleviate the disposition effect – a well-documented behavioral bias that causes low trading performance and has proven difficult to eliminate. The disposition effect is the tendency to sell stocks quickly when the price has increased while holding the stocks too long when the price has dropped. We approach this question by comparing the market efficiency of two trading groups: a group of traders who trade manually, and a group of traders who are allowed to deploy robots in trading sessions. To evaluate market efficiency, we develop real-time order book visualization algorithms and design robots that are equipped with multiple trading strategies. The order book visualization tool and the robot designed for this project can also contribute to future studies of human-robot interaction.

Study of Relationship Between Curiosity and Confidence

Jingjing Li

Mentors: Colin Camerer and Anastasia Buyalskaya

Epistemic curiosity was found to be correlated to confidence: very low or very high levels of confidence corresponded with lower levels of curiosity, whereas moderate confidence was correlated with higher levels of curiosity. This study aims to explore whether this correlation is causal by artificially adjusting the subjects' confidence levels in their answers to trivia questions. In this task with 25 three-choice trivia questions, the subjects indicate their level of confidence in each answer. A wrong answer is then randomly deleted and the subject's confidence levels in the remaining two answers are recalculated based on their original inputs, after which the subject rates how curious they are to find out the correct answer. About 12 days after the experiment, the subjects participate in a follow-up study, in which they are asked to answer all the questions based on their memory of the correct answer. This task will be run both on MTurk (n=300) and in the laboratory (n=30), where we use eye tracking software. We expect to see higher levels of curiosity, greater pupil dilation response (PDR), and better recall of the correct answers in trials where the adjusted confidence levels are closer to 0.5.

Temperatures of the Galilean Satellites

Yiluo Li

Mentors: Michael E. Brown and Samantha Trumbo

The four Jovian satellites, Io, Europa, Ganymede, and Callisto are often referred to as the Galilean satellites for their discoveries in 1610 by the Italian astronomer Galileo Galilei. In the 20th Century, Galileo orbiter was launched and arrived at Jupiter in 1995 to study the satellites for their distinctive features in the Solar System and their possibilities of hosting liquid water at the current epoch. In this research, we analyzed the published and the unpublished Galileo Photopolarimeter-Radiometer (PPR) data on the brightness temperatures of the satellites. We extended the previous thermal model for Europa and adapted it for the other Galilean satellites. By comparing the models and the PPR data, we were able to characterize the potential thermal anomalies, the thermal inertia maps, as well as the relations between data and the albedo variations. This will improve our understanding on the thermal behaviors of these satellites, which may be helpful aiding with the instrument design for the future missions.

Mapping of Connections Between Individual Neurons by *in situ* Readout of Short RNA Barcodes

Zhuoran Li

Mentors: Michael B. Elowitz and Amjad Askary

The network of connections between neurons is the structural basis for numerous functions of the brain. Mapping connectivity of neurons has been a great challenge given that high-throughput methods are required for decoding vertebrate brains which contain billions of neurons. Nucleic acid based barcoding has the potential to generate the required diversity for mapping complex neuronal networks. However, efficient detection of those barcodes in situ requires development of new methods and techniques. Here, by combining enzymatic amplification and HCR amplification, we developed new methods to detect short RNA sequences in situ. We show the efficiency and robustness of our techniques by co-localization test using two adjacent probes and HCR v3.0 split probe sets. We

further enhanced the efficiency by adding cross-linking fixation at various steps during the procedure and using RNase A to digest original target RNA. We also tried variations of the technique where most enzymatic steps are circumvented to enhance efficiency and simplicity of the technique and showed that they produce qualitatively different results. Overall, we show that our method, called RNA ZOMBIE, enables efficient detection of short RNA barcodes that can be used to label synaptic connections between neurons.

Using Tensor-Train Decomposition to Solve Numerical Partial Differential Equations

Zongyi Li

Mentors: Animashree Anandkumar, Rose Yu, and Kamyar Azizzadenesheli

Tensors are high dimensional arrays. Its number of entries grows exponentially with the dimensions. To deal with the curse of dimensionality, we use tensor-train techniques to represent the high dimensions tensor by products of smaller three-dimension tensors, which compresses the storage to be linear in dimension. We applying tensor-train techniques on numerical PDE methods like finite elements and Gaussian processes by compressing the coefficients of the PDE's solution and factorizing kernel matrices. We also explore the ordering problem of tensor-train and develop a greedy swap algorithm for it. We did simulations to show the significance of ordering problem and using tensor-train to decompose different kernels. In addition, we implement cross-approximation and spectral tensor train algorithm on Tensorly Package. In future, we will continue to explore compressing Green function for PDE with tensor train and implement the greedy swap algorithm for ordering problem.

Tristram Shandy as Material and Historical Fiction

Crystal Liang Mentor: Kevin Gilmartin

In *Tristram Shandy* (1759-1767), Laurence Sterne paradoxically subverted the emerging form of the novel before its conventions had fully been developed. Today, his novel is sometimes considered postmodern before the fact. How is this possible before the modern novel, and centuries before modernism, let alone post-modernism? As it turns out, what makes this such a rich and rewarding print narrative is that it engages a host of other fictional and representational modes in the eighteenth century at an early stage in the development of the novel. I researched eighteenth-century print culture and the rise of the novel, investigating such features as Sterne's unusual use of typography and interpolated matter, as well as the precursors of *Tristram Shandy* and the novel as historical genre. I find that *Tristram Shandy* is very much a work embedded in its time, and it is far better understood in its historical context—and particularly its material, print cultural context—than as a proto-postmodern novel.

Spin-Rate Limits of Asteroid Families and Their Structures

Xueer (Sherry) Liang Mentor: Chan-Kao Chang

Asteroid families are formed by collisions of a parent body with other objects. Different asteroid families have different spectral types and bulk densities. Asteroid density and structure are important aspects to study asteroid itself and to understand the formation and evolution of the whole asteroid system. However, it is hard to measure these physical properties. It's believed that asteroids follow the rubble-pile model (asteroids are created by gravitationally bound aggregations), so they have loose and fragile structures. Harris (1996) pointed out a 2-hour spin-rate limit and a corresponding bulk density of ~3 g/cm³ for asteroids with diameters of a few hundred meters or larger. His finding suggests that asteroids with different bulk densities should have various spin-rate limits. To verify this, we perform data analysis on the spin-rate limits of asteroid families with different spectral types. By analyzing data from Light Curve Database (LCDB) and Nesvorny HCM Asteroid Families, and using Sloan Digital Sky Survey (SDSS) colors, I drew a rotation period vs. diameter scatterplot and a spin-rate limit histogram for each asteroid family. By comparing those graphs, I found that asteroid families with different bulk densities have different spin-rate limits. This result supports the rubble-pile model.

Using RNA-Seq for Analysis of Differential Gene Expression in Peroxisome Biogenesis Disorders Cody Lim

Mentors: Joseph Hacia and Barbara Wold

Peroxisome biogenesis disorders (PBDs) are a class of progressive childhood neurological, autosomal recessive disorders affecting approximately 1 in 50,000 births in the United States. PBDs are caused by mutations in PEX genes, which are encode proteins for peroxisome assembly. Resulting buildup of very long chain fatty acids can lead to wide array of developmental issues. Currently, there exist no effective targeted therapies for PBDs, but rather palliative treatments for alleviating symptoms. One method of elucidating disease mechanisms and potential drug targets is through quantifying RNA transcripts in a cell via RNA sequencing (RNA-seq). Differences in expression profiles between diseased and healthy cells can be potential targets for genetic therapies, as restoring expression of a gene to healthy levels may block the progression of associated pathology. Transcriptomes from wild-type and diseased (PEX1-G844D, or PEX1 knockout) mouse bone/bone marrow cells were sequenced, and are

being analyzed using bioinformatics pipelines (STAR for aligning reads, HTseq for counting reads, and DESeq for differential analysis) to find genes of biological interest that have a statistically significant change in expression between phenotypes. Once these genes of interest are identified, they can be selected as targets for future drug screens.

Wireless Wearable Heart Sensor Based Off of Eddy Current Damping

David Lin

Mentors: Yu-Chong Tai and Tzu-Chieh Chou

The purpose of this project is to construct a heart monitoring device that will measure heart activity through eddy current damping. This method of monitoring effectively measures heart volume and flow over time, providing insight on heart behavior that traditional devices such as ECG fail to capture. The prototype device signal was measured on top of the heart against ECG and PPG devices, demonstrating a correlation between the different measurement methods after digital signal processing. However, a significant amount of noise still exists, making it difficult to locate more minute features in the signal. Currently this noise is being reduced through shield design and circuit design. Different coil designs differing in inductance and size are also being tested to optimize measurements.

Evaluating Supernova Neutrino Triangulation

Nora Linzer

Mentors: Kate Scholberg and Ryan Patterson

A core-collapse supernova releases a majority of the gravitational binding energy of a star, with 99% of this energy released in the form of neutrinos. In the event of a supernova within our galaxy, multiple current and future neutrino detectors would see a large burst in activity. The neutrino signal could be used to triangulate the supernova's location by finding the difference in arrival times between detectors. Neutrinos escape a supernova hours before light does, so triangulation would allow observers to point telescopes at the supernova before light reaches Earth, and image the the entire event. To evaluate the triangulation method, we generate random supernova neutrino signals, and quantify the error in calculated time delay between detections. With this information, we find the pointing precision of supernova neutrino triangulation as a function of supernova distance and location, detectors used, as well as neutrino background level and mass oscillation. In ideal conditions, the supernova search area could be reduced to as low as a few percent of the sky.

DNA Methylation Patterns in Blood Vessels of the Human Brain

Andre Liu

Mentors: Michael Wang and Elizabeth Hong

The proteins of the human cerebrovascular system contribute to the proper function of blood vessels in the brain. Since many cerebrovascular diseases result from defects in these proteins, a detailed understanding of the expression patterns of brain vessel-specific genes may be useful for deciphering the mechanisms of these diseases. In particular, DNA methylation is an epigenetic modification of DNA which is associated with regulation of gene expression. In this study, we characterize the states of specific methylation sites on genes which encode human vessel-specific proteins. First, we identified vessel-specific proteins using immunohistochemical data from the Human Protein Atlas. We prepared human cerebral vessel samples and whole brain samples, and then used a restriction enzyme assay coupled with quantitative PCR to determine the states of methylation sites of the genes encoding these proteins. We found differential methylation at some sites— for the genes SLC2A1 and MYADML2, as well as some others— between vessel and whole brain DNA of some samples. These results were validated by bisulfite modification analysis. In conclusion, we have identified methylation patterns in specific genes for cerebral vessel-enriched proteins and developed a workflow for testing the state of specific methylation sites on the genome.

Cortisol Detection in Sweat Using Extended Gate MOSFET

Qianhe Liu

Mentors: Zhenan Bao, Amir Foudeh, and David A. Tirrell

Cortisol is a stress hormone that has been shown to correlate with mental states such as anxiety, depression, and bipolar disorder. Prolonged exposure to stress releases cortisol from the adrenal cortex, which allows cortisol to be a potential biomarker for psychological stress estimation. An individual's cortisol secretion depends heavily on the time of day, so detection at the point-of-care is crucial. Current detection methods involve extensive processes using blood or saliva samples. In comparison, sweat is an advantageous sample choice considering its abundance and continuity on the body. The Bao Lab works on developing a wearable biosensor for measuring cortisol in real time using extended gate MOSFET with stimulated sweat samples. By using competitive immunoassay to detect cortisol, the device can be resistant to sweat's pH, salt concentration, and temperature changes, and provide the possibility for multi-use. At the current stage of research, multiple cortisol-CMO and antibody pairs are tested with

QCM to optimize the device's antibody attachment and detection abilities. Furthermore, the extended gate MOSFET is functionalized with mPEG-AA and tested with varying salt concentrations in attempt to overcome Debye length limitations. Ultimately, we hope to translate the low concentration of cortisol in sweat to a detectable electrical signal.

The Role of Contracts in Venture Capital Returns for Limited Partners

Sarina Liu Mentor: Michael Ewens

During contract negotiations between venture capitalists and startups, the former can receive a combination of preferred stock, dividends, and senior liquidation preference. Limited work has been done to validate whether realized returns to limited partners reflect investors exercising all cash flow rights available to them. A detailed analysis revealed that incorporation of contract terms into returns calculation changes the across-financing returns distribution to be a better approximation than common stock. The difference between the two is most significant in venture capital exits with relatively low valuations, which are in fact some of the most common outcomes. Using the probability that a range of gross multiples on the return occurs, an average multiple relating preferred and common can be calculated. Ultimately, when studying an overall fund with a portfolio of IPOs, good acquisitions, poor acquisitions, and failures, these aforementioned contract terms do play a meaningful role in returns earned for a limited partner.

Projection for ZZZ Production Cross Section Measurements at the HL-LHC

Xiaoling Liu

Mentors: Maria Spiropulu and Jay Lawhorn

Tri-boson production is one of the ways to study the anomalous Quartic Gauge Couplings (aQGC). In particular, we investigated the signal selection criteria for ZZZ production in the HL-LHC scenario. We wrote selection code which picks out the events that satisfy several constraints and that can successfully re-construct 3 desired Z bosons from the produced electrons, muons and jets. We ran the code on some selected samples produced from Delphes phase 2 Monte Carlo simulation for the HL-LHC Yellow Report, including the ZZZ signal samples and other background (e.g. TT) samples, and projected the results to the HL-LHC. We made plots of event variables and looked for variables that can potentially separate the signal from the backgrounds. Then we investigated the constraints on these variables to maximize the signal to background ratio for the semi-leptonic final states of ZZZ and the statistical significance of the expected yields for the various final states of ZZZ.

Culture Conditions Influence Iridescence in Marine Microbes

Jared Livingston Mentors: George O'Toole, Dianne Newman, and Lynn Kee

Iridescence is a biological phenomenon dependent on the formation of biological photonic crystals. While it is well characterized in multicellular organisms, it is poorly characterized among prokaryotes. Iridescent marine microbes have been isolated in the past, but iridescence has not been observed among prokaryotes in natural habitats and its function is poorly understood. In this study, we isolated several iridescent microbes from rocky shore seawater around Woods Hole, MA and classified them using genomic techniques. We used light microscopy to analyze the effect of several culture conditions on iridescence to better understand its biological significance. We chose these conditions, which include salinity, pH, and temperature, to reflect the variability of the rocky shore habitat of these microbes. Preliminary results show that nutrient availability influences structural color of iridescent bacteria. With the exception of low agar concentration or salinity, iridescence was observed in all conditions in which growth occurred, indicating that iridescence is a consequence of the growth pattern of these microbes on solid media.

Developing a Model of Supernova-Driven Star Formation in Evolving Galaxies

Jackie Lodman

Mentors: Charles Steinhardt and Sean Carroll

Observations of galaxies have revealed that they are enormously diverse, but despite these different end states, recent discoveries suggest they have a common evolutionary history. For example, we can predict the star formation rate of a galaxy using only its mass and the age of the universe (redshift). However, astronomers do not yet understand why this is the case. We developed a new model of star formation in evolving galaxies by considering the possibility of regulating the star formation rate via a supernova-gas feedback loop. This model is only now possible because of recent developments indicating a connection between gas temperature and mass distribution of stars in a galaxy, a connection too complicated for current numerical simulations. We show that this model drives a wide range of galaxies to an equilibrium solution, which can be compared to current and future observations.

Analysis of Heterogeneous Structures in Stable Crack Growth Conditions

Christopher Long

Mentors: Katherine T. Faber and Neal Brodnik

To design tougher and stronger composite materials, it is important to understand how materials design and structure affect macroscopic mechanical properties. One aspect of interest is elastic contrast between materials in a composite structure and its effect on fracture toughness. To investigate this phenomenon, it is important to understand how toughness changes as the specimen fails. To achieve this, fracture studies were done on double cleavage drilled compression (DCDC) specimens, which provide stable crack growth. Stereolithographically printed specimens with stiff and soft inclusions were subject to compressive loading and displacement maps were 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. In homogeneous specimens, the J-integral is expected to yield a discrete value intrinsic to the material, whereas in heterogeneous specimens, toughness depends on the size, location, and relative stiffness of the introduced heterogeneities. This investigation helps to inform composite design by providing understanding of how the position and composition of heterogeneities affects failure behavior.

Modulating Insulin Biophysics Through Incorporation of Non-Canonical Tryptophan Analogues at Residue B26

Alejandro López Mentors: David Tirrell and Stephanie Breunia

Insulin's effectiveness as a therapeutic drug in diabetic pa

Insulin's effectiveness as a therapeutic drug in diabetic patients is dependent on its ability to maintain both basal levels of insulin and higher levels after mealtimes. Insulin is injected as a hexamer, which dissociates into a dimer and then an active monomer. Mutagenesis of specific residues allows for greater control of dissociation equilibria and can also prevent degradation into fibrils; most current pharmaceutical formulations of insulin have been genetically engineered. Substitution of residue Tyr_{B26} for tryptophan has been shown to increase dissociation time. However, incorporation of non-canonical amino acids allows for further manipulation of protein properties beyond the limits of the natural genetic code. We seek to investigate the effects of non-canonical tryptophan analogues in insulin at residue B26. We mutated the respective residue on a proinsulin gene in a PQE80 plasmid, confirmed mutation by DNA sequencing, and electroporated the plasmid into a tryptophan auxotrophic *E. coli* strain. We successfully expressed proinsulin incorporating 7-azatryptophan but were unsuccessful at incorporating 5-hydroxytryptophan, as confirmed by MALDI mass spectrometry. We plan to refold and purify insulin by HPLC to then perform dissociation and fibrillation assays.

Ionospheric Storms and the Problem of Radio Wave Interference on Animal Navigation

Tegan Loveridge

Mentor: Joseph Kirschvink

Several studies have suggested that radio-frequency electromagnetic radiation can affect behavior in animals by turning off their magnetic sense, which they use for navigation. While this radiation tends to be man-made, we hypothesize that there is an important natural source. Coronal mass ejections (CMEs) and solar flares can create disturbances in the ionosphere, known as ionospheric storms. Depending on other factors such as latitude and local time and seasonal variations, these storms can result in an increase or decrease of the ionization density. These density changes can allow radio-frequency noise from subsequent solar activity to pierce through the ionosphere instead of being reflected. The question is whether radio waves of the necessary frequency range (around 1 - 2 MHz) are traveling through the ionosphere. To determine this, further investigation of ionospheric radio wave propagation during and after ionospheric storms is required.

Sensor Synchronization for Autonomous Flight of Unmanned Aerial Vehicles

Elaine Lowinger

Mentors: Soon-Jo Chung, Kai Matsuka, and Thayjes Srivasa

In autonomously operated vehicles, it is necessary to have accurate data that is based on the same internal clock as to have the sensors reporting data in a syn- chronized manner. This synchronization allows for better input for algorithms to understand position, and for further use in movement calculations and path finding. In the Aerospace Robotics and Control Laboratory at Caltech, new synchronization methods needed to be developed for increased precision and to better match the in lab drones, which use the VectorNav100 Rugged Inertial Measurement Unit (IMU) and Sony Blackfly USB3 Camera. In order to do so, testing had been done on various master and slave sensor set ups to test for efficiency, including having the IMU be the controller and an outside Arduino Mini Microcontroller act as the clock to trigger the sensors. With these controls, it was found that the IMU controlling the triggering rates would be harder to control, and going through more wires and hardware would have slowed down the triggering. After testing the various controller types, different wiring styles were used to ensure the most data was being transferred at the highest speeds. For the autonomous drones used in this lab, it was determined that

an Arduino Microcontroller and wiring each sensors' Sync In trigger lines to this Arduino while wiring their data transfer lines to the onboard computer through USB. The hopes of this research is the backbone of this structure in wiring and con- trollers can be implemented in other autonomous systems, and extend to more of the sensors used in autonomous movement for better data collection.

Exploring the Band Alignment in Transition-Metal Dichalcogenide Atomic Layers

Junlan Lu

Mentors: Harry A. Atwater and Zakaria Y. Al Balushi

Inspired by the exotic properties of graphene, the vast interest in "beyond graphene" two-dimensional (2D) and layered materials (2DLMs) have been driven by the compelling properties of individual atomic layers compared to their bulk counterparts. These materials are extreme surfaces that exhibit strong in-plane along with weak out-ofplane bonding, and are susceptible to physical, electrical and/or chemical modifications, opening up many avenues for novel applications. Particularly semiconducting 2DLMs present interesting optoelectronic properties when combined either vertically or laterally to form novel atomic scale heterostructures. Especially, transition-metal dichalcogenides, with stoichiometry MX_2 (M=transition-metal and X=chalcogen: selenium, sulfur and/or tellurium), which are a class of 2D materials that exhibit direct optical band gap transitions in individual monolayers and large exciton binding energies which allows them to be promising candidates for optoelectronic devices such as efficient light emitters. To maximize light emission in such devices, understanding the nature of the band alignment between such layers is essential. In this study, we investigate the band alignment of various 2D heterostructures that may lead to a staggered type I band alignment. Raman spectroscopy, Photoluminescence (PL) and timeresolved PL measurements were performed to understand the phonon modes and carrier dynamics in these heterojunctions. Furthermore, Kelvin Probe Force Microscopy and X-ray Photoemission Spectroscopy were utilized to assess the relative work function, and valence band offsets, respectively. The experimental results from this study provides new insights to understand the effectiveness of Anderson's rule in determining the band alignment in these heterostructures.

Investigating the Slow Neutron Capture Process in the Early Universe

Tiger Lu

Mentors: Terese Hansen and Sterl Phinney

Carbon Enhanced Metal Poor (CEMP) stars are stars that show unusually large enhancements in carbon and low concentrations of iron. A subset of these also show enhancements in elements created in the slow neutron-capture process (s-process), called CEMP-s stars. These are old stars which preserve the composition of the interstellar medium when they formed. The prevailing theory for these stars' peculiar elemental abundances is via mass transfer from a partner star. However, radial velocity monitoring of 22 CEMP-s stars have identified 4 as single stars. For these stars, enhancement of s-process elements cannot be explained via mass transfer, hence their abnormal abundance is likely the result of nucleosynthesis events in the early universe. By constructing stellar atmosphere models using iron absorption lines, and using spectral synthesis to determine abundances of the elements in question. We measure abundances of C, N, alpha and iron peak elements, and 15 s-process elements in these stars using high resolution spectra, and compare them to abundances predicted from progenitor models of the s-process.

Exceptional Points in Microresonator Brillouin Laser Gyroscopes

Yu-Kun Lu

Mentors: Kerry Vahala and Heming Wang

Microresonator Brillouin Laser Gyroscope has shown the capability to measure small rotations, even the rotation of the earth. In this work, a model of the counter-propagating stimulated Brillouin laser is developed. We theoretically demonstrated and experimentally confirmed that the critical point separating single mode and multimode lasing phase is an exceptional point (EP). Thanks to the Kerr nonlinearity of the cavity, the position of the EP can be controlled by tuning the input power of the pump lasers. Furthermore, the boost of Sagnac factor is observed when the system is operating near the EP, which greatly enhanced the sensitivity of the gyroscope. EPs in microresonator Brillouin laser gyroscopes pave the way for lasing mode switching and high-precision rotation sensing in a single on-chip microresonator.

Molecular Acoustically Targeted Chemogenetics

Brian Lue Mentor: Mikhail G. Shapiro

Abstract submitted and approved but withheld from publication.

Angular Momentum Transport in Massive Stars

Linhao Mao Mentor: James W. Fuller

The theoretical prediction of the rotation rate of stellar remnants of massive stars has been an unsolved problem for long. In this project, we found that the MHD instabilities in stellar interiors after main sequence may play a dominant role in angular momentum transport from stellar core to envelope and may cause significant angular momentum redistribution which may slow the spin of cores and its corresponding remnants. We develop a new criterion of the saturation of this instability and run MESA models to find that they agree well with the typical rotation rate of neutron stars and black holes.

Laboratory Experiments on Bedrock Channel Formation by Dry Granular Flows

Zewei Ma Mentor: Michael P. Lamb

Bedrock Gullies are common topographic features on steep slopes of the Earth, the Moon and Mars. Their formation is generally related to fluvial erosion processes, and since Martian topography is significantly channelized and many gullies exist on crater walls, the common assumption is they stem from fluvial origin. However, impact crater gullies on the Moon show that they can also form by dry granular flows. In this project we assemble a laboratory experiment which aims to analyze what kind of surface is shaped by dry gravel transport on a steep slope, rather than fluvial sediment transport. In this experiment, we use a 5m long and 0.65m wide tilted chute to resemble a steep slope filled with synthetic polyurethane foam, which serves as bedrock substitute. We apply 12 cameras to monitor the flume laterally and vertically and to record the motion of the dry gravel and the change of the surface in high spatio-temporal resolution. We use Python scripts to analysis the pictures and calculate the particle trajectories, velocities, and impact energies. After completed experiment calibration and workflow setup, and together with repeated spatial surface laser scans, this data shall be used to test a numerical erosion model of dry granular flows and to assess the meaning of this process for planetary surface formation.

Utilizing Poroelastic Resonance for Underground Location Tracking of Mosquitoes

Daniel L. Magley Mentors: Ada Poon and Hyuck Choo

The Malaria endemic in central Africa is one of great focus and research. The National Institute of Health (NIH) is working to identify the location of groups of mosquitoes which carry malaria precisely, so as to be able to target poisons and other eradication methods and eliminate them. The NIH believes that the prime breeding grounds for Malaria infected mosquitos are in the several meters deep root systems and termite burrows around a certain species of tree. Our group has been tasked with designing a method to locate these mosquitos to 10cm precision when they are underground, however, traditional methods like RFID face severe attenuation at such depths underground. For that reason, we looked to find a method utilizing Poroelastic resonant sound waves to actuate sound based ID tags on the mosquitos. In this work we present different common tunnel geometries and their respective resonant Poroelastic frequencies. We then propose a system to sweep and identify resonant frequencies of an unknown tunnel system.

A Computational Study of the Discrepancies Between Theory and Experiment for the Frictional Response of Liquid Nanofilms

Kishan Makwana Mentor: Sandra M. Troian

It remains challenge to accurately measure key hydrodynamic properties of liquid nanofilms, namely their response to applied shear-stress. The Blow-off technique was devised by Derjaguin in the 1950's to indirectly measure the viscosity of thin films by monitoring its evolution when stress is applied to the liquid's free surface. As ellipsometric measurements improved, microfilms were studied to reveal several distinct linear regions in its frictional response whereas ultra-thin nanofilms were found to have entirely non-linear regimes. Neither case is predicted by the simple Newtonian model often assumed. In the pursuit of a more complete theoretical description that includes all relevant physical phenomena on the nanoscale, the original theory was augmented with gravity, capillary and Van der Wall (VdW) forces. Finite element simulations were run to reconcile discrepancies between Derjaguin's original theory and experimental data. It was found that gravity and capillary forces have a negligible influence along the entire domain of the film's evolution however Hamaker's form of the VdW force encouraged greater diffusive motion very close to the liquid-substrate boundary. One concludes that bulk film properties are very well approximated by a simple Newtonian model. However, it is the aim of further research to firstly improve the Hamaker model in the case for nanofilms and secondly, to develop a binary or spatially-dependent viscosity model for microfilms to account for the multiple linear regimes presented in the historic data.

Measuring the Magnetic Shielding Factor of an Aluminum Vessel for the Detection of a Neutron Electric Dipole Moment

Morgaine Mandigo-Stoba Mentors: Brad Filippone and Wanchun Wei

The baryonic number observed in the Universe is an open problem in modern physics. It is believed that the baryonic number was zero at the beginning of the Universe, and asymmetry induced by CP violation beyond the standard model is the most plausible explanation. This violation could be accounted for with electric dipole moments (EDMs) of particles, with the neutron (nEDM) being particularly compelling because its neutrality makes it easy to manipulate and contain. The SNS-EDM Collaboration is attempting to detect an nEDM with an instrument that will use trapped free neutrons, called ultracold neutrons. The proposed detector will have a sensitivity of 10⁻²⁸ c em. This requires a uniform low magnetic field which is achieved in part by an aluminum cryostat. In this project, the magnetic shielding factor of the cryostat is measured in the frequency domain, and several other contributions to the nEDM experiment are made. These include the preparation of the liquid nitrogen shield, the development of data acquisition software in Python, and the performance of the first cool-down of the cryostat.

Scanning Tunneling Spectroscopic Studies of Doping Dependent Quasiparticle Excitations in Cuprate Superconductors

Qinghao Mao Mentors: Nai-Chang Yeh and Marcus L. Teague

Since the discovery of high temperature cuprate superconductors in 1986, many unconventional phenomena have been discovered but not fully understood, including the pseudogap (PG) phenomenon. Hoping to find out the origin of the PG, Prof. Yeh's group has conducted Scanning Tunneling Spectroscopy (STS) studies on YBCO, an important superconducting cuprate. As a follow-up of the previous studies in Prof. Yeh's group, this project focuses on STS measurements of YBCO's doping dependent quasiparticle excitations. By changing the Calcium doping rate, we can vary YBCO's hole-doping rate, which in turn changes the material's properties including local density of states, which are related to the PG. Before taking the measurements, we introduced double thermal shields to upgrade the current STS system. With the doping dependent spectra from STS measurements, we hope to provide useful insights into the origin of the elusive PG phenomenon.

Quantum SURFing

Daniel K. Mark Mentors: Gil Rafael and Samuel Savitz

We attempt to achieve 'quantum surfing' - transport of single particles by moving potential pulses. We find that dissipation is essential to achieve surfing. We implement two models of dissipation, and numerically study the surfing achieved with them. We seek to understand surfing through a random walk model.

A Novel Role of HMGA1 in Neural Crest Emigration

Krystyna R. Maruszko Mentor: Marianne Bronner

Members of the HMGA (High Mobility Group A) family of proteins participate in a wide array of nuclear functions such as binding DNA, modifying chromatin structure, and assisting in gene expression. Two HMGA genes, HMGA1 and HMGA2, are expressed in mammals during embryogenesis and tumor progression. In *mus musculus*, a null HMGA1 allele causes cardiac hypertrophy and lymphomas while a combination of null HMGA1 and HMGA2 genes causes prenatal death in most cases with the few survivors having reduced body size. In a recent study by Shashank Gandhi, it was discovered that HMGA1 plays a role in the development of the cardiac neural crest in G. gallus. To determine the role of HMGA1 in G. gallus development, we used three approaches: we used *in situ* hybridization to determine where and when HMGA1 mRNA transcripts are first detected, CRISPR-Cas9 to knock-out HMGA1, and utilized an overexpression construct for HMGA1 in stage 4 chick embryos. Do this, we discovered that by interfering with HMGA1 production, we see an early induction of EMT in neural crest (NC) cells. We also see that, in the gene regulatory network, HMGA1 acts upstream of HNK1 and Pax7, two NC cell markers.

Dynamical Phase Transitions in Sampling Complexity of the Bose-Hubbard Model

Nishad Maskara

Mentors: Alexey V. Gorshkov and John Preskill

In this work, we investigate the complexity of classically simulating the time evolution of the Bose-Hubbard model. In particular, we examine the sampling complexity, which measures the classical resources needed to simulate the output of a quantum system. We give an efficient sampling algorithm which works at short timescales for a well separated initial state, showing that in this regime, sampling is easy. Then we provide evidence for a dynamical phase transition from easiness to hardness as time evolves. Our work considers interactions that are both finite range and long range with power-law decay.

A Communication Complexity Approach to the Two Families Conjecture for Fast Matrix Multiplication

Surya Mathialagan

Mentor: Christopher Umans

The exponent ω of matrix multiplication is the minimum real number such that matrix multiplication can be done in $O(n^{\omega})$. Since many standard linear algebra and even non-algebraic algorithms rely on ω , finding ω is a problem that has received a lot of attention. The naïve matrix multiplication algorithm gives us $\omega \leq 3$, and the current best known upper bound is $\omega < 2.373$. It is widely believed that $\omega = 2$. Cohn and Umans developed a group-theoretic approach for a new matrix multiplication algorithm that reduces matrix multiplication to group algebra multiplication using techniques from group theory and representation theory. They pose conjectures describing conditions for constructions that could give $\omega = 2$, and the best current known bound using this method is $\omega < 2.41$. In this project, we focus our attention on one such conjecture, the Two Families conjecture, and we reformulate it as a two-party communication problem in a modified group-theoretic setting. We examine well-known communication complexity problems such as the equality and inner-product functions, and we provide optimal constructions in the new setting. We narrow the search scope of the Two Families conjecture to cyclic groups.

Constraining HI Self-Absorption Features Using Fermi-LAT Data

Jake Mattinson Mentor: Guðlaugar Jóhannesson

When estimating column densities of interstellar hydrogen clouds, large uncertainties come from regions of neutral hydrogen self-absorption (HISA), where a cold neutral hydrogen cloud sits in front of a warm neutral hydrogen background. The location of these features have been studied using hydrogen's 21 cm emission line surveys, yet their contribution to the density cannot be accurately determined without additional information. The high-energy gamma-ray emission from cosmic ray interactions can be used to estimate total column density of gas in regions of HISA. Using data from the Fermi Large Area Telescope, we build a model for the high-energy interstellar emission near the HISA features to estimate the local total column density. This is used to constrain the column density of HISA features, providing a more accurate estimate of the contribution of HISA to observable spectra.

Ab initio Simulation of Carrier Dynamics in High Electric Fields

William McCorkindale Mentor: Marco Bernardi

My project in the Bernardi group to numerically solve the Boltzmann Transport Equation (BTE) in the presence of an electric field; extra terms in the BTE arising from E-field drift lead to 'stiffness' and hence numerical instability when attempting to explicitly solve the BTE. Over the past month, I have made progress in implementing an implicit, parallelised algorithm for solution of the BTE by linearising the Backwards Euler method and using the ScaLAPACK library for solving the resulting linear algebra equations in parallel. This should open the door towards solving more physically interesting problems such as obtaining carrier drift velocity-field curves from firstprinciples, as well as provide the groundwork for more accurate, higher-order algorithms.

Modeling the Effect of Intracellular Signaling Mechanisms on Population Dynamic Behaviors in the Context of Paradoxical Signaling

Harman Mehta

Mentors: Richard Murray and Michaëlle Mayalu

Cells can communicate with each other by secreting signaling molecules that diffuse between them. Detection of an extracellular signaling molecule triggers cascades of intracellular signaling events that regulate diverse cell behaviors such as the proliferation, apoptosis, differentiation, and gene expression. In some cases, the same signaling molecule can affect opposing or antagonistic cell behaviors. This scenario is referred to as paradoxical signaling. We modeled the T-Cell population dynamics where the cytokine IL-2 acts as a signaling molecule triggering both cell proliferation and apoptosis leading to paradoxical signaling taking into account the internal mechanisms that lead to IL-2 production, proliferation and cell death. We were able to identify the effects of different parameters and initial conditions on cell population behavior. Paradoxical signaling can also be used to regulate synthetic cell circuits. We conducted experiments on bacterial cultures designed to implement paradoxical signaling for proof of concept. This is a more robust signaling mechanism since we can get a distinct ON and OFF stage for most parametrical values and can achieve homeostasis independent of initial cell levels.

The Self-Consistent Schrödinger Evolution of Self-Gravitating Disks

Walker Melton Mentor: Konstantin Batygin

While self-gravitating disks are one of the most ubiquitous objects in nature, the transfer of angular momentum within disks is still poorly understood. We investigate the secular small-inclination dynamics of a razor-thin particle disk as the continuum limit of a discrete Lagrange-Laplace secular perturbative theory and explore the analogy

between the secular evolution of self-gravitating disks and quantum mechanics. We find the 'quantum' Hamiltonian that describes the time evolution of the system and demonstrate the existence of a conserved inner product. Finally, we discuss the application of this formalism to the study of external perturbations and the gravitational rigidity of the disk.

Investigation of Radical Intermediates in Atmosphere Chemistry Based on Cavity Ring-Down Spectroscopy

Qinghui Meng

Mentors: Mitchio Okumura and Joey Messinger

The hydrocarbons emitted into the atmosphere seriously influence the components of atmosphere such as ozone, greenhouse gases, oxides of nitrogen, etc., and cause changes to the global climate. The chemical reaction mechanism of hydrocarbons in the troposphere and stratosphere is a central research focus of atmospheric chemistry, as it helps to understand the generation of ozone and pollutants in atmosphere. However, a practical mechanism is based on the accurate understanding of each step of gas-phase and aqueous-phase chemical reactions. Our group mainly focus on the detection of radical intermediates produced in gas phase reactions, which helps to determine the reaction process. We used the technology of mid-IR Cavity Ring-Down Spectroscopy (CRDS), working in the spectrum region from 3600cm^-1 to 3700cm^-1. We have detected the adducts produced in the benzene + OH and toluene + OH reaction. And the reaction between methyl vinyl ketone and OH will be studied in the future work.

Resource Usage in TX-TL

Sannat Mengi Mentors: Richard Murray and William Poole

In vitro TX-TL (TX-transcription, TL-Translation) are E. coli cell lysate based protein expression systems which can be used as a cell free breadboard for designing, testing, and probing aspects of gene circuit operation *in-vitro* allowing for fast prototyping and quantitative circuit calibration. However, the lifetime of these TX-TL systems is limited due to waste build-up and energy resource depletion. Our project aims to solve this issue by building a reservoir attached to the TX-TL reaction volume. Continuous contact between the reaction volume and the reservoir allows for the exchange of energy and waste chemicals leading to longer runtime of the TX-TL reactions. To aid our understanding of this process, we have built mathematical ODE models of resource utilization in TX-TL. We have designed a novel experimental set-up to use a reservoir inside a 96-well plate that can be put in a plate reader. Experiments with this platform have tested the membrane, models of diffusion, and how reservoir volume effects TX-TL longevity. Our initial results suggest that running a reaction on top of the reservoir results in higher levels of protein production than using a reservoir on the top. We hypothesize that access to oxygen is a primary cause for the differences caused by switching the reservoir and reaction volume.

Use of Ball Cratering and Low-Angle Ion-Etching in Combination With Nanoindentation to Characterize Hardness Gradients in Tetrahedral-Amorphous Carbon Coatings

Rebecca Mikofsky

Mentors: Lars Lorenz and Julia Greer

Hydrogen-free tetrahedral-amorphous carbon (ta-C) coatings are made of disordered (amorphous) carbon that is primarily sp³ hybridized (greater than 80%). In comparison, diamonds are an ordered lattice of 100% sp³ hybridized carbon. Like diamonds, ta-C coatings have high hardness and low-wear. These properties along with other useful characteristics like biocompatibility, chemical inertness, and thermal stability make ta-C films very useful in industry. High-quality ta-C films are made using filter-laser-arc physical vapor deposition technology. Graded ta-C films are created by depositing multiple layers with varied pulse lengths giving each layer different properties. To confirm the gradient in these coatings, ball-cratering and ion-etching were used to create cross sections of the thin coating by making a low-angle sloped surface. Nanoindentations were performed on these sloped cross sections to measure the hardness and indentation modulus of each layer in the film. The results of nanoindentation in the craters of the gradient samples were compared to other non-gradient and layered samples.

Development of Novel Uranyl Metal-Organic Frameworks for Use in Photocatalysis

Jayce Miller

Mentors: Michael Hoffmann and Kai Liu

Metal-organic frameworks (MOFs) possess high porosities and surface areas, making them well-suited for catalysis. In turn, the uranyl $(UO_2^{2^+})$ ion is a remarkable oxidant when photosensitized—strong enough to oxidize xenon. Creating new uranyl metal-organic frameworks with a variety of carboxylic acid linkers suggests a remarkable dependence of assembly modes on solvent and pH. A novel procedure for instant (<1 s) formation of uranyl metal-organic frameworks is presented. Synthesis and characterization of several new MOF structures, including the first aerogel compound of uranium, are also reported. After developing controllable strategies for deposition of the MOFs onto indium tin oxide (ITO)-plated glass, the electro- and photochemical activity of the uranyl ion trapped

inside the framework will be tested in the hopes of finding a highly efficient catalyst for water oxidation or a similar environmentally applicable reaction.

Parallelization of Nudged Elastic Band Calculations With Embedded Mean Field Theory

Michael Miller

Mentors: Thomas F. Miller III and Feizhi Ding

Embedded Mean Field Theory (EMFT) allows high level Density Functional Theory (DFT) quantum mechanical calculations to model a small subset of a large system, while cheaper, less accurate theory is used on the majority of the atoms. Because EMFT does not require specifying bonds or fixing the number of electrons, it is easily applicable in the study of reaction mechanisms and potential energy surfaces across a wide range of systems. In order to analyze reactions with EMFT, energy and force calculations are piped to the Nudged Elastic Band (NEB) algorithm, which uses them to estimate the reaction intermediates by successively relaxing the initial guesses and then performing a gradient climb to settle the structures at saddle points of the potential energy surface. My work has been to interface *entos*, a computational chemistry package in development that implements EMFT, with NEB and to compare the energies and structures derived by transition state searches using EMFT with those using conventional, non-embedded DFT. Results confirming the accuracy of combining EMFT with the NEB method in *entos* provides evidence that this new capability offers a speedy but effective tool for analyzing reaction mechanisms and transition states in large systems with small active sites.

Genetic and Molecular Analysis of chd-7 Using Transcriptomic Phenotypes

Kyung Hoi (Joseph) Min Mentors: Paul W. Sternberg and David Angeles-Albores

Chromodomain helicase DNA-binding protein 7 (CHD7) is a chromatin remodeling protein that is essential for normal development in humans. Mutations of this protein is strongly linked to CHARGE syndrome, characterized by a multitude of physiological and mental defects. Though we have a macroscopic understanding of its significance, little is known of the genetic and molecular processes mediated by CHD7, both which may help provide candidate targets for future drug development. We studied the allelic series of *chd*-7 by analyzing the transcriptomic phenotype of *C. elegans chd*-7 homozygotes and *trans*-heterozygotes via RNA-sequencing (RNA-seq). We characterized the genetic properties of three *chd*-7 alleles and constructed several allelic hierarchies based on this data. Additionally, we identified several genes that may be mediated by *chd*-7. Transcriptome profiling and epistasis analysis of these genes may yield novel genomic interactions with *chd*-7 and new components to existing pathways.

Analysis of the Role of Transcription Factors to Control Early T-Cell Development

Anik Mitra

Mentors: Ellen Rothenberg and Xun Wang

It is necessary to understand how T cells acquire their ultimate identity by controlling the expression of transcription factors (TF). The overexpression of a pre-commitment stage transcription factor PU.1 in a DN3-like cell line shows a phenotype with the downregulation of the T cells genes. Whether PU.1 is involved directly in regulating them, is not established. We hypothesize the existence of a mediator in this network. To find this, we have analyzed the ChIP-seq data for PU.1 affected genes and found Bcl11a to be a putative target of PU.1. We will perform a comparative study by overexpressing Bcl11a and structurally similar Bcl11b (but their expression pattern is different) to find any phenotypic change in the same cell line. Lyl1/Lmo2 is found to be important phase 1 transcription factors those elicit chromatin environment changes and a cellular reprogramming marked by the down regulation of lineage commitment marker Bcl11b. We hypothesize the existence of a transcription factor that acts on Bcl11b during this reprogramming. We will do an over-expression of Lyl1/Lmo2 followed by a CRISPR-deletion of putative target of Lyl1/Lmo2 genes in Bone Marrow cell culture.

Investigating the Effects of RF on the Human Brain Response to Geomagnetic Field Changes

Kabir A. Mohammed

Mentors: Joseph Kirschvink and Connie Wang

Magenetoreception is a sensory modality involving the detection of geomagnetic fields, present in a wide array of organisms, but its presence in humans has long been a topic of debate. The recent discovery by the Kirschvink / Shimojo groups that humans also possess a functional compass response that affects alpha waves in the human brain leads to the interesting question of what happens to this sensory system when exposed to radio frequency (Rf) signals in the low megahertz range, such as those from AM radio towers. The specific pattern of brain responses suggests that the human sense is based on nanoparticles of biogenic magnetite located in the head. The compass response is observed via an alpha-event related desynchronisation (alpha-ERD), a drop in amplitude of brainwaves in the 8-13 Hz range, in response to a rotating magnetic field. Rf signals at different frequencies and amplitudes are applied to determine whether the alpha-ERD response is affected. Preliminary results show an inhibition of the magnetosensory response using a range of frequencies from 0.1-2 MHz and down to 1 nT. We have proposed a radioreception model for how Rf is transduced through biogenic magnetite. The project is ongoing.

Impacts of the Autism-Associated Mutations in Chromodomain Helicase DNA-Binding Protein 7 on β -Catenin Signaling Pathway

Vladimir M. Molchanov

Mentors: Paul W. Sternberg, Kyung Hoi Min, Sandy Wong, and David Angeles-Albores

Mutations of the CHD7 and CHD8 genes, encoding chromatin remodelling factors, have previously been associated with CHARGE syndrome and autism, which are serious developmental disorders. Little is known about the molecular reasons underlying the relationship between mutations in these genes and these disorders. Here, we generated 3 disease-associated alleles of CHD7 and CHD8 using the *C. elegans* ortholog chd-7 using CRISPR-Cas9. Homozygotes of these alleles showed vulval and behavioral defects that varied in severity amongst the alleles. Following transcriptome profiling, we identified genes that were specifically differentially expressed in homozygotes of each disease-associated allele. We generated promoter-GFP constructs of 7 such genes to see alterations of the transcriptional phenotypes caused by chd-7 mutations. Previous literature suggested that CHD7 interacts with the Wnt pathway. To test whether this interaction is conserved beyond deuterostomes, we generated double-mutants of our chd-7 alleles with a null allele of the *C. elegans* β -catenin ortholog bar-1. We will study these mutants using a combination of developmental phenotypes and transcriptomic phenotypes to define the molecular and functional characteristics of this interaction.

Biocatalytic Oxygen Reduction by Small Laccase (SLAC) From Streptomyces Coelicolor

Allessandra F. Mondello Mentors: Harry B. Gray and Patrycja J. Kielb

Aerobic organisms have developed a way to utilize the oxygen found in their environment to sustain life. The oxygen can enzymatically get reduced completely to water, which requires the delivery of four electrons and four protons. However, reactive oxygen species, potentially formed in the middle stages of biocatalytic oxygen reduction, could harm the cell due to their high levels of toxicity. Since Tyr108 is near the active site of small laccase responsible for oxygen reduction, does it possibly play a role in the protection of SLAC from reactive oxygen species, or does it assist in the catalytic active site? To determine catalytic role of the Tyr108 in SLAC, the project consists of examining and comparing the catalytic performance of the WT and the mutant, Y108A. In order to do this, Michaelis Menten kinetics were used. This process provides insight into the speed of the reaction between the enzyme and the substrate as well as necessary concentrations for the reaction to thrive. In the end, the data demonstrated that the WT had a significantly higher catalytic efficiency than the mutant Y108A. This suggests that Tyr108 does play an important role in the catalytic active site as well as might being part of the protective mechanism for SLAC.

Temperature and Pressure Sensor Array for Artificial Skins

Antonio Monreal

Mentors: Chiara Daraio and Luca Bonanomi

New advancements in the fields of robotics and prosthetics are getting closer and closer to imitating the way humans are able to move and interact with the world. However, one of the key components to successfully replicating human behavior is allowing these devices to have similar sensory inputs as human skin. This increasing need for artificial skins in the fields of robotics and prosthetics has driven many recent developments such as flexible electronics and biomimetic sensors. In this project, we combine a temperature and pressure transparent flexible sensors to develop a sensor array capable of measuring both stimuli over a given area while maintaining their desired characteristics.

Spatially Phase-Shifting Interferometer (SPSI) System

Tanner Moore Mentors: Guruswami Ravichandran, Michael Mello, and Ares J. Rosakis

We develop a versatile prototype spatially phase-shifting interferometer (SPSI) system capable of combining photoelastic and Mach-Zehnder techniques to solve stress separation for specimens under dynamic loading conditions. A unique four beam replicator module creates four identical copies of a specimen beam that are analyzed simultaneously under four-step photoelastic and Mach-Zehnder algorithms to solve stress reversal ambiguities. While stress separation is a focus of development for the SPSI, the system's versatility makes it a platform for a wide variety of interferometric techniques that can be applied under both quasi-static and dynamic conditions. Coherent gradient sensing is one such technique that will be explored with the SPSI. We procure optical and optomechanical components and advance the design of custom modules to complete the system. After assembling the system modules and installing optics, work will shift to a transmission validation set up for double-passing an expanded beam though a specimen. In future progress, validation will utilize phase-unwrapping algorithms to uncover the complete stress tensor of the specimen.

Utilizing Deep Neural Networks to Extend the Discovery Reach in Signatures With Higgs Boson Decays to b-quark Jets With the CMS Experiment at the Large Hadron Collider

Eric A. Moreno Mentor: Harvey B. Newman

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

Causal Discovery Methods for Analyzing Mouse fMRI

John C. Moss Mentor: Frederick Duncan Eberhardt

Functional Magnetic Resonance Imaging (fMRI) is a standard neuroscientific technique used to study whole brain interactions. Rather than analyzing this data in terms of measured correlations between brain regions, we aim to identify underlying causal relationships with existing causal discovery techniques. In doing so, we contribute: (1) a principled methodology for applying FGES (a modern causal discovery algorithm) to fMRI, (2) an open-source implementation of a new causal discovery algorithm, NOTEARS, from Zheng et al. 2018, (3) a causal analysis of mouse fMRI, in collaboration with domain experts, and (4) a comparison on synthetic data of FGES and NOTEARS to a simpler technique based on the inverse correlation matrix (ICM). We find that FGES and NOTEARS outperform the ICM technique on synthetic data, and present a causal analysis of fMRI from wild-type and Cntnap2 knockout mice.

Examining Flavor Mixes of Astrophysical Neutrinos at Earth and at Their Cosmic Sources Sigiao Mu

Mentors: Markus Ahlers, Mauricio Bustamante, and Peter Schröder

The flavor composition of astrophysical neutrinos, as observed by neutrino telescopes such as IceCube, can provide critical information about their production mechanism at faraway cosmic sources. Although current science models flavor changes through a unitary mixing matrix dependent on experimentally derived "mixing parameters," new theoretical models of neutrino oscillation, if true, could allow for a more general mechanism at higher energies not tested in laboratories. By implementing general unitarity constraints, "tight" bounds on the possible flavor compositions detected at Earth were derived, given some initial neutrino mix. These bounds do not depend on experimental results and are therefore useful to test theories of new physics. Despite the usefulness of neutrino mixes for understanding their cosmic sources, current examinations of IceCube data remain simplistic, in that they only contain discrete benchmark values of the source composition inferred from best-fit mixing parameters. A more comprehensive, data-driven methodology for IceCube analysis was developed by incorporating the uncertainties in mixing parameters and in flavor detection at IceCube, uniformly exploring all possible neutrino production mechanisms. The resulting likelihood function was found to fit a value to the best-fit flavor composition at Earth that is consistent theoretical expectations.

Using Quantum Games to Test Clifford Group Relations

Marc Mühleisen

Mentor: Thomas Vidick

An important task in quantum information is finding techniques to verify calculations made by quantum computers. In certain cases, it is possible to test the outcome of a computation without relying on the functionality of any physical apparatus, a phenomenon known as quantum self-testing. In this study, we develop such a test using so-called quantum games, wherein a quantum computer is asked to make various measurements of a quantum state and to report the outcomes. Based on the outcomes, the computer may either win or lose the game—the point being that the computer should win if and only if it makes the measurements asked of it. We use analytical techniques, including a recent theorem of Gowers and Hatami on approximate representations, to characterize measurements made by the computer during our game as single-qubit Clifford observables. Future studies may be able to generalize our techniques to develop tests for multi-qubit Clifford observables, and eventually even universal quantum gate sets.

Complex Organic Formation in the Orion KL Nebula

Isabelle A. Muise Mentors: Geoffrey Blake and Olivia Wilkins

Nearly 200 molecules have been detected in the interstellar medium (ISM), of which one-third are designated "complex" because they have six or more atoms. The formation of complex organic molecules, such as methanol, in star-forming regions of the ISM can be observed using radio interferometers, such as the Atacama Large Millimeter Array (ALMA). We received Cycle 5 ALMA data from observations toward Orion KL, the closest archetype of massive star-forming regions to Earth. These data are packaged in large Flexible Image Transport System (FITS) files containing far more data than is relevant to the study of the nebula, making the data cumbersome to work with. Shrinking the FITS files was done by writing a Python script that selects the relevant pixels and places them in a new, more compact FITS file that is more convenient to work with. This will make identifying spectral lines much faster, allowing us to more easily analyze the distribution of target singly-deuterated methanol isotopologues (CH₂DOH, CH₃OD) in different areas of the Orion KL nebula. Analyzing the relative abundances of these isotopologues with respect to temperature variation across the nebula will enable us to constrain the reactivity of methanol in massive star-forming regions.

Transiting Exoplanet Detection Using Low-Cost Robotic Telescopes

Aru Mukherjea

Mentors: Dimitri Mawet and Nemanja Jovanovic

The transit method of detecting exoplanets uses photometry to identify stars around which there exist exoplanets. In order to maximize planetary detection rates, many stars should be monitored simultaneously for as continuous a duration as possible. Project PANOPTES aims to survey a large fraction of the sky using a large number of continuously observing low-cost PANOPTES units. We constructed a PANOPTES unit at Caltech for the dual purpose of testing and refining the pre-existing build instructions and to boost the collecting capabilities of the PANOPTES network. These instructions were followed to construct the hardware in the unit. Control software from Github was implemented in the unit, modified as needed, and tested alongside assembled hardware and electronics. Once fully tested and polar aligned, the unit will be able to image target stars to monitor them for transits, and possibly detect other transient phenomena such as variable stars and supernovae.\

Reaction of Clinopyroxene Crystals With Synthetic Carbonate Magma

Catrin Murphy

Mentors: Paul Asimow and Daniel Weidendorfer

Most magmas are primarily composed of silicon. However, some magmas are instead carbonate magmas. These magmas contain less than 20% weight SiO₂ and more than 50 modal% primary igneous carbonate minerals. Clinopyroxene reacts with such magmas at high temperatures to form an immiscible silicate melt and release CO_2 . The rate of this reaction, however, is unknown. Using cold-seal high-pressure experiments we determined the time scale this reaction occurs on. We also examined the minerals crystallized by such melts at varying temperatures.

Nanoporous Metals for CO₂ Reduction

Maya Mutic Mentors: Harry Atwater and Alex Welch

Climate change caused by an increase in CO_2 emissions is perhaps the world's most pressing issue. Solar fuels, hydrocarbons made from CO_2 , water, and sunlight, have the potential to decrease the level of CO_2 to make energy consumption carbon neutral. Recent research has made use of a photoelectrochemical cell (PEC) to reduce CO_2 to CO, a first step to convert the CO_2 into fuel. This project extends current research in optimizing efficiency of COproduction over the hydrogen evolution reaction (HER) in the PEC by examining properties of the metal catalyst used. Nanoporous Au shows promising results in maximizing CO production, and a variety of parameters such as temperature, thickness of the sample, and coatings can be changed to increase efficiency. Our sample consists of np-Au coated in an optimized formula of TiO₂ with Au nanoparticles placed on top. By exposing our sample to light, the np-Au should generate hot carriers at a high enough energy to favor CO_2R over HER, demonstrated by a photoresponse observed in the PEC.

Generation, Modulation, and Characterization of Single Photon Emitters in Few-Layer Hexagonal Boron Nitride

Arun Nagpal

Mentors: Harry Atwater and Benjamin Vest

The development of sources of single, indistinguishable, photons is an outstanding problem in quantum information systems. In this work, we investigate room temperature quantum emission from single-atom vacancies in few-layer hexagonal boron nitride (h-BN). Optical characterization is performed on both annealed and He ion-irradiated samples, defects are located based on their photoluminescence signature, and the second-order autocorrelation function, $g^2(\tau)$, is computed in order to evaluate the performance of the emitter as a single photon source. To do

this, we have developed an in-house confocal microscope that has imaging, spectroscopy, time-resolved photoluminescence, and Hanbury-Brown-Twiss (HBT) interferometry capabilities. We have successfully characterized emitters that could serve as sources in quantum information channels, both on exfoliated flakes and in-house CVD grown material, and analyzed the defect generation rate as a function of ion beam parameters.

Development of Protein-SPRITE and Nanobody Screening as High-Throughput Methods

Christoph Neumayer

Mentors: Mitchell Guttman, Sofia Quinodoz, and Mario Blanco

The 3-dimensional structure of the genome in the nucleus of each cell is folded in a highly complex manner. How this is achieved and regulated in response to both environmental stimuli or cell-intrinsic events such as transcription is still largely unclear. Recent advances in high-throughput methods such as Hi-C or SPRITE help in understanding 3D contacts of both DNA and RNA, but still lack of an understanding of the organization and function of proteins in the nuclear-meshwork of DNA and RNA. Protein-SPRITE aims to solve this problem by covalent linkage of molecular identifier to primary antibodies, that serve as a proxy for the target protein in a molecular complex. However, this is limited to number of antibodies commercially available. Therefore, an additional high-throughput method, termed nano-SPRITE, is of need. Using mRNA display on complex nanobody libraries, nano-SPRITE will possibly be able to identify high affinity nanobodies against every protein in the human genome. I could establish barcoding of primary antibodies applicable for Protein-SPRITE as well as mRNA-display of nanobody. These tools can now be used in following experiments to comprehensively map proteins within the 3D structure of the nucleus.

An Analysis of the Whole Rock Composition of S-Type Granites From Across the Archean-Proterozoic Transition by Method of X-Ray Fluorescence

Samuel R. Newall Mentor: Claire Bucholz

Due to significant changes in the character of the atmosphere, weathering, and style of plate tectonics, the Archean-Proterozoic transition was a dynamic period of Earth's history. The igneous rock record portrays this, showing a number of changing characteristics across the transition, but it has proven difficult to attribute certain changes in the rock record to the specific causes. This study attempts to make headway into understanding how changing conditions at the surface of the Earth (e.g., the rise of atmospheric oxygen) may have influenced the igneous rock record through examining S-type granites. S-type granites are those derived through the partial melting of sedimentary rocks, and hence isolate the effect of assimilation of sediments on the igneous rock record. By observing trends in these granites, we hope to better understand how a changing sedimentary reservoir across the Archean-Proterozoic transition may have influenced the igneous rock record. A first order dataset to interpret the S-type samples is their bulk chemical composition. I will present whole rock major elements obtained via X-ray Fluorescence (XRF) from S-type granite samples from the Superior Province (Canada), Colorado, and Finland.

Tetra(cyano-borane)bipyridylruthenate Adducts ([Ru(bpy)(CNBR₃)₄]²⁻) as Redox-Active Electrolytes for Symmetric Redox Flow Batteries

Danh Ngo

Mentors: Harry B. Gray and Brendon McNicholas

Transition metal cyanides capped with Lewis acidic boranes (BR3) such as tris(pentafluorophenyl)borane (R=C6F5) and BPh3 (R = Ph) exhibit anodic shifts in their M(n+1)+/Mn+ redox potential. This shift is directly proportional to the number of boranes added and to the Lewis acidity of the borane. Modulation of these electrochemical events while maintaining electrochemical reversibility is valuable for non-aqueous redox flow battery technologies. We synthesized a heteroleptic cyanometalate-borane adduct (cyanoruthenate) equipped with a redox-active bipyridine (bpy) ligand as a bipolar redox-active material for use in symmetric redox flow batteries. For the trispentafluorophenyl)borane adduct the catholyte consists of the Ru3+/Ru2+ couple, while the anolyte consists of the bpy/bpy- couple, resulting in a theoretical cell voltage of ~3.6 V. The tetra(cyano-BR3)bipyridylruthenate adducts exhibited considerable shifts in their MLCT bands (λ max = 390 nm, R = Ph) and (λ max = 350 nm, R = C6F5), resulting in visible phosphorescence for both compounds (τ = 210 ns, λ em = 500, R = Ph; τ = 810 ns, λ em = 470, R = C6F5). Thus, both compounds are also potential excited-state photo-redox agents or two-photon absorbers.

Asteroid Detection via the Zwicky Transient Facility and the Creation of a Citizen Science Asteroid Scanning Portal AJ Nielsen

Mentor: Tom Prince

Though approximately 85-95% of massive, potentially catastrophic asteroids have been categorized to date, those in a smaller size range of 5-100 meters, while still having the potential to cause catastrophe, have been poorly cataloged. Until relatively recently, detecting such small asteroids was rather difficult, as images of small objects detected in telescope images had to be linked over a period of several days. The Zwicky Transient Facility, a new

wide-field astronomical survey of the sky being undertaken by a new camera attachment to a telescope at the Palomar Observatory, has made it possible to detect small asteroids much more easily via a method known as streak detection. Using this streak detection method, several new asteroids were discovered and have had their orbits characterized in detail. As the manual, human-input part of the streak detection method is relatively easy to learn even for those not involved with the project, a portal was created on citizen science website Zooniverse, allowing for public volunteers to themselves categorize streak images as asteroids and potentially make new asteroid observations themselves.

Theoretical Mechanistic Studies

Julius Oppenheim Mentors: William A. Goddard III and Saber Naserifar

Determination of reaction pathways is necessary for understanding of any chemical system. However, not all systems and properties can be experimentally probed. In this project, we analyze various chemical systems: a C-C bond forming Mo catalyst, a carbonate forming covalent organic polymer catalyst, an ionic liquid/Li metal battery interface, the binding of DMSO to a Au(III)-corrole, and select reactions in the thermal decomposition of H_2O_2 . In order to accurately describe the systems, density functional theory (DFT), the complete active space SCF method (CASSCF), and new generation force fields (Rexpon) are implemented. Where possible results are compared against experiments by collaborators and new insight is derived for the systems (e.g. the salt present in the Mo catalyst system previously thought to be inert is actually key in stabilization of transition states and is the driving force for the reaction).

Characterisation of the Helium-Neon Laser Injection Lock for Light Amplification

Camilla Ora

Mentors: Nick Hutzler and Arian Jadbabaie

In Atomic, Molecular, and Optical (AMO) Physics, lasers play a central role in probing molecular systems with high precision at the quantum level. Such measurements, which are often manifested as exciting particular atomic and molecular transitions within particles having diameters on the order of angstroms, rely on sufficient power transmission, stability, and a narrow linewidth of the incident radiation. However, these features are often onerous to achieve, as lasers, particularly higher-power ones, are susceptible to frequency-drift from temperature fluctuations, mechanical vibrations, and air currents. We vanquish such limitations by building and characterising an *injection locked laser*, whereby a helium-neon (HeNe) laser injects light into a less stable diode (amplifier) laser at a nearby frequency, thus entraining the amplifier to the HeNe's resonance. The end product is a laser with a much greater power output, a narrow linewidth, and enhanced stability. Such a process will prove useful for numerous industrial and scientific uses, particularly in AMO physics, whereby high-power, stable lasers are currently the go-to means of searching for symmetry-violating properties.

Flag Algebras for Triangle-Free Graphs With Restricted Bandwidth

Will Overman

Mentors: Peter Keevash and Nets Katz

In order to define the bandwidth of a graph G on n vertices, assign a bijective labeling from the integers 1 through n to the vertices of G. The bandwidth of G is the smallest integer m such that if an edge between two vertices exists, then the difference between their two numeric labelings is less than m. Fan Chung and William Trotter proved in a 1984 paper that that the maximum number of edges in a triangle-free graphs on n vertices with bandwidth m below by .586mn and above by .612mn. The goal of this project was to apply a modified version of the flag algebra technique introduced in 2007 by Alexander Razborov in attempt to close the gap between these two bounds. The modifications for this problem involve being able to use the flag algebra method in a distance-labeled setting, which we hope could be extended to other problems in this setting.

Determination of Methods of Planetary Formation in T Tauri Disks

Kayla Owens Mentors: Geoffrey Blake and Dana Anderson

Two of the main theories of planet formation in circumstellar disks are core accretion, in which bodies incrementally grow and pass through a size range where they migrate rapidly inward, and streaming instability, where migration is less effective. Radial drift will bring in ices from the outer disk altering the composition of the inner disk. Therefore, these two methods produce differences in the spatial distribution of chemical species, which are detectable through disk emission. ALMA and *Spitzer Space Telescope* observations were collected for a set of T Tauri disks. We focused on the inner (~1 AU) and outer (~50 AU) disks to detect changes in the local HCN/CO ratios, which would indicate radial migration of solids. We ran a comprehensive thermo-chemical disk model to create profiles for several important species in the disk, then compared this to *Spitzer* results from the literature for the inner disk and results from fitting a Markov chain Monte Carlo model to the ALMA images for the outer disk. Future work will involve using these models to determine the HCN/CO ratios in the inner vs. outer disk and inferring the presence and type of planet formation in these disks.

Quantifying Vibrational Mode Contributions to the Thermal Conductivity of Amorphous Carbon and Diamond

Akash Pallath

Mentors: Austin Minnich and Jaeyun Moon

Amorphous materials are used widely in infrared detectors and heat insulators due to their intrinsically low thermal conductivity (also known as the amorphous limit). However, despite their random structure, some amorphous materials such as amorphous Silicon (*a*-Si) have higher thermal conductivities than many crystalline materials. Heat carrier transport in these materials is still not properly understood. Recently, using Molecular Dynamics simulations and Inelastic X-ray Scattering with a Synchrotron radiation source, Moon et al. identified that in *a*-Si, propagating acoustic waves exist up to 10 THz and conduct over 95 % of heat - this is due to the monatomic structure and high sound velocity of the material. Using Molecular Dynamics, we study acoustic vibrations in amorphous Carbon and Diamond - which are monatomic and also have higher sound velocities than a-Si - in order to explore the high extreme limit of thermal conductivity achievable by amorphous materials.

Effective Bounds for the Class Number of Imaginary Quadratic Number Fields

Mayank Pandey Mentor: Dinakar Ramakrishnan

The Gauss Class Number Problem asks one to find an effective procedure to find all imaginary quadratic number fields with a given class number, a certain measure of how close the rink of integers of a number field is to being a principal ideal domain. This was resolved by a result of Goldfeld together with a result of Gross and Zagier. Goldfeld's result gave effective bounds for the class number of imaginary quadratic number fields $\mathbf{Q}(\operatorname{sqrt}\{D\})$ for D < 0 assuming the existence of an elliptic curve with conductor N and high analytic rank when (D, N) = 1, and Gross and Zagier found a particular elliptic curve with this property. We consider generalizing Goldfeld's result to cases when (D, N) = /= 1.

Exploration and Optimization of Instance Segmentation Methods With Cell Imaging

Shivam N. Patel Mentor: David A. Van Valen

The problem of analysis of microscopic images is an important tool in biological research. The analysis must be conducted to obtain conclusions about multiple aspects of the sample studied. One of the more important aspect is to distinguish pixels corresponding to the cell and the background this process is known as cell segmentation. This could be further bifurcated into semantic segmentation which is to segment the background and the foreground pixels and the other : Instance segmentation which is to segment individually each instance of a cell. I worked on the implementation of the "MaskRCNN" neural network for cell segmentation and also contributed to Dr. Van Valen's deep cell project by writing code which integrated it. I worked on implementations of The Deep Watershed neural network and also developed a 3D analogue to it and also implemented and integrated both of them to the deepcell library. Finally I modified the Retinanet algorithm for object detection and deployed it as a component Mask RCNN and also implemented a feature of adding custom backbones in Retinanet.

On How Magnetic Sensors and Coils Aid the Medical World

Anjali Patil Mentor: Azita Emami

This paper will begin by discussing the motivations behind characterizing a magnetic sensor, the AK09970N, a 3D magnetic sensor IC with high sensitivity and wide measurement range Hall sensor technology, in today's medical world and describe the encompassing project. It will continue to discuss the process of interfacing the magnetic sensor and then discuss the details of the characterization of the sensor. This discussion will include a comparison of the accuracy of the sensor and power consumption along with other characteristics against the given datasheet of the sensor. We will observe how any deviations from the datasheet will affect the overall performance. After that, we will discuss the ideal magnetic coils that would allow for the greatest success in terms of the overall project.

Development and Field Testing of a Sustainable Toilet System for International Use

Caroline Paules

Mentors: Michael Hoffmann, Clément Cid, and Eitam Shafran

The United States benefits from the efficient removal and treatment of waste, which prevents many lifethreatening diseases and infections. However, globally, many areas lack the infrastructure for a dependable source of waste disposal and treatment: therefore, we have developed an off-the-grid, automated, and reliable toilet system for these locations with the hopes of slowing the spread of waste-borne diseases. While a Caltech-designed electrochemical waste treatment system has been functional for years, it had not yet been integrated into a compact, commercialized "e-Toilet" system. In our research, we traveled to Kerala, India to work alongside experienced engineers and designers to create the world's first automated, self-cleaning e-Toilet. Our responsibilities included the integration a variety of sensors to accurately pinpoint leaks, track water reservoir levels, predict pump damage, and verify electrode functionality. Additionally, we installed water-quality sensing devices that parametrized chlorine production, color reduction, and organics removal. Our system optimization and data collection will be used to inform engineers and maintenance workers how to provide upkeep for the system and proceed toward the goal of defeating waste-borne diseases in developing countries.

Dual Z2 Lattice Gauge Theory of the 3-D Ising Model With Nearest- and Next-Nearest-Neighbor Coupling

Changnan Peng Mentor: Anton Kapustin

It is known that the normal three-dimensional (3-D) Ising model on a cubic lattice is dual to the Wegner's 3-D Z2 lattice gauge theory. Here we find an unusual Z2 lattice gauge theory which is dual to the 3-D Ising model with not only nearest-neighbor coupling, but also next-nearest-neighbor coupling. Our gauge theory has on each edge four Z2 variables, each located on a vector perpendicular to the edge. The next-nearest-neighbor coupling in the Ising model is associated with the coupling between the Z2 variables on nearby vectors on each edge in the gauge theory. We will use numerical methods to locate the phase transition point of our gauge theory and to explore the universality at the phase transition.

Wavelength-Dependent Pump Probe Spectroscopy in the α -Transition Peak Energy Regime of Sr₂IrO₄ Isabelle Phinney

Mentors: David Hsieh and Alberto de la Torre

The perovskite iridate Sr_2IrO_4 first garnered interest because of its similarity in crystallographic structure, and magnetic and electronic structure, to the cuprate compound La₂CuO₄, a known precursor to high-T_c superconductivity. Studies of Sr_2IrO_4 can yield information on the physics behind superconductivity, which is still not well understood; improving this understanding will yield advances in both fundamental physics and engineering. The dynamics of the Mott-insulating phase will be studied through a combination of temperature, wavelength, and fluence-dependent pump probe spectroscopy, which allows us to investigate the electronic and magnetic structure of Sr_2IrO_4 via the recovery behavior of the photo-excited crystal.

Geology of Southern of Angel de la Guarda Island, California Gulf: Petro-Tectonics Constrictions for the Formation of Microcontinents

Adriana Piña-Paez

Mentors: Joann M. Stock and Leah Sabbeth

The block of continental basement of Isla Angel de la Guarda (IAG) is a microcontinent in the Gulf of California, located in the limit of Pacific-North America (PAC-NAM) plates. IAG is tectonically important in the Gulf of California because it lies in a zone of transtensional deformation, bounded by the same transform faults that accommodated the most displacement during the rifting of the Gulf of California. The geology of IAG includes crystalline basement overlain by a Neogene sequence of volcanic and sedimentary rocks, recording the change from the subduction regime with arc volcanism to a transtensive regime with more diverse volcanism. The petrography and geochemical analysis show the volcanism in the south of IAG is more diverse than the rest of the island, with compositions varying from felsic-intermediate to mafic-intermediate. The conclusion is that the diversification in the South of IAG is consequence of the projection of the transform faults that control the pull-apart basins in this zone of the island.

Distinguishing Models of Cosmic Expansion With Low Redshift Supernovae From Zwicky Transient Facility

Mark Poe

Mentors: Suhail Dhawan, Rahul Biswas, and Ariel Goobar

Through the use of relative distances to type Ia supernovae (Sne Ia), the expansion of the universe was discovered to be accelerating, and subsequent Sne Ia observations have been made with enough precision to allow constraints to be placed on models of accelerated expansion. Currently, there are many possible models of accelerated expansion available, and through observations of Sne Ia from Zwicky Transient Facility (ZTF), we aim to gain insight into anchoring the low redshift area of the Hubble diagram, in order to better distinguish between them. Since the observatory has only been active a short time, we will run analyses using simulated ZTF data of potential future observations, and resulting data from these analyses will allow us to quantify the low redshift anchor of the Hubble diagram and to determine which cosmological expansion models are viable for future work.

Aortic Centerline Calculation and Cross-Sectional Segmentation for Boundary Prediction With Convolutional Neural Networks

Tara S. Porter

Mentors: Albert Hsiao, Evan Masutani, and Babak Hassibi

Pressure gradient and wall shear stress measurements within the thoracic aorta are clinically useful for determining appropriate treatment for patients with aortic disease. To make such precise calculations, it is necessary to have a three-dimensional model of the aorta defining its boundaries and geometry. Current software to fill in the boundaries from magnetic resonance (MR) images is error prone and tedious, often bleeding into surrounding vessels and structures. This project aims to create an easier and more accurate method of generating a binary mask of the aorta. A unique algorithm for calculating the centerline of the vessel was developed, from which cross-sectional slices of the MR images and corresponding binary masks were defined for five different patient cases. The cuts were then used as training data for a convolutional neural network with U-Net architecture with the aim of producing the binary mask based solely on the MR image data. The model successfully predicts the three-dimensional aortic volume of test cases with a dice coefficient of 0.96 and loss of 0.04, giving a viable alternative to the current technique of semi-manual segmentation. Future directions include five-fold cross validation of the model and generalization of the centerline algorithm to vessels outside the aorta, such as the coronary arteries.

Belief Learning Mechanisms

Siddaharth Prasad Mentor: Federico M. Echenique

We explore questions of belief elicitation, in which an expected-utility-maximizing agent has a belief over states of a lottery (represented by a probability distribution over the states), and an analyst aims to learn the agent's belief to a high accuracy by asking the agent to choose between several pairs of vectors specifying monetary payoffs in each state. In the case where an agent evaluates his utility as an expectation with respect to his belief of the payoffs offered by the analyst, it is known that this problem is learnable. We aim to answer similar questions when the agent has extra parameters governing his choices, for example, initial investments in each state and a concave utility over money – and in particular want to design mechanisms that (1) learn the agent's parameters to high accuracy with as few questions as possible and (2) implement a payment scheme so that the agent is incentivized to truthfully answer questions according to his true parameters.

Effectiveness of RNA-Binding Biotinylating Enzyme BASU as a Method for in vivo RNA Pulldown

Sarida Pratuangtham

Mentors: Katalin Fejes-Toth and Qing Tang

The RNA-binding protein BASU is an enzyme that biotinylates itself and adjacent proteins. It is able to bind to a 15nucleotide RNA stem-loop motif, BoxB. In theory, this makes it useful for purifying RNA *in vivo*, as biotin binds very tightly to streptavidin, and this interaction can be exploited to pull down BASU-bound RNA. In this project, we aimed to determine the efficiency of BASU pull-down of a target RNA sequence containing either one or eight BoxB stem-loops. This was done via co-immunoprecipitation using streptavidin beads, with Western blotting and RNA prep to determine actual pull-down of the BASU protein itself and the target RNA. When one stem-loop was present in the target RNA, BASU pull-down was efficient and enrichment was observed; however, the target RNA itself could not be detected. Further study is needed to determine if pulldown can be improved by increasing the number of stem-loop motifs in the target RNA.

Optimizing Cell Culture Densities in Gas-Perfusable Tube Bioreactors for Oncolytic Vaccine Production Netra Unni Rajesh

Mentors: Yu-Chong Tai and Colin A. Cook

Oncolytic vaccines are a promising avenue for personalized cancer therapeutics; however, their production is largely limited by the capacity of virus generation in mammalian cells. A major obstacle with respect to maximizing cell growth in small volumes is the transport of oxygen within the culture system. To overcome this obstacle, we designed a polydimethylsiloxane (PDMS) tubular bioreactor. This device surrounds cells and media compartment with an oxygen permeable membrane, facilitating oxygen transport through radial diffusion. Vero monkey kidney cells, commonly employed in virus production, were cultured on Cultispher G macroporous gelatin-based carriers. The tube bioreactor was filled with DMEM culture media and subsequently inoculated using the seeded microcarriers. Media was perfused through the bioreactor at a rate of 0.006 mL/minute and the device was maintained over a four-day period. As an endpoint measurement, cells were extracted from the microcarriers and counted using a hemocytometer. Cells were also visualized directly on the microcarriers using an MTT reagent stain. Using this device, we achieved cell culture densities over 3 x 10⁷ cells/mL - a six-fold increase from present industrial Vero cell densities. By integrating multiple tube bioreactor units, we can facilitate high density cell culture and render oncolytic vaccine production more efficient.

Investigation of Motion Artifacts in Cardiac MRI Using Rosette K-Space Trajectories

Shreya Ramachandran

Mentors: Shreyas Vasanawala, Adam Bush, and Wei Gao

Magnetic Resonance Imaging (MRI) is a powerful technique capable of non-invasive evaluation of cardiac structure and function. Unfortunately, the constant pulsatile motion of the heart introduces motion corruption, lengthening scan time and hindering the clinical usefulness of MRI for physiologic diagnosis and monitoring. This work seeks to address this issue by using a flower-like, or rosette, k-space sampling trajectory which we hypothesize is more motion robustness at comparable scan time to clinical standards. We define and optimize a novel parametrization of the rosette shape and demonstrate superior undersampling artifact diffusivity, while maximizing number of echoes per acquisition. Using a simulated dynamic phantom of the heart, motion-induced artifacts for various rosette shapes are investigated. Motion robustness is validated using our rosette trajectory for an in-vivo cardiac MRI scan, in which the heart structure is evident. Finally, the self-gating ability of the rosette trajectory is verified for applications in retrospective cardiac motion correction. In totality, this work lays the foundation for rosette sampling optimization, which has broad clinical applications in cardiac cine imaging and non-invasive quantification of cardiac iron and blood oxygen levels.

Vibration Induced Locomotion Through Meta-Materials

Rajat Ranjan

Mentors: Chiara Daraio and Osama R. Bilal

Traditional robotic locomotives require an array of abilities to perform optimised movements. Bots based on rigid legged mechanics demand accurate positioning of joints for a stable stature. Accounting for random disturbances on irregular terrain increases complexities. It needs identification of upcoming obstacles and data processing to decide synchronised movement of limbs. Such complexities can be eased by making use of compliant structures which depend on material properties and shape variations to cause movements. We investigate a mini-bot comprising of Meta-Material structures which makes use of vibrations for planar movements. We focus on harnessing the motion of the bot through a controlled audio signal. Selected Meta-material includes embedded spirals having the tendency to vibrate normal to the plane in which input vibrations are made to traverse. The nature of response for individual spirals may be symmetric or asymmetric depending on its built and signal parameters. We analyse the response of each spiral for a range of frequencies using the simulation software COMSOL Multiphysics. This is to numerically approximate the responses and compare them through experiments. We envision producing complex patterns of planar motion due to the abrupt contact between the floor and the individual spirals at selected frequencies. With the known behaviour of spirals, we intend to build a mini-rigid structure with spirals strategically placed at chosen locations. Upon actuating a set of spirals with a range of frequencies, we expect to observe and predict the path of the bot.

Development of Virtual Reality Classroom Space and Lab

Netra Ravishankar

Mentors: Santiago Lombeyda and George Djorgovski

In this project, we are building a classroom in Virtual Reality(VR) and are exploring different user experiences in order to identify the main issues present in a real classroom setting that VR can solve. We observed several classrooms and labs of various sizes at Caltech and we took note of the behavior of students and teachers, the setup of the classrooms and labs, and the interactions between the students, teachers, and classroom/lab space. Using these observations, we came up with a model of a classroom that could be implemented in Virtual Reality(VR) for multi-player use. In order to simulate a classroom in VR, we established network and audio connection and set up basic interaction features, such as teleportation, asking questions, taking notes, drawing on a whiteboard, observing 3D models and graphs, viewing presentation slides, and collaborating in small groups. We are also exploring new techniques and approaches of implementing drawing and writing in VR as well as improving the effectiveness of interaction between students and the teacher in order to maximize the efficiency and ease of these activities in VR and hopefully bring new ways of teaching that are more effective in VR than a real classroom setting.

Designing Lattice Materials for Unidirectional Wave Propagation

XinYi Ren

Mentors: Chiara Daraio, Behrooz Yousefzadeh, and Brian Ramirez

Reciprocity is a fundamental property of elastic media that describes the symmetry of wave propagation: if you interchange the locations of the source and receiver, the transmitted wave remains unchanged. Being able to disobey reciprocity can be very useful in certain applications for vibration isolation. One approach to developing a medium with nonreciprocal wave transmission properties involves designing the internal structure of lattice materials. Lattice materials are made from repetitions of identical unit cells with a specific geometric design, and their internal microarchitecture controls how waves propagate within them. Our goal is to utilize the lattice material framework to develop a material that exhibits non-reciprocity. Using 3D modeling, printing, and waterjet cutting, we created samples that have different stiffnesses in compression and tension. We confirmed this behavior by

measuring the elastic response of the samples quasi-statically. We then used two connected cells to act as our source and receiver. We interchanged the source and receiver units and checked for reciprocity by comparing the dynamic response of the receiver. Non-identical responses would indicate non-reciprocity. The majority of the project involves measurements on samples with one or two cells. This forms the basis for subsequent studies on materials with multiple units.

Graph Based Multi-Class Semi-Supervised Learning in the Large Data Limit

Zhi Ren Mentor: Andrew M. Stuart

In recent literature on the graph Laplacian, it has been proven that the discrete graph operator gamma-converges to an elliptic differential operator in the TL2 topology in the continuum limit. In our project, we study the semisupervised learning problem that combines both the Laplacian regularization term in the continuum limit that describes the hidden structure of the data, and a misfit function part that arises from enforcing observed label information. We will generalize the previously known results on binary classification to multi-class classification; both the optimization approach and Bayesian approach are considered. In particular, we will show the existence of a unique minimizer for the objective function in an appropriately defined function space through the optimization approach.

Finding the Binding Target of Luminate®, a Therapeutic Peptide for Retinal Disease

Galileo Alessio Resca-Candini Mentor: Julia A. Kornfield

The purpose of the SURF is to find the binding site of Luminate—a peptide drug that finished Phase II development for a neovascular retinal disease treatment—via a pull-down assay of cell lysate to capture the receptor for the drug. The ligand, modified with a spacer and enrichment tag, used for the pull-down assay is synthesized through Solid Phase Peptide Synthesis (SPPS), purified by HPLC and characterized by Mass Spectrometry. The verification of the enrichment tag was preformed using Arg-Gly-Glu (RGE), Arg-Gly-Asp (RGD) containing control peptides, and blank control, targeting the integrin protein in pulldown assay followed by an SDS-PAGE assay and Western Blot. After successfully verifying that the enrichment tag functions, the pulldown assay is preformed using the synthesized drug to target receptors in cell lysate. This research may give us some indication of the receptor that Luminate targets.

On the Optimization of Protein Folding in the HP Model

Jacob G. Ressler-Criag

Mentors: Pablo A. Moscato and David Van Valen

Proteins are large macromolecules consisting of one or more chains of amino acids. During the formation of a protein, a DNA strand is transcribed into an amino acid chain which then folds into a minimal energy threedimensional complex. The shape or "fold" of the protein strongly influences both its interactions with other molecules and its function. However, while protein folding occurs rapidly in nature, its computational prediction from amino acid sequence proves NP hard and extremely energy intensive. In our research, we consider the protein folding problem under the Dill HP model in which we search for the maximum possible number of hydrophobic interactions for the protein on a lattice. In this study, we construct several novel heuristics, involving both ad hoc and naïve methods as well as a directional folding constraint program for the HP model across all lattices. In addition, we introduce a set-satisfaction optimization program to solve the HP model on the two-dimensional lattice. Our results show significant improvements over the baseline across all studies, and our introduction of two new mathematical programs for this problem anticipates future research areas.

Electric Field Conjugation With Kalman Filtering on a Single Mode Fiber

Milan S. Roberson

Mentors: Dimitri Mawet, Jorge Llop Sayson, and Daniel Echeverri

High dispersion coronagraphy is a strategy for imaging and characterizing exoplanets combining a coronagraph, to spatially filter and block light from the host star while allowing exoplanets light to pass through, with a high-resolution spectrograph to spectrally separate the planet's light from the residual starlight. Coupling the planet's light into a single mode fiber allows for additional suppression of starlight with wavefront control techniques like Electric Field Conjugation that can be made to minimize the overlap integral of the electric field with the fundamental mode of the fiber. We modify the EFC formalism by including observation and process noise in order to optimally weight inferred electric field measurements against the modeled evolution of the electric field, implementing a Kalman filter. The Caltech Exoplanet Technology Lab's transmissive testbed was realigned and placed in an enclosure to reduce air turbulence and increase agreement between the optical bench and our model of it required for EFC. After the required calibrations, we performed EFC with Kalman filtering to minimize coupling of simulated starlight into the SMF and increase the stability of the algorithm.

Optimisation of Uncertainty Quantification for Climate Models

Jonathan P. Rosser Mentor: Tapio Schneider

The use of machine learning techniques in climate science is an emerging area of research. This project aims to investigate the potential to improve parameter estimation and uncertainty quantification in climate models using machine learning methods. Specifically, we use a combination of Ensemble Kalman Inversion, Gaussian Process emulators and Markov Chain Monte Carlo for inexpensive estimation of parameters and uncertainties. We investigate strategies for generating optimal training points for emulation of a chaotic forward model within a Bayesian framework for estimation of parameters. Among the considered strategies we look at: Latin Hypercube sampling;perturbation with Gaussian noise; and Markov Chain Monte Carlo. We compare these strategies to identify their strengths and weaknesses in the context of the Lorenz 96 model which is a chaotic system of ordinary differential equations chosen to mimic certain features of climate models.

On the Computation of the Infinite Variety of Knot Floer Homology

Daniel Rostovtsev

Mentor: Yi Ni

Here, an algorithm for the computation of the infinite variety of Heegaard Floer homology is presented and implemented. By extending the logic of Beliakova, Manolescu, Ozsváth and Sarkar, a complex chain homotopic to the infinite variety of the knot Floer complex (CFK+/- ∞) is constructed on a rectangular diagram. The resulting procedure is far faster than the method obtained from a toroidal grid diagram, and allows for the computation of the positive and negative varieties of the Heegaard Floer homology, for which no other program is currently available. While the computation of the homology by itself is helpful, it may also allow for the explicit construction of Heegaard Floer complexes for relatively small knots, and thus their involutive homologies and concordance invariants as well.

Azimuthal Dependence of the Circumgalactic Medium in the FIRE Simulations

Andrew Rothstein

Mentors: Phil Hopkins and Cameron Hummels

The circumgalactic medium (CGM) plays an important part in galaxy formation and evolution. With the likelihood that the CGM makes up roughly 50% of the baryonic mass bound to galaxies, developing a better understanding of how the CGM interacts with galaxies is crucial for studying galaxy evolution. To learn more about inflows and outflows in the CGM, we map the azimuthal distribution of various gases, with special interest in Mg_{II} and O_{VI} , in the FIRE 2 Simulations. We look at galaxies with halo masses of $\sim 10^{11} - 10^{12}$ stellar masses within a projected radius normalized by the virial radius up to 1.25 looking over redshifts 0 < z < 1, z = 1.5, and z = 2. Four simulations were used with approximately five redshifts used from each, only the most disk-like were selected based on the magnitude of the angular momentum of the galaxy. We investigate this distribution through column densities of the gases. Contrary to similar observational findings, we find a preference for Mg_{II} along the major axis at high azimuthal angles and find no bimodal azimuthal distribution for O_{VI} gas.

Synergy of Targeted Low Intensity Ultrasound and Chemotherapy for Selective Cancer Therapy Ankita Roychoudhury

Mentors: Morteza Gharib, Mikhail Shapiro, and David Mittelstein

While chemotherapy is a powerful tool in cancer therapy, its method of action is partially non-specific and can damage collateral tissue. Our motivation is to mitigate nonspecific damage by coupling low intensity ultrasound with chemotherapy. The oncotripsy project pursued at Caltech involves applying carefully tuned ultrasound to induce cancer-cell selective cytodisruption. Using this *in vitro* high-throughput setup, we exposed leukemia/lymphoma cancer cell models and healthy cell models to ultrasound coupled with chemotherapeutic agents (vincristine or paclitaxel). We observed that coupling ultrasound with chemotherapy makes cancer cells more susceptible to chemotherapeutic agents and does not affect the healthy cells in the same manner. This synergistic effect between ultrasound oncotripsy and chemotherapy can increase the safety of cancer therapy.

Synthesis and Investigation of Some Potential Electrocatalysts Containing Ru and Mn Centers

Peter Saghy

Mentors: Harry Gray and Wesley Kramer

Water oxidation and CO_2 reduction are important processes with potential uses in green chemistry, artificial photosynthesis and even future Mars missions. Some complexes of ruthenium and 2,2'-bipyridine-6,6'-dicarboxylic acid have been described before as good water oxidation catalysts. Their catalytic ability is likely linked to the distorted shape of the complexes. We attempted the synthesis of some ruthenium and manganese based complexes of the diacid with various auxiliary ligands, like water, pyridine, N,N-dimethylamino pyridine or dimethyl sulfoxide. Manganese was chosen since it possesses similar properties to ruthenium due to the diagonal relationship of the two metals, and because some manganese-based CO_2 reduction catalysts have already been described. The ruthenium-based complex is going to be tested in electrochemical water oxidation reactions, and the new manganese-based compounds will be tested in water oxidation reactions and CO_2 reduction.

Network Characterization of Acrylate-Based Shape-Memory Polymer Microscale Architectures

Erika Salzman

Mentors: Julia Greer and Luizetta Navrazhnykh

Shape-memory polymers (SMPs) 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. Relating the polymer network structure of these SMPs to their shape-memory properties can lead to the optimization of the SMP microarchitectures for possible applications in biomedicine, including blood vessel stents and drug delivery. In this study, benzyl methacrylate-based SMP resins have been used to create a variety of microarchitectures via two-photon lithography under various writing conditions. In order to assess how fabrication conditions affect properties of the architectures, Raman spectroscopy was used to compare the architectures' degrees of polymerization, and dynamic mechanical analysis was used to measure their shape-memory characteristics. Boc-protected amine groups have also been incorporated into the SMPs via the thiol-Michael reaction, allowing for the possibility of introducing chemical functionality. The presence of these amine groups on the surface of the architectures was confirmed and quantified through deprotection and chemical dyeing.

Optimizing Data Analysis for Tests of Hard X-Ray Detectors

Julian Sanders Mentors: Fiona Harrison, Hiromasa Miyasaka, and Sean Pike

The Nuclear Spectroscopic Telescope Array (NuSTAR), equipped with Cadmium-Zinc-Telluride (CZT) detectors, observes in the 3-79 keV band, of which energies >10 keV were previously unexplored. The Harrison group continues the investigation of CZT and similar detectors for improved future observations in the hard X-ray band, testing CZT crystals from various vendors and characterizing their performance. Noise tests involve measurements of electronic noise, leakage current under high voltage, and the current flowing between pixels. Spectral resolution and calibration are determined by flood-irradiating the detector with an X-ray source. Performing these tests on three CZT detectors manufactured by Redlen Technologies showed highly irregular noise distributions, very strong noise at temperatures below 5 °C but adequately low noise otherwise, low leakage current below 600 V, low interpixel current at most pixels, and energy resolution comparable to those in the NuSTAR detectors. With more sophisticated spectral corrections, the Redlen detectors might surpass the NuSTAR resolution. Before fully characterizing these detectors, however, we must examine what is causing the odd noise behavior and perform more robust flood-irradiation experiments, with varied sources and more sophisticated spectral corrections. In particular, I am improving the efficiency, usability, and documentation of data analysis code for these experiments.

Using Molecular Dynamics and Density Functional Theory to Study the Oxygen Reduction Reaction in Proton Exchange Membrane Fuel Cells

Neil D. Sanderson Mentor: William Goddard

A fuel cell is an electrochemical device that converts chemical energy from a hydrogen fuel to electrical energy through a cell reaction. Specifically, this project focuses on oxygen-reduction reaction (ORR) in a Proton Exchange Membrane Fuel Cell (PEMFC). They present an environmentally friendly energy source as the only product of the reaction is water and no greenhouse gases are produced. However, improvements to the ORR efficiency must be made to make the PEMFC cost-effective for large-scale, commercial applications. Reactive molecular dynamics calculations suggest that certain configurations of a jagged nanowire surface increases ORR activity versus a more relaxed surface (e.g. Pt (111)). This report discusses what calculations have been done to investigate this. Another important factor in running simulations of fuel cell systems is proton (H⁺) diffusion as PEMFC's should maintain high proton conductivity under operating conditions. Here the analysis that has been done to understand the contributions of different mechanisms by which protons may transfer in an explicitly solvated system is also discussed.

Building the Automated Data Reduction Infrastructure for the WIRC+Pol Survey

Louis Santos

Mentors: Dimitri Mawet, Ricky Nilsson, Maxwell Millar-Blanchaer, and Samaporn Tinyanont

The WIRC+Pol survey studies brown dwarfs--bodies more massive than most planets but not massive enough to sustain fusion--in order to characterize their atmospheres using the polarization of the light they emit. Since they possess many structural similarities to gas giants and are more readily observable, brown dwarfs are good candidates to offer insight into the nature of exoplanetary atmospheres. WIRC+Pol takes hundreds of images per observing night, warranting the development of an efficient and automated data processing system. This summer, I constructed the database architecture, along with automatic data calibration and reduction methods, for all of the

heretofore unrefined data. This involved working with Python to interface with a MySQL database and use existing data reduction methods to automate the process of taking a raw FITS file, calibrating it, finding the sources in the image, and adding the various extracted data products to different tables in the WIRC_POL database. In order to make this information easily accessible, I upgraded and deployed the WIRC+Pol website, a user-friendly front-end for the database. The automated pipeline, database, and website work together to save time and effort spent on data processing, freeing time for observers to interpret and use data appropriately.

Exploration of Ultra-High Temperature Metamorphism in Eastern Connecticut

Madeline D. Schemel

Mentors: Jay Ague and Edward M. Stolper

Ultra-high temperature metamorphism (UHTM), where the rocks involved reach temperatures exceeding 900°C, has recently been accepted as a widespread geological phenomenon. In particular, forty different localities have been identified, on all seven continents. The existence of these extremely high-T domains has major implications for heat generation, heat transfer, and rheology during mountain building. That being said, the thermal regimes and tectonic settings behind UHTM are not well understood. We investigate these gaps in knowledge through a continued examination of UHTM in eastern Connecticut. UHTM has previously been discovered in the area and we extend this investigation by sampling and analyzing rocks from the Tatnic Hill Formation, which is composed of high-grade upper amphibolite and granulite facies metamorphic gneisses. The Formation crops out along the major tectonic boundary between composite Laurentia and the Avalonia microcontinent. Thermometry is done by first measuring the percentage of aluminous spinel in magnetite crystals; the aluminous spinel exsolved from the host magnetite during cooling. Reintegration of the magnetite-aluminous spinel compositions can then be used to get a minimum estimate of past rock temperatures based on solvus relations in the multicomponent spinel system. We present minimum T estimates for the Tatnic Hill Formation; results thus far indicate T values of at least 800-850 °C were reached during metamorphism.

Quantifying Uncertainty in Parameterizations of Droplet Collision Rates in Clouds

Joanna Schmidt

Mentors: Tapio Schneider and Anna Jaruga

Global Climate Models and Large-Eddy Simulation models rely on parameterizing processes that take place on scales smaller than the model grid resolution. Microphysical processes, like the formation of rain through collisions, therefore must be resolved through parameterization. A 0-dimensional adiabatic parcel model is used with a superdroplet microphysics scheme; this allows for aerosol and droplet distributions to be resolved. Simulations for different collision kernels, which represent different turbulent effects; aerosol distributions; and velocities are performed. The collision rate is calculated directly from the size distribution of the cloud and rain droplets. Collisions contribute 149 times more mass to rain than condensation does. The collision rates calculated from different simulations vary by two orders of magnitude. Aerosol distribution, parcel velocities, and collision kernels all affect the collision rate. Finally, the collision rates from the simulations are compared to existing parameterizations. The best fits of those parameterizations to the parcel model data are found. The uncertainty in current parameterizations is estimated from the variability in the parcel model simulations. A new functional form of the collision rate is also tested.

Testing the Integrity of Voter Registration Databases Using Repeated Record Linkage

Spencer Schneider

Mentors: R. Michael Alvarez and Seo Young Silvia Kim

The integrity of voter registration data is vital for the successful administration of an election. Voter databases, like any other large administration databases, can have integrity issues such as duplicate records, near-duplicate records, and incorrect or impossible information. While it's impossible to keep such a large database error free, the database should be tracked for sudden irregular changes. Especially as suspicion of election meddling increases, it is important to protect against the corruption of voter databases. We present a methodology for testing the integrity of a voter database using repeated record linkage of daily database "snapshots". Our process can detect potential duplicates, added or dropped records, and changes to records across snapshots. This information is extremely useful for election officials. Working collaboratively with the Orange County Registrar of Voters we have been receiving daily snapshots of their 1.5 million voter database for 2018. We have discovered that their database is quite dynamic and we've been able to track patterns in their workflow. The changes can provide guidance as to whether there are unusual activities in the current and future elections.

Dynamic Mechanical Analysis of Metallic Glass Nano-Pillars

Miranda Schwacke

Mentors: Julia Greer and Anthony Kwong

Previous research has shown that after room temperature aging of ZrNiAl metallic glass for three years, the yield strength and elastic modulus increased from 1.7 GPa and 70 GPa to 2.8 GPa and 82 GPa, respectively. The focus of this project was to provide insight into this change in mechanical properties using dynamic mechanical analysis

(DMA). Nano-pillars ranging in diameter from 300 nm to 1.3 μ m were fabricated both on aged and freshly sputtered samples of ZrNiAI metallic glass by focused ion beam milling. DMA was done on these pillars at room temperature and at frequencies between 3 and 700 Hz. For pillars of all sizes, a peak in the loss modulus occurred at 450 Hz and was identified as a β relaxation. The frequency of β relaxations in metallic glass display Arrhenius behavior. Thus, by repeating DMA at different temperatures, it will be possible to calculate the activation energy of the observed β relaxation, as well as the volume of shear transformation zones, the rearrangement of which is thought to be the mechanism of deformation in metallic glass.

The Decline of French Serfdom in the Medieval to Pre-Modern Periods: Courts, Village Assemblies, and Peasant Power

Yvette J. Sei

Mentor: Tracy K. Dennison

This paper seeks to track institutional changes, to document when legal and sociopolitical factors shifted, and to analyze how these changes led to the decrease in power among feudal landlords, focusing on the functions of the judicial system and local peasant village assemblies. It endeavours to determine who filled the power vacuums seigneurs left, and the effects of these changes on the peasantry itself. Additionally, as a general practice it will serve to improve our understanding of how socio-political and economic factors can work to oppress different groups, directly and indirectly, the study of which is eternally relevant. This project has utilized secondary sources in both French and English and its product will be a written interpretation and compilation of these sources. This paper could open doors into the investigation of the true conditions experienced by peasants before the revolution and help bring light to its real causes.

Tagging Jets at the LHC With Interaction Networks

Aidana Serikova Mentor: Maria Spiropulu

Jets are collimated showers of particles produced at colliders such as the CERN LHC. The task of identifying the nature of the elementary particle that started the shower (jet tagging) is a crucial tool for analyzing LHC data, e.g., when searching for new physics phenomena in events with jets. In this paper, we assess the performances of a jet-tagging algorithm based on interaction networks, a model based on the neural network capable of learning relations between objects in a complex system. The model is trained on a cocktail of jets originating from light quarks, gluons, b quarks, W bosons, Z bosons, or t quarks. Its performances are compared to those of other status-of-the-art deep-learning architectures: dense networks based on expert features, convolutional networks based on jet Images, and recursive networks based on lists of particle constituents. Our results show interaction network can be trained to accurately classify particles giving a rise to the jet showing more than 93 % of AUC for each class, thereby overperforming all previously mentioned results.

Algebraic Construction of Even Galois Representations

Zhengyuan Shang Mentor: Zavosh Amir-Khosravi

We found a construction of even Galois representations ρ from the totally real torsion points of CM elliptic curves E over real quadratic fields F. We derived congruence relations between the coefficients of the algebraic Masse form associated to ρ and the holomorphic modular form associated to E through the abelian surface A=Res_(F/Q)E in one example. We made progress in constructing even icosahedral Galois representations and their Masse forms.

Increasing Quantum Annealer Success Rates With Hamiltonian Path Changes

Sunash Sharma

Mentors: John Preskill and Elizabeth Crosson

We attempt to increase the spectral gaps of quantum annealers by introducing Hamiltonian path changes to the systems, and we attempt to gain a deeper understanding of the mechanisms by which successful path changes increase spectral gaps. Before the critical point of the computation, we observe the following for quantum annealers with symmetric cost functions: first, altering the beginning Hamiltonian to be powers of the transverse field seems to increase the spectral gap. Second, including this path change appears to increase the delocalization of the ground state of the quantum annealer. Third, the ground state with the path change can be approximated by a linear combination of the ground state without the path change and the constant vector. Future work on increasing spectral gaps may benefit from analyzing the change in ground state localization with and without path changes for a wider variety of cost functions, as such analysis may improve understanding of the mechanisms by which these path changes function in a more general context.

Measuring Redshift Completeness of Local Galaxy Catalogs Using ZTF Bright Transient Survey (BTS) Yashvi Sharma

Mentors: Shrinivas R. Kulkarni and Christoffer Fremling

Redshift completeness of local galaxy catalogs (z<0.05) has been estimated using supernovae (SNe) as signposts to galaxies in Kulkarni et. al (2018, ApJ, 860, 22). However, the small sample size of the SN catalog (from ASAS-SN survey) used in this previous analysis introduces binomial errors in the calculation of the redshift completeness factor (RCF) defined as the number of SN host galaxies with known redshift prior to SN discovery divided by the total number of newly discovered SNe. Furthermore, the ASAS-SN survey is only complete for SNe brighter than (V \approx 17 mag). In this project report, we present the Zwicky Bright Transient Facility (ZTF) Bright Transient Survey (BTS), and preliminary RCF measurements using the SNe discovered thus far. The BTS sample of SNe is flux limited (r \approx 19 mag) and currently we have discovered 102 Type Ia and 40 Core Collapse (CC) SNe. For these SNe we analyze the distribution of host galaxies with or without known redshifts as a function of absolute magnitude of the host and redshift. We conclude with comments on further improvement of this preliminary estimate as the BTS progresses and a large sample size (~1000) of SNe is obtained, and consider estimation of volumetric SN rates using the BTS SNe.

Optical Excitations in Magnetic Topological Insulators

Peiyue Shen

Mentors: Nai-Chang Yeh and Adrian Llanos

Magnetic topological insulators (TI) have caused great excitement recently in condensed matter physics. By doping TIs with ferromagnetic atoms, the time-reversal symmetry of the surface state Dirac fermions is broken, leading to novel phenomena such as the quantum anomalous hall effect, chiral 1D edge channel in magnetic domain walls, etc. Here we study the influence of circularly polarized(CP) light on Cr-doped $(Bi_0.5Sb_{0.5})_2T e_3$. CP-light is expected to couple to the spin degrees of the surface state(SS) Dirac fermions which are thought to mediate magnetic interactions between dopant atoms. Using anomalous hall effect measurements in the presence of precisely tuned circularly polarized light, we find that circularly polarized light can both im- prove or diminish the ferromagnetism of our samples: In pure Cr-doped TI samples which are highly insulating, CP light causes a decrease in ferromagnetism which we attribute to a photodoping effect. On the other hand, in samples consisting of a thick layer of pure TI deposited on a layer of doped TI, which are of much lower resistance, ferromagnetism is enhanced due to the presence of free carriers without of plane spins that can more effectively mediate interactions between isolated Cr dopants. Furthermore, these free carriers give rise to screening thereby attenuating the photodoping effect.

Designing a Bayesian Hierarchical Model Structure to Diagnose Psychiatric Dysfunction

Minho Shin

Mentors: John P. O'Doherty and Jeffrey Cockburn

The new field of computational psychiatry, to characterize psychiatric disorders in terms of underlying computational mechanisms, is regarded as one alternative to overcome the subjectivity of classical symptom-based approach for diagnosing mental dysfunction. This study specifically aims to investigate the advantage of building hierarchical structure for estimating subject-level generalized parameters, which will be used as factors to discriminate abnormal subjects from normal group. In order to accomplish this goal, we created a task battery that consists of three different behavioral tasks: (1) reward and avoidance reinforcement learning task; (2) goal-directed vs habitual learning task; (3) exploration and exploitation task. Due to clinical and technological constraints each task must be limited to 20 minutes of data collection, which is insufficient to reliably estimate model parameters with reasonable confidence. To address this issue, we have constructed a hierarchical task model through which parameter estimates for a given task can be improved by considering data from other participants performing the same task, and from disparate task data collected from the same participant. Here, we use simulations to demonstrate the benefits afforded by adopting hierarchical Bayesian model and its potential applications to an improved clinical diagnostic tool.

Simulating Molecular Diffusion Within a Cryogenically Cooled Buffer Gas Beam

David Shlivko

Mentors: Nicholas R. Hutzler and Nickolas H. Pilgram

The buffer gas beam is a powerful experimental technique for producing a cold and slow sample of molecules to be studied spectroscopically or otherwise. Unfortunately, the densities of buffer gas used in typical applications are too low to be effectively modeled by analytical or computational methods that assume a continuum fluid flow, and they are too high to be efficiently modeled as individual particles. This "intermediate" regime can be properly simulated with Direct Simulation Monte Carlo (DSMC) methods developed in the 1960s; however, the versatility of these statistical algorithms is limited in that small samples of molecules contained within relatively large quantities of buffer gas are poorly handled. Here, we develop an original algorithm that uses DSMC flow fields generated solely for the buffer gas cells with varying properties and geometries, allowing experimenters to compare the quality of resulting beams without physically constructing and testing each variation. Initial runs simulating the buffer gas cell currently used in Hutzler Lab yield results consistent with experimental observations, suggesting that this is a promising approach toward numerically modeling molecular diffusion within a buffer gas beam.

Development of Instrumentation for the Deep Synoptic Array: Low-Noise Amplifiers and Electronics

Amritpal Singh Mentor: Sander Weinreb

The proposed Deep Synoptic Array is a 110-element interferometer operating between 1.28 GHz and 1.53 GHz that seeks to detect and localize fast radio bursts, millisecond long radio pulses of unknown origin. Noise goals for the interferometer are 45 K system temperature and 15 K amplifier noise temperature at ambient temperatures. Probing transistors to understand their behavior resulted in a good model for an indium-phosphide DIRAMICS high-election-mobility transistor. Amplifier noise temperature below 12 K at about 1.1 GHz has been achieved using the DIRAMICS transistor in the first stage. Additions to the amplifier circuit may center the noise curve to between 1.28 GHz and 1.53 GHz. Further work is needed in testing the internal noise calibration circuit and testing the temperature dependence of gain.

Data-Driven Methods of Measuring Stellar Compositions From Keck Spectroscopy

Tawny Sit Mentor: Evan Kirby

A wealth of information about the evolution of stars and galaxies can be found in studying the compositions of stars, which are measured through spectroscopy. However, the traditional method of measuring abundances from line strength partially depends on highly uncertain atomic data, and it makes some assumptions that are sometimes overly simplistic. Because data-driven methods to measure abundances do not rely on the poorly defined underlying physics of stellar spectra, we explore using the data-driven code The Cannon to measure the abundances of stars using spectra collected with the DEIMOS spectrograph on the Keck telescope. We create a combined dataset of DEIMOS spectra of stars from nearby globular clusters and dwarf galaxies. Then, we train The Cannon on the spectra with the highest signal-to-noise ratio. We validate the spectral model The Cannon produces with other high signal-to-noise spectra as well as lower signal-to-noise spectra. We quantitatively assess the ability for The Cannon to recover measurements of effective temperatures, metallicities, and the abundances of magnesium, silicon, calcium, and titanium.

Follow-Up Observations of Local Group Novae With the Liverpool Telescope

Meghna Sitaram Mentor: Matt Darnley

Time-domain surveys, such as the Zwicky Transient Facility (ZTF), will greatly increase the number of transients detected and the amount of transient data to analyze and follow-up. To explore possible follow-up strategies, we undertook observations of recently discovered Local Group nova candidates using the Liverpool Telescope, the Neil Gehrels *Swift* Observatory and archival data. Six transients, AT2018cmi, AT2018bto, PNV J00424144+4117377, J00414889+4109148, J00420765+4119438, and J00425261+4118409, were spectroscopically confirmed as eruptions of M31 novae; five belonging to the Fe II class and AT2018cmi being a He/N nova. Additionally, photometric and spectroscopic observations of the 2018 nova eruption from the known dwarf nova V392 Per and of the Andromeda Stream nova AT2017fyp were also analyzed.

Effects of Optogenetic Stimulation of Selected Hypothalamic GABAergic Neurons Upon Mouse Movement and Virtual Object Fixation

Nathaniel Smith

Mentors: Doris Y. Tsao and Francisco Luongo

Prior experimentation has showed that optogenetic activation of GABAergic neurons in the periaqueductal grey region of the hippocampus induces pouncing behavior, during which the mouse chases and acquires an object in the visual field, holding onto it fiercely until optogenetic activation is terminated. The regions the targeted neurons project to are currently unknown, and the phenomenon itself is poorly characterized. Characterizing how the activated mouse behaves in the presence of objects across modalities can provide insight into the processes that must be occurring downstream of the hippocampus, narrowing the range of regional candidates for the behavior. A positive result across modalities would indicate that the mouse selects fixation targets from pooled sensory data in its high-level world-representation. Using virtual stimuli projected upon a screen, the present study sought to observe whether an activated mouse would display fixation and pouncing behavior towards a purely-visual virtual stimulus and altered movement patterns detectable through computational analysis. Analysis continues, though the effect with virtual objects is weaker than the effect with real objects. Further experimentation with selectively-impaired mice and objects across sensory modalities and multi-object/multi-modality trials should provide insight into the conditions and underlying mechanisms of successful fixation.

S-Wave Velocity Structure of Salton Trough and Los Angeles Basins, SE California, USA

Junhao Song Mentor: Joann M. Stock

S-wave velocity models are needed for the determination of structural details and model-based prediction of strong ground motion in Southeastern California. In this study, S-wave first arrivals were picked both manually and automatically along Salton Seismic Imaging Project (SSIP) Line 2. We also compare the picking results to evaluate a new automatic picking method's capacity of detecting explosive source. From these picks, we build a 2-D S-wave velocity model in Salton Trough basin using an inversion algorithm. We also invert the picks data from Los Angeles Regional Seismic Experiments Phase I (LARSE I) to develop seismic velocity models in Los Angeles basin. These results may be useful for understanding the subsurface structure around the San Andreas Fault (SAF).

Investigation of Adaptive Time-Stepping Algorithms for Simulating Sequences of Earthquakes and Aseismic Slip (SEAS)

Yanke Song Mentors: Nadia Lapusta and Valère Lambert

Modeling earthquake behavior involves resolving the complex interaction of processes active across timescales ranging from hundreds to thousands of years of tectonic loading, down to milliseconds during the dynamic rupture process. To make such problems computationally feasible, simulations of sequences of earthquakes and aseismic slip (SEAS) employ adaptive time-stepping algorithms in order to optimally sample the temporal evolution of fault behavior. The choice of time steps during the dynamic and quasi-static phases of fault slip can impact the accuracy and long-term evolution of the computed quantities (e.g. fault slip, slip rates, and stresses) as well as the computational cost of such simulations. In order to explore the trade-offs for an optimal time-step selection, we study the simulations of SEAS with various adaptive time-stepping algorithms, comparing long-term fault behavior as well as the computational costs in terms of the total number of simulated time steps. We begin with a quasi-dynamic formulation of a 2D antiplane problem based on the first benchmark simulation from the SEAS code comparison exercise supported by the Southern California Earthquake Center. We plan to expand this study to explore the optimal adaptive time-stepping methods for simulations that include fully dynamic stress interactions and enhanced dynamic weakening mechanisms, such as the thermal pressurization of pore fluids.

Predicting General Intelligence Using Resting State fMRI Data: A Machine Learning Approach

Sumedh A. Sontakke *Mentor: Ralph Adolphs*

Intelligence is a poorly understood psychological manifestation of the effects of the neurobiological construct that is the human brain. This project, as a part of a more elaborate multi-year study, aimed to predict a measure of general intelligence and broad cognitive abilities using resting state functional connectivity data in a large sample of subjects using machine learning techniques. A range of machine learning techniques were applied in addition to restructuring the representations of the brain. The effects of varying these schemes on prediction accuracy were studied. This provided anatomical insights into the functional connections that are strong predictors of intelligence thereby providing a direct link between the neurobiological constructs of the brain and the consequent psychological effects, in this case, intelligence.

GPU-Accelerated Visual-Inertial Odometry for Safe Autonomous Drones

Connor Soohoo Mentors: Aaron Ames and Andrew Singletary

With the era of autonomous drones approaching, we must be able to guarantee the safety of drones as well as any nearby bystanders. A truly safe autonomous UAV should detect and avoid all objects that interfere with the current trajectory path, and it should successfully reorient itself after an unknown interference, like a gust of wind. In order to dynamically recalculate its trajectory, the drone must have an accurate estimate of its pose and velocity in addition to up-to-date knowledge of its surroundings. We use a computer vision algorithm known as SLAM (Simultaneous Localization and Mapping) to build a 3D map of the surrounding environment. We built an optimized version of the open source ORB SLAM (Oriented FAST and Rotated BRIEF) library by off-loading the feature detection and tracking components to the on-board GPU. This variant runs in real time at around 20 frames per second on the Jetson TX2 processor board, which we intend to use to control our custom quadroter. This doubles the frame rate at which we can map the environment compared to the original open source version. We have implemented this optimization for both Monocular and Stereo vision.

Optimal Wavelength Range for Biosignature Detection Utilizing High-Dispersion Coronagraphy

Carlos Sosa

Mentors: Dimitri Mawet and Ji Wang

High-Dispersion Coronagraphy (HDC) filters star light utilizing a coronagraph, and it makes use of an optical cable and a high-resolution spectrograph (HRS) to facilitate the detection of exoplanets. HDC improves upon traditional

high-contrast imaging (HCI) techniques and allows for new classes of exoplanets to be detected. Unfortunately, the coronagraph has a limited bandwidth, restricting the wavelength range available for the detection of biosignatures. In order to conclusively determine the presence of certain biosignature gases, the wavelength range chosen should have the highest information content of the corresponding gas's spectrum. The Q factor was chosen as the parameter that represents the information of a spectrum, and regions that maximized Q were desirable for imaging purposes. The Q factor was calculated for various stellar spectra and it showed agreement with published results, providing a proof of concept for the technique. The same methodology was applied to a simulated data set of 7 biosignature gases, and the regions that maximized Q were identified.

Optimizing Image Processing Algorithms to Score Peroxisome Assembly in Cell Culture Models of Peroxisome Biogenesis Disorders

Maya S. Srikanth

Mentors: Joseph G. Hacia and Barbara J. Wold

Peroxisome biogenesis disorders (PBDs) are genetic disorders that results from defects in PEX genes responsible for the assembly of peroxisomes. Efforts to discover small molecule therapies for PBDs that promote normal peroxisome assembly are hindered by the inefficiencies of evaluating peroxisomes in patient cells. Here, our overarching hypothesis is that the application of the NIH ImageJ platform will streamline the process of evaluating the numbers of peroxisomes in cultured human cells in research laboratories. In turn, this could help to accelerate efforts to find targeted therapies for PBDs. Here, we utilized patient skin fibroblasts with the common disease allele engineered to express a green fluorescent protein fused to a peroxisome targeting signal 1 reporter (GFP-PTS1). At baseline, the reporter is aberrantly localized in the cytosol of patient cells. Peroxisomal assembly was identified by the migration of the GFP-PTS1 reporter into the peroxisome matrix, visualized as 'green puncta'. Fibroblasts were either untreated or treated with a compound that promotes peroxisome assembly (diosmetin) or vehicle control (DMSO) and then cultured under standard conditions for 5 to 10 days. We then quantified the number of cells with rescued, non-rescued, and intermediate peroxisome assembly phenotypes using two different methods: 1. an existing Photoshop-based method and 2. NIH ImageJ software. Five images of DMSO, diosmetin, and untreated cells were scored twice by two different people. The average scoring time for each method is reflective of ten images. We found that using the NIH ImageJ method provided an overall increased speed of scoring peroxisomal phenotypes (rescued, intermediate, or non-rescued) relative to the Photoshop method, regardless of treatment (P<0.05 two-tailed Student's T-test). With NIH ImageJ, the scorer can manually tag cells as one of the three choices and an automated cell count for each category is provided in a formatted table. The limitations of our study include not controlling for the differences in speed amongst different people and using a small population of scorers. To further augment the image scoring process with data regarding peroxisome assembly in drug-treated patient cells, a multi-step effort was undertaken. Firstly, an image-processing pipeline was built on CellProfiler, a free, open-source software for measuring and analyzing images. This pipeline was engineered to efficiently detect 'green puncta' on the image. Secondly, the pipeline was optimized to quantify peroxisome numbers, size, and distribution in a given image. There is much potential to further optimize the pipeline: implementing machine learning techniques and effective image-segmentation algorithms can significantly increase the accuracy of the process. Furthermore, extracting trends in size, distribution, and area of puncta in the context of a given cell can shed light on correlations between peroxisome assembly and various small molecule, gene, and cell-based therapies for peroxisome biogenesis disorders.

Evolution of the Ancient Martian Dynamo as Recorded by the ALH 84001 Meteorite

Sarah Steele

Mentors: Roger R. Fu and Joseph L. Kirschvink

While the unique Martian meteorite ALH84001 has been the subject of several previous paleomagnetic studies, key questions about the origin of its magnetization and its implications for the history of the Martian dynamo remain unanswered. Among the unresolved issues are the non-unidirectionality of magnetization in carbonate globules, which is potentially indicative of a prolonged period of remanence acquisition in a time-varying magnetic field, and the nature of magnetization in chromite grains, which may record Martian surface fields at 4.4 Ga. In this study, we take advantage of the micron-scale resolution of a quantum diamond microscope (QDM) to build on the results of past paleomagnetic studies of ALH84001. We first assess the unidirectionality of carbonate magnetization both among and within individual globules by both upper continuation of magnetic field maps and direct modeling of the micrometer-scale magnetism. We also characterize the magnetic properties of chromite grains, which have been difficult to study using other magnetic field imaging systems due to their small size and proximity among grains. Preliminary results including the magnetic imaging of 24 discrete carbonate grains and alternating field demagnetization to 30 mT suggest that the carbonates carry a unidirectional magnetization while the magnetizations of the chromites are randomly oriented. This may suggest that the Martian dynamo was weak during the initial crystallization of ALH84001, but was strong by the time the carbonates formed in the 4.0-3.9 Ga interval. We will pursue further demagnetization and paleointensity experiments to confirm and quantify the inferred Martian surface field intensities.

Design and Development of Revised Fan Array Wind Tunnel Control Software

Alejandro A. Stefan Zavala Mentors: Morteza Gharib and Christopher J. Dougherty

Fan Array Wind Tunnels consist of matrices of small, individually addressable fans. Some, such as the Fan Array Wind Tunnel at Caltech's Center for Autonomous Systems and Technologies, possess as many as 2,592 fans. In order to control these wind tunnels, a distributed, modular software approach is used, in which the wind tunnel is partitioned into "Slave" modules, controlled by a single "Master" device. Furthermore, in order to satisfy "research-grade" standards and generate complex, dynamic flow configurations, a new iteration of the existing Caltech fan array control software has been developed.

Optimizing Production of a Multi-Component Protein Nanoparticle Vaccine for East Coast Fever Ariel Stiber

Mentors: Neil King, Brooke Fiala, and Konstantinos Giapis

Two-component protein nanoparticles are an innovative branch of vaccine design that have the ability to display an array of antigens, producing a more robust immune response compared to traditional subunit vaccines *in vivo*. These computationally designed nanoparticles can be used to create a vaccine for East Coast Fever (ECF), a fatal disease affecting Kenyan cattle caused by the parasite *T. parva*. The development of a vaccine consisting of a genetic fusion of the parasite's key antigen, p67C, to one component of a two-component nanoparticle system is presented here. Testing this vaccine for the ability to prevent infection with *T. parva* requires the purification and assembly of a large amount of these nanoparticles for challenge studies. Optimization of both component purification and assembly conditions enabled the production of a high quality vaccine candidate. We found that the antigen-bearing component was best purified using both IMAC (immobilized metal affinity chromatography) and SEC (size exclusion chromatography) with a CHAPS detergent for endotoxin removal and then assembled using 50 mM glycine as an excipient to prevent aggregation. Further steps include the addition of immunomodulatory proteins to the second component of the nanoparticle to elicit a stronger immune response.

Simulating, Redesigning, and Validating New Drive System for the Leighton Telescope

Michael Stramenga

Mentors: Sunil Golwala and David Woody

An effective way to mitigate atmospheric noise fluctuations during mm/ submm telescope imaging is to preform scans at elevated slew speeds. However, at increased azimuth and elevation scanning speeds, a telescope's primary mirror experiences higher dynamic loading, resulting in higher deformation at the mirrors surface. In the case of the 10.4-meter Leighton Chajnantor Telescope (LCT), this deformation must not exceed a surface value of 11µm rms to ensure primary scientific objectives are satisfied. To determine if scanning at these elevated speeds are in fact beneficial to the LCT project, an in-depth understanding of the telescopes dynamics is needed. To achieve this, high fidelity Simulink models of the telescopes drive system and plant response were created to calculate accurate loading parameters. These parameters were then inputted into a SolidWorks Static and Motion Study simulation to better characterize the deformation experienced by the primary mirror. The results of this study will inform LCT scientists/engineers on the limitations and design requirements of a new drive system for the telescope.

The Effect of Sensory Cues on Water Detection in Rodents

Madelyn Stroder Mentor: Yuki Oka

Drinking water is essential for survival, but little is known how animals search for water sources. My aim is to investigate which sensory cues thirsty animals rely on to detect a water source. The objective is to determine whether olfactory or tactile cues are responsible for the initial sensing of water and replicate data for the insignificance of visual cues in water detection. Knowledge of this relationship between the brain, the needs of the body, and the environment has implications for other appetitive behaviors.

I investigated water detection using a behavioral platform I built, complete with eight water stations that activate in a pseudorandom sequence, touch sensors, an air puff punishment system, and systems to toggle visual, olfactory, and tactile cues. Latency and accuracy data provided comparisons between training data and data from specific sensory deprivation scenarios. The ongoing scenarios indicate the findings from the pilot study – the importance of olfactory and tactile cues in water detection – may hold under this more rigorous study. By examining water-seeking behavior under various sensory deprivations, this work contributes to the understanding of the neural basis of appetite and sensory perception of reward cues.

Minimization of Uncertainty in Neutron Lifetime Measurement in the UCN τ Experiment

Victoria Su

Mentors: Bradley Filippone and Eric Fries

The value of τ_n , the mean lifetime of the neutron, lends insight into the hydrogen to helium atom ratio of the primordial universe, unlocks the possibility of discovering new physics beyond the current standard model, and much more. Yet, the measured value of τ_n is relatively uncertain for its significance, and there is a large, currently unexplained discrepancy between the two values for τ_n as measured by the two main methodologies. The UCN τ experiment uses the bottle method where ultra-cold neutrons are generated and stored in a trap for a period of time to observe decay behavior. Through running simulations of the experiment, the effects of changing different parameters of the experimental setup were analyzed. A smaller trap is not able to contain as many higher energy neutrons as a larger trap since many neutrons would be lost to absorption against the ceiling of the trap when their energy is too high. When varying the scale of the trap and the maximum energy of generated neutrons, the most efficient setup that contained the most neutrons. Further analysis can look into varying the shape of the trap, making it taller/wider rather than scaling the entire trap. A more accurate simulation can be made by simulating the periodic 'bursts' of neutrons that are generated rather than generating all of the neutrons in the beginning of the simulation.

Energy-Aware Planning and Control of the ORB Robot

Hyung Ju Suh Mentor: Aaron D. Ames

The ORB (Omnicopter with Rolling and Bouncing capability) robot is an over-actuated aerial vehicle with 8 rotors, enclosed in a flexible spherical structure. Due to the spring-like properties of the outer structure, the robot can utilize the passive dynamics of bouncing and rolling to achieve locomotion with energy efficiency. Unfortunately, planning and control of combining such diverse behavior is quite difficult because the system displays hybrid-dynamic properties, where different continuous dynamics exist for each different discrete states. This challenge is further exacerbated by the cyclic nature of state transitions, where zeno-like phenomena can be observed until a final transition is made. This work first explores the full-state dynamics of the vehicle in each discrete state (flying, rolling, bouncing), then utilizes dynamic programming techniques to obtain energy-optimal solutions to planning and control in the vehicle's hybrid domain.

Multi-Variate Rational Regression With Memetic Algorithm

Haoyuan Sun

Mentors: Pablo Moscato and George Djorgovski

This research tries to address the difficulties of symbolic regression, the process of modeling data with algebraic expressions, in handling division. We propose dealing division with a continued fraction representation, from which rational function models can be extracted. A memetic algorithm, which is a paradigm of metaheuristic optimization based on the evolution of solutions by a set of computational agents that have problem domain knowledge, is implemented to generate solutions in this representation. A population of feasible solutions uses local search heuristics to improve model fitting and compete searching for function models that use a smaller number of variables. We utilize a tree-based population structure to improve the program's efficiency. Data sets from real world applications, such as the classification of flower iris, are used to measure the potential our approach and benchmark its performance against an established commercial software.

Novel Roles of Extracellular Matrix Proteins in Drosophila Cell Migration

Hsuan-Te Sun

Mentors: Angela Stathopoulos and Heather Curtis

Drosophila caudal visceral mesoderm (CVM) cell migration is an easily observable experimental system for studying a developmental process where errors can have serious consequences. Extracellular matrix (ECM) proteins may help regulate cell migration by activating functional enzymes, cleaving structural proteins, or organizing "tracks". We performed in situ hybridization staining of CVM-specific genes and analyzed their genetic knockout mutants via immunohistochemistry to discover novel roles in cell migration regulation for two proteins: Tolkin (Tok) and Neyo (Neo). Tok mutants exhibit CVM crossover, a rare and extreme phenotype previously only observed in FGF receptor Heartless (Htl) mutants. However, CVM crossover in Htl mutants is accompanied by crossover of the proximal trunk visceral mesoderm (TVM). After making a Tok,Htl double mutant and performing antibody staining, we discovered that the absence of Tok rescues TVM crossover, implicating this protease in a specific function involving both tissues. As for Neyo, we observed that the cells expressing this protein are initially located on the outside edges of the CVM groups when they just begin migrating, then shuffle and randomly distribute throughout. We hypothesize that Neyo-expressing cells act as leaders in a "sheepdog herding"-like mechanism and intend to do further tracking analysis to better characterize this subgroup.

The Role of O-Acyltransferase Genes on Worm Behavior

Jessica Sun Mentors: Paul Sternberg and Sarah Cohen

The nematode *Caenorhabditis elegans* (*C. elegans*) has over 21,000 genes, but detailed information is known for only a small fraction of these. There are 60 o-acyltransferase (oac) genes in *C. elegans* which have been named based on protein domain information, but what they do in the worm is unknown. Our work aims to elucidate the phenotypes of these genes using 22 deletion mutation strains of 15 of these genes which have been created by the Sternberg Lab, beginning with investigations into dauer diapause and lifespan. We will show that several of these strains show significantly lower rates of dauer entry as compared with wildtype, while none of the strains appear to differ from wildtype in recovery from the dauer stage. Our work into OAC effects on lifespan are ongoing.

Developing the Software Infrastructure of the Gattini-IR Survey

Sharne Sun

Mentors: Mansi Kasliwal, Ryan Lau, and De Kishalay

The Kasliwal group is exploring the infrared sky by commissioning a grounded, wide field telescope (Palomar Gattini), the first of its kind, at Palomar observatory. This telescope will have the ability to discover supernovae and novae heavily obscured by extinction, observe brown dwarfs, and reveal red stellar mergers that would otherwise be impossible in the visible spectrum. To begin with, I characterized the changes in the Near Infrared sky at Palomar observatories in order to predict the effects of changes in sky intensity on Gattini images. Afterwards, I have developed scripts in preparation for the large quantities of data that Gattini-IR telescope will collect. In order to transport and access this data, the information associated with individual candidates on specific dates will be packaged into AVRO data packets and stored in an SQL database. The marshal website is able to access this SQL database and display necessary information in an easily readable format. After the telescope is on sky, algorithms for sorting and filtering transient candidates will be required.

Revealing the Molecular Mechanism of Defect From hSRP54 Mutations That Cause Neutropenia

Xuemeng Sun

Mentors: Shu-ou Shan and Jae Ho Lee

Signal recognition particle (SRP) is responsible for the targeted delivery of approximately 30% of the newly synthesized proteome to the eukaryotic endoplasmic reticulum (ER). SRP54 is one of the components of human SRP and plays a central role in SRP function. It was reported recently that three mutations (G226E, T115A, and T117del) in SRP54 cause congenital neutropenia; however, the molecular basis of the mutational defects remains unclear. Previous work in the lab of Dr. Shan has developed mature assays to measure different aspects of SRP function. This project took advantage of these assays and aims to reveal the cause of defect at a molecular level. We have expressed the mutants and assembled them into holo-SRP. Using in vitro reconstituted targeting assays, we found that all three SRP54 mutations severely disrupt co-translational delivery of model proteins to the ER. By comparing the assembly efficiency between wild type and mutants, we rule out the possibility that mutants affect protein folding and SRP assembly. The future of the project will focus on testing the mutants' ability to contact with SRP receptor and their ability to bind GTP, by employing the GTPase assay. Ultimately, we will be able to answer which step of SRP function is defective and shed light on the molecular basis of disease.

Next-Generation Search for the Binarity in Planetary Nebulae

Wun Yung Shaney Sze

Mentors: Shrinivas R. Kulkarni and Nadejda Blagorodnova

The field of time domain astronomy is growing rapidly as astronomers race to build the biggest telescopes and the furthest-reaching surveys. As more and more stars get discovered everyday, we have to make sure that the technology that analyzes these stars are on par. Planetary nebulae are among one of these wondrous phenomena in the sky, remnants of exploding stars, forming multicolored clouds surrounding the cores of its hosting star. The Zwicky Transient Facility had its' first light in late 2017 and have been keeping track of the sky ever since, making a cinematic film every evening. Using one of the widest astronomical survey to date, ZTF's night-to-night variability allows for discoveries from new exploding stars to ancient planetary nebulae. Most of these planetary nebulae sources are single-cored, with a few exceptions that contains binarity. This paper will explore the fraction of binary sources in planetary nebulae, probing questions for the evolution of these nebulae. Other than verifying the known binary sources among literature, we will take advantage of ZTF's technology for discoveries of short-period binaries.

Analysis of Bacterial Communities in the Small Intestine of Environmental Enteropathy Mouse Model in 3D

Heli Takko

Mentors: Rustem Ismagilov and Roberta Poceviciute

The mouse model of environmental enteropathy (EE), an inflammatory condition of the small intestine, is established when *E. coli* and *Bacteroides* spp. human gut isolates are gavaged together to young malnourished mice but not when they are gavaged separately (REF). Spatial structure of the resulting bacterial community may shed light on the mechanism behind the observed synergy between the two bacteria. To interrogate the spatial structure of intestinal bacterial communities, taxon-specific FISH probes must be hybridized to ribosomal RNA molecules and their spatial location with respect to the host and to each other must be quantified. Presented here is my contribution to this effort. First, we evaluated optimal FISH reaction conditions for each probe of interest using two model species, *E. coli* and B. fragilis, both theoretically and experimentally *in vitro*. Then, we applied machine-learning based image analysis tools to analyze 3D images of the *in vivo* samples. We detected host epithelial boundary as well as bacteria and calculated the distance of bacterial cells from the host epithelium as well as co-localization between the two bacteria groups. With these optimized methods, we are working on understanding the observed synergy between *E. coli* and *Bacteroides* spp. in EE mouse model.

Regenerating Inactivated Carbene Transfer Heme Enzymes

Allison Tang

Mentors: Frances Arnold and Russell Lewis

Recent efforts in biocatalysis have engineered heme enzymes that catalyze carbene transfer reactions, a class of reactions that are synthetically useful but are unknown in biology. Although these carbene transfer heme enzymes show great potential as industrial biocatalysts, one of their major limitations is mechanism-based inactivation. During inactivation, the heme cofactor becomes irreversibly modified and the enzyme is no longer productive. We developed a method to regenerate these inactivated enzymes, using *Bacillus subtilis* truncated globin as our model protein and the cyclopropanation of styrene and ethyl diazoacetate as our model reaction. By denaturing the enzyme recovered after the reaction, we were able to remove the modified heme cofactor. We then added unmodified, active heme and screened for conditions where the heme reincorporates into the refolded enzyme. Through several rounds of optimization, we determined conditions that allow the enzyme to regain most of its selectivity and part of its activity. Further work would involve streamlining this process by conducting both reactions and regeneration in a continuous stirred-tank reactor.

The Effect of Surface Free Energies and Silicon Microwire Geometries on Hydrogen Bubble Positioning in Devices for Solar Fuels Production

Gianmarco Guin Terrones Mentors: Nate S. Lewis and Paul A. Kempler

Photoelectrochemical water splitting provides a means of generating hydrogen fuel from water and solar energy. Silicon microwires embedded in a Nafion proton exchange membrane can serve as part of an integrated solardriven water splitting device. However, hydrogen gas separates from the solution surrounding these microwires to form bubbles which prevent both mass and charge transport. Contact angle goniometry was used to characterize the different surface chemistries of a typical solar-driven water splitting device, and results indicated that hydrogen bubbles will preferentially reside on the Nafion proton-exchange membrane (at the bases of the microwires) and on platinum-catalyst sites. Bubble presence at these two locations is highly deleterious to device performance; therefore, it is important to design ways to encourage bubbles to settle at the tops of microwires. The approach taken was to vary the hydrophobicity of different components of the water splitting device and change the geometry of the microwire array. Preliminary results indicated that adjusting the surface free energies of different parts of the hydrogen-evolution device and modifying microwire dimensions can promote the Cassie state for hydrogen bubbles. Such bubble behavior would improve solar fuel device efficiency and viability, and would additionally allow for unassisted water-splitting operation.

Design, Synthesis, and Docking Studies of a Small Focused Chemical Library of PPARalpha Agonists to Target Nonalcoholic Fatty Liver Disease

Benjamin J. Thoma Mentor: Brian M. Stoltz

NAFLD (nonalcoholic fatty liver disease) represents one of the most serious metabolic diseases to face mankind in both a social and economic context, with developing nations often being the worst afflicted. Due to ongoing urgent need to deal with the issues associated with this disease, the design and synthesis of anti-NAFLD agents presents a constant challenge. In this work, a central quinoline-5,8-dione core was functionalised through regioselective amination reactions, copper(I)-catalyzed alkyne-azide cycloadditions (CuAAC) and [2+3] cycloadditions with substituted azides to generate a small targeted compound library of agonists for PPARalpha, a nuclear receptor strongly linked to NAFLD. The library was constructed rationally via *in-silico* molecular docking and visualisation of ligand binding to PPARalpha. Herein we present the design, pharmacological properties and predicted binding affinities of 12 compounds and compare them to commercially available fibrates used to treat nonalcoholic fatty liver disease. It is hoped that these drug-like molecules will be more potent agonists than commercial fibrates used to combat metabolic diseases and thus minimise dose-related adverse events.

Hardware Implementation of Artificial Neural Networks

Changda Tian

Mentors: Azita Emami and Benyamin A. Haghi

Artificial neural networks (ANNs) are widely used in our lives. In some situations which need fast response and self-control, traditional approaches of ANNs CPUs/GPUs based cannot meet our needs in speed. Therefore, designing low power and efficient chips for ANNs is necessary. We intend to implement ANNs on FPGAs. The core data operations in ANNs are matrix multiplication and activation functions. As FPGAs is not good at dealing with floating point numbers, we first designed a way to represent decimals with fixed-point numbers in FPGAs. Then we designed a method to do matrix-vector multiplications in FPGAs, using shift addition on basic multiplication of two fixed-point numbers. Next, we used multi-segment linear fit to implement the tangent hyperbolic function as one of the most popular one of the activation functions. We got results of our work from simulator. When given decimal numbers from -10 to 10, the errors are 2% for converting floating point numbers to fixed-point numbers and 2.79% for the tanh function. Therefore, using FPGAs to implement ANNs is a good start for the future ASIC designs. The next step is to implement the algorithms on an Altera FPGA.

Optical Injection Locking Using an Arduino

Alicia Tirone Mentors: Dave DeMille and Nick Hutzler

Many experiments are looking to measure properties of atoms using optical techniques. In order to accurately do this, lasers with narrow linewidths are necessary. One common way to achieve higher powered, single frequency lasers is through optical injection. This technique uses a stable laser with a very narrow linewidth but low power output to seed the frequency of a second laser (usually a diode) with higher power output. However, diode lasers are sensitive to thermal drifts, vibrational noise, and changes in the input current. This project focuses on using an arduino to provide current feedback to the diode that will actively correct the for drift in the optical injection as well as re-inject the diode if the setup becomes uninjected.

Oxygen Isotope Ratios of S-Type Granites Across the Archean-Proterozoic Transition

Allyson Trussell Mentor: Claire Bucholz

Throughout the Archean-Proterozoic transition, the maximum value of oxygen isotope ratios in igneous zircons has increased. This increase is proposed to be either the result of the onset of collisional plate tectonics and increased incorporation of supracrustal material with elevated δ^{18} O ratios into the source region of magma, or due to the rise of atmospheric oxygen levels c. 2.4 Ga and new sub-aerial weathering reactions. The igneous rocks from which these zircons were derived, however, often have a complicated or unknown petrogenesis. By instead examining δ^{18} O ratios in zircons from strongly peraluminous granites (commonly referred to as S-type granites), the petrologic issues associated with the igneous and detrital zircons used in previous studies is resolved. S-type granites are derived entirely from the partial melting of metasediments and should preserve a pure sedimentary oxygen isotope signature. Additionally, igneous zircons are highly resistant to alteration and exhibit slow O self-diffusion. We expect that the maximum values of δ^{18} O ratios in zircons from S-type granites will show a secular increase across the Archean-Proterozoic boundary, supporting an increase in δ^{18} O of sediments due to the rise of atmospheric oxygen and new weathering reactions.

Search for Displaced Dark Photons With Dimuon Resonances

Shu Fay Ung

Mentors: Maria Spiropulu, Cristián Peña, and Si Xie

The dark photon (A') has been conceived as a force mediator in the dark sector that is analogous to the Standard Model photon. Through kinetic mixing with photons, the A' could be produced if kinematically allowed and observed through their decay into leptons. We focused on the displaced signature of the $A' \rightarrow \mu^+\mu^-$ decay channel. Monte Carlo samples of the signal were generated with Pythia8 and ran through the full CMS simulation with scouting triggers. The scouting vertex reconstruction efficiency was investigated, which was required to infer the expected number of A' from the observed prompt dimuon spectrum. Muon vertex cut studies were also conducted to optimize background reduction. To yield the maximum signal to background ratio, the rapid decay in the prompt background compared to the signal could be used to place vertex cuts. Further work would look into improving the scouting vertex reconstruction and background reduction, which is vital due to the low A' production cross section.

Design of Gamma Ray Detectors and Associated Readout Electronics for a Time Reversal Experiment

Tine Valencic

Mentors: John Behr and Petr Vogel

The TRIUMF Neutral Atom Trap (TRINAT) experiment looks at beta decay in radioactive isotopes of alkali metals (⁹²Rb and ³⁷K) and searches for time-reversal violations on MeV scales. Detection is accomplished by measuring the momenta of three products of the decay – the beta particle, the gamma ray, and the recoiling nucleus. Time reversal is simulated conceptually by flipping the momenta of the three decay products, then smoothly rotating the result to target specific detectors. Asymmetries are present if, when the momenta are flipped, the number of events in the gamma detector changes. Such an observable is not sensitive to spin so, if detected, would point toward new physics different from contributions to the neutron electric dipole moment. Various scintillating materials were tested for their energy resolution, light output, and timing properties while a readout circuit was designed. Two bismuth germanate (BGO) crystals with silicon photomultiplier (SiPM) readout were then tested, calibrated, and mounted symmetrically on the atom trap.

The Spectral Calibration of VERVE

Judah E. Van Zandt Mentor: Dimitri Mawet

The radial velocity (RV) technique has proven to be the most fruitful exoplanet detection method to date. High precision measurements with state of the art equipment have achieved RV precisions on the order of 1 m s⁻¹. Given that Earth's induced RV on the sun is on the order of 10 cm s⁻¹, this regime represents the next milestone on the path to finding Earth-like planets orbiting distant stars. We introduce the Vacuum Extreme Radial Velocity Experiment (VERVE), a fiber-fed high-resolution echelle spectrometer designed to integrate interferometry to achieve RV precision at the 10 cm s⁻¹ level. We detail the spectral calibration of VERVE, including the development of a precise forward model and a data reduction pipeline to facilitate spectral extraction. We examine the model's agreement with the spectra of various calibration sources and present the results of a spectral extraction performed on a 780 nm laser source. We discuss further corrections to be implemented in the model and conclude by revisiting the implications of achieving 10 cm s⁻¹ RV precision once interferometry is employed in VERVE.

Studying the Emission Characteristics of Carrier-Envelope-Phase-Dependent Current From Interconnected Nanotip Devices

Praful Vasireddy

Mentors: Franz Kaertner, Phillip Donald Keathley, and Glen George

When a very high-intensity, short-pulse laser field is incident on a metal, electrons can be emitted through Fowler-Nordheim tunneling rather than multiphoton emission. This tunneling emission is dependent not on the amplitudemodulating intensity envelope of the incident pulse but rather on the oscillating carrier electric field. This fielddependence is observed as dependence on the carrier-envelope-phase (CEP) of the electric field: the phase difference between the intensity envelope and the carrier electric field. In this project, we study the CEP-dependent current output from interconnected, bowtie-shaped metal nanotip devices. We choose this structure as it should theoretically provide a greater signal-to-noise ratio (SNR). We study the SNR of these devices and compare them to previous experiments on different geometries. Based on our results, we characterize the type of noise that is limiting in this experiment, allowing us to determine how to best move forward with improving the CEP-dependent current output in future experiments and increasing the SNR. Additionally, we perform simulations on the fielddriven dynamics of the CEP-dependent current with the goal of informing future experiments and increasing CEPsensitivity. We use these simulations to begin development of a system to preemptively alter the input pulse in order to improve CEP-sensitivity.

Deep Learning for Forecasting Quadcopter Dynamics

Akshay R. Vegesna Mentor: Anima Anandkumar

Forecasting quadcopter dynamics is difficult because such aerial vehicles exhibit high sensitivity and long temporal dependencies in flight. We treat forecasting dynamics here as a regression problem in high dimensions, and use sequential deep learning models for this task. Specifically, we use Tensor-Train Recurrent Neural Networks (TT-RNN) since they have shown success in long-term forecasting of physical systems. From preliminary forecasting results, the TTRNN shows significant forecasting improvement over the untensorized Recurrent Neural Network baseline over a range of simulated environments. Furthermore since quadcopter flight is a physical dynamical system with constraints, we study the use of modified Neural Network architectures for this specific task. Two ways that this is done is by enforcing physical constraints as a Lagrangian loss term and forecasting the differences in dynamics instead of the dynamics themselves. We aim to apply this improvement of trajectory forecasts to aid quadcopter controllers.

Designing a Higher Capacity Automated Sample Changer for Superconducting Rock Magnetometers

Galilea Von Ruden

Mentors: Joseph Kirschvink and Isaac Hilburn

Paleomagnetism is the study of the magnetic vector components of rock samples to place constraints on the magnetic, geophysical and tectonic history of the terrains from which they were collected. Within a magnetically-shielded room, a superconducting rock magnetometer (SRM) measures the magnetic moment of each specimen at a series of demagnetization levels. The sheer quantity of measurements required for statically significant data entails per-minute sample changing and practically necessitates an automated sample handler to deliver, insert and remove specimens from the SRM. A vacuum-powered quartz-glass sample handler sits above the SRM aperture to insert and remove samples; the challenge lies in positioning precisely-oriented samples beneath it. This project improves upon existing systems, delivering higher standards of precision and sample-capacity by implementing a servo-controlled xy-stage on linear bearings to move a sample-laden plate to any position desired. The magnetically-sensitive environment presents material limitations; each component's magnetic field must not exceed background levels at the distance it exists from the samples, hence our copious use of aluminum, brass, and nonmagnetic steel, as well as long drive shafts to distance the highly-magnetic motors. This next generation of automated sample changing promotes further and more efficient paleomagnetic research.

Using Machine Learning to Implicate Structural Variants in Cancer and Other Diseases

Jagath Vytheeswaran

Mentors: Mark Gerstein, Sushant Kumar, and Mathieu Desbrun

Structural variants are multi-nucleotide mutations with significant implications in cancer, Autism Spectrum Disorder (ASD), and other conditions. Genome sequencing efforts have provided access to a wide array of structural variant datasets – the logical next step, then, is to analyze variants in the context of underlying conditions to determine what makes a variant deleterious. Structural variant datasets were gathered from various disease and control databases. Through consultation with literature and previous group work, a list of pertinent features was compiled, and these features were extracted from genomic annotation databases for each of the collected variants. Finally, multiple iterations of supervised and unsupervised models were trained on the data and refined, and downstream analysis was performed to create a prioritization method for structural variants with respect to diseases. The methods and tools were released to the open-source community to be used in other contexts and improved upon.

A Feature-Based Model for Artwork Valuation

Iman Wahle Mentors: John O'Doherty and Kyo ligaya

The valuation of artwork is often a subjective and ambiguous process across individuals. Using a set of painting features (ranging from high-level features like the concreteness of the painting, to low-level features like the average hue of the painting), we found that subjective preferences towards paintings can be predicted by a linear combination of these features. Furthermore, these features are weighted differently by different individuals to give their final preferences. Further work in this study will look at fMRI scans of participants evaluating paintings, in order to see if these hypothesized features are being represented in the brain during evaluation, and if the final preferences for the artwork can be recovered from scans.

Cloning of sup-45 as a Novel Heat Shock Response Regulator in C. elegans

Sophie Walton Mentors: Paul W. Sternberg and Han Wang

Organisms have developed complex mechanisms to deal with the damaging effects of heat stress, including upregulation expression of the heat stress proteins (Hsps) which serve to mitigate the effects of heat stress. *sup-*45 was identified in a screen for suppressors of heat shock induced GOA-1, and expression of *hsp-16.2* is virtually eliminated in *sup-45* mutants, indicating that it is necessary for heat shock inducible gene expression (Hadju-Cronin et. al, 2004). However, the gene identify of *sup-45* was unknown. In a forward genetic screen for suppressors of heat shock induced *lin-3c* overexpression, we isolated 3 new alleles of a *sup-45*. We cloned the *sup-45* as the gene Y55B1BR.2, encoding an uncharacterized gene. We showed that *sup-45* is expressed in many tissues and during all life stages of *C. elegans. sup-45* mutants are also short, grow slowly, and have defects in egg laying. We have created a functional translational fusion of SUP-45 with GFP attached at its C-terminal, which rescues morphological phenotypes and restores heat shock inducible gene expression. Using this translational reporter, we will determine the subcellular localization of SUP-45 and see how it changes upon heat shock. We will also investigate the interaction of *sup-45* with *hsf-1*, another well-known heat shock gene regulator. Specifically, we will use translational GFP reporters to test if SUP-45 is required for proper subcellular localization of HSF-1 upon heat shock and vice versa. We hope that our investigation of *sup-45* will provide insight into the important but complex mechanisms of heat shock response.

The Economic Impact of Banking Networks in Early 19th Century England

John Wang Mentor: Philip T. Hoffman

Saving and investment are essential in macroeconomic growth models—as more funds are saved, capitalists can borrow more money to invest in human and physical capital. How funds are transferred from savers to lenders and then borrowers is clear in America's modern financial system, but creating such a system takes time. Infrastructure needs to be put in place to connect borrowers to lenders, and historically, this is done in myriad ways, from the complex notary systems of 19th century France to the more classical banking networks of Great Britain. Even today, in developing countries, credit markets still lack the infrastructure found in developed economies. By analyzing banking, population, and factory data from England, we aim to interpret and explain the effects of credit market expansion during the Industrial Revolution. Furthermore, through analysis of time-dependent geographical data on the location of banks, we are working to explain the expansion of the banking network in England—where and when do banks open, and how does each bank influence economic growth in its region. In the long-run, we hope to develop a model that can explain how banking networks expand in developing economies and what effect they have on economic growth.

Interfacing Real Time Kinematic Positioning With Quadcopter to Achieve High Position Accuracy Oifan Wang

Mentors: Soon Jo Chung and Kyunam Kim

Relative position and attitude estimation accuracy is paramount in multi-agent navigation, often to the point where traditional positioning systems cannot provide. Thus, a positioning system using real time kinematic, a new satellite positioning technique, is use to achieve precise position estimation. In this system, a stationary base satellite receiver (base) is setup along with the vehicle satellite receiver (rover). The vehicle satellite receiver is interfaced with the onboard flight controller such that no interference detriments satellite data quality. With these goals in mind, we simplify the electric hardware system such that non-essential hardware is not included. Furthermore, interferences between multiple radio links onboard were investigated to ensure a stable link between the base and the rover. The communication protocol between satellite receiver and onboard flight controller is adjusted and parsed, and the position estimator is tuned such that the new positioning system can achieve centimeter accuracy, which is impossible to achieve with traditional satellite positioning system. This accurate positioning system will set the foundation for futures research in coordinated swarm navigation with quadcopters.

Global Inversion of Rock Uplift as Constraints on Geodynamic Models

Shi Wang Mentor: Michael Gurnis

We used an existing database of thermochronological data of continental rocks and work with and refine an inversion procedure to bound rock uplift to better constrain geodynamic models. Reconstruction of uplift velocity history requires an approach for solving the inversion problem of thermal conduction with convection and internal heat source. The past approaches to obtain uplift history from rock sample thermal history relies on the assumption of the temperature field. In this project, we present the necessity of considering the time-dependent change of temperature field by show the substantial mismatch between the synthetic velocity and the inferred velocity while assuming dT/dt on the geotherm. And try to develop a new approach for the inversion with adjoint method. Here we describe a new adjoint problem to recover velocity field with surface rock sample's thermal history and information observed about today's geotherm especially surface heat flow and surface temperature.

Synchrotron-Based XPS for the Study of Aerosol Particulate Matter

Stella Wang

Mentors: Nønne L. Prisle, Jack J. Lin, and Richard C. Flagan

Aerosols contribute the largest uncertainty when it comes to calculating the total anthropogenic forcing on Earth's climate. This is partially due to the notorious difficulty in characterizing the surfaces of aerosol particles and submicron droplets. Synchrotron radiation (SR) excited X-ray photoelectron spectroscopy (XPS) is a highly surface sensitive process and presents a novel method for studying the chemical interactions and surface processes on aerosol particles. This project demonstrates the potential for using SR excited XPS to study submicron particles and offers a comparison of particulates to their crystalline equivalents. Results from preliminary experiments on the hygroscopic properties of particulate matter show a shift in peak location with increasing ambient water vapor pressure and indicate an irreversible water vapor adsorption process for salt particles. These findings serve as a basis for future studies on the surface chemistry changes of aerosol particles during the uptake of water and formation of cloud droplets.

Foliated Fracton Order in the Majorana Checkerboard Model

Taige Wang Mentors: Xie Chen and Wilbur Shirley

The discovery of fracton models, a class of Hamiltonians that exhibits abnormal excitation patterns, challenges current understanding of topological phases, usually regard as the topological quantum field theory (TQFT). Chen *et al.* recently introduced the framework of the *Foliated Fracton Phase* to better understand the Type I bosonic fracton models, which attributes the abnormal properties of these models to the foliated structure of 2D topological layers. We carefully examined the general approach to study the ground state degeneracy (GSD), entanglement signatures, fractional excitations and the renormalization group (RG) transformation of fermionic fracton models under this framework. These characteristics suggest that the Majorana checkerboard model and the X-cube model plus decoupled background fermionic codes and bosonic codes, in which are applied searching the adiabatic transformation between the Majorana checkerboard model and the X-cube model plus decoupled background fermionic codes and bosonic codes.

Galaxy Cluster Detection via the Kinetic Sunyaev-Zel'dovich Effect

Laurel Weber

Mentors: Jamie Bock and Abigail Crites

This project provides a new way to measure the cosmological phenomenon known as the kinetic Sunyaev-Zel'dovich (kSZ) effect, which holds crucial information regarding the nature of our universe. The Linear Cluster Survey experiment (LinCS) is a millimeter wavelength imager designed to detect the kSZ effect at 150 GHz. The design of the array is based off of the previous Keck/BICEP 2 wafer layout and is integrated into the design of the TIME instrument. This paper details how the bolometers are positioned on a holder and fitted into the cryostat. LinCS will provide an additional lower frequency measurement to the TIME instrument while still being integrated into the layout of the cryostat. We further elaborate on the implications of detecting the kSZ effect via galaxy cluster surveys by analyzing various cosmological models. This includes comparing void models to dark energy models, opening the door for future experiments to shed light on kSZ consistency with void models versus the Copernican principle.

Developing Effectively Transparent Contacts Using Ethylene-Vinyl Acetate Superstrates

Ruby Wellen

Mentors: Harry Atwater and Sisir Yalamanchili

Solar energy is one of the most important and rapidly renewable energy technologies. Silicon is the most commonly used and cost-efficient material for solar cells. However, although the price of silicon has significantly decreased over time, the efficiency of solar cells has remained stagnant. In order to increase solar cell efficiency and also sustain low production costs, minimal and cheap design adjustments must be made. The Effectively Transparent Contacts (ETC) project aims to solve this issue by developing triangular contacts on solar cells. ETCs can increase the efficiency of solar cells by decreasing the optical losses in energy due to the flat face of the currently used contacts.

To further reduce changes in the production of solar cells, ETCs can be placed on existing contacts using the micromolding of silver ink in the capillaries of an Ethylene-vinyl acetate (EVA) stamp. In the industry, EVA is already used as a laminate for solar cells and therefore would be convenient for the commercial production of solar panels. As such, one focus of the ETC project is to investigate different methods for the development of efficient glass and EVA superstrates for the printing and lamination of conductive triangles.

Effect of Salt on the Thermodynamics and Phase Behavior of Dilute Polyelectrolyte Solution: A Monte Carlo Study

Cong Wen

Mentors: Zhen-Gang Wang and Pengfei Zhang

A single polyelectrolyte chain in solution tends to adopt an expanded rod-like conformation due to the Coulomb repulsion between charged monomers. As the temperature decreases, the counterions start to condense onto the backbone gradually and further lead to a chain collapse at low temperature; this phase transition is called coil-globule transition. In this project, by using a continuum Monte Carlo simulation in the canonical ensemble, we study the effect of salt on the nature of the coil-globule transition of a single polyelectrolyte in dilute solutions. The long-range electrostatic interaction is calculated by Ewald summation method, and the Metropolis method is used to generate samples. To locate the coil-globule transition point, we calculate the mean square end-to-end distance and radius of gyration of a single chain. We expect that the coil-globule transition temperature increases at small salt concentration and decreases at large salt concentration.

Low Drift Integrated Optical Gyroscope

Alexander White Mentors: Ali Hajimiri and Parham Porsandeh Khial

A new topology for silicon photonic integrated optical gyroscopes is developed that is robust over a wide range of temperature and laser drift. The new topology has the potential to improve silicon integrated gyroscope sensitivity, particularly bias instability, by an order of magnitude as compared to the current state of the art.

Rearrangement and Uniformization of Optical Tweezers Generated Via Acousto-Optic Deflector Ryan White

Mentors: Manuel Endres and Ivaylo Madjarov

There is great potential for research and simulation in the study of quantum phenomena through the use of manybody systems such as uniform arrays of atoms. Using an acousto-optic deflector (AOD), an incident laser can be split into multiple beams whose output angle depends on the frequency of an input signal to the AOD. These beams can be used to create optical tweezers to trap and move atoms in order to create such uniform systems. By programming the output of an arbitrary waveform generator (AWG), a signal was sent to an AOD to successfully create many equally spaced tweezers, which could then be rearranged at will by applying a frequency modulated signal. Ideally, the tweezers should also all have the same intensity, but because of imperfections in the system this is not a given. So, the AWG was also programmed to modulate the amplitude of a signal based on its frequency in order to achieve a more uniform rearrangement. However, this approach does not account for nonlinearities when multiple tweezers are introduced, which may be a topic for further study.

Development of Transition-Metal Metalated Difunctionalized Redox-Active Pyrrole Ligand Derivatives Sophie Rebecca Whitmever

Mentors: John Anderson, Harry Gray, and Andrew Mcneece

Biological systems frequently make use of stored equivalents of protons and electrons to achieve complex and challenging reactivity with small molecules. The Anderson group at Uchicago has developed a ligand framework designed to mimic this behavior by being able to, while bound to a metal center, store and transfer what amounts to a full equivalence of dihydrogen. This research presents the synthesis of two modified versions of a ligand similar to those used previously in the group which incorporate an additional secondary coordination sphere, envisioned to be able to store two equivalents of protons. These redox-active pyrrole ligand derivatives have been attempted to be metallated with titanium, iron and nickel and have demonstrated interesting binding behavior—as well as showing evidence of forming, in some cases, a ligand-based radical. This research presents the synthesis and characterizations of these ligands and some metal complexes, which have been studied via X-ray crystallography and proton NMR primarily (further characterization is in progress).

Frequent Items and Random Walks

Jonathan D. Willett Mentor: Kanianthra Mani Chandy

"Heavy hitters" algorithms identify high-frequency items in data streams while using a modest amount of memory.

This project modifies earlier algorithms to get an algorithm that computes an upper bound U(x) and a lower bound L(x) on the number of times that a heavy hitter x appears in the stream. The project uses the theory of random walks to explore the gap U(x) - L(x) for the case in which streams have stationary, memory-less distributions. The theory shows that for synthetic distributions of items such as Zipf distributions the gap is small. Experiments with streams of IP addresses show, likewise, that the gap is small.

Optimizing the Number of Convective Plumes in EDMF Cloud Parameterization Schemes Using Data From Coarse-Graining LES Simulations

Andrew Williams

Mentors: Tapio Schneider and Yair Cohen

The parameterization of turbulence and convection remains a major cause of the inter-model spread in climate predictions. The Eddy-Diffusivity/Mass-Flux (EDMF) parameterization unifies these two physical regimes by decomposing the grid box of a global climate model into two area fractions: one containing coherent updrafts and another containing the turbulent environment. To reduce computational cost, the EDMF parameterization currently neglects the variance of updraft activity and instead represents the updrafts solely by their mean values. In this project we investigate whether by including multiple updrafts in the EDMF scheme (rather than a single bulk plume, as currently used) it is possible to account for the variance of updraft activity, as prescribed by Large Eddy Simulations (LES). To achieve this, we used kernel density estimation (KDE) – with *N* Gaussian kernels representing the multiple updrafts - to approximate the probability density function of updraft activity generated

from LES for various convective regimes and domain sizes. We found that for all cases tested there exists an optimal number of updrafts which minimizes the Kolmogorov-Smirnov error between the two distributions. The effect of including multiple updrafts in the EDMF scheme on radiative quantities such as the liquid water path and cloud fraction is also investigated.

Test Design Based on Model Mismatch for Controlled Systems

Rebecka Winqvist

Mentors: Richard M. Murray and Sofie Haesaert

Finding safety and functionality guarantees for sophisticated safety-critical systems such as intelligent robots, autonomous vehicles and cyber-physical infrastructures is imperative. Recently developed frameworks enable automated synthesis of controllers and allows for a reduction in design faults. These methods rely on accurate models of systems with specifications expressed in temporal logics. Albeit being verified on a model of the system, the controller must also be tested on the true system. In this project we investigate the possibility and efficiency of designing tests based on the model's deviation from the true cyber-physical system. The aim is to propose a new method for designing tests to verify the robustness of the controller. Essentially, we adapt model-based testing tools used in software testing for controlled systems. We investigate which transitions in the abstract finite-state model of the system are more sensitive to mutations in the model and then exploit these transitions by applying different input sequences to the controller.

Kappa Opioid Receptor Binding of Biased and Unbiased Agonists

Kevin Winzey

Mentors: William A. Goddard III and Soo-Kyung Kim

The kappa-opioid receptor (k-OR) is a G-Protein Coupled Receptor (GPCR) that is a popular target for opioid drugs that act as painkillers. Having two separate pathways, one associated with analgesia and the other with sedation and dysphoria, the k-OR can be activated with selective, biased ligands that would induce only analgesic effects in pain patients. In order to be able to identify biasedness of ligands, we have taken the structures of experimentally-confirmed biased and unbiased ligands and docked them with several conformations of the k-OR protein. By minimizing and equilibrating the system through molecular dynamics, we identified key binding-site residues and important interactions between different segments of the k-OR. We predict that the biased ligands trigger only a specific pathway because they prevent a strong interaction between transmembrane regions 5 and 6. Using pharmacophore data and binding-pose information, we can then predict from docking results the biasedness of other k-OR ligands.

Effects of Mutations in vrk2 and robo1 on Sleep Behavior in Zebrafish

Katie Wong Mentors: David Prober and Steve Tran

Chronic sleep disturbances related to cardio-metabolic diseases and psychiatric disorders impact approximately 25% of adults worldwide, while 10% of humans have been diagnosed with chronic sleep disorders. GWAS data have identified numerous genomic regions associated with sleep duration, insomnia symptoms, and excessive daytime sleepiness. However, it is unclear which genes in each genomic region are associated with each sleep phenotype. Based on human GWAS data, we examined the role of *vrk2* and *robo1* in the regulation of sleep by conducting genetic loss of function experiments using CRISPR/Cas9 in zebrafish larvae. Starting at 4 days postfertilization (dpf), the locomotor activity and sleep of mutant zebrafish were continuously recorded for 72 hours. Following the behavioral experiment, larvae were genotyped using PCR to identify heterozygous mutant, homozygous mutant, and wild-type sibling controls. Analysis showed that homozygous mutant *vrk2* larvae were significantly more active compared to their heterozygous mutant and wild-type control siblings. In contrast, homozygous and heterozygous mutant *robo1* larvae were not significantly different compared to their wild-type sibling controls. Our results suggest that *vrk2* may be important in the regulation of locomotor activity.

Developing Effectively Transparent Contacts on Flexible, Ultralight Perovskite Solar Cells for Space-Based Applications

Gabriel L. Woolls Mentor: Harry A. Atwater

Perovskites could allow for the development of efficient, ultralight solar cells on flexible substrates, making them the most promising choice for space-based solar power applications. This is due mainly to the material's high power-to-weight ratio and its excellent resilience under high-energy particle radiation, which completely destroys its silicon and gallium arsenide-based competitors. In order to maximize current capacity and efficiency, we have worked on implementing effectively transparent contacts (ETCs) on perovskite-based solar cells, which have been demonstrated to increase the current capacity of heterojunction silicon-based cells. Micro-meter scaled triangular silver contacts, spaced micro-meters apart in a flexible polymer substrate, form a front contact grid that redirects incident sunlight to an active absorptive area of the solar cell, thus avoiding efficiency losses due to reflection. In this project we show how ETCs can be made compatible with perovskite solar cells by inverting the order of the cell layer-by-layer, effectively building a solar cell on top of a transparent polymer-based ETC superstrate.

Modeling Crust of Columbia River Basalts Using Ambient Noise Recordings

Mackenzie R. Wooten Mentor: Robert W. Clayton

Flood-basalt eruptions are the Earth's largest volcanic events and are thought to have caused massive extinction events. These events take part in the formation of hotspots and produce lavas that have covered much of the Earth's surface. The dynamics of these events have yet to be resolved however. One of the most recent flood basalt eruption, the Columbia River Basalts (CRB), is the site of volcanic propagation from the Yellowstone hotspot. The CRB shows evidence of a reconstructed crust and large crustal magma chamber, possibly due to the foundering and sinking of large portions of the lithosphere into the asthenosphere, which controlled the flow and distribution of volcanism in the area. In this study, we use two years of ambient noise recordings from a 60-station line array stretching from northern Oregon to southern Washington to solve for the shear wave velocity structure beneath this region. In addition, we use the difference between horizontally and vertically polarized shear wave velocities along this experiment to quantify radial anisotropy and illuminate any structural fabric that might be related with the areal extent of a large magma chamber in the lithosphere and the existence of a descending pluton beneath it.

Adaptive Electrical Properties of a 3D Tensegrity Lattice

Craig Worley

Mentors: Julian J. Rimoli and Thomas Heaton

Tensegrity lattices arrange cables and beams such that the beams are topologically independent throughout the lattice. The purpose of this experiment was to alter the geometry of the beams to ensure particular beams make contact during lattice compression and form a continuous path through the lattice. This would allow for energy to pass through the lattice that previously would not have, assuming the wire is non-conductive. The alterations made include changing from a circular to elliptical cross-section to limit deflection in the direction of the minor axis and adding a pre-bow shape to the beam in the desired direction of deflection. Abaqus Finite Element Analysis was utilized to simulate the behavior of the lattice as different configurations, cross sections and pre-bowing were tested. After discovering several configurations that worked in a single cell environment, we investigated the multicell structure behavior with the altered beam geometry to ensure the continuous paths are present. Future research focuses around validating the simulations via physical testing and further optimizing the lattice to be conducive to electrical and thermal energy.

Asset Design for Probabilistic Swarm Guidance Algorithm

Asta Wu

Mentors: Soon-Jo Chung, Rebecca Foust, and Sorina Lupu

NASA is considering multiple missions to Mars for a potential Mars Sample Return (MSR) campaign. On these missions, the empty space in the back-shell of the Mars spacecraft could allow for the deployment of a swarm of secondary assets, which could bring various instruments for data collection. The probabilistic swarm guidance algorithm determines the release time, angle of deployment, and initial velocity of each asset to achieve a desired pattern on the Martian surface – maximizing coverage area while being able to maintain a network of communication. This project is largely concerned with providing experimental validation of the algorithm as well as design and development of foldable gliders or other assets that could be used for deployment.

Progress Towards the Total Synthesis of Neoselagenellic Acid

Brenda Wu Mentor: Brian M. Stoltz

Neoselagenellic acid is a natural product isolated from the herb *Selaginella moellendorfii* Hieron. This interesting structure is part of a family of pyrrolidinoindoline alkaloids that display a broad range of biological activities. Herein, we describe progress towards the total synthesis of neoselagenellic acid, which hinges on palladium-catalyzed decarboxylative asymmetric allylic alkylation to install the quaternary center of the natural product. We have successfully developed a route to the acyl pyrrole intermediate that serves as the desired asymmetric allylic alkylation substrate, leaving a cross metathesis, Buchwald-Hartwig amination, and transamidation to yield the natural product.

Actively Cooled Load for 21CM Radio Telescope

David Wu

Mentors: Josef Frisch and B. Thomas Soifer

We investigated electronically cooled loads in the 500 Mhz to 1 Ghz range. Applications for such cooled loads include implementing them into the receivers of 21cm radio telescopes that require input noise temperature to be below 50 K and replacing cryogenically cooled RF input loads used in techniques that measure the noise temperature of amplifiers, such as the Y factor calibration method. Electronic feedback systems integrated in amplifiers can cool down thermal noise generated by resistors such that the equivalent noise temperature of the system is significantly lower than its physical temperature. Being supplied with a power source, such amplifiers, despite initial appearances, do not violate thermodynamic laws. With such feedback systems, the input of a low noise amplifier can act as a cryogenic load, which can replace complex physically cooled down loads for testing and calibration. We have demonstrated that such electronically cooled loads, discussed methods to calibrate this noise temperature, and examined the feasibility of using these loads instead of physically cooled loads in different measuring methods.

Development of Strategies for Binding DNA Origami to Graphene and Origami Dimer Formation for OASIS (Origami-Assisted Sandwich ImmunoSorbent) Assay

Emily Wu

Mentors: Paul Rothemund and Ashwin Gopinath

The development of efficient and effective detection and quantification methods is crucial for health management, whether in providing the ability to detect diseases, health conditions, and allergens. Our approach to achieve this is via the development of an electronic OASIS (origami-assisted immunosorbent) assay. One component of this development include the ability to bind origami to graphene in order to take advantage of FET-based technology and provide a route for electrical detection and signal production. Several strategies and chemistries are explored, including the binding affinity of poly-T DNA to graphene and an EDC (1-ethyl-3-(3

dimethylaminopropyl)carbodiimide hydrochloride) carbodiimide crosslinker reaction. Another component is to link two DNA origamis together in order to employ a sandwich-type assay approach. This includes investigating a simple linking mechanism that uses complementary DNA strands.

Predicting the Resolution of Sea Surface Height Measurements From Space

Weiguang Wu Mentor: Joern Callies

Precise measurements of sea surface height (SSH) are important for studying global ocean circulation. The Surface Water and Ocean Topography (SWOT) satellite mission, scheduled to launch 2021, will increase the precision of SSH measurements and begin to resolve submesoscales (10-100 km). So far, however, it has been unclear what signal dominates at submesoscales and to what scale SWOT can actually resolve it. By estimating the amplitudes of slowly evolving eddies and fast internal gravity waves, based on a combination of observations and theory, we determine the resolution scales for different types of motions. The results show that the resolution scale for slow eddies is strongly geographically dependent, increasing from 30 km in high energy regions to around 300 km in low energy regions. Our analysis further shows that SWOT will reveal the internal wave at the tidal frequencies in more detail than at present but will unlikely capture the internal waves at non-tidal frequencies. This analysis will help guide the interpretation of SWOT data once available.

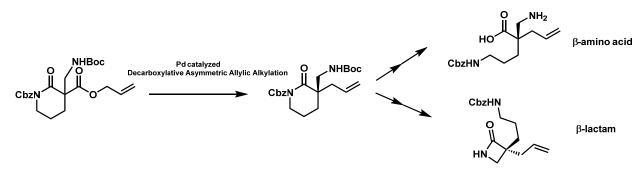
Studies Toward the Enantioselective Synthesis of β-Amino Acids and β-Lactams

Yuanzhe Xie

Mentors: Brian Stoltz and Alexander Sun

 β -amino acids are present in a great variety of natural products including peptides and play a significant role in biological and pharmaceutical research. They are also synthetic precursors of β -lactams, which are frequently used in the preparation of antibiotics. Thus there is significant interest in developing enantioselective syntheses of β -amino acids and β -lactams. In this project, we apply the decarboxylative asymmetric allylic alkylation to forge a quaternary stereocenter on various carboxybenzyl-protected lactams, which are precursors of β -amino acids.

We hypothesize the lactams can be hydrolyzed to form the desired quaternary β -amino acid as the Cbz protecting group weakens the amide bond of the lactam. The successful preparation of enantiopure β -amino acids would provide access to chiral β -lactams.



Study of the V_2O_5 Electroplating Process on 2D and 3D Structures for Battery Applications $\mbox{Grace Xiong}$

Mentors: Julia Greer and Xiaoxing Xia

Lithium ion batteries have been crucial in both the wireless technology revolution that has brought portable electronics and as a means of replacing the internal combustion engine. One method of improving cell efficiency would be to construct 3D electrodes. The usage of 3D electrodes would allow for greater flexibility in cathode design and allow for the usage of a thinner electrolyte such as lithium phosphorus oxynitride (LiPON). A new technique using electroplating and post-deposition washing to deposit V_2O_5 , selected as the cathode material due to its wide lithiation/delithiation potential window, wide availability, and relative ease of synthesis, has allowed for the study of V_2O_5 growth and the deposition of conformal V_2O_5 onto both 2D and 3D structures.

Alternate Interhemisphere Connections Given Agenesis of the Corpus Callosum

Mark Z. Xu

Mentor: Frederick D. Eberhardt

Agenesis of the corpus callosum (AgCC), a failure to develop the large bundle of white matter that connects the cerebral hemispheres, occurs in approximately 1:4000 individuals. Despite their lack of the primary interhemisphere communication channel, AgCC affected subjects exhibit the same bilateral resting-state networks as neurotypical brains (Tyszka et. al 2012). Additionally, AgCC affected subjects display higher levels of interhemisphere coordination than surgical commissurotomies (Paul et. al. 2007). These findings suggest that AgCC affected subjects still possess the capacity for interhemispheric transfer (IHC). It is thought that alternative connections might pass through the anterior commissure; however, this hypothesis has not yet been rigorously tested. Using functional magnetic resonance imagery (fMRI) data, we attempt to locate alternate connections in the AgCC affected brain using various statistical methods. We find evidence that such connections exist in the AgCC brain and not the control brain and present multiple probable locations for alternate interhemisphere connections, including the precuneus and the superior frontal gyrus.

Stability of Zero Modes in Dihedral Models

Wenqing Xu Mentor: John P. Preskill

There exist one-dimensional quantum models that can host zero-energy modes that enable highly stable storage and manipulation of quantum information. In particular, the Ising model without a transverse field can have zero modes derived from expressing the Hamiltonian as a Majorana fermion chain. These zero modes guarantee twofold degeneracy in all eigenstates. However, when a transverse field is activated, the zero mode may become unstable. There also exists abelian generalizations of the Ising model, whose zero mode stability, upon application of a transverse field, has been analytically and numerically characterized. We propose a non-abelian generalization of the Ising model and analyze its zero-mode stability in these chains. This is done by studying the model's spectrum, how it relates to non-abelian domain wall interactions, and characterizing how that spectrum splits. Specifically, we show that some non-abelian models can lead to several levels of exited state energies, which may help show the existence of zero modes under a transverse field.

Probing the Spin of Giant Planets as a Tracer of Formation History

Wenhao Jerry Xuan Mentors: Heather Knutson and Marta Bryan

Direct imaging surveys of exoplanets have been uncovering a growing population of massive planetary-mass companions orbiting at wide separations. So far, there is no consensus as to their dominant formation mechanism: forming like a star through molecular cloud fragmentation, or forming through more canonical planet-formation scenarios of core accretion and disk instability. Given the uncertainty in formation, the very definitions of planets and brown dwarfs are undergoing continual reexamination. We calculate the spin rate of the planetary-mass companion DH Tau b by measuring the rotational broadening of its molecular lines in high-resolution spectral data taken with the NIRSPEC instrument at Keck II. DH Tau b weighs 11 Jupiter masses, and orbits at a majestic 330 astronomical units from its host star, greatly expanding the parameter space of orbital distance in previous spin studies. By placing DH Tau b into the context of mass, orbital distance, and angular momentum trends found for a handful of other wide-separation planetary-mass objects, we shed light onto the formation histories of this population of planetary-mass companions. The process of performing this measurement will also allow us to improve upon and streamline a pipeline with which other targets in our dataset could also be processed.

Nanofabrication of Superconducting Quantum Circuit Components With a He and Ne Focused Ion Beam System

Joshua Yang

Mentors: Oskar Painter and Matthew Hunt

Research in the field of quantum information processing has made significant strides over the past decade, especially in superconducting microwave quantum circuits, a promising implementation that utilizes non-linear Josephson junctions to create macroscale qubits. Its information, however, lies within the microwave domain of light, which is inherently susceptible to thermal noise. Electro-opto-mechanical crystals (EOMCs) are devices that enable interconversion between microwave and optical frequencies of light; converting this information to optical frequencies shields it from noise and allows for long-distance communication. One vital EOMC component is the spiral inductor and nanogap capacitor (LC) circuit. Exploiting the unique patterning capabilities of a neon focused ion beam, we utilized a novel hard-mask lithography process that involves directly beam-etching a pattern into a 10 nm, atomic-layer-deposited aluminum-oxide layer and then transferring that pattern into the underlying aluminum via reactive-ion etch to produce nanowires of arbitrary shapes and lengths. By optimizing both the beam etch and reactive-ion etch parameters, we shrank the dimensions of the inductor, creating thinner (40 nm wide), longer (4 mm), and more tightly-wound (100 nm pitch) aluminum nanowire coils than previously achievable. These inductors should theoretically minimize stray capacitance and maximize inductance, leading to greater fidelity in the microwave-optical coupling.

Discovery of Lasso Peptides From Actinomycetales by Mass Spectrometry

Theodore S. Yang

Mentors: James Link, Wai Ling Cheung, and David A. Tirrell

Lasso peptides are bacterial natural products with a unique threaded loop topology that display interesting biophysical properties like protease and heat stability and species-specific antimicrobial activity. This study focuses on the characterization of new lasso peptides found in the closely related *Mycobacterium* and *Rhodococcus* genera. A *Rhodococcus rhodochrous* strain predicted to produce lasso peptides was tested in several growth conditions, and the biosynthetic gene cluster of a suspected *Mycobacterium arupense* lasso peptide was cloned and heterologously expressed in *E. Coli.* Extracts from the cell cultures were analyzed by liquid chromatography (LC) and matrix-assisted laser desorption/ionization (MALDI) mass spectrometry. Current mass spectra obtained from expression of the *R. rhodochrous* lasso peptide show larger than expected masses, possibly suggesting modification of the peptide before export. MS results from *M. arupense* are forthcoming. Further study of lasso peptide expression conditions for *Rhodococcus* is needed before structural analysis and tests for bioactivity.

Timing Layer Data in HL-LHC Higgs Decay Analysis

Alejandro Yankelevich Mentors: Maria Spiropulu, Cristian Peña Herrera, and Irene Dutta

The High-Luminosity Large Hadron Collider (HL-LHC) scheduled to be completed in 2026 will increase the number of collisions of the LHC by a factor of ten at the same energy and will therefore provide more data. This increase in luminosity will also increase the pileup of events. Higher pileup leads to more background, which makes detection of long-lived particles more difficult. The planned timing layer addition to the HL-LHC will provide timing data for charged particles with a resolution of 30ps and will allow for temporal separation in addition to spatial separation of detected particles. Monte Carlo simulations of the Higgs boson diphoton decay with upgrade parameters are studied in order to evaluate the expected increase in isolation efficiency of photons produced in this Higgs decay. The particle flow charged hadron isolation variable is calculated with and without timing data. For this variable, isolation improves when timing data is included. More complex algorithms that use other isolation variables may improve efficiency.

Efficient Estimation of Small Probabilities of Large Cascading Failures in Power Grids

Leyu Yao Mentor: Konstantin Zuev

Electric power grids are complex networks with heterogeneous distributions of loads, which makes them prone to cascading failures, where an initially small perturbation leads to a sequence of failures that spread through the connections between system components. Thus, it is crucial to estimate and enhance the reliability of power grids under cascading failures. We focus on developing a meaningful way to characterize the mitigating set of nodes in cascading failures, where deliberately switching off the nodes reduces the overall damage caused by the cascading failures. We implement a strategy proposed by Motter to reduce the damage by intentionally turning off nodes with least initial load on the US Western States Power Grids (USWS). A new strategy of assigning weights to links using the betweenness of their endpoints and removing fractions of leaves in the minimum spanning tree (MST) is developed and tested on USWS, which is more effective in most cases. We also aim to implement more realistic models for assessing the reliability of power grids in the presence of cascading failures.

FUS-Inducible Microbe Engineering of Gram-Negative Nissle 1917 E. coli for Cancer Therapeutics

Michael S. Yao Mentor: Mikhail G. Shapiro

Abstract submitted and approved but withheld from publication.

The Effect of Temporally-Regulated Neuronal Perturbations on Finch Behavior

Jessica Ye

Mentors: Carlos Lois and Walter Gonzalez

Although the mouse brain, the classical model for human neural systems, has been long-studied, much less is known about the finch brain. Unlike mice, finches sing songs that contain repetitive motifs and are resilient to noise perturbations. We seek to characterize the morphology and interactions between neurons in the HVC (high vocal center) involved in the generation of finch songs to model the process of recovery in neural systems. To visualize the morphology of neurons in the HVC, we stained finch brain slices with NeuN and DAPi and quantified the neuron-to-astrocyte ratio; about half of HVC cell bodies are neurons. We additionally injected a virus expressing green fluorescent protein and quantified the viral infection ratio. The injected virus contains an opsin that is activated by orange light, which will allow us to optogenetically perturb finches mid-song. To perform such real-time optogenetic perturbation, we developed a sound-triggered neural network in Matlab that recognizes finch songs. We found that for the sound-triggered neural network to work, a finch song must be longer than 600 ms. Analysis of HVC morphology and development of real-time optogenetic perturbation of finch songs will allow us to further investigate the processes involved in recovery of neural circuits in response to noise.

Promiscuity in Signaling Pathways Increases the Diversity of Addressable Sets of Cells Akshay Yeluri

Mentors: Michael Elowitz, Yaron Antebi, and Christina Su

The bone morphogenetic protein (BMP) pathway is critical in development, and is notable for its promiscuous architecture -- the various BMP ligands interact promiscuously with all BMP receptors, as opposed to other pathways where ligands are highly specific to certain receptors. We hypothesize that promiscuous architectures might allow for greater flexibility in simultaneously activating, or addressing, sets of cell types in biological systems. To test this, we developed a computational model, based on the BMP pathway, for promiscuous architectures. Using this model, we identified systems where the addressing of specific subsets of cell types was possible. No equivalent for many of these systems exists in a non-promiscuous architecture. These results demonstrate a potential benefit of promiscuous architectures, suggesting a biological rationale for the widespread presence of promiscuity in developmental pathways.

Gut Dysbiosis in Huntington's Disease

Jung Hyun Yoo Mentor: Ali Khoshnan

Huntington's disease (HD) is a hereditary neurodegenerative disorder caused by expansion of CAG trinucleotide repeat in *Huntingtin* (*Htt*) gene of chromosome 4. The age of onset of the disease, however, varies among the patients with equal CAG trinucleotide repeat numbers, suggesting that mutation in *Htt* may not be the sole contributor of HD pathogenesis. Gut microbes, among various environmental factors, significantly influence host physiology and brain functions. Change in the composition of gut microbiota (dysbiosis) is associated with neurodegenerative disorders such as Parkinson's disease (PD). Indeed, microbial metabolites affect the pathophysiology of PD in mouse models. My project was to explore whether a mouse model of HD (zQ175) exhibits dysbiosis in pre-symptomatic stage. I analyzed fecal microbiota of young heterozygous zQ175 and its wild-type littermate, separately housed based on genotypes, by means of quantitative polymerase chain reaction (qPCR) of

16s rRNA genes that vary among different bacterial taxa. Preliminary data suggest that some changes in the microbiota of HD mice may occur at different phylogenetic hierarchies from phylum to species levels. Studies are in progress to verify these changes with the samples from different mouse cohorts as well as from different facilities.

Investigating the Effects of UV Illumination on Elasticity and Stiffness Gradients

Eunice Yoon

Mentors: Chiara Daraio, Eleftheria Roumeli, and Paolo Celli

Professor Daraio's research group at Caltech has made significant progress in optimizing mechanical properties by tuning the designs and customizing materials of 3D printed structures. This project specifically explores the benefits of exposure to UV light. Using a stereolithographic 3D printer, many lattice structures were printed using both the Kelvin unit cell as well as the standard cube unit cell. Using the Instron testing machine, the strain and load of each structure is measured and analyzed. The preliminary research using the Kelvin lattices showed that the elastic modulus of structures cured for sixty minutes were about double that of non-cured structures. For the second part of this project, we will continue to characterize the effects of UV exposure on bulk structures and cubic lattice structures as well. Finally, an additional test of wave speed in water through the materials will be conducted. This will be a new method of calculating the elastic modulus, to help in the study of elasticity and stiffness in the printed structures. Designing and experimenting materials in this manner result in the fabrication of structures with favorable mechanical properties.

Investigation of Transition Mechanics in Gaseous Fluidized Particle Beds

Arthur Young Mentor: Melany L. Hunt

Experiments in a fluidized powder rheometer indicate transition behavior dependant on fluidization velocity and rotational speed. Modifications to the rheometer to facilitate pure liquid experiments were made, followed by experiments with Newtonian liquids that confirmed the existence of transition to Taylor Vortices in the short aspect ratio geometry of the rheometer. Shear stress measurements were taken of the glass particle bed following incipient fluidization that indicate a pseudo-laminar flow regime not unlike Couette flow, prompting an analysis using a modified Krieger-Dougherty viscosity model suitable for gaseous particle fluidization.

Visualizing Data From Direct Numerical Simulations of Turbulent Flows to Observe Effects of Varying-Phase Opposition Control

Christine Yu

Mentors: Beverley J. McKeon and Simon S. Toedtli

Understanding turbulence allows for design of better controllers for drag reduction, saving both energy and money. Therefore, we want to study varying-phase opposition control, a form of feedback flow control that detects and suppresses streamwise vortices through blowing and suction at the wall. However, due to their complex nonlinear interactions, creating accurate, comprehensive models of these flows is challenging. Though resolvent analysis, a low-order model using only the most relevant scales and information, successfully models the flow, the physical mechanisms from the model predictions are difficult to understand. This project approaches turbulence computationally and involves running direct numerical simulations (DNS) to obtain data about turbulent flows and varying-phase opposition control. To more easily study the physical mechanisms in turbulence that are difficult to identify by simply looking at raw data, we visualized aspects of the flow like the streamwise velocity fields, which appear drastically different under control with varying phases. Our visualizations show that changes in phase greatly impact the predictions of more efficient models, such as resolvent analysis, and work on methods to decrease drag and reduce transportation energy consumed in vehicles and pipes.

Autonomous Flying Ambulance: Mechanical and Control Systems Development

Evan Yu

Mentors: Soon-Jo Chung and Xichen Shi

The Autonomous Flying Ambulance is a UAV being developed to provide efficient patient transport in an increasingly complex urban landscape. Its unique configuration of wings and propellers enables the exploration of novel flight control methods as well as the ability to be repurposed for other tasks that require flight efficiency and maneuverability. The immediate goal of this project is to develop a scale model of the ambulance capable of demonstrating proficient, long distance, unmanned flight. We improved upon the existing model, an aerodynamic testing platform, to expand its mechanical and flight capabilities and incorporate autonomous control. These updates include improved structural integrity, heavily increased storage capacity for electronics and payload, and additional mechanical systems. Upon fabrication of the aircraft, we will begin implementation and testing of our experimental control system.

Supersingular Primes: A Computational Approach

Qiyao Yu Mentor: Dinakar Ramakrishnan

Prime numbers *p* such as 2,3,5,7,13, 37, 691 etc. are the indivisible building blocks of number systems, somewhat analogous to quarks for atoms. Primes are mysterious and possess unexpected properties. One way to study them is to consider sequences $S = \{a_2, a_3, ..., a_p, ...\}$ with elements indexed by primes *p*. The most important of such sequences are those defined by elliptic curves *E* or Fourier coefficients of modular forms *f* (of some weight *k*). We call *p* supersingular for *S* if *p* divides a_p . In this project, we find supersingular primes for the sequence *S* consisting of Fourier coefficients of newforms *f* at level N = 5, 7 and even weight *k*. To ensure computational efficiency, when k = 4, we express *f* in terms of products of Eisenstein series and obtain explicit formula for reduction modulo *p* of a_p . Supersingular primes up to 5*10^7 are found to be extremely rare at k = 4 for both levels. The number of such primes found are contained by the theoretical upper bound conjectured before. Within a fixed level *N*, we also look into the change of the number of supersingular primes as weight *k* increases.

Study of WecA and Mammalian Channels Expression in E. coli Strains Optimised for Expression

Katarzyna Joanna Zator Mentor: William M. Clemons

Integral membrane proteins (IMPs), proteins which spend their lives in cellular membranes are critical for cellular physiology and homeostasis; they form the largest class of drug targets. Their cellular production requires the additional steps of targeting to and insertion into the membrane; this additional complexity is thought to underlie their low success rate related total cost of production and limits research of the whole class of molecules. To aid in their study, i.e. purification, crystal structure determination, binding assays, drug screening, we seek to develop solutions to improve membrane protein expression.

E. coli has been modified into various strains optimised for protein expression in different ways; we seek to compare their relative efficacy across a set of target IMPs. WecA proteins from different bacterial species have been selected for testing along with human and mouse membrane proteins. Each gene sequence has been optimized for expression using the new IMProve algorithm, a data-driven approach to predict membrane protein expression. Thus, a series of wild-type and optimised sequences have been tested across bacterial strains commonly used for expression. Their expression and simultaneously their ability to fold properly are measured through GFP fluorescence, total and per cell, and SDS-PAGE gel band quantification with Coomassie Blue.

Modeling N_2 Binding at Belt Fe Sites of FeMoco With a Carbon-Bridged Diiron Complex

Matthew Zeitlin

Mentors: Theodor Agapie and Charlie Arnett

Nitrogenase enzymes are used by microorganisms for converting atmospheric nitrogen to ammonia, a reduction which occurs at a unique active site, the carbide-containing iron-sulfur cluster called the iron-molybdenum cofactor (FeMoco). However, while the resting state structure of FeMoco has been characterized, the mechanism by which nitrogen binds and is reduced is poorly understood. With recent spectroscopic data implicating an $Fe_2(\mu-S)$ site as crucial to FeMoco function, we have synthesized a novel ligand featuring a mesoionic imidazolate donor to bridge two iron centers, allowing us to evaluate the feasibility of binding nitrogen at a bridged position in a $Fe_2(\mu-S)$ model. Initial results demonstrate the ability of this new ligand scaffold to support well-defined bimetallic complexes and work remains ongoing to access a $Fe_2(\mu-S)$ motif on this ligand scaffold.

A Network Approach for Predicting the Stability of Place Cells

Hanwen (Lily) Zhang Mentors: Carlos Lois and Walter Gonzalez

The dynamic aspect of brain representation is gaining more and more attention as long-term recording of single neurons become possible with calcium imaging. Our study focuses on place cells, which are neurons that fire at particular locations in space. It has been shown previously that the place cell population participating in the representation of the same environment or spatial task changes from day to day. Yet the factors contributing to the stability of single place cells remain unknown. Our study found that the place cell population is less dynamic than previously reported. Furthermore, from the correlation network constructed from pairwise correlation between neurons, we show that place cells with high influence in the network, measured by eigencentrality, are more likely to be stable for many days. We seek to show that the states of these high centrality place cells can be used to predict the states of other neurons in the network and that their stability is crucial to maintaining the structure of the network. Our results provide valuable insight into the dynamical properties of brain networks and could potentially apply to many other brain areas.

Investigating Protein Depletion in Mouse Embryonic Stem Cells via the Auxin-Inducible Degron System

Isabella Zhang

Mentors: Mitchell Guttman and Joanna Jachowicz

The plant hormone auxin can be used to induce degradation of various proteins in plants. When the auxin-inducible degron (AID) system is transplanted into other eukaryotic species, it allows the rapid depletion of a specific protein in the presence of auxin. Auxin binds to the F-box transport protein TIR1 and promotes interaction between the AID degron of the target protein and TIR1, which leads to the degradation of the protein by proteasome. The AID degradation system allows for conditional, reversible depletion of a selected protein, making it a useful tool for analysis of genes that are essential to cell survival. To implement this system in mouse embryonic stem (mES) cells, plasmids containing the AID domain and the GFP reporter gene are transfected into mES cells expressing OsTIR1. This study examines the effects on GFP expression and the depletion time of tagged proteins in the presence of auxin.

Implementation of Zernike Phase Mask Sensor on the Vortex Optical Demonstrator for Coronagraphic Applications (VODCA) Test Bench

Manxuan Zhang

Mentors: Olivier Absil and Dimitri P. Mawet

As part of adaptive optics systems, non-common path aberrations (NCPA) occur due to manufacturing imperfections or distortions due to mechanical mounting with excessive pressure. The calibration and correction of NCPA is important as it can lead to significant improvements in performance. An implemented Zernike phase mask allows the detection of the wavefront on the Vortex Optical Demonstrator for Coronagraphic Applications (VODCA) Test Bench by applying a shift of $\pi/2$ to the wave, which converts the phase aberrations into intensity variations. Centering techniques such as using iterative minimization of Zernike coefficients have been employed to ensure the accurate measurement of the wavefront. The relationship between measured Zernike modes (using the Python tool pyZELDA) and the Zernike modes generated with the bench's deformable mirror was determined. With both of the above, the final goal is to create a simple and quick process to produce a flat wavefront using the phase mask for detection and the deformable mirror for correction. With a more accurate wavefront sensing solution, the performance of the VODCA Test Bench can be increased, which would lead to a better understanding of the behavior and intrinsic limits of Annular Groove Phase Masks.

Traffic Noise Recorded By the Optical Fiber Network in Pasadena

Shengxing Zhang Mentor: Zhongwen Zhan

As one of the main noises in the city, traffic noise plays an important role in urban seismology. Before we apply traffic noise to study geophysical issues, it is important to understand its pattern. A new seismic recording approach, distributed acoustic sensing (DAS), provides adequate data of traffic noise. In this project, my work is to use GPU to accelerate the calculation of Fast Fourier Transform (FFT) and develop tools to process large amounts of DAS data quickly. I finally need to get a 4-D array whose four dimensions are frequency, time, channel number and power spectrum density. Using some interesting cartoon to show the variation and pattern of traffic noise from the four directions and introduce the seismic observations and results to the public in a vivid way.

Developing New Viscosity Index Improver Molecules With Evolutionary Algorithm

Shuhao Zhang Mentors: William A. Goddard III and Andres Jaramillo-Botero

Lubricants are essential for the proper functioning of automotive engines. In order to adjust rheology properties, especially viscosity of lubricant used in automotive engines, series of viscosity index improver (VII) were developed. However, existing commercial additives cannot satisfy all sort of requirements, especially high-performance engine in special circumstance. In addition, due to the lack of a systematic method, the development of new additives are getting more difficult. We hereby report series of new high-performance VII molecules developed by evolutionary algorithm. According to the molecular dynamic simulation results, these additives can strongly enhance the shear-thickening properties of alkane based oil. Also, the method showed in this article can inspire the future development of new additives or even other molecule engineering researches.

Selection of AAV Variants for High Productive Efficiency

Xinyuan Zhang Mentors: Viviana Gradinaru and Xiaozhe Ding

Adeno-associated virus (AAV) is a small, nonenveloped virus that was adapted more than 30 years ago as a gene transfer vehicle. A wild-type AAV genome expresses 8 proteins in total, which are Rep78, Rep68, Rep52, Rep40, three structural Cap proteins (VP1, -2 and -3) and the eighth one, assembly-activating protein (AAP), which kept undiscovered until 2010 and was reported to stablize Cap poteins and active capsid assembly. It is reported that the production of AAVs can hardly meet the demand for it either for laboratory or clinical trials. The aim of this

project is to obtain AAV with higer productive efficiency with rounds of evolution of AAP. Our experiment shows that high-dose of AAP can increase the yield of virus to a certain degree. As there is no structural information of AAP, I use error-prone PCR to generate a library of AAP, and then use a 3-plasmid system to produce AAV. For each round, the produced AAV are collected and used to infect cells, and I will pick out enriched variants by sequencing and use these candidates as the templates for next round of evolution.

Profile Ssa1's Substrates in Membrane Protein Targeting With Native Pulsed-SILAC

Yuanjin Zhang Mentors: Shu-ou Shan and Hyunjo Cho

For membrane proteins, before arrival at the target membrane, improper exposure of hydrophobic transmembrane domains (TMDs) in the cytosol could lead to rapid and irreversible aggregation of membrane proteins. This disrupts the targeting process and causes mislocalization of the membrane proteins. Recently, Ssa1, a yeast cytosolic Hsp70, has been proven to be an essential part in conserved guided entry of tail-anchored protein (GET) pathway, capturing newly synthesized tail-anchored proteins(TAs) in a soluble form and transfer them to the next step. We wonder if Ssa1 is also responsible for protecting other kinds of membrane proteins, especially mitochondrial and ER proteins, in a soluble form during targeting. To profile Ssa1's substrates in membrane protein targeting, we used native pulsed-SILAC to quantitatively analyze the level of newly synthesized mitochondrial and ER membrane proteins in both Ssa1^{wt} and Ssa1^{ts} yeast strains. During labeling time period, Ssa1 in Ssa1^{ts} yeast cells is inactivated and leads to the failed targeting for its newly synthesized membrane protein substrates. Furthermore, we will characterize potential Ssa1 substrates based on their structure to further explore Ssa1's role in membrane protein targeting.

Extraction and Analysis of Data From Spectra of Young Stellar Objects

Yuling Aileen Zhang Mentor: Lynne Hillenbrand

Before a star becomes a member of the main sequence, it is a dynamic and highly active young stellar object. Such an object has unique spectral characteristics that reflect its intrinsic characteristics and the physics that drives its formation and evolution. To extract this information from a YSO spectrum, this project improved upon an iPython codebase to analyze spectra taken by the HIRES spectrograph. With improvements, the analysis module can identify object spectral type and radial velocity through cross-correlation to a standard star. Additionally, it can perform fits to absorption lines and measures of line width, as well as performing data quality measures. A group of suspected young stellar objects was analyzed using the improved code, and the resulting relations between spectral type and radial velocity for selected areas of the spectra were used to identify group characteristics and possible non-members of the group.

The Fundamental Implementation of Artificial Neural Networks With FPGA

Zheng Zhang

Mentors: Azita Emami and Benyamin A. Haghi

Machine learning algorithms are widely used in today's real world medical applications. One of the popular algorithms that have shown promise in this field are neural networks. CPUs/GPUs are not good choices to do the inference of artificial neural networks like CNN or RNN in implantable medical applications. Instead, some dedicated hardwares, like FPGA and ASIC are more suitable for their higher efficiency and lower power. For Implementing a whole neural network, doing the basic mathematical operations which are frequently used in neural networks are needed. Therefore, the first step of the program is chosen to implement the matrix multiplication and the activate function – tanh - with FPGA. The matrix multiplier could be implemented with either DSP slices or look-up table and flip-flops in FPGA. The activate function could be implemented with either linear fitting method or look-up table with block RAM. The fundamental implementation of matrix multiplier and activate function has been finished so far. The next step is to implement a complete neural network for inference.

SignSGD With Majority Vote in Large-Scale Deep Learning

Jiawei Zhao Mentor: Animashree Anandkumar

The large-scale distributed deep learning system is constrained by the cost of communication between machines. Therefore, we proposed a novel distributed deep learning system with signSGD which can reduce the cost of communication between machines and accelerate convergence performance. The system compresses the size of the gradient which can mitigate the pressure of communication. To test its performance, we implemented with the Amazon p3.16x instances on ImageNet and CIFAR-10 datasets. The result shows that our system is able to reduce the cost of communication and accelerate convergence performance efficiently.

Modeling a Sulfur Cogen Process Plant to Produce Green Hydrogen and Sulfuric Acid

David Zheng

Mentors: Michael R. Hoffmann and Cody E. Finke

Greenhouse gas emissions are deeply entrenched across diverse industrial sectors including energy, commodity chemicals, transportation fuels, agriculture and others. Moving towards a low or zero CO₂ future requires technology that not only replaces traditional industrial processes but also produces products at similar or reduced prices relative to conventional methods. Hydrogen is a commodity chemical that is widely used across industries including for petrochemical refining, fertilizer production, energy storage, and transportation fuel. Currently, hydrogen gas is produced via steam reforming methane (SMR), which produces 1.5% of the world's annual CO₂ emissions. The only commercially available CO₂ free hydrogen technology is >4X the cost of SMR hydrogen. In my research group, we propose to cogenerate hydrogen and sulfuric acid (second most consumed commodity chemical) to cost effectively produce green hydrogen. This process is promising because it is electrochemical (i.e. can us solar or wind energy) and the energy requirement (~22 kWhr/kgH₂) is smaller than both SMR (~27 kWhr/kgH₂) and water electrolysis (~55 kWhr/kgH₂). By designing a plant and using sulfur oxidation energy data, industrially quoted plant prices, and an algorithm for estimating levelized cost of hydrogen, we determined the cheapest price of hydrogen made by this process and compared it to SMR.

Real-Time Three-Dimensional Reconstruction With GPU Accelerated Structure From Motion Ruoyun Zheng

Mentors: Soon-Jo Chung and Alexei Harvard

Three dimensional reconstructions of an object from two dimensional images are primarily a post-production method used to create models of a region, potentially aiding with autonomous navigation. However, in order for such reconstructions to be useful, they must be conducted in real or near real time. Typically, a structure from motion method is used to calculate the reconstruction by tracking common features throughout images. To construct a map that can be updated in real time, we propose a GPU accelerated version of structure from motion to aid with an onboard reconstruction of an object and potential autonomous navigation benefits. Given some number of swarm drones equipped with cameras, we can use the images taken to produce reconstructions on board.

Enzyme-Catalyzed a-Amino C-H Functionalization Enabled by Directed Evolution

Andrew Zhou Mentors: Frances Arnold and Kai Chen

Enzymes can catalyze chemical reactions with high efficiency and exquisite selectivity in an economic and environmentally-friendly manner. Directed evolution - which mimics natural selection through multiple rounds of mutagenesis and selection - enables natural enzymes to perform unprecedented and unnatural reactions. Through multiple rounds of site saturation mutagenesis and HPLC screening, a cytochrome P450 variant – harbored in *E. coli* – was evolved to catalyze carbene insertion into an α-amino carbon–hydrogen (C–H) bond with high reactivity and stereoselectivity. The discovery of this catalytic system using an engineered cytochrome P450 provides a cheap and efficient way to generate a new class of structural motifs, which could have major implications in catalysis research and pharmaceutical synthesis.

Modular Forms and Their Finite Analogs

Daniel Zhou Mentor: Zavosh Amir-Khosravi

Modular forms are complex functions defined for the upper-half plane. However, an interesting idea pops up when a modular form approaches a rational number on the real line. In this case, the value of the modular form blows up to infinity, but still satisfies a transformation formula under the modular group, allowing a new definition of a finite modular form. We are analytically continuing the values of modular forms onto the real line for rational numbers only. In doing so, we define a finite analog of a modular form, defined for all rational numbers. In this project, the finite analogs of Eisenstein series, a family of modular forms, are explored. This method of defining a modular form on rational numbers worked for Eisenstein series, but not for cusp forms. Future work could include looking into a similar definition for Cusp forms and/or half-weight modular forms.

Building a Magneto-Optical Kerr Effect (MOKE) Setup

Preston Zhou

Mentors: Jagadeesh S. Moodera and David Hsieh

To characterize magnetic samples, we have built a MOKE setup to measure the Kerr effect in magnetic materials. The Kerr effect is the polarization rotation of reflected light off of a magnetized material. Our MOKE setup measures the Kerr effect with a B-field perpendicular to the film, also known as the polar Kerr effect. The reflected beam has a rotated polarization principle axis and is ellipsoidally polarized. Our high-sensitivity, low-noise MOKE setup was built to deliver fast measurements and endure for many years.

Solving the Cis-Activation Effect in Population Control Circuit

Junqin Zhu Mentors: Michael Elowitz and Yitong Ma

Population control is important for many types of cells, and a synthetic population control circuit in mammalian cells would be beneficial for engineering multi-cellular bio devices. An on-going project in our lab is to construct such a population control circuit in mammalian cells. In this circuit, auxin, as a representation of the population size, is produced intracellularly and should diffuse into the media and be sensed by other cells. However, we observed that in our current design, auxin does not diffuse efficiently and accumulates inside the cell (cis-effect), preventing population dependent regulation. We examined two possible ways to solve this effect. One is to secrete the auxin-producing iaaH enzyme outside of cell so that auxin is produced extracellularly. However, after screening different secretion tags, we were unable to find one that can successfully secrete iaaH outside. The second approach is to use auxin transporters to pump out the auxin. Preliminary data show that expressing PIN2, a plant auxin pump, can alleviate this cis-activation effect. Though more detailed characterization of this PIN2 expressing line is required, we are optimistic that this PIN approach will provide us a feasible way to overcome cis-effects and results in a functional population control circuit.

Investigation of Motivational Neural Circuits Underlying Drosophila Social Behaviors

Maxwell Zhu

Mentors: David J. Anderson and Eric Hoopfer

The neural circuitry underlying social behaviors like mating and aggression is poorly understood, especially with regards to circuits that might motivate an animal to engage in these behaviors. Previous research by Hoopfer et al. has identified a cluster of interneurons in the male brain, called P1 neurons, that, when artificially activated, not only cause displays of courtship and aggression but also induce a lasting preference for stimuli paired with activation of these neurons. This suggests that these P1 neurons might be part of a circuit motivating social behaviors. To characterize this preference behavior, we tested to see if this behavior could override another innate behavior – gravitaxis – and if flies could learn to self-stimulate in order to induce activation of P1 neurons. Then, P1 subpopulations were assayed to determine if courtship, aggression, and preference behaviors might be located in distinct clusters. Finally, we screened nineteen additional fly lines to look for other social behavior circuits that might have a valence and therefore a possible motivational component. Together, the data suggest that social behaviors such as aggression and courtship may not be completely hard-wired but may be adaptable via stimuli association and reward learning.

Inducing Transposable Element Activity in Dalotia coriaria

Shiyun Zhu

Mentors: Joseph Parker and David Miller

The symbiotic relationship between certain rove beetles and their corresponding ant species may be an important model system that can be used to understand symbiosis, especially from an evolutionary perspective. This study focuses on inducing mutations in a free living rove beetle *Dalotia*. The method we have chosen is to use RNA interference on the protein PIWI. This protein normally suppresses transposable element activity and knocking it down through RNA interference will lead to more mutations. Once the method has been proven to be able to induce more transposable element activity, we will need to ensure that the beetles are still fertile and will move on to introducing the mutant beetles to ants. This step will allow us to further explore the symbiotic traits within ants through artificially breeding beetles to become symbiotic with the ants, and help to show that evolutionarily speaking, these rove beetles are predisposed to develop a symbiotic relationship with ants.

TheseusNet: Machine Learning in Predictive Diagnostic Imaging of Chronic Obstructive Pulmonary Disease

Zimo Zhu

Mentors: Albert Hsiao, Tara Retson, and Mathieu Desbrun

Chronic obstructive pulmonary disease (COPD) is the 4th leading cause of death in the United States. The heterogeneity of COPD can make it difficult for clinicians to diagnose. We have chosen to investigate the viability of machine learning and deep convolutional neural networks (CNNs) in classifying patients and as a diagnostic tool. These neural networks can learn the characteristics and image features that optimally differentiate between classifications over a population of training data, using a process of backpropagation. We developed TheseusNet, a 2.5D convolutional neural network architecture implementing multimodality, an inception module, and exclusively average pooling, for increased detection of subtle details. TheseusNet was trained on 253 computed tomography scans and assessed for their predictive performance through r-squared coefficient of determination for regressions and receiver operating characteristics (ROC) for classifications. When classifying COPD, TheseusNet averaged an

area under ROC curve of 0.785. It also performed notably in the regression of total lung capacity (TLC), where it averages an R² coefficient of 0.6587. Our findings show that TheseusNet has achieved moderate success at the difficult task of COPD diagnosis. Beyond classification, it also performs well in extracting valuable information regarding lung function and capacity from CT, an important precursor to the correct diagnostic evaluation.

The Nature of Mid-Infrared Flares From Nearby Normal Galaxies

Zhuyun Zhuang Mentors: Shrinivas Kulkarni and Lin Yan

The nature of the Mid-Infrared (MIR) flares of the galaxies is still under debate. It can be interpreted either as the dust echo of tidal disruption event (TDE) or the heating dust caused by the active galactic nuclei (AGN) that just turned on. In this work, we study the multi-epoch optical spectra, taken by the Hale/200-inch (P200) Telescope in Palomar Observatory, of a sample of galaxies in the phases of MIR flares. Compared with the SDSS spectra taken before the MIR flares, some of the galaxies has found to change dramatically in the optical while the spectra of the rest remain unchanged, suggesting different mechanisms may be responsible for the MIR flares. Through measuring the net emission line flux changes, we can have a better understanding of physical processes behind such a phenomenon.

Optimizing CMS Event Simulation Using Evolutionary Computing Techniques

Alexander Zlokapa

Mentors: Maria Spiropulu and Jean-Roch Vlimant

Existing tunes for Monte Carlo event generators are commonly the result of a time-consuming manual effort that requires extensive expert knowledge. Since the discovery of new physics relies on finding discrepancies between simulated and experimental data, it is crucial to tune event generator parameters to minimize error against existing data, thus increasing the visibility of new phenomena. An automated framework is proposed in which existing PYTHIA 8 tunes are improved by evolutionary algorithms, enabling tuning on both electron-positron and proton-proton events from LEP, SLD, and CMS experiments. We compare the performance and evaluation time of several evolutionary algorithms and benchmark them against Bayesian optimization, yielding novel parameter settings that fit experimental data better than existing manual tunes. Furthermore, the easily parallelizable nature of evolutionary algorithms makes the tuning process computationally inexpensive, allowing far more rapid tuning than before. Ultimately, these results show that the combination of evolutionary algorithms with existing tunes can speed up the tuning process of future event generators, as well as providing a general yet effective method for creating detector-specific tunes.

Enzymatic Construction of Chiral Organoborons

Arjun Zutshi Mentor: Frances H. Arnold

Organoborons, compounds that contain carbon-boron bonds, have many applications in the scientific world.¹ Their diverse reactivity profile and excellent functional group compatibility make them an interesting class of compounds to study. Organoborons have been extensively explored as drugs against all disease categories, as biological probes, and as carriers for boron neutron capture therapy (BNCT).²⁻⁴ Currently, there are many chemical reactions that produce organoborons; however, these reactions are limited in efficiency, sustainability, and flexibility. Due to these limitations, the use of boron-based molecules in drug design and discovery have been heavily impeded. Very recently, the Arnold group has found that a cytochrome c protein from the thermohalophilic bacterium Rhodothermus marinus (Rma cyt c) could mediate the formation of C-B bonds via carbene insertion into B-H bonds of Lewis-base borane complexes, specifically to create a-borylesters.⁸ Through several rounds of directed evolution, a powerful approach to alter protein properties via successive rounds of random mutagenesis, Rma cyt c has been engineered to catalyze synthesis of organoborons with enantiomeric ratio up to 99:1 and turnovers over 400-fold greater than chemical catalysts for the same class of reaction. My SURF project focused on expand this enzymatic activity to include other important organoborons that possess high potential for drug development via directed evolution. These research endeavors will push frontiers of multiple research fields including protein engineering, synthetic chemistry, and biochemistry and lead to important applications of organoborons in disease diagnosis, treatment, and prevention. By developing a broad array of unprecedented enzymes for organoboron synthesis, this research will provide a paradigm for bringing new chemistries to life.



WAVE Fellows Program

> W A V E

Synthesis of 1,3-Disubstituted Isoquinolines for the Development of Asymmetric Isoquinoline Hydrogenation

Jake Aquilina

Mentors: Brian M. Stoltz, Fa Ngamnithiporn, and Eric Welin

Nitrogen-containing compounds are biologically relevant molecules, as they are prevalent motifs in pharmaceuticals and natural products. In spite of many available syntheses of these motifs, controlling the stereochemistry of these compounds is still a challenge. Asymmetric hydrogenation can be used as a synthetic method to produce these chiral saturated heterocyclic compounds such as tetrahydroisoquinolines (THIQs). To further understand the scope of this transformation, a set of decorated 1,3-isoquinolines (IQs) will be synthesized using a three-step general sequence consisting of N-oxidation, C–H Fagnou coupling, and Boekelheide rearrangement. The key C–H coupling proved to be challenging, thus we have optimized this transformation by exploring different reaction parameters, including ligand, base, additive, temperature, reaction setup, and catalyst loading. Once these IQs are successfully synthesized, we plan to initiate an investigation of their reactivity under our asymmetric hydrogenation reaction conditions.

Machine Learning Inspired Methods for Quantum Physics

Oscar Rodrigo Araiza Bravo

Mentors: Manuel Endres, Evert van Nieuwenburg, and Brian Timar

The study of quantum many-body systems is a cornerstone to our insight into the fundamentals of quantum matter. Understanding these systems promises to enable realizations of computational systems that outperform existing classical computers. However, finding a solution to a many-body problem requires an exponential amount of computational resources, and thus very few systems are analytically solvable. Recent results in Information Theory and Machine Learning have shown the predictive power of shallow neural networks (SNN) at representing low energy states of physical systems. Our work's ultimate goal is to test the efficiency of SNN in encoding the dynamics of 2D quantum many-body systems which so far has eluded most attempts with current numerical methods. Here we present the motivation and theoretical foundations behind the SNN approach. We also show the power of Restricted Boltzmann Machines (RBMs), a kind of SNN, to solve one and two dimensional static problems. In particular, we use RBMs to analyze one and two-dimensional models for finite-size, long range interacting atomic systems, called Rydberg chains, by presenting accurate predictions of quantum phase transition.

A Tail of Three Isoforms of the Hedgehog Protein Jean Badroos

Mentors: Alison Ondrus and William Goddard

The Hedgehog signaling pathway is known for its link to medulloblastoma, basal cell carcinoma, and many more cancers. The human Sonic, Indian, and Desert hedgehog proteins in this pathway (SHH, IHH, and DHH) have two identified domains: the C-terminal and N-terminal domains. The tail segment of the C-terminal domain, the sterol recognition region, is responsible for transferring cholesterol in an intein-like autoclevage event that leads to sterol attachment at the end of the N-terminal domain and starting the pathway. Despite the importance of how that reaction occurs on a molecular level, the C-terminal structure has never been solved or predicted. By cloning the C-terminal domain of SHH, IHH, and DHH into a vector backbone that can be manipulated by biochemical properties for protein purification, we are using high-throughput assays to obtain crystals of each of the proteins for X-ray structure determination. Additionally, by using molecular dynamics and docking sterols to the C-terminal domain with and without the addition of a membrane, docking the full—length protein, and performing calculations under different solvent conditions, we will determine a reliable prediction structure. Ultimately, visualization and modeling will clarify more about the function of the Hedgehog proteins and enable more specific drug development.

Sustainable and Accessible C-H Bond Oxidation by High-Valent Iron-Oxo Catalysis

David A. Cagan

Mentors: Harry Gray, Brian Stoltz, and Julian West

The development of methods for efficient and accessible oxidative carbon hydrogen (C-H) bond activation via simple, cost effective catalysts would be a valuable tool for organic synthesis. Because of the typically inert nature of the C-H bond, this sort of activation is often unattainable without expensive or environmentally hazardous materials. We have taken initial steps towards building upon and exploring the possible uses of iron catalysts for oxidative C-H bond activation by testing a variety of complexes with the hopes of stabilizing the formation of a high-valent iron-oxo (Fe^(IV)=O) species that would be the oxidizing agent for the activation of the aliphatic C-H bonds. Using mild conditions and room temperature stirring, we have found oxidative yields of up to 23% versus cyclooctane, thus demonstrating the viability of iron catalysts for C-H bond activation.

Implementation of Reaction Wheels and Balancing for Spacecraft Simulators

Karen Chen

Mentors: Soon-Jo Chung and Yashwanth Nakka

Spacecraft simulators are used to research spacecraft control and allow for rigorous ground testing of new features, thereby reducing risk to future space missions. Developing a faithful representation of spacecraft dynamics is an engineering challenge because strong forces that are present on Earth and not as present in outer space disrupt our desired simulation conditions. Our design at the Aerospace Robotics and Control Lab for upper stage attitude control consists of a mass balancing system and reaction wheels. We have installed four reaction wheels for redundancy and are implementing both a passive and active mass balancing system for improved control. This project focuses on the mechanical design aspect of upper stage balancing. Future work includes final assembly and testing on all five of our spacecraft simulators, and hopefully implementation on spacecraft.

Designing and Manufacturing Multi-Stable Origami Structures for Reconfigurable Antenna

Misganaw Demissie

Mentors: Sergio Pellegrino and Yang Li

Origami deployable structure mechanism is widely used for engineering purpose to resolve a problem in aerospace, medicine and for other engineering design. We use the origami mechanism to make a smooth and straightforward process of assembly and to manufacture a multi-stable configuration origami structure for the reconfigurable antenna. Multi-stable structures have been proposed to reduce that actuation complexity. The challenge is the transition of the mathematical problem paper thin origami material into engineering material and applying the origami principle to engineering design. To resolve this problem, we are using Laminar Emergent Mechanisms (LEMs) to develop a surface that applies the origami technique to thick materials to have a tremendous elastic range of motion. However, complex origami mechanisms have many degrees of freedom that are difficult to control and actuate. My project focused on using the LEMs method manufacturing different 2D hinges from the spring steel and glass fiber and testing the material properties to identify the elastic range and the maximum rotational angle to make that have a three stable origami configurable structure.

UAV Altitude Sensing Through the Utilization of a Two-Axis Gimbal System

Sergio Esteban

Mentors: Aaron Ames, Thomas Gurriet, and Andrew Singletary

An integral aspect of autonomous unmanned aerial vehicles (UAVs) is altitude detection. On all accounts, accurate altitude sensing will cultivate a more robust safety framework on autonomous flying systems. To support current UAV safety research, a gimbal system with range sensors was developed to strengthen UAV localization. On this gimbal system, altitude sensing is achieved by using an ultrasonic, LIDAR, and barometric sensor. To obtain accurate height data, the ultrasonic and LIDAR sensors must be kept pointing directly towards the ground during perturbations in UAV flight. A two-axis gimbal system was designed, manufactured, and programmed to facilitate the dynamic platform stabilization of the sensor printed circuit board during real-time flight. This system nullifies roll and pitch angles from UAV maneuvers to maintain accurate altitude acquisition.

A SLAM-Enabled Vision System for Semi-Autonomous Navigation in Bipedal Robots

Michael Estrada

Mentors: Aaron Ames and Jake Reher

One of the primary motivations for studying and developing Bipedal Robots is their ability to locomote similar to humans, bipedal mammals, or birds. This makes them excellent candidates for applications that require the robust navigation of cluttered, or even dangerous, human environments. Some examples of this include search and rescue operations in burning or otherwise structurally unsound buildings and inspection of areas with levels of radiation unsafe for humans. Despite the physical aptitude of bipedal robots to navigate these environments, some degree of environmental awareness and autonomy is ideal. With this work, we propose a vision system that can map the environment of a walking bipedal robot as a point cloud and continuously estimate its location, orientation, and velocity relative to its environment. We demonstrate the system on a network of three computers that are mounted to a Cassie bipedal robot. Robot Operating System (ROS) and the User Datagram Protocol (UDP) are used as communication layers over the network and a Simultaneous Localization and Mapping (SLAM) algorithm is used to perform the environmental analysis. The system is further operable in monocular or stereo camera configurations to minimize dependence on specific hardware.

Design and Development of Optimal Leg Mechanism With Enhanced Jumping Capability

Joshua Fernandez

Mentors: Soon-Jo Chung and Alireza Ramezani

Research in walking and jumping robots has emerged to give robots better ability to travel rough topography. Walking and jumping robots can maneuver obstacles that wheeled robots would not be able to and can be more energetically efficient than flying robots. Leonardo (Leg on Aerial Robotic Drone) is a walking and jumping robot

with flight capabilities that is intended for applications such as traversing dangerous terrain and celestial exploration. This project focuses on the development of the leg mechanism of Leonardo which enables the robot to locomote through walking and jumping. Optimized geometric parameters were implemented in the design to provide Leonardo with its maximum vertical velocity. Also, the leg design of LEO was updated to be geometrically strong, ensure smooth assembly, and include a brushless DC motor in series with a planetary gear box to provide high torques to drive LEO's legs. The new leg design was then 3D printed on a Markforged printer and reinforced with carbon fiber. After the leg was assembled, the design was tested as a monopod to evaluate its jumping capabilities.

Characterization of Complex Formation Between EMC2 and WNK1

Daniel Fuentes

Mentors: Rebecca Voorhees and Kurt Januszyk

Assembly of multi-subunit protein complexes is highly regulated to ensure production of stoichiometrically defined macromolecules. Regarding multi-subunit membrane protein complexes in the endoplasmic reticulum (ER), the stoichiometric regulation remains largely uncharacterized. As such, this project investigates the stoichiometry of a model protein complex called ER membrane protein complex (EMC). The EMC is composed of 10 subunits and plays an important role in protein insertion at the ER. Previous work in the Voorhees lab has demonstrated that unassembled EMC2, one of the soluble subunits of the EMC complex, is recognized by a short amphipathic helix at the C-terminus of a conserved kinase called WNK1. Further experiments are consistent with WNK1 playing a role in assembly of the EMC. Thus, a structural understanding of the binding domains for EMC2 and WNK1 will provide greater insight into the recognition of EMC2 by WNK1, and its putative chaperone activity. Characterization of the binding domains was investigated by mutating residues of the amphipathic WNK1 helix, followed by size exclusion chromatography to determine inhibition of complex formation. Preliminary results indicate that EMC2 and WNK1 wild type successfully form the complex. Future work includes testing the mutants, and detailed characterization of the binding domains by x-ray crystallography.

Freeze Casting of Porous Zirconia Through Sol-Gel

Graciela (Elizabeth) García Ponté

Mentors: Katherine T. Faber and Xiaomei Zeng

Shape memory materials experience diffusionless phase transitions through martensitic transformations where the material returns to its original phase after heat is applied (shape memory), or where it returns on its own (superelasticity). In ceramics, this transformation is optimized at high surface area-to-volume ratios, where cracking due to the transitions is reduced. Freeze casting is a technique used to make porous materials which have high surface area and low density. Sol-gel processing allows for good control over the fabrication of ceramic powders, and consequently, the microstructure. We propose that by combining sol-gel and directional freeze casting, a homogeneous, directional zirconia porous structure can be achieved. By controlling the chemical compositions of acetylacetone and water (Zr/AcAc/H₂O 1/0.1/7.5 molar ratio), and thus, balancing the processes of hydrolysis and polycondensation, a suspension was produced which was made into a porous foam by freeze casting. Freezing conditions at -30 °C yielded ceramic foams with minimal cracking, structures with micropores and 1-2 µm wall thickness. Ceramics sintered at 1500°C were found to have a higher grain density and larger grain sizes than those sintered at 1200°C and 1400°C. The mechanical properties were studied by compressing the sintered ceramics, and their correlation with the microstructure were explored.

Hindering Peptidoglycan Biogenesis Through Targeted Inhibition of MraY

Victor García

Mentors: William M. Clemons Jr. and Nadia Riera

Bacteria are remarkably capable of adapting their genome in response to environmental stress, most notably through horizontal gene transfer (HGT). HGT results in the integration of foreign genetic material into a recipient genome. This process can transform a commensal, symbiotic microbe into an antibiotic-resistant, virulent pathogen. The ever-increasing prevalence of multidrug-resistant bacteria renders current drugs ineffective and motivates the discovery of new antibiotics, through the exploration of novel protein targets. Since bacteria surround themselves with peptidoglycan, an essential and unique structural element in the cell wall. This structure and the protein machines involved in its synthesis, present promising drug targets. MraY (phospho-MurNAcpentapeptide-transferase) is an integral membrane enzyme responsible for catalyzing a critical step required in the biogenesis of peptidoglycan. In its absence cell fitness is significantly decreased leading directly to lysis, i.e. cell death. The details of MraY's molecular structure and interactions remain largely uncharacterized due to the widely appreciated difficulty in solving the atomic structure of membrane proteins. MraY protein was purified to a homogeneity and crystallized through vapor diffusion out of hanging drop and Lipidic cubic phase (LCP) methods. In screening forty-eight varying crystalizing conditions, four where successful in producing crystals which were shipped to beamlines 12-2 at the Stanford Synchrotron Radiation Lightsource. While the MraY crystals sent did not result in diffraction patterns current efforts lie in optimizing crystalizing conditions for conditions that resulted in crystal hits.

Alternative Mechanism to Sample Recurring Slope Lineae on the Surface of Mars

Jakqueline Granillo

Mentors: Joel W. Burdick and Amanda Bouman

Recurring Slope Lineae (RSL) are dark narrow lines discovered on the surface of Mars believed to be either water flows or grains of sand flowing downslope during warmer seasons. The desire to understand the composition and origin of RSL has led to the advancement of space technologies with the goal of finding evidence of life beyond Earth. Due to rovers' inability to reach these steep and rocky locations, this paper focuses on finding an alternative mechanism to deliver scientific instruments on a quadrotor aerial vehicle to further investigate these features. This paper talks about the design and development of an experimental setup which identifies the most efficient method of dropping a package, the best diameter of the anchor used to ensure the package is anchored, and the best shape of the package for stability purposes. Through experimentation, analysis showed that dropping or winching the package down is the best method for securing the scientific instrument on the RSL slopes. In addition, a pyramid-like shape with rubber outer surfaces will increase the coefficient of friction, minimizing roll and slip. Moving forward, the methods and package shape designed will be tested at the JPL Mars courtyard during field tests.

Fluid Feature Navigation With an Autonomous Underwater Vehicle

Maria Hernandez

Mentors: Beverley McKeon and Morgan Hooper

The goal of this project is to acquire and program an autonomous underwater vehicle for data collection that can actively respond to a fluid environment. Some major advantages of using autonomous vehicles are the efficiency and speed with which data can be collected. A robot has been purchased and assembled to serve as a tool in further research for the McKeon research group. The robot has passed leak tests and tests of the robot's full functionality are in process. In order to test the autonomy of the robot, a virtual environment will be used instead of a real physical fluid environment. The advantage of using the virtual environment is having more precise control of the flow the robot will encounter. When the project is completed successfully, the robot output will match what the robot is supposed to do when encountering certain fluid characteristics.

Quantum Teleportation Using Superconducting Nanowire Single Photon Detectors (SNSPDs) George Iskander

Mentors: Maria Spiropulu, Neil Sinclair, and Cristián Peña

A qubit, like the classical bit, is the fundamental unit in quantum communication. A qubit is a superposition between two states. Say Alice has a qubit which she wishes to transmit to Bob. Quantum mechanics stipulates that Alice can't make a measurement on this qubit, or it will collapse, and the information will be lost. So, how does Alice transmit this qubit to Bob? If Alice and Bob share an entangled state ahead of time, then transmission of this qubit can be achieved through light interference. This transmission of the qubit is called "quantum teleportation." Researchers in Calgary have successfully demonstrated quantum teleportation over a distance of 8 kilometers. Our research aims to show the feasibility of including repeaters, intermediaries between Alice and Bob who help along the transmission. We also aim to improve detector rates in the setup by using SNSPDs, detectors that can resolve individual photons, and which have been shown to achieve efficiencies of approximately 93%. Our setup is being built at Caltech, but will be shipped to Fermilab for the final experiment. Quantum teleportation shows promise in studying EP=EPR, a hypothesis that explains quantum entanglement through wormholes in general relativity.

Mechanisms of Chlorate Resistance in *Pseudomonas aeruginosa* Michelle LaJoie

Mentors: Dianne Newman and Melanie Spero

Pseudomonas aeruginosa is an opportunistic bacterial pathogen that can establish chronic infections in wounds and the lungs of cystic fibrosis patients. *P. aeruginosa* is also known to form metabolically heterogeneous biofilms. Cells on the biofilm exterior are more likely to access oxygen and show sensitivity to antibiotics while biofilm-interior cells may experience hypoxia and display tolerance towards conventional antibiotics. Previous work showed that chlorate kills antibiotic-tolerant cells in hypoxic regions of biofilms because chlorate targets populations that synthesize the anaerobically-induced nitrate reductase, Nar. Nar functions to reduce nitrate to nitrite, but can also reduce nontoxic chlorate to toxic chlorite. The goal of this work is to determine mechanisms of chlorate resistance in order to better characterize chlorate resistant while maintaining a functional Nar enzyme; we are currently attempting to evolve such strains. We have also isolated strains that survived chlorate exposure and are characterizing whether these chlorate resistant strains have Nar activity. Discovering that inactivating Nar mutations is the primary mechanism of chlorate resistance would provide additional support for chlorate use, as Nar is thought to support pathogen growth and survival in the host.

Simple and Disposable Nano-Engineered Laser-Scribed Electrodes for Anti-Cancer Drug Analysis

José A. Lasalde-Ramírez Mentor: Wei Gao

A simple, scalable and highly sensitive cyclophosphamide (CPA) sensor was developed via the direct deposition of the cytochrome P450 isoform, CYP3A4, onto laser-scribed graphene electrodes (CYP3A4/LSG). In this study, LSG electrodes are demonstrated as a potential matrix for biosensing applications due to their high surface area and exceptional electrochemical properties. The straightforward method of preparation of this sensor provides an innovative alternative for the scalable preparation of wearable biosensors. Moreover, the high sensitivity (22.25 nA/ μ M mm²) and linear range (0 to 80 μ M) of this sensor make it a prospective platform for the monitoring of CPA in plasma, saliva and sweat, of patients utilizing the anti-cancer drug.

Modifying Methods of Deconstructing Protein-Protein Interaction Networks to Enhance Interactome Screening

Angel V. Macias Mentors: Kai Zinn and Michael Anaya

Many biological processes are mediated by protein-protein interactions occurring in an organized manner in both space and time, often depicted as biological pathways. These pathways are frequently initiated by interactions amongst cell surface and secreted proteins. A screen of a subset of immunoglobulin superfamily cell surface proteins in *D. melanogaster* revealed a Dpr-DIP interaction network in which proteins in each subfamily selectively interact and are required for formation of synapses between photoreceptors and brain interneurons. The Dpr-DIP network contains a number of proteins lacking a known binding partner. The Bio-Plex Interactome Assay (BPIA) is a method for screening protein interactions that has proven to be effective through its efficiency (multiplexing) and sensitivity (high signal-to-noise ratio). Despite its advantages, the assay may still fail to detect weaker interactions. The aim of this study is to incorporate a self-assembling 60-mer bacterial lumazine synthase particle fused to a recombinant Protein A into the BPIA to enhance detection of weak binding interactions via avidity enhancement. Future studies will include a re-screening of the Dpr-ome and the Beaten Path-Sidestep interaction networks. Novel interactions may be investigated in genetic *in vivo* screens to understand their biological relevance, especially as it to pertains to nervous system development.

Constructing a Balanced Homodyne Detector for Low Quantum Noise Gravitational Wave Interferometry

John Martyn

Mentors: Andrew Wade, Kevin Kuns, and Aaron Markowitz

Achieving more efficient detection of gravitational radiation is a goal of contemporary experimental physics, as it will enable novel tests of general relativity and provide information on astronomical bodies that are difficult to observe through the electromagnetic spectrum. However, as gravitational wave interferometers increase their sensitivity, sources of quantum noise dominate over classical noise sources. Further reduction of noise requires gravitational wave observatories to use non-classical, squeezed states of light, in which the quantum noise of one quadrature is decreased while that of another is increased. A balanced homodyne detector can measure an arbitrary quadrature of light by mixing a weak signal with a strong source of light. This technique can be incorporated into interferometers to perform precise measurements using squeezed light. Since these highly quantum states are crucial to gravitational wave physics, numerous research labs seek to perform experiments with these detectors. The goal of this project is to construct the optical components and readout electronics for a balanced homodyne detector that may be used in various LIGO research labs performing experiments with non-classical light.

Nickel-Catalyzed Heterocycle Assembly via Intramolecular C-N Coupling

Joel Monroy

Mentors: Brian Stoltz and Marchello Cavitt

Modern pharmaceuticals are comprised of small molecules containing heterocyclic moieties. Facile methods for the development of such structures are of high importance since bioactivity can not readily be predicted based on structure alone. Synthetic methodologies are necessary to assist in the construction of heterocycles in an efficient, cost-effective manner. As an alternative to other less abundant and more commonly used group ten metals, nickel was employed to perform intramolecular C-N coupling of vinyl halide and aryl iodide sulfonamides to afford 2-methylene-1-tosylpyrrolidine and 1-tosylindoline, respectively. For 2-methylene-1-tosylpyrrolidine formation, 10 mol% Ni(COD)₂ and KO-*t*Bu (1.1 equiv.) in THF at room temperature afforded an 83% yield from the *N*-(4-iodopent-4-en-1-yl)-4-methylbenzenesulfonamide precursor. In 1-tosylindoline synthesis, the *N*-(2-iodophenethyl)-4-methylbenzenesulfonamide substrate was subjected to 10 mol% Ni(COD)₂, KO-*t*Bu (1.1 equiv.), and zinc dust (2 equiv.) in THF at 55 °C to give full conversion to the indoline product.

Simulating and Controlling the Power Network

Janie Neal

Mentors: John Doyle and James Anderson

The American power grid is almost a century old and due for an upgrade. People across disciplines who care about energy are talking about migrating to a "Smart Grid". A major feature of this smart grid is having an automated system with a controller that can handle and dissipate an increasing amount of disturbances that affect the power network. The Doyle research group has designed a method to create a controller that surpasses all previous methods called System Level Synthesis (SLS). This summer I am making a realistic model of the power system including the incorporation of solar energy with a special focus on discretizing a continuous model while minimizing uncertainties and inaccuracies caused by the process. Further, using SLS, I am creating a controller for the modeled system and testing the controlled system under the stress of many different disturbances. I am also designing new methods to visualize how the disturbances affect the system over space and time.

Development of Real-Time Flow Visualization Setup for the NOAH Captive Trajectory System Andrew Nwuba

Mentors: Beverley McKeon and Maysam Shamai

Particle Image Velocimetry (PIV) is a staple technique in fluid mechanics that provides quantitative data by analyzing fluid flows and generating velocity vector fields. Historically, Real-time Particle Image Velocimetry (RTPIV) is seldom used because it requires a non-trivial amount of computational power and specific hardware. Our study investigates the process of integrating hardware and software to execute RTPIV. In our experimental setup, we integrate: a Captive Trajectory system (CTS), a machine that moves the body being studied and records forces acting on the body; a high-performance computing cluster, which is a set of computers in parallel; a water tunnel that the CTS is mounted on; PIV software written in parallel, and a set of cameras that record the flow. We aim to outline how to use parallel computing architecture with the canonical PIV setup for RTPIV.

Towards Mg-S Batteries: Investigation of Electrochemical Oxidation of MgS Kim Pham

Mentors: Kimberly See and Sarah Bevilacqua

Mg-based battery chemistries are being explored as alternatives to Li-ion batteries (LIBs) due to the natural abundance, low cost, and safety of Mg, and ability to provide twice the volumetric capacity of LIBs. Ideal electrolytes display reversible deposition and stripping of Mg at the anode and enable Mg-ion transport to the cathode. One such promising cathode is S_8 which requires full reduction to yield MgS that must then be oxidized upon charging. An electrolyte that supports MgS oxidation, however, has yet to be demonstrated. Here, we use the magnesium aluminum chloride complex (MACC) salt system in various solvents to determine its effects on the redox processes at each electrode. To evaluate promising electrolyte systems, Mg-Pt cells are assembled to screen the electrolyte's anodic performance. To probe the oxidation of the MgS cathode, the electrolytes were assembled in Mg-S cells. Our results show that in addition to solvent, the presence of additives shortens the conditioning time of the electrolyte, decreases current density, and promotes corrosion of the MgS cathode.

Improving Thrust Efficiency of Unmanned Aerial Vehicles Using Jet Pumps

Tehreem Ahsan Raza

Mentors: Morteza Gharib, Marcel Veismann, and Christopher Dougherty

Center for Autonomous Systems and Technology at Caltech (CAST) is currently involved in developing a new concept of air transportation called "Flying Ambulance". This concept aims at combining the advantages of vertical take-off and landing (VTOL) and cruise efficiency of fixed wing aircraft in a vehicle. However, since rotorcrafts are inherently inefficient in generating lift compared to fixed wing aircrafts, the power consumption during vertical take-off and landing is considerable, effectively decreasing the range of the vehicle significantly. To maintain a reasonable operating range for the Flying Ambulance, we seek to explore new and more efficient ways of propulsion either during cruise flight or during the VTOL stages. Our focus for this research project is to investigate different approaches to increase propulsion efficiency in drones and other Unmanned Aerial Vehicles (UAV), which can then be applied to the Flying Ambulance.

A cGAL Effector Library of Neuropeptides in Caenorhabditis elegans

Jasmin Revanna

Mentors: Paul Sternberg and Han Wang

Developing efficient tools to study the function of genes in a robust and precise manner is ongoing. A particular system of interest is the binary GAL4-UAS system. The Sternberg team optimized three components of the GAL4-UAS system to make it functional for *C. elegans* across 15–25°C, and demonstrated its robustness for tissue-specific gene expression, site-specific genetic rescue, and channelrhodopsin experiments. The GAL4-UAS provides a few major advantages over the commonly used direct promoter-gene fusions. By crossing drivers and effector lines, a large amount of strains with effector genes expressed in different tissues can easily be created. We plan to create a large library of new effectors for the *C. elegans* community. Specifically, we are creating a subset of

effector plasmids for all neuropeptides that are expressed in a master neuron for sleep regulation in *C. elegans*. Neuropeptides in *C. elegans* falls into three large families: the insulin-like peptides (INSs), FMRFamide-related peptides (FLPs), *and* neuropeptide-like proteins (NLPs). The neuropeptide genes are expressed extensively throughout the nervous system, but also expressed in non-neuronal tissues. The creation of this plasmid library will help us study the effects of neuropeptides on *C. elegans* behavior by manipulating their expressions using different available cGAL drivers.

Preparing Component Integration of a Small Satellite From Computer-Aided Design of Cable Routes Nathan Sam

Mentors: Sergio Pellegrino, Thibaud Talon, and Charles Sommer

The use of small satellites such as cubesats have been more commonly used in academia or industry as they are more affordable to construct and have a simple, standardized design. However, due to their limited size, cabling internal components can become an issue. A solution to this issue is using the Electrical Toolbox of Solidworks to design cable routes in the 3D computer model of a satellite. We use reference planes to constrain the path of the cable to create an organized set of cables. This solution helps predict issues such as clearances between a cable and an internal structure, specific length requirements to route a pair of connectors, and validating the layout of the components in the satellite. The method is demonstrated on a reconfigurable space telescope called AAReST developed by Caltech along with the University of Surrey and the Indian Space Science and Technology Institute.

Hardware Solutions for Countering Long-Term Laser Frequency Drift

Perrin (Claire) Segura Mentors: Nick Hutzler and Arian Jadbabaie

In order to prevent frequency drift, lasers must be stabilized by a system that repeatedly measures the frequency and makes corrections if it has changed. The lasers used in precision measurements of molecules pose several unique challenges that render common methods of stabilization, which are often only effective for certain wavelengths or prevent large changes in frequency once the laser is stabilized, impractical. In light of these difficulties, we have developed a prototype for a simple electronic system that can be used to stabilize a laser at any desired frequency. The system measures the frequency difference between an unstable laser and a stable reference laser, and outputs a voltage proportional to this value subtracted from the desired frequency spacing. This signal is processed and sent to the unstable laser, increasing or decreasing its frequency as needed to zero the difference between the actual and desired spacing. Two prototypes have been constructed for this purpose, both of which were tested using an unstable ECL laser and a stable HeNe reference, and were repeatedly successful in briefly stabilize the ECL. Although future optimization is likely necessary before it can be deemed a reliable means of stabilization, this success remains promising evidence of the design's potential.

Deltaic Avulsions Over the Past Half-Century Captured by Satellite Imagery

Jose R. Silvestre

Mentors: Michael P. Lamb and Austin J. Chadwick

River avulsions pose a hazard to human life and property on densely populated river deltas and are responsible for distributing freshwater and nutrients to wetland ecosystems. Predicting when and where avulsions will take place is crucial for hazard mitigation and sustainable management of river deltas, but testing predictive models is challenging due to limited field data. Previous work on a handful of well-studied low gradient deltas suggests that avulsions preferentially occur at a node located approximately one backwater length upstream of the shoreline, whereas the apex of steeper fan deltas is tied to a change in topographic confinement. To test deltaic avulsion models at a broader scale, we present a compilation of more than 80 avulsions over the past 34 years and were captured by NASA Landsat. Our compilation supports the hypothesis that avulsion location correlates with the backwater length on lowland river deltas, and with canyon-fan transitions for steeper fan deltas. These results will help to test predictive models of avulsion location and timing on fans and deltas.

Lipid Regulation of the Hedgehog Developmental Pathway

Allison Skinkle Mentor: Alison Ondrus

Hedgehog signaling is vital in embryonic development and when awry is responsible for the manifestation of certain cancers. While decades of research implicates endogenous lipids in the regulation of Hedgehog signaling components, specific molecules which fulfill this regulatory role have yet to be identified. Here, we further investigate the regulatory role of lipids through perturbation of bulk membrane properties and genetic regulation of endogenous sterol concentrations. Altering bulk membrane properties through stabilization of lipid rafts evoked disparate pathway activation in response to agonists targeting Patch1 and Smoothened. Furthermore, we are using CRISPR/Cas9 to generate knockouts of the sterol converting enzyme Hsd11β1 and examine whether pathway

activation is altered in a manner correlated with exogenous addition of its sterol substrate cortisol. The present study uncovers novel connections between lipids and two major Hedgehog signaling components. This work in concert with current efforts in developing an unbiased metabolomics approach will allow us to pinpoint the exact lipids involved in regulation of the Hedgehog pathway and importantly reveal new drug targets for Hedgehog-derived cancers.

A Systematic Search for Absorption Features in the X-Ray Spectra of Ultraluminous X-Ray Sources Andrew Sosanya

Mentors: Fiona A. Harrison and Murray Brightman

Ultraluminous X-ray sources (ULXs) are variable, non-nuclear bright X-ray sources that exceed the Eddington luminosity limit for stellar-mass black holes (10 M \odot). The discovery of X-ray pulsations from ULXs suggests that certain ULXs may be powered by accretion onto highly magnetized neutron stars that are being spun up. However, past research shows that estimations of the magnetic fields of these neutron stars are still uncertain. We seek to find signatures of magnetic fields through cyclotron resonance scattering features (CRSFs) in ULX-abundant galaxies. Using data from the Chandra and XMM-Newton high-energy X-ray telescopes, we conducted a systematic search for absorption line that could be due to cyclotron resonant scattering and would suggest accretion onto magnetized neutron stars. These lines are prevalent in absorption, and we can estimate the magnetic field if we assume absorption by electrons, where the transition energy is $\Delta E = 11.6(1 + z) - 1(B/10^{12} G) keV$, where z is the gravitational redshift. After narrowing down potential sources, we present our findings from the spectral analysis of several ULXs. These findings provide further insight into the analysis techniques for future neutron star-powered ULXs and estimation of their magnetic field strengths.

Comparing the Efficiencies of Novel Zygotic Promoters for Cas9 Expression in Arabidopsis thaliana Sabrina Stulting

Mentors: Elliot Meyerowitz and Ting Li

CRISPR/Cas9 has increased the simplicity of targeted gene editing, allowing for a more accessible method to study and modify the genetic makeup of model organisms. This system, however, is limited by low rates of uniform and heritable mutations in *A. thaliana* due to the floral dip transformation method, which can be improved by optimization of Cas9 expression. In this project, the efficiencies of five novel zygotic expression enriched promoters in *A. thaliana* were tested and compared to several commonly used promoters for Cas9 expression. Each of these five promoters were selected for their high levels of expression early in the embryo development of *A. thaliana* based on a genome-wide gene expression microarray dataset—the use of these promoters for Cas9 expression could increase the rate of mutation transmission when included in CRISPR constructs. A T7 endonuclease assay was used to estimate mutagenesis efficiency and thus far "Promoter2" has the highest frequency of mutations, but all promising samples will be sent for sequencing to be further characterized. In continuation of this project, T2 plants will need to be analyzed to determine the heritability of the mutations created by each promoter.

Constructing a Comprehensive Database of Exoplanets Discovered With Gravitational Microlensing

Naylynn Tañón Reyes Mentor: Calen B. Henderson

The NASA Exoplanet Archive hosts a Microlensing Table that currently has data for only 28% of the 60 confirmed exoplanets discovered by gravitational microlensing. My goal is to construct a comprehensive database that includes all published models, which is particularly crucial for systems with degenerate solutions. As no such database is publicly available, I will complete the first database from the existing literature and integrate it into the Archive for public use. Using a combination of Linux and SQL, I will extract values for observables, model parameters, and physical properties for microlensing exoplanets from the literature, create corresponding data files for each model solution, and ingest them into the Archive's Microlensing Table. Python will be used to read data files as well as create output files and figures using input and calculated data. When an exoplanet is found using gravitational microlensing, there is often a set of degenerate solutions frequently yield different values for the physical properties of the planetary system. Once the database is completed, I will explore it for trends and correlations within the microlensing planet population and also compare microlensing planets to planet populations probed by other discovery techniques. Examining the demographics of all known microlensing planets will allow me to identify sub-populations and investigate how planetary properties vary as a function of stellar properties. Additionally, the project will enable follow-up studies to prioritize targets for validating the various models.

Development of a Salivary α -Amylase Point-of-Care Electrochemical Sensor

Augusta Uwamanzu-Nna Mentor: Wei Gao

Non-invasive chemical sensors have demonstrated growing applicability for continuous physiological health monitoring. Point-of-care testing (POCT), which relies on the detection of biomarkers found in various biofluids, has consequently become a reliable method for first-response testing at the bedside and even in remote and less industrialized areas. The biofluid of focus in the present investigation is saliva, which contains α -amylase, a digestive enzyme that has been linked to mental health and neurological disease states. An indirect detection method involving the breakdown of starch into maltose and other components by the enzyme and the subsequent reduction of the redox mediator, K₃[Fe(CN)₆]⁻³, by maltose was the chemical sensing mechanism utilized for the sensor. The sensor was fabricated using screen-printed carbon electrodes (SPCEs) and gold electrodes (AuEs) and tested using the electrochemical methods of potentiometry, cyclic voltammetry and amperometry. The AuEs have demonstrated the most promise and their continued investigation will lead to the development of a novel sensing microfluidic sensing chip. Anticipated results will ultimately indicate the ability of the sensor to reliably and quickly detect salivary α -amylase for POCT.

Variations in Surface/Subsurface Processes on Europa

Maya D. Yanez (1,2) Mentors: Morgan Cable (2), Cynthia B. Phillips (2) 1: University of Colorado, Boulder 2: Jet Propulsion Laboratory, California Institute of Technology

Interest in Europa has steadily increased since the first close-up images from the Voyager spacecraft in 1979. Its global subsurface ocean as well as the surface geology of its ice shell have launched many inquiries into its potential for harboring life. We are in an era where we will have a mission to Europa, possibly even two (the second being a lander mission concept) within the next two decades. It is becoming more and more imperative to maximize our understanding of Europa (especially its surface and subsurface) in order to properly prepare for these mission plans. Therefore, we provide a synthesis of the processes governing Europa's surface to a depth of one meter and a lateral area of ~two square-meters (i.e., typical lander workspace-scale). As the highest resolution data of Europa does not permit this scale of understanding, we performed various qualitative analyses of analogue environments (Mars, Moon, etc.) where we do have *in situ* data. We also begin to quantify the vertical and horizontal variation to be expected within a workspace area. We present the results of this search and analyses, and comment on the potential of various surface processes to destroy or preserve biosignatures.



Amgen Scholars Program

> A M G N

Synthesis of C5 Pleuromutilin Analogs

Alexandra Bodnar Mentors: Sarah Reisman and Sean Feng

Antibiotic resistance is a continuously growing global threat. As a result, the development of new antibiotics is of the utmost importance. Isolated from *Clitopilus passeckerianus*, pleuromutilin is a secondary metabolite that exhibits impressive antibiotic activity both in vitro and in vivo against Gram-positive pathogens and mycoplasmas (minimum inhibitory concentration (MIC) against methicillin-resistant Staphylococcus aureus (MRSA) = $0.5 \mu g/mL$, MIC against mycoplasma hominis = $0.3 \mu g/mL$). Reisman and co-workers recently completed the synthesis of pleuromutilin in 18 steps, enabling the flexibility and efficiency necessary to construct structural analogs of this natural product as potential antibiotics. The C10, C12, and C15 methyl groups reside in a hydrophobic pocket of the binding site, and variations at these positions may lead to tighter binding and therefore increased biological activity. Our group has focused on varying substituents at C5 position and we have implemented conformational analysis to determine which groups to vary at this position.

Sustainion Anion Exchange Membrane Embedded Microwire Arrays for Photoelectrochemical Devices Justin C. Bui

Mentors: Nathan S. Lewis and Harold Fu

Enough sunlight hits the Earth in one hour to power the entire world for a whole year. However, modern photovoltaics are incapable of storing captured solar energy during intermittent hours. Therefore, recent research in semiconductor photoelectrochemistry has focused on artificial photosynthesis in which sunlight is utilized to photoelectrochemically generate high energy density fuels. Research here focuses on the production of a solar tarp: a device consisting of an array of vertically oriented 3 μ m diameter silicon wires embedded into an ion-exchange membrane that can photoelectrochemically convert water and sunlight into a storable hydrogen fuel. In this study, these silicon microwires were embedded into a Sustainion anion exchange membrane to develop a device that can operate in alkaline environments. The microwires were protected with a titanium dioxide (TiO₂) protective layer to ensure their stability in base. A conformal 10 to 15 μ m layer of Sustainion was cast into the microwire array and characterized for ion conductivity and transparency. A bipolar membrane consisting of Sustainion and Nafion, which permits the transport of both protons and hydroxides, was fabricated to facilitate the operation of the device under a harsh pH gradient. This permits the use of earth abundant catalysts to perform water splitting and sets the stage for integration of the bipolar membrane into a dual-microwire array solar tarp device.

Accessing Aromatic 1,2-Dithiols via S₈ Insertion Onto Arynes

James Cox

Mentors: Robert Grubbs and Sankarganesh Krishnamoorthy

Aromatic 1,2-dithiols are a common structural motif in catalysts and enzymes. Despite their utility, 1,2-dithiols remain challenging to synthesize. Existing synthetic routes to dithiols involve multiple steps or harsh reagents, such as *n*-butyl lithium. The goal of this project is to develop an alternative aromatic 1,2-dithiol synthesis using reactive aryne intermediates. Benzyne is known to add elemental sulfur (S_8) and afford a variety of polysulfanes that can subsequently be reduced to the desired dithiol. This single-step addition of both sulfur atoms along with the mild generation of arynes from *ortho*-silyl triflates addresses the issues of previous synthetic strategies. After optimization, the addition of S_8 to benzyne was found to give 50% of the desired pentathiepin product by NMR spectroscopy. Treatment of the crude reaction mixture with sodium borohydride generates the desired dithiol, as indicated by NMR. Studies on the substrate scope of this method are underway.

Determining the Phenotype of Transcription Factors RUNX1 and RUNX3 Knockouts in T Cell Development Using CRISPR/Cas9

Janielle Cuala

Mentors: Ellen Rothenberg, Maile Romero-Wolf, and Hiroyuki Hosokawa

T cells are lymphocytes that are critical in the immune system to fight against infections or cellular abnormalities. T cells develop from hematopoietic stem cell precursors and are processed in the thymus. To understand the development of T cells, different players involved need to be investigated to see its effects. We are specifically looking to see whether a knock out of the transcription factors called Runx1 and Runx3 produce a phenotype in early T cell development. Runx1 and Runx3 are important regulators of T cell development, but not much is known about its phenotype on the differentiation and early development. Bone marrow cells were extracted, cultured, infected with the knock out through the CRISPR/Cas9 system, and harvested for analysis through a flow cytometer. Preliminary studies showed that a double knock produced a distinct phenotype indicating a functional redundancy within Runx1 and Runx3. Future works include replicating the data to confirm the results found in the preliminary studies. The cells will also be sorted to be sent off to RNA sequencing to determine which genes are affected with the knockouts to gain a better understanding of the control the transcription factors have on early T cell development.

Characterizing the Molecular Olfactory Recognition of Fruits in Drosophila

Daniel Cummins

Mentors: Carlos Lois and Elizabeth Hong

Olfaction in the fruit fly, *Drosophila melanogaster*, is well characterized in terms of receptor neuron activations to individual molecules, but the molecular sensitivity of *Drosophila* to mixtures of natural odorants, and how permutations of these compounds are processed in the olfactory system of *Drosophila*, remains unknown. Thus, this work first investigates the chemical composition of varying fruit samples by solid-phase microextraction (SPME) on the headspace of fermented and unfermented (rotting) samples over 5 weeks for the following fruits: mango, peach, kiwi, strawberry, and banana. Using gas-chromatography with mass-spectrometry (GCMS), the molecular composition of the headspace for each of the ten samples was determined. Upon standardization of each chemical with the SPME and GCMS systems, quantitative abundances for each molecule was also obtained. In future work, chemicals in greatest natural abundance will be assessed using a behavioral assay to determine what mixtures and concentrations are detectable to *Drosophila*. This assay, which we have also experimentally validated, consists of classically conditioning flies to avoid certain odors; aversion to shock-conditioned smells indicating flies can detect that particular chemical concentration.

Symmetry Project, Characterization of the Fan-Shaped Body Neurons by R38D01 and R72A10 Drivers Roland Jethro Del Mundo

Mentors: Carlos Lois, Ting-Hao Huang, and Aubrie De La Cruz

The goal of this project is to continue studying the wiring diagram of brain circuits in *Drosophila* using our new genetic strategy based on transneuronal activation of transcription (TRACT). The TRACT system identifies synaptic partners within the brain using a receptor-ligand pair based on Delta-Notch signaling. Our study seeks to analyze a specific asymmetric region in the Drosophila brain identified as the Asymmetric Body (AB), located in the right hemisphere. The structure is known to support long term memory, but has not been extensively studied. Approximately 7% of Drosophila have symmetrical ABs and perform poorly in long-term memory experiments. The goal for the Symmetry Project is to identify the 7% of flies that are symmetrical and determine whether the pre- and post-synaptic connections are also symmetrical or asymmetrical. So far, flies containing R72A10-lexA>26xlexAop-mCD8::GFP and R38D01-lexA>26lexAopmCD8 have been dissected and imaged with confocal microscopy to confirm that these are pre-synaptic and post-synaptic drivers, respectively. Ultimately, the TRACT ligand and receptor will be implemented with these drivers to identify pre- and post-synaptic connections to the AB.

Engineering Fluorescent Reporter Cell Lines for CRISPR/Cas9 Screens

Michael Doane Mentor: Alison Ondrus

The Hedgehog signaling pathway regulates development in higher eukaryotes. Mutation of Hedgehog pathway components can lead to various forms of cancer, most notably medulloblastomas and basal cell carcinomas. CRISPR/Cas9 screens enable the creation of thousands of cells, with one gene knockout each cell. By correlating Hedgehog pathway disruption with specific gene knockouts, it is possible to gain insight into the genes and proteins that are necessary to facilitate signal transduction. To introduce Cas9 protein into Hedgehog pathway reporter cells that express green fluorescent protein (GFP) in response to pathway activation, we designed two plasmids for inducible Cas9 expression. Restriction enzyme and PCR-based strategies were used to clone blue fluorescent protein (BFP) into two backbone vectors, pCW-Cas9 and lenti-iCas9-neo, for transduction into Hedgehog pathway reporter cell lines, enabling them to emit BFP signal when Cas9 is expressed. Dose-response assays were carried out on three reporter cell lines before introduction of Cas9 to evaluate response to the Hedgehog pathway agonists SAG and HH and the cholesterol-depleting chemical methyl-beta-cyclodextrin. These results will be used to calibrate the treatments used to elicit Hedgehog response in the CRISPR assays. Future studies will use these cell lines to carry out experiments correlating Hedgehog pathway activity to specific metabolic genes. Ultimately this research aims to provide new therapeutics to address aberrant Hedgehog signaling by targeting specific metabolic genes.

Fluorescent Tracking of *Caulerpa* Nuclei to Elucidate Tissue-Level Differentiation Mechanisms in a Giant, Meter-Long Cell

William Feist

Mentors: Elliot Meyerowitz and William T. Gibson

In developmental research there is a strong focus on model organisms with multicellular tissue and organ formation. While these model systems are useful for understanding human development, from a basic science standpoint, the added complexity from cell-cell interactions in these systems makes uncovering developmental principles unnecessarily difficult. We study the green algae *Caulerpa*, which is one of the largest single celled organisms. A giant coenocyte, *Caulerpa*, develops without many of the standard mechanisms observed in modern developmental genetics, i.e. cell division, stem cells and cell migration. As such, it affords the unique opportunity to study intricate development and differentiation without the complexities of cell-cell interactions. To better

understand how *Caulerpa* manages complex tissue differentiation, we intend to study the localization and distribution of nuclei before, during, and after differentiation. A fluorescent fusion protein construct localized to the nucleus will allow for simple monitoring and quantification of nuclei distribution movement. By observing the nuclei's role in differentiation, we can begin to understand *Caulerpa's* unique approach to life.

Characterization of Cobalt Sulfoselenide Catalyst for the Hydrogen Evolution Reaction

Aurland Hay

Mentors: Nathan Lewis and Katherine Rinaldi

Hydrogen production via the cathodic half-reaction associated with water-splitting has become a critical point of research in the attempt to reach carbon neutral energy technologies. To ensure kinetic efficiency, a catalyst is required to lower the overpotential of the hydrogen evolution reaction (HER). Typical catalysts for this system are noble metals such as platinum; however, the scarcity and cost of such materials prohibit their use in scalable sustainable energy systems. Recent research has focused on developing alternative HER catalysts with earth-abundant materials such as metal phosphides or selenides. *Operando* Raman studies of a cobalt selenide catalyst revealed structural changes following voltammetric cycling that increased the catalytic efficiency indicating polymeric selenium reduction. In this research, we examine the novel catalyst CoSeS via *ex situ* and *operando* studies. An electrodeposition technique was developed and optimized to produce catalyst films that showed consistency via both Raman spectroscopy, Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Spectroscopy (EDS) analysis. This catalyst exhibits moderate overpotentials and high stabilities under HER conditions when compared to other transition-metal chalcogenides. After galvanostatic treatment, changes to the spectroscopic signatures of the catalyst films were observed, such as a reduction in the peaks corresponding to polymeric selenium and sulfur, indicative of catalytic restructuring during activation. Further *operando* probing will provide insights into the activation mechanisms of this catalyst.

Genetic Dissection of Interspecies Interactions: Using RNAseq and Hybridization Chain Reaction to Profile Chemical Signal Production in *Dalotia coriaria*

Carrie Hicks

Mentors: Joseph Parker and Adrian Bruckner

During the Cenozoic Era, rove beetles evolved a variety of anatomical (e.g., bodies with petiolate abdomens and long legs that mimic those of ants) and chemical (e.g., defensive or appeasement glands) traits that allow them to bypass army ant defenses. Many Myrmecophiles have tergal glands that produce, hold, and emit defensive secretions capable of deterring ant aggression. We aim to understand how these complex evolutionary changes have occurred at the molecular level using the green house rove beetle, *Dalotia coriaria*. RNAseq, biochemical profiling and in vivo transcript visualization will be used to characterize the genetic logic of the defensive tergal gland. One of the most potent compounds found in the green house rove beetle's gland is 2-methyl-1,4benzoquione. It is hypothesized that that this compound is produced from an offshoot intermediate of tyrosine catabolism and subsequent oxidation to the final product via a laccase-like enzyme. In order to understand where this reaction occurs, hybridization chain reaction (HCR) will be used to locate transcripts of enzymes (e.g., laccase or tyrosine hydroxylase) in the glands. This information will be used to design an RNAi protocol that can temporarily knock down a targeted gene or a CRISPR-Cas9 protocol to knockout a gene so that behavioral and chemical assays can be conducted on the beetles.

Clonal Analysis of the Olfactory Placode in Chick Development

Rimma Levina

Mentors: Marianne Bronner and Alison Koontz

Vertebrate embryos have regions of thickened columnar epithelium called cranial placodes. These transient cells form in certain areas of the head and serve as a source of precursors for sensory organs such as the nose, eyes, and ears. The olfactory placode in particular gives rise to many cell types that populate the nose; however, there has been significant debate over whether certain derivatives in the olfactory system come from the olfactory placode or a different stem cell population called the neural crest. To address this controversy we are focusing on two of the cell types found in the olfactory epithelium, gonadotropin-releasing hormone (GnRH) neurons and olfactory ensheathing cells (OECs), which have been heavily debated. Using replication-incompetent avian retroviruses that encode a fluorophore to perform clonal analysis we sought to track single cells from the olfactory placode and observe whether or not they will differentiate into GnRH neurons and OECs. Our preliminary results indicate that we indeed use this newly developed technique to identify the stem cell source of the cell types in question.

Methacrylate Photoresists Development for Scalable Single-Beam Photolithography via Metasurfaces Jonathan Li

Mentors: Julia Greer and Luizetta Navrazhnykh

Nanostructures have been studied as a means to create lighter, but stronger materials. 3D architectures with nanoscale features are the most mechanically interesting, but current technologies for their fabrication are slow, limiting the scale to which these structures can be fabricated. Single-beam photolithography is a powerful technique we are developing to overcome the speed barrier in the nanofabrication of these structures. This method creates a 3D energy pattern via a laser shined through a metasurface which crosslinks epoxy groups within the photoresist to create the designed structure. Residual non-crosslinked photoresist can be developed away, leaving behind the desired nanostructure. Development of methacrylate and acrylate photoresists for this process is desirable over the currently utilized SU-8 photoresist because methacrylate and acrylate chemistries are functionally flexible, including compatibility with current additive manufacturing techniques; better understood mechanically; and potentially more structurally stable compared to SU-8. Current, development thus far has utilized polyglycidyl methacrylate (PGMA) and copolymerizing it with other methacrylates including benzyl methacrylate (BMA). The resolution limits of different photoresists created from these polymers will be tested via 2D interference patterns and the most successful candidates will move on to testing with the 3D structures.

Reaction Development of Nickel-Catalyzed Asymmetric Reductive Cross-Coupling

Brandon M. Liu

Mentors: Sarah E. Reisman and Kelsey E. Poremba

The recently developed nickel-catalyzed asymmetric reductive cross-coupling reaction is of synthetic interest due to its ability to couple two readily available electrophiles without the need for preformed organometallic reagents. Recent reports within this field have demonstrated success in coupling vinyl bromides and *N*-hydroxyphthalimide esters. In this study, we aimed to further investigate the scope of this reductive cross-coupling and demonstrate its synthetic utility through the preparation of cylindrocyclophane natural products. Cylindrocyclophanes are a class of C₂-symmetric [7.7]paracyclophane natural products with anticancer properties. We envision the preparation of cylindrocyclophanes from the cyclodimerization of a complex coupling fragment containing both vinyl bromide and *N*-hydroxyphthalimide ester functionalities. We have further studied the general conditions of the nickel-catalyzed asymmetric reductive cross-coupling reaction and progressed in the preparation of the complex cylindrocyclophane cyclodimerization fragment.

Architecture of the Nuclear Pore Complex Inner Ring

Alex Lyons

Mentors: André Hoelz and Thibaud Perriches

The Nuclear Pore Complex (NPC) is the sole gateway into the nucleus of the cell and mediates all transport into and out of the nucleus. The NPC is a massive assembly containing 34 unique proteins called nucleoporins arranged in an 8-fold symmetric ring surrounding a central channel. The NPC is organized in three layers: a central transport channel with unstructured regions forming a barrier, the inner ring complex, and a rigid outer ring on the nuclear membrane. It is well known that both the inner ring complex network and the interaction between the NPC layers relies upon the interaction of unstructured nucleoporins termed linkers with large folded domains called scaffolds. However, the nature of most of these interactions has yet to be understood. Our goal is to conduct a structural and biochemical analysis of one linker with two of its scaffold partners. We attempted to resolve these interactions biochemically through site directed mutagenesis, where specific amino acids are altered using mutagenesis PCR and expressed through recombinant protein expression to reveal their significance to the interaction. In order to define the interactions structurally, we utilized x-ray crystallography by observing how x-ray beams were diffracted by crystal lattices of the interacting proteins.

The Impact of Olfactory Experience on Local Inhibitory Connectivity in the Fly Olfactory Circuit Elizabeth Maurais

Mentors: Elizabeth Hong, Annisa Dea, and Zhannetta Gugel

Sensory experience has been shown to play a role in development of neural circuit formation. The *Drosophila* olfactory system is an excellent model to investigate the impacts of sensory experience because it is highly compartmentalized allowing for control of sensory input. This project seeks to understand how chronic exposure in early life to specific odors that activate individual sensory channels impacts the connectivity of local inhibitory circuits in the first olfactory area of the brain. Local inhibitory neurons were visualized with a genetic label that sparsely expressed GFP. Immunostaining and confocal microscopy were also essential to the investigation, and finally image analysis allowed for data processing. The significance of these results will show olfactory experience's role in local inhibitory neuron connectivity.

Identifying Regulatory Pathways in Mitochondrial Complex I Function and Assembly Brandon Ng

Mentors: David Chan and Christopher Fiorese

Mitochondria play an essential role in mammalian cells by generating ATP through oxidative phosphorylation. Complex I (NADH:ubiquinone oxidoreductase) is an essential component of the oxidative phosphorylation machinery and is composed of 45 subunits encoded by both nuclear and mitochondrial DNA, and a precise stoichiometry of the subunits is required for the proper function of the complex; however, it is unclear what quality-control mechanisms regulate the matching of Complex I subunit levels. We aim to better understand these quality-control mechanisms by conducting gene-trap screens to study how the cell responds to core Complex I subunit knockouts. In the present study, we aim to create a reporter system in a haploid cell line with a fluorescent protein tagged onto a subunit of Complex I to visualize how the fluorescent-tagged subunit levels respond to deletion of Complex I subunits; haploidy allows a forward genetic screen to discover genes involved in regulating subunit levels in response to changing Complex I levels. We have been successful in transducing Hap1 wt and mitochondrial DNA-deficient Hap1 ρ^0 cells with two different reporter proteins on two different subunits. Future work entails conducting a genetic screen via GeneTrap and performing an MG132 Proteasome inhibitor assay as a positive control.

Optimization of Nanoporous Gold Antennas for In-Situ Carbon Dioxide Reduction Intermediate Detection

Levi D. Palmer

Mentors: Harry A. Atwater and Giulia Tagliabue

Solar-driven CO₂ reduction is a promising but challenging photo-electrochemical process with multiple protonelectron coupled reactions and several intermediate steps, resulting in a large number of possible products. Therefore, monitoring intermediates on the metal catalyst in-situ would afford new strategies for improving reaction selectivity and efficiency. Conveniently, plasmonic CO₂ reduction catalysts drive both detection and activity of reaction progression, and a tunable resonance of plasmonic microantennas allows for localized IR molecular vibration detection in surface-enhanced infrared absorption spectroscopy (SEIRAS). Additionally, recent work on nanoporous (NP) gold proved that an increased catalyst surface area generates augmented catalytic activity. Here, we combine design components of NP-gold microantennas for monitoring CO₂ reduction intermediates in-situ using SEIRAS. Both infrared and visible variable-angle scanning ellipsometry were used to characterize the NP-gold for finite element method simulations, predicting the absorption and reflection losses of light incident to the NP-gold antennas. Ideal film dimensions required maximum global light absorption and peak reflection at the vibrational resonance of the molecular intermediate. After simulating optimal antenna width and pitch, electron-beam lithography and evaporation were used for the catalyst structuring. Comparing PMMA vibration intensity across SEIRA antennas allowed for the selection of parameters for increasing detection of trace reaction intermediates.

Elucidating the Morphological Context and Mechanism of Syntrophic Electron Transfer in Methane Seep ANME-SRB Consortia on a Subgroup Specific Basis

James Park

Mentors: Victoria J. Orphan and Grayson L. Chadwick

Anaerobic methanotrophic (ANME) archaea and sulfate reducing bacteria (SRB) live in tight syntrophic association, coupling their metabolisms, to carry out the important geobiological process of methane oxidation in deep sea environments. One of the fundamental questions behind this interaction is the mechanism of electron transfer between ANME and SRB. There are two canonical mechanisms for electron transfer: direct electron transfer and diffusion of a chemical intermediate. There are also diverse morphologies associated with ANME-SRB aggregates, and we hypothesize that the mechanism of electron transfer is connected to morphology. We have developed a method using fluorescence in situ hybridization (FISH) and laser microdissection to image aggregate morphology, isolate a single aggregate, and phylogenetically identify the ANME and SRB, correlating ANME-SRB subgroups to their respective morphologies. Using this method, we have linked various species of ANME and SRB to specific morphotypes. We will also combine FISH with Bioorthogonal Noncanonical Amino Acid Tagging (BONCAT), which fluorescently labels newly synthesized cellular proteins, to determine the phylogenetic identity of anabolically active ANME and SRB cells incubated with proposed chemical intermediates. These results will be interpreted in the context of a genomic database of ANME and SRB to link genomic potential with metabolic activity and morphology.

Genetic Variation and Social Behavior of Symbiotic Ants and Beetles

Yein Christina Park

Mentors: Joseph Parker and Julian Wagner

Over the past millions of years, many species of beetles have independently evolved to live symbiotically in ant colonies. One species of interest is *Sceptobius lativentris*, a symbiotic beetle that climbs on top of its host ant, Liometopum occidentale, and scrapes off the ants' chemical coating. Unlike free-living beetles, sceptobius are wingless and cannot survive for more than about ten hours without its host ant. Despite this limited mobility, these beetles have been found in almost every liometopum colony. To determine how often these beetles move between ant colonies, ants and beetles were collected from various colonies in the Southern California area, and the sequences of several rapidly mutating regions of DNA (mitochondrial complex and an intertranscriptional spacer) were compared. No significant genetic variation between the beetles and ants from the different colonies was found, suggesting either that there is significant movement between colonies or that the colonies are too recently separated for any genetic variation to appear. In light of these results, an alternative whole genome sequencing approach was applied to identify regions with low rates of single nucleotide polymorphisms, which are indicative of recently selected genes that may be critical in the symbiosis with the host ants.

Applications of Deep Convolutional Neural Networks for Multiplexed I on Beam Imaging Annotation Cole Pavelchek

Mentor: David Van Valen

Multiplexed ion beam imaging (MIBI) is a novel imaging technology based on mass-spectrometry for simultaneous visualization of upwards of 50 targets. Each target in an image is visualized by an independent channel corresponding to a specific mass-tagged antibody. However, this data can be esoteric, and the high numbers of channels can be overwhelming for even seasoned pathologists. This is further complicated by the fact that one image can contain upwards of 6000 cells, making hand-annotation prohibitively time-consuming. Furthermore, current classification methods require significant post-processing and iterative rounds of clustering, and are inaccessible for those less familiar with computational methods. While MIBI is groundbreaking, its application is bottlenecked by the lack of effective annotation methods. Deep convolutional neural networks offer a promising solution. I built a deep-learning based pipeline for automatic annotation of MIBI images. Utilizing DeepCell, MaskRCNN, and RetinaNet, this pipeline performs semantic segmentation, instance segmentation, and cellular instance classification within minutes, and with accuracy comparable with or superior to current methods. Once deployed to the cloud, this pipeline will permit researchers and medical centers easy access to rapid, accurate annotations without requiring training in computational methods, permitting use of multiplexed ion beam imaging in ways that were previously impossible.

Photoinduced Copper-Catalyzed Stereoselective Carboamidation of Unactivated Alkenes Nick Watkins

Mentors: Jonas Peters, Teddy Donnell, Caiyou Chen, and Jian He

In drug development and discovery, the presence of chiral centers is correlated with an increased prospect of clinical success. Additionally, it has been reported that C–N bonds are present in over 80% of all approved drugs. Because many of these C–N bonds are derived from alpha-amino acids, one can easily manipulate the drug scaffold by changing these elementary building blocks. Due to a paucity of techniques capable of producing enantiopure beta-amino acids, these analogous starting materials are infrequently used. Here, a novel three-component system has been developed to provide access to such compounds from readily available starting materials. A copper system was investigated for its capacity to facilitate the photoinduced carboamidation of beta,gamma-unsaturated amides. Solvents, bases, reaction temperatures, and reagent equivalences were screened, giving little improvement in product yield due to facile elimination and off-cycle termination pathways. Due to the difficulty in improving reaction results, the stability of the proposed secondary radical intermediate should be probed before further screening.

The Impact of Experience on Drosophila Olfactory Circuit Connectivity

Emily Ye

Mentors: Elizabeth Hong and Annisa Dea

Neural plasticity is a hallmark characteristic of the nervous system yet the fundamental principles underlying this phenomenon remain relatively unknown. In this study, we utilize the olfactory system of the model organism *Drosophila melanogaster* to ask whether chronic sensory stimulation modulates changes in olfactory projection neuron morphology, the first central olfactory neurons in the brain. One main advantage of the *Drosophila* olfactory system is its highly compartmentalized organization. Olfactory receptor neurons (ORNs) expressing the same ligand receptor are organized spatially into glomeruli in the antennal lobe and synapse with secondary projection neurons (PNs). Thus, deliberate selection of the odor environment allows for precise control over ORN and PN activation. We apply MultiColor FlpOut to a Gal4 driver line labelling a small subset of PNs, allowing single-cell

resolution visualization via confocal microscopy. Utilizing NBLAST, an algorithm for morphometric similarity analysis based on local geometry and relative position of neurons, anatomical differences in PN mushroom body inputs and lateral horn innervation can be extracted with high sensitivity and accuracy. Results of this study will determine whether anatomical connectivity plays an underlying role in plasticity caused by chronic activation.

LIGO

THE LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY

> L G O

Design and Testing of Composite Mirror Adaptive Optics

Aria Chaderjian Mentors: Jon Richardson and Aidan Brooks

Adaptive optics works to reduce optical losses in LIGO detectors, making them more sensitive to gravitational wave events. Mode-mismatch between cavities, which is caused by uncertainty in the radii of curvature and orientation of the optics of the interferometer, is one of the main sources of loss in Advanced LIGO. Thermal actuators change the radius of curvature of various optics to dynamically change the beam size, allowing mode mismatches to be reduced. Finely-tunable astigmatic mirrors have the potential to be very useful in gravitational wave detectors for beam reflections at non-normal incidence, but have never been tested. These astigmatic composite mirrors are constructed by bonding a fused silica mirror to a metal back constructed from aluminum and copper, which have different coefficients of thermal expansion. When heated, the mirror is differentially distorted in the x- and y-directions, resulting in an elliptical reflected beam profile. We will model and test these mirrors using a Hartmann sensor.

Real-Time Temperature Monitoring and Control for Cryogenic Systems

Mandy Cheung Mentors: Aaron Markowitz and Brittany Kamai

Approaching the next generation of the Laser Interferometer Gravitational-Wave Observatory (LIGO), namely LIGO Voyager, there are planned improvements to the detectors' primary optics. It is theorized that utilizing coated silicon test masses, cryogenically cooled to 123K, in place of the current fused silica mirrors will drastically reduce coating thermal noise. In making such a change to the interferometer, it is necessary to rigorously test and examine the material properties of the coated silicon at 123K. The project aims to contribute a reliable way with which to accurately monitor and control the temperature of the silicon samples during testing. This method will be used to help in experimentally analyzing which high-emissivity coatings is optimal for noise-reduction purposes, and also the temperature dependence of the coated silicon.

Visualizing 2PN Binary Black Hole Spin Precession

Alicia De Piña Lima Mentor: Davide Gerosa

In the post-Newtonian regime, the time it takes the two black-holes to orbit each other t_{orb} is much shorter than the time it takes the spins and the orbital angular momentum to precess about the direction of the total angular momentum t_{pre} which, in turn, is much shorter than the time it takes the binary's orbit to shrink due to gravitational-wave emission t_{RR} . In short, the dynamics of precessing binary black holes has the following timescale hierarchy: $t_{orb} \ll t_{pre} \ll t_{RR}$. This inequality has been exploited in [1], where it was shown that relative orientations of the three angular momenta are fully specified by the magnitude of the total spin, which oscillates on the precession time [1]. Given the variables identified in [1] that respect the timescale separation of the dynamics of precessing binary black holes (ξ , J, S), we build an interactive 3D visualization routine in Python to explore the phenomenology of spin precession.

References

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A Study of Gravitational Wave Memory and Its Detectability With LIGO Using Bayesian Inference Jillian Doane

Mentors: Alan Weinstein and Jonah Kanner

Gravitational waves are produced by accelerating masses, but in most cases they are too weak to detect. In 2015 LIGO announced its first gravitational wave detection which was produced by the merging of two black holes 1.3 billions years ago. The detectable component of gravitational waves, known as the oscillatory waveform, is predicted to have a smaller, lower frequency counterpart called the memory: the permanent warping of spacetime. In addition to memory's small amplitude compared to the oscillatory waveform, low frequency noise sources on earth make it difficult for ground based detectors to reach the SNR (signal to noise ratio) needed to detect this component. While memory is likely not currently detectable due to LIGO limitations, it is of interest to characterize future detector sensitivities to know where and when to look for this phenomenon. Here we implement Bayesian parameter estimation to calculate the likelihood of a simulated set of LIGO data with a template, both of which include memory. Next we explore binary systems of varying masses and distances along with the noise curves of various observatories in order to establish the SNR needed to detect gravitational wave memory. Our final goal is to find a ballpark SNR value for when memory will be detectable.

In-Situ Laser Mode Spectroscopy for Mirror Phase Mapping

Sandrine Ferrans Mentors: Rana Adhikari, Koji Arai, and Gautam Venugopalan

This project is focused on improving the sensitivity in LIGO by characterizing mirror figure error that contributes to optical losses in the laser. As a result of scattered light, optical losses increase shot noise and destroy the squeezed state of light. Surface perturbations in the mirrors will be evaluated with In-Situ laser mode spectroscopy using the 40 meter prototype laser interferometer gravitational wave detector. Mirror figure error will cause the resonant frequencies of the Hermite-Gaussian modes to shift from their ideal theoretical spacings. Mirror phase maps, a physical representation of the mirror, can be reconstructed by analyzing the shift in mode spacings with Bayesian inference. The success of aLIGO is largely due to precise optical measurements. By mapping the surface of the mirror down a precision of 1 Angstrom, the optical losses and noise can be evaluated minimized.

Physical and Statistical Analysis of Scatter in Fabry-Pérot Arm Cavity of Advanced LIGO

Wenxuan Jia

Mentors: Anamaria Effler and Valery Frolov

In the dual-recycled Michelson interferometer of Advanced LIGO, the optical scatter exists in the resonant Fabry-Pérot arm cavities due to imperfections of test mass surface. We studied scatter in observation run 2 with measurements of photo diodes on the arm cavity baffle, and investigated its relation with other factors sampled from auxiliary data channels. The steady-state scatter during locks of interferometer is analyzed and compared with FFT-based simulation. Regression analysis with informed knowledge from simulation is carried out to the transient scatter measurements, during which the main beam moves on the test masses by the alignment system. With the regression model, the beam position on test mass can be inferred from scatter distribution on baffle and cross-calibrated with dither-based methods. The scatter with the new end test mass installed can be predicted for the upcoming observation run 3.

Investigation of Optimal Nonlinear Temperature Control

Shruti Jose Maliakal Mentors: Andrew Wade and Rana Adhikari

The realisation of gravitational-wave detectors with higher sensitivity demands an improvement in their Brownian thermal noise floor. In an experiment to directly measure this Brownian noise of a novel mirror coating, readout is limited by variations in bulk temperature that cannot be controlled adequately using PID thermal feedback. The use of machine learning neural networks which actively learn to find the optimal set of control parameters as a function of the state of the system is a prospective upgrade from PID. A physical model of the system must be developed to train potential algorithms. Initially, a simple but representative model including only the vacuum can was chosen and made into an OpenAI gym environment. A suitable reinforcement learning algorithm that can control the system in real time must be chosen. DeepQ, PIDNN, ACKTR, and Curiosity are algorithms being tested on the environment. On gauging its success, further complexity can be added to the environment to obtain a closer simulation of the real physical situation. Experiments were also performed on the system to obtain more accurate values of parameters and improve the model. The final aim is to train the network with real data and obtain the optimised heat actuation.

Cryogenic Zero-CTE Temperature Locking of Monolithic Silicon Cavities

Disha P. Kapasi

Mentors: Johannes Eichholz, Chris Wipf, and Rana Adhikari

This project makes use of two 1550 nm lasers which are independently locked to identical short monolithic crystalline silicon optical cavities at 123 K (zero crossing of coefficient of thermal expansion for silicon) and stabilized against frequency fluctuations. Although the cavity placed within a cryostat is cooled and maintained at 123 K, there is no way of determining the absolute temperature of the cavity since the temperature sensors are placed on the heat shield. By designing a current driver for visible laser diodes one can modulate the temperature of the silicon cavity. We sense the corresponding length modulation using the beat note of the resonating IR lasers and obtain a qualitative measure for the temperature relative to the zero-crossing. Then we construct a feedback loop out of this by demodulating the beat frequency time series against the modulation source and feeding back to the heaters on the cavity thermal shields, with the goal to become insensitive to first order to temperature fluctuations.

Noise in IFO Subsystems

Nolan King Mentors: Dick Gustafson and Keita Kawabe

Radio Frequency (RF) signals are used in the sensing and control subsystem of the interferometer to lock the output port to a dark fringe. This is necessary to maintain the sensitivity of the instrument. RF noise in this subsystem can cause the interferometer to lose lock or cause incorrect readings such as whistles in the differential

arm length signal (DARM) as read at the output port. It was previously discovered that a significant contributor to RF noise in the sensing and control system were the ground isolation transforms known as baluns, making a redesign of the component necessary. A corrected design is proposed and prototyped and the resulting attenuation of RF noise is measured. High precision GPS disciplined oscillators are utilized in the data acquisition subsystem to supply a clock for the analog to digital converters (ADC) used to record various signals, including the DARM signal. Jitter of the one pulse per second signal used to discipline these oscillators was previously measured to be ±40 ns. This jitter becomes phase/frequency noise in the oscillator output, resulting in small variations in the sampling period of the ADC. We present a model of the noise and asses its potential effects on the DARM output of the interferometer.

Sub-Classification of Blip Glitches Using Q-Transforms and Convolutional Neural Networks With GravitySpy

Melissa Kohl Mentor: Alex Urban

In the Advanced LIGO observation runs, detection of gravitational waves is directly dependent on the sensitivity of the detectors. Transient noise, called "glitches," restricts sensitivity along with continuous noise, and mimics and obscures real gravitational waves. One machine learning software package used to classify these glitches, GravitySpy, is successful when the spectrogram of the glitch has a very distinct and unique shape. However, GravitySpy's spectrogram of one of the most common types of glitches, called a "blip," has an indistinct shape due to so few cycles being in-band, and tends to ring off template signals of binary black hole mergers, making it especially necessary to eliminate blips for future observing runs. GravitySpy also searches for glitch sources by cross-examining auxiliary channels, but blip glitches are infrequently witnessed and still have unknown sources. Spectrograms with different parameters than those used by GravitySpy could expose subclasses of blips with unique shapes that would help in identifying sources. Manual inspections of small-domain spectrograms of random blip glitches, nearly indistinguishable in GravitySpy, reveal six distinct possible subclasses. In addition, the implementation of convolutional neural networks has provided preliminary evidence of fundamental differences between these hypothesized subclasses, confirming the assumption that there are multiple types of blips and aiding in future searches for blip sources.

Searching for Lensed Gravitational Waves From Compact Binary Coalescences

Ka Yue Alvin Li

Mentors: Alan J.Weistein and Surabhi Sachdev

Einstein's general relativity predicts the radiation of gravitational waves when masses accelerates, for instance, as the components of a binary black hole system orbit each other. This was confirmed when LIGO (The Laser-Interferometry Gravitational-wave Observatory) made the first detection of gravitational waves from a binary black hole merger on 14 September 2015. The success of gravitational waves detection opens a new window for scientists to study the Universe. In Einstein's general theory of relativity, it is also predicted that light rays bend when passing by masses in spacetime, a phenomenon known as gravitational lensing. As a manifestation of Einstein's equivalence principle, everything in motion, independent of their nature, is gravitationally lensed in the same way. In such sense, gravitational waves will also be lensed, resulting in multiple signals which differ in arrival times and amplitudes. Since the amplitudes of such signals may differ, there are cases that they are not identified as signals. In this research, we aim to search for lensed signals of the binary black hole signals detected by LIGO. We generate templates of possible lensed gravitational wave signals for detected events by simulating gravitational wave signals which may have insufficiently high signal-to-noise ratio to be distinguishable from detector noise. We will further attempt to infer the intrinsic properties of the gravitational lenses from the lensed gravitational wave signals identified.

Constructing a Balanced Homodyne Detector for Low Quantum Noise Gravitational Wave Interferometry

John Martyn

Mentors: Andrew Wade, Kevin Kuns, and Aaron Markowitz

Achieving more efficient detection of gravitational radiation is a goal of contemporary experimental physics, as it will enable novel tests of general relativity and provide information on astronomical bodies that are difficult to observe through the electromagnetic spectrum. However, as gravitational wave interferometers increase their sensitivity, sources of quantum noise dominate over classical noise sources. Further reduction of noise requires gravitational wave observatories to use non-classical, squeezed states of light, in which the quantum noise of one quadrature is decreased while that of another is increased. A balanced homodyne detector can measure an arbitrary quadrature of light by mixing a weak signal with a strong source of light. This technique can be incorporated into interferometers to perform precise measurements using squeezed light. Since these highly

quantum states are crucial to gravitational wave physics, numerous research labs seek to perform experiments with these detectors. The goal of this project is to construct the optical components and readout electronics for a balanced homodyne detector that may be used in various LIGO research labs performing experiments with non-classical light.

Utilizing Machine Learning to Search for LIGO Sources

Sarah McCarthy

Mentors: TJ Massinger and Jess McIver

LIGO is one of the most sensitive instruments ever built, and with great sensitivity comes a significant amount of noise. Currently, the LIGO Scientific Collaboration is searching for ways to more efficiently differentiate between signal and noise, on both hardware and software. To date, the PyCBC pipeline has aided in the analysis of several gravitational wave detections. We utilized outputs of PyCBC software to compile larger amounts of data, including signal and noise, into SNR density plots, and we modified them so that they could be easily interpreted by an image classifier. We expected the signal density plots to be much more well-localized than for noise, based on observations of known instances of signal and noise. After selecting the parameters that demonstrated features in the density plots, we created a convolutional neural network to search for these patterns. We trained and tested the neural network over increasingly large and varied data sets.

Modeling and Measuring Eccentricity in Binary Black Hole Inspirals

Simona Miller

Mentors: Alan Weinstein and Jonah Kanner

Due to the emission of gravitational wave (GW) radiation, most compact binaries are expected to circularize before emitting GW in the LIGO frequency band. However, if a binary black hole system resulted from dynamical capture or hierarchal triple interactions close to the end of its life, there is a probability that the system could retain non-negligible eccentricity while in the LIGO band. As such, observing eccentricity from a gravitational wave signal could be a clear signature of dynamical origins. Despite the observational importance of eccentricity, the techniques needed to detect and characterize eccentricity currently remain in their early stages. We seek to model and assess detectability and identifiability of eccentric binary black hole systems, aiming to discover how accurately we can estimate parameters of an eccentric waveform. In particular, we search for degeneracies between eccentricity and other higher order effects, such as spin precession. We employ a variety of data analysis techniques, including calculating overlaps between waveforms, constructing likelihood distributions, and performing Bayesian inference.

Searching for Signs of a Galactic Excess of Gravitational Waves

Serena Moseley Mentor: Thomas Callister

No source of gravitational waves from the Milky Way galaxy is known to radiate within both the amplitude and frequency ranges of Advanced LIGO or Virgo. It is, however, possible that an unknown galactic source is emitting gravitational radiation at frequencies accessible to current detectors, but is too weak to be individually resolvable. If so, it would be easier to identify the source if we could recover the sky distribution of the population. We develop a method of mapping the sky distribution of unmodeled gravitational-wave bursts to determine whether there exists a galactic excess of gravitational waves in the aLIGO-Virgo frequency band. We simulate both an isotropic population and a galactically-distributed population of gravitational-wave bursts and inject these two sets into the parameter estimation code Bayeswave in order to generate posterior probability distributions on our simulated signals' sky locations. We will ultimately combine these into probability distributions of source locations for each of our two populations and demonstrate that we can correctly classify our two distributions based on their recovered localizations.

Developing Phase Map of Cavity Mirrors Using Laser Mode Spectroscopy

Keerthana S. Nair

Mentors: Gautam Venugopalan, Koji Arai, and Rana Adhikari

The LIGO interferometers are Michelson Interferometer with Fabry-Perot cavities introduced to it. The cavity is defined by two mirrors which we call the Initial Test Mass (ITM) and End Test Mass (ETM). The light which enters the cavity bounces between the cavity mirrors and the total distance light travels inside the cavity increases. These are certain features which leads to the power loss of light inside the interferometer cavity. One of the features which contribute towards this power loss is known as the Mirror Figure error. Mirror figure errors are the low frequency surface defects present on the test masses which results in the low angle scattering of light. Through this project we are trying to develop an in-situ technique to precisely characterize the figure error of an optical cavity. We call this technique the Mode spectroscopy. This project involves running cavity scan experiment in the LIGO 40m-prototype as well as analysing the data obtained.

Seismic Cloaking for LIGO Kaila Nathaniel Mentor: Brittany Kamai

Metamaterials are carefully designed building blocks densely packed into a structure. They are usually artificially made, but new developments indicate metamaterials could be made out of natural materials such as trees. These new metamaterials offer a potential avenue for reducing seismic noise at low frequencies, which are typically from human sources. Seismic noise is an issue for highly precise interferometers, such as those used for gravitational wave (GW) detectors. As an example, the strain amplitude of GW170817 (the 2017 binary neutron star merger) was on the order of 10⁻²², while average seismic activity at LIGO-Livingston and LIGO-Hanford is ~10⁻⁹ at 10 Hz. Skillful detector design has vastly reduced seismic noise, and we are able to measure the first GW signals. In this study, we investigate the feasibility of using trees as a seismic metamaterial that could further shield the LIGO detectors from seismic activity. This seismic cloak would reduce low frequency surface waves away from affecting the detector, thereby increasing sensitivity. This study models the energy transfer as waves pass through bandgap filters to see the extent of noise reduction. We start with acoustic cloaking as an analog for seismic cloaking to quantify the relationship between the incoming waves and the structure of the cloak. Our goal is to quantify the energy transfer near the cloak to determine how the detectors can be shielded from seismic activity. Future directions of this work would move towards solving the full scale elastodynamic equations to build a realistic model of the environment around the LIGO detectors. Results from this work could have a future impact on large-scale high sensitivity detectors.

Extending the Reach of Gravitational-Wave Detectors With Machine Learning

Tri Nguyen

Mentor: Michael Coughlin

We apply Long Short-Term Memory (LSTM) Neural Networks as a time-series regression analysis technique to filter instrumental noises from gravitational-wave detectors at LIGO. Unlike traditional neural networks, LSTM networks can store and use information from their past inputs, and thus is robust in handling sequential data like gravitational-wave signals. Once trained on the detector noise data, an LSTM network should be able to learn, predict, and subtract both the linear and non-linear noise coupling mechanisms. This would result in a sensitivity improvement, most greatly at the low-frequency limit 20-100 Hz where noise features are expected to be easier to learn, and allow the detection of gravitational-wave sources currently below the noise floor. In this paper, I discuss our analysis pipeline and current progress.

Real-Time Universal Transfer Function Synthesizer

Izabella Pastrana

Mentors: Johannes Eichholz, Rana Adhikari, and Christopher Wipf

Advanced LIGO's existing Control and Data System design utilizes a global emulated real-time system that employs analog-to-digital and digital-to-analog converters clocked slowly up to 64kHz. These frequencies are suitable for processes which do not require high control bandwidths, such as feedback to temperature or suspensions. However, faster components—like the servos for laser amplitude and frequency stabilization—would benefit from being monitored at higher frequencies, necessitating higher clocking frequencies and high frequency transfer function measurements. A vector network analyzer (VNA) with custom transfer function measurement capabilities was thus developed and implemented on the Red Pitaya, a data acquisition and signal generation platform whose processor consists of a field-programmable gate array (FPGA) and a central processing unit (CPU). The Red Pitaya–based VNA introduces error estimation and adaptive sweeping across frequencies for a series of transfer function measurements. The integrated error estimation, which is generally not a feature of commercial network analyzers, can be incorporated into the fitting process, helping add credibility to the estimated transfer function of a system under measurement. This can then be used as input for the adaptive sweeping function which allows improved resolution in feature-rich frequency ranges or regions with low signal-to-noise ratio.

Thermal State of Advanced LIGO Test Masses: Implementation of a Real-Time Mirror Degradation Monitor

Guadalupe Quirarte Mentors: Carl Blair and Joseph Betzweizer

Advanced LIGO (aLIGO) utilizes high-reflectivity fused silica mirrors interacting with high power laser beams enclosed in cavities where the optical power reaches 800 kW. During aLIGO operation the detector does not run continuously, environmental disturbances such as earthquakes result in the loss of power in the optical cavities. Certain alterations due to these changes in high laser power can result in detrimental effects on the detectors that potentially impact detector sensitivity and duty cycle. Studies on observation run 2 highlight an anomalous absorption in one aLIGO test mass mirror coating. Identifying such anomalies will become more important as the detectors approaches design sensitivity. I analyzed thermal state models of aLIGO test masses and developed a nested Kalman Filter with the ultimate purpose of providing real-time monitoring of the change in coating absorption. The monitor I created utilizes the test masses 8 kHz mechanical eigenfrequencies to probe the test

mass temperature. The system uses a first order exponential model derived from finite element analysis. The model is fit from the eigenfrequency response to a 0.1 W step in laser power heating on the HR surface, equivalent to 1ppm absorption of a 100kW beam. The model time constant is 6.3 hours, and has an amplitude of 8.114 Hz/W. The inner Kalman Filter state is the eigenfrequency. The outer Kalman Filter updates the model amplitude state once per lock, this provides an estimate of the coating absorption. The monitor has been tested on simulated data and on eigenfrequency measurements taken during the month of July 2017.

Optical Loss Characterization at the 40m Prototype Lab

Pooja Sekhar

Mentors: Gautam Venugopalan and Koji Arai

Advanced LIGO is a very sensitive instrument and is prone to a wide range of noise sources. Scattering of light due to the irregularities on the surface of test mass reduces the power circulating in the Fabry Perot cavities leading to a lower signal to noise ratio and might also couple back into the instrument imparting a random phase noise. The main purpose of this project is to characterize all the scatter loss in the 40m lab using a CCD camera with Gigabit Ethernet connection. It involves finding telescopic lens solution that focuses the test mass onto the camera sensor. The next main goal is to use a neural network to resolve the angular motion of test mass from the beam spot motion observed in the video captured using the GigE camera. In this regard, the neural network being developed in Keras is trained and tested on simulated video of Gaussian beam spot motion in a noisy background by applying a sinusoidal signal. Several hyperparameters of the network need to be found that minimizes the loss value by multiparameter optimization algorithm.

Improving Earthquake Monitoring for Gravitational-Waves Detectors With Historical Seismic Data Sky Soltero

Mentor: Michael Coughlin

A remarkable level of isolation from the ground is required for Advanced gravitational-wave detectors such as the Laser Interferometer Gravitational-Wave Observatory (LIGO) to function at peak performance. These ground based detectors are susceptible to high magnitude teleseismic events such as earthquakes, which can disrupt proper functioning, operation and significantly reduce their duty cycle. As a result, data is lost and it can take several hours for a detector to stabilize and return to the proper state for scientific observations. With advanced warning of impeding tremors, the impact can be suppressed in the isolation system and the down time can be reduced at the expense of increased instrumental noise. An earthquake early- warning system has been developed relying on near real-time earthquake alerts provided by the U.S. Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA). The alerts can be used to estimate arrival times and ground velocities at the gravitational-wave detectors. By using machine learning algorithms, a prediction model and control strategy has been developed to reduce LIGO downtime by ~30\%. This project presents further prediction improvements under consideration to better develop that prediction model and decrease interruptions during LIGO operation.

Differentiating the Signal From the Noise: Towards Optimal Choices of Transient Follow-up Bethany Suter

Mentors: Alex Urban and Michael Coughlin

With the advent of the follow-up of large localization regions from gravitational-wave detectors and gamma-ray burst transients with wide field-of-view telescopes, efficient follow-up of the many identified candidates is required. Due to limited telescope time, it is important to create prioritized lists based on the many candidates identified. Towards this end, we use models derived from GW170817 to differentiate between kilonovae, gamma-ray burst afterglows, and supernova transients. We show how to use these models to limit the lists of transients required to follow-up. We explore the dependence of the transients excluded based on the number of days of photometry and spectra available and the passbands monitored. We also investigate the effect of this reduced follow-up on estimations of the properties of the transients. We show that at least four nights of photometry are required to benefit significantly from this approach. We implement a whitening technique for the spectra model in order to increase the quality of the fit and decrease the number of days needed to identify the transients.

Stabilization of a 2um Laser Using a Fiber-Delay Mach-Zehnder Interferometer

Vinicius D. Wagner Mentor: Andrew Wade

In the pursuit of enhanced detector sensitivity, the future LIGO Voyager update will likely incorporate crystalline silicone cryogenic test masses whose transparency window allows for the transmission of lasers of longer wavelength. Less is known about the pre-stabilization performance and limiting noise sources of such devices in this context, which this project explores by using a 2um laser in all-fiber delay-line Mach Zehnder interferometer.

A delay line is incorporated in the interferometer in the form of a path length mismatch, which serves as a frequency discriminator when the signal is stabilized at mid-fringe. This stabilization effort is done by employing a closed loop feedback between the 2um laser and an identical MZ interferometer whose longer arm is actuated upon with a thermal plate. The ideal conclusion of our experiment would be additional data that can support the usage of a longer wavelength laser on the new generation LIGO Voyager.



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Observations of Magnetar PSR J1622-4950 at Radio Wavelengths

Ariel Amsellem, University of Chicago Mentor: Walid Majid, Jet Propulsion Laboratory, California Institute of Technology

Magnetars are thought to be a distinct class of rotating neutron stars with spin periods in the range of ~1-10 s. These objects are believed to be powered by the decay of their intense magnetic fields. The magnetar population of ~30 objects, constitute a small fraction of the known pulsar population, now standing at ~2,600. Transient X-ray and gamma-ray outbursts are distinct features of magnetars, yet, only four magnetars have been detected at radio wavelengths. One of these radio magnetars is PSR J1622-4950, rotating with a spin period of 4.3s with an estimated magnetic field of ~3e14 G, was recently reactivated in April 2017 at both radio and X-ray frequencies. We have carried out a systematic analysis of radio data taken over a span of almost a year and a half, typically simultaneously over two widely separated frequency bands, S-band (2.2 GHz) and X-band (8.4 GHz). This analysis has yielded a rich set of observables, including the evolution of the magnetar's spin period, flux density, spectral index, rate of bright single pulse emission, and pulse morphology. There appears to be a gradual increase in the period over these observations, which is a well-documented characteristic of most magnetars. These period measurements appear to be broadly consistent with predictions based on earlier observations. Even though the flux density of this magnetar has been variable, there has been a steady increase in single pulse rates over the span of observations at both S- and X-Bands, with the rate at X-Band almost always greater than at S-Band.

Automated Pipeline for Venusian Cloud Tracking

Nicholas Ardavin (Jet Propulsion Laboratory) and Kenyon Prater (Jet Propulsion Laboratory) Mentors: Attila Komjathy (Jet Propulsion Laboratory, California Institute of Technology) and Siddharth Krishnamoorthy (Jet Propulsion Laboratory, California Institute of Technology)

At 2.3 microns, a gap in the absorption spectrum of Venus' CO2-atmosphere allows observations of the nightside, where the lower clouds show up as silhouettes, backlit by thermal emission from below. Observations in this region are of particular interest for determining wind velocities via cloud tracking. Wind velocity measurements allow us to compare observed winds with those predicted by Global Circulation Models (GCMs). Of particular interest are latitudinal wind-velocity profiles, time-varying cycles in the Venusian atmosphere, and correlation of wind speeds with surface features. We are currently investigating all of the above.

We present an automated pipeline for data reduction, from raw images of Venus' nightside to useful wind velocity maps using cloud-tracking methods. By stacking subsets of the sharpest Venus images, we are able to achieve angular resolutions of 0.5" or better, corresponding to an approximately 150 km resolution near the center of Venus' disk. From these image stacks we are able to extract wind velocity fields over the night side with at least 20 latitudinal divisions, RMS errors of approximately 5 m/s, and temporal changes in wind speeds at the 10% level or less. We use this pipeline to reduce data from the IRTF's SpeX instrument, spanning over 15 years of observation. In particular, we compare methodology and results between two image sets: an IRTF campaign from April-May 2017 and Akatsuki IR2 images taken in 2016.

Cryogenic Slip Test on the Cold Electronics Assembly for the Euclid Mission

Urmi Bhaumik (California Institute of Technology)

Mentors: Andrew Berg, Warren Holmes, Christopher Ruiz, and Fang Zhong (Jet Propulsion Laboratory, California Institute of Technology)

The Euclid telescope will be launched in 2020 to explore deep space and explore fundamental ideas including the inception on the universe. The cold electronics assembly (SCE) is part of the electronic system in the NISP (Near Infrared Spectrometer-Photometer) instrument that is part of the telescope and is designed to operate the infrared detector array to transmit digitized image data to host electronics and perform digital programming and timing of the detector. The SCE is of specific interest as it has been redesigned; it is comprised of multiple components including an aluminum chassis which is bolted to a PCB. The coefficient of thermal expansion between these two components is notably different. So, a thermal cycling test is being conducted to determine whether the PWB will slip relative to the aluminum during cool down to operational temperature due to the stress from the relative thermal contraction.

Capturing Onboard Summarization to Monitor Image Change (COSMIC): Araneiforms (Spiders) Anneliese Braunegg (Case Western Reserve University and Jet Propulsion Laboratory)

Mentors: Lukas Mandrake, Kiri Wagstaff, and Gary Doran (Jet Propulsion Laboratory)

Mars exhibits various transient and seasonal landforms of scientific interest. Presently, study of these landforms is restricted by the Mars Reconnaissance Orbiter's (MRO's) limited storage capacity and downlink bandwidth. COSMIC seeks to solve this problem by using machine learning to develop classifiers (to be included in future MRO-like missions) that can identify landforms of interest and prioritize images containing them for storage, onboard change-detection analysis, and downlink. The Araneiforms sub-project aims to develop a classifier specifically for araneiforms (informally, "spiders"), a seasonal landform of interest due to their CO₂ sublimation-driven formation and spider-like appearance, unparalleled on Earth. To develop an initial classifier, we first

create a task on the crowd-sourcing website Zooniverse wherein citizen- scientists label araneiforms in images of Mars. Next, we train the TextureCam pixel classifier (originated at JPL) on this labeled data. Finally, we seek to improve and augment the classifier by performing hyperparameter optimization, including image metadata fields in the feature set, and adding additional image filters. The resulting classifier will serve as a proof- ofconcept prototype that, together with prototype classifiers for other Martian landforms, will demonstrate COSMIC's objective of automating landform classification to be feasible and will kickstart development of the classifiers for future Mars orbiters.

The MISR Plume Height Project: Digitizing Smoke Plumes

Angela I. Ceja, Pasadena City College

Mentors: Abigail M. Nastan and Mika Tosca, Jet Propulsion Laboratory, California Institute of Technology

MISR (Multi-angle Imaging SpectroRadiometer) is an instrument aboard the NASA Terra Satellite. It consists of nine cameras, which are positioned at different angles. These nine cameras capture images of the Earth. The MISR Plume Height Project focuses on providing information regarding aerosol heights, aerosol properties, and wind corrected height values. It requires a trained worker to observe the scenes containing the plumes, and then digitizing them to obtain height data. Furthermore, this project has achieved digitizing plumes from past years. The goal of this project for the summer of 2018, is to digitize plumes from July to December of 2011. The trained worker corrects the misregistration, draws a polygonal shape around the plume, and indicates wind direction. Fundamentally, Scientist can have access to plume data that have been digitized and use it for fire radiated energy models, climate models, aerosol models, or air quality forecast models.

Optimizing an End-Effector for Underwater Mobile Manipulation

Kristine Chelakkat, Jet Propulsion Laboratory, California Institute of Technology Mentors: Matthew Gildner and Justin Koch, Jet Propulsion Laboratory, California Institute of Technology

The Underwater Mobile Manipulation task aims to develop an underwater robotic system capable of perceiving and interacting with environments pertinent to the offshore energy sector. To fulfill the purpose of such a system, an end-effector capable of manipulating these desired objectives is crucial. Utilizing a process of modelling and prototyping multiple designs, the gripper was designed to control two targets: the hot stab and the valve paddle. The fingers of the gripper were designed to clamp onto the round body of the T-bolt as well as the flat surface of the paddle. For additional contact and efficacy, additional removeable components that mount onto the fingers cup the T-bolt. A palm with slots for increased T-bolt interaction and a flat roof for paddle mounting was added to the top of the gripper. To ensure accurate positioning, hard stops that clamp onto the housing were manufactured to help calibrate the fingers. We have completed preliminary testing in air with the T-bolt and will continue testing to verify effectiveness underwater and with the paddle.

Visualization for Mars 2020 Terrain Relative Navigation

Eric Chen, Jet Propulsion Laboratory, California Institute of Technology Mentor: Andrew E. Johnson, Jet Propulsion Laboratory, California Institute of Technology

Many sites of scientific interest on Mars contain hazards such as scarps, rock fields, and craters, and are too dangerous for landing. For Mars 2020 some of these sites will be reachable with the new Terrain Relative Navigation (TRN) system, which will allow landers to divert away from large, known hazards. In order to figure out where to divert, TRN relies on the Lander Vision System (LVS), which matches features from camera images during descent to an onboard map to determine the lander's position. Many factors, including terrain relief, camera distortion, and high attitude rates may cause incorrect matches (outliers), but it is difficult to definitively attribute outliers to these causes, and understand how they affect accuracy. The objective of this project was to create post processing and visualization tools to help interpret data logged from previous LVS tests and simulations. These tools will be used to investigate incorrect landmark matches and their causes, and ensure any issues discovered will not affect the LVS system on its first flight on Mars 2020.

Real-Time Image Streaming Server Platform for Digital Holographic Microscopy

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Digital Holographic Microscopy (DHM) and Light Field Microscopy (LFM) are created in hopes of detecting extant microbial life on Enceladus, Europa, and other icy worlds. DFM is a represents an alternative technique with no moving parts and higher throughput than traditional microscopy, making it potentially useful in space for detection of extant microorganisms provided that sufficient numbers of cells can be collected. LFM is a 3D microscopic imaging technique that produces 3D images with fluorescent light. JPL is developing a microscope that integrates these techniques and is intended for remote use. As part of this development, I am developing a software to stream data in real time from the microscope to remote users. The software can stream data through multiple users at a time, save data into a TIF image file, and record the timestamps of all the data being recorded. In

Mentor: Christian Lindensmith²

addition, it is capable of receiving commands from users for commands to possibly change settings of the camera and so forth. When placing the DHM/LFM into a remote lander in search of biological samples, the image streaming platform can deliver real-time quantifiable data from anywhere in the world on the same network.

Constraints on the Dark Energy Survey's Photometric Galaxy Redshifts

Rodrigo Córdova-Rosado, Harvard University, Jet Propulsion Laboratory/California Institute of Technology Mentors: Jason Rhodes and Daniel Masters, Jet Propulsion Laboratory/California Institute of Technology

Dark energy, a force that counteracts gravity and accelerates the expansion of the universe on the grandest of scales, continues to confound the astrophysicists. In order to constrain its behavior in the universe, cosmologists are undertaking large surveys to understand its effects. The Dark Energy Survey (DES) is surveying an eighth of the sky for galaxies with redshift 0.2 to 1.5 to observe weak lensing effects and analyze cosmic shear. DES measures galaxy photometry in the four distinct $g \ r \ i \ z$ bands, and hope to constrain their redshift from these photometric measurements. The error associated with these photo-z's contribute significantly to the DES cosmological parameters' error from weak lensing. Invoking Self Organized Maps (SOM), we establish a novel method of estimating the N(z) associated with the tomographic bins created to organize the SOM cells which capture galaxies with discreet color properties, based on the photometric measurements. By using a better constrained photometric survey for a smaller subset of the sky, we can leverage the few known redshifts to inform our color measurements across the SOM, and estimate N(z) for the full survey sample. This method has proven to constrain the mean difference between estimated and true N(z) for a simulated survey within 4%.

Centroiding as Signal Intensity Deconvolution

William Conner DiPaolo, Jet Propulsion Laboratory/California Institute of Technology Mentor: Ryan Rogalin, Jet Propulsion Laboratory, California Institute of Technology

NASA's Deep Space Optical Communications program aims to replace traditional radio-based communications links with better performing optical counterparts in space missions, including the upcoming 2022 Psyche mission. Being able to track the spacecraft transmitter is crucial for the performance of the ground receiver, yet no known work handles estimation of the beam centroid when only rudimentary access to the signal (the number of photons that have hit each *quadrant* of the receiver) is allowed at far range. We close this control loop by making a reduction to the task of signal intensity reconstruction via an inverse problem, proving sample complexity bounds for a previously unpublished method, and presenting two novel estimation schemes that empirically perform better in the near and medium range settings. Our centroid estimation method is the first consistent procedure in the literature, and our contributions also hand the DSOC team immediate guarantees for decoding, which relies on signal intensity estimates.

DUV Raman Spectroscopic Analysis of Microbes

Angelica Escobar, Jet Propulsion Laboratory, California Institute of Technology Mentors: Rohit Bhartia and Haley Sapers, Jet Propulsion Laboratory, California Institute of Technology

Deep UV (DUV) Raman Spectroscopy is a technique used to observe vibrational and low frequency modes of molecules allowing for molecular identification in the deep ultraviolet region. This technique is favored due to its ability to obtain spectra from its fluorescence free region and its high sensitivity in the detection of organics. DUV Raman spectroscopy is widely used in the analyses of organics as well as bacterial cells. An investigation involving two different bacteria is carried out using defined media to mimic a practical environment with the intent of observing any changes, commonalities, and/or Raman signatures in their growth cycles. A 100-hour growth curve involving the bacteria, *E. coli* and *B. subtilis* respectively, is carried out and analyzed using DUV Raman spectroscopy throughout the organisms' growth cycles to study and observe any changes in the Raman spectra and if those changes correlate to physiological changes in the cell. Along with DUV Raman Spectroscopy, cell counts are conducted and an optical density reading is measured followed by a Modified Lowry protein assay in order to quantify the protein levels in the cultures.

Genetic Inventory of Microbes Present on Spacecraft and Spacecraft Associated Surfaces

Paula Fogel, Cornell University

Mentors: Lisa Guan and Parag Vaishampayan, Jet Propulsion Laboratory, California Institute of Technology

The Mars 2020 mission, which will cache Mars soil and core samples for possible future return, requires that a "Genetic Inventory" of potential microbial contaminates on the spacecraft be captured. A catalog of microbes present on spacecraft and spacecraft associated surfaces helps account for biological contamination from Earth. This information may be used to be establish a baseline of possible Earth-based biological contaminants for future sample return missions to ensure scientific integrity. Since any future return samples would likely be analyzed for indicators of the presence of life, including nucleic acids, a genetic inventory catalogs DNA present on the spacecraft prior to launch in order to mitigate any findings of biological material as false positives. The aim of the Genetic Inventory (GI) project is to create a "passenger list" of the organisms and nucleic acids that have been

found on Mars 2020 spacecraft and spacecraft associated hardware. The focus for this summer was figuring out the optimum DNA extraction and concentration techniques for processing the low-biomass samples that come from spacecraft sampling. This will the first genetic inventory study of spacecraft to use whole genome sequencing and amplicon sequencing for taxonomic analysis.

Supercritical CO₂ Extraction and On-Line Chromatography for Ocean Worlds

Richa Ghosh, Jet Propulsion Laboratory, California Institute of Technology Mentor: Bryana Henderson, Jet Propulsion Laboratory, California Institute of Technology

Ocean Worlds have gained recent interest due to their potential of originating and sustaining life. With future *in situ* missions to Ocean Worlds such as Europa in reach, instrumentation technologies in order to accurately analyze biomarkers from complex or unknown matrix materials are needed. Supercritical fluid extraction (SFE) coupled with supercritical fluid chromatography (SFC) where supercritical CO₂ (scCO₂) is the solvent is promising for the extraction and detection of these biomarkers. Several advantages of the SFE-SFC method include temperature operation of 25°C – 50°C, reduction of necessary chemicals and shortened analysis time. A SFE-SFC online benchtop instrument, which has already been assembled, has previously demonstrated extraction, separation and detection of several nonpolar analytes such as free fatty acids, heterocycles, carotenoids, acids and polycyclic aromatic hydrocarbons using scCO₂. In this work, an array of screening applications to determine the capabilities and limits of the SFE-SFC instrumentation was conducted. High-throughput analysis of nonpolar species was done by determining the range of molecules that can be analyzed by SFE-SFC and under what conditions. Samples of different materials (such as soil, water, etc.) were spiked with known biomolecules and then chemical analysis was performed in order to validate the method. In addition, the range of compounds that can be extracted was also studied.

The Ergodic Theory of Mean Satellite-Ground Station Visibility Time

Andrew Graven, Cornell University, Cornell University Mentor: Martin Lo, Jet Propulsion Laboratory

The classical method of calculating mean satellite-ground station visibility time entails integrating over the trajectory of the satellite on time scales of 5000-10000 days. This technique is accurate in most cases but it's also very slow. Through the use of Ergodic theory, my mentor discovered a faster stochastic method of making this calculation for non-periodic circular orbits. My project for the summer has been to extend this method to the much more complex case of elliptical orbits. Ultimately, we obtained a triple integral which yields the correct result to within .5% in most cases and does so in 1/500th the time. We expect this technique to be especially useful in the rapid determination of optimal satellite trajectories and ground station placement. Beyond Earth, this will be useful for planning networks on the Moon and on Mars.

Acknowledgments

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Software Development to Visualize Spectroscopy of Jupiter's Atmosphere

Laura Hu, Jet Propulsion Laboratory, California Institute of Technology; California Institute of Technology Mentor: Glenn Orton, Jet Propulsion Laboratory, California Institute of Technology

Software was developed to produce 3D near-infrared spectral images of Jupiter's atmosphere, from scanning a 1D spectrometer slit across the disk of Jupiter. Near-infrared spectroscopy measures the interaction of particles in the atmosphere with radiation in the near-infrared wavelength range, some 2-3 times longer than light at visible wavelengths. These measurements reveal important characteristics of the atmosphere, such as the chemical composition and cloud properties. Computer programs were written to process the raw measurements. The processed spectra, each represending a thin column of pixels oriented in the north-south direction, are then stacked side by side in the east-west direction to create full images of Jupiter, each"pixel" of which contains a full spectrum. The spectrum at each pixel of the image can be considered a third dimension. These images display relative radiance at each position of the planet, similar to a heat map. Images are generated for each interval in the wavelength range. The software automatically conducts this procedure for a given number of measurements and displays the final images in a user-friendly manner.

COSMIC (Content-based Onboard Summarization to Monitor Infrequent Change): Detection of Martian Swiss Cheese Terrain via Pixel-Wise Random Forest Classification

Daniel Jeong (Columbia University and Jet Propulsion Laboratory, California Institute of Technology Mentors: Lukas Mandrake and Gary Doran (Jet Propulsion Laboratory, California Institute of Technology

While the transmission of data through space provides us with invaluable information and insight about the cosmos, it is not without constraints. Limitations in bandwidth (i.e. data transfer rate) and space-ready hardware capabilities and the lack of autonomy in space instruments render data collection inefficient and slow down the

rate of scientific discovery. In an attempt to address such restrictions, the objective of the COSMIC (Contentbased Onboard Summarization to Monitor Infrequent Change) project is to develop machine-learning-based capabilities that allow Mars orbiters to autonomously identify scientifically significant regions, landmarks, or spectral compositions and summarize the changes that occur in them. My work is concentrated on working with HiRISE browse images of Swiss cheese landforms, which are pits and troughs that form in the Martian residual south polar cap (RSPC) as a result of the interactions between the seasonal deposition (winter) and sublimation (spring-summer) of CO2 ice (Buhler et al., 2017). More specifically, it consists of three parts: devising a method to generate high-quality labels through a crowd-sourcing platform called Zooniverse, training/testing a pixel-level random forest classifier called TextureCam, and optimizing the classification performance by engineering useful features (e.g. image filters) and hyperparameter tuning.

Planetary Broadband Seismometer Development: FPGA Based Lock-In Amplifier

Yonatan Juarez, Jet Propulsion Laboratory, California Institute of Technology Mentors: Talso Chui and Inseob Hanh, Jet Propulsion Laboratory, California Institute of Technology

The Planetary Broadband Seismometer(PBBS) is a device that is intended to measure low frequency signals in the Ocean Worlds, embedded in noisy environments. To make this possible, the PBBS will need to exceed the performance of current state-of-the-art seismometers. The focal point of this seismometer design is to successfully implement a capacitive displacement sensor, which can measure a small acceleration below 10⁻¹¹ g in the frequency range between 0.01 to 10 Hz. To achieve this sensitivity, we implemented a digital lock-in using commercial, FPGA based A/D and D/A boards to test their noise performances. A digital lock-in software is programmed using LABVIEW FPGA SW. In this digital lock-in architecture, a reference sinusoidal signal (a look-up table) is generated by a FPGA program. And a simulated input signal is low-pass filtered before mixing (multiply operations) with the reference signal. A digital filter (low-pass) is then applied to eliminate the high frequency components of the mixed signal.

Calibrating and Archiving Mid-Infrared Images of Jupiter's Atmosphere

Min Hyuk Kim, Jet Propulsion Laboratory, California Institute of Technology Mentor: Glenn Orton, Jet Propulsion Laboratory, California Institute of Technology

Mid-infrared images of Jupiter were taken at NASA's Infrared Telescope Facility with the Mid-IR Spectrometer and Imager (MIRSI) and at National Astronomical Observatory of Japan with the Cooled Mid-IR Camera and Spectrograph (COMICS). These images need to be submitted to NASA's Planetary Data System (PDS) in an archive using the latest standards so that the data are available to future scientists studying Jupiter. This endeavor in archiving commenced in 2015 with SURF student Malavika Ventnakesan and continued by 2016 SURF student Victoria Beizer. This project required researching the current PDS standards and becoming familiar with the dataset. Ancillary files that are necessary to understand the data were collected for the archive in addition to the raw and reduced data. Each image required an XML label that included relevant information about when and how it was taken. The final archive was submitted to NASA's Planetary Data System for review. Once it is accepted, scientists will be able to use the data to support future research related to Jupiter. In addition, the initial process was begun to provide final calibrations of mid-infrared images from TReCS instrument at Gemini South, VISIR at the Very Large Telescope, and MIRAC at the IRTF using IDL programs developed by SURF intern Jagath Vytheeswaran and my mentor.

Improving Explanations for Unexpected Image Content Detection

Jake Lee, Columbia University and Jet Propulsion Laboratory Mentors: Kiri Wagstaff and Umaa Rebbapragada, Jet Propulsion Laboratory, California Institute of Technology

The scientific discovery process relies on the ability of researchers to quickly recognize and interpret data with unexpected properties. This is especially the case with experiments based on image analysis, which often rely on exhaustive human review. We previously augmented the DEMUD tool to discover novel images by representing image content with features derived from a convolutional neural network. In addition to making meaningful prioritizations, DEMUD was able to generate interpretable explanations (e.g., highlighting unusual colors or shapes in the images). However, these explanations were often too blurry or confusing to be useful. Our current work significantly improves the quality of these explanations by capturing more precise features. Colors, shapes, and textures are now clearly distinguishable, reducing uncertainty in interpreting them. By improving the explanations, we hope to provide a better understanding of DEMUD's decisions, in turn increasing the user's trust in DEMUD's prioritizations. Work is ongoing to further refine these explanations and measure the impact of the improved explanations via user studies.

Developing and Improving SatStressGUIv6.0

Edgar Lopez^{1,2}

Mentors: Robert Pappalardo¹ and Alex Patthoff^{1,3}

¹Jet Propulsion Laboratory, California Institute of Technology, ²University of California Los Angeles, ³Planetary Science Institute

SatStressGUI is an open source program that provides a graphical user interface to compute stress orientations and love numbers for diurnal tidal stresses, nonsynchronous rotation, ice shell thickening, obliquity, and polar wander. The program also generates stress plots and models cycloid-style lineaments which can be correlated to observed fracture patterns. Over the course of the internship, I have fixed a host of bugs, added features to enhance user experience, and improved the accuracy of calculations. SatStressGUI's interface was built using the WXpython toolkit. Through debugging and constraining user input SatStressGUI has gained robustness.

Ice Stability in Permanently Shadowed Craters at the Lunar Poles

Jose M. Martinez-Camacho, Jet Propulsion Laboratory, California Institute of Technology Mentor: Catherine M. Elder, Jet Propulsion Laboratory, California Institute of Technology

Surface temperatures on the Moon are typically too warm to sustain water ice for long time-scales. However, craters and other topographies can cast permanent shadows that produce temperatures cold enough to trap water ice (110 K) and other volatiles for billions of years. These potential ice deposits are valuable to human exploration due to their potential to be used as a resource. Understanding the distribution of water ice on the Moon can also help us understand the mechanisms that deliver water to planetary bodies. In this project, we model temperatures within craters located near the lunar poles. The model will use ray tracing to produce shadows and secondary reflections on the crater surface and will solve the 2D heat diffusion equation to estimate temperatures throughout the crater. These results will allow us to investigate the thermal stability of volatiles on the Moon within these surface features.

Constraining Mantle-Plume Induced Subduction With Venusian Corona

Cathy Miao, California Institute of Technology

Mentor: Suzanne Smrekar, Jet Propulsion Laboratory, California Institute of Technology

While Venus is similar to the Earth in many aspects, it lacks plate tectonics, and therefore, convergentboundary plate subduction. However, mantle-plume induced subduction has been proposed to be a formation mechanism for some of the quasi-circular, volcanic features, known as coronae. In this project, we examine 82 Venusian coronae using Magellan radar and topography data to identify features that have some or all of the characteristics of plume-induced subduction. More specifically, we look for features such as partial trench arcs, trench volcanic flooding, smaller scale corona-like features, small strain extensional fractures, and linear edges. We flexurally fit selected corona to estimate values including elastic thickness, mechanical thickness, and heat flow, to better constrain this form of subduction. Our elastic thickness estimates have been consistent with previous results, and have generally fallen in the range of 5-20 km, with the largest coronae having larger elastic thicknesses. Relatively high heat flows (averaging 87 mW/m^2) and low elastic thicknesses (averaging 12.4 km) were found, possibly due to local plume effect or regional variation. Further research could include increasing the number of coronae analyzed, as well as fitting other regions proposed to be subduction sites on Venus.

Moonquake-triggered Mass Wasting Processes on Icy Worlds

Mackenzie Mills; Johns Hopkins University and Jet Propulsion Laboratory/California Institute of Technology Mentors: Robert Pappalardo and Mark Panning; Jet Propulsion Laboratory/California Institute of Technology

Mass wasting and severe tectonization is recognized in images of icy satellites, with substantial smooth material between structural ridges in some cases. We analyze *Galileo* images of Ganymede and *Cassini* images of Enceladus to determine the dimensions of inferred normal faults in order to estimate seismic moments (M_0) and moment magnitudes (M_w) using included equations, and then we consider whether mass-wasting could account for smooth material. After identifying the faults of interest, we measure length (L), infer a fault dip and dip-slope dimension, and estimate depth to the brittle-ductile transition, fault area (A), and the slip for a single fault event (d).

$$M_w = \frac{2}{3} \log M_o - 6.06 \qquad M_o = \mu Ad$$

where μ is the shear modulus for ice and units are mks. From 6 regions of Ganymede, we inferred seismic moments of 8 x 10^{14} – 4 x 10^{18} Nm and moment magnitudes of 4.6 – 6.5. Because these moons' gravities—and therefore normal stresses—are fractions of Earth's gravity, the magnitude, slip per event (d), and frequency of quakes may be different from terrestrial quakes. The amount of material that could be moved due to gravity was estimated and allows for inference of whether seismic shaking is a viable hypothesis for mass wasting on icy satellites.

Methods for Assisting NASA Project, Europa Clipper, for ATLO Bioburden Determination

Lyssa Morgan, Cal Poly Pomona Mentor: Hyung (Roy) Park, Jet Propulsion Laboratory

The Europa Clipper spacecraft will conduct detailed reconnaissance of the Galilean moon Europa. This project focuses on ways to assist in accurate and consistent enumeration for bioburden determination to prevent forward contamination. Swarming prevents accurate enumeration and to determine if environmental factors influence swarming motility several conditions where altered from the NASA Standard Assay (NSA). The results suggest that removal of Tween 80 from the wipe processing method and condensation from the lid of the agar plates reduced swarming seen from wild type bacteria: *Bacillus cereus, Bacillus safensis, and Bacillus subtilis*.

Preliminary method validation for Membrane filtration (MF), that could provide a more accurate representation of microbial populations present on spacecraft hardware, was carried out for possible future implementation. MF allows for greater volumes to be tested to achieve more accurate microbial population enumeration comparative to the current NSA.

Environmental Monitoring following current SOP for sampling and processing was carried out to assess the laboratory bioburden in several critical areas for sample processing. Samples were taken using a combination of current NSA protocol, exposure readings, membrane filtration, and Air-sampler System MAS-100 NT (Millipore). In addition, Matrix-Assisted Laser Desorption/Ionization Time-of-Flight Mass Spectrometry (MALDI-TOF MS) was used on bacteria found from sampling events to determine if the species of bacteria could be determined.

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Fine-Scale Waves in Jupiter's Atmosphere Detected by JunoCam

Hamish Nicholson, Jet Propulsion Laboratory, California Institute of Technology; Harvard College Mentors: Glenn Orton and Thomas Momary, Jet Propulsion Laboratory, California Institute of Technology

Mesoscale waves have been detected previously from Voyager, New Horizons and Galileo images (see Table 1 of Simon et al., 2015, Geophys. Res. Lett. 42, 2612) with spacing between waves of 110 to 305 km. Larger waves have been detected by Hubble Space Telescope, as well as more recent 5-micron images from Juno's JIRAM experiment and the Very Large Telescope's VISIR experiment with wave spacings between 1200 and 1400 km. Here, we report the detection of smaller-scale waves in the atmosphere of Jupiter from the Juno mission's JunoCam imaging instrument, with the spacing between waves ranging from 55 to 270 km. These waves appear in all of Juno's close approaches to Jupiter (perijoves), starting with perijove 3, in the form of wave trains that are narrow in latitude and extended in longitude. The majority of these waves appear within 5 degrees of latitude from the equator, although examples exist as far as 30 degrees from the equator. Most of the wave fronts appear to be perpendicular to their predominantly longitudinal extent, but some of the waves with more subtle features are tilted and one set appears to be arranged in a spiral around a vortex.

Dry Heat Microbial Reduction of ATCC 29669 Bacterial Spores Embedded in Loctite EA 9394 Epoxy

Gregory Nielsen, Jet Propulsion Laboratory, California Institute of Technology Mentor: Wayne Schubert, Jet Propulsion Laboratory, California Institute of Technology

Space research and exploration is advancing at a rapid pace as we search for life on foreign planets. Biological contamination control is important to both the planetary protection discipline and science community. Cross contamination is an important consideration for missions to discover alien life as it could bias scientific data. To avoid contaminating other planets, we need to know what microorganisms are on our equipment and how to reduce and/or destroy those microbes. The hardy *bacillus* strain ATCC 29669 was discovered in a spacecraft assembly cleanroom from the NASA mission Viking, and is used as a model organism to study heat inactivation. In this work, ATCC 29669 spores were embedded in Loctite EA 9394 epoxy and heated at 115°C, 125°C, 150°C and 170°C. These embedded samples were then cryogenically ground and plated using tryptic soy agar. Colony forming units per gram measurements were obtained from colony counts and used to calculate D-values at each temperature. This data will help provide a reference for a minimal heating standard for spacecraft and scientific payloads sent to do research on foreign bodies.

This work was carried out by the Jet Propulsion Laboratory, California Institute of Technology. Government sponsorship acknowledged.

Quality Assurance of Processes Related to Europa Clipper Spacecraft Verification

Morgan O'Donnell, University of Central Florida

Mentors: Arman Seuylemezian, Emily Seto, and Roy (Hyung) Park, Jet Propulsion Laboratory, California institute of Technology

NASA's Europa Clipper mission aims to send a spacecraft to conduct fly-bys of one of Jupiter's moons, Europa, to conduct a study of its environment and investigate if its surface is capable of potentially sustaining life. Due to the nature of the mission and the possibility that material from Earth that remains on the spacecraft could interfere with unknown life, NASA has set stringent planetary protection guidelines for the Europa Clipper. The addition of new bioburden enumeration methods such as membrane filtration, in conjunction with optimization of current standard operating procedures (SOPs), may be used to more accurately assess small amounts of contamination on the Europa Clipper. This project focuses on membrane filtration to be potentially be used in tandem with the NASA standard assay, optimization of colony counting methods regarding bacteria that display swarming motility, performance qualification (PQ) testing on laboratory equipment, and environmental monitoring (EM) of the lab space. The work of this project will not only contribute to quality assurance of the Europa Clipper project but will have the potential to be implemented on many other NASA projects, due to the shared SOPs of sampling and testing

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Dust Devil Orientation and Martian Surface Winds

Vicente Ochoa (Jet Propulsion Laboratory, California Institute of Technology) Mentors: Leslie Tamppari and Vivian Sun (Jet Propulsion Laboratory, California Institute of Technology)

Dust devil tracks were first seen on the Martian surface using a camera onboard the Viking Orbiter. Dust devils are whirlwinds formed by increasing surface temperature, which can cause air to rise quickly. The rising air can pick up fine dust material, exposing the lower regolith. The lower regolith is often lower in albedo and so it often leaves a dark linear streak on the surface, showing where dust devils have traveled. More than 500 images taken by the Context Camera in the 65-72N latitude band of Mars were analyzed and visible dust devil tracks were traced. By analyzing overlapping images, new dust devil tracks were identified. The dust devil track orientation was used as a proxy for the wind direction and compared to the winds detected by the Phoenix Telltale wind indicator. This can help us understand the relationship between dust devil tracks and nearby surface winds.

Infrared Detector Calibration and Modeling of Critical Phenomena

Anusha Pai Asnodkar, Jet Propulsion Laboratory, California Institute of Technology Mentors: Inseob Hahn and Russell Trahan, Jet Propulsion Laboratory, California Institute of Technology

The calibration of visible light detectors down to µas astrometric accuracy has been previously achieved by instruments for exoplanet detection such as ESA's DICE experiment under the NEAT mission. We seek to attain comparable levels of astrometry with infrared detectors for improved detection of Earth-mass exoplanets via differential astrometry. Experiments involving laser interferometry and centroiding optical point sources provide data that can be fit to sinusoidal fringe intensity patterns and point-spread functions respectively. These fits can be used to characterize distortions inherent to the detector's manufacturing imperfections such as asymmetries that change over the field of view, intrapixel nonuniformity, and detector imperfections.

We pursued a secondary project in modeling crossover critical phenomena to understand the behaviour of materials near the critical point. The preexisting crossover parametric equation of state for Ising-like systems was expanded to include more fitting terms constrained according to the universal ratios of critical amplitudes and critical exponents that quantify the universality of critical phenomena. We aim to describe physical properties such as specific heat and isothermal susceptibility near the critical point with improved precision using this expanded parametrization.

Visualization of Robotic Vehicle and Spacecraft Data

Hee Won (Michelle) Park, California Institute of Technology Mentor: Marc Pomerantz, Jet Propulsion Laboratory

At JPL, a web browser-based software system called Ranger has been designed and developed to visualize NASA spacecrafts, robotic vehicles, and planetary data for engineering and public outreach customers. For this project, we utilized Ranger to develop a WYSIWYG scene of the planets in our solar system and their respective moons. Additionally, VR has been implemented into Ranger so that users can have a fully interactive experience while traveling between the different celestial bodies and spacecrafts. Alterations have been made so that Ranger scenes are more compatible for viewing through the VR headset. In regards to engineering, VR is extremely useful for data visualization, as it allows engineers to view virtual prototypes of engineering products in 3D and helps gain a better understanding of the product or spot any potential risks before creating it in the real world.

Micro-Cold Trap Detection and Characterization on the Lunar Surface

Shehan Parmar, Jet Propulsion Laboratory, California Institute of Technology Mentors: Sylvain Piqueux and Catherine Elder, Jet Propulsion Laboratory, California Institute of Technology

Lunar micro-cold traps are putative centimeter-scale (or larger) regions cold enough for ice or other volatiles to be trapped and stable over long time periods on planetary bodies. The objective of this project was to demonstrate their existence on the Moon and characterize their properties. The southern hemisphere of the Moon, particularly at latitudes 85° and higher, exhibits partially or permanently shaded regions with sub-110 K temperatures as demonstrated by Lunar Reconnaissance Orbiter Diviner reflected solar and emitted infrared radiances measured through nine spectral channels.

Micro-cold traps, however, are sub-resolution and thus too small to be detected directly by Diviner. But near Noon, because they are surrounded by the otherwise warm (illuminated) regolith, multispectral observations should result in anisothermal behavior (i.e. variable brightness temperature as a function of wavelength due to the uniqueness of Planck curves associated with black or grey bodies). Deconvolving these Planck curves yields the properties of the end members (fractional area and brightness temperature), demonstrating that micro-cold traps could be present in the field of view, although not resolved. This approach has been successfully used to map sub-resolution rocks or Mars and the Moon, leveraging the fact that rocks are warmer at night than the surrounding terrains due to their high thermal inertias.

Anisothermality has been indeed observed at various locations of the South Pole, with cold end-members consistent with water ice trapping temperatures (110 K or lower), and warm surrounding regolith. Areal fraction of micro-cold trap can mathematically can range from 40 to 100% to match the observations (depending on the temperature of the warm endmember) but should realistically remain closer to the lower bound. Future lunar sampling missions may want to consider sampling micro cold traps.

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Atmospheric Photochemistry Models of Habitable-Zone Exoplanets in the TRAPPIST-1 System Luke Peterson^{1,3}

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Small exoplanets in the habitable zone of nearby red dwarf stars present a unique possibility to characterize habitable exoplanets within the next decade. TRAPPIST-1, an ultracool red dwarf star, was recently found to have seven Earth-sized exoplanets, and three are in its habitable zone. Constraints on the planetary masses from orbital dynamics and radii from transits indicate that most of these planets have a predominantly rocky composition. Climate models have shown that the planets e and f in the system can sustain a global liquid water ocean, for 0.2 bar CO_2 plus 1 bar N_2 , and 2 bars CO_2 , respectively. Observation and reconstruction of the Lyman-alpha emission of TRAPPIST-1 indicate that it has a moderately active chromosphere. Using an atmospheric photochemistry model, we investigate how the stellar irradiation drives chemical reactions in the atmospheres of TRAPPIST-1 e and f, where we assume habitable compositions predicted from the climate models. Our models show that substantial amounts of CO and O_2 must coexist with the CO_2 , and in some cases, overtake CO_2 as the most abundant gases. The CO and O_2 are produced by photodissociation of CO_2 , and they cannot recombine efficiently unless an unlikely direct recombination reaction in the ocean is assumed. Also, our models find that SO_2 , one of the presumed gases from volcanic outgassing, cannot accumulate in the atmospheres. It is quickly oxidized in the atmosphere and then rained out as H_2SO_4 . These findings indicate that CO and O_2 should be considered together with CO_2 as the primary targets in the search for atmospheric signatures from habitable-zone planets of TRAPPIST-1.

Tracking Water Ice, CO₂ Ice, and Geological Composition in Active North Polar and Mid-Latitude Martian Dune Fields

Joseph Plumitallo, Fordham University and Jet Propulsion Laboratory/California Institute of Technology Mentor: Serina Diniega, Jet Propulsion Laboratory/California Institute of Technology

Dunes within the martian north polar regions have been observed to form alcoves near their brinks, with time of formation constrained to periods with seasonal frost. The process of dune-alcove formation is hypothesized to occur in two-phases: initial alcove formation when frost is forming, followed by mass-wasting driven by springtime sublimation of CO_2 frost. Due to the connection hypothesized between dune-alcove activity and frost, the objective of this project was to track water ice, CO_2 ice, and geological composition in north polar and mid-latitude dune fields where dune-alcoves have been observed. Moving into the mid-latitudes allows us to examine frost, geological

composition, and alcove formation over more dune fields, with similar dune-alcove activity. Tracking frost and geological composition allows us to better compare water and CO_2 ice appearance, and geological composition over different dune fields, with and without dune-alcoves. To perform these analyses, we used GIS software (JMARS) to search through spectral data from the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) to find where, when, and how much of a certain substance was present at the time the image was captured. Ultimately, comparing frost and geological context over different dune fields will further constrain the driving forces linked to alcove formation.

Automated Pipeline for Venusian Cloud Tracking

Kenyon Prater (Jet Propulsion Laboratory) and Nicholas Ardavin (Jet Propulsion Laboratory) Mentors: Attila Komjathy and Siddharth Krishnamoorthy (Jet Propulsion Laboratory, California Institute of Technology)

At 2.3 microns, a gap in the absorption spectrum of Venus' CO2-atmosphere allows observations of the nightside, where the lower clouds show up as silhouettes, backlit by thermal emission from below. Observations in this region are of particular interest for determining wind velocities via cloud tracking. Wind velocity measurements allow us to compare observed winds with those predicted by Global Circulation Models (GCMs). Of particular interest are latitudinal wind-velocity profiles, time-varying cycles in the Venusian atmosphere, and correlation of wind speeds with surface features. We are currently investigating all of the above.

We present an automated pipeline for data reduction, from raw images of Venus' nightside to useful wind velocity maps using cloud-tracking methods. By stacking subsets of the sharpest Venus images, we are able to achieve angular resolutions of 0.5" or better, corresponding to an approximately 150 km resolution near the center of Venus' disk. From these image stacks we are able to extract wind velocity fields over the night side with at least 20 latitudinal divisions, RMS errors of approximately 5 m/s, and temporal changes in wind speeds at the 10% level or less. We use this pipeline to reduce data from the IRTF's SpeX instrument, spanning over 15 years of observation. In particular, we compare methodology and results between two image sets: an IRTF campaign from April-May 2017 and Akatsuki IR2 images taken in 2016.

Redshift Calibration for the Dark Energy Survey

Kerianne Pruett: University of California, Davis; California Institute of Technology/Jet Propulsion Laboratory Mentors: Jason Rhodes and Daniel Masters, California Institute of Technology/Jet Propulsion Laboratory

Determining accurate galaxy redshifts using only photometric imaging is a major problem astrophysicists around the globe are working to solve. Because photometric redshifts can be biased, and spectroscopy is too costly to collect for millions of galaxies, we need a way to get estimates in a faster, more accurate way. To achieve this, we present an analysis of the Dark Energy Survey year 3 data in a new way, by using a machine learning algorithm called the self-organizing map. By mapping the galaxies according to their colors we can systematically analyze the photometric redshift values and their uncertainties in the colorspace of the survey. By combining the year 3 data with the overlapping multi-wavelength survey COSMOS we were able to obtain spectroscopic redshifts to calibrate this mapping. We determine how to best organize the galaxies, how calibrated the survey is, error in calibration, and how much spectroscopy needs to be obtained for full calibration. Upon full calibration we will have better redshift estimates for billions of galaxies by seeing where they lie in colorspace, without needing to obtain further spectroscopy.

Human Tracking for Robot Navigation Using Monocular and Stereo Vision

Hongsen Qin, Jet Propulsion Laboratory, California Institute of Technology Mentor: Brandon Rothrock, Jet Propulsion Laboratory, California Institute of Technology

The premise of human tracking involves estimating human body key points in complex, multi-person scenarios, and has useful applications in collaborative human-robot behaviors such as leader-follower. State-of-art human pose estimation and tracking is built upon deep learning models and have shown impressive performance on difficult datasets. These methods traditionally operate on 2D video, however, and have limited use for robot perception. This work presents our effort to extend these 2D methods to incorporate registered stereo to localize and track humans in 3D using a tracking by detection approach. We show that our work addresses the problem of losing tracks during missed detections through trajectory inference, as well as disambiguating tracks via depth, and demonstrate a dramatic improvement in performance over the 2D baseline.

Development of Hardware for the Chroma-D Focal Plane Array: Power Regulator Board and FPGA Connector Design

Malia Rebollo, California Institute of Technology, Jet Propulsion Laboratory Mentor: Peter Sullivan, Jet Propulsion Laboratory, California Institute of Technology

Imaging spectrometers measure light across wavelengths of electromagnetic radiation to aid in understanding geology, climate change, and global ecosystems. Spectrometers with decreased mass, power and cost are needed to address arising questions. One new image sensor for spectrometers is the CHROMA-D focal plane array that has a digital output. This allows for fewer external parts and a larger format than previous designs, but it requires new board layouts for power and control. Thus, a power regulator board was created which uses feedback loops to deliver the proper voltage to the CHROMA-D, while also sending and receiving information from the controlling FPGA. A second board was designed to connect the power regulator board, CHROMA-D, and image output to an FPGA. The PCBs for these boards will be used to ensure that the CHROMA-D will receive the correct voltage and signals, while the schematics will be applied in the design of future flight-worthy boards.

Developing A New TLAS System: In-Situ Undersea Methane Detection

Alexander Reeves, California Institute of Technology and Jet Propulsion Laboratory, California Institute of Technology

Mentor: Max Coleman, Jet Propulsion Laboratory & Geological and Planetary Sciences, California Institute of Technology

Tunable Laser Absorption Spectrometry (TLAS) offers faster and lower-cost measurements of dissolved gases in seawater than mass spectrometry, the previous best option. However, to date TLAS measurements have relied on passing water through a semipermeable membrane to extract a gas sample. With the introduction of a new Capillary Absorption Spectrometer, expected to be four orders of magnitude more sensitive than previous instruments, smaller sample sizes are possible, and vacuum degassing promises to be an advantageous alternative to the semipermeable membrane approach. I constructed a prototype three-valve sampling system to degas bulk liquid samples using vacuum. Using a sample size of 0.43 grams of water, the system exhibits a cycle time of under three minutes and appears to avoid isotopic or chemical fractionation of the dissolved gases. A larger sample size of 0.64 grams exhibits a correspondingly longer cycle time of under four minutes. My work also indicates that a less expensive and less bulky two-valve system may be possible to implement with very similar performance.

Identification of Bacterial Isolates From Mars Science Laboratory Spacecraft

Darío Alfonso Rodríguez Steinhardt, Jet Propulsion Laboratory, California Institute of Technology Mentor: Arman Seuylemezian, Jet Propulsion Laboratory, California Institute of Technology

The planetary protection group at JPL has been closely monitoring the microbial bioburden of spacecraft and associated surfaces since the Viking missions in order to comply with COSPAR planetary protection policy. The NASA standard assay is the currently used technique to quantify the microbial bioburden present on spacecraft and associated surfaces. Any colonies resulting from this assay are pure cultured, identified, and preserved in -80 degrees C. Of the 1,500 MSL isolates, 713 MSL isolates were identified using Matrix-Assisted Laser Disorption and Ionization Time of Flight Mass Spectrometer (MALDI-TOF MS). Of the 713, 14 were classified as fungi, 42 did not grow, 42 were mixed, and the remaining 615 were pure cultured and run on MALDI-TOF MS. Of the 615, 153 were classified to the species level. A 147 isolates require 2 of the 4 replicates to be repeated due to inconsistent results. The remaining 315 isolates generated good consistent spectra, however had no match in the database. These isolates were subsequently grouped and sent for 16S rRNA sequencing.

Enhancing GalSim for Dark Energy Investigations

Nataly Rosales Espitía^{1,2}

Mentors: Melanie Simet^{1,2} and Jason Rhodes²

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Weak gravitational lensing is the effect created by the gravity of different objects interfering with the space around it which causes light rays from distant galaxies to be slightly deflected as they are traveling to Earth. These distortions can provide information on how dark matter is distributed, how the distribution of matter has changed over time, and the nature of dark energy. The GalSim software is a galaxy image simulation software that makes images of astronomical objects by considering the many properties that distort a real image. In order to render these images, the software chooses between Discrete Fourier Transform (DFT) or photon-shooting. DFT and photon-shooting are two digital signal processing algorithms that are widely used to render the distortion of light due to gravitational fields. These two algorithms have trade-offs in speed and accuracy depending on the astronomical profile and the cross-over flux. Cross-over flux is the flux at which one method is faster than the other. This project's intention is to tabulate the cross-over flux for a number of different profiles which would guide people who are making their scripts to switch from one draw method to the other. The importance of this is that it will create a faster and more accurate rendering of images from these properties. This in turn would allow for more precision quantities of properties values to be chosen in applications like weak gravitational lensing.

Near-Infrared Imaging for the Juno Mission

Vishnu Santhosh, Jet Propulsion Laboratory, California Institute of Technology; University of Texas, Austin *Mentor: Glenn Orton, Jet Propulsion Laboratory, California Institute of Technology*

My overall project is oriented toward supporting the Juno mission's investigation of Jupiter's dynamics and cloud history, which sheds light on similar processes in other planets in the solar system. A suite of near-infrared images of Jupiter in reflected sunlight acquired over many years was investigated near a wavelength of 2.16 μ m, which is in the middle of relatively strong CH₄ and H₂ absorption and is sensitive to clouds and hazes in Jupiter's upper troposphere, to examine the evolution of atmospheric phenomena during this period. The analysis focused on specific features of Jupiter such as the Great Red Spot and the polar regions. For example, the poles, which have a concentrated high-altitude haze, developed a streak which occurred during the middle of 2018, which was not visible earlier. During May 2017, the Great Red Spot produces a prominent wake region to its northwest, likely due to high winds.

Visualizing Uncertainty in High Dimensions

Maya Shen (Jet Propulsion Laboratory, California Institute of Technology) Mentor: Amy Braverman (Jet Propulsion Laboratory, California Institute of Technology)

Remote sensing data are estimates of quantities of interest in nature. Drawing accurate scientific conclusions from these estimates requires quantifying and understanding their uncertainties. However, retrieved quantities can be very high-dimensional, and visualizing uncertainty in high- dimensions is a notoriously hard problem. Here, we visualize uncertainty for estimates of atmospheric profiles of temperatures at 100 different altitudes, made by the Atmospheric Infrared Sounder instrument (AIRS). We communicate uncertainty by showing all possible true states that *could* have resulted in a particular retrieved state. We present a brief overview of existing solutions, and leverage good design principles to inspire and guide our own work. Employing a variety of techniques and tools, including Monte Carlo simulations, dimension reduction, and the software sketchbook and language "Processing", we visualize the uncertainty in simulated AIRS data. Our methodology facilitates exploration of uncertainty in high- dimensions, and we plan to extend it to retrievals from other missions.

The Relevance of Growth Techniques to the Mechanical Performance of Ice: Methodologies for Future Europa Testbeds

Txai Sibley, Jet Propulsion Laboratory, California Institute of Technology Mentor: Katherine Siegel, Jet Propulsion Laboratory, California Institute of Technology

Testbed development is essential to hardware testing and the success of lander missions. Preparing testbeds for the Europa Lander Concept mission poses a unique challenge; cryogenic ice has not been thoroughly studied. This study aims to help establish procedures for future Europa testbeds by determining the effects of certain growth techniques on the mechanical behavior cryogenic ice. Microstructural effects and mechanical properties are explored through the variation of freezing methods (uniaxial growth, freezer parameters) along with sample types (DI water, boiled DI water, controlled grain size). These experiments will determine the sensitivity of cryogenic ice behavior to certain synthesis methods and are directly applicable to the formulation of relevant ice-making procedures.

Least-Squares Fitting of the Spectra Energy Distributions of 30,000 Mass-Losing Stars Using a Million Model Library: A Dictionary-Based Python Code

Gokul Srinivasaragavan, Jet Propulsion Laboratory, California Institute of Technology Mentor: Raghvendra Sahai, Jet Propulsion Laboratory, California Institute of Technology

Red Giant Branch and Asymptotic Giant Branch Stars experience mass-loss due to the effects of radiatively driven dusty molecular wind. Dieter Reimers discovered an empirical formula to derive the mass-loss rate of a star as a function of luminosity and effective temperature with two power-law exponents and a constant. However, it is based only a handful of data sets for which mass-loss properties were available.

My project's goal is to derive mass-loss properties of large samples of dying stars by deriving the constant and power law-exponents in Reimer's Law by fitting model Spectral Energy Distributions that contain the luminosity, effective temperature, and mass loss rates of models to observed Spectral Energy Distributions. Old Python code exists that does these fits, however it does so incredibly inefficiently and is not a viable method when a large number of observed stars and models exist. I was able to use Python dictionaries to fix these inefficiencies, which paves the way for figuring out the theoretical formula for various large data sets.

Characterization of Microbial Diversity Aboard the International Space Station

Divya Sundararajan, Bryn Mawr College

Mentors: Kasthuri Venkateswaran and Jason Wood, Jet Propulsion Laboratory, California Institute of Technology

The International Space Station (ISS) has a thriving microbial population, largely due to hitchhiking microbes that arrive with the astronauts cycling through the station. Evaluating the diversity aboard the ISS is essential to the health of the astronauts and the integrity of the projects conducted aboard. In this project, we study microbial diversity on the ISS and compare it to that in the Spacecraft Assembly Facility (SAF) cleanroom from 2001 to 2018. Data on the taxonomy of microbes on the ISS and in SAF was collected from literature to quantitatively measure diversity at different levels. Diversity in the ISS and SAF at the family and species levels was graphed over time to study how diversity may have changed. Despite minor fluctuation between years, diversity values were shown to be higher in newer missions as compared to older missions. This is likely because as data collection methods have increased in efficiency over the years, microbial diversity artificially appears to have undergone an increase. Thus, these modern methods (i.e high-throughput metagenomics) are shown to be merely painting a better picture of diversity than the old culturing methods.

Searching for Evidence of Impact Heating With Diviner

Sophie Taylor, Jet Propulsion Laboratory, California Institute of Technology Mentor: Catherine M. Elder, Jet Propulsion Laboratory, California Institute of Technology

In this project, we hope to further constrain impact crater modeling by searching for the thermal signature of an impact in the existing Diviner data. To do this, we looked at both LROC's temporal images of recent impacts and lunar flashes recorded by the Marshall Space Flight Center hoping Diviner had imaged the site in the hours after the impact. We then searched Diviner data globally for any nighttime temperatures above 250 K. Out of the 260 lunar flashes listed, Diviner only had data at one location six hours after supposed impact—no heat signature was detected. The margin of error for the flash location was slightly larger than the area observed by Diviner, so either the impact cooled completely within six hours or it was not observed. Neither the global search for nighttime temperatures above 250 K nor the LROC temporal image pairs yielded any obvious signs of impact heating. Going forward, the dynamics of the lunar flash impact observed by Diviner will be analyzed, assuming it fell within Diviner's observations and cooled completely in six hours.

Modeling the Free Floating Evaporating Gaseous Globule IRAS 20324+4057

Charles Thut, Jet Propulsion Laboratory, California Institute of Technology Mentor: Raghvendra Sahai, Jet Propulsion Laboratory, California Institute of Technology

Dr. Sahai and colleagues have classified a new type of star forming molecular gas clouds called free-floating evaporating gaseous globules (frEGGs). One such object is IRAS source IRAS 20324+4057 (I20324). The cloud has been shaped by the presence of massive type O and B stars. Using the 3D radiative transfer code RADMC3D, I have been modeling I20324 to gain insight into its physical structure. Revisions to the model are applied, and then from the model we can extract simulated observations and attempt to match them to the observations that have been taken of the object. The model began as a sphere of gas and dust with temperature and density decaying exponentially from the center. I have modified the model to be an ellipsoid with separate density and temperature centers, and a two-piece temperature distribution which decays in an ellipsoidal pattern, and then remains constant outside a certain radius to simulate heating by the O and B stars. Although an optimal model was not found, I automated much of the process for creating new models, which allows for rapid adjustment of the parameters for the model, and evaluation of the fit of the new models.

COSMIC: Content-Based Onboard Summarization to Monitor Infrequent Change

Asher Trockman (University of Evansville)

Mentor: Lukas Mandrake (Jet Propulsion Laboratory, California Institute of Technology)

Given the limited bandwidth of the Deep Space Network, Mars science missions generate more data than can be transmitted back to Earth. Repeat observations are highly expensive, making observations of scientifically significant transient events such as fresh impacts and avalanches very rare. COSMIC will increase the orbital science coverage of Mars without requiring any additional bandwidth. Operating onboard an orbiter, it will provide and store image summarizations of the classes of observed landmarks and terrain types. Surface changes can then be detected in small summaries rather than storage-demanding raw image data. We report on the performance of several convolutional neural network architectures for summarizing the Martian surface as imaged by HiRISE. We seek to understand images at the pixel level, using fully convolutional networks to segment images into araneiform, dust devil track, fresh impact, Swiss cheese, and background regions. With the help of citizen scientists, we are constructing a large data set of pixel-level labels of the Martian surface, and we contribute a novel technique to address the resulting multi-label classification problem. COSMIC motivates the High Performance Spaceflight Computing initiative by demonstrating that heightened performance can increase science yield.

Mechanical Properties of Europa-Inspired Ice

Melody Wang, Jet Propulsion Laboratory, California Institute of Technology Mentor: Katherine Siegel, Jet Propulsion Laboratory, California Institute of Technology

The search for extraterrestrial life is still ongoing, and Europa's icy surface and possible ocean underneath may provide habitable environments. The Europa Lander concept project at JPL focuses on the journey to Europa and the collection of data underneath the moon's ice shell. The work presented here describes the mechanical properties of ice to better understand the equipment necessary to collect and break ice on the moon. The mechanical properties of ice is greatly dependent on factors such as microstructure and temperature. Ice samples grown using a variety of methods were tested on equipment such as a cryogenic Instron for mechanical properties including ultimate compressive strength and Young's modulus. The ice samples differ in areas such as nucleation sites, grain boundary size, solutes, and others. Future improvements to increase the number of consistent and accurate samples are also discussed. Understanding the types of ice that may be present on Europa and recreating them on lab will greatly benefit materials selection of the lander to achieve its goal.

Infrared Detection of Waves in Jupiter's North Equatorial Belt

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Mentor: Glenn Orton, Jet Propulsion Laboratory, California Institute of Technology

Upper-tropospheric waves have found to be present in Jupiter's North Equatorial Belt (NEB) during and after a recent instance in which Jupiter's North Equatorial Belt (NEB) expanded in latitude to the north. This is expected to be part of a cyclic series of such events. Although these visible expansion events are well documented, previously conducted surveys cannot conclude whether the upper-tropospheric waves were also present only during previous expansions, or whether they could be initiated by other dynamical phenomena. Tracking the appearance and variability of these waves during non-expansion periods is necessary in order to distinguish between possible hypotheses for their origin. A program to find the relative intensity of the upper-tropospheric NEB waves was implemented on a suite of images acquired at near-infrared wavelengths between 2.00 and 2.23 microns from 1995 to present. Analyzing the temporal evolution of the intensity of these waves, using their variance from the mean, allows us to find the dates at which the waves present at the NEB are the most prominent, not only in their amplitude but also in their latitudinal span. The results obtained allow a cross-comparison between the dates at which the highest variance peaks appear and the dates at which NEB expansions or other planetary phenomena are documented to have taken place, and therefore to establish (or disprove) a correlation between them.

Correlation of Alcove Formation and CO₂ Condensation in Martian Dune Fields

Fan Wu, University of California Santa Barbara; Jet Propulsion Laboratory/California Institute of Technology Mentor: Serina Diniega, Jet Propulsion Laboratory/California Institute of Technology

Mars is a dynamic planet with small-scale annual changes driven by atmospheric circulation and frost-related processes. Studying frost-surface processes can help us better understand Mars's polar geology and overall climate. The purpose of my project is to identify overlapping occurrences of martian dune activities with CO₂ frost appearance in the northern mid-latitudes as correlation between dune alcove and frost formation might signify frost-surface interactions. I tracked CO₂ frost and snowfall formation within Mars Climate Sounder (MCS) data for six northern mid-latitude dune fields for Mars Years (MY) 28-34. Frost forms during autumn and winter and during nighttime for most MYs within all fields. Lyot Crater, NML010, and NML047 have no daytime frost. We also identified which fields had alcoves to compare to CO₂ frost formation despite its southern location and sparse observed frost formation. Preliminary results indicate that an interaction of frost and snowfall may cause alcove formation. This information can help us know what to look for and what questions to ask in future studies in how atmospheric processes impact surface changes on Mars.

Verification of CH4:CO2 Hot Spots in the Los Angeles Basin

Jennifer Wu, California Institute of Technology

Mentor: Stanley Sander, Jet Propulsion Laboratory, California Institute of Technology

The significant contribution of the Los Angeles basin to California's greenhouse gases motivates a need to quantify the city's greenhouse gas emissions and identify their sources. The California Laboratory for Atmospheric Remote Sensing Fourier transform spectrometer (CLARS-FTS) is part of a network of measurement methods that attempts to address this concern. CLARS-FTS is situated on Mt. Wilson and points toward 33 targets in the Los Angeles basin, measuring methane, carbon dioxide, and carbon monoxide concentrations throughout each day since 2011. This project focuses on examining methane and carbon dioxide data. Excess methane to carbon dioxide ratios were plotted across the Los Angeles basin for each measurement cycle. These plots were examined for hot spots, or measurement cycles that showed ratios that were higher than usual. The reliability of these data points was then considered through examining uncertainties from the spectral fitting. This work will provide useful information to utilities and regulatory agencies to identify large methane leaks and therefore minimize their environmental impact.

Numerical Modeling of Saturn's Normal Modes

Xiaohan Helen Xue, California Institute of Technology Mentor: A. J. Friedson, Jet Propulsion Laboratory, California Institute of Technology

The Cassini mission to Saturn has detected density waves in the C and D rings that have been determined to be forced by the normal oscillations of the planet. We try to identify these normal modes and to compute their corresponding frequencies. Matching these free oscillation frequencies to those of the waves forced in Saturn's rings then has the potential to reveal new information regarding Saturn's internal structure, since different internal structures give rise to different calculated modes. We generate sets of varying internal structure models using the Cowling approximation, and, focusing on those that are most likely to perturb the rings, we compare the resultant calculated modes and try to judge whether some internal structure models may be more realistic than others.

Searching for Martian Sedimentary Iron Oxide Deposits

Christopher Yen, Jet Propulsion Laboratory, California Institute of Technology Mentors: Abigail Fraeman and Kathryn Stack Morgan, Jet Propulsion Laboratory, California Institute of Technology

Iron is abundant in the crusts of both Earth and Mars, and acts as a tracer of changing aqueous geochemistry and atmospheric composition. Depending on the pH of the environment, ferric iron and ferrous iron differ in their solubility. The pH of an aqueous environment is also affected by the oxidation process of iron. Thus, the presence or absence of iron oxides in the sedimentary rock record is important for understanding the aqueous history, atmospheric evolution, and habitability of terrestrial planets. Ferric oxides observed within lacustrine mudstones at Gale crater identified by orbital and Curiosity data suggest variable past redox conditions either in primary environments or secondary diagenetic processes. A global study of the mineralogy of Martian sedimentary deposits could assess whether the association between sedimentary formations using orbital hyperspectral data and high-resolution images. Results show crystalline hematite in potential primary sedimentary settings to be rare across the Martian surface, while other mineral assemblages such as phyllosilicates are more common. The dearth of newfound iron oxide deposits raises important questions about iron mobility and concentration on early Mars, and comparative planetary evolution.