Student-Faculty Programs
2014 Abstract Book
STUDENT-FACULTY PROGRAMS

2014 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 2014.

Table of Contents

Summer Undergraduate Research Fellowships (SURF) 1
MURF Undergraduate Research Fellowships 93
Amgen Scholars Program 97
Laser Interferometer Gravitational-Wave Observatory (LIGO) 105
SUMMER UNDERGRADUATE RESEARCH FELLOWSHIPS
Finding the Repressor of PU.1 Expression in Early T cells: A Potential Role for BCL11b
Amir Abdolrahim Poorheravi
Mentors: Ellen Rothenberg and Satoshi Hirose

Expression pattern of the transcription factor PU.1 is a decisive factor in determining differentiation of hematopoietic stem cells into different hematopoietic lineages, including T cells. Early T cell progenitors require a relatively high level of Sfpi1 (PU.1 encoding gene) but commitment of the cells into T cell fate at the DN2 stage requires a stage specific mechanism for PU.1 repression. It has been shown that specific upstream regulatory elements of the Sfpi1 gene called CE4a and CE4b are necessary for down regulation of PU.1 after commitment. Also, Runx1 protein has been shown to be necessary for CE4 mediated repression. However, Runx1 is not a T cell specific factor. Hence, other T cell specific transcription factors must silence Sfpi1 in presence of Runx1 as a nonspecific factor. We suspect that Bcl11b, which is a T cell specific transcription factor expressed in DN2 and later stages of T cell development, silences the Sfpi1 gene and represses expression levels of PU.1. We used Scid.adh.2C2 cells (also known as P2C2 cells) which are a pro T-cell line similar to early DN3 cells. Dual luciferase assays and short interfering RNA assays were conducted on cells transfected with plasmids containing reporter genes preceded by Sfpi1 regulatory elements to determine whether Bcl11b is necessary for repression mediated by the CE4 region and whether eliminating Bcl11b would result in resuscitation of PU.1 expression.

Estimating Causal Graphs From Videos of Behaviour
Luke K. Abraham
Mentors: Pietro Perona and Krzysztof Chalupka

For computational vision to be truly useful, computers simply being able to identify features in videos is insufficient: we need computers to understand the relationships between these features. For this project, the data I used was drawn from videos of interacting flies, and was labelled with relevant features and behaviours. I first tested whether a simpler algorithm than the one originally used to predict behaviours could achieve similar results, and found that it could not. I then sought causal relationships amongst the variables (so that the effects of interventions on the flies might be predicted), using a variety of causal inference algorithms. This potentially has direct biological benefits, but also should provide insight into how we might make a computer understand how humans behave.

Magnetoreception in Humans
Jacob Abrahams
Mentor: Joseph Kirschvink

A sufficiently diverse set of animals possess magnetoreception, the ability to detect magnetic field, that it is likely humans have an ancestor which is magnetoreceptive. Our goal is to see if humans may have a latent magnetic sense. We are studying this by exposing humans to magnetic fields and attempting, via classical conditioning, to train them to be able to know whether or not a field is present. Past research in our lab found very promising results, and our work this summer has been to improve the experimental setup and begin testing subjects in a more controlled setting. A group in Germany published a paper in Nature recently (Engels et al., 2014) which showed that the presence of low level, very low frequency radio waves deactivates some birds’ magnetic sense, so our work has mainly been designing and building an aluminum Faraday cage to house the coils we use to generate the magnetic field in case humans also have a magnetic sense which is impaired by electromagnetic noise. Our work going forward, now that the Faraday cage is finished we plan to begin running the experiment again on human subjects.

Exploring Problems in Arithmetic Circuit Complexity
Aman Agarwal
Mentor: Chris Umans

In computational complexity theory, some of the most basic problems involve polynomials and their rich algebraic structure. In this project, we explore complexity theoretic questions about some such problems, including factorization (univariate and multivariate) and Polynomial Identity Testing. In a recent result, the equivalence of polynomial identity testing and multivariate factoring was shown. Inspired by this result, we have sought to find reductions between problems related to factoring (univariate and multivariate) and polynomial identity testing (with or without a polynomial bound on the degree). In this paper, we describe the specific problems we worked on, our approach as well as observations.
Non-Thermal and Thermal Shock Influences on Isotopic Clumping in Calcite
Yury Aglyamov
Mentors: John Eiler and Max Lloyd

Isotope clumping describes the tendency of heavy isotopes to gather in the same molecule more often than random chance suggests, especially at low temperatures. In carbonates, clumping is often measured via mass-spectrometry, and the data used to determine thermal history; but the possibility remains that other factors affect clumping. Moreover, the kinetics of clumping re-equilibration at temperatures above 600 Celsius is not well-understood, as it takes place in seconds. Here, an analysis of the effects on isotopic clumping of stressors such as impacts, radiation, and partial decarbonation is described, as well as data on the reaction rate of clumping re-equilibration at 1000 Celsius.

Improving the Protein Detection Sensitivity of the Single Cell Barcoding Chip
Roshan C. Agrawal
Mentors: James R. Heath, Alex Sutherland, and Jing Yu

The Single Cell Barcoding Chip (SCBC) is a microfluidic device that uses capture antibodies to detect protein expression at the single cell level, and thus any improvement in its ability to detect proteins at low concentrations would be a considerable gain in its power as a measuring tool. However, the antibodies used are not directly bonded to the chip, but rather single-stranded DNA is first patterned onto the surface of the chip and then the antibodies are exposed to and bind to the DNA. Thus the density of DNA is an important factor impacting the protein detection sensitivity of the device. The density of DNA on the device has been shown to correlate directly with the sensitivity of the device, but previous studies have also suggested that at the maximum density level achieved so far, a sensitivity limit has been reached. In order to determine if this is true, the sensitivities of a device with the maximum DNA density and one with a measurable but small difference in density were compared using recombinant proteins at varying concentrations. The results indicate that the increase in DNA density had nearly no affect on detection sensitivity, which leads us to conclude that attempting to increase the DNA patterning density would not be an effective way to increase sensitivity. Another possible target in improving detection would be to somehow increase the efficiency of antibody binding to the DNA.

Mechanistic Studies of Nickel-Catalyzed Negishi Couplings of Unactivated Alkyl Halides
Saaket Agrawal
Mentors: Gregory C. Fu and Nathan D. Schley

Cross-coupling chemistry with unactivated alkyl halides can potentially be a powerful and general method for C-C bond formation. Though significant improvements have been made to catalytic conditions, mechanistic understanding remains limited. Herein, we describe progress towards mechanism elucidation of nickel-catalyzed Negishi couplings of unactivated alkyl halides. EPR studies of our system have shown the presence of a Ni(I) alkyl intermediate in the catalytic mixture, a departure from the Ni(II) resting state recently shown to exist in the nickel-catalyzed Negishi arylation of propargylic halides. This suggests that the mechanism of catalysis may be a function of nucleophile and electrophile identity. Further studies are aimed at a deeper understanding of the mechanism.

Testing MKID-Based Dark Matter Detectors
Elliot Ahn
Mentor: Sunil Golwala

MKID-based dark matter detectors are appealing because of their fabrication simplicity. The resonators in the MKIDs are coupled to a single microwave feedline. To test these dark matter detectors, both the MKIDs and the feedline must be tested. The feedline was tested by transmitting and reading a signal through the feedline without the MKIDs. To test the MKIDs, we designed a fiber-optic system inside our cryogenic refrigerator. The design consists of a steerable MEMS mirror to focus light on different parts of the detector, allowing for the testing of different MKIDs. The MEMS mirror allows our tests to be highly repeatable because we can focus light on the same spot of our detector if necessary. Unfortunately, the feedline signal was unsatisfactory, so the MKIDs were not tested. Once the MKIDs are attached to the feedline and the fiber-optic design is complete, the detector will be ready for testing.
A Model System for Artificial Intercellular Signaling in *E. coli*
Monique Alkiewicz
*Mentors: Richard Murray, Anu Thubagere, and Victoria Hsiao*

Synthetic biology is the idea of combining biology and engineering in order to design and construct a biological system and/or device that is beneficial for society. The International Genetically Engineered Machine competition (iGEM) is a group competition where students are given a kit of biological parts and use that for synthetic biology. The 2014 iGEM team created a model that synthesized and regulated the FsrABC, LamBCDA and AgrBCDA system. Our specific subgroup worked on the two-component systems FsrAC and LamAC, which consists of the histidine kinase (FsrC and Lam C) and the response regulator (FsrA and LamA). We cloned the plasmids FsrA, FsrC, LamA and LamC using standard cloning techniques like Gibson assembly and PCR. Then, a double transformation needs to be performed to combine plasmids FsrAC and LamAC. If successful, GFP will be expressed once it is inserted in a plate reader for testing. Then, we can combine it with the other subgroup projects and test if the histidine kinase is activated with the selected ligand.

Simulation of Crystallization in a Magma Ocean
Jeffrey An
*Mentor: Paul Asimow*

In Earth’s early history, the entire planet consisted of molten rock, or magma. As the Earth cooled, crystallization into solid rock mostly likely occurred at an intermediate depth in the magma column. The crystals formed would be denser than the surrounding magma, causing them to sink to hotter regions and re-melt. This simulation models the distribution of crystals and heat in the system over a long period of time, a behavior that is currently unknown. The system was modelled using five conservation equations: liquid and solid mass, liquid and solid momentum, and energy, as well as two more equations derived from a phase diagram. Using the Euler method, the system numerically tracks enthalpy, volumetric solid fraction, and solid and liquid velocities. The simulation accurately describes steady state behavior for cases with no crystal formation, although the system reaches the steady state far too quickly. Cases with crystal formation develop numerical instability after longer periods of simulation time.

Gender Effects on Dynamic Unstructured Bargaining With Asymmetric Information
Jolenda Ang
*Mentors: Colin Camerer and Gideon Nave*

This project investigates the effects of gender on dynamic economic bargaining. This present study utilizes a simple economic game paradigm simulating bargaining with private information between an informed player (who is aware of the endowment) and an uninformed player (who is unaware of the size of the endowment) to examine the differences in economic behavior via Z-tree. We expect the results to show that women are more risk-averse and more co-operative towards making economic decisions, with a higher proportion of executed deals. Subsequent work will be aimed at the influence of intra-gender differences and possible cultural differences on asymmetric bargaining.

An Analysis of Observational Cloud Data to Determine Major Sources of Variability
Katie Antilla
*Mentor: Yuk Yung*

Clouds are one of the most important factors in climate models, yet their patterns and interactions with the rest of the environment are currently not very well understood. Improving cloud modeling would lead to better climate simulations and thus more accurate predictions for the future. To do this, we are analyzing the Version 6 cloud data collected from 2003 to 2012 by the Atmospheric Infrared Sounder (AIRS) instrument suite from NASA’s Aqua satellite. Performing Empirical Orthogonal Function (EOF) analysis on the AIRS high-, middle-, and low-altitude cloud data reveals the primary spatial and temporal patterns of cloud distribution, allowing us to identify the major sources of variability. The results show that the pattern of sea surface temperature (SST) fluctuations known as the El Niño Southern Oscillation (including both classic ENSO and ENSO Modoki) is the leading factor influencing cloud distributions over time. Furthermore, by performing EOF analysis on SST data and then linearly regressing the results with the AIRS data, we can verify that variations in SST have a strong influence on cloud distribution, particularly for high-altitude clouds.
Hebbian and Perceptron Learning in DNA-Based Hopfield Networks
Diana Alexandra Ardelean
Mentors: Lulu Qian and Kevin Cherry

Engineering at the nanoscale using DNA strand displacement reactions is becoming more attractive in the scientific community and has already led to a diversity of devices that exhibit a variety of dynamic behaviors, including DNA ‘walkers’ that perform simple nanomechanical tasks, and DNA circuits that implement logic functions and neural networks functions. With these DNA circuits, preprogrammed synthetic biomolecular machines have been implemented to respond intelligently to given instances, such as automatons that can play games or machines that can recognize patterns. Towards more sophisticated molecular information processing, a few theoretical approaches have been explored to create adaptive biomolecular systems that are capable of learning from unexpected events encountered during autonomous operation. Through my research I am developing biomolecular implementations of simple learning strategies, such as the Perceptron and the Hebbian learning algorithms, within Hopfield associative networks. The project involves understanding the learning algorithms at the theoretical level, simulating them using abstract chemical reactions networks, and finally, designing a DNA strand displacement implementation that is experimentally feasible and compatible with the previously demonstrated DNA neural networks. With further investigation, this work could lead to the first experimental realization of adaptive behavior in synthetic molecular systems.

Predicting 3-Dimensional Structures for Human Olfactory Receptors
Manasa Ashok
Mentors: William Goddard, III, and Soo-Kyung Kim

G protein-coupled receptors (GPCRs) are an important protein family of receptors, since they perform diverse tasks, and mediate our ability to see, smell, taste and feel pain. Olfactory receptors (ORs) constitute a large portion of these GPCRs in the human body, with 398 functional ORs identified through genome analysis. Predicted structures for a human olfactory receptor OR1G1 has already been identified, and structures in each of the 6 OR clusters have been predicted using OR1G1 as a template, due to the high sequence and structure homology among ORs. Using the BiHelix and SuperBiHelix methods, we have sampled helical rotations and tilts to generate millions of conformations for the family heads of the 6 clusters. These conformations were ranked to find the lowest energy conformations, and hydrogen bonding networks between the 7 helices were studied further to find the most likely structures. Binding sites in these structures can then be found using known odorants, through the DarwinDock method, allowing for the identification of ligand-receptor interactions that might suggest conformational constraints between all the hORs.

Synthesis and Characterization of Tungsten Arylisocyanide Complexes for Use as Powerful Photoreductants
Jackson Atwater
Mentors: Harry B. Gray and Wesley Sattler

Tungsten arylisocyanide coordination complexes have been synthesized and characterized for use as photosensitizers to determine their ground and excited states electronic structures, with the ultimate goal of performing electron transfer chemistry. The isocyanide ligands (ArNC) have been prepared by formylation of the corresponding aniline (ArNH2) to give the corresponding formamide (ArNHCHO), followed by dehydration. Three novel complexes, W(CNPhOMe2)6, W(CNPh2OMe5)6, and W(CNPhEt2)6 have been synthesized and characterized by various spectroscopic techniques, including 1H and 13C NMR, steady-state electronic absorption and emission and time-resolved luminescence spectroscopies. W(CNAr)6 complexes are highly luminescent in solution, emitting yellow to near-IR light. The complexes emit with different maxima (λmax values ranging from 550 nm to 750 nm) when irradiated. Future work will focus on further characterization of the complexes electronic structures and excited state kinetics by determining rate constants for both radiative decay and different nonradiative decay pathways. This will be accomplished by measuring quantum yields and excited state lifetimes at various temperatures, as well as measuring their extinction coefficients in solvents of different polarity. The molecular structures will be determined by single-crystal X-ray diffraction.
Local Depletion of Macrophages Using Clodronate to Alter Inflammation Following Joint Injury
Karsyn N. Bailey
Mentors: Steven A. Olson, Bridgette D. Furman, and Justin Bois

Post-traumatic arthritis (PTA) is an accelerated form of arthritis that most commonly develops following fracture of the articular surface of a joint. Following articular fracture, C57BL/6 mice showed significant signs of PTA, whereas a different strain of mice, MRL/MpJ mice did not exhibit these signs, suggesting that inflammation and the infiltration of synovial macrophages plays a role in the pathogenesis of PTA. Previously, Macrophage Fas-Induced Apoptosis (MAFIA) mice demonstrated increased joint inflammation with joint injury following a local depletion of macrophages using the dimerizing agent AP20187. To further elucidate the mechanism of macrophage depletion and joint inflammation, a different method of macrophage depletion was investigated. In this study, male C57BL/6 mice were subjected to a closed intra-articular fracture of the tibial plateau and treated with clodronate via intra-articular injection of liposomes in order to locally deplete macrophages within the joint. Mice treated with clodronate were assessed for joint inflammation and synovitis. Bone morphological changes and inflammatory cellular infiltrate were evaluated in both mouse strains to examine the effect of macrophage depletion.

The Spectral Action of the Packed Swiss Cheese Cosmology
Adam Ball
Mentor: Matilde Marcolli

The Cosmological Principle asserts that the universe is homogeneous and isotropic. However, it is apparent that this is not true on smaller scales. One potential reconciliation of this contradiction is the so-called Packed Swiss Cheese cosmology (PSC). It supposes that space takes the form of fractally clustered spheres. In order to gauge the validity of this theory, we need to determine what physical phenomena it predicts. Using the tools of noncommutative geometry I aim to calculate the action functional for the PSC, which will provide rich information about the model and allow us to check its consistency with some of our existing knowledge of the universe.

Characterization of the Quantum Optical Properties of Color Centers in Silicon Carbide
Alex Ball
Mentors: Andrei Faraon and Niels Verellen

Crystal defects (color centers) in diamond have been shown to exhibit quantum properties such as optically detected magnetic resonance (ODMR) and coherent spin control at room temperature. This makes them promising candidates for realizing quantum-based technologies such as quantum computing and magnetic nanosensing. Silicon carbide (SiC), a compound with well-established fabrication techniques and a wider range of possible defects, has recently been shown to contain color centers with these same properties. Therefore it is valuable to investigate novel color centers in SiC for their quantum optical properties. In this project, an experimental setup for measuring ODMR signals is implemented. Nickel, chromium, nitrogen, and carbon doped SiC; as-grown 4H-SiC; and copper doped silicon samples are investigated. The setup is shown to be capable of fully automated ODMR measurements from room temperature down to 4 K, with a detection range of 900 nm to 1700 nm and microwave excitation of up to 3 GHz. Future efforts will involve measurements of spin coherence times and systematic investigation of other SiC color centers.

RR Lyrae Distribution in the Galactic Halo
Sophianna Banholzer
Mentor: Judy Cohen

Many methods have previously been used to estimate the density and the mass of the Milky Way galaxy. A new method for classifying RR Lyrae stars was recently developed using data from PTF, analyzed with a random forest classifier, thus resulting in a large sample of probable RR Lyrae stars. This sample was used to estimate a density distribution for the outer halo. Fitting a power law to the sample revealed that the density did not fall off as sharply in the outer halo as previous studies suggest. These density calculations can be combined with radial velocity measurements in order to estimate the mass of the galaxy.
An Investigation Into Photocatalyzed Olefin Metathesis Polymerization and Its Applications in Surface Chemistry
Richard Barz
Mentors: Robert H. Grubbs and Raymond Weitekamp

A photoactivated ruthenium catalyst has been developed that is able to locally catalyze olefin metathesis, to cross-link together polymer chains into a rigid structure. Using this strategy, many resists have been prepared in one-pot procedures from various different starting dienes and mixtures of dienes. The procedure to cleanly develop the photosensitive wafer has been optimized, enabling the further exploration of the process scope. We have successfully incorporated a large variety of functional groups into the resist through the addition of small molecule dopants. By selecting fluorescent compounds, for instance, it is possible to use fluorescence microscopy to confirm the successful incorporation of these dopants into the patterned material. From here, we are working to demonstrate a wide variety of simple chemical reactions directly on the surface of the resist, with many applications from device manufacturing to molecular biology.

Frogonomics: Amphibian Decision-Making Under Uncertainty
Elizabeth A. Beaver
Mentors: Colin Camerer and Gidi Nave

The purpose of our study is to determine the decision-making capabilities of the three-clawed frog, *Xenopus laevis*. Because *Xenopus* possess a basal ganglia but lack a neocortex, any behavioral biases they exhibit will further our understanding of roles these areas play in our own brains. Many behavioral experiments have been done on rats, pigeons, and primates, but very few have been done on amphibians because it was assumed they were incapable of higher learning. Our goal is to determine that *Xenopus* are capable of making value-based decisions. Once we have determined that, we can begin running other studies. Such studies include a sunk-cost equivalent (done by swimming distance), and delayed gratification studies.

Unfortunately, *Xenopus* take a very long time to train. Recently, the frogs have begun responding to the presented stimulus/food reward. Now that they are responding to the stimulus more consistently, we can begin to determine their ability to make value-based decisions. A previous study showed that *Xenopus* have "perfect pitch," which means they are capable of determining the location/pitch of multiple frequencies in the water. By using different frequencies and associating them with different rewards, we can conduct the aforementioned experiments.

Investigating Explicit and Implicit Social Inferences in Response to Naturalistic Nonverbal Cues
Michael Belcher
Mentors: Ralph Adolphs and Robert P. Spunt

Social inference broadly refers to the ability to use other people’s observable behaviors (e.g., smiling) to estimate their internal states (e.g., friendly). A number of functional magnetic resonance imaging (fMRI) studies have investigated the neural basis of social inference, but most relevant work on the topic has relied on eliciting social inferences using explicit verbal instructions. Such protocols provide a poor model of naturalistic social interaction in human adults, where social inferences must often be made solely on the basis of nonverbal cues. Therefore, this project was motivated to develop and characterize a large set of naturalistic nonverbal social stimuli. We have collected and normed hundreds of photographs of naturalistic social scenes and emotional expressions. Nonverbal visual stimuli are far more ecologically valid than explicit verbal stimuli, because visual stimuli are unconstrained by instruction and can capture spontaneous inferences. The normed stimuli we collected will be used in behavioral and neuroimaging investigations of naturalistic social inference in both neurotypical humans and individuals with autism.

Automated Sequence Analysis for DNA Strand-Displacement Systems
Joseph Berleant
Mentors: Erik Winfree, Niranjan Srinivas, and Chris Thachuk

Embedding computation within chemical or biological systems has exciting applications, such as smart medicines and the bottom-up fabrication of nanostructures. However, reliable chemical computation requires the ability to design molecules that interact only in specific ways. DNA complexes are a promising source of these molecules because, ideally, a DNA strand will bind only to another strand with a complementary sequence, allowing molecular interactions to be restricted as needed. Of course, DNA strands may also interact weakly with partially complementary strands or with themselves to produce unexpected and undesired structures. Understanding and predicting this non-ideal behavior is essential to making DNA-based computation possible. While chemical kinetics and thermodynamic principles have been applied to capture this behavior, it is still very difficult for researchers to analyze a particular DNA system and pinpoint the non-idealities likely to pose a problem in a laboratory setting. We have begun creation of an automated sequence analysis tool that allows researchers to determine how ideally a particular DNA system will behave and whether it properly implements the desired computation. This tool would save time and resources by reducing the likelihood that a proposed DNA system will fail when tested experimentally.
Designing Planners for M-Blocks
James Bern
Mentors: Daniela Rus, John Romanishin, and Richard M. Murray

The M-Block is a novel modular robotic platform currently in development that follows a pivoting cube model of motion. We develop and test in simulation and hardware shape reconfiguration algorithms for both the 2D case of pivoting squares and for the full 3D case of pivoting cubes. Our algorithms leverage past work on controlled module density, and operate by using reversible moves to convert an initial configuration into a straight line. In the 2D case, we show that excluding three small subconfigurations is sufficient to guarantee successful reconfiguration in $O(n^2)$ moves. We also provide a simple procedure for reducing the physical space required for a full reconfiguration procedure. Finally, we introduce a parallel variant of the reconfiguration algorithm, wherein multiple cubes may be moving at any given time.

Experimental Analysis of Behaviour of Granular Materials Under Static Loading
Prathamesh Bhat
Mentor: Guruswami Ravichandran

The collective behaviour of a granular media is complex to understand and has not been satisfactorily characterized. Inter-particle forces between individual grains in a granular assembly are linked to the macroscopic behaviour of granular media like constitutive behaviour, friction and wave propagation. Patterned cylinders of different materials and sizes are used to model the granular assembly. An experimental setup is designed and fabricated to study different configurations of granular assembly under static loading. Speckle patterning on cylinders facilitates the calculation of particle displacements and strains using Digital Image Correlation (DIC). A Granular Element Method based mathematical framework was used to solve the boundary value problem in the experiments and the inter-particle forces can be calculated using this framework. This technique allows for the visualization of force chains as certain grains in the assembly can take comparatively larger loads and hence are more susceptible to mechanical failure. Development of force chains and the changes in their patterns will be observed for different configurations of granular assembly. Ultimately, the project aims at putting up some thumb rules based on experimental observations which can be used to predict the pattern and extent of force chains in a granular assembly under static loading.

Effect of Bow Shocks on Acoustic Noise in Supersonic Wind Tunnels
Srinivasa A. Bhattaru
Mentors: Joseph Shepherd and Bryan Schmidt

The analysis and characterization of acoustic noise in any sort of wind tunnel is extremely important to ensuring good data collection and accurate flow models, especially supersonic flows. In this project, we attempted to analyze the acoustic noise present in a common model of supersonic shock tunnel, as well as observing how the power and frequency of that noise changes past the shockwave generated by any object in the stream. A technique known as focused laser differential interferometry, or FLDI, was modified to work with the available wind tunnel; several test runs of the tunnel showed successful application of the FLDI setup, as well as valuable data on the full range of noise frequency in the tunnel and its variance across a bow shock wave.

Mass Spectrometry With Two-Dimensional Nanoelectromechanical Systems
Marcus Bintz
Mentors: Michael L. Roukes and Peter Hung

Nanoelectromechanical systems (NEMS) represent the next wave in miniaturizing various electrical and mechanical devices used in a variety of fields, including physics, biology, and engineering. In NEMS mass spectrometry, the adsorption of an analyte particle onto a device causes a sudden detectable shift in the frequencies of the device’s vibrational modes, which can be used to measure the mass of the particle. If sufficient number of modes are tracked, inertial imaging theory allows for determination of the size of the particle as well as higher order moments in its mass distribution. Most current NEMS mass spectrometry techniques rely on the use of effectively one-dimensional systems such as doubly-clamped beams and cantilevers. A shift to two-dimensional NEMS such as membranes suggests the possibility of improved mass sensitivity and the capability to determine two-dimensional moments in the analyte’s mass distribution. For this experiment, we utilize circular membranes of stacked aluminum nitride and molybdenum and a matrix-assisted laser desorption/ionization (MALDI) mass-deposition system. Here we present results that confirm our ability to detect simultaneous frequency jumps necessary for reconstructing the mass of adsorbed analyte. We also discuss progress on the extension of inertial imaging theory to two-dimensional systems.
Effects of a Superconducting Lead Endcap on the Magnetic Field Profile for the nEDM Search  
Antra Biswas  
Mentors: Bradley Filippone and Simon Slutsky

Discovery of a non-zero electric dipole moment in the neutron (nEDM) would indicate a CP violation, with implications for extending the Standard Model and confirming predictions about matter-antimatter asymmetry. Experiments using shifts in precession frequency to measure the nEDM require a uniform magnetic field to prevent false signals. We investigate the effectiveness of a superconducting lead endcap in promoting field uniformity inside an open-ended cylindrical coil. Measured field maps in the superconducting state closely match simulations and indicate that the endcap causes field peaks to shift away from magnet center, decreasing field gradients in desired regions. Simulations also suggest that the endcap may prevent field effects caused by imperfections in the geometry of an axial lead shield that surrounds the coil.

BetaCage Prototype: Readout Electronics Pulse Simulation  
Charles Blakemore  
Mentors: Sunil Golwala and Alex Zahn

Produced in collaboration with University of Alberta and South Dakota School of Mines, the BetaCage is a particle detector that uses a time-projection chamber and a series of multi-wire proportional chambers (MWPC’s) to reconstruct the path and energy of an ionizing particle incident on the detector. In order to better understand the signals we might receive from such an interaction, a simulation has been developed in Python that models the deposition of ionized electrons onto the detector’s sensing wires, including the avalanching process and the subsequent propagation through readout electronics. We have found that theoretical results, in the form of voltage pulses, match many of the qualitative features of actual recorded pulses from beta-particle detections. In an effort to better match theoretical results, the readout amplifier developed by our peers at University of Alberta has been characterized and its behavior incorporated into the pulse simulation. We hope to use this simulation to more accurately assess the energy of incident particles, as well as increase the resolution of reconstructed tracks.

Minimising Quantum Back-Action Noise in Quantum State Tomography of Cavities  
Bence Börcsök  
Mentors: Rana Adhikari, Yanbei Chen, and Nicolas Smith-Lefebvre

Cancelling the quantum back action noise in time-dependent homodyne detection for quantum state tomography of a broadband cavity was discussed previously by Miao et al. [Phys. Rev. A 81, 012114 (2010)]. We extended the method for finite bandwidth cavities. The fact that the internal optical field in the cavity contains information about the state of the mirror at earlier times, thus neither the internal optical field nor the mirror are Markovian systems, was formulated. A general method was proposed for any system when the same dynamics governs the preparation and the verification stage. The method involves causal factorisation of the connection matrix in frequency domain, which is only possible to carry out analytically for simple cases. A perturbative method was discussed, which treats the general connection matrix as perturbation around a known one. The calculations were carried out for the finite bandwidth cavity. It was found that the finite bandwidth of the cavity increases the noise level. The noise level was calculated for parameters of a typical experiment and an experiment was designed to compare the theoretical results with measurements.

Antireflection Properties of Holed Silicon in the Infrared Range  
Arjun Bose  
Mentors: Sunil Golwala and Simon Radford

Since modern astrophysics requires much larger millimeter and submillimeter detector arrays than ever before, previous antireflection (AR) treatments, such as textured designs and liquid coatings, are no longer viable solutions to antireflection. A more viable option may be to create an antireflection treatment with layers of silicon with various holed patterns in order to create a gradient index (GRIN) coating, which can be integrated into any lens the infrared and far infrared spectrum. In creating the theoretical designs for such a treatment, a ray tracing software (Radiant Zemax) was used for large-scale design of the optimal gradient index is, and a computationally intensive electromagnetic wave simulation software (Ansys HFSS) for small-scale design of optimal hole pattern for each index. The ideal gradient had a quadratic relationship to radius with rotational symmetry along the optical axis while the optimal hole patterns required 25μm square cells for effective indices between 1 and 2 and 50μm square cells for effective indices between 2 and 3, and 100μm square cells for effective indices between 3 and 3.46.
Development of a Low Phase Noise Cryogenic Sapphire Oscillator
Dryden Bouamalay
Mentor: Keith Schwab

Ultra-stable microwave sources have become increasingly important in experimental physics. The goal of this project was to develop a low phase noise microwave source using a cryogenic sapphire crystal oscillator. By coupling co-axial cables to the sapphire crystal at low temperatures, an extremely stable microwave source can be made by causing the sapphire to resonate in the whispering gallery mode configuration. We constructed a sapphire crystal oscillator with an observed quality factor of several hundred thousand at room temperature, with a much higher quality factor expected for cryogenic temperatures. In addition, we began construction of an external circuit to process the signal.

First-Principles Nonlocal Response in Atomically-Sharp Plasmonic Nanostructures
Luke Bouma
Mentors: Harry A. Atwater, Prineha Narang, and Ravishankar Sundararaman

Confinement of surface plasmons in sharply faceted systems such as probe tips and nanoprisms can enable electromagnetic field enhancement for applications in sensing and nanophotonics. Although well-understood at macroscopic scales, the surface plasmon response at atomic length scales deviates from purely classical models; effects including the nonlocality of the dielectric response as well as the spill-out of electrons impact the optical response of these systems. Previous efforts to model sub-nanometer length scale nonlocality have used semi-empirical corrections in hydrodynamical models of Maxwell’s equations, and neglect electron spill-out. We study the nonlocal response of atomically-sharp systems from a first-principles approach that implicitly includes nonlocality and electron spill-out as an emergent feature. By considering the linear frequency response of jellium cones with cylindrical symmetry, we lower our computational cost from comparable three-dimensional approaches, enabling calculations closer to experimentally relevant length scales. We present these calculations, and discuss their implications for sub-wavelength concentration of light for sensing applications.

Optimization of a Protein Catalyzed Capture Agent Against Oncogenic KRas G12D
Mary M. Boyajian
Mentors: James Heath and Ryan Henning

The KRAS gene is in the Ras gene family of GTPases and its mutations are among the most frequently detected in numerous cancers (Schubbert, et al., 2007). However, this oncogene is difficult to target directly because it has a picomolar affinity for GTP/GDP which cannot be outcompeted at intracellular GTP/GDP concentrations (Ostrem et al., 2013). An alternative approach is the use of protein catalyzed capture agents. The Heath group has found a capture agent that binds to KRAS (G12D), a mutated form of KRAS which is responsible for a large proportion of all cancers due to KRAS mutations. In this project, the cyclic KRAS-binder is optimized to improve affinity and the synthetic route is simplified.

Impact of Karlovitz Number on Vortex Evolution Through a Premixed Flame
Christopher P. Bradley
Mentors: Guillaume Blanquart and Bruno Savard

As a canonical test case of premixed turbulent combustion, the vortex-flame interaction is investigated for the transformation of vorticity through the flame. This is analyzed as a function of the length and velocity scale of the vortex, which may be related to the Karlovitz number in premixed turbulent combustion. This analysis is performed using theoretical analysis of the vorticity equation and results from Direct Numerical Simulations. The vorticity is found to transform with different behavior due to the variable importance of viscous dissipation, dilatation, and baroclinic torque. The importance of these effects are shown to be based on the velocity and length scale of the vortex in relation to the velocity and length scale of the flame. The conditions under which these effects are dominant is outlined and confirmed through comparison of the theoretical and simulation results.

Development of a Novel Transparent Electrostatic Gate for GaAs Heterostructures
Sarah A. Brandsen
Mentors: James P. Eisenstein and Johannes Pollanen

The development of a transparent top gate could strongly improve ongoing projects involving two-dimensional electron systems (2DES), such as research on the anisotropic stripe state and various quantum Hall effects. These phenomena are often observable only in high quality samples where the 2DES experiences a uniform electric field from nearby silicon donors. For this reason, the sample is typically illuminated with red light during cool down in order to excite the silicon atoms and provide a fully ionized donor layer. However, it is also desirable to electrostatically gate the sample by placing a thin sheet of (opaque) metal on top, as this allows the experimenter to control the charge density of the 2DES. Current experiments are limited by the inability to both gate the sample and subject it to red light. For this reason, we aim to develop a transparent charge-carrying layer that acts as a novel gate.
A New High-Resolution Magnetostratigraphic Record From the Paleoproterozoic Pethei Carbonates, Northwest Territories, Canada
Alec R. Brenner
Mentors: Joe Kirschvink and Sarah Slotznick

A paleomagnetic analysis and fold test, conducted on a high-resolution sample set from four localities in the ca. 1.8-Ga Douglas Peninsula Formation (base of the Pethei platform carbonates of the Great Slave Lake Supergroup, Northwest Territories, Canada), is presented. Additionally, the magnetic susceptibility signal of a ~350-m thick section of the larger Pethei Group displays a hierarchy of ka- to Ma-scale cycles. If interpreted as Milankovitch forcings, possibly expressed through the effects of insolation on biogenic carbonate precipitation relative to continental siliciclastic export, sediment accumulation rates could be constrained for the Pethei carbonates. The implications of our analysis are also discussed in the contexts of true polar wander reconstructions, knowledge of global geodynamics and the supercontinent cycle, and the development of the carbon cycle during Paleoproterozoic time.

The Black Hole Mechanics Analog of the Generalized Second Law
William E. Bunting
Mentors: Donald Marolf and John H. Schwarz

In this paper we derive a generalized second law of black hole mechanics for black holes with non-compact horizons in asymptotically AdS spacetime. We show via AdS/CFT that because a CFT in a fixed black hole background spacetime that acts as a heat bath necessarily has decreasing free energy with time the dual non-compact black hole will also have a decreasing free energy with time. That is, we generalize Hawking’s Area Theorem to black holes with non-compact horizons. The key piece of technology used for this analysis is the Fefferman-Graham expansion, which tells us the asymptotic structure of the bulk spacetime given fixed data for the CFT. This allows us to write the properties of the asymptotic bulk horizon in terms of their CFT duals.

Determining the Structure of Nup170
Slava Butkovich
Mentors: André Hoelz and Dan Lin

In eukaryotic cells, transport between the cytoplasm and the nucleus is regulated by nuclear pore complexes (NPCs). NPCs consist of proteins called nucleoporins (nups). Nup170 is a nucleoporin in yeast whose human homologue, Nup155, was linked to atrial fibrillation and early sudden cardiac death. Previously, the overall shape of Nup170 had been determined to low resolution by electron microscopy, but we seek to determine the structure to atomic resolution (~3 Å) using x-ray crystallography. To do this, Nup170 constructs are expressed in E. coli and purified. Protein crystals are grown in various chemical conditions and then sent to the Stanford Synchrotron Radiation Lightsource (SSRL). X-ray diffraction occurs, giving structural information. The structure of a C-terminal construct has been determined to 4.3 Å. Crystals of several N-terminal constructs have diffracted to resolutions of ~8 Å and have provided guidance on what future constructs are likely to produce better diffraction patterns. Further research will be able to determine the structures of Nup170 fragments to higher resolutions.

Error Propagation of Derived Quantities in Young Stellar Objects
Chuxiao Cao
Mentor: Lynne Hillenbrand

Young stars have a variety of active phenomena which make them dynamic and difficult to accurately characterize. In making models of young stars and clusters, and understanding their formation and evolution, confidence in the observational data is required. To analyze the extent to which errors in photometry and spectral type influence errors in ages and masses for young stellar objects, a stellar pipeline is written. This pipeline dereddens stars, propagates errors, and interpolates between tables to derive a variety of relevant quantities, such as extinction, luminosity, temperature, and stellar radius. A best-fit mass and age are then calculated by interpolating across a set of isochrones and constructing a Bayesian probability distribution from the propagated values and errors with assumed prior distributions for stellar age and mass. By computing statistics of the two-dimensional probability distribution function in age/mass space and integrating over each axis, it is possible to determine quantitative error bounds for each young star’s age and mass. An analysis like this will provide a useful calibration of typical error ranges for different kinds of young stellar objects, and provide a maintainable pipeline that may be used standalone or as part of a database system.
Characterization of the Hydrogen Features in the Near-IR Spectrum of Elbaite Tourmaline
Jennifer Caseres
Mentor: George Rossman

An accurate determination of the total amount of hydrogen in tourmaline is difficult to obtain. Hydrogen cannot be directly measured by electron microprobe, the most common method of analysis for tourmaline composition. Other measurement methods, such as hydrogen manometry and inductively coupled plasma-atomic emission spectroscopy, are difficult and often destructive. A simpler method was proposed by Ertl et al. (2010) that involved measurement of the integrated area of the OH overtone bands in the near-IR spectrum. The near-IR spectrum of tourmaline remains incompletely characterized, and some individual components have not been identified. The hydrogen in samples of elbaite tourmaline was isotopically exchanged for deuterium using a modification of Desbois & Ingrin’s (2007) method of heat treatment in a D2O atmosphere. This allowed OH overtone bands to be identified upon re-examination of the near-IR spectrum and to be separated from the non-hydrogen features in the same region.

Controlling Plasmonic Mode Dispersion in Resonant Guided Wave Networks
Krishnan Chander
Mentors: Harry A. Atwater and Howard Lee

Surface plasmon polariton waveguides support the propagation of plasmonic modes at nanoscale dimensions and at THz speeds, thus combining the signal transmission advantages of electronic and photonic circuit technology. When waveguides are made to intersect at junctions that form a mesh, they create a resonant guided wave network (RGWN), whose resonant properties are determined by phase shifts of the wave through the junctions. The proposed waveguides are fabricated with indium tin oxide (ITO), a transparent conducting oxide whose charge carrier concentration, and in turn refractive index, can be tuned through voltage application via the field effect dynamic. This can change the propagation of a plasmonic mode, and so the objective is to determine how the phase of the interfering waves and the resonance of the RGWN can be tuned when voltage is applied. This has applications in designing an ultracompact digital circuit for transmitting signals out of specific ports (e.g. color router or logic device). More work has yet to be done in measuring how well a plasmonic mode can be excited in the RGWNs using far-field microscopy, and then transmission measurements with voltage application can be made.

Study of the Shashlik G4 Simulation for CMS Precision Timing at HL-LHC
Chien-yi Chang
Mentor: Maria Spiropulu

For the Compact Muon Solenoid (CMS) Upgrade at High Luminosity Large Hadron Collider (HL-LHC), a cost effective Shashlik design based on radiation-hard crystal scintillator LYSO for the upgraded forward Electromagnetic Calorimeter (ECAL) has been proposed along with the test bench study of picosecond-resolution timing device to address the challenges of high pileup, provide improved vertexing and resolution for photons and jets in the ECAL and the trigger. Preliminary CMS simulations have shown that a device with about 10 ps resolution could be used to reduce the contribution of PU to the jet energy in the forward region by a factor of 10, and thereby substantially improve the reconstruction accuracy and resolution of forward jets. This project, which focuses on the profile of the scintillation showers through Geant4 simulation, is conducted to optimize the geometry and timing resolution of detector. An analysis of the Monte Carlo simulation serves as a consolidation of the May Test Stand at Caltech and also a prediction for the ongoing Test Beam at Fermilab.

Financial Networks and Contagion
Kalyn Chang
Mentor: Matthew Elliott

In a financial network, interdependencies between organizations can result in contagious financial distress and failure. The risk of a large part of the financial system collapsing motivates government intervention in times of crisis. Better understanding this risk can help inform government policies and evaluate regulations aimed at preventing a future financial crisis. Previous research suggests that widespread contagion is most likely to occur when there are intermediate levels of integration, the exposure of organizations to each other, and diversification, how varied organizations’ interconnections are. At intermediate levels of integration and diversification, organizations are dependent enough on other organizations to be vulnerable to other organizations’ failures and connected enough to other organizations to spread failure throughout the network. This changes when heterogeneous failure thresholds are introduced to the general model. Simulations were run to see what happened when organizations’ failure thresholds were varied. Preliminary results suggest extensive contagion can occur even when integration and diversification levels surpass the intermediate range because at high levels of interconnectivity, fragile organizations are even more prone to failure with heterogeneity than without. Further simulations modeling other aspects of financial systems and their effects can be run to gain more insight about contagion in financial networks.
Kevin Chang
Mentors: Mark Simons, Romain Jolivet, and Bryan Riel

The 7.8 Mw Kokoxili earthquake ravaged the Kunlun fault in northern Tibet in November 2001. We used interferometric synthetic aperture radar (InSAR) data from the ESA ERS-1 and ERS-2 satellites to create high resolution interferograms measuring the surface displacement due to this large earthquake. We used ISCE software, the successor of the previously used ROI-PAC software, to process pairs of SAR data averaged at four looks and construct these interferograms.

In terms of slip distribution on the fault, we plan to run the Classic Slip Inversion library to take the GPS and InSAR data and find the best-fit model for the interferograms as well as a range of likely models. A fully Bayesian approach will be used to model the slip distributions. We will construct Green’s functions in a layered elastic half-space and account for error in the elastic structure of the crust.

Building Capture Agents for the Detection of Plasmodium Lactate Dehydrogenase (pLDH) as Malaria in vitro Diagnostics
Ann Chen
Mentors: James Heath and Aiko Umeda

Conventional protein detection methods that identify malaria utilize antibodies for their high affinity and selectivity for their target protein. However, these antibodies are expensive and unstable, especially in the presence of thermal fluctuations. As an alternative to traditional antibody-based capture agents, more cost-effective and stable peptide-based multi-ligand protein capture agents have been developed through the Huisgen 1,3-dipolar cycloaddition reaction and one-bead-one-compound (OBOC) peptide library screens. In this study, capture agents against pLDH, a malaria biomarker, are being constructed based on the in situ click screen strategy. We chose two distinct sites on the surface of pLDH as target epitopes so that resulting two capture agents can simultaneously bind to the protein. After screening with 5-mer OBOC libraries, we identified the biligands, hevwh-(YLGHK)cyclic and (GHWSAN)cyclic-RGRRY as suitable candidates. These candidate capture agents have been individually scaled up and tested for their affinity and selectivity for pLDH. Using (GHWSAN)cyclic-RGRRY in place of a capture antibody and hevwh-(YLGHK)cyclic in place of a detection antibody, we were able to detect pLDH in a solution in a sandwich ELISA, effectively eliminating the need for antibodies in a protein detection method. We expect that peptide-based multi-ligands will serve as drop-in replacements for antibodies as robust capture agents in malaria diagnostics.

Implementation of a Non-Endogenous Two-Component System in Escherichia coli and Characterization of Combinatorial Promoters
Anthony Chen
Mentors: Richard Murray, Victoria Hsiao, and Anu Thubagere

As part of an overall project to build an E. coli based synthetic circuit analogous to mammalian circuits that regulate insulin and glucose concentrations extracellularly, we seek to test and implement a two-component AgrBDCA system, which is endogenous to Staphylococcus aureus, in E. coli. Because the auto-inducing peptide (AIP) which normally binds and activates the membrane-bound histidine kinase AgrC is not readily available, an SH3 scaffold system has been attached to AgrC and the response regulator AgrA, which allows AgrC to phosphorylate AgrA even in the absence of AIP. Fluorescence of this circuit will then be compared to fluorescence of a control circuit that constitutively has fluorescence. Additionally, we seek to characterize combinatorial promoter constructs, which have potential applications for the overall project. After cloning cells with test constructs, fluorescence values after addition of inducers at various concentrations indicate that a combinatorial promoter consisting of pTet and pLac operators behaves as an AND-gate, while a combinatorial promoter consisting of pBAD and pTet operators behaves as a single-input gate. Further work will be done to explore how changing the order and position of the pLac and pTet operator parts affect the logic of the pTet-pLac combinatorial promoter.
Optimization of Tungsten Phosphide for Catalysis of the Hydrogen Evolution Reaction  
Ching-Hwa Anita Chen  
Mentors: Nathan S. Lewis and Chance Crompton  

Artificial photosynthesis is an environmentally friendly process that uses solar energy to split water into oxygen and hydrogen. Researchers are racing to develop earth-abundant catalysts for the hydrogen evolution reaction, the part of artificial photosynthesis that reduces protons to energy-dense H₂ fuel. Tungsten phosphide produced by the solvothermal method has recently been established as a viable candidate, but has been limited by its synthesis technique to the form of strictly stoichiometric WP nanoparticles. Using an alternative method called temperature-programmed reduction, we have created tungsten phosphide in various non-stoichiometric ratios, optimized around W₀.7P. The catalysts are acid-stable and appear as a silvery film when grown on a titanium substrate. Results from cyclic voltammetry reveal that they are capable of reaching overpotentials lower than 140 mV, which surpass those of previously tested WP nanoparticles. As the current industrial favorite, platinum, becomes ever more rare and expensive, it is important to discover an earth-abundant, acid-stable, and efficient catalyst to replace it when it finally runs out.

3D Photonic Lattices With Weyl Points  
Hongjie (Valerian) Chen  
Mentors: Harry Atwater and Siying Peng  

The intersection of two bands resulting in a change in Chern number is known as a Weyl point. Weyl points have been shown to be stable in momentum space, and the associated surface states are predicted to be topologically non-trivial. It is known that Weyl may potentially lead to various interesting phenomena. In this study, we attempt to fabricate photonic crystals with Weyl points. The band structures of various double gyroid structures were calculated using finite-difference time-domain simulations. The effects of using different materials for these structures were also studied. We looked for materials with large refractive indices, low extinction coefficients, and the ability to be deposited conformally at low temperatures. It was found that amorphous silicon would be suitable. 3D two-photon lithography was used to fabricate various double gyroid structures. High index materials were then deposited using either atomic layer deposition or plasma-enhanced chemical vapour deposition. The structures were then studied with Fourier Transform Infrared Spectroscopy to determine their band structures. Weyl points have yet to be found.

Optical Filter Design for Polyhedral Specular Reflector Spectrum-Splitting Module  
Kevin Chen  
Mentors: Harry A. Atwater, Carissa Eisler, and Cristofer Flowers  

One method to generate renewable energy is harnessing sunlight with photovoltaic cells. The Atwater group currently focuses on developing a spectrum splitting module, containing long-pass filters that laterally disperse photons onto subcells with matching band gaps. Modeled performance nearly doubles that of traditional silicon-based flat-plate solar panels by significantly reducing heat waste in thermalization, lack of absorption, and relaxing lattice matching constraints. The project focuses on optimizing performance of SiO₂/TiO₂ chirped Bragg-like reflectors. Single-layer SiO₂ and TiO₂ thin films were produced by sputtering deposition. Ellipsometry was used to characterize samples by providing optical constants data at wavelengths ranging 300-1700nm. Initial filter designs’ reflectivity and transmission were tested under simulation in open-sourced program OpenFilters as a function of total filter thickness, number of layers, and layer thickness distribution. The results offered insights in cost-performance tradeoffs that are relevant to commercialization. Actual multilayer dielectric stacks will be constructed by electron-beam evaporation and tested by ellipsometry.
Oligosaccharide and Glycopeptide Glycan Analysis Utilizing Gas-Phase Free Radical and Acid-Catalyzed Reactions
Lily Chen
Mentors: Jesse L. Beauchamp and Daniel Thomas

While the significance of glycans in organic processes has been increasingly demonstrated, the structural complexity of glycans inhibits effective analysis. Consequently, there has been a continued search for improved methods of examining glycans. We sought to determine the effectiveness of biomimetic reagents PRAGS, FRAGS I and FRAGS II (Figure 1) and develop a protocol for studying glycoprotein glycans. Though not every glycan was subjected to all variations, model oligosaccharide samples containing Man5GlcNAc2, lewis-B-tetrasaccharide, lewis-Y-tetrasaccharide, lacto-N-fucopentaose V, LNDFH I, lacto-N-tetraose, maltoheptose, NA2 and M3N2 have been used to test derivatization levels under different reaction conditions. Furthermore, model glycan samples were subjected to LTQ mass spectrometry, reverse phase liquid chromatography mass spectrometry (RP-LC-MS), and hydrophilic interaction liquid chromatography mass spectrometry (HILIC-ESI-MS) in order to identify the best equipment for examining sample contents. In addition, the purification process of glycans from glycopeptides is being refined using fetuin, IgG, RNase B, and ovalbumin. Thus far, MeFRAGS has been shown to derivatized N-linked glycans poorly. In addition, HILIC-ESI-MS has been shown to produce the clearest amount of accurate signals in spectra, so upon successful development of optimal purification and derivatization protocol, results will indicate the effectiveness of PRAGS and FRAGS towards glycans from glycopeptides.

![Figure 1](image.png)

**Figure 1.** Biomimetic reagents for mass spectrometric sequencing of glycans. Blue box shows functional group for coupling to glycans; red oval shows free radical precursor. Bond highlighted in red undergoes homolytic cleavage to generate radical.

A Mid-Holocene Relative Sea-Level Curve for the Sunda Shelf Using Coral Microatolls
Lucy Chen
Mentors: Aron Meltzner, Adam Switzer, and Joann Stock

Understanding causes of change in relative sea level (RSL), or sea level relative to land, is important for protecting coastal communities, ecosystems, and infrastructure. In response to deglaciation, sea level has risen and landmasses have deformed in response to changing loads of ice and water. Several models attempt to predict these changes, but there is insufficient data against which they can be calibrated. To construct a high precision record of mid-Holocene RSL in Southeast Asia, we examined coral microatolls that grew on the Sunda Shelf – specifically, Mapur Island in Indonesia. We processed x-rays of slabs from these microatolls, and recorded details of their growth patterns, which have been shown to precisely track RSL. Using the radiocarbon ages of the slabs, we created graphs charting the rise and fall of RSL from 7250 years before present (BP) to 6650 yr BP. Records from two sites suggest RSL rose from 7220 to 7040 yr BP and from 7030 to 6830 yr BP, with a possible brief drop in between; RSL then fell from 6830 yr BP onwards. We await to compare this with the RSL data collected from Belitung Island, 500 km to the southeast of Mapur.
**PID Controller Implementation for Digital Feedback in Optical Linear Chirps**
Oliver Chen  
*Mentors: Amnon Yariv and Mark Harfouche*

Wideband optical swept-frequency sources have found immediate applications in optical chirped radar as well as 3D biomedical imaging. Unfortunately, the inherent non-linearity of the optical sweeping mechanism limits the repetition rate and the dynamic range of the ranging systems. To correct for these non-linearities, an analog feedback system is used to adjust the chirp rate toward the desired setpoint. However, the current analog design is inflexible and making alterations to the system is cumbersome. In order to increase reconfigurability of the feedback mechanism without necessarily modifying hardware with every updated design, a digital system was used to replace the analog system. A proportional-integral-derivative (PID) controller on a field programmable gate array (FPGA) integrated chip was implemented in order to create a digital feedback system to linearize an optical lasered frequency chirp. The ability of the feedback hardware to control the injection current to a laser in real-time stems from the high-capacity computational ability of the FPGA chip. This digital feedback system can replace traditional analog feedback systems in optical applications due to inherent flexibility and reconfigurability of simulated hardware.

**On-Demand Power Source for Medical Electronic Implants: Harvesting Energy From Acousto-Mechanical Vibrations of Human Vocal Folds**
Sophia Chen  
*Mentor: Hyuck Choo*

Microelectronic sensors and systems are being increasingly used in implantable bio-medical sensing applications for their small size and low power consumption. Despite their long-term operation, however, the batteries that power these implanted devices will eventually need to be replaced or recharged, resulting in additional surgery and discomfort to patients. We are currently looking to replace or supplement these batteries with longer-lasting implantable power generators harvesting energy from the acousto-mechanical vibrations of the human vocal folds resonating throughout the skull. We analyze the frequency at which these vibrations resonate, and build an energy harvesting setup tuned to the appropriate range. Using a piezoelectric (vibration-driven) energy harvesting setup, we investigate the possibilities of turning these vibrations at different points in the skull into a power source for medical electronic implants, which will demonstrate the feasibility of an implantable energy harvesting setup.

**Data Analysis of the Ultraviolet Sky Brightness and Light Curves at the South Pole**
Yichen Chen  
*Mentors: Anna M. Moore and Yi Yang*

Analysis of the Astronomical U and SDSS g’ sky brightness and light curves has been applied to the data acquired by the Gattini-South Pole UV telescope. The telescope, with the goal of characterizing for the first time the ultraviolet observing conditions of the South Pole for future large-scale experiments of imaging the cosmic web, acquired ultraviolet imager and spectrograph data at the South Pole for the 2011 and 2012 winter seasons. Preprocessing, astrometry, aperture photometry, sky brightness calibration, and light curves were produced for the imager dataset. During the 16 days when the Sun was at the lowest elevations, the median sky brightness was 20.72 mag arcsec\(^{-2}\) in Astronomical U and 21.12 mag arcsec\(^{-2}\) in SDSS g’. The minimum sky brightness in good transparency condition was 22.21 mag arcsec\(^{-2}\) in U and 21.84 mag arcsec\(^{-2}\) in g’. We therefore conclude that if we filter out the brightest aurora lines (391.4nm and 427.8nm), which are the dominating contribution to sky brightness, the South Pole will be an excellent site for ultraviolet observations.

**Regulation of the Mevalonate Pathway by Sumoylation Controls Metabolism With Age**
Kaitlin Ching  
*Mentors: Paul Sternberg and Amir Sapir*

Throughout an organism’s life, metabolic pathways are dynamically regulated to meet the changing needs of tissues and cells. The mevalonate pathway produces many important metabolites, including cholesterol and coenzyme Q. We have found that HMG-CoA synthease (HMGS-1), which catalyzes the first step in this pathway, is sumoylated in vivo. Sumoylation increases in the absence of ubiquitin-like protease 4 (ULP-4), indicating that ULP-4 cleaves a small ubiquitin-like modifier (SUMO) from HMGS-1. Exogenous mevalonate rescues the *ulp-4(-)* phenotype, suggesting that sumoylation inactivates HMGS-1. A *ulp-4::gfp* reporter construct indicates that ULP-4 translocates to the mitochondria when HMGS-1 is oversumoylated. This may sequester it to prevent its cytoplasmic interaction with HMGS-1, thereby downregulating the mevalonate pathway. Using CRISPR-Cas genome editing technology, we will study the ULP-4/HMGS-1 circuit further. For example, we will mutate the sumoylation site in the *hmgs-1* gene to determine the effect of this modification on HMGS-1 activity and mevalonate pathway flux in vivo. Given the tight regulation of HMGS-1 and its position in the mevalonate pathway, this regulatory circuit could be targeted to better control cholesterol levels and cancer progression.
High-Responsivity Metal-Semiconductor-Metal Photodetectors Employing Waveguide-Plasmon Polaritons
Dahan Choi
Mentors: Harry Atwater and Ragip Pala

We examine the effect of Fano resonance on the absorption and transmission profiles of an optimized plasmon-enhanced metal-semiconductor-metal photodetector platform. Since variation in array geometry will lead to shifts in peak location and amplitude in the absorption spectrum, we have designed and optimized the stripe array properties and semiconductor back-layer parameters to realize and optimize absorption enhancement due to Fano resonance. Structures were simulated numerically through the finite difference time domain method, and modeled analytically. By using a photodetector geometry with square gratings of size 120nm by 80nm, silicon dioxide separation of 7nm, silicon absorbing layer thickness of 70nm, absorption enhancement of up to 10times were simulated using FDTD. After comparing the results from the numerical simulations to the results of analytical modeling, experimental testing could be done to verify the results of the simulation and analytical modeling.

Directed Evolution and Analysis of Improved L-1,2-propanediol Oxidoreductase and Cinnamyl Alcohol Dehydrogenase
Nelson Chou
Mentors: Frances Arnold and Jackson Cahn

Biocorversion of lignin and cellulose in agricultural residues into biofuels, biochemicals, and wide variety of industrial resources is a growing industrial opportunity. However, this process has been met difficulty due to the production of aromatic aldehydes during the pretreatment process of woody material to bio-based feedstocks. These toxins inhibit the proliferation of cells vital to the production of ethanol, lactate, and other chemicals. A solution to this present problem is to engineer enzymes in cells that convert aromatic aldehydes into respective less-toxic alcohols. For instance, the conversion from furfural to furfuryl alcohol by the enzyme L-1,2-propanediol oxidoreductase (FucO) has been improved by Directed Evolution, which relies on high-throughput screening and selection of the best-performing protein after critical amino acids of the protein are randomly altered by site mutagenesis. Another method to improve the bioproduction of ethanol is cofactor switching enzymes from NADPH to NADH-dependence when breaking down toxins. The switch is important because NADH-dependence would alleviate the stress on NADPH pool that is used for biocatalysis. Cinnamyl Alcohol Dehydrogenase (CinADH) that converts cinnamaldehyde was cofactor switched in this manner, then evolved by site-saturation mutagenesis in a similar process as fucO. Armed with enzymes that have been cofactor switched and/or mutagenesis-improved, we aimed to optimize in vivo assays to confirm experimentally that cells containing these improved proteins outperformed those with wild type ones. By optimizing growth conditions and aldehyde addition, we were able to robustly demonstrate that these engineered proteins do better jobs in eradicating cell-inhibiting compounds, thereby allowing efficient biofuels production by cells.

Angular Dependence of Incident Radiation on Planar Double High-Contrast Grating Mirrors
Meng Shuen Chua
Mentors: Andrei Faraon and Amir Arbabi

We present the effects of non-normal incidence on spectral filtering using planar double high-contrast grating mirrors. Simulation is done using rigorous coupled-wave analysis on different planar surfaces, including SiO2, GaP and SiN. There is a significant deviation of resonant wavelengths depending on various factors, such as the polarization of the incident radiation, polar angle $\phi$ and azimuthal angle $\theta$.

Investigation of H2 Activation and Catalytic Olefin Hydrogenation Using a Bimetallic Nickel Complex
Bridget Connor
Mentors: Jonas Peters and Jon Rittle

Understanding the role of bimetallic cooperativity in processes like small molecule activation and catalysis is an area of growing interest due to the suspected collaboration between metal centers in many of nature’s enzymes which carry out these same transformations. With this goal in mind, Ni2[SiP2O] was synthesized and cooperation of the two Nickel centers was investigated in the context of $\text{H}_2$ activation and catalytic olefin hydrogenation. The reaction of Ni2[SiP2O] with $\text{H}_2$ yielded a continuum of products depending on the pressure of $\text{H}_2$ used. We propose, based on IR and NMR data, that these complexes contain two terminal hydride ligands and a varying number of $\text{H}_2$ ligands. The presence of a terminal hydride ligand on each Nickel atom suggests that the two centers cooperate to split $\text{H}_2$. The Ni2[SiP2O] system was also found to catalytically hydrogenate styrene, 1-octene, and cyclohexene. It remains unclear whether cooperativity between Nickel centers is important for this reaction.
Organization and Automation: Optimizing Paleomagnetic Research Equipment
Christopher P. Cousté
Mentors: Joseph L. Kirschvink and Sarah P. Slotznick

In cutting edge research projects, scientists lack the benefits of commercialization and standardization that allow for incredibly efficient use of technology. When designing a device from scratch that does something very few people have succeeded at doing, it promises to be harder than assembling Ikea furniture. In order to ensure that data is irrefutable, the scientist needs precise machining and well-organized construction and programming. In addition, the design must be clever, to connect existing technology with brand new innovation, as well as malleable, to deal with unexpected problems that need to be accommodated. This paper will demonstrate several ways that it has proven useful for scientists to hire engineers to investigate their science machines and see if there are any ways to adapt the structure, mounting, mechanisms, layouts, interfaces, or even operating systems to optimize the process of doing science. By spending time organizing and optimizing several systems, we see that data comes in faster, scientists have an easier experience getting their data, and real discoveries can be made.

Characterizing Carbon Nanotube and Graphene Conductivity Through Sheet Resistance
Melissa Cronin
Mentors: Morteza Gharib, Luciana Cendon, and Cong Wang

Graphene and carbon nanotubes are extraordinary materials which are strong, lightweight, and conductive. The Gharib group has shown that graphene grown by the carbon vapor deposition method can have a flexible band gap induced, opening it’s potential for use in high efficiency multijunction solar cells. Previous work with carbon nanotubes indicates that using graphene-wrapped carbon nanotubes as battery electrodes would result in smaller and safer batteries through the elimination of electrode deformation and leakage. We seek to analyze the conductivity of graphene and carbon nanotubes through measuring their sheet resistance. To perform this measurement we set up a Wentworth Labs probe station, alongside Keithley Models 2400, 6221, and 2182A. These instruments will be used to produce a sweeping voltage from -200V to +200V, produce a nA current, and read a nV voltage respectively. We are constructing a LabVIEW program in order to handle the complex measurement, and synchronize the data collection of the three Keithleys in order to produce the most accurate measurement of sheet resistance. In the future, we can use the probe station to perform any type of electrical measurement, from analyzing the doping of graphene to the efficiency of a solar cell.

Motivic and Computational Complexity of the Potts Model With an External Magnetic Field
Shival Dasu
Mentor: Matilde Marcolli

The partition function of the Potts model can be expressed in terms of famous combinatorial graph polynomials for restricted Hamiltonians. We investigate the Hamiltonian with variable edge interaction and external magnetic field, for which the partition function is the $V$-polynomial. Because the partition function is a polynomial, we can use motivic methods from algebraic geometry to characterize the complexity of the partition function. We also characterize the computational complexity of the partition function and determine that the zeros of the partition function are not polynomial countable. Future work includes providing conditions for when the partition function uniquely determines the underlying graph of the Potts model.

Monolayer Seeded Growth of Protecting Thin Oxide Films on Silicon(111) for Solar Energy Applications
Anne Davis
Mentors: Harry Gray and Chris Roske

Anthropogenic climate change and the disappearance of fossil fuels merit the discovery of new methods to meet our future energy demands. Splitting water into hydrogen and oxygen by harvesting energy from the sun is one proposed scheme to create clean and sustainable fuels. In this process, semiconductors absorb sufficiently energetic photons from the sun which are then directed to split water. Small band gap semiconductors such as silicon are necessary to achieve the highest levels of solar efficiency; however, in this chemically demanding process, these small band gap semiconductors tend to be unstable. In our work, silicon(111) surfaces were successfully functionalized to seed the growth of protective aluminum oxide films using atomic layer deposition. This method of functionalization created stable surfaces with few electronic defects. Metal was then deposited on top of the aluminum oxide layer in order to fabricate highly efficient solid state solar cells. Materials were extensively characterized by infrared spectroscopy, X-ray photoelectron spectroscopy, surface recombination velocity, gas chromatography mass spectroscopy, nuclear magnetic resonance spectroscopy, and atomic force microscopy to determine the quality of synthesized surfaces.
Characterization of M-dwarf Eclipsing Binaries From the Kepler Field
Daniel DeFelippis
Mentors: John A. Johnson and Jon Swift

M-dwarfs are cool stars that are less than half the mass of the Sun, and they account for at least 70% of the stars in our galaxy. However, current stellar models show systematic differences in stellar parameters compared to the most accurate astronomical measurements. Determining the source or sources of these discrepancies has been difficult due to the dearth of well measured M-dwarfs, which are difficult to characterize because of their low luminosities and complicated atmospheres. We have identified 35 eclipsing binary (EB) pairs of M-dwarfs from the high-precision photometry provided by the Kepler Space Mission. The four years of nearly continuous photometry for these EBs provides the means to measure model-independent stellar parameters for their primary and secondary components, but only with complementary radial velocity (RV) measurements. We therefore performed over 200 observations of 24 select M-dwarf EBs distributed over 27 nights during the summer of 2014 with the high-resolution optical and near infrared spectrographs available on the Keck 10-meter telescopes to measure RVs by cross-correlating our spectra with stellar template spectra. By simultaneously modeling the Kepler light curves with these RVs, the M-dwarfs’ parameters can be determined to great accuracy and precision, nearly tripling the number of well characterized M-dwarfs available to date.

Biological Synthesis and Characterization of Materials for Use in Lithium Ion Batteries
Natalie DeFries
Mentors: Horgil Hur and Taeyang Kim

The goal of this project was to investigate cathode and anode materials for improving current Li-ion batteries. Materials’ electrochemical properties can be improved by forming particles with a well-defined morphology. Te(0) nanorods were synthesized by anaerobically incubating Shewanella oneidensis MR-1 with Fe(III)-citrate as the initial electron acceptor, Te(IV) as the final electron acceptor, and lactate as the electron donor in a nutrient medium with HEPES buffer. The Te(0) nanorods were further incubated in DMSO for 1 d in an unsuccessful attempt to induce a change in morphology. Fe3(PO4)2 (vivianite) nanospheres were synthesized by anaerobically incubating S. oneidensis MR-1 with Fe(III) oxide, PO43−, and lactate in a nutrient medium with HEPES buffer. LiFePO4 (triphylite) was formed by hydrothermal reaction, autoclaving Fe3(PO4)2, Li3PO4, and ascorbic acid to prevent excess iron oxidation at 180°C for 12 h. The LiFePO4 exhibited an interesting morphology, disks about 9 µm in diameter, composed of many smaller cubic particles. Materials were characterized with scanning electron microscopy (SEM) and X-ray diffraction spectroscopy (XRD). In future experiments, there will be further electrochemical characterization to measure capacity and loss of capacity with cycling, and charge/discharge rate of materials.

Characterization of Prompt Atmospheric Lepton Fluxes
Paul Dieterle
Mentors: Paolo Desiati and Maria Spiropulu

High-energy neutrino astronomy is a relatively new branch of observational astrophysics which uses neutrino detection - rather than conventional photon detection - to characterize, understand, and pinpoint the sources of cosmic rays, including active galatic nuclei, gamma-ray bursts, and supernovae. To detect high-energy astrophysical neutrinos, neutrino observatories, such as the recently completed IceCube, need to understand the sources of event backgrounds. These backgrounds are the product of cosmic ray interactions in the atmosphere, which produce unstable particles that decay into muons and neutrinos. In addition to the relatively well-characterized, conventional pion and kaon neutrino production decay channels, there are more exotic pathways in which heavy, charmed mesons promptly decay into muons and neutrinos. These pathways are especially relevant at high energies – precisely the energies of interest for extraterrrestrial neutrino observation. Here, we use the Monte Carlo particle shower propagator CORSIKA along with the high-energy hadronic interaction model DPMJET to simulate and characterize prompt neutrino and muon fluxes. We show that there are fundamental differences between the prompt and conventional neutrino and muon fluxes and comment on the experimental feasibility of observing prompt events with neutrino telescopes.
Targeting \textit{para}-Terphenyl Diphosphine Molybdenum Compounds Bearing Multiply Bound Ligands
Bogdan Alexandru Dimitriu
\textit{Mentors: Theodor Agapie and Joshua Buss}

Molybdenum complexes featuring multiply bound ligands have been shown to act as efficient catalysts for organic transformations and are utilized as model complexes for metalloenzyme active sites and reactive metal surfaces. We present the synthesis and characterization of a number of molybdenum compounds, supported by a \textit{para}-terphenyl ligand framework. A hydride/hydrosulfido molybdenum complex was synthesized and its solid state structure was determined via single-crystal X-ray diffraction. This is the first example of a Mo(H)(SH) moiety characterized in the solid state. The reactivity and electrochemistry of the newly generated compound was further investigated with the aim of forming Mo(S) complexes relevant to proton reduction catalysis. In addition, the methine transfer reagent, 7-chloronorbornadiene was synthesized and subsequently used in an attempt to generate a molybdenum-methyldiene moiety.

Quantifying the Entrainment of Nanoparticles From Surfaces by Impinging Air Jets
Kayané K. Dingilian
\textit{Mentors: Richard C. Flagan and Ranganathan Gopalakrishnan}

The removal and inhalation of particles from nanoparticle coatings is a growing concern in the work environment. In order to better understand the effects of these released nanoparticles on human health, the particles must be quantified in both their size and concentration distributions. To simulate these conditions, a fine layer of carbon black aerosol nanoparticles was deposited onto a glass substrate through diffusional deposition of a low flow of air containing carbon black particles. The resulting aggregates ranged from approximately 40 nanometers to 20 micrometers. The substrate was passed through a series of air jets, and the amount of remaining carbon on the surface was measured each time. By finding the surface area coverage at a location on the slide measured by scanning electron microscopy and assigning it to the intensity fraction at the same location measured by the optical setup, the optical readings were calibrated. The calibration data was used to interpolate the surface coverage based on further optical measurements. Preliminary experiments have indicated a removal of about 0.5 percent surface coverage. As experiments continue, the procedures for each setup are further refined to allow for greater sensitivity in capturing the removal of carbon black particles from the surface.

Passive Electrical Sensor Fabricated on Contact Lenses for Medical Sensing
Sith Domrongkitchaiporn
\textit{Mentors: Axel Scherer and Muhammad Mujeeb-U-Rahman}

Passive electrical sensors were fabricated on top of a contact lens of area $1 \text{ cm}^2$ to measure eye fluid components such as glucose. This is done because some of the chemicals in the eye fluid reflect that of the body. These sensors can be used to help diabetes patients since these sensors are simply wearable and does not need to cause pain to patients from finger pricking. However, these sensors can be made to sense any chemicals depending on the functionalization process. We fabricated these sensors on a flat Polyethylene Terephthalate (PET) before curving it into a contact lens shape using the vacuum forming process before cutting the lens out testing it. The sensors are completely biocompatible with the eye. Both communication and powering is done wirelessly.

Adoption of the Q Transcriptional Regulatory System for Exploration of Notch-Delta Signaling
Hannah Dotson
\textit{Mentors: Michael Elowitz and Emily Capra}

Notch-Delta signaling is a complex, highly conserved pathway that plays an integral role in cell fate decisions. When a Delta ligand binds to the Notch extracellular domain (NECD), the Notch intracellular domain (NICD) is cleaved and translocates to the nucleus, leading to the activation of target genes. These signaling events can be monitored by a NECD-Gal4/UAS system. In this “diverted reporter” system, the yeast Gal4 domain replaces the NICD of human Notch1 and activates a citrine reporter controlled by an upstream activating sequence (UAS) promoter. However, many cells express multiple Notch receptors, and the NECD-Gal4/UAS system alone cannot differentiate responses from different receptors. To monitor the response from two Notch receptors simultaneously, a second, orthogonal reporter system for Notch response was constructed using the Q regulatory system from \textit{Neurospora}. In the new system, the QF domain replaces the NICD of several human Notch receptors and activates a turquoise reporter controlled by the QUAS promoter. The NECD-QF/QUAS system has been tested in CHO (Chinese Hamster ovary) cells. It will be used in conjunction with the NECD-Gal4/UAS system to monitor the response of multiple Notch receptors simultaneously to better understand Notch signaling.
Monitoring Animal Behavior With the Intel 3D Camera
Esther Du
Mentors: Pietro Perona and Louise Naud

Tracking animals and monitoring their behavior accurately is a very important part of behavioral research. Currently, the method used to track the animal movements is to use standard video cameras to videotape the movements and then have someone sit there and annotate the movements and behaviors of the animals. This process is not only tedious but can also be highly subjective as different people may interpret the same movements in different ways. Therefore, attempts have been made to replace this tedious task with an automatic visual recognition system. Using depth data from the Intel Interactive Gesture Camera along with two other standard grey-scale video cameras, we are able to develop 3D models that can replace the current method used to monitor animal behavior in the laboratory. In this project, a software application has been created that will allow researchers to stream and record video and change settings for all three cameras at once. Researchers can then use this application to easily obtain the data necessary to automate the process of monitoring animal behavior.

Do Flies Have Fear? An Investigation of a Fear-Like Behavioral State in Drosophila
Rebecca Du
Mentors: David J. Anderson and William T. Gibson

Understanding the neural circuitry controlling innate behaviors, such as fear responses, is of fundamental relevance to psychiatric disorders. There are relatively few robust behavioral paradigms for studying innate fear responses in genetically tractable model organisms, in part due to the lack of well-controlled species-relevant stimuli. Recently, Drosophila melanogaster was shown to exhibit an escape response (termed the Drosophila Shadow Response, or DSR) to a moving overhead shadow. In this SURF project, we are investigating two different behavioral dimensions of the shadow response (hopping and freezing) by designing Matlab algorithms to analyze videos of previous fear experiments and using statistical tests to determine significant results. Preliminary analyses of hopping and freezing in response to shadow stimuli suggest that there is a high correlation between bouts of jumping and the passing of a shadow, and also that the shadow induces an increased level of freezing compared to baseline immediately afterward. Additionally, we are carrying out experiments that test whether the number of shadows given, which carries a negative valence, has an effect on the time it takes starved flies to return to a food patch, which has a positive valence. Once the experimental phase is concluded, more analysis can be undertaken in order to further investigate the fear-like behavioral state.

microRNA-132 Regulates Hematopoietic Stem Cell Function and B-Cell Development
Xiaomi Du
Mentors: David Baltimore and Arnav Mehta

microRNAs are 22bp non-coding RNA sequences that help regulate a wide variety of immune functions and cell-fate decisions. Each microRNA targets several hundred mRNA sequences and decreases their protein expression by inhibiting translation. We have identified microRNA-132 (miR-132) as a key regulator of hematopoietic stem cell (HSC) function and B-cell development. It modulates these pathways by targeting two transcription factors, FOXO3 and SOX4. We performed quantitative real-time polymerase chain reaction (qPCR), Western blotting, and luciferase assays to confirm that over-expression of miR-132 down-regulates FOXO3 and SOX4. This effect is specific to miR-132 because we do not observe the same down-regulation when the miR-132 binding site is mutated. To study the effects of miR-132 in vivo, we compared the phenotypes resulting from over-expressed and knocked out microRNA-132 to those of over-expressed and knocked down FOXO3 and SOX4. miR-132 over-expression leads to rapid HSC proliferation, followed by exhaustion; this is rescued by co-expressing FOXO3., miR-132 over-expression also causes B-cell developmental defects due to the reduced SOX4. These observations establish that miR-132 is significant to maintaining the balance of hematopoiesis.

Light-Trapping Techniques for Silicon Solar Cells
Cody Dunn
Mentors: Harry Atwater and Christopher Chen

One of the primary loss mechanisms in a solar cell is the reflection of incident light at the cell’s surface. Reflected photons are lost and not converted into useful energy. Surface reflection can be reduced by implementing surface texturing and anti-reflective coatings. Proper texturing on silicon wafers can be achieved with an anisotropic etching solution consisting of KOH and IPA. Several ratios of KOH to IPA were tested at various temperatures for various lengths of time. Among those solutions tested, placing wafers in a 2% by weight KOH, 10% by volume IPA solution for 30 minutes at 75°C was determined to produce the desired pyramidal surface structure and most consistent reduction in reflectance. Future work will include depositing antireflection coatings such as silicon nitride, silicon dioxide, and indium tin oxide onto textured and polished substrates to measure the differences in reflectance due to texturing, and textured Si wafers will be made into diffuse junction solar cells and tested with standard solar cell metrology.
**Constructing DNA Neural Networks for Classifying Analog Signals**  
Emily Elhacham  
*Mentors: Lulu Qian and Anu Thubagere*

Increasing efforts in molecular programming and dynamic DNA nanotechnology are leading to precise information processing within autonomous molecular systems using various biochemical circuits, including DNA-based neural networks. DNA strand displacement reactions, where two strands hybridize to each other and displace one or more strands in the process, serves as a key element to many engineered molecular systems. In this work, we aim to extend previous work on DNA-based neural networks from recognizing digital signals with high or low values to more sophisticated signal classification that involves analog signals with continuous values. Several strand displacement reactions will be brought together to implement an artificial neuron that has three basic functions: applying an arbitrary weight to each of the analog inputs, summing all weighted inputs, and comparing the sum to an arbitrary threshold. If the threshold is exceeded, the input signals will be classified as one group, otherwise as another group. This work will provide the basis of a systematic approach for linear and even non-linear classification of molecular signals, and provide potential solutions for accurately identifying disease profiles composed of mRNA and microRNA expression levels in targeted therapeutics.

**The Stellar Initial Mass Function of Local Dwarf Spheroidal Galaxies**  
Clarke Esmerian  
*Mentors: Joshua Simon and George Djorgovski*

A star's initial mass is the central factor governing its subsequent evolution. Consequently, the stellar Initial Mass Function (IMF) – the population distribution of stellar masses at formation – contains important information about the properties of a stellar population. The observation of systematic variation in the IMF with environment could help to further our understanding of the processes governing star formation. As well, a specific IMF must be assumed in the calculation of scientifically interesting properties of distant galaxies, and thus an environment-dependent IMF would introduce substantially greater complexity to these calculations than has previously been considered. In this project, we aim to characterize the dependence of the IMF on environmental properties (such as metallicity) by studying the stellar populations of dwarf spheroidal galaxies – old, low mass, low metallicity satellites of the Milky Way – with data from the *Hubble Space Telescope* Archive.

**Progress Towards the Total Synthesis of Eucomic Acid**  
Benzi Estipona  
*Mentors: Brian Stoltz and Rob Craig*

Eucomic acid is a naturally occurring compound derived from the genus *Vanda*. Eucomic acid, as well as many other glycopyranosyloxybenzyl eucomate derivatives, has recently been shown to serve as a global stimulus of cytochrome c oxidase in the body. This has been directly linked with attenuation of the cell aging process as well as serving as a preventative measure for cancer. Here, we utilize the methodologies previously established by the Stoltz group, namely, the asymmetric alkylation of many dioxanone substrates, to elucidate a total synthetic pathway from cyclohexanone dimethyl ketal, a readily available substrate, to the intended natural product. To achieve this, we make use of the palladium catalyzed Tsuji reaction to form the enantioenriched alpha-hydroxy methyl ester, which serves as the basic framework for many biologically active compounds. Currently, we have successfully synthesized the precursor for the Tsuji substrate, and future work will be focused on the advancement of this substrate to the desired natural product.

**Vibrational and Thermal Stability Analysis of Deformable Mirrors for the Autonomous Assembly of a Reconfigurable Space Telescope (AAREST)**  
Erin E. Evans  
*Mentors: Sergio Pellegrino and John Steeves*

The AAREST Project aims to demonstrate the feasibility of a low-cost telescope design utilizing many small independent spacecraft, each outfitted with its own deformable mirror that can be reconfigured into a single segmented aperture. The two primary technologies under development for the AAREST Project are lightweight deformable mirrors and an unfolding carbon-fiber boom. Each mirror is made using a thin glass wafer substrate coated with a reflective metal surface as well as multiple piezoelectric membrane and electrode layers to actively deform the mirror surface. In order to validate that these mirrors will survive the mission, thermal stability and acoustic loading tests must be completed. To confirm survival at low temperatures, I designed and built a thermal vacuum chamber capable of cooling the deformable mirrors to ~40 °C using multiple Peltier coolers. This chamber will be used to optically characterize the mirrors' thermal deformation and recommend design changes to mitigate these deformations. To determine the survivability of these mirrors during launch and imaging, I also aided in the development of an acoustic loading test setup capable of obtaining mirror deformations under the approximate sound pressure level of the Delta IV launch vehicle. This paper discusses the design and implementation of these test setups, as well as the results obtained from these, which will be used to ensure survivability upon mission launch.
Effects of Morphology on the Flapping Dynamics of Inverted Flags
Boyu Fan
Mentors: Morteza Gharib and Julia Cossé

The behavior of inverted flags has received recent attention in the study of the interaction of flexible bodies with fluid flows. It has implications in a variety of natural phenomena, such as the fluttering of leaves in the wind. As opposed to a conventional flag, defined by a fixed leading edge and a free trailing edge, an inverted flag has a free leading edge and a fixed trailing edge. The reversed flow orientation of inverted flags has led to a surprising observation. Over a narrow range of wind speeds, they exhibit a large-amplitude flapping motion that is not present in their conventional counterparts. We present an experimental investigation on the effects of morphology on the flapping behavior of inverted flags. Different morphologies are studied in a wind tunnel to assess the underlying parameters that govern their dynamics. We observe a significant shift in the limit-cycle flapping mode that is a function of flag shape parameters.

Observation of Magnetism-Induced Massive Dirac Spectra and Topological Defects in the Surface State of Cr-Doped Bi₂Se₃-Bilayer Topological Insulators
Wentao Fan
Mentors: Nai-Chang Yeh and Chien-Chang Chen

Direct observation of the magnetism-induced gap-opening phenomenon on the surface state of strong topological insulators has been a missing part in most recent studies. Here we report detailed observations of the proximity-induced massive Dirac spectra below a 2D Curie temperature ($T_{c,2D}$) in bilayer structures consisting of an undoped Bi₂Se₃ layer on top of a Cr-doped Bi₂Se₃ layer. Our observations revealed the spectral gap to be spatially inhomogeneous, with its mean value and spatial homogeneity increasing with decreasing temperature ($T$), increasing Cr-doping concentration ($x$), and increasing c-axis magnetic field ($H$). We also found spatially localized spectral resonances around isolated Cr impurities in gapless regions on the surface, and the resonances were taken as signals of the surface-state topological defects.

Investigating the Photoluminescence of Silicon Nanocrystals
John D. Feist
Mentors: Yves J. Chabal, Sara M. Rupich, and Konstantinos Giapis

Silicon nanocrystals (SiNCs) show great promise as in vivo photoluminescent dyes for biomedical applications and as composite materials for optoelectronics, due to their biocompatibility and tunable photoluminescence and electronic properties. However, the mechanisms by which these NCs emit are poorly understood for lack of atomic level characterization. Here, we investigate by spectroscopic methods (IR, Raman) the effect of solvents on the PL of SiNCs (such as PL emission frequency shifts) to better understand the factors that influence their emission (e.g. structural or chemical). We confirm a previous observation that the PL wavelength shifts from ~600 nm (red) to 450 nm (blue) upon immersion in protic solvents (e.g. alcohols). We utilize PL, PL excitation, attenuated total reflectance Fourier transform infrared spectroscopy, and x-ray photoelectron spectroscopy to correlate the blue shift to surface chemical composition. Preliminary data suggest that this shift is due to surface oxidation (SiO₂ formation at the surface of the SiNCs) rather than chemical effects (e.g. alkoxy termination of the surface). Modeling is underway to estimate the required SiO₂ thickness (i.e. reduction in SiNC diameter) to fully account for the wavelength emission. Further experiments starting with larger diameter NCs (near IR emission) should help test this mechanism.

Generating Smart Region Proposals Using Interpolation and New Neural Networks
Michael Feldman
Mentors: Pietro Perona and Steve Branson

To locate and classify objects in large and complicated images, detection algorithms and neural networks are often used to extract and then score region proposals. Our algorithms use regression and other interpolation techniques to estimate the true locations of objects, this allows for a reduction in the number of regions that must be extracted and scored. Given data that contains the center coordinates of region proposals and the corresponding scores, we use radial basis function interpolation. We then find the maximums on the interpolation surface, which correspond to the rough locations of objects. Then, we use the Nelder-Mead downhill simplex method to obtain better estimates of the objects’ locations. New neural network layers were trained to score optimal bounding boxes highly. In the future, we plan on combining these algorithms with a standard detector.
**Pose Detection for Pedestrians in the Wild**  
Ingrid Fiedler  
*Mentors: Pietro Perona and David Hall*

Automatic pose detection has applications in fields from behavioral psychology to biometrics. However, many pose detection systems require extensive cooperation of the subject and are limited to very controlled environments. This project seeks to detect the pose of pedestrians in the wild, i.e. without special clothing, backgrounds or equipment beyond a camera to make the task easier. The pose detection system is based on a robust cascade pose regression system originally designed to detect the pose of a face, mouse or fish, objects with much less relative movement and self-occlusion than the human body. Applying the pose estimator to people entailed constructing a pedestrian model, assembling a sufficient training set—which needs to be quite large in order to handle the frequent occlusion of limbs—and investigating parameters of the detector. This work will contribute to the labeling of pose ground truth for the publication of the Caltech Rose Bowl dataset.

**Synthesis and Mechanism for the Formation of Tris(pentafluorophenyl)corrole**  
Katherine Fisher  
*Mentors: Harry B. Gray and Carl Blumenfeld*

We report the mechanism and a scalable, high-yielding procedure for the synthesis of tris(pentafluorophenyl)corrole (tpfc). NMR and preparative high-performance liquid chromatography (HPLC) were used to elucidate the mechanism for the formation of the corrole-forming precursor. This precursor was found to be formed by the oligomerization of pyrrole and aldehyde subunits, with pyrrole capping on either end of the oligomer to prevent porphyrin formation. Subsequent oxidation by DDQ was used to cyclize the corrole precursor and form tpfc. Reaction conditions including temperature, catalyst, and reactant concentrations were screened to afford maximum yield of the corrole-forming oligomer. Using this procedure, tpfc was isolated with 11% yield.

**Fabrication of Metallic Glass Nanolattices to Exploit Size Effects in Ductility**  
Patrick Flynn  
*Mentors: Julia Greer and David Chen*

Metallic glasses have important applications due to their strength relative to their crystalline counterparts. Furthermore, size reduction in these metallic glasses below ~100nm is known to induce a brittle-to-ductile transition. The project aimed to use nanolattices to proliferate this size effect, creating strong, tough, ultra-lightweight structures. Using two-photon lithography direct laser writing, the desired truss structure was scribed into positive photosist on a glass substrate sputtered with conductive ITO. The photosist was developed and exposed to O2 plasma to expose the ITO. Potentiostatic electrodeposition was used to fill the pores with an amorphous Ni-P alloy. Undeveloped photosist was removed, leaving the solid 3D metallic glass nanolattice. Future research could include characterizing the mechanical properties of the trusses under compression to examine the extent of the size effect in the larger 3D architectured structure.

**A Study of the Kinetics of mRNA Splicing in the NF-κB Transcriptome**  
Luke Frankiw  
*Mentors: David Baltimore and Devdoot Majumdar*

The prevailing notion in current literature is that much of mRNA splicing occurs both linearly and co-transcriptionally; however, little work has been done on dynamic systems. My project aims to determine the nature of splicing among the NF-κB transcriptome at different stages of NF-κB induction. I developed and implemented an RNA sense-strand purification technique to "pull-down" specific cDNAs relevant to the NF-κB pathway. This technique has allowed for cleaner Illumina sequencing data. Furthermore, the enrichment offered through the sense strand purification will allow us to use Pacific Biosciences full-transcript sequencing. By sequencing full-length transcripts, we will be able to determine the exact composition of single mRNA molecules at different stages of induction. Finally, through the summer I have utilized "digital" PCR to analyze the composition of mRNA transcripts for a specific gene in the transcriptome. Preliminary dPCR data shows some non-linearity in the order introns are spliced.
**Rapid Prototyping of Moderate Complexity Biomolecular Circuits: Attenuator Controlled Scaffold-Assisted AND-Gate**
Anton Frisk
*Mentors: Richard Murray, Clare Hayes, and Vipul Singhal*

Over the past years, the field of synthetic biology has gained a significant array of tools and parts, making way for increasingly complex biomolecular circuits to be constructed. Developing biological circuits is a key process when genetically engineering organisms for various purposes, thus the techniques used have a vast potential in many fields such as bio-medicine, environmental monitoring, fuel production and more. The development of biocircuits can be facilitated by assembling parts in a less complex, cell-free, environment which contains only the machinery for gene transcription (TX) and translation (TL), which have been extracted from bacteria. In this project, a novel biocircuit was designed which combines inputs into a logic AND by expression the proteins NRI, NRII, sig54 which together activate the glnA promotor. The circuit around this AND-gate construct uses antisense-attenuators to control the NRI and NRII production. To aid circuit prototyping, a model has been made of the individual circuit constructs which shows the overall circuit logic. Testing in a cell-free TX-TL system has been used to determine the functionality of the constructs and evaluate design parameters.

**Using Corpus Statistics and WordNet Relations for Solving Remote Association Tests**
Constance B. Fu
*Mentors: Jehoshua Bruck and Yue Li*

At present, in the field of natural language processing and information retrieval, a non-trivial issue is the ability for artificial intelligence to accurately determine the sense of a word in a given context. This project focuses on the solving of remote association tests (RATs), puzzles in which one is given an input of three words and are solved by some fourth word related to each of the input words. Since RATs capture word associations, solving them accurately could have wide-ranging applications such as the further development of artificial brainstorming and search engines. Previous work on a RAT solver yielded a ~90% accuracy rate using crowd sourced data from Human Brain Cloud (HBC) to create a data structure (directed, weighted graph) that represents unique words as nodes and associations as edges. We improve the accuracy and speed of our algorithm by refining this data structure. In particular, instead of nodes for each unique word (i.e. a one-to-one mapping between nodes and words), there is a node for each unique sense of a word. We use the WordNet database, a semantic lexicon for the English language that groups words into groups of synonym rings to achieve this.

**Control Synthesis for Automated Rover Planning**
Joaquin Gabaldon
*Mentors: Richard M. Murray and Ioannis Filippidis*

When designing software for a rover, one of the most important elements to consider is the system that will control the actions and motions of the rover. Currently, the instructions for these actions are for the most part produced manually, as the rover usually does not synthesize these instructions for itself. Because of this, the rover must wait for instructions to be created for it before it begins a task, which consumes a great deal of time that the rover could otherwise use to complete science objectives. The aim of this project is to fix this problem by creating a software package that takes in higher-order objectives, such as locations to visit or science tasks to complete, and automatically generates a correct-by-construction planner that directs the rover on how to perform its tasks. These planners are synthesized by first implementing the Temporal Logic Planning toolbox (TuLiP) to break the objectives down into smaller sets of directions, and then implementing the Open Motion Planning Library (OMPL) to deal with local path planning.

**Discovering Rare Transient Events**
Aalok Gangopadhyay
*Mentor: Ashish Mahabal*

Astronomical objects that exhibit variation in their brightness are called transients. The Catalina Real Time Survey (CRTS) which covers around 3/4th of the sky, searches for these transients. Each region of the sky is visited periodically after an interval of certain number of days. If an object is persistently detected at a particular location, then it is given a unique objectID and is placed in the Photcat (Photometric Catalog). About 500 million such photometric objects have been discovered so far. Detections that fail to find a match in the Photcat are put in the Orphancat. Since persistence in location is an important criteria for a Photcat object, many rare transient events that exhibit fast transient behavior would be present in Orphancat. This project is aimed at finding such rare-transients. But these would correspond to a very small fraction of the Orphancat detections. Thus the initial part of the project focussed on investigating all the other scenarios that are responsible for giving rise to Orphancat detections. After having understood these, filtering techniques were designed that helped in eliminating detections that are not of interest to us. An important challenge currently faced is designing techniques to eliminate those scenario that do not follow a distinct pattern.
The Genetics of Sex Pheromones in C. elegans Hermaphrodites and Their Regulation by an Oocyte-Somatic Signaling Process
Amanda Gao
Mentors: Paul Sternberg and Daniel Leighton

The oocyte-somatic signaling process is vital to mammals and the development of their offspring. This process is poorly studied in invertebrates. We are using Caenorhabditis elegans in hopes of better understanding their development and behavior and using them as model organisms to uncover oocyte-somatic signaling proteins. We do this by mutagenizing worms with ethyl methanesulfonate (EMS). Propagating the P0 generation to the F2 generation, we created F2 clonal lines. Pheromones were collected from this clonal line using M9, a phosphate buffer. Chemotaxis assays were used to determine if there were worms producing pheromones earlier than expected. Upon finding these worms, we aim to perform genetic mapping on the nematodes producing pheromone early, allowing us to hypothesize the genes that regulate this process. We will then use sequencing to determine the position of the genes. The implication of this project is that a better understanding of pheromone production and regulation will shed light on the oocyte-somatic signaling process.

Towards the Iridium Catalyzed Generation of All-Carbon Quaternary Chiral Centers
Kevin Gao
Mentors: Brian Stoltz and Corey Reeves

The asymmetric construction of all-carbon quaternary stereocenters has important implications for pharmaceutical applications and natural product synthesis. This ubiquitous structural motif forms the foundation of many complex molecules found in nature and small molecule therapeutics. Developing methods for their installation is critical to enabling the synthesis of complex natural products and producing medicinally essential molecules. In this effort, applications of current Stoltz group Iridium-catalyzed alkylation research will be extended to include a novel class of acyclic TMSE β-ketoester substrates. Rapid, two-step synthesis of these substrates via acylation and alkylation of phenyl ethyl ketone, and derivative ketones, will enable the investigation of Iridium catalysis. Exploration of the Iridium chemistry will commence with examination of the effects of additives, bases, ligands, precatalyst, reaction duration, concentration and other reaction parameters. Future work will involve optimizing the substrate synthesis or extending the scope of substrates to be studied.

Behavioral Experiments on Empathy and Pain in Humans
Katharyn Garcia
Mentor: Steven Quartz

Empathy, the ability to relate to another’s experience, is considered an important part of moral decision-making. Many experiments have been done involving empathy for monetary loss or other abstract harm, but very few have been done using physical pain, which is a much more salient stimulus. This project is a behavioral experiment in which human subjects made choices between monetary loss vs. physical (thermal) pain to themselves, as well as between loss to themselves (monetary or physical) vs. loss to others. We investigate the differences in self-regarding choices vs. social choices. Continuing work will reveal more about how physical pain affects moral decision-making.

SUSY High Level Trigger at CMS Using Razor Variables
Edward J. Garza
Mentors: Maria Spiropulu and Javier Duarte

Supersymmetry (SUSY) is a proposed symmetry that relates bosons to fermions, giving each particle a superpartner. As an extension of the Standard Model, supersymmetry could explain dark matter and provide vast insight into the grand unification and string theory. At the Compact Muon Solenoid (CMS), one of the detectors at the Large Hadron Collider (LHC), signs of SUSY are being analyzed. However, only about 1 in every $10^5$ collisions that occur can be saved. In order to limit the number of saved events, a trigger system is implemented. There are two levels: Level 1 and the High Level Trigger (HLT). I am working on kinematically reconstructing the collisions to determine which events to record at the HLT. Because SUSY particles are thought to decay into a lightest symmetric superpartner (LSP) that only interacts via the weak force, there should be missing transverse energy (MET) in the detectors. One way to look for MET and thus SUSY events is by using razor variables.
A Transcriptional Model for the Feed-Forward Loops of the MET Pathway
Albert Ge
Mentors: Eshel Ben-Jacob, Bin Huang, Mingyang Lu, and Erik Winfree

The MET pathway is a protein network which governs two cell motility phenotypes: amoeboid and mesenchymal. The decisions made by the MET pathway have been linked to metastasis of cancerous cells. Though some of the protein interactions in the pathway have been studied experimentally, little is known about the physical dynamics of the network, and how it changes as a function of the inducing signal. In this project, transcriptional-protein models of the feed-forward loops (self-activating, self-inhibiting, and feedback) in the MET pathway are formalized. Using the models, nullclines were plotted as a function of protein concentration, and analyzed to determine stable and unstable solutions to the system. Bifurcation diagrams were also graphed to observe how each steady-state solution may change with varying input signal. Finally, time dynamics of the systems were examined for peaks in protein concentration. The simulations suggest that feedback systems are relatively independent of the input signal, in comparison to self-activating and self-inhibiting systems. Coupling these loops together may further tie together theoretical with experimental data.

Mechanical and Electrical Properties of Bio-Composite Materials Composed of Plant Cells and Graphene Nanoplatelets
Temesgen Gebrekristos
Mentors: Chiara Daraio, Raffaele Di Giacomo, and Guillaume Blanquart

Plant cells possess a cell wall that contains different bio-polymers including cellulose, lignin and pectin in a complex structure containing also metallic ions. These cell walls have been shown to maintain their characteristics when cells are dehydrated and form materials with extremely high temperature sensitivity when combined with carbon nanotubes. This project focuses on the production method and study of new materials composed of plant cells and graphene. These materials have mechanical characteristics similar to wood together with low electrical resistivity and can be used as thermal heaters. We produced bio-composite materials using various percentages of a commercial dispersion of graphene nanoplatelets in N-butyl acetate and cell lines from *Bombax costatum*, *Schinopsis quebracho colorado* and *Nicotiana tabacum*. We found material samples' stiffness to increase with decreasing moisture content. We consequently improved the production method by adding a dehydration procedure at 75°C for 8 hours to reduce moisture and evaporate solvent present in graphene. We also found samples' stiffness to increase with increasing the percentage of graphene up to 5-10%wt. The materials could be self-heated up to 75 °C by applying low voltages. These materials could potentially be used at the same time for structural applications and large surface heaters.

The Cone of Betti Tables Over the Homogeneous Coordinate Ring of Three Noncollinear Points in \( \mathbb{P}^2 \)
Iulia Gheorghita
Mentors: Steven V. Sam and Matthias Flach

It was conjectured by Boij and Söderberg and proven by Eisenbud and Schreyer that, over the graded polynomial ring, for every strictly increasing degree sequence \( \mathbf{d} \), there exists a Cohen-Macaulay module with a pure resolution of type \( \mathbf{d} \), and that the Betti table of every Cohen-Macaulay module can be decomposed into a rational linear combination of pure Betti tables with a fixed codimension. Similar results have been shown for other Cohen-Macaulay rings. We seek to describe the cone of Betti tables of the Cohen-Macaulay modules over the ring \( B = \mathbb{C}[x, y, z]/(xy, yz, xz) \) by first passing to the \( \mathbb{Z}_3 \) invariants of the resolutions of modules with compatible \( \mathbb{Z}_3 \) action and then formulating a relationship between the cone generated by the equivariant Betti tables and that generated by the original Betti tables.

Reanalyzing Kepler Light Curves for Individual Signals of Smaller, Long Period Exoplanets
Helen Giles
Mentors: Charles Beichman and Rachel Akeson

The Kepler mission was designed to discover Earth-sized planets around stars other than our own Sun. Since the start of the mission in 2009, there have been almost 1000 new planets discovered. However, many are much larger than Earth, similar to the gas giants in the Solar System. The list of the stellar candidates for having planets is generated by a computer analyzing their light curves, but due to protocols of the programs involved, there may be many signals for long period planets that they miss. In particular, the mission software required a minimum of 3 detected transits for inclusion in the mission catalogs. We are therefore looking for planets producing at most 1 or 2 transits which would represent periods of two or more years. These systems would be of particular interest since they would be planets which did not migrate significantly away from their birthplaces. The aim of this project was to reanalyze all light curves for these signals and then follow up any which seemed to show likely transits, and to also improve the ability of the computer to calculate initial parameters of the system.
A Platform for Analyzing Naturalistic Virtual 3D Scenes for Computer Vision Applications
Evren Gokcen
Mentors: Pietro Perona and Mason McGill

Increased computing power and advanced rendering technology make feasible the use of 3D graphical models as valuable data for computer vision scientists. For real-world image and video data, annotation using present methods may be computationally expensive, as with contours; imprecise, as with depth; or impossible, as with optical flow. Synthetic data mitigates these issues and expands control of scene objects, camera angles, etc. To exploit and expand the benefits that synthetic data could provide vision research, we are generating an open-source platform for analyzing datasets of synthetic 3D scenes. Extending Blender, an open-source 3D animation suite with a built-in scripting API, we will be able to render scenes to display, for example, natural appearance, optical flow, or depth. We are generating two synthetic scene datasets: Synthetic Pascal and Navigation/Flow. Synthetic Pascal’s purpose is to prove that visual classification algorithms trained with synthetic data can perform well classifying natural data. Navigation/Flow contains hundreds of short stereo video clips of navigation through synthetic scenes, with corresponding pixel-wise optical flow metadata, which, along with generated depth measurements, has applications in autonomous navigation. Using readily available computers, this open software platform can facilitate the use of a vast amount of vision data for researchers.

Isomerization of the Arylpalladium Intermediate in the Palladium-Catalyzed Synthesis of QUINAP
Ashay Makarand Gore
Mentor: Scott Virgil

QUINAP is a chiral ligand that is very useful for enantioselective synthesis in chiral chemistry. A novel method of the asymmetric synthesis of QUINAP via dynamic kinetic resolution was recently developed. This synthesis involves an isomerization process of the arylpalladium in which the isoquinoline piece can adopt two positions in relation to the naphthalene ring. Thus, a deuterium labeling experiment with kinetic analysis will be conducted to provide insight into the direction of rotation of the isoquinoline piece during the isomerization process. The goal of this project is to synthesize the three deuterated versions of QUINAP needed for this experiment.

Structure Determination of Free Fatty Acid Receptors
Stefan J. Grampp
Mentor: Ravinder Abrol

This project aimed to determine accurate structures of the human free fatty acid receptors FFA1, 2, 3, and 4. These proteins were modeled with GEnSeMBLE structure prediction methodology, combining homology-based and ab initio methods.

The extent of the transmembrane helices was determined by a consensus of secondary structure prediction algorithms. The shapes of these helices were determined by assuming homology with the transmembrane helices of three similar human proteins, CXCR1, PAR1, and HT2BR. Another set of helical shapes was determined ab initio via extensive molecular dynamics modeling starting from a straight helix. The helices were then placed in a bundle based on a template GPCR, and bi-helical interaction energies were evaluated to determine the most stable rotation angle for each helix.

The structures produced via the homology methods and those produced ab initio were then energetically compared to find the most stable structures overall. Helical interaction energies were then re-evaluated for the best structures using helix rotation and helix tilt angles to produce final structures. These structures will be used to model ligand binding sites and then to screen for novel molecules that could serve as therapeutics targeting free fatty acid receptors.
Active Mirror Control for the Autonomous Assembly of a Reconfigurable Space Telescope (AAReST) Project
Eric Grohn
Mentors: Sergio Pellegrino and Manan Arya

The AAReST project aims to build a space telescope with a large segmented primary mirror consisting of many smaller mirrors. These smaller mirrors are mounted on individual “mirrorcraft” spacecraft that can assemble themselves in orbit to construct the aggregate mirror. In order for the array of mirrors to produce the correct shape for the aggregate mirror, each small mirror must be mounted on 3 actuators that adjust its position on-the-fly. Previous work built a laboratory testbed for prototyping the optics of the telescope. My project was to implement autonomous mirror control on the testbed. First, the hardware components were reviewed to ensure that they could communicate and were suitable for the system as a whole. Some incompatibilities were identified between the sensors and the microcontroller that will require changes to the future design. Second, two control algorithms were implemented. The first algorithm is a search algorithm that moves the mirror in an outward spiral until a bright object (e.g. a star) is found. The second algorithm is a pointing algorithm that moves the mirror such that the bright object appears in the center of the camera. These algorithms will be further developed and ultimately used by the telescope in-flight.

Thermodynamic Assessment of Candidate Oxides for Solar-Driven Thermochemical Fuel Production
Webster Guan
Mentors: Sossina Haile and Tim Davenport

Doped cerium oxide (ceria) have been shown to be promising materials for solar-driven thermochemical reactions as a sustainable and efficient method for hydrogen gas.1-4 However, detailed understanding of the thermodynamics of reduction is required in order to optimize the efficiency of a thermochemical reactor utilizing these materials. This study aims to determine the thermodynamic parameters ($\Delta H_{\text{red}}$ and $\Delta S_{\text{red}}$) of reduction of selected doped ceria and perovskite-based oxide materials as a function of temperature and oxygen partial pressure by thermogravimetric analysis (TGA). The selected materials for this study include a range of compositions (5%, 20%, 40%, and 60%) of praseodymium-doped ceria (PCO), of interest due to the high reducibility of Pr and its high solubility in ceria. Initial analysis has found that with higher concentrations of Pr it becomes more difficult to reduce the remaining Ce at higher temperatures under humidified hydrogen atmospheres, while under oxygen atmospheres, at higher concentrations of Pr a substantial fraction of Pr becomes reducible at higher temperatures of interest to thermochemical reactions.

References

Correlation of AGN Accretion With Galaxy-Wide Star Formation as a Function of Spectral Type out to z ~ 2.5
Yi Gui
Mentors: Nick Scoville and Daniel Masters

Using photometry from X-ray to the far-infrared from the Cosmic Evolution Survey (COSMOS), we study the correlation of star formation rate (SFR) to active galactic nuclei (AGN) accretion luminosity on nuclear obscuration. We define a sample of 163 X-ray selected sources from Chandra that have far- to mid-infrared detections and 1024 Chandra-detected, Herschel-undetected sources which we stack to determine the average far-infrared luminosity. Dust-corrected SFRs are derived from rest frame 60 μm luminosity using power law relationships between far-infrared (FIR) luminosity and SFR, and AGN luminosities are obtained from the Chandra 0.5-2 keV band. We compare least-squares models of X-ray luminosity to IR luminosity in bins of redshift and X-ray luminosity without separating by spectral type and find no correlation at low X-ray luminosity but positive correlation at high X-ray luminosity ($L_{\text{X-ray}} \sim 10^{44.4}$ erg s$^{-1}$). When separated by spectral type, unobscured (type 1) sources show no correlation at low X-ray luminosities and positive correlation between X-ray and IR luminosity at high X-ray luminosities. Obscured (type 2) sources display a positive correlation at all X-ray luminosities. Our results may be evidence against AGN unification models since the relationship between SFR and X-ray luminosity is not similar for the spectral types.
Modification on Silicon/Polymer Interfaces for the Design of Solar Energy Conversion Device
Anna B. Gunnarsdóttir
Mentors: Nate Lewis and Betar M. Gallant

Silicon microwires embedded in a polymer are a promising design for fabrication of inexpensive, robust solar energy conversion device. The polymer acts both as a functional component of the device for ion conduction and as a mechanical support, making it important to understand the mechanical-stability of the Si-polymer interface. Functionalization methods have been used to modify the Si surface and the resulting interfacial shear strength arising from Si-polymer bonds has been measured mechanically by in situ single wire pull-out test. We found that Si microwires embedded in Nafion have interfacial shear strength ranging from 8-20 MPa for four surface chemistries. SiOx, Si-H, Si-(CH2)10COOH and Si-CH3 with Si-CH3 having the lowest interfacial shear strength. To gain better chemical understanding of the physical origin of mechanical shear strength, we are investigating the surface coverage on surfaces relevant to microwires, namely Si(211) and Si(110). Functionalization of Si(211) with undecylenic-acid has been performed with various reaction times and has been analyzed with XPS and FTIR spectroscopy. Once maximum coverage is achieved, we will further apply this understanding to mechanical testing of Si microwires in an anion-conducting membrane with electrostatically charged sites, which are proposed to lead to stronger interfaces via electrostatic interactions.

Using Online Annotation and Computer Vision to Improve Ground Truth Estimations
Páll Gunnarsson
Mentors: Pietro Perona and Steve Branson

The advent of computer vision carries with it the daunting task of annotating datasets. A task which today is increasingly crowdsourced to the general populace. Due to the unreliability of individual annotators, methods to correctly estimate ground truths from annotations have become important. We suggest an improvement on state of the art methods by using online annotation and computer vision. Online annotation uses a different amount of annotations per image, as long as an image’s ground truth prediction exceeds a confidence threshold. This allows us to train a computer vision algorithm on the finished images and use it to assist in predicting the classes of the remaining images.

Stability and Activity of Noncovalently Immobilized Molecular Catalysts on Carbon Surfaces
Ayush Gupta
Mentors: Harry B. Gray and James D. Blakemore

Interfacing well-defined molecular catalysts with electrode surfaces is a key step toward constructing devices for selective solar-fuel production. Noncovalent interactions between pyrene-appended metal complexes and graphitic carbon surfaces can be used to immobilize catalysts on electrode surfaces, but questions remain about the stability and activity of such assemblies. We now report synthesis of a ruthenium(trisbipyridine) analogue (1) suitable for Noncovalent immobilization on graphitic surfaces. Immobilization of 1 is readily achieved by soaking a carbon electrode in a solution containing 1 overnight. Cyclic voltammetry data show the expected redox cycling of 1 on the surface. X-ray photoelectron spectroscopy (XPS) studies demonstrate that complex 1 is attached to the graphite electrode both before and after redox cycling. The compound displays the same electrochemical properties when immobilized and in solution, consistent with the mild conditions used for surface attachment. The complex also proved to be very stable on the surface with repeated cyclic voltammetry sweeps down to very negative potentials. Further data along this line will also be presented for an iridium-based catalyst and a manganese-based catalyst for CO2 reduction.

Variable Elimination for Scalable Receding Horizon Temporal Logic Planning
Mattias Gustavsson Fält
Mentors: Richard Murray and Vasumathi Raman

Linear Temporal Logic (LTL) has successfully been used for specifying a wide range of behaviors for systems and environments. Correct-by-construction controllers can be constructed from these specifications but the complexity of controller synthesis quickly grows with increasing size of the environment. A receding horizon framework was therefore recently proposed which guarantees the existence of a controller through symbolic checks of the specification. The synthesis of the controller can then be performed in run-time, where the current state of the environment is known. This effectively reduces the complexity of the controller synthesis, but for many problems with large dynamic environments, this is not enough. Ad-hoc methods to locally restrict the environment have previously been used with the risk of losing correctness. We have developed a method of reducing specifications by eliminating locally redundant variables, while maintaining the correctness of controllers. We demonstrate the method on problems that were previously unsolvable due to the complexity of the environment. We also consider using the reduced specifications to identify problems on which controllers can be reused.
Characterization of a Putative [4Fe-4S] Complex in UvrC and Its Role in DNA-Mediated Charge Transport
Sirus Han
Mentors: Jacqueline Barton and Michael Grodick

DNA-mediated charge transport (DNA CT) is the fidelity-dependent ability of DNA to transfer electrons through the aromatic systems that run up the helices. It has been demonstrated via a combination of genetic and molecular assays that two proteins, Endonuclease III and MutY, participate in nucleotide excision repair, facilitated by DNA CT. Both of these proteins contain an uncommon [4Fe-4S] cluster which until recently was thought to be only structural in function. However, since these clusters are only redox active at physiological potentials when bound to DNA, it is hypothesized that they aid the repair proteins in locating damage.

The Barton Group has identified UvrC as another protein that participates in NER that may contain a [4Fe-4S] cluster. Strong evidence for the cluster’s existence in UvrC was obtained through EPR. Now, genetic knockouts are being constructed using the λ-red recombinase system which hijacks the recombineering machinery of a phage to swap in an antibiotic resistance gene in place of the native gene. These knockouts will then be used in conjunction with similarly constructed MutY knockouts to further examine the effects of these [4Fe-4S] clusters in DNA repair using electro-chemical techniques.

Spontaneous Emission Enhancement of Quantum Emitters Coupled to Hyperbolic Metamaterials
Victor Han
Mentors: Harry Atwater and Ruzan Sokhoyan

We study the spontaneous emission enhancement of a quantum emitter (an atom, quantum dot, etc) coupled to a hyperbolic metamaterial composed of several planar layers of dielectric, metal, and ITO each ~5-20nm thick. Using the finite difference time domain (FDTD) method to simulate our structures, we investigate how spontaneous emission enhancement of an emitter varies depending on the spatial position of the emitter relative to the metamaterial. In our analysis we consider both infinite and finite length metamaterials as well as the case where the emitter is embedded inside the metamaterial. Our work allows us to understand how much of the emission enhancement is due to the entire metamaterial rather than the metal component of it alone and is important for designing future experiments involving quantum emitters coupled to hyperbolic metamaterials.

Synthesis and Characterization of A:B Stoichiometric Strontium Doped Lanthanum Manganites for Solar-Driven Thermochemical Fuel Production via Isothermal Cycling
Sheila Handler
Mentors: Sossina M. Haile, Michael Ignatowich, and Chih-Kai Yang

Variable valence oxides, in which the cation can adopt several oxidation states, have proven valuable in the process of solar-driven thermochemical fuel production. In particular, strontium-doped lanthanum manganite, which has the perovskite structure, is an attractive material due to the high degree of nonstoichiometry that can be achieved before decomposition. Different compositions of strontium-doped manganites were synthesized via the solid-state synthesis. The chemical compositions of these compounds are of the form (La_{1-x}Sr_x)MnO_3, with x between 0.2 and 0.5. It has already been established that Strontium-doped lanthanum manganite is a good material for two temperature thermochemical fuel production. In addition, the Haile group and others have found some evidence that the material’s kinetic response depends on the ratio of Sr and La cations to Mn cations. This ratio dependent response has been investigated via in situ isothermal thermochemical cycling to determine the optimum ratio of Sr to La. Findings suggest that LSM compositions with higher Sr content perform better than the current state of the art material, ceria.

Welfare and Contagion in Financial Networks
Jonathon A. Hazell
Mentor: Matt Elliott

I take a general model of financial networks under contagion and add microfoundations. I then classify the entire set of social equilibria and show them to be characterised by clusters, a novel finding. Moreover, there is always a divergence between private and social optimality. I also endogenise private trading equilibria, to show the extent to which private and social incentives diverge. Finally I explore the implications of risk averse managers, versus risk-neutral firms, in the context of financial contagion.
Alternative Methods of Recording Neural Activity
Bryan D. He
Mentors: Lakshminarayan Srinivasan and David Rutledge

Current methods of recording neural activity include procedures such as electrocorticography (ECoG) and scalp electrodes. However, methods related to ECoG require highly invasive surgical procedures, and methods like scalp electrodes record weak signals. We explore methods of recording neural signals that are less invasive than normal surgical methods, but are able to record cleaner signals. The signal strength is evaluated for Visual Evoked Potentials (VEP), Steady-State Visual Evoked Potentials (SSVEP), and Steady-State Auditory Evoked Potentials (SSAEP). In addition, we seek to allow these methods to localize the source of a signal and detect frequencies that cannot be detected by scalp electrodes. We also found that cardiac activity measured by the electrodes is highly repeatable with low variation, so we also study how to filter out cardiac activity from the recorded signals.

Developing an Electrochemical Assay for Detection of Dna2 Nuclease Activity
Jianing Jenny He
Mentors: Jacqueline K. Barton and Helen Segal

Dna2 is a helicase-nuclease that is involved in DNA repair and replication. Mutations in Dna2 are linked to the pathogenesis of human diseases and developmental disorders such as cancer, Seckel syndrome (a form of dwarfism), and progressive myopathy. Thus, a complete understanding of the biochemical mechanism of Dna2 is important for understanding human health and disease.

Dna2 has an iron-sulfur cluster that is conserved in eukaryotes, from yeast to humans, but the role of the 4Fe-4S cluster is still unknown. The Barton lab has proposed that 4Fe-4S clusters in DNA binding proteins participate in DNA-mediated redox signaling. DNA acts as a molecular wire to transport electrons through the n-orbitals along undamaged DNA over distances as long as 100 base pairs.

Thus far, the only studies of DNA CT in a biological system have focused on characterizing DNA repair proteins from E. coli, a prokaryotic organism. The goal of this project is to develop an electrochemical assay to study proteins like Dna2 from eukaryotic organisms that also signal one another via DNA CT. The results of this electrochemical assay compare to those of a gel electrophoresis assay as described in a 2013 PNAS paper, proving the legitimacy and usefulness of this assay. This work will potentially provide insight on how enzymes with 4Fe-4S clusters use DNA CT to repair DNA in eukaryotic cells. These results could set a foundation for expanding the current model for DNA CT and DNA repair in prokaryotic organisms to more complex organisms.

Triangulations of Hyperbolic 3-Manifolds
Alex Henny
Mentors: Yi Ni and Maria Trnkova

The topological software SnapPy, descended from Jeff Weeks’s SnapPea, provides a wealth of information about hyperbolic 3-manifolds. While many of these manifolds have been triangulated with the help of these programs, not all of the triangulations are well-behaved. In particular, a number of them, including VoI3, contain both positively- and negatively-oriented hyperbolic tetrahedra. We use Thurston’s Spinning Construction to obtain an ideal triangulation of VoI3 consisting of positively-oriented (and perhaps flat) tetrahedra. Perhaps more advanced methods can be used in the future on other manifolds, to obtain minimal, ideal, positive triangulations where now there are negatively-oriented components.

Kerogen and Pyrite Formation in the Santa Barbara Basin
Emilia S. Hernandez
Mentors: Alex L. Sessions and Morgan R. Raven

The Santa Barbara Basin is a fairly unusual marine environment due to its suboxic bottom waters, which allow for sulfate-reducing bacteria to flourish undisturbed by burrowing animals. Because of kinetic isotope effects, certain chemical reactions, particularly biologically mediated ones, have different fractionations of stable isotopes associated with them. The classic way to study these is to use an elemental analyzer (EA); however, a large amount of material is needed for this method and can therefore only be used to study fractionations of bulk material. Inductively coupled plasma – mass spectroscopy (ICP-MS) has recently emerged as a way to study the isotope ratios of trace elements, but its main drawback is that all of the sulfur must be converted to sulfate, which is not possible for the kerogen fraction. We have used a combination of these two analytic techniques to study the redox history of sulfur species in fractions taken from two cores from the Santa Barbara Basin.
Role of Retinoic Acid Pathway on Zebrafish Enteric Nervous System Development
Stephanie Hong
Mentors: Marianne Bronner and Rosa Uribe

The enteric nervous system (ENS) controls the peristaltic movement of food through the gastrointestinal tract. During development, it derives from vagal neural crest cells (VNCC) that migrate into the developing gut to become a diverse class of neurons. In avian and mouse embryos, the Retinoic Acid (RA) signaling pathway has been shown to induce migration and population growth of VNCC, improving the ability of VNCC to colonize the gut in chains. It is not known if the RA pathway plays a functional role during zebrafish ENS development. To begin addressing this question in zebrafish, embryos were treated with exogenous RA at varying times during ENS development and assayed by in situ hybridization and immunohistochemistry for genes that mark neural crest cells or the gut environment. When treated with RA from 26-52 hours post fertilization (hpf), NCC distribution in the vagal and gut regions was expanded compared to control-treated embryos. Furthermore, RA treatment resulted in morphed and irregular patterning in the pharyngeal arches, of which NCCs are a precursor, and an expansion of mRNA encoding the signaling molecule sonic hedgehog, which has previously been implicated in ENS development. When RA was applied past 48 hpf, no difference in neural crest or ENS progenitor marker expression was observed. These results indicate that the RA pathway plays an early role in influencing VNCC migration into the developing gut and suggest that RA is a highly conserved signaling pathway that VNCC utilize in order to colonize the developing gut.

Implementation of a Non-Endogenous Two-Component System in E. coli and Characterization of Combinatorial Promoters
Andrew Hou
Mentors: Richard Murray, Victoria Hsiao, and Anu Thubagere

As part of an overall project to build an E. coli based synthetic circuit analogous to mammalian circuits that regulate insulin and glucose concentrations extracellularly, we seek to test and implement a two-component AgrBDCA system, which is endogenous to Staphylococcus aureus, in E. coli. Because the auto-inducing peptide (AIP) which normally binds and activates the membrane-bound histidine kinase AgrC is not readily available, an SH3 scaffold system has been attached to AgrC and the response regulator, AgrA, which allows AgrC to phosphorylate AgrA in the absence of AIP. Fluorescence of this circuit will then be compared to fluorescence of a control. Additionally, we seek to characterize combinatorial promoter constructs, which have potential applications for the overall project. After cloning cells with test constructs, fluorescence values after addition of inducers at various concentrations indicate that a combinatorial promoter consisting of pTet and pLac operators behaves as an AND-gate, while a combinatorial promoter consisting of pBAD and pTet operators behaves as a single-input gate. Further work will be done on exploring how changing the order and position of the pLac and pTet operator parts affect the logic of the pTet-pLac combinatorial promoter.

Coding for Interactive Multiparty Communication
William Hoza
Mentor: Leonard Schulman

We investigate robust interactive multiparty communication in the presence of adversarial errors. We show that any n-party T-step protocol can be compiled into a simulation protocol which tolerates an adversarial error rate of $\Theta(1/n)$, which is optimal. We give upper and lower bounds of $O(mT)$ and $\Omega((m/nk)T)$ for the runtime of such optimal simulation protocols, where m and k are the number of edges and the edge connectivity of the graph underlying the original protocol. We show that with shared randomness, on graphs for which any two connected vertices have $\Omega(n)$ common neighbors, protocols can be compiled into optimal simulations running in $O(T \log n)$ steps. We also consider an error model with a weaker adversary, who has a budget of errors he can introduce on each edge. We show that any n-party protocol on a graph with diameter D can be simulated by a protocol which tolerates a per-edge adversarial error rate of $\Theta(1/D)$, and we give a matching negative result. However, we also prove a black-box negative result which suggests that simulations with reasonable resource usage can only tolerate a per-edge adversarial error rate of $O(1/n)$.
Voltage Controlled Surface Plasmon Bandgap on OFET Structure
Daniel Hsu
Mentors: Nicholas Fang, Dafei Jin, and Hyuck Choo

We are building a tunable device that can vary the surface plasmon bandgap using an applied voltage, much like a nanophotonic switch. The device is fabricated as a bottom-gate bottom-contact organic field effect transistor on a glass slide with an interdigitated gold pattern forming the source and drain electrodes under a monolayer of organic semiconductor. The organic semiconductor chosen is TDBC J-aggregate dye due to its high splitting of the surface plasmon dispersion relation. When we excite surface plasmons using the Kretschmann configuration at a single laser incidence angle, the two intersections of the wave-vector line with the split dispersion relation forms a surface plasmon bandgap. Surface plasmons with frequencies within the bandgap are forbidden. We then tune this bandgap using an applied voltage on the gate and source electrodes. This forms a nanophotonic switch by controlling whether a surface plasmon of a particular frequency falls within the bandgap or not. From the absorption spectrum of the Kretschmann configuration we have already observed clear surface plasmon splitting behavior and we are incorporating the gate voltage to tune the plasmonic bandgap. We are also studying effects of the accumulated major hole carriers from the p-type J-aggregate semiconductor on surface plasmon behavior.

Variability of Young Stars in the Orion Cluster of North American/Pelican Nebulae
Tianyi Hu
Mentor: Lynne A. Hillenbrand

Before young stars settle into the main-sequence stage, their luminosity varies over time, causing variability in the light curves. Variability in pre-main-sequence young stars can be caused by various physical phenomena including sudden increased accretion of materials or obscuration by dust cloud. The Palomar Transient Factory (PTF) has conducted a multiyear optical wavelength-monitoring program and covered several square degrees of the North American and Pelican Nebulae. Using a compilation of over 45,000 observed stars, we examined their lightcurves using various statistical tests. The von Neumann ratio was isolated for further analysis as it contains a long left tail for values less than 1. Examination of individual lightcurves indicates stochastic (lightcurve with no obvious patterns) young stars are concentrated between values of 0.4 to 0.7. Periodic young stars and pulsating giants are on the more extreme end at values less than 0.2. The von Neumann ratio test is a valuable statistic to filter the large dataset of stars for interested young stars.

Structure of Membrane-Bound Chemoreceptor Arrays in Archaea and Implications for Chemotactic Signaling
Audrey Huang
Mentors: Grant Jensen and Ariane Briegel

Most motile bacteria sense and respond to their environment through a membrane-bound chemoreceptor array, the structure and function of which has been studied extensively. Most motile archaea possess a similar chemotactic signal transduction system involving chemoreceptor proteins homologous to those in bacteria, but its structure is largely unknown. We use whole-cell electron cryo-tomography to image these chemoreceptor arrays in evolutionarily diverse wild-type archaearchal strains preserved in near-native plunge-frozen state. We show that both membrane-bound and cytoplasmic chemoreceptor arrays are hexagonally packed with a highly conserved lattice spacing of 12 nm near the polar flagella they control, much as they are in bacteria. Each vertex of the lattice is a trimer of receptor dimers, as they are in bacteria, and observed lengths confirm the current signaling and methylation model of chemoreception. We further discuss the evolutionary relation between bacteria and archaea based upon this similarity.

Development and Analysis of Intuitive Information Retrieval
Edward Huang
Mentors: Jehoshua Bruck and Farzad Farnoud

Collections of data can be so large that traditional techniques of information retrieval and processing are impractical. Of these “big data” collections, retrieval and processing of archives of scientific publications are particularly challenging, as they differ from conventional texts due to vastly different usages of words and phrases within individual disciplines. In this work, inspired by the way operations of information storage and retrieval in human memory are represented, we build an associative model of words from scientific corpora. The idea is to assume that associated or similar words often appear together in the same texts. To measure similarity between words, we use a contingency table, which records the appearances of words in publications. We use the table to compute a similarity score between -1 and 1, with 1 denoting that the words always appear together. The final goal is to optimize our method such that it can determine the similarity score between two pieces of scientific publications without human input. This technique differs from a commonly used method, called latent semantic analysis, in that multiplicities of words in texts impact similarity scores. Further development of the technique requires testing different methods of calculating similarity scores, recognizing words with different meanings based on their contexts, as well as optimizing to improve performance.
Characterizing the Effect of TREM2 on Microglia in Murine Alzheimer's Disease Models
May Hui
Mentors: Li Gan, Meredith C. Reichert, and Raymond Deshaies

From 2000 to 2008, only Alzheimer's disease (AD) has seen a significant increase in mortality, compared to other top killers in the US. Recently, it has been shown that R47H, a rare missense mutation in TREM2, confers a significant risk for AD. Because TREM2 is involved in regulation of microglial phagocytic activity, we hypothesize that a knockout of TREM2 could result in microglial hyper-activation, and thus worsen neuronal loss through systemic inflammation. This project thus seeks to characterize the effect of TREM2 dosage on microglial phenotype and phagocytic capability in a murine model of AD. Analysis of the motor cortex has revealed a significant increase in microglial cell count, soma area, and diameter in TREM2 knockout mice, suggesting an activated phenotype. To compare differences in function, we will perform phagocytosis assays on wild-type and TREM2 knockout microglia.

Reference

Effect of Mismatches on Spin Selectivity of Electron Transmission Through Double-Stranded DNA
Sylvia Hürlimann
Mentors: Jacqueline K. Barton and Theodore Zwang

In recent years, double stranded DNA (dsDNA) has been shown to have a large spin polarization in electron transmission that is several orders of magnitude larger than what the current theory predicts. A study of how mismatches affect the spin polarization of dsDNA could shed light to the biological implications of the effect and help improve the theory. Alkyne labeled dsDNA was attached to a self-assembled monolayer of 12-azidododecane-1-thiol on nickel surfaces using a Cu(I) catalyzed azide-alkyne cycloaddition in order to inject a current in the dsDNA and vary its spin polarization. Progress has been made towards attaching the dsDNA to nickel and investigating the effect that mismatches in dsDNA has on spin selectivity. Further measurements need to be made using chronoamperometry and chronocoulometry to quantify the effect that mismatches have on spin polarization of dsDNA.

Data Analysis Automation for Thermochemical Fuel Production
Vy-Luan Huynh
Mentors: Sossina Haile and Michael Ignatowich

Variable valence oxides, such as Ceria, are invaluable to thermochemical fuel production and show increased performance with chemical modification. They are commonly subject to characterization by thermogravimetric analysis and in-situ thermochemical cycling. These experimental investigation techniques can be streamlined by programs. The principal objective of this project is to implement computerized automation for analyzing data produced by the Haile lab’s thermochemical fuel research. Results include successful, mechanical reproductions of thermogravimetric and in-situ thermochemical cycling analyses. The thermogravimetric analysis program takes as input the path of an experiment raw data spreadsheet file, then fits models to its data points and calculates mass loss, oxygen pressure, and entropy/enthalpy values accordingly. The in-situ thermochemical cycling program takes the dissociation rate raw data file as input, and utilizes its temperature and time stamp values to calibrate and analyze the hydrogen and oxygen involved. The principal conclusion is that such automation can be successfully performed in this situation, thus removing repetitive, error-prone tasks from humans and improving lab efficiency and work quality.

Comparison Between Flapping and Jet Propulsion as Means of Aquatic Locomotion
Suhail Idrees
Mentors: Morteza Gharib, Chris Roh, and Nathan Martin

In nature, two of the most prevalent means of underwater locomotion are flapping laterally, and ejecting a jet of fluid in the reverse direction, both with respect to the direction of motion. Even after millennia of evolution, both mechanisms exist; one has not categorically triumphed over the other in the race of natural selection. To understand why both mechanisms are thriving in nature, we have built a simplified mechanical model of an underwater thruster that can flap as well as produce jets. Using this model, we compared the dynamics and kinematics of each mode of propulsion. This allows us to visualize an imaginary organism that can choose between both modes using the same set of muscles, and thereby decide if one is fundamentally superior to the other.
Computational Investigation of Transition Metal Catalysts for CO₂ Reduction With Projector-Based Embedding Techniques
Danil V. Ilyin
Mentor: Thomas Miller

Carbon dioxide reduction may provide means to reduce atmospheric CO₂ and advance our understanding of renewable fuels, chemicals, and artificial photosynthesis. Using a novel computational projector-based embedding scheme, we study potential transition-metal catalysts such as fac-Re(bpy)(CO)₃. Projector-based embedding significantly increases accuracy of calculations while greatly reducing their computational cost. The electronic density of a system is partitioned into orthogonal subsystems A and B, and high-level calculations on subsystem A are embedded within the exact quantum-mechanical environment of subsystem B. This yields accurate results comparable to high-level calculations on the whole system, yet at a fraction of the computational cost. We expect to see significant improvements over traditional density functional theory approaches in accuracy, and over coupled-cluster wave function methods in speed and computational demands. Potential future applications include mechanistic studies and catalyst design.

Engineering Chimeric Antigen Receptors for the Treatment of HIV
Erin M. Isaza
Mentors: Pamela J. Bjorkman and Rachel P. Galimidi

Chimeric antigen receptors (CARs) are engineered receptors that graft the specificity of a monoclonal antibody onto a T-cell—the cells are removed from a patient, modified to express the desired receptors via retroviral vectors, and reintroduced into the patient. While CAR T-cells have proven effective in treating leukemia, the only attempt in using CAR T-cells to attack HIV proved unsuccessful. However, in the time since this former study, broadly neutralizing antibodies against HIV, which bind to a wide variety of antigens, have been discovered. We propose to engineer CAR T-cells expressing broadly neutralizing antibodies, which bind to and neutralize HIV with a much higher avidity and are safer than the previous generation of anti-HIV CAR T-cells.

A Novel Cell-Specific System for in vivo Studies of Immunological Tolerance
Vasant Iyer
Mentors: David Baltimore and Mati Mann

Immunological tolerance is the process by which immune cells become accustomed to host tissue and to benign foreign matter that the immune system deems harmless; this process is critical in preventing unwarranted inflammations and autoimmune disorders. Although it has been shown that self-recognition and immunoregulatory molecules such as MHCII and IL-10 play a significant role in maintaining systemic tolerance, little is known about how tolerance is conferred and what cells mediate it; investigating these properties of tolerance requires developing a method to disrupt MHCII and IL-10 production in specific cell types in vivo. We developed such a system by creating adeno-associated viruses (AAV), encoding Cre recombinase under the transcriptional control of promoters obtained from cell-specific genes. Similar vectors encoding luciferase were used to optimize the vector transfer process, into the lungs of adult mice. Plans for further work include using this system to silence MHCII or IL-10 expression in cell types of interest and quantifying the subsequent responses of mice to induced inflammations, elucidating the roles of these cell types in maintaining lung immunological tolerance.

MySQL Bioinformatics Database Construction
Nauman Javed
Mentors: William Clemons Jr. and Axel Müller

Bioinformatics databases such as GenBank and Uniprot have become key tools in modern proteomic and genomic analysis. However, the utility of these databases is often limited by inconsistencies in accession numbers, sequence annotations, and genomic locations, which creates redundancies and difficulties in advanced queries and inter-database mappings. In this project we seek to consolidate several gene and protein databases into a centralized MySQL database with non-redundant gene to protein mappings, sequence annotations, and source information. The database will also pre-calculate common bioinformatics features including computationally heavy parameters such as transmembrane domain locations and mRNA secondary structure. Such a database will allow for the efficient processing of advanced queries that are otherwise difficult with the currently available databases.
Effect of Social Influence on Human Risk-Preference: An fMRI Study
Emily Lara S. Jensen
Mentors: John O’Doherty and Shinsuke Suzuki

Social influence has been shown to impact a person’s decision making due to their desire to conform to group norm. Seeing as an individual’s risk-preference has the potential to profoundly affect his or her life in multiple ways, we thought it important to study whether this inherent risk-preference can change under social influence. Previous studies have shown how insular activity correlates with both risk-preference and social cognition separately, which suggests there may be a link between risk-preference and social conformity. In our study, we examined this hypothesis using the fMRI neuroimaging method to observe 26 subjects while they performed various gambling tasks. The subjects’ individual risk-preferences were determined initially and monitored for dynamic change throughout the experiment to give us our behavioral result. We found that, after observing other people gamble in either risk-averse or risk-seeking ways, our subjects were more likely to gamble similarly. These behavioral results will be compared with those of the fMRI once the images are processed in the future. Our findings may have potential implications both clinically for pathological gamblers and widely for bubbles in the financial market, though further research would be necessary to determine such practical applications of our result.

Transient Atmospheric Effects in Pulsar Companions
Adam S. Jermyn
Mentor: Sterl Phinney

Pulsars emit radiation over an extremely wide frequency range, from radio through gamma. Recently, systems in which this radiation significantly alters the atmospheres of low-mass pulsar companions have been discovered. These systems, ranging from ones with highly anisotropic heating to those with transient X-ray emissions, represent an exciting opportunity to investigate pulsars through the changes they induce in their companions. In this work, we present both analytic and numerical work investigating these phenomena, with a particular focus on atmospheric heat transport, transient phenomena, and the possibility of deep heating via gamma rays.

Building a Virtual Caltech
Katherine Jiang
Mentors: George Djorgovski and Ciro Donalek

So far, immersive virtual reality has been the realm of role-playing games rather than academia. With the users being fully integrated with their virtual surroundings, there is amazing potential for virtual communities, economies, and other aspects of modern societies and human interactions without the limit of distance and other barriers against meeting. Our research aims for a scholarly setting for social and scientific interaction for students, instructors, and other visitors. The OpenSimulator platform is used to develop a virtual Caltech containing collaboration and presentation venues as well as landmark buildings, as well as host a virtual data visualization laboratory that can display data in up to 10 dimensions. Within our virtual Caltech campus, we successfully created a presentation-ready Beckman Auditorium complete with seating and stage and plan on continuing the expansion of virtual Caltech to create a more comfortable and familiar environment for our users.

Genome-Wide Characterization of lncRNA-Protein Interactions
Rushikesh Joshi
Mentors: Mitchell Guttman and Mario Blanco

It has become apparent that our genome is primarily comprised of non-coding RNAs (ncRNAs), and not protein coding messenger RNAs (mRNAs). Advances in high-throughput RNA sequencing have established the existence of thousands of large non-coding RNAs (lncRNAs). Experimental procedures have been developed to isolate lncRNAs, to explore their diverse biological and regulatory roles.

As is true with classical ncRNAs, the function of lncRNAs depend on RNA-protein interactions. The prevailing hypothesis proposed by our group is that lncRNAs act as flexible, modular scaffolds, and are essential for assembling protein complexes based on highly specific, discrete, protein-binding domains within the lncRNA.

By UV irradiating mouse embryonic stem cells we can crosslink in vivo RNA-protein interactions via the formation of a covalent RNA-protein adduct. We have been able to utilize computational methods to identify the discrete interaction domains with single-nucleotide resolution. To verify our results, we used previously determined high resolution three-dimensional structures of known RNA-protein complexes to compute RNA-protein inter-atomic distances; highlighting regions of close interaction.

We next plan to create a genome-wide map of protein-binding sites across all lncRNAs. Once a map is established, we can begin isolating these discrete binding sites, to determine their regulatory roles in the genome.
Exploring Microbial Biofilm Morphology Through Comparative Study and Modeling
Zofii Kaczmarek
Mentors: Lars Dietrich, Christopher Kempes, and Dianne K. Newman

Although many bacterial biofilms form complex patterns, little is known about the mechanisms underlying the formation of these multicellular structures. *Pseudomonas aeruginosa* colony biofilms that are grown on the surface of an agar plate develop a wrinkled structure to increase oxygen uptake under electron acceptor-limited conditions. Wrinkle width is adjusted to changes in electron acceptor availability, such as oxygen or the endogenous, redox-active phenazine pigments. We sought to identify genes that play a role in wrinkle formation by screening for mutants with atypical wrinkle morphologies. We screened 27 mutants that were made in the hyperwrinkled phenazine-null background (denoted ∆phz) for deviations in wrinkle thickness. We identified 3 mutants and selected one strain, ∆phz∆ccoN4, was selected for further study. Our findings provide an illustration of the mutability of wrinkle widths. This study can serve as a foundation for more in-depth examinations of genes relevant for the wrinkling process.

Computing Photometric Redshifts With Self-Organizing Maps
Adam Kalinich
Mentors: Peter Capak, Dan Masters, and Charles Steinhardt

Computing unbiased and accurate photometric redshift estimates is still a challenge in astrophysics. Euclid’s weak gravitational lensing experiment requires a bias much lower than current methods provide. Creating a Self-Organizing Map (SOM) may allow us to use spectroscopic redshifts to calibrate photometric redshift estimates. Self-Organizing Maps are an unsupervised machine learning technique, used to create a two-dimensional representation of higher-dimensional data. We implement the algorithm to create a SOM of color space and show the useful properties of the resulting map. The SOM can be used to separate galaxies from non-galactic objects such as stars and Active Galactic Nuclei. Objects clustered in the SOM tend to have similar photometric redshift estimates and spectroscopic redshifts. Further work on the algorithm and combining it with other new algorithms could lead to large improvements in computing photometric redshifts.

Wil Kao
Mentor: Nai-Chang Yeh

We employ cryogenic scanning tunneling spectroscopic techniques to investigate the evolution of the density of states of (Y_{1-x}Ca_x)Ba_2Cu_3O_{7-δ} superconductors (0 ≤ x < 1) with respect to the hole doping level (p), under both zero-field condition and with an applied magnetic field of 2T for superconductivity suppression. We are especially interested in the hole-type over-doped regime (with the number of holes per CuO_2 plane p = 0.21) and its comparison with the optimally doped limit (p = 0.16). This study will help manifest the interplay between coexisting high-temperature superconductivity and competing orders (such as the charge density waves) in the ground state. Our studies of the spatially resolved tunneling spectra and Fourier-transformed local density of states suggest that the pseudogap phenomena are directly related to the presence of competing orders in the ground state, and the competing orders diminish with increasing hole doping. In addition to the spectroscopic studies of over-doped cuprate superconductors, we are in the process of developing a novel instrument consisting of a cryogenic scanning tunneling microscope (STM) combined with a scanning electron microscope (SEM) for the Kavli Nanoscience Institute at Caltech. The rationale for developing the cryogenic STM/SEM system is to overcome the limitations of small field-of-view and slow scanning speed of a typical STM system. We have made progress in the temperature control and ultra-high vacuum system of the STM component. Upon its completion, the STM/SEM combination is expected to achieve orders-of-magnitude improvement on the scanning efficiency for studying spatially resolved topography and tunneling spectra of novel electronic systems.
Developing Mass Spectrometry Assays for Phosphorylation of Postsynaptic Proteins
Maria Karelina
Mentors: Mary B. Kennedy and Dylan Bannon

The complexity and speed of protein signaling pathways that govern synaptic plasticity in the postsynaptic density have create a need to find methods of investigating modulation of protein activity with a higher time resolution and throughput. This study focused on creating a High-Performance Liquid Chromatography (HPLC) and Selected Reaction Monitoring (SRM) workflow for detecting heavy isotope-labeled peptides whose sequences contain phosphorylation sites of proteins involved in postsynaptic signaling. We found that many peptides of interest had properties that can cause low detection in the mass spectrometer, or difficulty with elution from the column. We were able to greatly improve the behavior of several standards by re-acetylating them at cysteine residues, and by scanning peptides with glutamate at the N-terminus for both the pyro-glutamate and glutamate isoforms. We identified the desired peptides that had sharp elution peaks and sufficient intensity on the mass spectrometer. These will be added to a digested hippocampal sample to determine accurate elution times and to identify two to three characteristic fragment ions for use in SRM assays. This data will then allow for the use of these heavy peptides as standards for investigations of the postsynaptic density during synaptic stimulation.

Modeling of Rayleigh-Taylor Instabilities
Juliana Kew
Mentor: Guillaume Blanquart

Rayleigh-Taylor instabilities (RTI) are found notably in the expanding gas shells of supernovae, but for this project they were induced by simulating a heavy fluid on top of a lighter fluid. The evolution of RTI at a level more complex than the size of the mixing layer is poorly understood and difficult to model, currently requiring vast quantities of time and memory. In this project, several simulations were run with different initial conditions and the resulting functions of average vertical velocity for a given density compared. The goal was to find any general rules these functions followed and to determine when, if ever, they became independent of initial conditions.

Many-Body Localization in Modular Systems of Quantum Spin Chains
Emil T. Khabiboulline
Mentors: John Preskill and Ling Wang

Many-body localization (MBL) is an exciting phase transition that is marked by the failure of an isolated quantum system to adhere to the laws of thermodynamics. That is, the system does not thermalize and thus does not lose its initial information, thereby making MBL states a promising form of quantum memory. Through simulations, we study the antiferromagnetic Heisenberg spin-1/2 chain, imposing quenched randomness to promote MBL. Our investigation extends to modular systems composed of this prototype. This analysis is enhanced by novel measures based on the reduced density matrix, which by nature isolates a subsystem of choice. We see signatures of an MBL transition that are comparable between the modular quantum systems.

TWILIGHT: A 3D Dust Radiative Transfer Model
David K. Khatami
Mentor: Barry F. Madore

We present TWILIGHT, a fully three-dimensional dust radiative transfer model that handles the scattering, absorption, and reemission of light from stars. TWILIGHT is built on a newly-invented semi-RayTracing technique that has the advantage of being very efficient at rendering complex objects with arbitrary geometries i.e. no symmetries are assumed about the dust structure or distribution of stars. Compared to similar codes relying on Monte-Carlo methods, the new method has orders of magnitude improvements of efficiency, and has the unique capability of automatically rendering 130 snapshots of each individual run at different viewing angles. Both qualitative and quantitative tests were performed on TWILIGHT with past literature results. We successfully performed various radiative transfer benchmarks, including brightness profiles of a foreground nebula, and a plane-parallel slab with a point-source and collimated beam. Qualitatively, TWILIGHT handled very high optical depth objects very efficiently and with no slowdowns. With the framework completed and performing as expected, we next plan on examining scientific applications, specifically with the complex structures of galaxies. An analytic galaxy was successfully rendered, consisting of 8 million cells and completing in under an hour on a single-core user laptop. Future work focuses on incorporating polychromatic capabilities as well as implementing parallelisation for use on clusters.
Inter-Brain Dynamics in Social Interaction  
Dae Hyun Kim  
Mentors: Shinsuke Shimojo and Sang Wan Lee

Although K. Yun, K. Watanabe, and S. Shimojo have shown that electroencephalography (EEG) signal connectivity accounts for high-level behavioral strategies, such as interpersonal interaction, precise identification of the corresponding neural dynamics during interaction still remains a great challenge due to the lack of proper method of analysis. We observe two specific interpersonal interaction tasks: face-preference task, and social interaction task. By using the eigenvectors obtained from the EEG raw data via using covariance-Gram matrix analysis, we show that the underlying patter across channels have a tendency to converge as a person approaches a final decision in the face-preference task. The same analysis was utilized to obtain results from the EEG raw data from social interaction task.

Development of Single Domain Binding Proteins in Improving Perfusion Efficiency in PARS and Engineering of AAV9 Vectors for Increased Target Efficiency and Gene Delivery  
Hyun Min Kim  
Mentors: Viviana Gradinaru, Bin Yang, and Benjamin Deverman

Tissue clearing and imaging enables the visualization and production of three-dimensional anatomical and phenotypical maps that can reveal essential structures and connections. PARS, Perfusion-Assisted Agent Release in Situ, presents a method to perform whole-body clearing and immunolabeling, thus enabling the production of maps at the subcellular level via microscopy. However, a current challenge with PARS is that large molecules such as antibodies easily permeate into the periphery of the brain but do not penetrate as easily into the interior of the brain during perfusion due to the blood-brain barrier. Thus, we developed and produced single domain binding proteins that are smaller and more stable, improving the efficiency of permeation into tissue during perfusion to improve immunolabeling while performing PARS. Furthermore, vectors for AAV9 viruses that could penetrate the blood-brain barrier upon injection via the vasculature were developed. These vectors increase cell-type specific binding and can thus target specific neural cells. Due to their highly improved efficiency in staining specific cell types, these viruses can also be used for immunolabeling to map the nervous system, and can also be used for gene delivery to provide therapeutic approaches to treating disorders such as Huntington’s Disease.

Specification Refinement With Assumption Mining for Receding Horizon Linear Temporal Logic Planning  
Joon Sik Kim  
Mentors: Richard M. Murray and Vasumathi Raman

Linear Temporal Logic (LTL) is used in various application domains for synthesizing controllers. In particular, when solving an LTL synthesis problem with large number of states, we can use a receding horizon framework for computational efficiency. In this framework, we split the original problem into several subproblems (horizons) described by respective short-horizon specifications, solve it one by one and move to the next step, rather than trying to plan for the entire path from the beginning. Currently, this process is accompanied by an invariant refinement process, in which we eliminate states that produce any path that makes the specification unrealizable in any horizon. We propose a comparable specification refinement process by using assumption mining techniques. This aims to reduce the conservativeness of the current invariant refinement process and possibly provide some insights to constructing global specifications that should hold throughout the whole execution.

Life-Cycle Savings During Short Risky Income Spikes: Evidence From NFL Athletes  
Joshua Kim  
Mentors: Colin Camerer and Kyle Carlson

Life-cycle models require the consumer to solve a very difficult optimization problem. In this paper we test the limits of consumers’ sophistication in a setting with exceptionally challenging income paths, the careers of National Football League (NFL) players. Newly drafted players transition abruptly from a state of low income to a relatively short career of very high but risky income. Players face the difficulties of optimizing given this unusual income profile and resisting the temptations posed by large amounts of cash on hand. We use salary data and post-retirement survey data to create a life-cycle model with an income process like that faced by NFL rookies. Under commonly used parameterizations, simulated consumers experience outcomes very different from those observed among NFL players. Using public records, we show that players are much more likely to file for bankruptcy than optimally-saving consumers facing an NFL income process. Models with quasi-hyperbolic consumers generate bankruptcy outcomes closer to the observed data.
Kinetic Characterization of CSN-Mediated Deconjugation of Nedd8 From SCF Ubiquitin Ligase
Minsoo Kim
Mentor: Raymond J. Deshaies

The current model of SCF (Skp1, cullin, and F-box) ubiquitin ligase regulation involves a massive waste of energy. For a target substrate to be ubiquitinated, the corresponding F-box-Skp1 complex has to first bind to a cullin, thereby forming a SCF complex. However, CAND1 could displace the F-box-Skp1 complex from the cullin. When the SCF complex gets neddylated, CAND1 can no longer bind to the cullin and the substrate is more likely to get ubiquitinated. However, CSN that is present nearby could deneddylate the cullin and hence allow CAND1 to bind. As a result, in the current model, it is hard to regulate SCF complexes efficiently. In order to clarify the exact mechanism of how cullin-RING ubiquitin ligases (CRLs) are regulated through neddylation and deneddylation, it is necessary to characterize kinetic properties of CSN. In the following paper, Kd of both neddylated and unneddylated cullins were measured by using a fluorescence binding assay.

Unknown Conserved Genes From C. elegans to Humans
Shawn J. Kim
Mentors: Paul W. Sternberg and Ravi David Nath

Caenorhabditis elegans (C. elegans) is a multicellular organism in the phylum of Nematoda. C. elegans is made of 959 somatic cells, and has a complex developmental process, including embryogenesis, morphogenesis, and final growth to an adult. Important developmental principals are conserved from C. elegans to humans. The simple nervous system of C. elegans controls a great diversity of behaviors that can be easily quantifiable. C. elegans are estimated to have over 20,000 distinct genes. Many of these genes are orthologous with human genes, meaning that they have evolved from a common ancestral gene. Therefore, there is a high probability that orthologous genes have similar functions. Of the multitude of orthologous C. elegans genes, the Sternberg Lab has identified 1000 orthologous genes whose functions remain unknown. From this list, we identified 152 genes that are the only members of a particular undefined gene family, which means they are less likely to be genetically redundant. We noted that 30 of the 152 genes in an unknown gene family are found in neurons. Given C. elegans simple nervous system and genetic flexibility, we can identify the function of a gene by comparing the behaviors between wild-type worms to mutant worms with a null-allele. To look specifically at the effect of knocking out these genes, I have screened 19 genes of those 152 conserved unknown genes by applying tracking assay, pumping assay, and avoidance assay to the strains, each of which has knocked out one gene.

Mechanical Characterization of 3D Printed Materials
Shi En Kim
Mentors: Chiara Daraio, Sebastian Krodel, Jan Rhys, and Richard Flagan

3D printing has been widely used in for rapid prototyping, but that the 3D printed products’ material properties have yet to be characterized hinder 3D printing’s advancement into the mass production stage. Thus, my project aims to investigate and catalogue how the aspect of the printing process affects the properties of the 3D printed material produced by the Objet500 Connex and Fortus 400mc printers. We perform the tensile test on 3D printed ASTM standard geometries, and investigate for their Young’s Moduli, ultimate strengths, and percent maximum elongation in relation to the printing direction. It is discovered that the material printed by the Fortus printer, Polycarbonate is especially anisotropic, and the TangoPlus material printed by the Connex printer is conspicuously viscoelastic. Other factors of the printing process are investigated using the design of experiments method as a more efficient means to obtain the influence of printing spacing, printing orientation, and printing position on the material properties.

Wave-Driven Mass Loss in Supernova Progenitors
Hannah Klion
Mentors: Eliot Quataert, Christian Ott, and Rodrigo Fernández

There is evidence that some massive stars lose a significant fraction of their mass to episodic outbursts as opposed to continuous winds. In extreme cases, stars may eject 1-10 solar masses of their envelopes in the last year to decade of stellar evolution. When such a star undergoes a core-collapse supernova, the outgoing shock interacts with the circumstellar material, which could explain some of the most luminous supernovae observed. In one proposed mechanism for these outbursts, the super-Eddington fusion luminosity that occurs during the late stages of stellar evolution drives vigorous convection, which converts a fraction of the fusion luminosity into gravity waves that propagate through the star. The dissipation of these waves can unbind several solar masses from the stellar envelope. This project aims to develop and study models for understanding the outbursts from massive stars undergoing this process. We also use the 1-D stellar evolution code MESA star to study the effects of energy deposition in the envelope of the star during the late stages of its evolution.
Proton Transport in $\text{Cs}_1-x\text{Rb}_x\text{H}_2\text{PO}_4$ and $\text{Cs}_1-x\text{K}_x\text{H}_2\text{PO}_4$

Ian Koss  
Mentor: Sossina M. Haile

$\text{CsH}_2\text{PO}_4$ is an ionic compound notable for its high proton conductivity, which makes it suitable for use as an electrolyte in fuel cells. When rubidium or potassium are partially substituted for cesium to form compounds of the form $\text{Cs}_{1-x}\text{Rb}_x\text{H}_2\text{PO}_4$ or $\text{Cs}_{1-x}\text{K}_x\text{H}_2\text{PO}_4$, the material's conductivity is greatly reduced. Surprisingly, this decrease in conductivity is accompanied by a decrease in conduction activation energy, an anomaly which has no ready explanation. The current study is intended to provide a means of further investigating proton transport in these materials by comparing diffusivity with conductivity. In this study, the proton self-diffusivity is determined by electrical conductivity relaxation using the time-dependence of in situ conductivity measurements when switching between atmospheres of protonated and deuterated water vapor. Measurements of proton self-diffusivity and conductivity are used to evaluate the possibility of differences in correlation effects or charge carrier concentration between several $\text{Cs}_{1-x}(\text{Rb, K})_x\text{H}_2\text{PO}_4$-type compounds.

A Factor Model for Autoregressive Conditional Heteroskedasticity

Nikola B. Kovachki  
Mentor: Benjamin J. Gillen

Risk in security markets is always changing. Though market efficiency drives asset prices to follow a random walk at short time horizons, this dynamic volatility in asset prices is distinctly predictable. As such, effective risk management requires an econometric model that accommodates this dynamic volatility. We estimate a dynamic factor model based on Engle (1982)'s Autoregressive Conditional Heteroskedasticity (ARCH) approach. In particular, we estimate a benchmark factor model with ARCH effects in the volatility for the factor itself as well as in the idiosyncratic returns for individual securities. We fit the model to a set of daily returns on ETFs and evaluate the dynamic volatilities for each security and for an equal-weighted portfolio of securities. Using the fitted model, we evaluate the accuracy of conditional Value at Risk (VaR) measures for both individual securities and a dynamic portfolio strategy designed to maintain a constant VaR by investing in the equal-weighted portfolio of securities.

Phase Synchronization of Multiple Nonlinear Nanomechanical Oscillators

Lev Krayzman  
Mentors: Michael Roukes and Warren Fon

Synchronization is a ubiquitous phenomenon in nature, appearing in diverse areas ranging from physics and chemistry to biology and ecology, as well as in engineering. It is the adjustment of rhythms—specifically phase locking—between weakly interacting oscillators. Although there has been a relatively large amount of theoretical as well as observational work regarding the subject, it has not been extensively tested in experimental studies. The purpose of the current project is to demonstrate synchronization in multiple nonlinear nanomechanical self-sustained oscillators. Additionally, this project can provide some needed experimental insight regarding the process of synchronization, as well as open doors for future applications, such as new sensors and oscillators. This experiment employs nanomechanical resonators which are highly tunable and nonlinear. Weak interaction can be achieved via electronic signal routing between the oscillators in the array. Currently, a self-sustained oscillator is being constructed using a square membrane as the resonator. A key step is the construction of a reproducible modular oscillator, which can then be used to scale up. The project has goals of building arrays from as small as two to as many as one hundred devices.

Design and Simulation of a 270 GHz Polarimeter to Measure the Galactic Dust Foreground

Ankit Kumar  
Mentors: Jamie Bock and Roger O'Brient

Foreground galactic dust can contaminate the observing field of Cosmic Microwave Background polarimeters aiming to detect the faint B-mode CMB polarization. In order to characterize this foreground, a new higher frequency 270 GHz focal plane will be deployed to the Amundsen Scott South Pole Station this winter. The design process for this new focal plane has modified existing work. A redesign of the microstrip feed network that services the slot antennas accommodates higher frequency components. Simulations of this network in HFSS confirm a desirable absence in crosstalk. A new band defining filter has been designed in Sonnet to reduce the fractional bandwidth of the antenna response by an approximate 25 percent. This project has also aided the ongoing testing of the BICEP 3 focal plane, as well as other experimental focal plane designs.
Updated Model for a Lymphomyeloid Developmental Switch Controlled by PU.1 and Notch Signaling
Neil A. Kumar
Mentors: Ellen Rothenberg and Hao Yuan Kueh

Prior to committing to the T-cell fate, thymic hematopoietic stem cells may differentiate into a number of other cell fates, such as NK cells, erythrocytes, myeloid cells, and many others. However, as these HSCs progress along the T-cell differentiation pathway, alternate cell fates are silenced by various environmental signals and transcription factors. This project specifically studies the effects of two opposing, intracellular signals (PU.1 expression and Notch signaling), and uses non-linear dynamics to model the mechanisms behind why these HSCs tend towards one of two potentials: T lymphocytes and myeloid cells. By defining the threshold of commitment to a potential as a lymphomyeloid "switch", this qualitative model attempts to characterize this switch as a function of Notch, PU.1, and a number of intermediate transcription factors in order to define the biology behind this differentiation pathway. This model also advances the current efforts of the Rothenberg lab in that it seeks to isolate the direct influences from the indirect of Notch, PU.1, and an intermediary, Gata3, in order to clarify the mechanisms at work in this system.

Optimization of Single-Cell Barcode Chip Fabrication
Snigdha Kumar
Mentors: James Heath and Jungwoo Kim

Currently, cancer patients are often treated with signal transduction pathway inhibitors to prevent the proliferation of tumor cells. Such treatments have a low success rate since oncogenes operate using multiple pathways rather than just one pathway. Instead of studying pathways in isolation, members of the Heath Lab have taken a different approach. They have constructed the single-cell barcode chip (SCBC), which isolates individual cells within microchambers that contain antibody arrays, which detect panels of protein. Using this tool, researchers can analyze multiple pathways, identify protein-protein interactions, and gain quantitative insight on cell fluctuation patterns. The SCBC is a two-layer microfluidic network, consisting of a DNA barcode microarray glass slide and a layer of polydimethylsiloxane (PDMS). Samples are loaded into the microfluidic device, and proteins are tagged using biotinylated antibodies and fluorophore-labeled streptavidin, leaving a barcode pattern on the slide. Researchers of the Heath lab have tested the efficacy of their clinical therapies by using SCBCs to test the change in protein-protein interactions in their samples. Although the single-cell barcode chip has been successfully used, its structural parameters and procedures are not optimal. To enhance the single-cell barcode chip, we have changed several procedural times, developed new methods for how DNA samples are loaded, and increased the number of silicon molds available to pattern our PDMS.

Metallic Nanoparticles for Hydrogen Electro-Oxidation on Samarium-Doped Ceria-Based Anodes for Solid Oxide Fuel Cells
Netgie Laguerre
Mentors: Sossina Haile and Anu Khan

Fuel cells offer superior efficiency in terms of energy conversion as well as low levels of harmful emissions such as greenhouse gases. Solid oxide fuel cells(SOFCs) in particular, promote improved catalysis at high temperature, but at the high cost of requiring materials able to withstand 800ºC-1200ºC. To enable the commercial use of SOFCs, we aim to improve catalysis at lower temperatures, 500ºC-600ºC. As a result of the rate limiting step for SOFCs being the electrode surface reactions, these regions are one of our primary focuses for optimizing the performance of SOFC via catalysis. In this work, we sputter deposited films and then annealed nickel and platinum films on yttria-stabilized zirconia substrates. SEM was used to analyze the morphology of resulting films. Next, nanoparticles were deposited using this method on samarium-doped ceria(SDC) symmetric cells and characterized using electrical impedance spectroscopy(EIS) to assess the effect of metal particles on surface reaction resistance. By characterizing the Ni and then Pt nanoparticles formed by annealing sputter-deposited metal films, we sought to scale the distinct areas of surface interfaces that result from nanoparticles, Ni and eventually Pt, coated electrode surfaces, which in our case was the surface of SDC, to the measured decrease in impedance.
Perception of Occlusion by the Mouse Visual System
Jessica Lam
Mentors: Doris Tsao and Tomo Sato

The mouse brain constantly performs the complicated task of invariant recognition, or identifying objects despite variations in their appearance. In particular, the visual system can quickly recognize an object even if it is partially occluded by other objects. This ability is vital since we live in a world where objects have 3D relations with one another and usually appear occluded. In order to perceive occlusion, the visual system must correctly assign edges to objects and stitch together the disconnected pieces that are produced by the occlusion. However, the neural mechanism behind this ability is still unknown. In this study, we present occluded stimuli to mice and use a behavioral task to assess their ability to perceive these occlusions. Mice were trained to do a foraging task in which various stimuli moved across the screen as they ran on a wheel. The task was to stop only for the target stimulus. After the mice are trained on the basic, un-occluded shapes, we determine whether they recognize more complex, occluded stimuli. Once the behavior tests are conducted, two-photon imaging will be used during the task to determine the neural mechanisms behind this ability to perceive occluded objects.

Investigating the Relativistic Jet Phenomenon in Radio Galaxies With NuSTAR Data Analysis
Jake P. Larson
Mentors: Fiona Harrison, Elizabeth Rivers, and Dominic Walton

Radio galaxies, also referred to as radio-loud active galactic nuclei, are a small portion of active galactic nuclei in our observable universe. They emit radio waves from large, protruding structures that they form called relativistic jets. Using the Nuclear Spectroscopic Telescope Array, or NuSTAR, we can observe these radio galaxies at much higher energy bands than previously possible, especially in the high energy X-ray range up to 79keV. Raw data collected from the telescope is then processed using XSPEC spectral analysis software to model the data. The parameters of these models are then compared to values obtained from radio quiet AGN, in order to possibly discover which aspects of these radio loud galaxies could possibly be linked to relativistic jet production. For this investigation, the radio galaxies analyzed were 3C120, 3C382, and 3C390.3. Moving forward, a larger sample of radio galaxies should be modelled to search for consistent trends amongst all radio-loud active galactic nuclei.

Is There a Common Clock Across the Senses?: Investigating Information Transfer Across Sensory Modalities
Elizabeth Lawler
Mentors: Shin Shimojo and Noelle Stiles

This project studies the brain's encoding of time across the senses. In particular, we investigate the crossmodal relationship between visual and auditory frequency perception by recreating the results of a discovered crossmodal aftereffect. In this aftereffect, repeated exposure to a pulsed adaptor stimulus (a beep) leads to changes in the perception of the rate of a following visual stimuli (a flash), where a relatively fast adaptor causes later stimuli to be perceived as slower, and a relatively slow adaptor does the reverse. This effect occurs even when the adaptor and test stimuli are different modalities (auditory and visual). After subjects were exposed to 5 Hz adaptors, they will perceive subsequent test stimuli centered around 4 Hz to be slower than before; the reverse occurred after exposure to 3 Hz adaptors. A new setup (an Arduino board), that is more portable than the device previously used was created to re-test this crossmodal effect. The Arduinos portability will allow later testing of the neural correlates of the aftereffect with EEG. In addition to the recreating of a previous effect, a new experiment was attempted where subjects were tested on sine images of different frequencies after exposure to beep adaptation stimuli. This new experiment investigated the transfer of adaptation from temporal rate (beeps) to spatial rate (sine images) via crossmodal correspondence, specifically the possibility for the adaptation in time perception to be transferred to a spatial frequency task.

Electrophysiology of Surface Representation in Mice
Minh Nhat Le
Mentors: Doris Tsao and Tomo Sato

Surface representation, the visual process of assigning surfaces to different objects, is crucial for the perception of occlusion. Due to this process, we do not perceive occluded objects as individual fragments, but as continuous surfaces that connect with each other behind the occluder. An experimental scheme involving a virtual foraging task was designed to test whether surface representation is present in mice, and if mice can recognize objects partially hidden behind an occluder. A functional setup using this scheme has been built and modified in order to improve the performance of the mice on the foraging task. Good performance of the mice on this task will be a basis for future electrophysiological experiments, which can reveal the neural circuits involved in surface representation.
Time-Series Analysis of Classification Features of Light-Curves From the Catalina Real-Time Transient Survey
Chengyi Lee
Mentors: Ashish Mahabal, S. G. Djorgovski, and Ciro Donalek

Automated classification of astronomical objects act as useful filters to allow for researchers to focus valuable resources on rarer, less-understood objects. To aid the classification the 500 million astronomical objects covered by the Catalina Real-Time Transient Survey (CRTS), several features are calculated from the light-curves of each astronomical object. This paper aims to help increase the efficiency of telescope resources by studying the variation of different features with respect to the number and sampling of points in the light-curve of the object as well as its classification. In this paper, we will discuss the robustness and expected variation of the each of the 22 features as the number of measurements decreased, as well as how they differ by the classification of the light-curve. We will also explore possible new time-dependent features that may aid in transient classification.

Reversible Dynamics for the Bak-Sneppen Model
Ga Yeong (Grace) Lee
Mentor: Tom Alberts

The Bak-Sneppen model of biological evolution aims to study self-organised critical behaviour in populations with natural selection and spatial interactions. In the model, N species arranged on a circle are each given a fitness parameter ranging from 0 to 1 according to a uniform random distribution. The species with the minimum fitness parameter as well as its two neighbours are replaced with independent fitness parameters, and the process repeats. Despite its easy definition, the Bak-Sneppen model has withstood most attempts at mathematical analysis in the past. In particular there is very little understanding of the stationary distribution for large values of N. In this project we examine the case where N=4, and attempt to analyse the stationary distribution via the previously unexplored reversible dynamics.

Razor Analysis of Dileptonic Top Quark Pair Events
Hyunseok Lee
Mentors: Harvey B. Newman, Maria Spiropulu, and Dustin Anderson

Searches for supersymmetry (SUSY) and other proposed extensions of the standard model (SM) have recently benefited from the development of so-called “razor” kinematic variables, quantities that combine information about the angular shape and mass scale of events to discriminate strongly between SUSY-like and SM-like signals in data. We aim to measure the distribution of the razor variables in dileptonic top + jets processes and compare with Monte Carlo predictions. Top pair production is predicted by SM but it resembles a SUSY signal, and a detailed measurement of this background process for SUSY searches would help the search for new physics by improving signal discrimination. Examining the process at extremes such as high jet multiplicity and comparing with Monte Carlo data would also provide a test of high-order predictions in quantum chromodynamics.

Efficient Quantum State Tomography Using the Multi-Scale Entanglement Renormalization Ansatz
Jong Yeon Lee
Mentors: John Preskill and Olivier Landon-Cardinal

We further investigate a recently introduced efficient quantum state reconstruction procedure targeted to states well approximated by the multi-scale entanglement renormalization ansatz (MERA). First, we introduce an improved optimization scheme that can be easily generalized for MERA states with larger bond dimension. Second, we provide a detailed analysis of the error propagation and quantify how it affects the distance between the experimental state and the reconstructed state. Third, we explain how to bound this distance using local data, providing an efficient scalable certification method. Fourth, we examine the performance of MERA tomography on the ground states of several 1D critical models.

Flee or Freeze? Causes of Differing Defensive Behavior in Mice
Margaret Lee
Mentors: Markus Meister and Melis Yilmaz

In nature, mice react defensively when faced with a predator in order to maximize their chances of survival. The Meister Lab simulates the presence of an aerial predator with a black expanding disc in the upper visual field. Mice react to this stimulus by either fleeing to a nest or freezing in place. What makes the animal decide between these two options? We investigate the role of an escape route (such as a nest) in this decision. We also develop a program for detecting the position of the mouse and changing the position of the visual stimulus automatically, which allows us to easily test many experimental conditions.
Determining the Signaling Pathway That Leads to Selective Binding of Cdc48 to Its Adaptors Npl4-Ufd1
SangAh Lee
Mentors: Raymond J. Deshaies, Rati Verma, and Robert Oania

Clearing naturally occurring misfolded proteins in cells by protein degradation is important since they aggregate and sequester essential cellular components, thereby predisposing the organism to neurodegenerative diseases such as Alzheimer's and ALS. An evolutionary conserved small protein ubiquitin (Ub) is involved in tagging toxic proteins by covalent modification, which results in their degradation by the 26S proteasome. Ub-tagged protein is disassembled from other bound protein partners prior to degradation by ATPases of the proteasome or by another ATPase called p97/VCP in mammalian cells or Cdc48 in budding yeast. The activity of p97/VCP or Cdc48 is regulated by several adaptors that also have the ability to recognize and bind polyUb chains. My experimental system is the budding yeast *S. cerevisiae*. The focus of my project is Cdc48 and how its activity is regulated by its adaptors Ufd1-Npl4 and Ubx1. The former complex functions in endoplasmic-reticulum-associated degradation (ERAD), whereas the Cdc48-Ubx1 complex triggers a different protein degradation pathway. It has been reported that Cdc48 is covalently modified with the small ubiquitin-like modifier SUMO and this modification is enhanced by ER stress. Our hypothesis is that sumoylation enhances the binding of Cdc48 to Ufd1-Npl4 versus Ubx1, and that this is important for ERAD.

Box Office Prophecy: Information Aggregation in Motion Picture Revenue Forecasting
Yoon Lee
Mentors: Charles Plott and Ben Gillen

Motion picture industry is an area of notorious uncertainty. Box Office Prophecy, however, is an experiment designed to explore the predictability of box office performance and assess the nature of information regarding the potential success of theatrically released films. Inspired by the fact that a properly designed information aggregation mechanism can collect and aggregate the information held in the form of the subjective intuitions from a disperse collection of individuals, the research involves data that were collected through a process designed and tested in the laboratory using experimental methods to quantize beliefs and test for information content. Film students in Australia engaged in a pari-mutuel betting exercise about the box office revenues of upcoming films. We organize a mass of somewhat disorganized data and evaluate the performance of an information aggregation mechanism implemented in the project. This paper finds that accurate predictions can be made using an information aggregation with a pari-mutuel betting system.

Multiplexed Electrochemical Sensing on High Density Neural Probes
Justin Leong
Mentors: Michael Roukes and Jessica Arlett

State-of-the-art neural probes to monitor the levels of dopamine and other neuromodulators in the brains of small animals lack the spatial precision necessary to measure variations within the cortical and hippocampal layers, which are ~100 micron thick. However, technology for in vivo multiplexed neural probes in electrophysiology can measure 1000 sites simultaneously in the brains of small animals, which is the spatial resolution necessary in electrochemical sensors for measuring variations within the cortical and hippocampal layers. We will develop highly multiplexed, multi-site neural nanoprobes for electrochemical sensing with spatial and temporal precision similar to that of the cutting-edge electrophysiology probes using the same fabrication techniques. We have designed microfluidic channels to test these probes. Continued voltammetry experimentation on larger electrochemical probes will pave the way for the validation of the nanoprobes at spatial resolutions of ~100 microns and ~1 second temporal precision.

Relativistic Hydrodynamics With Fourier Pseudo-Spectral Methods
Massimiliano Leoni
Mentors: David Radice and Christian Ott

The equations of Relativistic Hydrodynamics are of central importance in the study of a variety of phenomena, ranging from core collapse supernovae to binary neutron stars mergers, from black hole formation to heavy-ion collision. Traditional numerical solution methods are not very accurate, while spectral methods are known to be very accurate, but require a stabilization technique. In this work we investigate the numerical solution of the relativistic Euler equation by means of Fourier pseudo-spectral methods, possibly combined with stabilization techniques, especially various flavors of artificial viscosity. We present the results of various tests we performed, discussing advantages and drawbacks.
A Model System for Artificial Intercellular Signaling in E. coli
Bianca Lepe
Mentors: Richard M. Murray, Anu Thubagere, and Victoria Hsiao

Synthetic biology focuses on the construction of artificial gene circuits within host cells in a bottom-up fashion where pieces of DNA are put together to create a more complex system. The systems can be individually tailored to exhibit specific behaviors in a variety of cells. The 2014 Caltech iGEM team’s goal is to create a model system to manufacture a biological compound and regulate its concentration outside the cell. The team is testing three two-component systems - FsrABC, LamBCDA, and AgrBCDA - to see which system works best at achieving the goal within E.coli cells. For our subgroup, the histidine kinases and response regulators of the FsrABC and LamBCDA were tested. The plasmids were constructed using traditional cloning techniques including polymerase chain reaction (PCR) and Gibson cloning. Then, they are tested for functionality via GFP expression on a plate reader. Further testing will be done with the ligand export system subgroup to ensure that the ligands are binding appropriately to the corresponding histidine kinase receptors.

Tropical Geometric Properties of Ultradiscrete QRT Maps
Eileen Li
Mentor: Christopher Ormerod

Ultradiscrete QRT maps are automorphisms of tropical elliptic surfaces that can be described in terms of a tropical analog of the group operation on elliptic curves. We develop a theory of linear systems on these surfaces, namely we give a description of the Picard lattice by determining the cohomology of the surface via a combinatorial argument, and we show the QRT map acts linearly on the Picard lattice.

Augmentation and Development of ClassLess: The Young Stellar Object Database
Jessica Li
Mentors: Lynne Hillenbrand and Nairn Baliber

ClassLess was designed by my mentors in order to support and facilitate further research on young stellar objects (YSOs). YSOs provide a plethora of data across a broad spectrum of wavelengths, which astronomers and astrophysicists can analyze to study the details of stellar and planetary evolution. As research interest in YSOs grows, so too does the need to organize and manage such information. Rather than being inconveniently dispersed among independent papers, surveys, and catalogs, YSO data will be intuitively searchable through ClassLess. A procedure for comprehensively finding and uploading data was also created. Young star cluster L1641 was chosen to test the functionality and efficiency of the methods. As data about YSOs in L1641 were gathered, processed, and uploaded, oversights, bugs and other inefficiencies within the data upload procedure were encountered and addressed. Modifications have been made to the procedure to improve the data gathering process, so that ClassLess may soon have active scientific usage.

Estimating Earthquake Magnitudes Using Machine Learning in the Community Seismic Network
Kevin Li
Mentor: Julian Bunn

We aim to develop a system that accurately estimates the magnitude of an earthquake seconds after the initial ground shaking based off incoming accelerometer readings from the Community Seismic Network (CSN). The CSN is an earthquake detection network that utilizes the ground motion measuring capabilities of inexpensive sensors distributed across the Pasadena area. The CSN can currently generate maps of peak ground acceleration for damage assessment before accurate measurements of the earthquake epicenter or magnitude are known. However, our damage assessment capabilities would improve greatly if we also had an immediate estimation of the magnitude. Because the CSN sensors sacrifice fine measurement precision for low-cost efficiency, the development of a magnitude estimation system faces the challenge of handling particularly noisy data. Our study tries to overcome this challenge from a machine learning perspective, using the repertoire of data the CSN accumulated over the past years as a basis for developing and training an estimation algorithm. While we show that the raw CSN data cannot actually provide sufficient training for supervised learning, we also show that the data can be filtered into more workable forms through unsupervised clustering. Attributes of the filtered data show promise for an effective magnitude estimation model.
**In vivo Study of Corneal Re-Epithelialization Using an Electrospun Nanofibrous Scaffold**
Lauren Li  
*Mentors: Julia A. Kornfield and Amy Fu*

The cornea can only fulfill its role as the primary refractive element of the eye by retaining a specific structure necessary for transparency. In healthy cornea, this structure is made possible through the uniform diameter and spacing of collagen fibrils within its stromal layer. However, corneal trauma triggers keratocytes to differentiate into fibroblasts and myofibroblasts. Blindness results as these cells synthesize collagen fibrils which are dissimilar to that of the native cornea in both fiber type and organization. To solve this problem, the Kornfield group has developed a composite scaffold with electrospun nanofibers embedded within a photo-polymerized hydrogel matrix. By characterizing this scaffold *in vitro*, it has been shown that the scaffold is well-suited for corneal applications due to its transparency, and ability to recruit corneal cells and modulate their repair phenotype. Here, we treat mice that have undergone epithelial debridement on their corneas with either our composite scaffold or with phosphate buffered saline (PBS) as a control. The wound area is then monitored through fluorescein staining, and the corneas are prepared for histology following wound closure. Through these *in vivo* experiments, we aim to determine if our scaffolds are biocompatible and effective when applied to corneal epithelial wounds.

**Classifying Homogeneous Games**
David Lichko  
*Mentor: Michael Aschbacher*

It is natural to ask how symmetric a voting system with a given number of voters can be. A homogeneous game is a voting system with two candidates where the automorphism group is transitive on the voters. This imposes a condition on the Sylow 2-subgroups of the groups called odd-transitivity. These games and their groups have been studied previously, and for almost all even numbers of voters it is still unknown whether a game exists. Under the assumption that the group is also primitive, we examine the combinatorial properties of the games with a given number of players and the structures of the possible symmetry groups.

**Band Edge Engineering by Functionalizing Silicon Surfaces**
Allison Lim  
*Mentors: Nathan S. Lewis and Noah Plymale*

Even though silicon is used intensively in solar cells, it is not optimized for the generation of hydrogen fuel. Two issues arise when attempting hydrogen and oxygen evolution with silicon. While the Fermi level of p-Si enables it to act as a photocathode for proton reduction, p-Si oxidizes when placed in water and is inefficient. One proposed solution is functionalizing p-Si surfaces; two-step chlorination/alkylation methods allows functionalization of Si surfaces with alkyl groups, like methyl (CH₃), to protect the surface from oxidation. However, the dipole moment of CH₃ makes p-Si thermodynamically unfavorable for the formation of hydrogen from a photocathode. We functionalized p-Si(111) with 4-fluorobenzyl groups (BzF) to manipulate the band edges of p-Si for hydrogen evolution. Similarly, the band edges of n-Si could be engineered so n-Si could be used as a photoanode for oxygen evolution. This second issue arises because the silicon’s band gap (1.12 eV) is too small to span the hydrogen and oxygen evolution potentials (1.23 eV). BzF was also used to functionalize n-Si surfaces to prove we could manipulate bands on surfaces backfilled with methyl groups. Surfaces were characterized by performing electrochemical measurements with the surface in contact with mercury, XPS, AFM, and IR spectroscopy.

**Geometric Representations of Last Passage Percolation Models**
Bryant Lin  
*Mentor: Tom Alberts*

Last passage percolation is a model in statistical mechanics that is simple and elegant yet centrally important to many other fields of study. In the problem, non-negative i.i.d. random weights are attached to the vertices of graph, allowing the length of a nearest-neighbor path to be the sum of the weights in the path. We are interested in the statistics of the *path ordering* of the lengths in descending order. In particular, what is the probability of each path ordering occurring, and what are the expected lengths of the paths? We introduce the geometric approach of describing the set of weights that satisfies a path ordering. The V-representation of the region is determined iteratively as a result of the double description method. When the graph structure is an integer lattice \(Z^d\), we are also able to describe a large portion of the orderings with zero probability. For small lattices and binary tree structures, computational results are available and confirm theoretical approaches.
Glucose Sensing Based on Surface-Enhanced Raman Spectroscopy
Chih Wen Lin
Mentors: Hyuck Choo and Yonghwi Kim

Monitoring the glucose level is an important clinical management method for diabetes mellitus. Surface-Enhanced Raman Spectroscopy (SERS) is possible to provide a non-invasive and more convenient way to detect glucose level. This project experiments on glucose detection on SERS substrate with decanethiol (DT) and a mixture of decanethiol and mercaptohexanol (MH) linker molecule. Glucose water solutions peaks at 77cm⁻¹, 847 cm⁻¹, 916 cm⁻¹, 1063 cm⁻¹ and 1123 cm⁻¹. Spectra with DT only partition layer do not have apparent glucose peaks. Spectra DT/MH moisture partition layer show clear glucose signal at 912 cm⁻¹, 1123 cm⁻¹ and 1371 cm⁻¹. Further work will focus on quantitative detection based on the multi peak with glucose in water solution and glucose on SERS substrate.

Development of a Scalable and Efficient Computational Framework for the Structure Prediction of G Protein-Coupled Receptors
Christina Lin
Mentor: Ravinder Abrol

G protein-coupled receptors (GPCRs) are a family of membrane proteins that control cellular response. Each GPCR exists in multiple conformations, differing in helix tilts and rotations. Identification and analysis of the lowest-energy conformations of GPCRs are essential to understanding the proteins’ function. The BiHelix and SuperBiHelix methods are able to completely sample the conformational space available to GPCRs in the lipid bilayer environment, which spans from 35 million to 10 trillion possible conformations per starting structure. The existing program runs on a fixed number of 12 processors by assigning each helix pair’s conformational sampling to one processor, as the first attempt at this parallel sampling problem. The program will be rewritten using two different parallelization strategies to be able to utilize any number of available processors, based on conformations rather than helix pairs. One strategy implements a Python language library called Jug, and the other is written from scratch. The better parallelization strategy will be chosen for the final implementation to facilitate an efficient conformational sampling of GPCRs, reducing the time needed for structure prediction by at least half.

Measurement of the Thermal Conductivity of Aerogel Using Time-Domain Thermoreflectance
Chloe Ling
Mentors: Austin Minnich and Nicholas Dou

Aerogel is a synthetic material created from replacing the liquid component of a gel with a gas. It is known for its spectacular properties, which make it an excellent material choice for many applications, such as engineering spacecraft. As a result, much can be gained by studying its properties. This work focuses on studying the low thermal conductivity of aerogel using time-domain thermoreflectance (TDTR). In this method, a pulsed pump laser heats the sample and a pulsed probe laser measures the reflectance, and thus the temperature, shortly after. By measuring the temperature with varying delay times between pump and probe, it is possible to determine the conductivity of the sample. TDTR has the potential to be an extremely accurate optical technique to measure low conductivity materials, since it would be able to maintain low and steady power from the lasers. This research focuses on building and aligning a TDTR apparatus in the Minnich lab, calibrating it with materials with known low conductivity, and finally measuring aerogel's conductivity. From this, we hope to better understand the properties of aerogel as well as optimize and perfect a methodology that can be used in future thermal measurements.

Searching for Anomalies in the Lengths of Transmembrane Alpha Helices
Amarise Little
Mentors: William Clemons and Axel Müller

Proteins in the transmembrane region coil into alpha helices, and cross the cell membrane in a perpendicular manner. Identifying anomalies, such as re-entrant loops or helices that cross the membrane diagonally, can be helpful in determining the topology of a certain protein. The objective was to find, among transmembrane proteins, these helices of anomalous lengths. Using a database of proteins with transmembrane regions, lengths of all transmembrane alpha helices were calculated. This was done by using the coordinates of the predicted membrane region in conjunction with the transformed coordinates of the atoms associated with a certain protein. This helped differentiate the transmembrane atoms from the atoms outside of the membrane. Lengths of chains inside of the membrane were obtained by counting the number of residues in a contiguous chain of atoms. After calculating the lengths of chains, it is seen that the lengths, from about 1800 proteins, results in a normalized distribution, with lengths above the 95th percentile showing anomalies in their transmembrane structures.
Engineering Synthetic HEGs for Species Eradication Using CRISPR
Albert Liu
Mentors: Bruce Hay and Omar Akbari

Some pest species such as *Aedes aegypti* are vectors for human disease, and also can be eliminated from the environment without incurring a significant ecological impact. Thus, complete removal of the pest species becomes a positive and desired outcome. Homing endonucleases (HEGs) are selfish genetic elements that cut and copy themselves into chromosomes they are absent from. Copying is achieved by taking advantage of the organism’s natural DNA repair machinery, and consequently HEGs are able to drive and fixate within populations. Using CRISPR we were able to create synthetic HEGs that home into either yellow-g or VM genes in *Drosophila melanogaster*, both of which are theorized to be necessary for female fertility. As the HEG spreads throughout the population, all homozygous females should be sterile, eventually resulting in a population crash once all remaining females are sterile. So far we have results demonstrating ectopic homing of the constructs. Consequent experiments include confirmation of homozygous female sterility, quantification of the CRISPR/Cas-9 mediated cutting/homing rates, and attempted population crash experiments. As CRISPR is universal across species, once a population crash in *Drosophila melanogaster* is confirmed, transferring the system to pest species of interest should pose little difficulty.

Fabrication of Inductor-LED Array for Spatial Imaging of Magnetic Field
Eric Liu
Mentors: Paul M. Bellan and Xiang Zhai

In plasma physics, the spatial distribution of the magnetic field in and around the plasma is of great importance, since it provides the current distribution of the plasma as well as how the plasma will tend to evolve through the Lorentz force. This project is focused on the design and fabrication of printed circuit board (PCB) devices with a rectangular array of inductor-LED circuits, to obtain a simple but more spatially complete profile of the magnetic field. The arrays will then be photographed with a fast camera (Imacon) during plasma events. Each circuit measures the change in the perpendicular component of the local magnetic field over time, with a relatively low cost per data channel and better overall spatial resolution as compared to other probes with similar functions. We are currently completing fabrication of the prototype arrays, which have all of its inductors in the same spatial orientation. The next step is the design of a stand for the devices within the vacuum chamber and a shield to block out the plasma light; subsequent work will involve the fabrication of arrays with inductors in two different spatial orientations.

Structural Properties of Three-Dimensional Kagome Structures on the Nanoscale
Kimberly Liu
Mentors: Julia Greer and Lucas Meza

Building on past work with strong and lightweight nanoscale trusses, this project seeks to improve on the strength and stiffness of previously tested structures with the three-dimensional Kagome lattice geometry. Trusses were fabricated with two-photon lithography and exposed with focused ion beam milling in a SEM environment. Oxygen plasma was then used to etch away the polymer, resulting in hollow nanotrusses that were fit for testing. These structures were compressed by a nano-indenter to collect stress and strain data, which can calculate Young’s modulus and strength. Relative densities of the Kagome structure were also calculated, and used to characterize the Young’s modulus and strength with respect to density. In addition, matrix methods from linear algebra were used to evaluate the Kagome structure and identify potential states of self-stress and zero-energy states, or collapse mechanisms. This analysis will help predict how the nanotrusses behave under compression. The behavior of this geometry give insight into the overall effects of structure on strength and damage tolerance for a given density.

Surface Modification of Glaucoma Valves
Weitong Liu
Mentors: Julia R. Greer and Alessandro Maggi

Several valves have been fabricated to treat glaucoma, which is a harmful disease caused by an increase in fluid pressure in the eye that eventually leads to blindness. Due to the host’s immune response, none of previously fabricated valves work over long periods of time as a consequence of layers of cells coating the valve hence blocking the valve’s drainage system and impairing the functioning of it. Our aim is to modify the PDMS’s surface so that the cells will have minimum amounts of flat surface to adhere to. To achieve this, we fabricate a jagged nanostructured surface by spin coating a nanoparticle mask and by wettability or increasing the aspect ratio of it. We also try to functionalize PEG on flat PDMS surface. Finally, we test if there is a change in its ability of cell adhesion.
Computational Complexity of 3-Manifold Invariants
Catharine Wing Kwan Lo
Mentors: John Preskill and Gorjan Alagic

The Witten-Reshetikhin-Turaev invariant (WRT invariant) gives the same value when two 3-manifolds are homeomorphic. In this project, we will show that approximating the WRT invariant is \#P-hard. The main problem was solved by showing how to map a Boolean formula to a manifold so that the WRT invariant of the manifold counts the number of solutions to the formula. Counting the number of solutions to a formula is a well-known \#P-hard problem. This mapping makes crucial use of concepts from quantum computation. Following ideas of Freedman, we will then use the aforementioned fact to prove the existence of manifold representations that cannot be significantly simplified. This result is conditioned on a widely accepted conjecture in computational complexity.

Novel Ferromagnetic Glasses With High Magnetic Performance and Bulk Processability for Power Electronics Applications: Correlating Magnetic Performance to Alloy Composition
Peter Lommen
Mentors: William Johnson and Michael Floyd

Hysteresis losses are a great source of energy loss in our electric power system; these losses may be reduced by utilizing magnetic core materials with “soft” magnetic properties, i.e., low hysteresis materials, which can quickly change their magnetic polarization, while still attaining a high overall field strength. The existence of magnetic domains in crystalline magnetic materials is responsible for the slow reversal of a magnetic polarization. The Johnson lab specializes in the development of bulk metallic glasses: metal alloys devoid of a crystalline structure, by virtue of their composition and manufacturing process. This project focuses on the development of alloys, primarily composed of iron, nickel, cobalt, and nonmetallic elements, which have a robust glass-forming ability and soft magnetization. The composition of test-alloys were previously determined by a “biased random walk” algorithm to optimize glass-forming ability and peak magnetization. We then produce amorphous samples of each alloy via injection casting, and then test the magnetic properties with an AC/DC hysteresisgraph.

Determining the Effects of Pulsating Charging and Temperature on Dendrite Growth in Lithium Metal Batteries
Mark Lorden
Mentors: Michael Hoffmann and Asghar Aryanfar

Dendrite growth in lithium metal batteries can lead to short circuiting. In order to find methods of suppressing dendrite growth, an electrolyte solution which is known to promote dendrite growth (lithium perchlorate) was used for these experiments. Two main methods were studied in terms of success at dendrite suppression: charging/discharging pulsation and temperature. Though there is no conclusive data yet, the high temperature experiments have shown reductions in the size of the dendrite formation. More experiments of the same nature are to be run to collect data to analyze.

In-Situ Lithiation of 3D Nano-Lattice Electrodes for Li-Ion Batteries
Alexander X. Lozano
Mentors: Julia R. Greer and Wendy Gu

Si based anodes for Li-Ion cells are a promising candidate for increasing the energy density batteries as they have a theoretical capacity of 4200 mAh/g, almost ten times the storage capacity of the currently used graphite anode. That being said, Si expands up to 400% upon lithiation causing cracking and a loss of electrical contact ultimately leading to a low cycle life. To solve this problem, the Si has been incorporated into a nano-lattice configuration that can avoid strain by expanding locally at designed structural points rather than globally. The nano-lattices were fabricated and tested in-situ inside an SEM so that their expansion during cycling can be observed. Electrochemical testing indicates that the Si nano-lattices are able to perform as a Li-ion battery anode and efforts are underway to ascertain their gravimetric and volumetric charge density.
Development of a Dielectric Barrier Discharge Ionization Imaging Mass Spectrometer (DBDI-IMS)
Andrew Lucas
Mentors: J. L. Beauchamp, Josh Wiley, Daniel Thomas, and Kevin Barraza

Imaging mass spectrometry uses mass spectrometric techniques to map the spatial distribution and abundance of specific chemicals on a surface such as a tissue sample. Our approach employs a dielectric barrier discharge ionization (DBDI) source to implement plasma-based ionization of surface analytes at atmospheric pressure for mass spectrometric analysis. Chemical analysis is performed using a Thermo Scientific LTQ-XL mass spectrometer equipped with an atmospheric pressure inlet for ion sampling. When combined with an x-y translation stage, this experimental methodology can be used to scan a surface and develop a two-dimensional image showing the spatial distribution and abundance of analytes on the surface. A key goal in our effort has been to achieve high spatial resolution (small pixel size) while maintaining reasonable sensitivity for detection of targeted analytes. Several designs for the ionization sources and ion sampling interface to the mass spectrometer were tested to determine spatial resolution and detection sensitivity. The implementation of a system for DBDI-IMS, the factors that determine spatial resolution, and initial results are presented. Spatial resolution of 2 mm has been achieved, with the potential for significantly smaller pixel size employing an improved source and collector design.

Planets From the Mergers of White Dwarfs
Michaelangelo Valentino Lucas
Mentors: Anthony L. Piro and Christian Ott

Past efforts to detect planets orbiting other stars have led to the discovery of thousands of such extra-solar planets that can vary greatly from our own. One relatively unexplored and novel process that may result in such planets is the merger of two white dwarfs, dead stars that are left over from stars like our sun. White dwarfs in tight binaries merge due to the emission of gravitational waves which remove angular momentum and energy from the binary orbit. After the merging process, the matter from the debris disk is accreted onto the central remnant causing an increase in the disk’s radius to conserve angular momentum. Approximating the disk as a ring, time dependent differential equations describing the mass and radius evolution were obtained and solved numerically. In our preliminary work, we found that planets with roughly the mass of Jupiter may form after about after $10^5$ years. These results will inform future theoretical work towards a more complete model of the disk evolution and motivate future observational searches for habitable extra-solar planets around white dwarfs.

Glutamine Synthetase as a Contrast Agent for Magnetic Resonance Imaging of ATP
Alison Lui
Mentors: Mikhail G. Shapiro and Arnab Mukherjee

Magnetic Resonance Imaging (MRI) has become a staple of medical diagnosis. By selectively enhancing and reducing the magnetic susceptibility of specific chemicals, newly developed organo-metallic contrast agents have the potential to greatly increase the functionality of current methods of MR imaging and push the boundaries of this already well-established technology. Glutamine synthetase (GS), a magnesium-containing protein that normally reacts with adenosine triphosphate (ATP) in mammals, was found to act as a sensor for ATP under MRI if its active sites were disabled. Our experiments tested the range of this new protein’s (GSATP) capabilities by varying the concentrations of applied manganese and ATP both in solution and when the protein was expressed by mammalian cells. While we were unable to define a quantitatively consistent signal change over multiple scans, we were able to visualize a significant amount of contrast in MRI signal attributable to GSATP expression that did vary with ATP concentration. Moving forward, we plan to continue work with GSATP using different MRI pulse sequences to test its imaging capabilities in vivo.

Optimizing Ad vected Tracer Transportation in GEOS-Chem
Lilly Luo
Mentors: Paul Wennberg and Rebecca Schwantes

GEOS-Chem is a 3-D transport model used to study chemical reactions in the Earth’s atmosphere. The program divides the atmosphere into thousands of boxes based on latitude, longitude, and altitude. Ad vected tracers are chemical species chosen, usually based on their lifetime or reactivity, to be transported between boxes during a simulation. The process for determining the number and type of chemical species to advect is somewhat arbitrary in GEOS-Chem. Transporting too few tracers can lead to imprecise results while transporting too many tracers can lead to computational inefficiency. This study seeks to optimize advected tracer transportation by quantifying how tracer transportation affects precision and run time. Under the assumption that species with shorter lifetimes are less likely to be transported, tracers will be removed one-by-one, with shorter-lived tracers removed first. Using this method, we will examine the effects of tracer transportation on precision and run time to determine the optimal number and type of tracers to advect in atmospheric simulations. Future research might be able to remove tracers based on relative chemical reactivity, in addition to lifetime, to improve computational efficiency without altering results.
Understanding Transcriptional Interference Between Nearby Genes and Its Memory Effect
Yitong Ma
Mentors: Michael Elowitz and Mark Budde

The regulation of genes in mammalian cells remains incompletely understood, even though it is an essential biological process. Many factors, including transcription machinery, chromatin state, and spatial proximity influence the transcriptional output. The unpredictability of regulation is also a major challenge for genetically engineering mammalian cells for both scientific discovery and human therapeutics. Here we use a highly controllable synthetic transcriptional activation and reporter system to investigate the contributions of these various factors. Specifically, we investigate the capacity of transcription at one locus to affect transcription at a nearby locus in this system. We first measured the expression of nearby genes and were able to draw the expression map of simultaneous inference. We discovered a negative effect of downstream to upstream and proposed a mathematical description for that effect. We also found a memory effect of interference, where prior expression of the upstream gene delays expression of the downstream gene. We demonstrated that this hysteresis effect will last for one to two cell cycles, highlighting the dynamic nature of this system.

Structural Studies of HIV-2 Envelope Glycoprotein gp120
Sumana Mahata
Mentors: Pamela J. Bjorkman and Yunji Wu

Human immunodeficiency virus type 1 (HIV-1) and type 2 (HIV-2) are lentiviruses that threaten the public health of millions worldwide. HIV-1 has been extensively studied, and its high mutation rates and glycan shielding prevents most individuals from exhibiting any neutralizing antibodies against it. However, HIV-2, which is less pathogenic than HIV-1, is not as well studied. Patients with HIV-2 are almost always able to produce effective antibodies to neutralize the virus. Studying the structure of HIV-2 allows for comparison with HIV-1 and thus would provide insight into the differences between the two strains, namely the disparity in pathogenicity between them. Recently, a few papers have described a soluble, stable and cleaved HIV-1 gp140 trimer, known as BG505 SOSIP.664 gp140, whose structure closely resembles the native state of the HIV-1 envelope protein. We have therefore sought to design and express the analogous construct in HIV-2 in order to produce soluble trimers that will be very useful for structural studies. Since we received the gene blocks of the HIV-2 SOSIP constructs, we have begun generating the DNA constructs and proteins for them. We hope to study these proteins via co-crystallization with binding partners or via negative stain electron microscopy.

Exploring the Spatial Distribution of Phages in Soil
Anahita Mahmoudabadi
Mentors: Rob B. Phillips and Gita Mahmoudabadi

Bacteriophages are viruses that infect bacteria and are very abundant in the biosphere. It is not clear what threats or benefits phages potentially bring to humans, or how they differ across various individuals. It is also not clear how the geographical location of an individual relates to the types of phages that he or she contains. To learn more about phages, it is essential to find out more about their bacterial hosts, however the hosts of phages are unknown to us because most bacteria are not culturable. A potential solution to this challenge would be to discover phages via their DNA sequence rather than traditional assays which require culturing the bacterial hosts. It is possible to design primers that target a unique viral gene, such as the terminase gene in the phage genome. Terminase packages the DNA into the phage capsid and is essential for phage survival, making it a good marker for detecting phages. The Phillips lab has previously designed primers that target the Terminase large subunit and tested them in oral plaque samples from different patients. The objective of my SURF project is to see whether the markers in the human mouth can be found in the soil. I would like to see whether there is a correlation between the geographical location of individuals and the types of phage markers they host, and determine if geography plays a role in variations between the marker sequences.
The Effect of Escape Mutations on the Glycan Shield of HIV
Allison Maker
Mentors: Max Crispin and André Hoelz

It is challenging to find a vaccine or cure for the HIV virus because of the high mutation rate of the virion genome, which impedes a broadly neutralizing cellular and antibody response. However, a number of broadly neutralizing antibodies (bnAbs) have been isolated from patients with long-standing HIV infection. Many bnAbs recognize the glycans of the viral envelope spike glycoproteins. The spike is composed of a trimer of gp120/gp41 heterodimers glycosylated with N-linked glycans. Both the glycans’ location and chemical structure are more conserved than the proteins underneath, making the glycoproteins an attractive target to antibody recognition and response by vaccine candidates. We aim to determine the effect of point mutations that impede glycans’ attachment to the structure of the glycan shield using a recombinant model of the functional viral spike (soluble BG505 SOSIP.664 gp160ecto) to investigate the impact of glycans’ deletion on a panel of anti-glycan bnAbs and to compare the effect of the trimer mutations to those on the monomer to determine the role of quaternary architecture on the shield structure. We have generated all 28 glycan site knock-outs across gp160ecto mutations and are currently expressing this panel for glycan analysis and examination of bnAb epitope conservation.

Rapid Prototyping of the Two-Input Biomolecular XOR Gate Using NOR Gate Modules
Pulkit Malik
Mentors: Richard Murray, Clare Hayes, and Vipul Singhal

Synthetic biology deals with the idea of creating biomolecular pathways specifically designed to do various tasks in cells, and in the process gain a better understanding of how exactly these processes work. We will show that using the TXTL prototyping system, a classic engineering approach to design that starts with a model and iterates for complexity, the process for understanding these pathways will be faster and more efficient by rapidly producing a moderately complex circuit. The circuit that is being constructed is an XOR logic gate from NOR gates. Circuits are designed using naturally occurring activator and repressor pathways. The process started with a model using data from literature and previous experiments to test viability of the XOR gate. In order to improve on the modeling, part characterization was done. The circuit was split into two modules, and each was tested separately, and compared to the modeling done with new part characterization. The complete circuit will be tested in the TXTL system. Once the expression is optimized in vitro, the circuit will be cloned into cells and tested in vivo.

Assaying Optic Nerve Development in Patient Stem Cell Derived Retina
Janani Mandayam Comar
Mentors: David Cobrinik, Jennifer Aparicio, Mark Borchert, and Paul Sternberg

Optic Nerve Hypoplasia (ONH) is a major cause of neonatal blindness characterized by underdevelopment of the optic nerve—a bundle of retinal ganglion cell (RGC) axons. Leading hypotheses suggest that RGCs either do not develop in sufficient quantities or develop initially, but undergo apoptosis upon failure to project axons properly. This study addresses these hypotheses by comparing RGC production and survival in patient and control-derived induced pluripotent stem cell (iPSC) retinal tissue spheres. Initially, human embryonic stem cell (hESC)-derived retinal spheres were used to develop immunofluorescence (IF) and Western Blot assays to quantify Brn3, an RGC marker, from weeks four through twelve. Due to the challenges in discriminating tightly packed cells in IF, a method comparing the total area of the marker signals was used. Western and IF results indicate RGC production is greatest during weeks five through seven. However, analysis of several spheres, using both methods, shows great variability, even when normalized to total and progenitor cells, indicating that a large sample number could be required to determine if the number of patient and control RGCs differ. Future work will include further establishment of the RGC production curve, quantification of RGC survival with an apoptotic cell marker, and development of an axon outgrowth assay.

Investigation of Feedback Methods for Directing Wireless Power Transfer
Ajay Mandlekar
Mentors: Ali Hajimiri and Florian Bohn

Directing wireless power via adaptive feedback over short-range distances has many potential applications. The purpose of this project is to implement methods to send radio-frequency waves to desired locations in space over short to medium ranges by adjusting phases and amplitudes of element transmitters to maximize the received power at a nearby receiver. For this project, various hardware and software components had to be developed to implement a closed-loop feedback system involving the transmitter and the receiver. In particular, embedded system software on the transmitting side controls the amplitude and phases of the element transmitters while receiving feedback data from the receiver over a wireless communication channel. On the receiver side, hardware and software interfaces for commercial tablets and phones running the Android operating system have been developed. These together form the feedback control loop to maximize the wireless power transfer from the transmitter to the receiver. Future work will focus on implementing more sophisticated communication between the transmitter and the receivers as well as different control algorithms.
Direct-Write Lithography of Chemically Functional Nanostructures
Nikolaj Kofoed Mandsberg
Mentors: Harry Atwater and Raymond Weitekamp

Photoactivation of a latent ruthenium catalyst can locally initiate olefin metathesis in order to cross-link a polymer, forming a rigid domain inside the material. Using 2-photon absorption, we can activate the catalyst inside a small volume of the polymer, enabling direct-write lithography in three dimensions. We are investigating 3D patterning of a new type of metathesis-based photoresist, which can be modified with a wide variety of chemical functionalities. The ability to pattern diverse materials directly will enable rapid prototyping of a number of existing and future technologies, including microfluidics, microelectromechanical systems (MEMS), and biomaterials. As a first step towards this goal, we are trying to engineer resists which reliably form free-standing 3D nanostructures. A consistent method to obtain these free standing nanostructures will enable straightforward optimization of the associated laser writing parameters, in order to improve the accessible resolution and nanostructure quality. We are working to develop an adaptable platform for materials chemistry, through characterization and utilization of the chemically functional interfaces of these nanostructures.

Timing Studies at the CMS Test Stand and Test Beam for the Upgraded CMS Detector
Aashrita Mangu
Mentor: Maria Spiropulu

In an effort to couple emerging high-energy technologies with the Higgs characterization and beyond, a precision timing program for the Compact Muon Solenoid (CMS) upgrade has been proposed. Recent studies have shown that precision timing can help distinguish energy deposits from pile-up, and optimize physics object reconstruction at the High Luminosity Large Hadron Collider (HL-LHC). In order to determine the timing performance of the full detector, various photodetectors, which are used by the Shashlik and Dual Readout calorimeters, are being tested and characterized. To better characterize interesting particle interactions as a part of the development of a high precision timing system for the CMS upgrade, the timing resolution on the order of ~O(100) picoseconds currently achieved by the Electromagnetic Calorimeter (ECAL) needs to be brought down to the scale of ~O(10) picoseconds. The goal of this project is to develop and optimize the readout of the calorimeter cells designed for the HL-LHC upgrade. A critical part of this design is the fast electronic readout of signals collected by the photosensors. In this study, the design of electronic systems using Silicon Photomultipliers (SiPMs) was optimized and tested at the Fermi National Accelerator Laboratory (FNAL) test beam facility to achieve a time resolution on the order of ~O(10ps).

KMS Weights on Building C*-algebras
Jake B. Marcinek
Mentor: Matilde Marcolli

In expanding on the investigation initiated by Consani-Marcolli of the relation between the algebraic geometry of p-adic Mumford curves and the noncommutative geometry of graph C*-algebras associated to the action of the uniformizing p-adic Schottky group on the Bruhat-Tits tree, Carey-Marcolli-Rennie develop a graphical theory for KMS weights. Our goal is to generalize this theory to higher order buildings. We develop the theory for rank 2 buildings of type $\tilde{A}_2$ and their quotients by actions from groups of type rotating automorphisms with finitely many orbits. We provide explicit examples of the construction and classification of building weights for small cases. We also explore approaches to various rank 2 buildings in general.

Measuring the Release Rate of Growth Factors From an Injectable Heparin-Based Hydrogel for Corneal Wound-Healing
Jacqueline J. Masehi-Lano
Mentors: Julie Kornfield and Amy Fu

The cornea is the clear, convex window covering the eye that provides 2/3 of the eye’s focusing power. Transparency of the cornea comes from the orderly nanostructure of its stromal layer, which is maintained by keratocyte cells. When the cornea is injured, keratocytes differentiate into myofibroblasts, which quickly close the wound. However, myofibroblasts contain stress fibers that scatter light and distort the refracting surface of the cornea, leading to monocular blindness. Here we study the effects of three growth factors (GFs) that are known to modulate the myofibroblast phenotype: epidermal growth factor, platelet-derived growth factor and fibroblast growth factor. Because preliminary results of the 2D experiments reveal that higher GF concentrations (such as 50 and 100 ng/mL) successfully reduce $\alpha$-SMA expression in about 90% of cells, the GFs were bound in a 7% heparin-based 3D hydrogel and ELISA was used to characterize the release of the GFs from the hydrogels over a two-week period.
Testing FIRE Suite Simulations of Galaxy Formation
Naiien Matschke
Mentor: Philip Hopkins

Galaxy formation is a process that takes place over such an immense amount of time that creating an accurate model of it using observational data is essentially impossible. As a result, efforts in recent years have focused primarily on using modern computing resources to simulate millions of gas and dark matter particles as they interact, cool, and condense from post-Big Bang conditions into stars and galaxies, in order to understand how different physics affect the process. Until recently, few simulations included stellar feedback, the interaction of stars with the cosmic rays, gas, and dust that are present in galaxies. The Feedback in Realistic Environments suite of simulations aims to provide an improved model of galaxy formation by accounting for stellar feedback. In this study, the results of several runs of the suite are analyzed, comparing properties such as the distribution of particles at different temperatures to those seen in real galaxies, and observing how varying initial conditions result in different galactic structures, demonstrating that the inclusion of stellar feedback produces more accurately-sized galaxies than in previous simulations. Visualization techniques are also developed for researchers intending to use the suite, and future work will primarily focus on fleshing out its features.

Improved Methods of Discretization for Temporal Logic Planning
Robert Mattila
Mentors: Richard M. Murray and Yilin Mo

In this article, we consider the problem of synthesizing correct-by-construction controllers for discrete time dynamical systems. As a first step, the dynamical system is abstracted into a finite transition system according to a partition of the continuous state space that is based on a reachability analysis. The synthesis problem is then converted into a two player game between the environment and the system on the finite transition system where high-level specifications given in linear temporal logic have to be fulfilled by the system. Our contribution is a new way of performing the abstraction. We exploit the system's winning set: the set of states from which it is always possible for the system to satisfy the specifications, regardless of how the environment may act. The merit of our approach is twofold. Firstly, it allows us to focus the computational resources on certain regions of the state space instead of discretizing everything to an equally fine level. Secondly, it provides us with a definitive termination criteria for the algorithm. As a final point, we demonstrate the performance of the new algorithm on numerical examples.

Utilizing Antibody-Oligo Coupling to Characterize Protein Complexes in IncRNAs
Emily Mazo
Mentors: Mitch Guttman and Amy Chow

Characterizing protein complexes currently depends on time-and-resource-intensive methods such as mass spectroscopy; these methods are non-scalable and hold our ability to quickly discover the proteins that RNA molecules interact with, which helps us to determine their functions (and the methods by which they carry out such functions). Similarly, it is possible that some large non-coding RNA molecules can form several different protein complexes, which may carry out different functions; methods such as mass spectroscopy are incapable of identifying the protein complex at the single RNA molecule level, which is required for determining whether different complexes can be formed. By coupling DNA oligo tags to antibodies, we have created a protein-identification assay that can quickly identify the proteins that interact with a given IncRNA. Utilizing the principle of combinatorial barcoding, we will in the future use this A-O assay to characterize, on the single-molecule level, the protein complexes of individual IncRNAs and quantify the frequency of protein complex permutations.

Modeling the Reionization of the Universe to Constrain the Nature of Dark Matter
Daniel McAndrew
Mentors: Andrew Benson and Fiona Harrison

The early universe consisted of dense, hot primordial plasma, but it expanded and by redshift 1,100 had cooled enough for the first hydrogen atoms to form in the process of recombination. At the time of recombination, the universe was mostly uniform, but small differences of energy density propagated, eventually causing formation of the earliest galaxies inside of dark matter halos. By redshift 30, the first galaxies and quasars began to emit photons. From measurements of the cosmic microwave background and the Gunn-Peterson trough, we know that by just after redshift 6, these photons reionized most of the hydrogen in the intergalactic medium in the process of reionization. By using the Galacticus model, we can simulate the evolution of the thermal and ionic states of the universe to model reionization. We can vary the properties of the simulated dark matter and observe the effects on reionization. If these changes cause reionization to occur too late to accord with observational constraints, or not occur at all, we can place constraints on the nature of dark matter.
Reproducibility of Histone Modification ChIP-seq Datasets
Kayla McCue
Mentors: Anshul Kundaje, Irene Kaplow, and Ellen Rothenberg

Reproducibility is an important part of any credible scientific investigation, and this has become an issue of growing importance in regards to high-throughput sequencing experiments. In particular, Chromatin Immunoprecipitation Sequencing (ChIP-seq), a method to discover genomic locations of DNA-binding proteins and reversible modifications to the DNA-protein complex in cells, has recently come under increased scrutiny for reproducibility. Methods of analysis, like the Irreproducible Discovery Rate (IDR), have sought to extract reproducible portions of the purported genomic locations from irreproducible ones. However, the IDR framework, as it currently exists, is much better suited for transcription factor datasets than for histone modification datasets. This is partially due to the fact that transcription factors tend to bind to specific DNA sequences, while histone modifications can shift without impacting regulation. Another factor is that histone modifications can cover both long and short stretches of DNA, while transcription factors generally exist at a consistent genomic scale. To account for this, we propose a new approach for using IDR for histone modifications, wherein we select differently sized bins and consider the reproducibility of signal in these bins. With this tactic, we hope to provide a method of quality control that is applicable to all ChIP-seq datasets.

Designing an Application to Allocate Polling Place Resources for Elections
Sean McKenna
Mentor: Michael Alvarez

To reduce overall wait times to vote and minimize discrepancies across precincts in the same jurisdiction, we seek to develop an application with two outputs: a suggested allocation of voting machines across precincts and a method of identification for the precincts most vulnerable to long waits if turnout rises unexpectedly. We achieve this in an application which simulates voting and wait times in all precincts in a jurisdiction based on user-defined input parameters. The application allocates voting machines through a greedy algorithm. Then, it runs additional simulations to indicate the increase in wait times relative to increased turnout. To refine the application, one or more comparisons will be completed to evaluate the accuracy of the application’s predictions against the observed conditions in jurisdictions during previous elections.

Simulation of Micro Coining Process Using Abaqus/Explicit
Rounak Mehta
Mentors: Guruswami Ravichandran and Zachary Sternberger

The micro forming process allows the production of miniature metallic parts which have diverse applications. In this study, we simulate the manufacture of test samples for Rayleigh-Taylor and Richtmyer-Meshkov Instability Experiments. Three dimensional ripples are coined on the surface of a tantalum sample by a micro coining process. A quasi static simulation of this process was performed using Abaqus/Explicit. A representative unit section of the die and sample was modeled to save computational time. The variation in minimum pressure required for complete pattern transfer to the sample with varying conditions such as sample thickness and amplitude of 3D ripple was observed.

Frogonomics: Amphibian Decision Making Under Uncertainty
Christina Meyer
Mentors: Colin Camerer and Gidi Nave

Economic decision-making in humans has been discovered to be very predictable under certain financial constraints and pressures. Why this is true and where this behavior originates from is still not understood. We hypothesize that the root of these behaviors might be found in the basal ganglia, a small part of the brain associated with the formation of habits. To test this theory, we worked with Xenopus laevis (African three-clawed frog), since they share only the basal ganglia with humans and lack a neocortex. These frogs have also been shown to have a perfect pitch to the frequency of waves created in the water, which makes them ideal to train. To train them and see if they obey stochastic dominance, a stimulus creating waves was run in the water and they were fed after every stimulus. Three different types of food were given, each associated with a different frequency for every frog. After seven weeks, the frogs began to show a consistent response to the stimulus, turning towards and even attacking it. Decision-based testing has not been conducted yet, but we hypothesize that they will be able to differentiate between a frequency associated with food and one not. This will then allow us to better understand the role of the basal ganglia in human decision making.
Characterizing Microbial Diversity at Woods Hole
Alice J. Michel
Mentor: Dianne K. Newman

The history of life on earth is dominated by unicellular life, within which exists a vast diversity of metabolisms, structures, and functions. However, analysis of a particular metabolism of the microbial world can prove difficult due to the fact that cells are often small, fragile, intolerant of laboratory conditions, and leave no trace in the fossil record. Nonetheless, there is a class of bacterial lipids that are well-preserved over billions of years called 2-methylhopanoids. If the function and distribution of 2-methylhopanoids were known in living organisms, we might be able to uncover something about the ancient past. The hybridization chain reaction (HCR) is a promising new method for the study of 2-methylhopanoids in situ. It allows for the subcellular localization of mRNA transcripts and may be applied to environmental samples in the future. Here we present some of the first attempts at HCR on bacteria known to produce 2-methylhopanoids. In addition, the availability of resources at the Marine Biological Laboratory in Woods Hole, MA, allowed for the attempted isolation of several other intriguing microbial metabolisms.

Modeling Whistler Waves Propagation in Plasma
Lucio Maria Milanese
Mentor: Paul Bellan

Whistler waves are characterized by a particular dispersion relation which makes higher frequency modes travel faster, thus producing the descending tone from which they take their name. A code has been developed to simulate the propagation of whistler waves in a uniform magnetized plasma. The code solves two coupled vector equations, which are discretized in time and space; a direct method based on Gauss-Jordan elimination has been implemented to solve the vector Helmholtz equation. The comparison between numerical results and analytic predictions has proved to be excellent for the problems which have been addressed. Optimal boundary conditions for the different cases have been determined. Further potential modeling includes the simulation of point-like sources, as well as of the propagation of waves in plasmas which are not homogeneously magnetized. During the development of the code, several IDL functions and procedures have been written which can be employed as useful building blocks for a wide range of similar problems.

An In Depth Look at the Cause of the Dips in the Light Curve of Hercules X-1
Talia G. Minear
Mentor: Fiona A. Harrison

It is suspected that the accretion disk around the neutron star in the Hercules X-1 system is a warped surface emitting filaments of matter that move in and out of our line of sight and are responsible for the dips in the light curve of the system. While a basic idea of the cause of these dips is known, the size and density of these filaments is not. This is what this project is investigating, the results of which will better the understanding of binary neutron star systems. Analysis of these dips started by plotting the light curve of Hercules X-1 in a period during which these dips occurred. Light curves with a high time-resolution were used to investigate the duration of ingress and egress of the dips, Hardness ratios were used to obtain an idea about spectral changes during the dips, and X-ray spectra was analyzed to get an accurate description of the absorbing medium during the dips.

The Role of Heat Shock Proteins in the Guided Entry of Tail-Anchored Proteins (GET) Pathway
Andrew Montequin
Mentors: Shu-ou Shan and Meera Rao

While the majority of membrane proteins undergo co-translational targeting, tail-anchored (TA) proteins differ in that they are inserted into the ER membrane via several unique chaperone proteins after translation through what has come to be known as the GET (Guided Entry of Tail-Anchored Proteins) pathway. One of the questions that remains unsolved with regards to the GET pathway deals with how the pathway discriminates against proteins that are not destined for the ER membrane and only selects TA proteins. Sgt2, a chaperone protein that is believed to be responsible for recruiting TA proteins, is known to have binding sites for specific heat shock proteins that can possibly play a role in either selecting for TA proteins or selecting against non-TA proteins. Determining which of these two possibilities, if either, is correct is the main goal of this project. In order to test this, the gene for Get3, which codes for the protein that Sgt2 hands off TA proteins to, was knocked out of a yeast strain that already had mutations made to the heat shock protein binding sites. After extracting the cytoplasmic contents of this yeast strain, a TA protein (Bos1) was able to be translated with different levels of mutations that make it an increasingly worse substrate for translocation through the GET pathway with varying concentrations of Get3 added. When proteins are translocated through the GET pathway, they are glycosylated, resulting in a size difference that can be quantitatively measured with SDS-PAGE. This will then give insight into what role the heat shock proteins play in the GET pathway.
Fabrication of Nanoporous Metallic Glass  
Stephanie Moon  
Mentors: Julia R. Greer and David Chen

Amorphous metallic alloys, or metallic glasses (MG), are attractive engineering materials for their high strengths and high elastic limits. Recently, MGs have been shown to be ductile at the nanoscale while brittle at the bulk scale. This size-dependent behavior in mechanical failure modes may be due to the increased surface area to volume ratio in the small scale. This project aims to synthesize nanoporous MG via potentiostatic electrodeposition in order to exploit this size effect of ductility in MGs and bring it up to larger scales through the use of hierarchy. Nanoporous MG has a large surface area to volume ratio and a stochastic and isotropic structure, effectively allowing material and structural effects to be decoupled. In order to achieve the desired nanoporous film of MG, different methods of electrodeposition were performed on various polymer templates. The templates made of poly(methyl methacrylate) photoresists were found to be incompatible with the electrolytic solutions for plating both Fe-W and Ni-P MGs. Colloidal nickel phosphate templates are currently being explored. After a successful synthesis and electrophoresis of the nanoparticles, the plated MG samples will be cut into pillar shapes via focused ion beam milling followed by compression tests and analysis. These experiments will help elucidate the fundamental deformation mechanisms in MGs and study the viability of proliferating material size-effects through the use of a stochastic hierarchy of scales.

An Adaptation of the Potts Model for Linguistic Parameter Change  
Matthew Morgan  
Mentor: Matilde Marcolli

Human languages can be concisely described by a lexicon along with a list of parameters that are primarily rules for combining elements of the lexicon. Much research has been done defining precisely what these parameters are. In our project, we adapt a model used in physics for spin glasses, the Potts Model, to attempt to model how languages evolve over time. In particular, this model accounts for languages that interact with each other more influencing each other more, the increased likelihood of nearby parameter changes after a parameter is changed, and the internal dependencies of some parameters on others in a given language. We also programmed a Monte-Carlo simulation to see how our model performed, compared to documented historical language changes.

Optimizing the Functionality and Stability of CIBER 2’s Instrument Shutter Deployment  
Sheila Murthy  
Mentors: Jamie Bock, Phil Korngut, and Alicia Lanz

The newest model of Cosmic Infrared Extragalactic Background Experiment, CIBER 2, is a sounding rocket payload designed to examine the fluctuations of the extra-galactic light in near-IR. At the start of testing, CIBER’s instruments open to allow observation of the sky. The amount of light received by them is controlled by a magnetic shutter blade, whose position relative to the instruments’ opening is determined by two solenoids. Its resting state, which covers the opening, as well as left and right positions control the aperture through which background light enters the instrument. This design, specifically the blade mechanism, was optimized to withstand vibrational and cryogenic testing to ensure that CIBER’s instruments function in space-like conditions.

Using Fossil Microatolls to Quantify Relative Sea-Level Change in Mid-Holocene Southeast Asia  
Xinyi Nan  
Mentors: Aron Meltzner, Adam Switzer, and Joseph Kirschvink

Microatolls are flat, disc-shaped coral colonies that live in shallow waters in many tropical regions around the world. Because they grow and respond to sea level and leave behind annual growth bands, they are invaluable as high-resolution indicators of sea-level change. Each microatoll records the relative sea level during its lifetime, and we can reconstruct sea-level change by overlapping the histories of contemporaneous, cohabitant corals. For my research, I focused on three microatolls that lived 7200 to 6600 years ago off the coast of Mapur Island, Indonesia. Last year, students working on corals from 6800 to 6400 years ago in Belitung, an Indonesian island 550 km southeast of Mapur, found that sea level rose and fell several times but, in general, increased from 6800 to 6500 years ago and decreased afterward. Our results corroborate these trends and show that the increase in sea level began as early as 7200 years ago. The use of microatoll banding has greatly increased the precision to which we can describe sea-level history. Future work in this field will contribute even more to our knowledge and understanding.
Monitoring Patient Motion Using Kinect Sensors to Optimize Spinal Cord Injury Therapy
Chiraag M. Nataraj
Mentor: Joel W. Burdick

The motive of this research was to utilize depth sensor technology to track body motion. Currently, many algorithms exist to do— one of the most popular ones is SCAPE, which has two stages. The first stage is the initialization phase, whereby the generic human model is modified to resemble the actual human. The second stage is the tracking phase, whereby the generated model is then used along with keypoints to track the motion of the person. The key contribution of this research is in the first phase. Normally, the initialization is done by hand by selecting several keypoints on both the captured image and the model. This research seeks to automate that process using a combination of edge detection and point-to-point correspondence given that the initial pose is roughly known.

Genetic Expression and Physical Internalization of Gas Vesicles for Ultrasound Contrast in Mammalian Cells
Suchita Nety
Mentors: Mikhail Shapiro and Raymond Bourdeau

Ultrasound is among the most widely used non-invasive imaging modalities in biomedicine, yet its high spatial and temporal resolution have not yet been fully exploited for molecular imaging due to the lack of suitable intracellular contrast agents. Gas vesicles, hollow protein-shelled nanostructures from buoyant microorganisms, have recently been identified as a new class of ultrasound contrast agents. We sought to port gas vesicles from their native prokaryotic hosts into mammalian cells through two approaches: establishing heterologous expression by introducing the gas vesicle-encoding gene cluster into mammalian cells and physically delivering purified gas vesicles into mammalian cells to provide specific cellular ultrasound contrast. We have successfully introduced the full synthetic gas vesicle-encoding cluster into HEK293 cells, and verified that all 12 proteins are being translated. We are assessing the presence of functional gas vesicles using both ultrasound imaging and transmission electron microscopy. In order to prepare purified gas vesicles for delivery into cells, we have implemented various conjugation strategies to label the gas vesicle surface with moieties such as fluorophores and cell-penetrating peptides. We hope to visualize uptake of gas vesicles by HEK293 cells and RAW 264.7 macrophages cultured on transwell inserts using immunofluorescence and confocal microscopy.

Finite Sets With No Singleton Intersection
Tian Nie
Mentor: Richard M. Wilson

Let $A = \{0, 1, \ldots, q - 1\}$ be an alphabet of $q$ elements. Let $C \subseteq A^k$ be a $q$-ary code of length $k$. The Hamming distance $d(a, b)$ between two code words $a = (a_1, a_2, \ldots, a_k)$ and $b = (b_1, b_2, \ldots, b_k)$ is the number of coordinates $i$, $1 \leq i \leq k$, with $a_i \neq b_i$. Let $D$ be the set of all Hamming distances $d(a, b)$ between any two code words $a$, $b$ in $C$. Delaunay proved that if $|D| = s$, then $|C| \leq \sum_{i=0}^{s}(q - 1)^{k-i}$. However the bound is not tight. In this project, we are interested in reducing the degree of the bound in the general case as well as studying some special cases, such as only restricting one distance. We will also study analogous results in the problem of subsets with restricted intersection.

Geometry of Brachistochrones and Tautochrones in Radially Dependent Force Fields
Chinmay Nirkhe
Mentors: Tom M. Apostol and Mamikon A. Mnatsakanian

In force fields $F = ky$, the brachistochrone and tautochrone curves are cycloidal arches. Between any two points, there exists a brachistochrone. This research extends these historically famous properties by demonstrating that in radially dependent force fields $F = \pm kr$, the brachistochrone curves are hypocycloidal or epicycloidal arches. A proof for the existence of a brachistochrone between any points in these fields is also given. Furthermore, criterion for a curve to be a brachistochrone or tautochrone in radially dependent force fields $F = \pm kr$ are demonstrated and numerical solutions to these curves are given.
Identifying and Characterizing TCRs From Elite Controller T Cells
Won Jun Noh
Mentors: David Baltimore and Alok Joglekar

Current methods of HIV therapy, such as the use of antiretroviral drugs, are insufficient in fully suppressing HIV, as improvements must be made to effectively control latently infected cells and newly created drug-resistant species. Further investigation of HIV elite controllers, a rare subpopulation of HIV-positive patients known to be able to achieve broad control over HIV without any separate treatment, may contain the key to finding a potent, long-lasting treatment for HIV infections. Recent studies on elite controllers have shown that the controller status is related to CD8+ Cytotoxic T Lymphocytes (CTLs) that are restricted by certain HLA-B alleles. Our collaborators at Bruce Walker’s laboratory have shown that certain B27-KK10-specific CTL clonotypes from elite controllers exhibit higher potencies in eliminating HIV-infected cells. Considering that the only genetic differences between these clonotypes lie in T cell receptors (TCRs), we expect that controller status is related to the TCRs. In this study, we isolate and characterize elite controller TCRs by amplifying TCRα/TCRβ transcripts from the RNA extracted from B27-KK10-specific elite controller CTLs. As of now, we have been able to isolate, design, and link various combinations of TCRα/β regions through the use of spliced overlap PCR and Gibson isothermal assembly. By cloning these constructs into lentiviral backbones, we were able to package lentiviral vectors, which were then used to transduce jurkats. We tested TCR surface expression levels through flow cytometry that utilizes B27-KK10-specific tetramers. TCRs that are able to recognize B27-KK10 will be studied further to test their abilities to control HIV.

Side Group Liquid Crystal Polymers With "Side-On" Azo-benzene Side-Groups for Photoresponsive Materials
Pedro Ojeda
Mentors: Julia Kornfield and Zuleikha Kurji

Photoresponsive soft materials can be used in medical applications, for example in biocompatible electrodes for Deep Brain Stimulation of Parkinson’s patients. Side-Group Liquid Crystal Polymers (SGLCPs), where rigid liquid crystal groups are grafted onto nearly every repeat unit of a polymer backbone, couple the flexibility of the polymer backbone with the liquid crystalline order of the side groups. The Kornfield group has used “end-on,” or terminally attached, SGLCPs as the active matrix in photoresponsive materials, but, to date, they have not yet attempted to synthesize “side-on,” or laterally attached, SGLCPs. However, neutron scattering experiments of 1% “side-on” and “end-on” SGLCPs in deuterated LC solvent show that “side-on” SGLCPs are much more extended than end-on SGLCPs. Here we designed and synthesized a photoresponsive (azo-benzene containing) “side-on” side group for the first time. We compare the characteristics of three side-on SGLCPs: with no azobenzene, with a fraction of azobenzene-containing “end-on” side groups, and with a fraction of azobenzene-containing “side-on” side groups.

Spatial and Temporal Expression Patterns of Transcription Factors in the Sea Urchin Apical Plate
Ariel O’Neill
Mentors: Eric Davidson and Roberto Feuda

The overarching goal of the project is to reconstruct the underlying gene regulatory network determining cell fate in the apical plate during early development of Strongylocentrotus purpuratus. In order to reconstruct the gene regulatory network, we need three types of data on transcription factors known to be expressed in the apical plate: the temporal expression, the spatial expression, and the effects of perturbing one transcription factor on the expression of others. Over the summer, we have begun analysis of temporal expression data acquired for roughly 50 transcription factors in order to graph their levels of expression with respect to time. We have also tested and refined our protocol for whole-mount in situ hybridization for obtaining spatial expression patterns and have taken pictures of these expression patterns for a small set of transcription factors.

Improving Surface Spectroscopic Techniques With Nanoscale Gratings
Suzannah Osekowsky
Mentor: Kristjan Leósson

In the years following the discovery of tainted milk products in China, worldwide food safety organizations have proclaimed the importance of testing for melamine, the tainting agent. Surface-enhanced Raman spectroscopy (SERS) is a proven testing method; however, in its current implementation, SERS equipment is bulky and expensive. This project seeks to create nanoscale gratings to enhance SERS capabilities in turbid liquids such as milk, using coupled and superfocused surface plasmons to selectively enhance the electric field at the surface of the grating. Doing this in a uniform manner will ultimately allow for more accurate SERS analysis with smaller sample sizes and using much less expensive equipment. The gratings are created by using electron beam lithography to deposit gold patterns onto a layer of polymer index-matched to water. Future work will characterize the most advantageous features of these patterns and use them for SERS analysis.
Reconstructing the Sea-Level History at Mapur Island, Indonesia, Over the Past 8000 Years
Berk Özdalyan
Mentors: Aron Meltzner, Adam Switzer, and Joann Stock

Glacial isostatic adjustment (GIA) models attempt to explain land deformation in response to ice and water loads, which is important for forecasting relative sea-level (RSL) change. Their accuracy in reproducing past events determines their credibility. In an attempt to calibrate GIA models, we use coral microatolls to reconstruct the mid-Holocene RSL history of Mapur Island, Indonesia, on the Sunda Shelf. Because corals’ highest level of survival is limited by low water, microatolls track changes in RSL; their annual growth bands allow for accurate determination of the rates of such change. We find that RSL rose by 12–13 cm over the lifetime of each of two microatolls studied thus far, which were dated to between 7300 and 6900 yr BP; the younger coral reached 106 cm higher than modern equivalents. These observations suggest RSL at the site rose between 7300 and 6900 yr BP.

Magnetic Manipulation of Microglia and Magnetic Repulsion of Superparamagnetic Beads
Torkom Pailevanian
Mentor: Ali Hajimiri

Immunotherapy uses the body’s own immune system to seek out and kill cancer, unlike the drugs that chemically do the same task. Past experiments have shown that macrophages loaded with specific synthetic DNA molecules have the ability to eradicate brain tumors. When these cells are loaded with micron sized superparamagnetic beads, they are susceptible to magnetic manipulations. Circuitry has been designed to generate small localized magnetic fields is being used to test loaded macrophages in vitro. Experiments have been conducted to show that standalone beads can be moved to desired locations by generating a magnetic field with a specific distribution. Viability experiments have determined the maximum non-toxic magnetic loading of macrophages to use in manipulation experiments. Current experiments have not been successful in replicating an ideal cell environment which is an area of ongoing research. In addition a potential method of magnetic repulsion using high frequency circuitry is being developed.

Development of an Efficiency Calculator and Data Analysis Program for Thermochemical Cycling
Cheol Woo (Peter) Park
Mentors: Sossina Haile and Michael Ignatowich

With the appropriate catalyst, usable chemical fuel can be effectively derived from H2O and CO2 splitting by employing a solar-driven 2-step thermochemical cycle. The project focuses on developing programs that will help the search in finding new materials and optimal thermochemical cycling conditions for finding the best thermochemical reactor design that maximizes solar energy conversion efficiency. A graphical user interface (GUI) for a solar thermodynamic efficiency calculator has been developed. The GUI takes input thermodynamic data of nonstoichiometric metal oxides and performs a full-range optimization of thermodynamic efficiency to help users find optimal reaction conditions for thermochemical energy conversion. An automated thermochemical cycling data analysis program has also been developed to analyze data generated from in situ thermochemical testing. The program provides quick and accurate analysis of large data, thus increasing the speed for the search of an optimal catalyst for thermochemical cycling.

Efficient Video Annotation Using a Tracker and a Detector
Jeong Park
Mentors: Pietro Perona and Steve Branson

In contrary to the ease of obtaining videos, annotation of the video datasets has been extremely costly. We describe an active-learning based approach to semi-automate the annotation process. Given a sparse set of annotated keyframes, a detector is trained with the frames near the keyframes. A tracker, then, interpolates the non-key frames by tracking both forward and backward from the keyframes. The detector, which showed above 90% recall rate on the specific dataset that contains the keyframes, not only updates and validates the tracking results to reduce drifting, but also provides room for annotating appearance of objects that are not caught in the keyframes. To ensure the accuracy of bootstrapping, we either query unmatched detections to oracle or set them as “ignore” windows to avoid wrong negative sampling. We demonstrate our approach by annotating challenging pedestrian video datasets with less than 10% of the human effort that would have otherwise been necessary for naive frame-by-frame human annotation.
Defective Carbon Nanotubes as Catalyst in Solid Acid Fuel Cell Electrodes  
Jin Ho Park  
Mentors: Sossina M. Haile and Vanessa Evoen

In recent years, Solid Acid Fuel Cells (SAFCs) have been drawing much attention. Currently, platinum is used as an electrical catalyst that helps the movement of current. In order to make this technology commercially viable, however, it is necessary to develop alternative catalysts that can replace the expensive platinum. In this experiment, we have found CNT to be a one of candidates for such a catalyst, since the correlation between the defect density of CNT and electron transportation allows more defective CNTs to transport more electrons. To characterize the defectiveness of CNTs, we used Raman spectroscopy and Scanning Electron Microscopes (SEM). We also revealed possibilities and limitations of CNTs as a catalyst in SAFCs using AC impedance.

Experimental Validation of Inertial Imaging Theory  
Sunyoung Park  
Mentors: Michael Roukes and Adam Neumann

By using inertial imaging theory, not only the inertial mass but also the position, and the shape of single molecule can be measured in real time. A general idea of inertial imaging theory is using resonant frequency change of a resonator before and after adding small particle. The main objective of this project is to identify the validity of inertial imaging theory experimentally in macrosystems. For measuring resonant frequencies of a cantilever, we use photo sensitive detector (PSD). We have worked on getting high quality signal with low background. With the experimental set up, we look forward to measuring at least four resonance modes. Our final goal is to measure ten resonance modes before and after adding small mass particle. Also, we will figure out the experimental limitations of the theory.

Study of Patterns in the Bacterial Genome Between GC Content and Environmental Factors  
Vincent I. Park  
Mentors: William M. Clemons and Axel Mueller

GC content refers to the percentage of guanine and cytosine contained in DNA or RNA fragments. It has been correlated with genomic features such as methylation rate, recombination rate and expression levels and has also been claimed to affect genome replication, DNA repair mechanisms, lineage- and niche-specific molecular adaptation, codon usage, and amino acid composition. There is speculation that GC content is linked to the environmental factors in which bacteria thrive in. In order to find patterns between GC content and environmental factors among fully sequenced bacteria, queries were taken from a MYSQL database that draws information from NCBI, PFAM, JGI and other databases along with membrane protein topology and mRNA secondary structure prediction information. Results show that aerobic bacteria have a mean of 56% GC content while anaerobic bacteria have a mean of 45% GC content. There are no significant correlations between GC content and temperature range, motility, salinity, and biotic relationships, respectively.

Optimisation of the Design of a Mechanical Oscillator for an Electro-Optomechanical Wavelength Converter  
Thomas G. Parton  
Mentors: Oskar Painter and Johannes Fink

Simulations of a mechanical nanobeam capacitively coupled to a superconducting circuit have been performed with the aim of optimising its design to achieve to greatest electromechanical coupling and mechanical Q factor. These properties are desirable in the quest to create an efficient optical-to-microwave signal transducer, which aside from being a notable technological accomplishment has potential applications in quantum computing.

A Biosynthetic Pathway Using Biochemical Protecting Groups to Dye Cloth With Indigo  
Aleena Patel  
Mentors: John Dueber, Zachary Russ, Arthur Fong III, Shyam Bhakta, Nicole Chernavsky, Matthew Chan, Taner Dagdelen, and Jesse Beauchamp

The Special Projects in Synthetic Biology (SPSB) team at UC Berkeley has developed a biosynthetic pathway that implements biochemical protecting groups to control the spontaneous oxidation of indoxyl that forms indigo. The enzymatic protection of indoxyl by transferases and deprotection by hydrolases permits controllable release of indoxyl. The indigo-dyeing industry requires a soluble form of indigo to vat-dye large surface areas of cloth. The current industry must dump toxic byproducts into waste-water to produce soluble leuco-indigo before dyeing cloth. Protected indoxyl offers an environmentally friendly alternative that does not require harmful reducing agents to produce a soluble form of indigo. SPSB has identified two sulfotransferases, native to Homo sapiens, and expressed them in E. coli and S. cerevisiae. In vitro experiments confirm that these sulfotransferases are capable of protecting indoxyl with sulfate to prevent spontaneous formation of indigo in aerobic conditions. Sulfatases that hydrolyze indoxyl sulfate to release indoxyl when desired and transporter enzymes that export indoxyl sulfate out of the cell have also been explored to complete the biosynthetic pathway.
Switching Control Synthesis in the Presence of Uncertainty for an Aircraft Electric Power System Testbed
Linnea Persson
Mentors: Richard M. Murray and Scott C. Livingston

Traditional aircraft systems are largely dependent on mechanical, pneumatic and hydraulic subsystems. Recent technology advancements are changing this in a way such that the aircraft systems to a higher degree depend on electrical components, making the electrical subsystem more complex. Measuring the state of such a complex system would require a large number of sensors, which is why applying state estimation techniques to aircraft electric power systems is being considered. Even with only partial sensing of the system, it is possible to rule out some states as incompatible with a certain measurement. By repeatedly rerouting power and taking new measurements, the set of possible states can be reduced even more. In this project, state estimation has been implemented on an aircraft electric power system testbed, and the effect that different sensor placements has on measurement efficiency has been examined. Finally any progress towards synthesis of control protocols in the presence of uncertainty is discussed.

Single-Crystal Cuprous Oxide Photoelectrodes
Alex Pien
Mentors: Nathan Lewis and Stefan Omelchenko

P-Type cuprous oxide is useful for water splitting and for photovoltaics due to its nature as a cheap, readily-available metal oxide which is easy to produce. Through the use of the thermal oxidation of copper followed by the floating-zone method, single-crystal cuprous oxide can be grown which exhibits high charge carrier mobility and has a very small concentration of defects. Therefore, the photoelectrodes have high carrier collection and internal quantum yield. Additionally, a polishing procedure has been developed resulting in a root mean squared surface roughness of less than 3 nm. Nonaqueous photoelectrochemistry was performed in cells containing the decamethylcobaltocene redox couple or the cobaltocene redox couple. Based on prior experiments, the photoelectrodes exhibit open circuit voltage values of 820 mV and short-circuit current densities of 3.1 mA-cm⁻².

A Measurement of Correlation Between Unresolved Planck Sources and the Redmapper Cluster Catalog
Rishabh Pipada
Mentors: David Spergel and Jamie Bock

The cross-correlation of infrared maps and optically-selected galaxy clusters provide insight into the spatial correlation between the unresolved dusty galaxies that make up the cosmic infrared background (CIB) and galaxy clusters. The Planck high frequency maps provide a full-sky map of the CIB and the Redmapper catalog contains galaxy clusters at 0.1 < z < 0.5. The cross-spectrum is well-fit by a power law with index of ~ -1.1, similar to the results from cross-correlating other datasets. Further analysis of the cross-spectrum can provide insight about the large-scale bias of the Redmapper clusters, provide the framework for a halo model and enable the detection of the signature of early reionization in the CMB.

A Low-Rank Approach for Solving a Semidefinite Relaxation of the Clustering Problem
Aleksis Pirinen
Mentors: Brendan Ames, John Bruer, and Joel Tropp

Clustering is a fundamental problem in many research areas, most prominently in machine learning and statistics. Recently, several convex relaxations have been proposed for approximately solving the NP-hard clustering problem. Most notably, several approaches based on semidefinite relaxation have been shown to correctly partition randomly generated data consisting of a moderate number of densely connected clusters. Due to the difficulties that come with requiring the optimization variable to be positive semidefinite, these relaxations tend to be intractable for large data sets. In particular, these relaxations often suffer from having to perform expensive eigendecompositions in each iteration. In this paper, we consider a first-order method for solving one such semidefinite relaxation. We propose a nonconvex approach for solving this semidefinite relaxation, based on low-rank factorization of the semidefinite variable. The resulting formulation, while nonconvex, eliminates the need for projections onto the semidefinite cone and significantly reduces the dimension of the decision variable. We show empirically that our heuristic is significantly more efficient than the existing convex optimization approaches, without sacrificing the desirable recovery properties of the semidefinite relaxation.
Active Galactic Nuclei Emission Band Comparison With NuSTAR

Alexander Place

Mentors: Fiona Harrison and Mislav Balokovic

Active galactic nuclei (AGN) are supermassive black holes at the center of some galaxies that accrete more radiation than a typical black hole. These super luminous black holes emit radiation at all wavelengths of the electromagnetic spectrum. Studying and modeling these emissions can give insight into the structure of AGN. However, AGN observations require sophisticated instruments which can be particularly expensive to operate. To reduce the number of observations necessary, this project studied the correlation between the infrared, optical, and X-ray emissions of 24 Seyfert 1 AGN. Once these correlations are well established an observation in any one of these bands can be used to infer the spectra in the other bands, reducing the need for more observations. Optical data from the Palomar Hale telescope, infrared data from the WISE mission, and X-ray data from the NuSTAR mission were reduced using standard pipelines and reduction techniques. These spectra were then modeled and compared.

Graph Grammars and the Insertion Lie Algebra of Quantum Field Theory

Alexander M. Port

Mentor: Matilde Marcolli

This project aims at extending the use of Lie algebra methods from the setting of perturbative Quantum Field Theory, in the context of the Connes-Kreimer approach to renormalization, to a very different context: the theory of graph grammars and graph languages. Lie algebras are a fundamental object in mathematics: they describe the notion of infinitesimal symmetries. The occurrence of Lie algebras in perturbative Quantum Field Theory, in the context of renormalization, is a recent discovery. On the other side of this project we have the theory of formal languages, which falls within the context of applications of mathematics to theoretical computer science. The primary purpose of this proposal is to explore the similarities between the notion of insertion of graphs used in describing the Lie algebra of Feynman graphs in Quantum Field Theory and the production rules of graph grammars, in order to import the use of Lie theoretic methods from the context of renormalization to the context of formal languages.

The Mechanics of River Erosion and Waterfall Formation at Steep Slopes

Juliane Preimesberger

Mentors: Michael Lamb and Joel Scheingross

The Earth’s surface is a dynamic landscape that evolves over timescales of seconds to millions of years due to the influence of various surface processes. Rivers, especially, play a key role in shaping Earth’s landscape and can set the pace of the evolution of the planet’s topography through bedrock erosion. High gradient rivers (slopes >10%) provide much of the erosion that occurs on the Earth’s surface, but have not been studied as extensively as low gradient rivers have been. This project simulated a high gradient channel using a laboratory flume with the capabilities to tilt to 30% slope and recirculate sediment. Before any experiments were undertaken, extensive calibration work was done: sediment flux can be measured accurately within 15%, and bed topography scans are accurate within 1 millimeter. After calibrations were completed, experiments were carried out to better understand the mechanics of river erosion at steep slopes and to determine if the same erosional processes documented in slopes <10% are also present at steeper slopes. The project specifically investigated the formation of waterfalls, steps, and plunge pools in steep river channels. Initial experimental results highlight the competing influence of waterfall erosion and river incision on bedrock channel evolution.

Spontaneous Nanoscale Pattern Formation in Chalcogenide Films Electrodeposited Under Simultaneous Illumination by Two Discrete Light Beams

Anjali Premkumar

Mentors: Nathan S. Lewis and Azhar I. Carim

Selenium-tellurium (Se-Te) alloy films grown via photoelectrochemical deposition spontaneously adopt a lamellar structure that is sensitive to the wavelength, intensity, polarization and angle of incidence of the illumination. We report that deposition using simultaneous illumination with two discrete light beams results in additional morphology control and enables the synthesis of structures inaccessible utilizing only a single beam. Growth under illumination from two narrowband sources of differing wavelengths resulted in patterns where the period was a function of the relative intensity ratio of the sources and intermediate to the values that would result from illumination with either of the two sources. Growth using two sources of differing linear polarizations resulted in mesh structures. The angle between the lines of the mesh was dependent on the difference in polarization vector of the sources, and the spacing between the lines was a function of the wavelength of each source. This work represents an advance towards realizing a solution-based, rapid, and scalable process for the growth of ordered nanostructures with intricate three-dimensional nanoscale architectures.
3D Reconstruction and Modeling of a Plasma Loop
Federico Presutti
Mentors: Paul M. Bellan and Quoc Bao Ha

Plasma behavior is particularly complex due to countless internal interactions of both electromagnetic and hydrodynamic nature, thus, physics still lacks a theoretical framework that can deterministically describe the behavior of plasmas. The focus of current plasma research is containment. Spheromaks are a method of creating and containing plasma. They resemble coronal mass ejection. NASA’s STEREO (Solar TErrestrial RElations Observatory) project has been able to reconstruct solar mass ejections in 3 dimensions with twin imaging satellites. A similar method was developed to reconstruct the structure of short lifetime spheromak plasmas using two photographs of the same plasma loop. With this method it is possible to recreate the shape of the plasma as it evolves throughout its lifetime. With these results it is also possible to provide starting conditions or constraints for simulations.

Splitting Methods for Penalized Eigenproblem
Maria Priisalu
Mentor: Brendan Ames

We consider penalized eigenproblems where the leading eigenvector of a positive semidefinite matrix, subject to some structural constraint, is sought. This is, in general, posed as a nonconvex optimization problem. We propose a new nonconvex optimization approach for this task, based on variable splitting and augmented Lagrangian methods. In particular, we decouple the nonconvex structural constraints and objective function, and alternate between minimizing a convex relaxation of the objective and projecting the solution onto the feasible region (here, either the unit sphere or manifold of column orthogonal matrices). We empirically demonstrate that our method improves on existing heuristics for this problem in the quality of the solution for synthetic data, as well as a feature selection component in a linear discriminant heuristic for high-dimensional classification.

Investigating the Effect of A-site Non-Stoichiometry on Cathode Performance
Parul Pubbi
Mentors: Sossina Haile and Chris Kucharczyk

The high theoretical efficiency of solid oxide fuel cells is curtailed by the high temperature at which they must operate to decrease electrical impedance and facilitate the oxygen transport kinetics at the cathode site. The influence of non-stoichiometry in the mixed ionic electronic conductor \( \text{La}_{0.6}\text{Sr}_{0.4}\text{Cu} \) was examined by using the chemical solution process in order to synthesize the compound with a 1:1, 0.9:1, and 0.95:1 ratio and test for correct phase and material performance at intermediate temperatures. Materials with all three vacancies held the desired perovskite phase, and the 10%-deficient powder is expected to have higher performance at intermediate temperature than pure \( \text{La}_{0.6}\text{Sr}_{0.4}\text{Cu} \) as a result of the improved oxygen transport. Subsequent work involves annealing to test phase stability throughout the thermodynamic regime and determining the electrical conductivity of the material via symmetric cell measurements.

Rotational Spectra and Structure of Valproic Acid
Abhijit Krishna V. Puranam
Mentors: Geoffrey Blake and Brandon Carroll

This work examined the spectra of valproic acid in the microwave region to determine its rotational spectra and its structure. This compound is used in the pharmaceutical industry in the treatment of epilepsy and bipolar disorder, but the mechanism by which the compound treats these disorders is not fully understood. The spectra will allow the exact structure of valproic acid to be determined which will be useful to clinical research regarding this compound. To obtain this spectra a chirped pulse, microwave, Fourier transform spectrometer was used from 8 to 17 GHz. Improvements in this technique in ultra-cold environments (2 K) allow relatively easy elucidation of rotational spectra and molecular structure. These spectra were then fitted to theoretically generated spectra which were based \textit{ab initio} calculations of the structure of valproic acid. Thus, the final rotational constants and molecular structure of Valproic Acid were determined.
Characterization of Differentiation Gene Expression During Late Gastrulation of *S. purpuratus*

Eric Qiao  
*Mentors: Eric Davidson and Jonathan Valencia*

Recently, a near-complete survey of transcription factors expressed in *Strongylocentrotus purpuratus* during embryogenesis has been performed. However, the expression of terminal differentiation genes (e.g., those including metabolic genes, detoxification genes, and genes coding for digestive enzymes) and their modes of regulation are less well-known. By relating transcription factor expression to differentiation gene expression, a link can be established between the gut physiology of the sea urchin and the developmental regulatory factors that comprise its gene regulatory network (GRN). In order to do this, we selected sea urchin genes that are homologous to genes encoding human liver- and pancreas-specific proteins and investigated their spatial expression in whole mount *in-situ* hybridization experiments. Embryos were assayed from 24 to 96 hours post fertilization with 12 hour intervals but with emphasis on later stage embryos. Many of these genes, such as *Cpa3*, showed specific expression in a ring of cells within the developing gut. The spatial and temporal characterization of these differentiation genes provides a valuable foundation in understanding the regulatory states they occupy and as a result, will provide insight into their mechanism of regulation.

Transmission Enhancement of Epidermal Metasurfaces

Brynan Qiu  
*Mentors: Ada Poon, John Ho, and Azita Emami*

The integration of wireless technology with miniaturized implantable bioelectronics could enable new classes of diagnostics and treatments. However, the large mismatch in electromagnetic properties between air and biological tissue severely limits the efficiency of wireless transmission. By structuring the surface of the skin on a subwavelength scale, flat electromagnetic devices known as metasurfaces could potentially improve transmission by several orders of magnitude. Such surfaces can modify the radiation wavefront, enabling momentum mismatch to be overcome, but existing metasurfaces themselves exhibit low transmission. Two approaches for transmission enhancement of a candidate metasurface structure have been theorized and applied. Simulations of an improved metasurface design demonstrate a 10.4 dB increase in power transmission efficiency with improved beam steering. This enhancement in transmission allows for the practical development of conformal metasurfaces for wave focusing, steering, and other applications.

Convection Currents and Deep Ocean Climate Change

David Qu  
*Mentor: Yuk Yung*

Decade long periods of hiatus in the long term trend of global-mean surface warming have been observed in the past century. During these hiatuses, the solar heat energy trapped by greenhouse gases in the Earth's atmosphere continues to propagate. Some of the leading hypotheses that explain where this excess heat goes account for the deep ocean's role in convection. In this project, we use the German Estimating the Circulation and Climate of the Ocean (GECCO) model to analyze the deep ocean's temperature profile. The GECCO dataset shows complex patterns in the global mean temperature of the ocean at different depths. The complexity arises from activity in the different ocean basins. For example, the Southern Ocean shows clear trends of warming that is caused by convection currents from warmer oceans. Future research can assess the consequences of these patterns as they evolve throughout the next century.

The Blazar Heated Intergalactic Medium at *z* < 2

Matthias J. Raives  
*Mentors: Juna Ariele Kollmeier and Philip F. Hopkins*

It has been recently discovered that TeV blazar emissions can heat the intergalactic medium (IGM) via plasma beam instabilities, becoming a significant factor in the evolution of the IGM as early as *z* = 3. This mechanism deposits a constant amount of energy per unit volume of the IGM, thus underdense regions gain more energy per unit particle. In this paper, we use cosmological hydrodynamic/N-body simulations which include the effect of blazar heating to examine the statistics of gas in a heated and non-heated universe. We show the that simulations which incorporate blazar heating result in a dramatically different IGM. We explore these statistics in light of past, present and future observations of the IGM.
High-Sensitivity Pump-Probe Spectroscopy to Investigate Ultrafast Phase Transitions in Calcium Ruthenate
Patrick J. Rall

Mentors: David Hsieh and Darius Torchiinsky

In the Hsieh Group we study optically induced ultrafast phase transitions in quantum materials. One of the techniques we use is pump-probe spectroscopy. This technique involves shining a femtosecond laser (pump) pulse onto a crystal to excite electrons out of equilibrium, and then shining a second time delayed (probe) pulse onto the same spot on the crystal in order to measure its instantaneous reflectivity. By taking measurements over a wide range of time delay values, one can extract the temporal evolution of the reflectivity following the initial excitation, which in turn yields information about electronic relaxation processes. The material that we focus on is Ca$_2$RuO$_4$, which is a spin-orbit coupled correlated electron system that undergoes a thermally driven metal-to-insulator transition that is concomitant with a structural distortion. Our goal is to explore the possibility of optically inducing this transition through an ultrafast non-equilibrium pathway. Via implementing shot-to-shot normalization using a combination of boxcar integration and lock-in detection, as well as careful tuning of silicon diodes and other detectors, we build a high-sensitivity pump-probe experiment to effectively study time-resolved reflectivity behavior. The experimental data is analyzed to understand the experimental signatures of the phase transition, the temperature and pump fluence thresholds required to induce it, as well as to gain a concrete assessment of sensitivity improvement.

Structure of an Organorhodium Intermediate in the Production of Solar Fuel
Mario Ramos-Garcés

Mentors: Harry B. Gray and James D. Blakemore

The reduction of protons to dihydrogen, the reductive half of water splitting, requires a catalyst to proceed at a reasonable rate. In molecular catalysis for hydrogen generation, reduced metal complexes react with protons to generate hydrides that can be further reduced or react to generate dihydrogen. Progress in understanding the electronic structure of these reduced metal complexes, however, has been challenging due to their high reactivity and sensitivity to air and moisture. In this project, Schlenk and glovebox techniques have been used to isolate rhodium(I) complexes that are model intermediates in proton reduction catalysis by group 9 metals. Specifically, low-valent rhodium complexes of Cp* (Cp* is pentamethylcyclopentadienyl) with a bidentate chelate ligand (1,10-phenanthroline (phen), 5,6-dimethyl-1,10-phenanthroline (Me$_2$phen), or 4,4’-dimethyl-2,2’-bipyridyl (Me$_2$bpy)) were isolated by treatment of rhodium(III) precursors with sodium amalgam or thallium formate. The isolated complexes were characterized by $^1$H and $^{13}$C NMR spectroscopy. X-ray crystallography was also used to determine the structure of Cp*Rh(phen). The nature of these complexes will be discussed, as well as preliminary findings regarding their electronic structure as explored with electronic absorption spectroscopy.

Understanding the Tectonic Interaction at the Pacific-North America Plate Boundary by Applying Machine Learning Techniques on the OBS Data From the ALBACORE Project
Nishant Rao

Mentors: Julian Bunn, K. Mani Chandy, and Monica Kohler

Many offshore seismic events near the west coast region of North America were difficult to map due to lack of data and limitations in sensor deployment. The Asthenospheric and Lithospheric Broadband Architecture from the California Region Experiment (ALBACORE) was undertaken with an objective to understand the tectonic interaction at the Pacific-North America plate boundary and characterize the physical properties from the data obtained. A network of Ocean Bottom Seismometers (OBS) and hydrophones was functional offshore for a year and the data, low pass filtered below ~5Hz, revealed many unrecorded earthquakes as compared to the United States Geological Survey (USGS). Further, it was also found that the k-Sigma picking algorithm used earlier to pick the seismic events can be improved in terms of reducing number of false positives remarkably by accounting the second moment of the data. Machine learning was applied to train the algorithm in determining relevant changes in parameters. The hydrophone data was also useful in characterizing the tidal motion near the coastal line and far from it.
Phosphine Catalyzed Asymmetric Intermolecular Oxygen γ-Addition
William Reichard
Mentors: Gregory C. Fu and Daniel Ziegler

There exist many methods which can be used to introduce stereocenters into the alpha and beta positions of carbonyl compounds, however there are few known methods which can be used to introduce stereocenters in the gamma position. A phosphine catalyzed process for the asymmetric gamma addition of oxygen nucleophiles to carbonyl compounds is under development. Conditions which currently offer the best yield (85%) and high enantiometric excess (96%) are shown below.

\[ \text{OMe} \quad \text{tBuO}_2\text{C} \quad \text{PMB-OH} \quad 10\% (R)-\text{SP} \quad \text{toluene, r.t.} \quad 0.25 \text{ M, 24 h} \quad 85\% \text{ yield} \quad 96\% \text{ ee} \]

Micropillar Fabrication on Human Trabecular Bone by Electron-Beam Lithography and Reactive-Ion Etching
Stephanie Reynolds
Mentors: Julia Greer and Ottman Tertuliano

As the median age of our population increases, bone disorders such as osteoporosis are becoming more prevalent. Because of this, bone scaffolding treatments need to be improved. This requires a more complete understanding of the mechanical properties of bone at length scales that vary several orders of magnitude so that we may better replicate the biomaterial. However, mechanical testing at the microscale generally involves using a focused ion beam to fabricate micropillars, which takes time and skill and could result in ion implantation. As an alternative, this project aims to create a micropillar array on the surface of human trabecular bone, using a combination of electron-beam lithography and reactive-ion etching. Though this project has not yet been completed, we have found that oxygen plasma can be used to etch away the organic matrix of bone, leaving behind hydroxyapatite crystals. Further research will require the selection of a suitable chemical wet-etching or physical dry etching procedure to remove hydroxyapatite, followed by the integration of electron-beam lithography to create a mask and thus a micropillar array. If successful, we will have designed a high-throughput method of fabricating bone micropillars for mechanical testing.

Synthesis and Characterization of Cobalt(III) Hydrides
Gerri Roberts
Mentors: Jonas Peters and David Lacy

Cobalt complexes with diimine-dioxime ligands have been shown to catalyze the hydrogen evolution reaction. The mechanism of this process is not yet known, though the current proposed mechanisms involve cobalt(III) hydride intermediates. Due to their high reactivity, cobalt(III) hydrides have only been characterized with stabilizing phosphine ligands that are not catalytically relevant. For example, the Co(III) hydride complex with a nitrogen macrocycle, \([\text{CoH(dmgH)}_2\text{P(n-C}_4\text{H}_9)_3]\), has been reported before, but some conflicting results warrant further study. We aim to reproduce the literature synthesis of this hydride and complete its characterization. We also aim to use the information from this study to synthesize new hydride complexes and explore their properties in context with hydrogen evolution electrolysis.

Measuring Surface Coverage of Methylated Si(111) Surfaces Using Infrared Spectroscopy
Constance D. Robinson
Mentors: Nathan S. Lewis and Shu Hu

Photoelectrochemical cells are an important area of inquiry as the world faces an energy crisis. These cells require materials with useful electrical and chemical properties in ambient conditions. In particular, key chemical reactions and charge transfer steps occur at the interface between silicon and the surrounding air or solution, and functionalizing silicon surfaces provides control over these interactions. Mixed monolayers potentially allow for surfaces to be functionalized with groups that allow for secondary chemistry, while protecting sites that don't have these reactive groups with methyl groups for example. However, characterizing such surfaces is sometimes not possible using X-ray photoelectron spectroscopy (XPS), especially when there are no heteroatoms, such as in a mixed allyl/methyl monolayer. By the same principle as the Beer-Lambert Law, it is expected that it is possible to quantify the coverage of methyl groups on a silicon surface using only infrared (IR) spectroscopy by measuring the area of characteristic peaks in the IR spectrum. We find that there is a correlation between coverage and peak area. It is unclear at this point whether it is strong enough to be useful in characterizing mixed monolayers with methyl groups.
NMR Spectroscopy of Aqueous Solutions of Thioesters and Metallic Ions
Joseph Roddy
Mentors: Paul Bracher and Douglas Rees

We have developed a method that allows $^1$H NMR spectroscopy to serve as a viable means of measuring the kinetics of organic reactions in aqueous solution despite the presence of high concentrations of transition-metal ions. Many metal ions are paramagnetic, and when present in aqueous solution above ~10 mM, these ions can render NMR spectroscopy unreliable due to peak broadening of the water signal. In order to obtain viable NMR spectra and measure reaction rates, we devised a method that removes these ions prior to analysis by precipitating them as phosphate (or to a lesser extent, arsenate) salts. We show that removal of paramagnetic ions by our method can improve spectra, and also show control experiments that indicate samples treated with this procedure suffer no changes in concentrations of the organic solutes we wish to measure. Potential applications of this method include determination of reaction rates of paramagnetic metal-catalyzed hydrolysis of esters and thioesters by integration of NMR spectra.

Studies Toward the Synthesis of [Cu(CF3)4]-
Andrew M. Romine
Mentors: Vladimir V. Grushin and Robert H. Grubbs

The homoleptic, mono-anion [Cu(CF3)4]- is one of the most intriguing Cu(III) derivatives reported. This remarkably interesting, stable anion, however, remains poorly studied due to the lack of a straightforward and efficient procedure for its preparation. Multiple studies were performed toward the development of a new, operationally-simple, and high-yielding method for the synthesis of [Cu(CF3)4]-. In the first phase of research, inorganic Cu salts were in the presence of Ruppert’s reagent, CF3SiMe3, as the CF3 source and various oxidants (air, O2, H2O2, K2S2O8) in various solvents. Although the formation of [Cu(CF3)4]- in these experiments was detected by $^{19}$F NMR, the yield was ca. 50% at best. Furthermore, the reactions were insufficiently reproducible in many instances. Therefore, in the second phase of the projects the synthesis of [Cu(CF3)4]- by air-oxidation of CuCF3 in DMF (obtained by the direct cupration of CHF3) in the presence of CF3SiMe3/KF was attempted. This approach appeared considerably more fruitful; after preliminary, incomplete optimization, [Cu(CF3)4]- could be produced in this way in nearly quantitative yield. In a scale-up experiment, [PPN]+ [Cu(CF3)4]- was obtained and isolated as a spectroscopically pure compound in >99% yield on a gram scale. The structure of this salt was confirmed by single-crystal X-ray diffraction.

CO2 Reduction Catalysis of Electrodeposited Transition Metals and Transition Metal Alloys
Jeffrey N. Rosenberg
Mentors: Nate Lewis and Daniel Torelli

The objective of the project is to find a new CO2 reduction catalyst based on electrodeposited transition metals and alloys capable of producing more reduced products. Alloy combinations were chosen based on metal carbide binding energies and a combination of high CO2 reduction and low HER catalytic activity. These combinations would hopefully result in compounds with combined or intermediate characteristics of the two metals. Samples were created by electrodeposition or coelectrodeposition onto graphite disc substrates then were tested at potentials from -1V to -2V vs. Ag/AgCl to characterize CO2 reduction catalytic activity. We have shown that electrodeposited Ag is more selective for CO2 reduction than bulk Ag benchmarks, specifically noting increased faradaic efficiency for CH4. The Ag was further analyzed by XPS to rule out trace Cu or other transition metals. SEM/EDS was preformed to characterize the structure of the deposition material, revealing micro branched clusters with nano mesh as the active sites. Issues of decay and variability in results require further investigation of the material, including study of deposition conditions, substrate dependence, and more work with alloys.

A Neurocognitive Computational Approach to Understanding Theory of Mind
Isabelle Rosenthal
Mentors: Ralph Adolphs and Damian Stanley

Theory of Mind (ToM), the mental ability to represent other people's beliefs and intentions, remains a faculty that is poorly understood on a computational level. While a “mentalizing network” of implicated brain structures exists, the interaction of these structures and their specific functions still requires further study. In this experimental protocol, ToM is investigated through a novel, multi-trial task which bears a similar structure to past ToM tasks, but requires subjects to update their representations of an agent's beliefs and intentions continuously over time, while also introducing a factor of uncertainty. Using pilot data, both Rescoria-Wagner update rule models and Bayesian models of subjects’ representation of agent belief and intention were constructed which were able to describe participant behavior with ~70% accuracy. These models were used to select optimal versions of agents to use in the main experiment (Mentalizer task), for running on subjects in an MRI. This neurological data collected with the Mentalizer task can be used in conjunction with our models to identify neural correlates of uncertainty and surprise, and to gain a better understanding of the computations underlying ToM.
Characterization of Liquid Metal Oxide for Micropropulsion Applications
Tatiana Roy
Mentors: Sandra M. Troian and Colleen Marrese-Reading

Micro-electrospray thrusters are in development for the fine adjustment of the position and orientation of small spacecraft, such as CubeSats. These thrusters use liquid indium droplets as the propellant, driven by an electric field. The current design for the emitters requires the liquid indium to wick up a nanopillar. Though simulations have been done to characterize the wicking behavior of the liquid indium, it has been found that these simulations did not take into account the formation of an oxide layer over the liquid indium. Since these thrusters are designed for what is necessarily an extremely well-controlled application, it is very important that we characterize this oxide layer in order to understand how it is affecting the thruster performance. We are performing v-groove wicking experiments that will allow us to carefully observe the wicking behavior of liquid metals with an oxide layer, and studying the mechanical properties of the oxide layer itself.

Segmental Residue-Specific Incorporation of Non-Canonical Amino Acids Into Proteins
Xander Rudelis
Mentors: David Tirrell and Kai Yuet

Strategies for biosynthetic incorporation of non-canonical amino acids (ncAAs) into proteins can be classified as either “residue-specific” or “site-specific”. In a residue-specific method, a ncAA replaces a canonical amino acid wherever the messenger RNA template which directs the protein’s synthesis dictates the original amino acid. In a site-specific method, a ncAA replaces a canonical amino acid at the specific location within the protein. Inteins are structural components of proteins which excise themselves from the protein. In the process, they also catalyze the formation of a peptide bond between the adjacent sequences (exteins). Thus the protein remains intact with no trace of the intein (cis-splicing). Split inteins, engineered from natural inteins, can catalyze trans-splicing of separate proteins. In an effort to combine the simplicity and high yield of residue-specific incorporation and the specificity of site-specific incorporation, we propose an intein-based strategy that enables residue-specific incorporation of ncAAs into segments of proteins.

Wide Field-of-View Talbot Microscopy for 3-D Fluorescence Imaging
Donghun Ryu
Mentors: Viviana Gradinaru and Rajan Kulkarni

Recently, CLARITY, a novel method for rendering tissues and whole-body (including brain and organs) optically transparent was developed. CLARITY works by removing lipids, which induce the scattering of light, while retaining fine structure and biological molecules within tissues. In order to visualize large transparent tissues using the CLARITY method, confocal microscopy, two-photon microscopy and light-sheet microscopy have been attempted. However, none of these microscopy methods achieve simultaneous wide field-of-view (FOV) and long working distance (WD) imaging of whole clarified tissues. Here, we present a novel microscopy method for wide FOV and 3D fluorescence imaging, termed Talbot microscopy. The unique component of the Talbot method is a micro-lens grid to generate focal spots at the sample; these focal spots from the micro-lens grid can be periodically generated due to the Talbot effect, which could provide sufficient working distance to image cleared tissues which are a few centimeters-thick. Also, the Talbot prototype provides wide FOV since the FOV is determined by the size of a laser beam and the FOV of a camera. Unlike objectives of confocal, two-photon and light-sheet limit the FOV, large number of focal spots focused into large SLR lens allows wide FOV. We predict that this wide FOV and long WD of the Talbot microscopy will allow us to investigate the global structure of cleared thick tissues.

Probing Early Galaxy Formation With High-Redshift Archaeology
Allan E. Sadun
Mentors: Peter L. Capak and Charles L. Steinhardt

The universe’s first massive galaxies are believed to have formed between 500 and 1000 Myr after the Big Bang, due to theoretical and observational constraints on either side, but this formation has not been directly observed and has not been characterized well. Understanding the formation of these galaxies will shed light on our understanding of dark matter clumping, and the James Webb Space Telescope will help when it launches in 2018. However, it may be possible to draw conclusions before then by an indirect analysis of more recent galaxies. The star formation history of a galaxy leaves a ‘fossil record’ in its current spectrum, and several studies have successfully determined star formation histories of low-redshift galaxies using ‘galactic archaeology’. We investigate the noise resilience of this technique as applied to dusty, high-redshift galactic photometry as well as to dusty, high-redshift galactic spectra, and evaluate the precision necessary for a conclusive probe into the formation of galaxies between redshifts 6 and 10. Finally, we review a few existing high-redshift data sets and examine the utility of a follow-up spectroscopic or photometric survey within the next five years.
fMRI Motion Correction for Accurate Implementation of Gaze Estimation
Sarthak Sahu
Mentors: Ralph Adolphs and Mike Tyszka

Gaze estimation in videos is an essential tool in social cognition research because it allows researchers to identify objects and features receiving visual attention in a scene. One of the most common methods of gaze tracking is through the use of infrared illumination and its corresponding reflections from the cornea known as glints. A major drawback of using glints to estimate gaze is that if they are lost in the video then the gaze calibration breaks down and accuracy is lost. Unfortunately, any slight movement of the head, even with the use of restraints, can result in the loss of these glints, which would render the video useless. The goal of this project is to develop a python program that accurately implements a gaze estimation method using a single calibration that would work independently of glints.

Reconstructing Paleoenvironment Around Lake Ghirla Using Sediment Core Samples
Yuka Sakazaki
Mentors: Alex L. Sessions and Stefanie B. Wirth

A series of sediment cores was taken from the bottom of Lake Ghirla, Italy – they are layers of lake history spanning 13,000 years, containing various information about the environment in and around the lake. Here we focused on the total organic carbon (TOC) concentrations and the organic carbon isotope ratios (δ13C), which can be used to infer the change in productivity of plants according to their various types. In order to make these organic carbon measurements, inorganic carbon was removed by treatment with 10% hydrochloric acid. Then the carbon concentrations and isotope ratios of the remaining sediment were measured using an elemental analyzer. According to the TOC results so far, the overall productivity has been fluctuating with an increasing trend from 10,000-4,000 years ago and a decreasing trend from 4,000 years ago to present. From the fairly steady increase in δ13C values, plants with C4 metabolism seem to have been increasing in productivity faster than plants with C3 metabolism.

Experimental Observations of Lattice Defects in a Two-Dimensional Macroscopic Particle Interaction Model
Aashrith Koundinya Saraswathibhatla
Mentors: Dennis M. Kochmann and Charles Wojnar

The study of microstructural defects of crystalline solids is very crucial in understanding the material properties. As the experimental study of these defects at the atomic level is very difficult, a macroscopic model is built using thousands of packed small-sized spheres which represents the crystal structure of a metal. The model consists of an assembly of thousands of plastic spheres, three millimeters in diameter, in a single two-dimensional layer. This assembly gives insight into the behavior of defects such as grain boundaries, vacancies and dislocations. Experiments were also performed to observe the changes in grain boundaries during fracture. Further, the project will be extended to study the changes in microstructural defects such as patterns of spheres in grains, changes in vacancies, slipping of grain boundaries and sliding of dislocations when spheres are subjected to vibration to illustrate the effect of temperature in crystalline solids.

Designing a Toolbox of RNA Thermometers
Rohit Satija
Mentors: Richard Murray, Shaunak Sen, and Dan Siegal-Gaskins

RNA Thermometers (RNATs) are temperature-sensing elements present in the 5’-UTR regions of genes in certain organisms and have a property of changing their secondary structures in response to temperature shifts, consequently regulating gene translation. Previously, frameworks for designing simple synthetic RNATs with different temperature profiles have been reported. However, it is generally unclear how to systematically tune temperature response profiles. To address this issue, we have developed certain platforms in cells as well as in cell free expression systems to validate, test and quantify RNAT activity. We have also investigated computational tools for designing novel RNATs. Finally, we aim to test these computational predictions by experimentally synthesizing novel RNATs and using them to generate a temperature-dependent pulsed gene circuit. These results should present temperature-dependent RNAs which can be used to increase robustness or sensitivity of bio-molecular circuits.
Identification of Variable and Periodic Astronomical Sources in the Galactic Plane Using the Palomar Transient Factory
Gandalf Saxe
Mentors: Thomas A. Prince and Eric Bellm

The Palomar Transient Factory (PTF) is a wide-angle, high cadence automated survey telescope designed to systematically explore the transient and variable sky. Up until recently, PTF measurements were mostly limited to a region at least 20 degrees from the Galactic Plane. This is due to the difficulty of reliably separating sources in crowded fields by automation. However, the PTF group have developed techniques to operate at lower galactic latitudes, all the way down to zero degrees, i.e. the Galactic Plane itself. No other sensitive survey has ever been able to survey the Galactic Plane with good cadence and comparable sensitivity.

Our aim is to identify and characterize variable sources in the new data. This includes querying large databases, performing various cuts to further reduce false positives, verifying detections by studying source images, cross matching with other surveys and doing follow-up observations with 60" telescope at Palomar for spectrum. So far multiple objects with variations of 2.5+ magnitudes of brightness have been found and are in the process of being verified for final characterization.

Device-Independent Tripartite Quantum Key Distribution From Three-Player Non-Local Games
Mahrudd Sayrafi
Mentor: Thomas Vidick

Quantum entanglement, one of the most counter-intuitive phenomena in quantum theory, has long been studied in information theoretic contexts. It is known that use of entanglement in multiparty game strategies can lead to arbitrarily large advantage over classical players. These violations of classical bounds, known as Bell’s inequalities, are due to the nonlocal nature of the correlations. Here we introduce a protocol for key distribution among three parties who share nothing other than entangled quantum states and we show that the parties can use nonlocal games to prove the security of the protocol without any initial assumptions about the states or the measurements except for the no-signaling assumption. Further, we aim to make the protocol resilient against a corrupted player by enabling the two remaining players to use the partial entanglement to produce a key independently. This research contributes to the study of non-locality in the reduced bipartite state of an entangled state that maximally violates a tripartite inequality.

Enantioselective Nickel-Catalysed Reductive Cross-Coupling to Form Alpha-Aryl Nitriles
Robert Scanes
Mentors: Sarah Reisman and Nathaniel Kadunce

In recent years there has been much success in the development of reductive cross-coupling methods, which provide many advantages over classical cross-couplings due to the requirement of fewer steps and the utilisation of safer, more stable and often cheaper reagents. In this work nickel catalysed enantioconvergent reductive cross-coupling methodologies are optimised between alpha chloronitriles and aryl iodides to form alpha aryl nitriles. This is with particular aim to developing general approaches for these and similar couplings. A promising novel phosphinooxazoline (PHOX) ligand is formed and tested for activity in these couplings (results pending). Syntheses of two bioactive target molecules are attempted, demonstrating the utility of the developed cross-couplings.

Heat-Bath Algorithmic Cooling in Noisy Open Quantum Systems
Nicholas Benjamin Schiefer
Mentors: John Preskill and Fernando Pastawski

Many applications of quantum mechanics, including fault-tolerant quantum computation and magnetic resonance imaging, require the simultaneous near-certain preparation of qubits in their ground state. Through a combination of quantum gates and interactions with a surrounding heat bath, heat-bath algorithmic cooling allows this qubit initialization process to produce qubits with an entropy far below the Shannon limit. While a number of provably-optimal algorithms have been developed for heat-bath algorithmic cooling, existing proposals have been analyzed under the unrealistic assumption that certain, so-called *computational*, qubits can be kept completely isolated from the environment. We consider an extended model of the thermalization process that considers the noisy effects of imperfectly-isolated computational qubits. Through analytic and computational methods, we find that existing optimal algorithms often perform worse under this noisy model for realistic parameter regimes than under previous thermalization models. We also propose an algorithm that produces a final preparation of qubits in their ground state with a higher probability than existing methods in the presence of thermalizing computational qubits. Because the efficacy and efficiency of many applications depend on the achievable purity of the initialized qubits, better heat-bath algorithmic cooling methods have the potential to improve the performance of many applied quantum systems.
Modeling the Thermal and Physical Evolution of the Sedimentary Rocks of Mount Sharp, Mars
Caue Sciascia Borlina
*Mentor: Bethany Ehlmann*

Gale Crater, landing site of the NASA Mars Science Laboratory (MSL) mission, has a unique sedimentary stratigraphy which remains preserved in a 5 km high mound called Mount Sharp. Understanding the processes of sedimentation, erosion and formation of the mound can reveal important information regarding past habitability and the presence of water at the surface of the planet. Two plausible scenarios for Mt. Sharp’s formation include: 1) a complete filling of the crater followed by partial removal; 2) building of a central deposit with morphology controlled by slope winds. Here we consider depths of burial predicted for both scenarios, and we relate them to a thermal model. The results are compared with chemical and mineralogical instrument analysis by MSL to identify the presence of minerals that serve as markers for particular temperature regimes. Results may explain the past chemical and geological history of the red planet, describing how transformation happened across the years and why we see a dry and cold environment on modern Mars.

Probing the Inner Regions of Protoplanetary Disks Using NIRSPEC
Charles Scott
*Mentors: Geoff Blake and Nathan Crockett*

Understanding the mechanisms by which young planetary systems, so called protoplanetary disks, evolve continues to be a fascinating area of research within astronomy. Observing time dependent variability of the gas within several AU of the central star provides valuable insight into the distribution and structure of these systems in regions where terrestrial planets are thought to form. Using the spectro-astrometric technique, which probes such gas, we analyzed observations collected in the M-band spectral region taken over the past three years from the Near Infrared Echelle Spectrograph (NIRSPEC) on the Keck II telescope in Hawaii. Specifically, we looked for time variability in both the spectro-astrometric and flux line profiles of CO emission lines of a sample of young nearby protoplanetary disks. From these data, the signals expected from protoplanetary disks and outflows as well as indications of time variability are observed.

In-vivo Testing and Optimization of Integrated CMOS Glucose Sensors
Mehmet Sencan
*Mentors: Axel Scherer and Muhammad Mujeeb-U-Rahman*

Continuous monitoring of body analytes is beneficial for health. Implantable, fully-integrated, millimeter-scale, wireless sensors can achieve continuous monitoring in a minimally invasive and effective manner. Presented is a development and evaluation of a continuous glucose monitor in subcutaneous tissue of rats. Millimeter-scale wireless electrochemical sensors were implanted subcutaneously in healthy rats. Tissue and organ samples were taken for histopathology. The sensors will be optimized and functionalized for glucose sensing and implanted in diabetic rats. The functionalization chemistry will be tested for enzyme leaching and performance during continuous and termittent operation. Mean absolute relative difference (MARD) between the sensor and a commercial reference will be evaluated both in-vivo and in-vitro.

Light-Directed *in situ* Synthesis of Oligonucleotide Barcodes for Mapping the Spatial Distribution of Proteome in Single Cells
Jinyoung Seo
*Mentors: Long Cai and Chang Ho Sohn*

Cells adapt to variations in their environment by altering the ensemble of proteins they express. Thus, obtaining the quantitative *in situ* information on both the identities and cellular locales of proteins in a given proteome of individual cells is of paramount importance for understanding a cell’s phenotype in a systematic fashion. In this project, we aimed to develop chemical methods to encode the spatial information of proteins of interest in individual cells by synthesizing site-specific oligonucleotide barcodes *in situ*. Synthetic strategies are based on solid-phase oligonucleotide synthesis by the phosphoramidite method. A key challenge is to find optimal reaction conditions for the highest accuracy, maximum yield, and minimum perturbations to cellular components. Intracellular environment of fixe cells is, however, extremely complex; intricately cross-linked cellular matrix and proteins contain nucleophilic functional groups. In order to examine the feasibility of the synthetic approaches, we characterized the coupling reaction, nucleophilic substitutions between activated phosphoramidites and 5’-hydroxyl groups, on fixed mouse fibroblast cells, using single-molecule fluorescence *in situ* hybridization and *in situ* hybridization chain reaction. In addition, we will investigate the robustness of the reactions by synthesizing four nucleotides on linearized pUC19 plasmids in fixed *E.coli* cells. The elongated plasmids can be confirmed by denaturing polyacrylamide gel electrophoresis after amplified by linear PCR.
Validation of Nanoscale Measurements Using NEMS Mass Spectroscopy
Marec Serlin
Mentors: Michael Roukes and Adam Neumann

Nanoelectromechanical systems (NEMS) are a class of devices integrating both electrical and mechanical functionality on nanoscales. We can manufacture NEMS with characterizeable resonances known as NEMS resonators. These can detect the mass of adsorbed particles with exceptional sensitivity through a process known as NEMS-based mass spectrometry. NEMS mass spectrometry provides several advantages over conventional methods: it provides a resolving power that increases for very large masses and allows for real-live molecule-by-molecule acquisition of spectra. As each molecule in the sample adsorbs on the resonator, four driven vibrational modes are tracked to determine its mass, position of adsorption, and size moments. We validate this technique by systematically investigating the sample adsorption process and the size moment determination statistics from the NEMS frequency data. We verify the state of the particles, once adsorbed, and characterize their sizes using Atomic Force Microscopy (AFM). We compare the established statistical methods to a Bayesian model using experimental data as well as theoretical data created using a Monte Carlo simulation. The results of the statistics on the experimental frequency data are compared to the sizes characterized by AFM to validate the process.

Fabrication of Nanotruss Cathodes for Lithium/Air Batteries
Parth Shah
Mentors: Julia Greer and Chen Xu

The principle objective is to fabricate nanotruss cathodes for a lithium/air battery. Nanotrusses are 3-Dimensional hierarchical structures with micron-sized pore sizes and high surface area, suitable for Li-Air battery cathodes. Prior to the fabrication of the nanotruss, a substrate consisting a stainless steel back contact with one side completely covered by SiO₂ except a 500umx500m well in the center is fabricated. Next, a nanotruss is "written" into the well using two-photon lithography. The written polymer structure is then coated via sputtering with materials commonly used in Li-Air research, such as Au or Ti. In addition, a microlattice fabricated via a self-propagating waveguide technique is also being fabricated as a Li-Air cathode. The scalability in the manufacturing of the microlattice, combined with its extreme lightweight and superb mechanical properties, may prove to be an air cathode with novel properties.

Characterizing Young Variable Stars in the Monoceros R2 Cluster
Elly Shao
Mentors: Lynne Hillenbrand and Luisa Rebull

The Mon R2 cluster within the Monoceros R2 molecular cloud is a stellar nursery rich in young stellar objects (YSOs). This cluster was monitored with the Spitzer space telescope in the mid-infrared over a 44-day period, resulting in time series photometry for 710 point sources. We have assembled spectral energy distributions for these sources from the VRI band in the optical, to JHK in the near infrared, to Spitzer observations at 3.6 to 24 μm. Out of these sources, we have confirmed 174 YSOs, 166 short-term variable sources, and 63 long-term variables. YSO cluster members are defined through their infrared excess and X-ray emissions. The short-term variables are identified through a high Stetson index, a high χ² when fitted to a flat light curve, or periodicity. The long-term variables are identified by comparing the mean magnitudes of this observing campaign with preexisting data. The YSOs exhibit a wide range of variable behavior, likely due to inhomogeneity in the circumstellar disk.

Optimization of Distance and Power for the Mars Rover
Samriddhi Sharma
Mentors: Richard Murray and Ioannis Fillipidis

The Mars rover operates on limited resources and time, and so we want to maximize the number of objectives completed for distance and power. Power and objective optimization deals with completing the maximum value of objectives while consuming the least power. This project deals with implementing code to optimize the rover for battery, as it is currently manually driven. To achieve this objective, we first obtained data regarding voltage drop over time, as the rover continuously drives straight, turns right, turns left, drives up various inclines. With this data, we know how the battery depletes for the rover's different actions. Then, we incorporated this data into a script that finds a feasible path across a given map with a cost upper bound on the path.
Investigating Potential Interactions Between Gut Microbiota, Serotonin, and the Immune System
Gauri Shastri
*Mentors: Elaine Hsiao and Jessica Yano*

Gut microbiota play an important role in producing neuroactive molecules. Our lab has shown that particular subsets of spore-forming bacteria normally present in the intestine are critical for promoting host serotonin biosynthesis. While little is known about this particular community of microbes, recent studies indicate that indigenous spore-forming bacteria elevate levels of immunosuppressive T regulatory cells in the mouse colonic lamina propria. In light of the increasing appreciation that serotonin modulates various aspects of innate and adaptive immunity, we asked whether the immunosuppressive and serotonergic functions of spore-forming bacteria are conferred through convergent mechanisms, or whether they occur through independent, parallel pathways. To determine whether serotonin is necessary for the ability of spore-forming bacteria to induce colonic T regulatory cells, we isolated lymphocytes from the colonic lamina propria of germ-free (GF) mice, conventionally-colonized (specific pathogen-free, SPF) mice, GF mice colonized with spore-forming bacteria, and GF mice colonized with spore-forming bacteria and intrarectally injected with parachlorophenylalanine (PCPA), an inhibitor of serotonin synthesis. Lymphocytes were stained with antibodies to identify T regulatory cells. The percentage of T regulatory cells from the colonic lamina propria was measured by flow cytometry. To determine whether serotonin is sufficient to induce colonic T regulatory cells in GF mice, we measured T regulatory cell levels in GF mice intrarectally injected with serotonin. Finally, we measured colonic T regulatory cells from mice harboring a genetic mutation in the serotonin transporter, SERT, which enables serotonin uptake by cells. Overall, our findings reveal a potential interaction between microbiota-mediated increases in serotonin biosynthesis and colonic T regulatory cells.

Biological Imaging Using Genetically Encoded Magnetic Reporters
Jiemin Jenny Sheng
*Mentors: Mikhail G. Shapiro and Pradeep Ramesh*

The boundaries of observation have often been limited by visual perception. In order to surpass this limitation, it is necessary to develop a novel method of non-invasive imaging. The method that we propose is a genetically encoded, contrast enhancing, MRI agent. We wish to exploit this function in individual cells by genetically engineering cells to produce T2 contrast agents. In order to tackle this problem, we turn to magnetotactic bacteria. Magnetotactic bacteria form magnetosomes naturally; the iron oxide magnetosomes are ideal candidates for T2 agents in cells. Recent efforts have led to mammalian expression of many of these native magnetotactic bacteria proteins as demonstrated through a series of assays including western blot analysis and confocal microscopy. Through this, we have demonstrated that bacterial proteins may be expressed in mammalian cells. The challenge remains to express the entire set of proteins sufficient for magnetosome formation. We hope that with future efforts we will soon be able to demonstrate compartment formation and crystal nucleation, both essential for the formation of magnetosomes.

Jingwei Shi
*Mentors: Sossian Haile and Yoshihiro Yamazaki*

Solid-oxide fuel cells have the potential to have the rare combination of efficiency and sustainability. One obstacle preventing widespread implementation of solid-oxide fuel cells is finding a suitable proton conducting electrolyte with high conductivity in the intermediate-temperature region. Yttrium-doped barium zirconate has been identified as a good candidate that fits this criterion, but the discovery of fundamental processes that underlie proton conduction suggests that there are better candidates for the dopant element. The interaction between proton and dopant (proton trapping) is one process that directs the search for ideal dopant elements that minimizes this interaction. The goal of studying the proton conductivities of gadolinium, erbium, and lutetium-doped barium zirconate is to confirm that erbium gives the lowest proton trapping energy and highest proton conductivity.
Enhancement of the Efficiency of the Solar-Powered Wastewater Treatment System by Modifying the Properties of Semi-Conducting Metal Oxide Coatings on the Electrochemical Cells
Jieun Shin
Mentors: Michael Hoffmann and Kangwoo Cho

In the solar-powered wastewater treatment system developed by Dr. Michael Hoffmann’s research group at Caltech, one of the key steps in the fundamental mechanism involved is the oxidation of wastewater at the anode in order to initiate the formation of reactive chlorine species (RCS) for decomposing organic contaminants. In order to enhance the electrochemical activity of Titanium anodes, double layer hetero-junction electrodes were fabricated and the optimal thickness of the semiconducting metal oxide layers was investigated. IrO2 layers were employed between a Ti plate and TiO2 overcoats in order to facilitate efficient electron transfer by establishing the ohmic contact. The thickness of semiconducting layers was adjusted by repeating the coating procedure on top of previous layers by the process of thermal decomposition, and the concentration of the RCS was quantified by the potentiostat analysis and the colorimetric DPD method. The current efficiency is expected to increase as the number of iridium pre-coat layers increases due to better conductivity. The thickness of TiO2 overcoats would not really affect the current efficiency of the electrodes, since the metal hydroxyl radicals adsorbed on the outermost surface of the Titanium oxide coating are primarily responsible for generating the RCS only through the surface interactions.

Automating Microscope: Developing Front End GUI Software
Ji-Soo Shin
Mentor: Long Cai

In Professor Cai’s lab, we aim to build a 3D microscope with relatively cheap equipment (2D microscope), and further perform completely automated experiment on it. To do so, my task was to develop complete GUI front end environment that control next six dimensions: X stage, Y stage, APT stage, Z stage, Motor, and Channel. The user of the program will be able to perform various scan that combines all these dimensions; for example, varying channel across varying Z-Stage while matching APT Stage along with specific Z-Stage will be one of many things the program will allow the user to do. In this program, my final goal has become to give full control to the user to do all kinds of scan. To put it easily, the basic idea will be to make a massive streamline function that handles 7 dimensional matrix (currently five dimensions – X,Y, APT, Z, Channel – and two dimensions of image can be handled by the program), and the structure of program allows easily for any user to directly increase the number of dimensions. And, this main controller function has penta nested for loops that will adjust itself accordingly to the user’s input, thus allowing even more freedom than the user would have had in the software micromanager. With this program, I previously set my goal to develop the clone of software micromanager; however, this program will be further developed to the one that will suit this particular lab environment.

Design of Waveguide Splitblocks for TIME-Pilot
Corwin Shiu
Mentors: Matt Bradford and Steve Hailey-Dunsheath

TIME-Pilot will probe the redshifted 157.7μm line of singly ionized carbon [CII]. [CII] tomography will enable the statistical detection of the dwarf galaxies believed to have been responsible for the balance of UV photons during reionization, and will further our understanding of early star formation, and the process of reionization. TIME-Pilot will use a novel technique, 3-D spectral intensity mapping, through the use of 32 single polarization spectrometers, arranged in two stacks of 16 for each polarization. The spectrometers use a parallel plate grating architecture to diffract and focus single mode onto a transition edge sensor (TES) array. We report the waveguide designs that couple incident radiation from direct drilled feed horns into the spectrometer stacks and discuss design principles to minimize loss over the 180-330GHz band.
Identification of the Most Efficient Alkyne Beads for Enrichment of Newly Synthesized Proteins Tagged by Bio-Orthogonal Noncanonical Amino Acid Tagging (BONCAT)
Dayeon (Judy) Shon
Mentors: David A. Tirrell and Shannon Stone

Cells are constantly producing proteins, and without an efficient tagging method, it is impossible to distinguish newly-synthesized proteins from pre-existing proteins. BONCAT and stable-isotope labeling with amino acids in cell culture (SILAC) are used to specifically tag proteins in a time-resolved manner. Using BONCAT, the tRNA synthetase responsible for protein production uses azidohomoalanine (AHA) as a surrogate for methionine. AHA contains an azide functional group that can be pulled down with alkyne beads using a copper-catalyzed azide-alkyne cycloaddition reaction. Tagged proteins are then isolated and identified through liquid chromatography-mass spectrometry (LC-MS/MS). Using pulsed SILAC, cells are labeled with either "light" or "heavy" lysine, and previously synthesized proteins are identifiable from new proteins through a shift in mass. For this particular experiment, AHA and light/heavy lysine were incorporated into a strain of methionine- and lysine-auxotrophic E. coli. Various alkynyl or cyclooctyne beads were clicked with the samples and tagged proteins were isolated. The heavy/light ratio of peptides was determined for each bead through LC-MS/MS to determine which bead results in a higher ratio of newly-synthesized proteins. We hope to maximize protein enrichment to identify proteins important in the infection process for bacterial diseases so new treatments can be developed.

Delocalization Phenomena for Quasi-Periodic Schrödinger Operators
Laura Shou
Mentor: Christoph Marx

The spectral theory of quasi-periodic Schrödinger operators captures an interesting physical phenomenon known as "metal-insulator transitions". An important quantity to study these transitions is the Lyapunov exponent (LE), which relates the spectral properties of the operator to asymptotic behavior of the associated dynamical system. By complexifying the phase and hence examining the complexified LE, the spectrum can be partitioned into subcritical, supercritical, and critical energies. For Schrödinger operators with potential given by a trigonometric polynomial of cosines (called generalized Harper's model), we use the complexified LE to prove a criterion for subcritical energies in the spectrum. This subcritical behavior implies zero LE and pure ac spectrum, which physically corresponds to delocalization and metal-like behavior. We also study this criterion numerically.

Measuring Cosmogenic 3He in Rock Samples From the Channeled Scablands to Characterize the Megaflooding of Glacial Lake Missoula
Elliot Simon
Mentors: Michael P. Lamb and Isaac James Larsen

The Channeled Scablands is a region in eastern Washington that was theorized to have formed by the megaflooding of the glacial Lake Missoula at the end of the last ice age. Despite years of research, there have not been definitive age constraints placed on many formations in the Scablands. For this study 46 samples were collected from various terraces at different locations around the Missoula Valley along the Columbia River. Two minerals, ilmenite and augite, were isolated from these samples and run through a Mass Spectrometer to calculate the concentration of cosmogenic 3He in the samples. This concentration is used to find the exposure ages of the samples. Exposure ages range from 12 to 500 ka and increase with increasing elevation of terraces at locations such as Moses Coulee. This suggests multiple floods of different heights corresponding to flooding and refilling of glacial Lake Missoula. Additionally, the ANUGA Open Source Hydrodynamic Modeling Project was used to create a computational 2-D hydraulic model of the Columbia River and Moses Coulee. This model was then used to analyze different inundation heights and flow speeds of different floods of the area.

Photocurrent Density Improvement of Bismuth Vanadate Using Nanoparticulate Earth-Abundant Transition Metal Oxide Water Oxidation Catalysts
Timothy S. Sinclair
Mentors: Harry B. Gray and Astrid M. Müller

Earth-abundant transition metal oxides are promising water oxidation catalysts for their low cost and high stability. Recently, many transition metal and mixed metal oxide catalysts have been deposited from solution onto bismuth vanadate photoanodes using electrodeposition or photoelectrodeposition. To understand which transition metal or mixed metal oxide catalysts improve photoelectrochemical performance of bismuth vanadate photoanodes, we will mechanically deposit nanoparticulate catalysts from pulsed laser ablation on unmodified BVO₅ films we fabricate by spin-coating and electrodeposition. Using nanoparticulate catalysts will allow us to ensure that the BiVO₅ surface is unchanged in the catalyst deposition process. Therefore, physical measurements of the bare photoanodes prior to catalyst deposition will be truly comparable to measurements made after.
Monte Carlo Simulations for SUSY Events
Nikita Sirohi
Mentors: Maria Spiropulu and Javier Duarte

In order to find evidence for supersymmetry (SUSY), we need to know with some statistical confidence that a SUSY particle was created. However, to get this sort of evidence we need to know what signatures to expect in the detector from the SUSY particles, i.e. what types of decay products, and what regions of kinematic phase space. Given that there are a tremendous number of SUSY particles and ways they could decay, there is a large set of possible outcomes from a collision. In particular, parameters such as the masses of the created SUSY particles could drastically impact the detector signature. The goal of my project was to use various Monte Carlo generators to simulate collision events to be used by other members of the group when data from actual collision events is obtained. The models used had two protons collide and create dark matter only, dark matter and squarks, and squarks only, and then had the squarks decay further into daughter particles.

Feasibility of Self-Correcting Quantum Memory: A Novel Tool for Calculating Memory Times
Karthik Siva
Mentors: John Preskill and Beni Yoshida

The primary challenge for constructing large-scale quantum computers is the need to protect qubits from decoherence, the process by which the information encoded in the entanglement and correlations within the hardware is lost due to coupling with the environment. As a result, the feasibility of self-correcting quantum memory, a hypothetical quantum memory device that could store information for arbitrarily long periods of time without the need for constant error-correction, has been a subject of intense study among quantum information scientists. In this project, a novel theoretical tool for calculating the memory time of a class of quantum codes called stabilizer codes is developed based on the Peierls argument for a phase transition in the 2D Ising model. In particular, one proposal called the “welded” code is studied by mapping its string-like logical operator onto a classical model and proving its doubly exponential memory time by such a physically transparent argument based on the free energy barrier. This claim is further verified by a numerical Monte Carlo-like simulation of the code.

Phonon Enhanced LE-KID Far Infrared Detector
Agne Skripkaite
Mentors: Jonas Zmuidzinas and Christopher McKenney

Kinetic Inductance Detectors (KIDs) developed for far-infrared astronomy at Caltech offer tremendous advances in multiplexing due to both the resonator readout scheme and simple single-layer lithography process making it an attractive technology for large scale (~10^5 pixels) arrays. MAKO and SuperSpec, both projects in Zmuidzinas' group, have demonstrated that these detectors have sensitivities suitable for ground based measurements. In general operation an absorbed photon breaks cooper pairs in the superconductor forming quasiparticles and changing the kinetic inductance. For this project a modified KID device has been fabricated in which the optically sensitive element is placed on a thin island via back-etching of a silicon on insulator (SOI) wafer. In this configuration the phonons emitted from the KID when quasiparticles recombine forming cooper pairs could bounce back into the same KID and be reabsorbed thus enhancing the response of the device. However, the physics of phonons under these conditions have not been fully explored. Through measurements of the resonator lifetime and by comparing suspended and unsuspended devices we hope to measure a lifetime enhancement due to phonon reabsorption.

3D Network Model of Topological Insulator
Jun Ho Son
Mentors: Gil Refael and Andrew Essin

The Chalker-Coddington network model is a simplified model of one dimensional modes integer quantum Hall system that successfully captures the critical behavior of integer quantum Hall plateau-plateau transition in the presence of smooth disorder. In this work, network model is extended to 3D to study the critical behavior of the 3D topological insulator. In our 3D network model, three 1D modes on a sphere represent electron orbits, and those spheres are stacked in face-centered cubic geometry. Localization properties and critical behavior of the 2D network model are recovered by studying the eigenvalue of the transfer matrix. Using same technique, we expect that one can observe and study the metal-insulator transition on our 3D network model for topological insulator and related system.
**Live Imaging Reveals Novel Dynamic Events in Transitioning Mouse Gonocytes**

Tara Sowrirajan  
*Mentors: Scott E. Fraser and Carol Readhead*

Early developmental events in the testis are important and set the scene for future spermatogenesis. After birth, gonocytes, the precursors to spermatogonia stem cells (SSC) which differentiate to Type-A spermatogonia proliferate and become transiently motile in a poorly understood process. Aberrations could lead to altered fertility or pre-malignant states. Overlapping gonocytes subpopulations at varying developmental stages makes them difficult to study. Transgenic mice carrying enhanced green fluorescent protein under the control of the Oct4 promoter (Oct4:GFP) and a ubiquitous mTd Tomato gene were used for the live imaging of neonatal seminiferous tubules. The gonocytes express Oct4 and therefore were labeled green and could be visualized in a background of cells labeled with membrane tomato. Testes were harvested from neonatal mice (P0 –P5) and placed in a slide chamber in medium, the seminiferous and imaged live (4D) with a Zeiss 780 microscope. The shape, size, volume and movement of the gonocytes was quantified using Imaris. Although the average number of gonocytes remained constant during the neonatal period the other parameters changed. The gonocytes moved from the center of the seminiferous tube to the periphery where they remained. Their volume at P0 decreased by two thirds once they were attached to the tubule wall. Reduction in volume may be achieved by the process of cytoplasmic shedding, which was captured dynamically at P2 and P3. This mechanism is not understood but will be studied at a molecular level in the future.

**Interseismic Deformation in the Ventura Basin**

Ollie Stephenson  
*Mentors: Mark Simons and Romain Jolivet*

The Ventura basin, lying 60 km to the northwest of Los Angeles, is a densely populated sedimentary basin in the western Transverse Ranges province of Southern California. The basin is bounded by the Oak Ridge fault to the south and the San Cayetano fault to the north. Previous studies suggest that convergence across the basin is in the range 7-10mm/yr, highlighting the potential for a major earthquake and hence the need for a reassessment of the seismic hazard in the region. Building on work from summer 2013 we use GPS based estimates of tropospheric delay to remove atmospheric errors from InSAR (Interferometric synthetic aperture radar) data covering the Ventura area and then produce a detailed velocity map of the region as well as time series of ground motion. The data obtained reveal in detail motion on the faults in the region. We now intend to model the observed velocity field using a simple elastic model with faults locked to a certain depth and slipping below that. By inverting for fault locking depth and slip rate for the main faults around the basin it may be possible to improve estimates of seismic hazard in the region.

**Cytochrome P450 TxtE-RhFRed: A Novel Platform for the Directed Evolution of Aromatic Nitration Biocatalysts**

Ye (Juliet) Su  
*Mentors: Frances H. Arnold and Sheel C. Dodani*

In recent years, biocatalysis has accumulated interest as a greener alternative to traditional industrial synthetic methods. Of these chemical reactions, direct aromatic nitration remains largely unexplored. Recently, TxtE was identified as a cytochrome P450 that catalyzes the direct aromatic nitration of L-tryptophan to L-4-nitrotryptophan, marking it as an ideal platform for using directed evolution methods to design novel nitration biocatalysts. However, TxtE is a microbial, Class I P450 system that requires separate reductase components (ferredoxin and ferredoxin reductase) to reconstitute its activity, resulting in an expensive and time-consuming catalyst design process. To this end, we have encoded the TxtE heme and P450 RhF reductase domains into a single polypeptide chain (TxtE-RhFRed). Using this unique fusion platform, we have developed a high-throughput screen that will enable the directed evolution of this protein for increased catalytic efficiency and the nitration of non-natural aromatic substrates.
Development of On-Chip Spectrometer Array for the Tomographic Ionized-Carbon Mapping Experiment (TIME)
Guochao (Jason) Sun
Mentors: Jamie Bock and Roger O'Brient

The Tomographic Ionized-Carbon Mapping Experiment (TIME) will make a 3D spatial and spectral map of the intensity of [CII] emission from the Epoch of Reionization. Utilizing lithographed superconducting microstrip lines, its spectroscopy system couples power received by the planar phased array antenna to TES bolometers via half-wave, “staple” resonators. Measurements of prototype spectrometers based on silicon nitride wafer showed unwanted features such as unevenly-spaced channel responses with variations in amplitude. In this project, we designed and simulated an alternative configuration for the 80-channel spectrometer array on HFSS, whose geometry was adjusted to accommodate amorphous silicon substrate. Relationship between Q factor and line spacings was also characterized from the simulations. We hope such explorations can lend us some insight on how to resolve the problems of the prototypes and optimize our design. The geometry of the channelizer can be finalized and passed on to fabrication once ongoing fine tuning is finished. The ultimate configuration will provide TIME with the desired efficiency, sensitivity and resolution.

Heterogeneous Metabolic Dynamics in Bacillus subtilis
Surya Sundararajan
Mentors: Michael Elowitz and Adam Rosenthal

Labor division in a multicellular organism requires heterogeneity; certain subgroups of cells complete different tasks for the whole population. While it is expected for every single-celled organism in a species to be relatively homogeneous since they have to perform similar tasks, this is not the case for several species of bacteria. We are working towards an overarching project to explore how the subpopulations of B. subtilis interact with each other. We have determined that B. subtilis splits into three subpopulations, two acetate-producing populations and a population expressing high levels of the alsS gene, which converts the potentially toxic acetate to nontoxic acetoin. Each subpopulation was hypothesized to perform different metabolic tasks, and our goal was to determine how the three subpopulations interact with each other. We observed the metabolic dynamics within different subpopulations through growth curves of different subpopulations in various limiting media, HPLC analysis of produced metabolites, and a genome-wide map determined through RNA sequencing data analysis. Connecting all of this information will allow us to understand how interactions between the subpopulations improve the fitness of the bacterial colony.

Biological Relevance of cpSRP43 Disaggregase Activity
Cynthia Sung
Mentor: Shu-ou Shan

Protein aggregation and misfolding has been implicated in a wide range of diseases such as Alzheimer’s and Parkinson’s. A unique chaperone protein, cpSRP43, has been shown to effectively prevent and even reverse the aggregation of its substrate protein, LHCp. cpSRP43’s effective disaggregase activity has been studied only in vitro. This project is focused on observing the biological relevance of the disaggregase activity of cpSRP43 in actual plants. The project involves the use of wildtype and various mutant cpSRP43 (superactive and defective) proteins and transforms them into the cpSRP43-knockout plants. After the successful transformation into plants, their growth will be closely observed, including the genotype and phenotype of the plants. With further research, the effects of wildtype and various mutant cpSRP43 on their disaggregase activity will better be understood.

Determination of Density and Viscosity of Fluids of Different Phases at High Pressures Using Microcantilevers
Alp Mehmet Sunol
Mentors: Can Erkey, Gamze Eris, and Mark Davis

Microcantilevers oscillating due to a driving force have a certain resonance frequency and quality factor that depends on the dimensions and density of the microcantilever and the density and viscosity of the fluid the cantilever is immersed in. Therefore, microcantilevers have the potential to be used for simultaneous viscosity and density measurements. While vibrating 200 µm ferromagnetic nickel microcantilevers with a magnetic driving force, the resonance frequency and quality factor of the cantilevers immersed in CO2, N2, Ar, and their mixtures are recorded at 35.0 °C using a lock in amplifier and a MATLAB program. Experimental resonance frequency and quality factor data are used to predict density and viscosity over a range of pressures up to 3500 psia using a theoretical model based on simplified hydrodynamic function of a cantilever. The theoretical values of density and viscosity are observed to match the actual, known values of the fluids within a certain degree of accuracy. Experiments with different fluids, different cantilevers, and a modified cantilever displacement detection system can advance this research by verifying or increasing the accuracy of the method and increasing its range of application to more fluids and a wider range of conditions.
Hybrid Mode Matching: Integral Equation Techniques for Electromagnetic Waveguides
Marcus W. Suzuki
Mentors: Oscar P. Bruno and Emmanuel Garza

Numerical mode matching methods are common to model electromagnetic fields on the junction between waveguides, but when these junctions have sharp discontinuities, these methods usually yield low order convergence. Through numerical experiments we found that a direct implementation of the mode matching method for the bifurcated parallel-plate waveguide achieved only first order accuracy. We propose and implement a hybrid mode matching – integral equation method on which we solve for the fields away from the junction by using eigenmode expansions, while in the region near the junction we use a high-order integral equation solver, and then match the fields at the common boundaries. The proposed method improves the traditional mode matching technique by being high-order accurate even in the presence of sharp discontinuities and at the same time it treats junctions of arbitrary geometry in a general framework.

The Electrical Properties of Phosphorene
Rebecca K. Tang
Mentors: Jim Eisenstein and Chandni U.

Since the discovery of single-layer graphene in 2004, interest in 2D electronic materials has increased drastically. Phosphorene, a single layer of black phosphorus, is a relatively new and unstudied 2D material that, unlike the highly conducting graphene, is a semiconductor and therefore has many potential applications in electronics. We apply the standard methods used to fabricate graphene field-effect transistors (FETs) to make back-gated phosphorene FETs. Methods include Scotch tape exfoliation onto Si/SiO₂ wafers, electron-beam lithography, and chromium-gold evaporation and lift-off. FETs are submerged in liquid He-4 at 4K. 4-probe voltage measurements using a lock-in amplifier are taken to determine the resistivity of the sample across a range of gate voltages. From this data, it is possible to determine electron/hole mobilities and observe potentially interesting features.

Using Molecular Dynamics to Study the Mechanical Effects of Interface Morphology on Fe-Fe/W Nanopillars
Amal Tariq
Mentors: Julia Greer and Zach Aitken

In order to further develop nuclear power as a feasible energy source, materials capable of coping with the high-stress environment of a nuclear reactor need to be developed. The harsh operating conditions include bombardment with energetic particles which results in cascading structural defects that alter the system’s mechanical properties. Research has shown that small-scale heterogeneous interfaces serve as effective sinks for crystalline defects and effective recombination sites for interstitials and vacancies. Currently the interface between BCC iron and iron/tungsten metallic glass is being studied experimentally using nanopillar testing methodology. In order to more thoroughly understand the atomic processes occurring at the interface, molecular dynamics (MD) was used to simulate tensile tests for this material system. Using experimentally verified cross-potentials, we successfully modeled the Fe/W metallic glass system and bulk bicrystals that follow the crystallographic orientation of the experimental nanopillars. Tension tests were run by parametrically altering the interface morphology and varying the angle between the interface normal and pillar axis. We investigated the atomic processes at the interface using the Ovito visualization software. The generated data is used in conjunction with experimental data to provide deeper insight into the effect of the interface on the mechanical properties of the material.

Cytotoxic and Cytostatic Gold(III) Corrole
Darius Teo
Mentors: Harry B. Gray and John Termini

We have synthesized and characterized a water-soluble gold(III) corrole (1-Au) that is highly toxic to cisplatin-resistant cancer cells. Relative to its 1-Ga analogue, axial ligands bind only weakly to 1-Au, which likely accounts for its lower affinity for human serum albumin (HSA). We suggest that the cytotoxicity of 1-Au may be related to this lower HSA affinity.
Synthesis and Characterization of Nickel Complexes for Small Molecule Activation
Agnes Eva Thorarinsdottir
Mentors: Theodor Agapie and Graham de Ruiter

The ever growing energy demands of society have led to an increased focus on processes that can convert abundant and inexpensive materials to valuable energy sources. Such a conversion often involves small molecules, including H₂, CO and CO₂, using multi-metallic catalysts, which are frequently observed in nature. The design and synthesis of catalysts that are able to convert small molecules into useful fuels utilizing proton coupled electron transfer (PCET) still remains a challenging task. In that respect, nickel catalysts are of particular interest due to their easily accessible oxidation states, ability to catalyze reactions spanning a large electrochemical window (~1.5 V) and low cost. Here we present, the synthesis, reactivity and properties of multinuclear nickel complexes with 1,3,5-triarylbenzene derivatives as a ligand framework. The availability of six pyridines moieties and three alkoxide donors allow for coordination of multiple metals. Reacting this ligand with Ni(OAc)₂ readily provided the trinuclear nickel complex LNi₃(OAc)₃, where the acetate ligands could be exchanged for triflates. Exchanging the acetates, resulted in the formation of the trinuclear complex LNi₃(OTf)₃, which might serve as a stepping-stone towards oxy/hydroxo-nickel clusters. These are of particular interest since they are known to form reactive Ni(III) intermediates that are able to react with small molecules. Consequently the reactivity of the LNi₃(OTf)₃ with various oxygen donors will be presented. Furthermore the reactivity of the prepared complexes towards activation of small molecules, such as H₂O, O₂ and CO₂, will be discussed.

Model Selection for Mutual Fund Performance Predictability
Torin Thosath
Mentor: Ben Gillen

A multitude of scholarly articles discuss the correlations within data sets of mutual fund managers’ decisions, the current market environment, and their performance. These studies are somewhat limited in their analyses of the efficacy of the regression methods they use; the current research that compare various methods of analysis is focused primarily on comparing older techniques with newer, more refined versions of the same processes. This project observes a number of methods of combining a multitude of recent models. The efficacy of these model mixing methods is studied through returns of a variety of subsets of mutual funds. Further analysis would entail the addition of new methods of combining models.

Ir-Catalyzed Intramolecular Diastereo- and Enantioselective Allylic Alkylation of β-Ketoesters
Georgijs Trenins
Mentors: Brian M. Stoltz and Wen-Bo Liu

Asymmetric construction of adjacent all-carbon quaternary and tertiary stereocentres via catalytic stereoselective reactions has been of much interest in the past few decades due to the possible applications in total synthesis and related disciplines. The motif described above is very common in natural products, but presents a challenging synthetic target due to steric constraints and selectivity issues. Based on an intermolecular diastereo- and enantioselective allylic alkylation method recently developed by our group, we proposed an intramolecular reaction that may allow easy access to a wide variety of (hetero)cyclic compounds with defined stereochemistry and easily derivatizable functional groups, thus widening the scope of chiral building blocks available for the synthesis of complex biologically active compounds. Significant progress has been made in developing synthetic routes to substrates required for optimizing the reaction conditions of the allylic alkylation. It is our hope to complete the synthesis of some of these substrates and perform an initial catalyst screen by the end of the program. Future work may include a more thorough study of reaction conditions, substrate scope and the use of this method in total synthesis.
Data Driven Learning for Earthquake Detection
Shivam Mani Tripathi
Mentors: Julian Bunn and K. Mani Chandy

An earthquake monitoring system consists of a large sensor network that detects ground motion (acceleration values) using sensors, sends this data to a server (cloud/ backend) and uses statistical algorithms to detect earthquakes and issue warnings about impending seismic shaking. The project explored a number of such statistical and Machine Learning based algorithms by analyzing the large amount of data streams collected by Community Seismic Network (CSN). The project compared results from a number of such approaches, such as the Gaussian Mixture and Hidden Markov Models, Deep Belief Network as well as CSN’s new K Sigma algorithm, the basis of comparison being reduced False Positives and False Negative rate each algorithm reported while looking for significant seismic event (a Pick) within the data streams. Then project then explored algorithms for obtaining an earthquake's hypocenter based on results from the above experiment. The project concludes that given a sufficiently large dataset, hazard detection can be made accurate by using machine learning and statistical techniques.

Is Visual Cortex Necessary for Looming Avoidance Response in Mice?
Huey-Ru (Debra) Tsai
Mentors: Markus Meister and Melis Yilmaz

Recently, a graduate student in the Meister lab at Caltech, Melis Yilmaz, has uncovered a new visually guided behavior. In Yilmaz's study, the visual stimulus is a dark expanding disk from above. It was designed to imitate a large object approaching or looming from overhead. When the mouse is shown the stimulus, it rapidly responds by either fleeing into a shelter or freezing in place. Yilmaz proposes possible retinal circuits that regulate the behavior. However, there remains a critical question regarding the neural processing of this behavior: is visual cortex necessary for the looming response? In this study, we attempt to silence the visual cortex to see if the behavior remains intact.

Force Response of Nanofilms: How to Measure Nanoviscosity
Charles Tschirhart
Mentor: Sandra Troian

Classical fluid mechanics has been used to successfully describe macroscopic samples of fluid for centuries, but it was not until recently that scientists gained access to experimental equipment capable of investigating extremely small samples of fluid. Over the past few decades, research into the exciting and bizarre phenomena exhibited by extremely thin films of fluid has blossomed. It was discovered relatively recently that fluid viscosity, previously thought to be a constant property of a fluid for a given temperature and pressure, changes unpredictably at nanometer-scale size regimes. This effect is thought to be a result of the influence of surface forces on the behavior of the molecules within the fluid, and it is in some sense a product of the breakdown of the continuum approximation at such small scales. This phenomenon is extremely difficult to measure using conventional experimental methods in hydrodynamics; methods exist for determining fluid viscosities, but most are either unreliable or unsuitable for very small quantities of fluid. We perform experiments in which we apply shear stresses to extremely thin films of fluid and examine the resulting changes in the film profiles in order to determine the effective viscosities of fluids at molecular scales. We connect the deviations from classical hydrodynamics that we observe to the chemical structure of the molecules composing the fluid, with an ultimate goal of developing models that can be used to extend the equations of classical hydrodynamics to nanoscale liquid systems.

Spatiotemporal Dynamics of Sonic Hedgehog Signaling: Modeling and Experiment
Vipul Vacharajani
Mentors: Michael Elowitz and Pulin Li

The Sonic Hedgehog (SHH) signaling pathway is a morphogenetic pathway conserved across families of organisms. Through the formation of extracellular gradients, SHH instructs the patterning of multiple distinct gene expression domains within diverse tissues, including the limb and neural tube. The SHH signal circuit also contains conserved positive and negative feedback elements that are unique among morphogenetic signaling pathways. Understanding the design principles underlying this pathway provides insight into the question of how morphogen signal transduction influences patterning on an intra- and extracellular level, and how different morphogens differ from each other.

We have modeled a simplified version of the SHH signaling pathway incorporating both negative and positive feedbacks, to complement ongoing experimental work to produce a synthetic, tunable SHH signaling system. Our model provides predictions and suggestions for future experiments. In parallel, we have developed a one-dimensional culture system to facilitate better experimental measurement of the spatiotemporal dynamics in this synthetic system.
Comparative Exoplanetary via Transit Spectrophotometry
Victor Venturi
Mentors: Jessie Christiansen and Solange Ramirez

Transiting exoplanets are usually the ones we have more information about. In order to study their composition, one of the most practical methods is transit spectrophotometry, which consists of the analysis of the light emitted by their host stars and partially blocked by the planets, or, more specifically, the interpretation of the planets’ transit depths. Transit spectrophotometry, however, is a relatively recent field of exoplanetary science, and, thus, all of the data concerning transit depths is spread in different papers and publications. The main goal of my project is to build a database containing transit depths of different exoplanets, which will be integrated to the NASA Exoplanet Archive. In order to build this database, we had to first determine all the parameters about exoplanets that astronomers were interested in knowing, which was accomplished by reading several different papers and comparing what kind of information was present in all of them. The next step was to look for papers that had data on transiting exoplanets and to ingest it to the database. Our database will also be interactive, allowing its users to plot the data. This feature will help astronomers to study the exoplanets in the database.

Neurogenetics and Bayesian Methods to Understand Strategic Mechanisms of the Human Brain
Ratnalekha V. Viswanadham
Mentors: Ming Hsu and Antonio Rangel

Integrating genetics data, behavioral data, and brain-imaging data allows finding new genetic reasons and modifiers of a given phenotype and interest in how cognitive functions (specifically learning in the patent-race game) and mental disorders work in the brain by studying genetic variations. Dynamic causal models (DCMs) allow for understanding the interaction between various active brain regions (phenotypes), and partitioning these models into families allows the development of categories of models to describe the nature of the relationship between activations of regions. Applying Bayesian model reduction and family partitions of DCMs of genetic, brain-imaging, and behavioral data will generate summary statistics to develop a linear hierarchical model to describe the relationship between blood-oxygen level dependent (BOLD) responses and single-nucleotide polymorphisms (SNPs). Further work would include integrating not just SNP and BOLD signal data but also behavioral data into the linear hierarchical model. Further work would also include making prediction errors also a function of genetic regressors, as previous research indicates that genes influence prediction errors.

Fabrication of Silver Nanoparticle and Polymer Composite Photonic Crystals Using Two Photon Lithography
Mugdha Walke
Mentors: Julia Greer and Victoria Chernow

Photonic crystals are an important technology in the field of optical research, as they can control the propagation of certain frequencies of light. The photonic crystals currently being fabricated in the Greer Lab operate in the infrared range, having a periodicity of around 4 microns and a band gap of 7.5 microns. The aim of this project is to add properties in the visible range to the photonic crystal, which can be done through the addition of silver or gold nanoparticles, as they exhibit surface plasmon resonance at the visible range. This will be achieved by applying two photon lithography on a thin film composed of SU8 or IPL photoresist and silver nitrate to produce a nanolattice structure with silver nanoparticles embedded in it. Next steps in the research would be to conduct tests for the photonic bandgap of the crystal through FTIR spectroscopy. We can then tune the bandgap and obtain a stress-strain profile of the crystal via nanomechanical compression.

Flow Loop Experiments Using Polyalphaolefin for Use in Experiments on the Cooling of Electronic Chips of High Heat Flux
Hannah Walsh
Mentor: Beverley McKeon

Lockheed Martin is performing a study on the cooling of electronic chips of high heat flux. A conventional offset strip fin cooling apparatus will be tested, as well as three alternative concepts. In this study, a flow loop was constructed and experiments were performed to verify the functionality of the flow loop to be used to test the offset strip fin device in future experiments. The experiment for which this construction was built involves flowing polyalphaolefin (PAO) through an offset strip fin cooling apparatus. A modified flow loop was constructed to ensure the eventual experiment will be ready to start once the fins are received. The modified setup was built using a fifteen-gallon reservoir to contain the PAO; a gear pump capable of pumping viscous fluids; metal pipe connections to direct the flow from the single flow from the pump into six directions; plastic tubing to connect these pipe constructions to the offset strip fins both on entry and on exit; and hoses to connect the metal pipe construction back to the reservoir holding the PAO. The eventual future experiment uses T-type thermocouples to measure the temperature of the PAO flow as well as the temperature of the offset strip fin apparatus. These sixteen thermocouples were set up and tested. Heating pads, which will simulate the heating from avionic chips in the offset strip fin experiment, were wired and tested. The final flow loop was completed and is fully functional. Future work on the cooling on electronic chips of high heat flux will proceed smoothly once the apparatus is obtained.
**Analysis and Identification of an Intraocular Pressure Waveform**  
Margaret Walter  
*Mentors: Hyuck Choo, Jeong Lee, and Taeyong Kim*

Certain ocular diseases such as glaucoma cause an increase in the internal pressure of the eye, damaging nerves. An implantable pressure sensor would give patients the ability to monitor their own intraocular pressure and then consult a physician if necessary. One device to do this has been developed using a microscopic Fabry-Perot interferometer with the plates implanted between the intraocular membranes, and Raman spectroscopy measurements taken to determine the distance between the plates and thus the pressure in the eye. However the signal produced is difficult for a machine to recognize and link to the pressure environment of the sensor. To analyze the signals and convert their differences into numerical quantities, various signal processing techniques were investigated, such as using Fourier transforms, polynomial fit, and simple peak matching. A program combining these techniques to compare frequency shift across pressures and angles is currently being tested for consistency over samples at the same pressure.

**CMS Trigger Studies for Supersymmetry Searches With the Razor Variables**  
Ann Wang  
*Mentors: Maria Spiropulu and Javier Duarte*

Supersymmetric extensions of the Standard Model are the next steps in discovering new physics and explaining phenomena such as dark matter. At the Compact Muon Solenoid (CMS) Detector, high energy events from the Large Hadron Collider (LHC) can be studied for signs of supersymmetry (SUSY). One technique for SUSY searches involves employing razor kinematic variables, which help separate SUSY events from Standard Model background. Due to the high number of events produced at the LHC, however, two trigger levels, Level 1 and the High Level Trigger (HLT), must be implemented at the CMS detector to select for physically interesting events to record. Several selection criteria, which include both angular and energy information, are studied in the context of the razor variables at these trigger levels. A detailed analysis of jet clustering algorithms is also conducted for the HLT.

**Visual Illusions Arising From Retinal Circuits**  
Charles Wang  
*Mentors: Markus Meister and Hiroki Asari*

The retina is a layer of neurons in the back of the eye that participates in visual processing. For example, motion can be detected by retinal circuits before information is even passed on to the brain. Illusions exist that induce perception of motion or dimming where there is none, or where the opposite actually occurs. However, it is not known where in the visual system these illusions originate and what the underlying neuronal mechanisms are. We thus explored whether the visual processing in the retina contributes to these illusions. Specifically, we presented illusory stimuli to the isolated mouse retina, and recorded the firing activity of ganglion cells, the output neurons of the retina, that detect directional motion or dimming. Then, by analyzing the signal from relevant ganglion cells, we asked if the illusions indeed arise in the retina.
Directed Evolution of Rhodopsin Fluorescence and Spectral Properties
Siyuan Stella Wang
Mentors: Frances Arnold and Robert Scott McIsaac

Rhodopsins are light-responsive proteins found in all three domains of life. Variants of these proteins can be transgenically expressed in higher eukaryotes; some variants can selectively transport ions across biological membranes in the presence of light (referred to as actuators) while others exhibit voltage-dependent changes in fluorescence (referred to as sensors). While considerable work has been done on tuning the absorption spectrum of actuators\(^1\), very little has been published on developing brighter rhodopsin-based biological sensors. Recently, a mutant of Archaerhodopsin-3 (Arch) of *Halorubrum sodomense* (a known fluorescent voltage sensor) containing seven mutations in the retinal-binding pocket, had improved brightness of nearly two orders of magnitude over the wild-type protein\(^2\). However, the limits of Arch’s fluorescence have yet to be systematically explored. In this project, we perform site-saturation mutagenesis at residues along the retinal chromophore followed by moderate-throughput screening to identify brighter variants. We also perform site-saturation mutagenesis at three additional sites (T80, D106, and F161) recently reported to enhance fluorescence of Arch\(^3\). Finally, we will explore the ability of non-natural analogs to bind Arch to tune its spectral properties and clone a recently published rhodopsin sodium pump\(^4\) and test its ability to express in *E. coli*.

References

Exploring Ecology of Microorganisms Involved in the Anaerobic Oxidation of Methane and Inferring Syntrophic Relationships Based on Spatial Layouts of Microorganisms
Laura Watson
Mentors: Victoria Orphan and Alexis Pasulka

Methane is a greenhouse gas which contributes to global climate change. Aggregates of anaerobic methanotrophic archaea (ANMEs) in syntrophic relationships with sulfate-reducing bacteria (SRBs) carry out the anaerobic oxidation of methane (AOM) in seep ecosystems. To learn more about the microorganisms that are involved in AOM, I have been using techniques to determine the concentration and size of aggregates and couple fluorescence *in situ* hybridization (FISH) with nanoscale secondary ion mass spectroscopy (nanoSIMS) data. The specific mechanisms of AOM are not well understood and AOM-conducting organisms are very slow-growing and difficult to culture. Therefore, we are conducting laboratory experiments using a well-defined culturable 3-member syntrophic association (*M. extorquens, E. coli,* and *S. enterica*) to compare their spatial organization and activity patterns against model predictions of growth and substrate transfer in AOM aggregates. We have established the ability to distinguish each species using epifluorescence microscopy and determined the growth dynamics of 3-species culture, with exponential growth beginning between 10 and 15 hours after inoculation. The co-culture can be grown and fixed on poly-l-lysine coated glass slides, which is compatible with nanoSIMS analyses. These results will help contribute to a better understanding of the metabolic interactions in aggregates at a single-cell resolution.

On the Lyapunov Exponent of Quasi-Periodic Jacobi Operators
Jake L. Wellens
Mentor: Christoph Marx

In the context of solid-state physics, quasi-periodic Jacobi operators arise as effective Hamiltonians in a tight-binding model of a crystal layer in the presence of an external magnetic field. The Lyapunov exponent of such operators determines the asymptotic behavior of solutions to the corresponding time-independent Schrödinger equation. Here we prove a criterion for such operators to induce dominated splittings, and use this to prove conditions for subcriticality when the sampling functions are given by trigonometric polynomials satisfying certain degree conditions. We also use recent continuity results to obtain asymptotic formulas for the complexified LE of Jacobi operators with trigonometric polynomial sampling functions. In certain examples, our approach allows us to obtain exact formulas for the Lyapunov exponent.
CLARITY Optical Imaging Application to the Analysis of Tissues and the Efficiencies of Retrograde Transduction by Adeno-Associated Viruses
Samuel Changhoon Wie
Mentors: Viviana Gradinaru, Rajan Kulkarni, and Ben Deverman

CLARITY is a revolutionary novel method that can provide access to molecular and structural information that is significant to understanding a large-scale intact biological system without destroying the structural integrity of the sample tissue. CLARITY involves rendering thick tissue optically transparent through crosslinking to hydrogel monomers, extracting refractive lipids via a detergent, and mounting in refractive index-matched media for imaging. This project investigates whether polymethacrylic acid, a non-swellable polymer, would prevent the hydrogel softening and disintegration, risking tissue damage, that results from swelling. This study also tests the optimal antibody concentration for analyzing neural innervations in various mouse tissues. These results will be applied to understand how human skin cancer interacts with blood vessels and neurons, and potentially determine the location of the tumor initiating cells. AAV have proven to be potent vectors for gene therapy due to its non-pathogenic nature in the host cell and its sustainable therapeutic gene expression. Various AAV serotypes have undergone CLARITY imaging to determine their efficiencies in retrograde transduction in the brain and peripheral nerves.

Manufacturing Capture Agents for Detection and Treatment of Botulinum Neurotoxin
Michelle Wong
Mentors: James R. Heath and Blake Farrow

Currently, the most common method of detection and treatment for the botulinum neurotoxin utilizes an equine antibody for its high specificity and affinity. Although this antibody is successful in combating the neurotoxin itself, it is unstable in varying conditions and can elicit harmful immunogenic responses in humans. The goal of this project is to use the innovative epitope targeting and in situ click screening technology to develop a peptide-based capture agent with engineered cooperativity that can mimic the specificity and affinity of antibodies while still being more stable and less harmful than the current anti-toxin. Initial assays show that our newly synthesized peptide binds at extremely low concentrations suggesting impressive inhibition in the picomolar range, but also show the need for more extensive assays, therefore, testing in live cells is ongoing.

A Compact Broadband Nonlinear Optical Rotational Anisotropy Spectrometer for the Determination of Crystallographic and Electronic Symmetries
Antoni Woss
Mentors: David Hsieh and Liuyan Zhao

The rotational anisotropy of nonlinear optical harmonic generation from a crystalline material can be used to probe the symmetries of both its lattice structure and underlying ordered electronic phases. However, current experimental setups require the optics and detectors to be mechanically rotated during measurement, which precludes the use of broadband single photon detectors and limits the speed of data collection that in turn introduces low frequency noise sources. In this project, I designed, constructed and tested a new method to perform rotational anisotropy measurements that increases the frequency of data collection by ~1000 fold and removes almost all rotating parts. This is achieved using a novel triple beamsplitter geometry and a spatially sensitive detection scheme. This compact setup enables broadband detection and vastly improves the signal-to-noise ratio of the data, which opens the possibility of extending rotational anisotropy experiments into the time-resolved regime.

Building Access Control Modeling and Synthesis
Benjamin H. Wu
Mentors: Richard Murray and Vasumathi Raman

Building access control has been conventionally implemented with a centralized database subject to periodic updates, which creates holes in security. In order to fix these holes, it becomes necessary to allow near-instantaneous system updates that interfere with neither any other security goals nor with the convenience of users of the security system. The primary problem is the possibility of a system update creating an environment in which valid users of the access system suddenly become unable to leave the building. This research seeks to develop, through model checking and synthesis, a system or a control policy development process that prevents such occurrences. As a first step, we have developed a series of policies pertaining to a particular building structure, namely one in which there is a single hallway that connects a variety of rooms and no more than a single interior room inside of one of the rooms connected to the hallway.
**Improving the Immersive 3D Data Visualization and Expanding to New Platforms**

Jiyoun Xiao  
*Mentors: George Djorgovski and Ciro Donalek*

As datasets in scientific research grow increasingly complex and harder to represent, drawing conclusions from these datasets has become more challenging for the researchers. The growing size of datasets also makes it harder for researchers to manipulate their views within the visualization plots. In order to represent the datasets in a more intuitive and simpler way, this data visualization computer program was developed to enable users to immerse themselves in the 3D world of data points of different shapes, sizes, positions, colors and textures. The project is built on previous work done in Djorgovski’s group, so it’s more focused on making improvements on the established program. To better visualize large datasets with this program using personal computers, actions were required to accelerate the visualization plotting process. Through analyzing the CPU and GPU usage under hierarchies, adjusting data input structures, and upgrading common mistakes, the visualization speed has improved. To make it more portable and easier for display, an Android App is developed for this application. During the change in platform, the interface is also reinvented for a more comfortable user experience.

**Evaluation of Neutron Spin Transport in the Measurement of nEDM**

Xi Xu  
*Mentors: Bradley Filippone and Christopher Swank*

Whether a neutron has a permanent electric dipole moment (EDM) is of special interest in current physics studies. The existence of an EDM in neutron would violate time and parity reversal invariance, and may shed new light on the study of dark matter in early universe. In the most recent experiments, differences in neutron spin frequencies under different electro-magnetic field are measured to obtain estimates on neutron EDM. Due to limitations on apparatus set up, in current experiments, the neutron beam has to pass a sheet of Metglas material before entering the measurement cells, which may cause neutron’s spin reorient and may affect accuracy of the measurement. As previous experiments had shown very different results regarding the reorientation of the neutron spin, a simulation of the reorientation process would be the main focus of this SURF project. The magnetic field profile of the Metglas material will be simulated and spin wave function will be solved for a neutron passing through the simulated magnetic field, using Runge-Kutta algorithm with adaptive stepping. The simulation results would then provide a reference for future experiments, and will help improve experiment accuracy.

**Export Proteins and Signaling Peptides in a Model Insulin Regulation System in *E. coli***

Yuanyuan (Tina) Xu  
*Mentors: Richard Murray, Victoria Hsiao and Anu Thubagere*

Several debilitating disorders are caused by the improper function of a hormone regulation system in the body. If a model of this system can be recreated in an organism that is easier to manipulate research into these disorders could be accelerated. The Caltech iGEM team has designed a system in *E. coli* that is analogous to hormone regulation in humans. Our sub project focuses on the export domains and signaling peptides of three systems, the agrBCDA, lamBCDA, and fsrABC systems, which will be used to model a signaling system analogous to the glucose regulation system of the human body. The experiment will be conducted using plasmids transformed into *E. coli*. The *E. coli* signaling molecules will then be released into the media, facilitating communication and quorum sensing between the two cells and completing the circuit. During the course of this project all the necessary plasmids have been created. The plasmids are being assembled and those that have successfully been assembled have been transformed into the target cells and tested for the expression of the proteins of interest. Initial data is promising, but more research could be done into the specific mechanisms of how each system works and also other systems that could be more efficient and also adaptable in organisms other than bacteria.

**Position and Energy Reconstruction of a Prototype Low-Background Multiwire Proportional Chamber**

BetaCage Radioactivity Screener  
*Cassidy Yang*  
*Mentor: Sunil Golwala*

Rare-event searches require high sensitivities in detectors, but misidentified background surface events often reduce sensitivities below desired levels. Current screening technologies do not have sufficient sensitivity to meet the needs of these rare-event experiments to reduce radiocontamination. The BetaCage Multiwire Proportional Chamber (MWPC) design has high sensitivity to non-penetrating particles, a low energy threshold to detect low-energy betas, sufficient energy resolution to identify the parent isotopes of the detected particles, position information to distinguish surface contamination from detector and external backgrounds, and shielded and radiopure interior to reduce background events. As radioactive particles travel through the chamber, they ionize gas particles, which are collected in the form of pulses by the MWPC system. We seek to digitize and read out the pulses using an open-source Reconfigurable Open Architecture Computing Hardware (ROACH), which is a Virtex-5 FPGA-based computer that has an on-board RAM and transfers data via an Ethernet interface. The shapes of the pulses can then be used to reconstruct the energies of the incident particles, and the location of the triggered events can be used to reconstruct positions along the path of the radioactive particle.
Using CRISPR/Cas9 to Induce Non-Homologous End-Joining in *S. purpuratus* Embryos
Nathan Yao
*Mentors: Eric Davidson and Miao Cui*

The CRISPR/Cas9 system is a recently discovered system allowing for site-specific genome editing by using a small guide RNA (sgRNA) for a given target site alongside the Cas9 nuclease from the CRISPR immunity system of *Streptococcus pyogenes*. Upon triggering the error-prone intracellular DNA repair pathway of non-homologous end-joining (NHEJ) in sea urchin embryos, the resulting mutations can be detected by cleavage with the T7e1 endonuclease. Confirming the occurrence of NHEJ *in vivo* helps determine the viability of the CRISPR/Cas9 system to execute potential site-specific knock-in and knock-down of a given gene sequence. A protocol developed for this system could greatly expedite the study of gene regulatory networks, help establish transgenic lines, and support other applications where genome manipulation is necessary.

Study of Topological Polaritons in Triangular Photonic Crystals
Kexin Yi
*Mentors: Gil Refael and Torsten Karzig*

We introduce a new scheme of opening a topological gap for the recently proposed topological polaritons (topolaritons) in photonic crystals with triangular lattice symmetry. The topolariton states emerge from a winding coupling between photons and semiconductor excitons combined with a periodic exciton potential to open up a topological gap. We show that in photonic crystals opening the gap can be substantially simplified close to the Dirac points. With the presence of the winding photon-exciton coupling that breaks time reversal symmetry, the Dirac cones are separated, leading to a topological gap with the size of the periodic exciton potential. Compared to the previous proposal, this scheme significantly reduces the amount of parameter tuning required to open the gap and obtain the chiral polaritonic edge modes. It also shines light on the searching for possible experimental realizations of this new topological state.

Intersections of Cycles in Matchings
Kevin Yin
*Mentor: Richard M. Wilson*

We investigate BCC 22.15, a group of 3 problems posed by Roland Häggkvist at the 22nd Combinatorial Conference. We present a solution to Problem 1 by showing that any cubic bridgeless graph $G$ contains two circuits $C$ and $Q$ whose edge sets intersect in a matching $M$ such that $G-M$ is bridgeless. Problem 2 asks whether there exists some cubic bridgeless graph $G$, circuit $C$ in $G$, and edge $e$ in $C$, such that for every circuit $Q$ that contains $e$ and intersects $C$ in a matching $M$, $G-M$ contains a bridge. We present partial results on Problem 2.

The Molecular Basis of the Osmotic Shock Pathway’s Nuclear Checkpoint
Ellen Yu
*Mentors: André Hoelz and Ferdinand Huber*

The three-tiered MAP kinase cascade is a eukaryotic protein system that assists in the transduction of extracellular stimuli to regulate gene expression in the nucleus. The MAP kinase HOG1 has been shown to translocate to the nucleus in response to osmotic stress through specific interaction with nuclear import receptor NMD5. While selective nuclear import is typically achieved using nuclear localization signal sequences on cargo proteins, it has been shown that the checkpoint for the import of HOG1 is instead site-specific phosphorylation by MAPKK PBS2. Of relevance is p38, the human homolog of HOG1. Strongly implicated in cancer regulation, p38 is gaining attention as a pharmacological target. High structural and sequence homology between p38 and HOG1 suggest that the interaction between NMD5 and HOG1 can potentially serve as model for controlling the nuclear import of p38. We aim to provide the molecular basis for such an interaction using x-ray crystallography. Independent expression of NMD5 and HOG1 has been achieved, and ongoing crystallization trials show promise for future experimentation.
Uncovering Microbial Metabolites That Promote Host Serotonin (5-HT) Biosynthesis
Kristie Yu
Mentors: Elaine Hsiao and Jessica Yano

The gastrointestinal (GI) tract harbors a great abundance and diversity of microorganisms, collectively called the microbiota, that critically regulate host functions, including metabolism and activity of the nervous system. Over 90% of the body’s serotonin (5-HT) is produced by enterochromaffin cells, a specialized endocrine cell type located in the GI tract. 5-HT is a neurotransmitter involved in many regulatory processes, and disruption of 5-HT metabolism is linked to many disorders, such as depression and irritable bowel syndrome. Serum 5-HT levels in mice raised in the absence of microbial colonization (germ-free) are decreased by about 60%, as compared to serum 5-HT levels in conventionally-colonized (wildtype) mice, indicating that the microbiota regulates 5-HT metabolism. We demonstrate that metabolites from colonic luminal contents of mice colonized with a defined subset of microbes sufficiently promote 5-HT production in cultured chromaffin cells, suggesting that particular members of the microbiota produce biochemicals that modulate host 5-HT synthesis. To determine the identities of candidate serotonergic metabolites, we profiled small molecules present in colonic luminal contents of germ-free, conventionally-colonized, and gnotobiotic mice by LC/GC-MS-based metabolomics screening. Metabolites that significantly co-vary with 5-HT levels were identified, and tested for their ability to induce 5-HT production by cultured chromaffin cells. Metabolites that sufficiently increased 5-HT levels when applied at physiologically relevant concentrations in vitro were then tested in vivo for their ability to elevate 5-HT biosynthesis and abrogate 5-HT deficiencies in germ-free mice. Mice injected with particular microbially-modulated metabolites exhibit increased 5-HT concentrations in both colons and serum compared to controls, indicating that these metabolites can also affect 5-HT production in vivo. Overall, we demonstrate that specific metabolites modulated by limited bacterial species from the gut microbiota regulate host 5-HT levels, and further raise the interesting possibility of developing novel microbe-based treatments for serotonergic disorders.

Patrick Yu
Mentors: Harry Atwater and Michelle Sherrott

Monolayer materials have remarkable electrical and optical properties that differ tremendously from their bulk counterparts. Some monolayer materials that are now being heavily researched are graphene and MoS₂ due to recent discoveries in applications such as thin film solar cells and plasmonics. Due to its ultra-thin characteristic and unique band structure, graphene can be used to fabricate effective plasmonic devices which can then be analyzed using a technique called angle-resolved cathodoluminescence (CL) nanoscopy. Angle-resolved CL nanoscopy focuses electron beams on samples that scatter cathode rays at mid infrared to visible wavelength ranges. A detector collects these cathode rays and this allows the determination of spatially-resolved information about the optical modes present and plasmon resonant frequencies of the devices. These insights would better explain the fundamental physics behind how plasmons behave in the devices which can lead to more exciting applications. Graphene has also been shown to exhibit high electrical conductivity, which could make it an excellent contact material in thin film solar cells. Another material that is ultra-thin and lightweight is MoS₂ which is different from graphene in that it is a direct bandgap semiconductor whereas graphene has no bandgap and is thus considered a semimetal. MoS₂ has been shown to absorb up to 10% incident sunlight in a thickness of less than 1 nm, which is an order of magnitude greater than current materials used for solar cells, such as GaAs and Si.¹ The motivation behind using MoS₂ is that it acts as a good thin film semiconductor that has low series resistances, large voltage capacities, and near-optimal I-V (current to voltage) curves. Coupled with metal-like materials like graphene, MoS₂ can be used to create optimal thin film solar cells, such as Schottky junction solar cells. However, efficiencies of thin film solar cells often suffer from the losses that take place during light absorption, and because MoS₂ is only a single atomic layer thick, it cannot absorb 100% of incident light, limiting its performance. Implementing a light trapping technique will help to improve the light absorption of the MoS₂ which will increase the overall efficiency of the solar cell.

REFERENCE:
Analysis and Characterization of Chimera in *Aurelia aurita*
William Yuan
*Mentor: Lea Goentoro*

The Moon Jellyfish, *Aurelia aurita*, was found to have the curious ability to produce chimera; that is, tissue can be grafted from one individual to another without regard for body plan or other compatibility. This ability is probed to determine what, if any, limitations exist with regard to age and speed of recovery, and to understand it relative to other healing mechanisms observed by *A. aurita*. In addition, a new live neural staining protocol using methylene blue is developed and optimized for *A. aurita* generally, and applied to these produced chimera. Staining is used to track the progression of nerve and muscle cells as the chimeras heal and synchronize. Better understanding of chimera helps rationalize the healing process overall, and opens the door for “engineering” jellyfish for practical purposes.

Developing Temperature-Sensitive Fusion Proteins From a Bacterial Coiled-Coil for Thermal Activation of Neurons
Sasha Zemsky
*Mentors: Mikhail Shapiro and Dan Piraner*

Thermosensitive proteins may enable selective activation of neurons with an external heat source, providing a noninvasive method of studying neural pathways. One candidate is a coiled-coil protein derived from a bacterial transcription factor, which transitions from a dimer to a monomer within a narrow temperature range. However, the coiled-coil dissociation temperature may be concentration dependent, and it is difficult to control protein concentrations within cells. To address this issue, two different coiled-coil fusion constructs were produced using restriction cloning and expressed in *E. coli*. The first consisted of two monomers fused to GFP. This construct has previously been shown to act as a reporter of coiled-coil dimerization, as the GFP excitation pattern changes when the coiled-coil dissociates. Future experiments will use fluorescence measurements to observe how the coiled-coil dissociation temperature varies at different concentrations. The second construct consisted of coiled-coil monomers fused to the Spycatcher/Spytag protein tagging system, which allowed two monomers to become covalently linked to establish a constant local monomer concentration. This should fix the dimer dissociation temperature to 41-42°C, which is ideal for heat shock activation. Future experiments will use CD spectroscopy to verify this hypothesis.

Development of Characterization Tools for Integrated Electro-Optical Devices
Andy Zhou
*Mentors: Ali Hajimiri and Behrooz Abiri*

Advances in silicon photonics processes have opened up many new opportunities and allowed for novel approaches to solving various problems in circuit design and data communication. The ability to fabricate optical and electronic devices in the same chip fabrication process allows for fully integrated electro-optical systems. A feed-forward equalizer (FFE) for optical communications and a frequency-modulated continuous wave coherent camera were implemented in the OpSIS/IME silicon on insulator process, which is mainly developed for optical devices. Several transistors were also fabricated in the same process to be tested and possibly be used in conjunction with optical devices. This project involves developing the methods and tools for testing and characterizing these devices. We designed boards to interface with the equalizer and the coherent camera to couple input signals, to generate and provide supply voltages, and to process the outputs. We also wrote a script to control test equipment to automatically measure and generate the current-voltage characteristics for the batch of transistors. Preliminary measurements show that the OpSIS/IME transistors are functional. Furthermore, tests on the FFE show that it can be successfully controlled to equalize a bandwidth-limited communications channel.

Rapid Prototyping of Moderate Complexity Biomolecular Circuits: Four-Input AND Gate
Tiffany Zhou
*Mentors: Richard M. Murray, Clare Hayes, and Vipul Singhal*

In the field of synthetic biology, researchers are "forward-engineering" their own genetic circuits using well-known genetic components in order to better understand the complex relationships between a circuit’s architecture and its behavior in a cell. However, the construction and characterization of synthetic biological systems can be time-consuming and costly. We explored the possibility of a more systematic and streamlined approach to the development of genetic circuits with the use of a cell-free “breadboard” environment called TX-TL. We designed and tested a multi-input logic gate circuit consisting of three AND logic gates, layered such that the output of one serves as the input of the next. Components of this circuit were developed, characterized, and debugged in TX-TL, aiming to ultimately have the circuit functioning *in vivo*. The circuit was also modeled using an existing TX-TL toolbox (built on top of MATLAB), and this model was used to verify the basic dynamics of the circuit and test hypotheses as the circuit is implemented. The results of this project demonstrate the ability to prototype circuits that function *in vivo*, with iteration in *in vitro* assays and models to streamline development of predictable, *in vivo* functionality.
Historically, simulations have incorrectly predicted the metal abundance of galaxies. The FIRE simulations are a set of cosmological simulations which include physical processes (such as stellar feedback, radiation pressure, supernovae) that have not yet been simulated on cosmological scales. We present the mass-metal relation for galaxies within this set of simulations at several redshifts between $z = 0$ and $z = 2$ and compare the results to observed data. The results give insight towards the evolution of the mass-metallicity relation, as well as a look at the impact the simulated physical processes have on the metal content of galaxies.
MURF UNDERGRADUATE RESEARCH FELLOWSHIPS
**Heterobimetallic NiFe and CoMg Complexes as Structural and Functional Models of Carbon Monoxide Dehydrogenase**
Charlie Arnett-Guardado  
*Mentors: Jonas C. Peters and David C. Lacy*

The transformation of carbon dioxide to value added C1 chemicals remains a challenge. Given the difficulty of activating carbon dioxide toward functionalization, synthetic chemists have sought inspiration from biological systems that mediate similar transformations. Given the prevalence of the heterobimetallic moiety in the active site of metalloenzymes designed for the activation of carbon dioxide, the development of synthetic models of these species is desirable. These biomimetic model complexes may then be probed in order to elucidate the mechanistic principles and structure-function relationships that are operative in Nature. The goal of the present study was to investigate the reduction of carbon dioxide to formate. Bio-inspired heterobimetallic M'M" complexes (M' = Ni, Co; M" = Mg, Fe, Zn) where M' is a redox active metal ion bound to an N4 macrocyclic ligand and M" is a Lewis acidic metal ion were prepared to study the role of cooperativity in the activation of CO2 by carbon monoxide Dehydrogenase (CODH).

**Visualizing Structural Responses of Community Seismic Network Instrumented Buildings Using Data From Four 2014 Earthquakes**
Santiago Arrangoiz-Arriola  
*Mentors: Monica Kohler and Thomas Heaton*

The Community Seismic Network (CSN) is a dense network of low-cost accelerometers whose main function is to assess shaking intensity due to earthquakes. These sensors are located throughout the greater Pasadena area in houses, public spaces, and 10 buildings ranging from five to 52 stories. CSN sensors collect continuous wave form data which is later used to calculate maximum accelerations, velocities, and relative displacements due to earthquakes in each floor. Simple models were created for each building using SketchUp and imported to MATLAB using a set of functions that read and plot a three-dimensional structure. Data was obtained from four recent events: M4.4 in Fontana, CA, M3.0 in Hollywood, CA, M4.4 in Encino, CA, and M5.1 in La Habra, CA. After detrending, the data was filtered using a 4th order Butterworth filter with a passband of 0.3 Hz to 10 Hz. In some cases, missing information was interpolated linearly. With the corrected data, color-coded static plots were created for each building and event, as well as dynamic animations showing how the building responded to the event. Eventually, CSN could allow first responders to monitor and evaluate damage in structures in real time with a fast, cheap and relatively accurate method.

**The Moral Price of Pain: Self- vs. Other-Regarding Decisions Involving Pain and Money**
Joel Auerbach  
*Mentor: Steven R. Quartz*

Drawing heavily from economic theory, most empirical studies of morality to date have used money as the main currency for moral help and harm. However, the moral salience of money represents a highly complex domain, whereas a more basic category of interaction, such as preventing or allowing physical pain, may provide a more informative model of moral behavior. As part of a larger ongoing research program, we present pilot work attempting to establish a preliminary relationship between subjective values of money and pain depending on whether outcomes affect oneself or another person. In Study 1, participants were asked to make decisions about whether to receive a certain amount of thermal pain or lose a certain amount of money from an initial endowment. In Study 2, participants were asked to decide whether to accept harm (money or pain) for themselves or allow another to undergo it. Results and implications for future work will be discussed.

**Modeling the Influence of Situational Variation on Theory of Mind**
Wilka Carvalho  
*Mentors: Ralph Adolphs, Bob Spunt, and Damian Stanley*

Recent advances in neuroimaging techniques and decision-making research, combined with model-based analytical techniques, are paving the way for research on the brain and insight into its function. This study is part of an ongoing project to use model-based behavioral and functional magnetic resonance imaging (fMRI) methods to understand the neurocognitive processes that allow us to make inferences about what happens inside the minds of other people. The study focused specifically on trait inference: how we create and maintain accurate representations of the traits of other people. We developed a test in which participants (Judges) learn how different people (Targets) respond behaviorally to various situations. Over the course of the experiment, Judges' trait learning is assessed by having them predict the Target's behavior. We will administer this test to neurotypical and non-neurotypical individuals - with trouble in this respect, such as those with Autism Spectrum Disorder (ASD) - and use the test performance to fit Bayesian mathematical models of the computations necessary for social learning. We hope to learn about how social norms, individual behavior, and already inferred traits are integrated to create new, and update current, trait inferences.
Optimizing the CRISPR/Cas 9 System to Delete Enhancer Sequences at the brinker Locus in Drosophila
Melissa Cruz
Mentors: Angela Stathopoulos and Leslie Dunipace

CRISPR/Cas-9 is a genetic editing system in which the Cas-9 endonuclease is guided to a specific target DNA sequence by a customizable guide RNA molecule (gRNA). We are working to optimize the CRISPR/Cas-9 system in order to study the temporal action of cis-regulatory modules (CRMs) acting in the Drosophila embryo. In particular, we aim to use the CRISPR/Cas-9 system to individually delete two CRMs, the 5’ and 3’ CRMs at the brinker locus. Thus far we have created transgenic lines expressing gRNAs specific to the deletions for the 5’ and 3’ CRMs through site directed transgenesis. These lines were then crossed with a Cas-9 expressing line and the progeny was screened for the deletion, the 5’ CRM deletion has shown a 12% mutation efficiency. In parallel, we are creating marked transgenic lines by combining homologous recombination with CRISPR in order to insert a visible marker into the deleted region facilitating screening. Any transgenic and mutant lines identified will be analyzed using in situ hybridization to test for effects of deletions on endogenous brinker expression. Our specific goal is to compare the efficiency of different modes of generating deletions and whether screening by marker selection rather than PCR is easier and faster.

Predicting the Binding Modes of Antifreeze Proteins to Methyl α-D-Mannopyranoside Sugar Crystals
Arnold Diaz
Mentors: William A. Goddard III, Fan Lui, and Sook-Yung Kim

Antifreeze proteins (AFPs) are a class of polypeptides that can be found in organisms that live in sub-zero temperatures. These proteins lower the freezing point of water by a few degrees without affecting the melting point; termed thermal hysteresis (TH). The objective of this project is to predict the binding modes of antifreeze protein from the beetle Dendroides canadensis (DAFP1) with the sugar crystal methyl α-D mannopyranoside (MADM). Bio-software and molecular dynamics (MD) simulations were used to model both structures and calculate the free energies of the binding planes. The binding-site motif of DAFP1 was compared to three different planes on a supercell of the MADM crystal. The planes correspond to an X, Y, or Z plane of the supercell MADM crystal. The Z-plane (1 0 0) of the supercell MADM crystal, matched the crystal lattice found on the DAFP1 binding site. MD was run on the Z-plane and the protein, to determine the free binding energies of the complex. The simulation and MD results were used to validate the experimental results.

Analysis of Acetaldehyde-Water Clusters Using Chirped Pulse Fourier Transform Microwave Spectroscopy
David Feng
Mentors: Geoffrey A. Blake, Ian A. Finneran, and P. Brandon Carroll

Microwave spectroscopy remains a powerful diagnostic in physical chemistry, with modern methods incorporating digital electronics to produce microwave spectra of molecular species, in order to accurately determine their rotational constants. These constants, in conjunction analysis with other rotational effects such as centrifugal distortion and internal rotation, can provide important structural information regarding the species of interest, such as bond lengths and bond angles. This work examines CH$_3$ - CHO - (H$_2$O) (acetaldehyde-water cluster) which is of relevance to atmospheric chemistry as a possible intermediate in the reaction of acetaldehyde and OH in the Earth’s atmosphere. The 8-18 GHz bandwidth of an acetaldehyde-water mixture has been taken by broadcasting a chirped pulse into its gas phase sample, in which we then collect the free induction decay data that follows the sweep. The temporal data is Fourier-transformed into the frequency domain, where we then inspect the spectrum for possible acetaldehyde-water transitions. We manually assign predicted peaks and best-fit them into the experimental spectrum using a variety of microwave spectroscopy software packages developed over the past decade, enabling accurate spectral fits. Initial predictions of rotational constants, dipole moments, and other relevant parameters are derived from ab initio quantum chemistry computations using Gaussian 9.0.

Utilizing the 1-pt Probability Distribution Function to Characterize Dark Matter, Populations of Millisecond Pulsars, and Various Backgrounds Simulated for the FERMI Experiment
Natalie M. Harrison
Mentor: Jennifer Siegal-Gaskins

The objective of this research is to see whether utilization of the 1-pt Probability Distribution Function to characterize models of Dark Matter, Millisecond Pulsars, and isotropic and galactic diffuse backgrounds, will give us a quantitative discrimination between what we see modelled in the FERMI-LAT detector for gamma rays produce from Dark Matter and Millisecond Pulsars. The 1-pt PDF is a simple distribution of the number of pixels in the maps outputted by the simulation in the FERMI-LAT detector that contain a specific number of hits. Our preliminary results show some promise for this statistical tool in being able to differentiate the two models. If this statistic is successful, we can attempt to understand the origin of the excess of gamma rays that the FERMI experiment sees in the center of the galaxy.
Spit Gfp as a Tool for Membrane Protein Expression
Anthony Jones
Mentors: William M. Clemons and Stephen Marshall

Green fluorescent protein (GFP) has been a powerful and versatile tool in Biochemistry. It has been used to study membrane proteins, allowing researchers to quantify expressing and determine topology. While the use of GFP has facilitated higher throughput membrane protein expression tests, it has several key limitations. We have observed that expression studies of TatC membrane proteins that use a whole GFP reporter results in large amounts of soluble GFP observable by Western Blot assays. Because fluorescence from TatC-GFP fusion proteins and soluble GFP cannot be distinguished, the usefulness of GFP as a reporter in measuring TatC expression limited. Our ongoing research seeks to determine if a split GFP reporter will provide greater utility for testing membrane protein expression. The split GFP reporter involves fusing the final beta strand from GFP to a membrane protein and separately expressing a full-length GFP molecule truncated to the final beta strand. The two components of the GFP can interact to yield a functional GFP molecule. Fluorescence is expected to increase with membrane protein expression because more of the final GFP beta strand will be present to interact with the truncated GFP. Split GFP however has only been used in membrane protein topology studies for the purpose of mapping the N or C-terminus of a particular protein. The aim of our studies is to develop a method in which split GFP can be used for the quantification of membrane protein expressed by a cell without the production of background GFP.

The Stress of Active Matter: Exploring Inertial Effects
Luis A. Nieves-Rosado
Mentors: John F. Brady and Sho Takatori

A relatively new area of study in the fields of rheology and fluid mechanics is the study of the behavior of self-propelled particles. These particles, usually in the colloidal size regime, have the ability to convert the chemical energy of the medium into motion. Although these particles are inherently far from equilibrium, recently there has been some interest in the study of their thermodynamic properties, with a focus on the mechanical pressure or stress of such systems. While traditional studies in this field are in the low Reynolds number limit, relaxing this assumption allows exploration of a large range of size scales, permitting one to study movement in general, and the patterns that are common in all size scales. This work utilizes the LAMMPS molecular dynamics package to study the stress of active matter systems over all levels of inertia and activity. The inclusion of inertial effects could serve to extend the knowledge and methods of colloidal self-propelled particles to study and understand the behavior of larger moving object such as fish and birds, an important goal of condensed matter physics.

The Design of a Re-Entrant Cavity Resonator for Mechanical Squeezing
Kristine Farielle Rezai
Mentor: Keith Schwab

Since the development of quantum mechanics, the study of the quantum behavior of real world systems has been pursued. Scientists have become interested in studying the behavior of a mechanical device coupled to an optical or microwave cavity to probe the quantum behavior of mechanical objects, and in recent years have succeeded in cooling these objects down to their ground states. While the Schwab group has achieved squeezing almost down to the zero point level, they have yet to definitely surpass it. A quantum-limited amplifier is available for use in the experiment, but additional microwave engineering is necessary before it can be implemented. A tunable re-entrant cavity resonator has been designed for use in the apparatus, and a cancellation circuit is being developed for the installation of this new amplifier.

BONCAT Study of Persister Cell Resuscitation
Nathan Rollins
Mentors: David Tirrell and Weslee Glenn

Persisters, responsible for chronic infections such as those that plague the lungs of patients with cystic fibrosis, rely on an emerging phenotype of dormancy. It is known that this behavior is achieved through stochastic fluctuations of toxin and anti-toxin levels, triggering the freeze of biochemical synthesis and thereby negating the action of most antibiotics. However the mechanism of resuscitation, the process of returning to regular cellular behavior from dormancy, is mostly not understood. This is the subject of our research. In this study, we utilize bio-orthogonal non-canonical amino acid tagging (BONCAT) in order to isolate and identify the proteins up-regulated during the resuscitation stage. Analyzing the medically relevant bacteria P. aeruginosa under treatment of ciprofloxacin, we look to unveil the mechanisms of resuscitation in order to rationally improve the efficacy of antibiotic therapies.
**A Study of Photosensors for the Mu2e Calorimeter**  
Ashlyn Shellito  
*Mentors: David Hitlin and Frank Porter*

The proposed Mu2e experiment at Fermilab will search for evidence of charged lepton flavor violation (CLFV) in the form of coherent conversion of a muon to an electron on an aluminum nucleus. The Mu2e detector will search for electrons with energy approximating the muon rest mass of 105.6 MeV using a system comprised of a straw tube tracker, crystal calorimeter, stopping target monitor, cosmic ray veto, and proton extinction monitor. The goal of this project was to determine an optimal photosensor for use with the BaF₂ crystal calorimeter system including crystal and readout specification and testing. Photosensors used in this experiment include photomultiplier tubes (PMTs), avalanche photodiodes (APDs), and silicon photomultipliers (SiPMs). An optimal photosensor is defined as one which has enough timing resolution to discriminate between the fast and slow spectral components of BaF₂, and must also operate in a 1 Tesla magnetic field. BaF₂ crystals were coupled to each type of photosensor and tested in a light-tight box both with and without radiation sources. Further work is scheduled to test APDs and SiPMs which have a UV-extended epoxy coating.

**Regioselectivity and Rate of Palladium Catalyzed Wacker Oxidation of Alkenes Using NMR**  
Renee J. Sifri  
*Mentors: John D. Roberts and Zachary K. Wickens*

Ketones serve as important synthetic intermediates in target-oriented synthesis. They are used in a wide range of drugs and natural products and are important in many biochemical pathways. Efficient synthesis of ketones has been a leading concern in modern research. A recent preparation of functionalized ketones through olefin cross-metathesis/regioselective Wacker oxidation has proven to be efficient and regioselective for ketone synthesis. By altering the directing groups (electron withdrawing heteroatoms) attached to these alkenes, ketone synthesis was shown to be regioselective. The initial rate and final selectivity of the major and minor products were studied using NMR. Furthermore, varying reaction conditions, such as acidic and nonacidic solutions and different solvent polarities were also studied to see if rate and selectivity changed. Selectivity remained constant in both acidic and nonacidic conditions but solvent differences affected the final yields of products. Information about palladium coordination and inductive effects of directing groups is acquired from plotting final selectivity against electronic character of the alkene.

**Progress Toward the Total Synthesis of (+)-Kopsoffine**  
Kyle Virgil  
*Mentors: Brian Stoltz, Katerina Korch, and Beau Pritchett*

Alkaloid natural products are found widely throughout humans, animals, plants, bacteria and fungi. (+)-Kopsoffine is a heterodimeric indole alkaloid composed of the alkaloids eburnamonine and kopsinine, which by themselves have exhibited vasodilatation and anti-cholergenic activity, respectively. The asymmetric synthesis of (+)-kopsoffine explored here utilizes a crucial palladium-catalyzed asymmetric allylic alkylation to generate lactam intermediates that offer a suitable foundation for the total synthesis of eburnamonine, kopsinine, and kopsoffine thereafter. Beginning from diallyl malonate, two distinct synthetic routes to the key enantioenriched lactam were investigated and optimized. Additionally, efforts toward the final cyclization reactions leading to eburnamonine were conducted. Future studies on (+)-kopsoffine will focus on final optimizations of the total syntheses of eburnamonine and kopsinine, as well as the Stille cross coupling reaction between them to yield (+)-kopsoffine.
Selective Oxidation of Allylic Fluorides Into Anti-Markovnikov Products
Brian Carr  
Mentor: Robert H. Grubbs

The Nitrite-Wacker oxidation of terminal allylic fluorides influences the general structure and functionalization of organic compounds. The synthetic sequence used to generate these allylic fluorides has proven to be efficient, without the presence of major byproducts. After subjecting multiple allylic fluorides to the optimized Nitrite-Wacker conditions, a general trend could be observed with regards to inductive effects. Fluorides themselves were found to influence Wacker selectivity through electron-withdrawing effects, ultimately favoring the formation of the anti-Markovnikov β-fluoroaldehydes as the major product, with the Markovnikov ketones as the minor. As well, allylic fluorides with additional electron-withdrawing groups, such as ethers and carbonyl compounds, established a cooperative effect with the allylic fluorides, resulting in a higher selectivity for the anti-Markovnikov product. Moreover, the synthesis of these β-fluoroaldehydes is unprecedented, and since a quarter of all pharmaceutical drugs contain a fluorine atom, the development of medicinally important compounds are possible.

Structural and Kinetic Characterizations of Defective Potent VRC01-Like Antibodies Against HIV-1
Courtney Chen  
Mentors: Pamela J. Bjorkman and Louise Scharf

Recently there have been several reports of a “cure” for HIV. Most famous of these are the “Berlin” patient and Mississippi baby. While these cases are promising, they also represent unique instances that are still being studied. Consequently, the discovery of a cure for HIV is still a pressing issue. Current designs of immunogens for vaccines have been spearheaded by expansion in discovery of potent and broadly neutralizing antibodies (bnAbs) against HIV-1. Particularly of interest to the Bjorkman group are antibodies of the proposed class of Potent VRC01-like (PVL) antibodies, which are CD4 binding site bnAbs that share characteristic amino acids. With our collaborators at Rockefeller University, we have an unprecedented set of data on a range of PVL antibodies with in-depth characterization of several PVLs and sequences that span from germline to intermediate, semi-potent forms to mature bnAbs. My project aims, therefore, to study variant PVL antibodies and attempt to identify crucial changes needed to transition from a low affinity form to powerful bnAb. PVL antibodies have been identified from several patients, suggesting a conserved, plausible route of evolutionary attack on HIV, indicating there exists the potential to induce an immune response forming PVL antibodies.

Developing Genetic Methods to Control Insect Populations
Wen Min Chen  
Mentors: Bruce Hay and Omar Akbari

Harmful insects, including agricultural pests and disease vectors, cause billions of dollars worth of crop losses and millions of deaths. Current solutions include applying insecticides, laying traps, and installing barriers to mitigate damage. However, for many insects there are no effective conventional methods to control pest populations. The release of genetically engineered insects carrying lethal genes provides a cheap and environmentally-friendly method to reduce insect numbers. There are two systems under development: a vanillic acid-repressible dominant lethal (VanDal) system, and an X chromosome shredder system. The VanDal system contains a lethal transgene that is not expressed when insect food is supplemented with vanillic acid, allowing efficient sex-separation of sterile insects. When these sterile insects are released into the wild, they interbreed with wild insects yet do not produce viable offspring, reducing the population. The X chromosome shredder system utilizes homing endonucleases to target DNA sequences unique to the X chromosome. Males expressing this construct would only generate sperm containing the Y chromosomes, greatly distorting the sex-ratio of the offspring. Eventually there would be no female insects left, leading to a population crash. The VanDal system needs to be optimized for lethality, while constructs for the X-shredder system are being tested.

Transcriptional Response to Ascarosides in C. elegans
Sarah M. Cohen  
Mentor: Paul W. Sternberg

Nematodes are among the most successful animals on earth, yet little is known about their pheromone systems. A group of small molecules called ascarosides has been found to mediate mate finding, aggregation, and developmental diapause in a broad range of nematode species. The mechanism for these responses, however, remains poorly understood. We aim to profile the RNA transcriptional response to ascarosides using the model organism, Caenorhabditis elegans. Specifically, we will use RNA-seq to study the transcriptome response of C. elegans when exposed to a group of diapause-inducing ascarosides (ascr#2, ascr#3, and ascr#8) during the larval stage when they first receive cues from their environment and are able to switch their developmental programming in order to adapt to these cues. We will further compare the response of wildtype C. elegans with that of daf-22 mutants, which lack an enzyme necessary for ascaroside biosynthesis. By comparing these transcriptional responses, we will determine whether early exposure to ascarosides is important in shaping the transcriptional response that drives diapausal induction.
**Directed Evolution of Microbial Rhodopsin Spectral Properties**
Candice Crilly
*Mentors: Frances H. Arnold and R. Scott McIsaac*

Variants of microbial-derived, light-responsive proteins, called opsins, can be transgenically expressed in neurons to both control and monitor their activity. Opsin-mediated perturbations are fast, specific, and reversible, making them ideal for perturbing neural physiology in a way that is orthogonal to the brain’s native chemical and electrical signals. These proteins can be engineered to run “backward”, causing the protein to transduce a change in membrane potential into an optical signal instead of moving ions across the membrane. However, fluorescent opsin variants are extremely dim, a major limitation for imaging applications. The goal of this project is to test the limits of opsin fluorescence by engineering mutants of Archearhodopsin-3 (Arch) with higher quantum yields using directed evolution. By applying site-saturation mutagenesis at residues near the retinal-binding pocket, followed by moderate-throughput screening, we hope to identify mutations that increase Arch brightness. We are also mutating two residues outside the pocket that may improve protein stability (and thus increase fluorescence). We are screening 12 site-saturation mutagenesis libraries (~1200 clones) to identify variants. We will also clone a newly discovered sodium-pumping rhodopsin and test its ability to express in E. coli. If successful, we will use directed evolution to modify its spectral properties.

**Implementation of Non-Endogenous Bacterial Quorum Sensing Systems in E. coli: Signaling Peptide Export**
Galen F. Gao
*Mentors: Richard Murray, Victoria Hsiao, and Anu Thubagere*

iGEM—the International Genetically Engineered Machine competition—is an annual, worldwide synthetic biology competition in which teams from different universities attempt to construct highly modular, artificial biological systems. This year, the Caltech 2014 iGEM team focused on the implementation of non-endogenous bacterial quorum-sensing systems in E. coli, in hopes that successful transfer of these systems into E. coli will promote enhanced prototyping of intercellular—in addition to intracellular—signaling and regulation in synthetic biology’s favorite model organism. One of the key challenges in developing such systems in a non-native environment is ensuring that the peptide signaling molecule used in these systems actually will be produced and exported out of a bacterium for its neighbors to receive. To this end, the genes encoding the signaling peptides and their accompanying membrane “helper” proteins were cloned into E. coli with a 3xFLAG protein tag appended to the ligand for experimental identification. Liquid cultures were grown and spun down, and their supernatants were collected to verify the presence of the exported ligand via Western blotting. Preliminary results suggest successful expression and export of the signaling peptide in the fsrABC system. Final results and conclusions from this work will be given at the presentation.

**Investigation of an Enantioselective Catalytic Aldol Reaction Between Aldehydes 1 and Methoxyoxazole 2**
ShuMing Huang
*Mentors: Sarah Reisman and Geanna Min*

An enantioselective catalytic Aldol reaction to form oxazoline 4 was investigated as part of a synthetic effort toward the first total synthesis of (+)-MPC1001B. The existing reaction suffered from a reaction time of more than twenty hours, high loading of aluminum catalyst that was acquired via a two-step sequence, moderate yield and enantioselectivity. The objective of this study was to increase the yield and enantiomeric excess of the 4 while decreasing the catalyst loading of the Al catalyst. This involves preparing aldehyde fragment 1 via a six-step sequence, Al catalyst via a two-step sequence, and the oxazole fragment 2 via two-step sequence from commercially available compounds.
**Correlating Cardiac Flow Vortex Formation Indices With Acoustic Vibration Patterns**

Vivian Huang  
*Mentor: John Oluseun Dabiri*

Vortex formation-based cardiac flow indices may provide a robust measure of heart health, particularly as an early indicator of mitral valve dysfunction, abnormal left ventricular flow, and resulting congestive heart failure. Current methods to observe left ventricular (LV) flow include ultrasound and magnetic resonance imaging, but these costly technologies are not universally accessible to frontline clinicians. We seek to quantify diagnostic markers based on acoustic vibrations generated by different vortex flows.

We model vortex formation in the heart using a calibrated piston/cylinder setup in a water tank. Since disease states may manifest in abnormal blood flow, we investigate a range of maximum stroke ratios. Using digital particle image velocimetry (DPIV), we obtain velocity and vorticity fields correlated with specific piston stroke length to diameter (L/D) ratios. Pressure fields are derived from velocity fields using the Queen 2.0 Pressure Estimator algorithm (Dabiri et al., 2014). We also plan to implement an axis-symmetric approximation in MATLAB to estimate the integrated force exerted by the flow, which may correlate well with acoustic patterns measurable by a suitable auscultation device. Ultimately, we hope to determine whether markers based on acoustic patterns may reliably characterize the third heart sound (S3) for early stage auscultative diagnoses.

**Affinity of SynGAP for the Postsynaptic Density Scaffold PSD-95**

Ariella M. Iancu  
*Mentor: Mary B. Kennedy*

Synaptic strength is closely tied to the number of AMPA-receptors (AMPARs) in the postsynaptic density (PSD)—the more AMPARs there are, the more strongly the neuron depolarizes when the synapse is activated. AMPARs are retained in the synapse by a diffusional trapping mechanism believed to involve binding sites on scaffolding proteins, such as PSD-95, a scaffolding protein of the MAGUK family with three PDZ domains, an SH3 domain, and a guanylate kinase domain. AMPARs associate with proteins called TARPs, which bind directly to the PDZ domain of PSD-95 when they are phosphorylated during strong synaptic activity. This traps AMPARs in the synapse. PSD-95 also binds to an abundant synapse-specific GTPase-activating protein, synGAP, which indirectly regulates AMPARs by regulating GTPase-activating proteins Ras and Rap. We hypothesize that modulation of binding of synGAP to PSD-95 upon synaptic activation may affect trapping of AMPA receptors. Using a pull-down assay, we measured synGAP’s binding affinity ($K_D$) to PSD-95, and its change in binding affinity in the presence of Ca$^{2+}$/Calmodulin.

**A Toolbox for Massive-Scale Engineering of IncRNA Constructs**

Soumya Kannan  
*Mentors: Mitchell Guttmann, Amy Chow, and Patrick McDonel*

Large non-coding RNAs (lncRNAs) are a recently discovered class of functionally diverse RNA molecules, the mechanisms of which still largely remain a mystery. A current hypothesis proposes that IncRNAs can act as modular scaffolds, meaning that they contain discrete and independent protein-binding domains that bring together certain proteins into complexes. Presently, the capability exists to delete entire IncRNAs in cells, which allows for the study of each IncRNA’s overall function. The next step in understanding the mechanisms of IncRNA function requires the ability to dissect them into parts and observe the effects of deleting and permuting protein binding domains. A flexible framework to create any mutant or synthetic construct is necessary to test the modularity hypothesis. Here, we have created a method to design short oligonucleotides in silico and assemble them into full IncRNAs. This allows us to synthesize many existing IncRNAs or mutants in large volumes with minimal work, ultimately providing a framework to study IncRNA modularity and directly engineer new IncRNAs with synthetic functions.

**Characterizing the Role of the DPF2 Tandem PHD Domain in Transcriptional Regulation**

Steven Klupt  
*Mentors: André Hoelz and Ferdinand Huber*

DPF2 is a member of the d4 protein family that contains a tandem plant homeodomain (PHD domain). Despite being widely expressed in humans, the biological functions of DPF2 are largely unknown. However, DPF2 was recently found to act together with AML1 as a transcriptional regulator involved in myeloid differentiation of hematopoietic stem/progenitor cells. Thus, DPF2 may serve a critical role in preventing the onset of acute myeloid leukemia, which results from improper myeloid differentiation. In order to better understand the role the PHD domain of DPF2 plays in transcriptional regulation, we sought to characterize the interaction between this domain and acetylated histone tails. Such an interaction has been observed in a homologous protein, DP3. We expressed and purified the DPF2 PHD domain, and attempted to crystallize it both with and without acetylated histone tail peptides. We obtained x-ray diffraction data, and determined a high-resolution structure of the domain without acetylated histone tail peptide bound. We used isothermal titration calorimetry to investigate the biochemical basis of interaction between the PHD domain and acetylated histone tail peptides. In doing so, we are in the process of identifying several mutations of DPF2 that prevent it from binding to histones.
Elucidating the Role of Cell Death in a Bacterial Colony

Ji Hoon Lee
Mentors: Michael Elowitz and Jin Park

Though a unicellular organism, gram-positive bacterium \textit{B. subtilis} displays a wide range of multicellular behavior such as biofilm formation and programmed cell death. Sigma factors are bacterial transcriptional regulators that allow specific binding of RNA polymerase to gene promoters. In our study, we show that the intracellular fluid (ICF) released upon cell death specifically increases sigX activation in its neighboring cells, while the levels of other sigma factors were unaffected by ICF. Furthermore, our single-cell experiments reveal that ICF accelerates the 3D complex formation of the bacterial colony, hinting at the possible relationship between ICF released via cell death and macroscopic processes such as biofilm formation. Finally, we show that the pre-treatment of cells with ICF protects colony growth rate against bacitracin. Although further investigation is necessary to firmly establish our findings, our study provides clues suggesting that \textit{B. subtilis} may compromise the survival of individual cells in order to confer a protective advantage to the colony through biochemical factors released via cell death.

Py-Im Polyamide-Induced Replication Stress in LNCaP Cells: A Cell Cycle Study Through DNA and Protein Activation Assays

Jihoon Lee
Mentors: Peter B. Dervan and Thomas F. Martinez

Pyrole-imidazole (Py-Im) polyamides are a class of small, programmable molecules whose structures can recognize and bind to specific sequences in the minor grooves of DNA. They are cell permeable and localize to the nucleus of live cells, where they bind to the chromatin within. As a result, in the cellular environment Py-Im polyamides have the potential to alter gene expression by displacing natural activators and transcription factors; it has also been suggested that the binding may also lead to replication fork stalling. This has important mechanistic implications regarding Py-Im polyamides’ observed antitumor ability. To study the potential effects on replication, androgen-sensitive LNCaP human prostate cancer cells were treated with specific Py-Im polyamides targeting the consensus Androgen Response Element (ARE). The treated cells were then analyzed for the activation of replication fork, DNA repair-related, or apoptosis-signaling proteins using Western blots and luminescent caspase-3/7 detection. Additionally, a flow cytometry assay was also conducted, in which relative cell cycle stage populations were surveyed in order to observe changes in the cycle as a result of possible replication stress. The role of the p53 gene in Py-Im polyamide-induced G1 cell cycle arrest was also investigated.

Stability and Efficiency Characterization of Silicon/Graphene/Metal and Silicon/Boron Nitride/Metal Interfaces

Jacqueline Maslyn
Mentors: Nathan S. Lewis and Adam C. Nielander

We are investigating silicon as a photoanode in a water-splitting photoelectrochemical cell that is light-absorbing and stable toward oxidation in aqueous solution. Graphene is an atomic monolayer of sp² hybridized carbon atoms that has been shown to protect silicon from electrochemical oxidation in aqueous solution by acting as a chemical diffusion barrier. Boron nitride is an sp² hybridized monolayer comprised of boron and nitrogen atoms. In order to improve the efficiency of oxygen production, metal catalysts are deposited on the photoanode. However, silicon in contact with a metal is known to develop gap states that pin its Fermi level via chemical reaction between the silicon and metal, reducing the efficiency of the device. An intervening monolayer of graphene between the silicon and metal is investigated as a strategy to prevent Fermi level pinning at the interface. Metal islands (platinum, nickel, copper, titanium, silver) are evaporated onto n- and p-doped silicon, silicon/graphene, and silicon/boron nitride samples. The interfaces are characterized using linear voltammetry, Raman spectroscopy, and x-ray photoelectron spectroscopy. We investigate whether graphene and/or boron nitride is a barrier to diffusion, the extent of Fermi level pinning at the interface, and the order-of-magnitude series resistance presented by the intervening monolayer.
Mapping the Gene Regulatory Network Underlying Apical Plate Development in Sea Urchin Embryos
Mary D. May
Mentors: Eric H. Davidson and Roberto Feuda

The development of an organism is an extremely complex process, controlled by large gene regulatory networks (GRNS). GRNS are composed of sub-circuits, which represent regulatory linkages amongst transcription factors and cis-regulatory modules that control the expression of the genes for these transcription factors. Studying the GRNs of an organism during development gives insight into how a complex animal with different tissues, organs and body parts can develop from a single cell. Analyzing the spatial and temporal expression of genes involved in apical plate development in sea urchin embryos, through whole-mount in situ hybridization (WMISH) which reveals the domains in which specific genes are expressed and through nanostring experiments which reveal the temporal expression of each gene, allows to interpret data from perturbation experiments. A high throughput analysis of apical plate gene expression in sea urchin embryos was used to map when and where specific genes are expressed in the apical plate during development and the results will be used to inform future perturbation experiments with antisense morpholinos in order to determine and confirm regulatory relationships between transcription factors.

Measurement of αβ T Cell Receptor Mispairing for Selection of Effective Gene Therapy TCRs
Meghna S. Pagadala
Mentors: David Baltimore and Michael Thomas Bethune

The heterodimeric α/β T cell receptor (TCR) is the sole determinant of T cell specificity. In TCR gene therapy, patient T cells are transduced with tumor-specific α and β TCR genes to impart anti-tumor immunity. However, introduced TCR α and β chains can mispair with the transduced T cell's endogenous TCR β and α chains, respectively, reducing the number of tumor-specific TCRs on the surface and potentially generating autoreactive TCRs. So far, a TCR's propensity to mispair has been an undefined property. We are developing a quantitative assay to measure the extent to which mispairing occurs for TCRs of clinical interest. We identified two antibodies that bind the constant portions of the endogenous TCR α and β chains. These epitope sites were mutated in the transduced TCR chains and synthetic epitope tags were added to the N-terminus of these chains to enable their orthogonal recognition by a second set of two antibodies. Using a sandwich ELISA, we capture the transduced α or β TCR chain with a tag-specific antibody and then detect the β or α chain to which each is paired using a second antibody. Signal is observed only when both capture and detection antibody targets are present. Therefore, all possible αβ heterodimers can be distinguished by using different antibody pairs and each heterodimer can be quantified by comparison to a standard curve. The ability to measure mispairing of TCRs will enable selection of clinical candidates that are safer and more effective.

Biochemical and Structural Dissection of the Coat Nucleoporin Interactions
Samantha Parsons
Mentors: André Hoelz and Ana Correia

Massive proteinaceous channels, called nuclear pore complexes (NPCs), provide the sole conduit between the nucleus and cytoplasm by tightly regulating bidirectional nucleocytoplasmic transport. The NPC is extremely large with a mega assembly of ~1000 protein chains. Because of the size and flexibility, it has been difficult to yield high-resolution structures using standard techniques such as electron microscopy (EM) and X-ray crystallography. In order to determine the structure of the NPC, independent complexes are investigated and put together to create a model of the NPC. This project focuses on the biochemical and structural characterization of the interaction between three coat nucleoporins: Nup120, Nup145c and Nup85. This contributes to the complete structural characterization of the Nup84 complex. We focused initially on determining the minimal interaction regions between these three nucleoporins and are now trying crystallize different sub-complexes that constitute the Nup84 complex “triskelion”.

Quantitative Analysis of the Neural Circuit of Aggression
Talmo Pereira
Mentors: David J. Anderson and Brian J. Duistermars

Sexual arousal, anger, anxiety, apathy. These are essential and evolutionarily-conserved arousal states that despite their prevalence in nature, remain poorly understood. In the hopes of better understanding how specific neural circuits give rise to these arousal states, and on the heels of ethological speculation, we turn to the fruit fly, Drosophila melanogaster, as a model organism for aggression. Here we propose to leverage modern techniques in genetic neuro-manipulation to investigate how separate classes of neurons identified as being involved in aggressive behaviors are related. Using behavioral assays combined with simultaneous activation and silencing of two separate populations of neurons we hope to demonstrate that a class of neurons specifically controlling wing threats are downstream of a set of neurons that influences all aggressive behaviors. In order to facilitate these experiments, we are developing, in tandem, a pipeline to automate behavior detection and quantitative analysis in recorded videos. All told, we hope to contribute new insights into ethological models of complex animal behavior and provide tools for the community at large.
The Effects of Different Transcriptional Drivers in the Maintenance of Early T-Cell Specification
Shuyang Qin
Mentor: Ellen V. Rothenberg

Several transcription factors – TCF1, GATA3, and ETS1 - are thought to have critical roles in the regulation of the T-cell commitment program. Changes in surface markers cKit and CD25 indicate the early T-cell transition stages, in which DN1 cells are phenotypically characterized by cKit+/CD25-, DN2 by cKit+/CD25+, DN3 by cKit-/CD25+, and DN4 by cKit-/CD25-. TCF1 (encoded by Tcf7) and GATA3 have been found to be heavily upregulated during the DN1-DN2 transition quickly followed by the upregulation of ETS1, which we suspect is regulated by both transcription factors. Their expressions not only change the transcription of important T-cell specific genes, but may also be necessary for initiating the T-cell program and preventing the diversion to other lineage fates. Specifically, we observe that downregulation endogenous mRNA expression via shRNAs in mice fetal liver hematopoietic progenitors generate specific phenotypes when analyzed by flow cytometry, such as reduced viability or a block in development, as compared to their control counterparts. We aim to discover, through quantitative RT-QPCR, potential downstream target genes to give a further insight into the functional roles of TCF1, GATA3 and ETS1.

Construction of Thermally Responsive Transcriptional Systems via Both Endogenous and Exogenous Mechanisms
Ryan Rezvani
Mentor: Mikhail Shapiro

Noninvasive stimulation of neurons has become a field of great interest with the advent of technologies like channelrhodopsin, as used in the field of optogenetics. Methods of thermally controlled transcriptional activation can provide a more customized activation of a gene of interest in a possibly less invasive manner, and with a potentially deeper penetration depth. This study explores the potential of two thermally responsive control systems, an endogenous mammalian heat shock responsive dependent on a transcription factor – promoter interaction, and an exogenous protein from bacteria that acts as a repressor until the application of heat. In order to correct for a weak expression level, some simple circuits have been tested with the heat shock promoter system. Thus far, transcriptional activation via the endogenous mammalian system has been demonstrated via microscopy and fluorescence quantification, and one of the circuit designs, a positive feedback loop, was confirmed to boost signal post heat shock. These initial experiments support the notion of feasibility for the eventual implementation of these transcriptional systems in neurons.

Fold-Change Detection Circuitry: Probing the Regulatory Mechanism of Temporal Ratio Computation in Wnt Signaling via Protein-DNA Interactions
Bryan Ryba
Mentors: Lea Goentoro and Jaehyoung Cho

The Wnt pathway plays a significant role in the phenotypic development of Xenopus laevis embryos. Past studies have shown that siamois, a target gene of Wnt signaling, is governed by fold-change detection (FCD) involving the protein known as β-catenin. An 11-base pair (bp) promoter region upstream of siamois is known to be necessary for FCD to occur. The purpose of this project was to characterize the protein-DNA binding interactions between this non-canonical 11-bp promoter and the β-catenin/TCF3 complex that is believed to mediate FCD. Electrophoretic mobility shift assays (EMSA) were performed with a labeled 11-bp promoter, embryo protein extracts, and various oligonucleotide/antibody competitors in order to characterize the binding of this complex to the 11-bp promoter. Significant competition by canonical and putative TCF sites located upstream of siamois implicates a potentially complex mechanistic basis underlying the protein-DNA interactions necessary for FCD. Antibodies specific to the C- and N-termini of TCF3 inhibit binding of the β-catenin/TCF3 complex to the 11-bp probe as well. ChIP-PCR experiments performed on stage 10 Xenopus embryos were used to identify additional sites upstream of siamois that bind the β-catenin/TCF3 complex during FCD. 3C assays were used to probe the chromosomal architecture underlying these mechanisms. Collectively, these experiments will assist in further characterization of the mechanisms underlying FCD.
Development of the CRISPR-Cas Nuclease System in H. bacteriophora for Genetic Studies of Symbiont-Host Interactions
Alexander J. Sercel
Mentors: Paul W. Sternberg and Hillel Schwartz

As the importance of understanding the complex relationships between host animals and their bacterial symbionts becomes increasingly apparent, researchers seek new techniques and model organisms to study these interactions. Heterorhabditis bacteriophora, a nematode anatomically and genetically similar to the model organism, C. elegans, displays a mutualistic obligate symbiotic relationship with bacteria of genus Photobacterium. This partnership has the potential to be used as a genetically tractable system to study bacteria-host interactions.

We aim to establish methods for the CRISPR-Cas engineered nuclease system in H. bacteriophora to study gene function. We have selected two H. bacteriophora genes orthologous to C. elegans unc-5 and unc-30—genes which cause a viable uncoordinated phenotype when knocked out—to target for loss-of-function mutations. These genes should yield obvious phenotypic indication of site-specific CRISPR-Cas activity, which will significantly enhance the throughput of our screening compared to using molecular techniques. Demonstrating conservation of gene function between C. elegans and H. bacteriophora and establishing methods for CRISPR-Cas genome engineering in this species will facilitate further genetic and genomic studies of the relationship between H. bacteriophora nematodes and Photobacterium bacteria, and enable a greater understanding of how we interact with our own bacterial communities.

Border Ownership Neurons in Mice
Christine Tseng
Mentors: Doris Tsao and Tomokazu Sato

The differentiation between foreground (figure) and background (ground) by the visual system is crucial for object recognition and the perception of form. One theory as to how this separation occurs posits that the shape of the figure is determined by the assignment of ownership to visual borders. Neurons in V1, V2, and V4 in the macaque that respond to contrast edges were found to respond also to the location of the figure whose border they belonged to. The goal of this project was to find analogous border ownership neurons in the mouse, which is an increasingly popular model for vision. We planned to detect these neurons with in vivo two-photon calcium imaging as we showed images with various sets of occluders to the mice. However, we have had trouble getting the mice to perform the required behavioral task. We hope to train and detect border ownership neurons in the future.

Discovering the Enzyme(s) That Catalyze the Reduction of Phenazine-1-Carboxylic Acid (PCA) in Pseudomonas aeruginosa
Ben Wang
Mentors: Dianne K. Newman and Nathaniel Glasser

Pseudomonas aeruginosa is a Gram-negative opportunistic pathogen and is most well-known for causing lethal lung infections in persons with cystic fibrosis (CF). These bacteria synthesize redox-active compounds called phenazines that not only serve as virulent factors but also directly enable the survival of the producing organism. Phenazines are often found in a reduced state when carrying out their functions. Last summer it was found that dihydrolipoamide dehydrogenase (DLDH) catalyzes the reduction of PCA. This redox-active enzyme is the third subunit of both the α-ketoglutarate dehydrogenase and pyruvate dehydrogenase complexes and can hypothetically donate electrons to PCA via its bound flavin molecule. In order to understand the mechanisms of this reduction on a structural level, this summer’s project has focused on solving a crystal structure of DLDH physically bound to PCA, and to measure kinetic parameters ($K_m$ and $K_{cat}$) of this reduction. So far a three angstrom crystal structure of LpdG has been solved, although there is no obvious electron density for the phenazine at this stage. Efforts are currently underway to obtain a higher resolution structure of DLDH physically bound to PCA. As phenazines are important virulence factors for P. aeruginosa, understanding the reduction pathway of phenazines can provide a novel avenue for treatments against the pathogen in chronic infections.

Interspecific Study of the Diversification of Life in Microorganisms
Lawrence Wang
Mentors: John C. Doyle and Christopher P. Kempes

Evolutionary development and diversification of life has led to the development of anatomically modern humans from unicellular prokaryotes with various evolutionary transitions in between. The first such evolutionary transition is from the simple-celled prokaryote to the complex-celled eukaryote. The focus of this study is to understand and explain this transition by exploring important basic features of unicellular prokaryotes and eukaryotes. We have explored features such as genome size and number of ribosomes compared to cell size and have found that the data for unicellular prokaryotes fit well with our predictions, whereas the data unicellular eukaryotes do not. The larger size and additional complexity of eukaryotes allows for more variation in the composition of the cell, which may explain the lack of a strong correlation in unicellular eukaryotes.
Developing a Pathway for Extracellular Electron Transport in *E. coli* by Directed Evolution of mtrA Protein From *Shewanella oneidensis*

Caroline Werlang

*Mentors: Frances Arnold and Ardemis Boghossian*

Cell-generated electrical signals are of vital importance to biosensing and medical devices as they allow for an electrical connection between cells and artificial devices; unfortunately, the natural impermeability of the lipid bilayer makes interfacing cells and electrodes difficult. *Shewanella oneidensis* is an anaerobic bacterium that creates a detectable electrical signal by reducing extracellular iron via its cymA-mtrABC protein pathway. We expressed this pathway in *E. coli*, with cymA replaced by *E. coli*'s homolog napC, but this synthetic system transports electrons at one tenth the rate of the natural system. Since the napC-mtrA interaction previously has been found to be the limiting factor in this pathway, we improved the efficiency of the system via directed evolution of mtrA. We tested a library of several thousand mutants generated by error-prone PCR through a novel anaerobic screen for *in vivo* iron reduction activity.
LIGO

THE LASER INTERFEROMETER
GRAVITATIONAL-WAVE OBSERVATORY
Extracting CCSN Progenitor Parameters via Pattern Recognition
Laksh Bhasin
Mentors: Alan Weinstein and Sarah Gossan

Core-collapse supernovae (CCSNe) are among the most energetic events in the universe, releasing up to \(10^{53}\) erg \(= 100\) B of gravitational potential energy. Based on theoretical predictions, they are also expected to emit bursts of gravitational waves (GWs) that will be detectable by second-generation laser interferometer GW observatories such as Advanced LIGO (aLIGO), Advanced Virgo, and KAGRA. In a novel, spectrogram-based pattern-recognition approach, we investigate the inference of progenitor parameters from numerical GW signals produced by state-of-the-art rotating core-collapse simulations. After associating physical processes with characteristic spectrogram features, we develop several machine-learning (ML) algorithms that can accurately (often within ±20% relative error) determine progenitor parameters from optimally-oriented CCSN signals located D \(\sim 1\) kpc away from Earth. In the future, our analysis could be implemented in the aLIGO data analysis pipelines to help determine the inner core dynamics of the next galactic CCSN; this information would otherwise be inaccessible via electromagnetic radiation.

Time Delay of Gravitational Waves Propagating Through a Galaxy Toward a Non-Stationary Observer
Emory Brown
Mentors: Yanbei Chen and Atsushi Nishizawa

We consider the effect on observed time delay of gravitational waves observed by an earth-based gravitational wave detector due to the motion of the earth through the galaxy’s mass distribution. A solution is presented for sources located in an arbitrary direction at both infinite and finite distances. The typical effect we expect to observe is a time delay derivative of about a quarter second per year with a maximal effect only slightly greater.

Searching for Higher Order Cladding Modes in Fiber Optic Based Optical Levers
Brian I. Charous
Mentors: Eric Gustafson and Aidan Brooks

Advanced LIGO uses fiber-coupled diode lasers as input to its optical lever system. The optical levers make up an auxiliary system that provides error signals in pitch and yaw in the first step of the lock of the interferometer. Currently, the optical levers contain noise which makes it harder to bring the interferometer into lock and sometimes provide false positives of seismic noise. A possible source of that noise is in the optical fibers; if excess light is coupled into the cladding of the otherwise single-mode fiber, the fluctuating higher-order mode could appear as beam wiggle and be interpreted as test mass motion. In addition, a small ring appears around the core of the laser spot at the end of its throw, decreasing the precision of the optical levers. In this experiment, we examined whether the single-mode optical fibers used could really be carrying higher-order modes, and if the ring around the core of the beam could be reduced or eliminated. Our analysis indicates that the optical fibers do not contain excess mode content, and the ring may be caused by diffraction in the optics of the optical lever telescopes.

Optimization of Michelson Interferometer Signals in Crackle Noise Detection
Horng Sheng Chia
Mentor: Gabriele Vajente

The search for crackle noise has been limited by the presence of various sources of noise, including laser frequency noise, laser intensity noise and the misalignment of end mirrors in the Michelson interferometer. We developed an optimization algorithm that finds the best parameters that minimize the coupling of these noises into the output. These parameters include microscopic length difference, macroscopic length difference of Michelson arms, and the angular alignment of end mirrors.

Extracting Physics From the Stochastic Gravitational Wave Background
Brittany K. Christy
Mentors: Eric Thrane and Tjonnie Li

A gravitational-wave background is expected to arise from the superposition of many gravitational-wave signals, which are too weak to detect individually, but which combine to create a “stochastic” gravitational-wave glow. By measuring the stochastic background, we can probe a wide range of interesting science, from neutron stars to the inflationary epoch shortly after the Big Bang. This project is focused on studying the stochastic gravitational wave background that we hope to detect with the Advanced LIGO-Virgo detector network. In particular, we are developing software to analyze data from the Advanced LIGO-Virgo network, and infer the characteristics of the stochastic gravitational wave background. Using advanced statistical tools to extract information from tiny signals buried deep in the noise will give insight about the broad spectrum of sources that contribute to the stochastic gravitational wave background.
Investigating the Possibility of Dynamical Tuning of a Laser Interferometer
Chasya Eli Church
Mentor: Kiwamu Izumi

We investigate the feasibility of implementing dynamical tuning for the Signal Recycling Cavity in laser interferometric gravitational wave detectors. Compared with the conventional static signal recycling, dynamical tuning allows for a better signal-to-noise ratio when detecting chip signals from binary star systems, as it gives us the ability to track the signal frequency. One of the factors that affect the ease of implementing dynamical tuning is the length sensing and control system. The signal response to cavity length variation tends to be nonlinear and therefore introducing a microscopic length offset is not a straightforward task. However, using numerical simulations that model the length signals of ALIGO (specifically, the plane-wave-frequency-domain interferometer simulator, Optickle), we are able to run a virtual sweep to produce plots of such signals. Using these simulations, we search for the signals that respond linearly to the signal recycling cavity length, as well as investigate a possible expansion of the linear range.

Transportation of Ultra-Stable Light via Optical Fiber
Emily Conant
Mentors: Evan Hall, Rana Adhikari, and Tara Chalermsongsak

It has been demonstrated that polarization-maintaining single mode optical fiber can be used to transport frequency-stable light. It is desired to transport stable light to other labs in West Bridge to serve as a frequency reference for various experiments investigating different sources of noise in gravitational-wave detectors. Stable light has been obtained from ultra-stable Fabry-Pérot cavities. We have mode matched stable light into the fiber and are using a double-pass acousto-optic modulator (AOM) configuration to cancel fiber phase noise. We use a beamsplitter to interfere the stable light and double passed light onto a photodiode, which is connected to a phase-locked loop (PLL) to measure the beat frequency. From there, we analyze the noise in the system by measuring the power spectral density of the PLL control signal with a spectrum analyzer. We measured the expected dominant sources of noise in the set up by using a similar PLL set-up and found a large source of noise coming from the AOM driver. This was replaced with a low noise driver and we will proceed to transport the fiber to another lab once we identify and suppress any other possible noise sources.

Investigating the Effect of Magnetic Fields on Advanced LIGO
Christina Daniel
Mentor: Robert Schofield

A false gravitational wave signal can be produced by an external magnetic field inducing a current in the gravitational wave channel and/or artificially displacing the test masses hung from magnetically-controlled suspension systems. To monitor large, site-specific magnetic fields at frequencies as low as 10 Hz—the desired sensitivity of Advanced LIGO—we install and calibrate eleven magnetometers around the LIGO Hanford Observatory. In addition, a Schumann Resonance or Ultra Low Frequency (ULF) magnetohydrodynamic wave can affect both LIGO sites at approximately the same time, producing the effect of a gravitational wave. Fortunately, monitoring small, geomagnetic field variations with a sensitive magnetometer may enable us to subtract the noise out of the cross-correlated, stochastic gravitational wave background.

Investigating the Effect of Lenses in a Long Interferometer Arm
Brian Dawes
Mentor: Sheila Dwyer

Current gravitational wave interferometers are approaching fundamental limits to their sensitivity. In order to build more sensitive gravitational wave detectors, significant changes must be made to the current advanced LIGO design. One simple way to increase the sensitivity of a next generation detector is to increase the length of its arms. However, as the length of the arm increases, the beam width also expands. A larger beam would require larger optics and a larger beam tube, both of which are costly and can be difficult to manufacture. In this paper, I examine the possibility of placing lenses within the beam tube of a 40km long interferometer in order to maintain a narrow beam throughout the entire detector arm. I first examine different configurations of lenses that could achieve this and then investigate how motion of the lenses can add noise to the detector to propose limits on the required seismic isolation of the lenses. I also show these lenses can be created from flat pieces of fused silica through thermal lensing and thermal expansion effects.
Kalman Filter Based State Estimation for the LIGO 20m Reference Cavity
Reetika Dudi
Mentors: Aidan F. Brooks, Matthew Abernathy, and Vivien Raymond

The purpose of this project is to investigate the optimum application of the Kalman filter formalism to the reference cavity located at the Caltech 40m interferometer. The Kalman filter approach utilizes a model of the internal dynamics of a system in order to predict some state at a later time, and this prediction is used to constrain noisy measurements of the system. In the case of the reference cavity, the state variable is the spatially varying temperatures of the cavity and its surrounding environment. The internal dynamics of the reference cavity are governed by the law of heat-transfer through radiation, conduction and convection. As a first approach, we have investigated simple thermal models in the 1D and 2D axisymmetric cases using the Kalman filter matrix formalism. As the project progresses, we intend to investigate the application of the Kalman filter in order to estimate the internal temperature state of the cavity from length measurements inferred from the phase information at the output of the cavity.

Improving the Detection Rate of Gravitational Waves From Coalescing Binary Black Holes With Precessing Spins in LIGO/Virgo Data
Sara Frederick
Mentors: Stephen Privitera and Alan Weinstein

The Advanced LIGO and Virgo gravitational wave detectors will come online within the next year and will increase the detectable volume of LIGO/Virgo by three orders of magnitude. Coalescing binary black holes (BBH) are anticipated to be among the most likely sources of gravitational radiation observable by the detectors. The component black holes of these systems are predicted to have substantial spin, causing precession of the orbital plane in some cases. This feature greatly influences the observed gravitational waveforms from these sources. Recent LIGO/Virgo searches have used waveform models that neglect the effects of the component spins. However, there exist waveform models that include effects of spins aligned with the orbital angular momentum. We explore the use of an aligned spin template bank to search for BBH gravitational wave signals including precession. We characterize the ability for aligned spin template waveforms to increase the detection rate of precessing binaries in Advanced LIGO detectors. If black holes are highly spinning as predicted, use of aligned spin template banks in upcoming searches will increase the detection rate of these systems in Advanced LIGO and Virgo data, providing a deeper understanding of the sources.

Inference on Binary Neutron Populations
Naomi Gendler
Mentors: Larry Price and Vivien Raymond

The aLIGO network stands to make hundreds of detections over the lifetime of the project. While there is much to be learned from the parameters of single events, the parameter distribution of the population of events is also of great interest for astrophysics, as this kind of parameter inference will help to develop gravitational-wave astronomy. The goal of this project is to develop the tools for estimating such population distributions and accounting for selection bias in such inferences. We will then apply the method to a simulated population of binary systems of neutron stars in order to estimate their mass distribution.

Implementation of Frequency Offset Locking Feedback Control for the 40m Prototype Interferometer
Andrew Hall
Mentors: Koji Arai, Manasadevi P. Thirugnanasambandam, and Eric Quintero

The Arm Length Stabilization (ALS) system that is employed within the Laser Interferometer Gravitational Wave Observatory (LIGO) interferometers, relies upon piezoelectric actuators to actuate upon the resonant crystals within the lasers, in order to keep them frequency locked to the interferometer arm length. These actuators, however, have a limited bandwidth, which is sometimes exceeded. It is our goal to design a supplementary control system that will actuate upon a slow, temperature control servo, which will keep the error signal to ALS within its functional bandwidth. This frequency offset locking (FOL) system will use the beat frequency between the auxiliary and prestabilized lasers as its error signal, which will be obtained through a fiber coupled optical system. This signal will then be digitized, and fed into a digital PID control loop, which will generate a corrective analog signal, which will then actuate the temperature servo.
An Optical Setup for Crackle Noise Detection
Carell A. Hamil
Mentor: Gabriele Vajente

"Crackling noise" is a broad band noise that occurs in metals when they are stressed, due to the mechanical upconversion of the local deformations due to grain slippage or similar microscopic events. It has long been suspected that there are multiple instances of crackling noise in the LIGO Interferometers, and as such, a crackle experiment has been developed where the crackling noise in the maraging steel blades of a Michelson Interferometer will be measured. The steel blades present a straightforward mechanical system which can be driven and stressed easily. Since the crackling noise in LIGO is vertical noise and the coupling to the horizontal motion of the test masses is very small, the vertical noise in the blades are measured directly in the crackle experiment, to have maximum sensitivity to the crackling noise. A proposal for a crackle experiment with increased sensitivity has been proposed, and this project will be concerned with the construction and alignment of the optical setup for the upgraded crackle experiment. Following this, the response of the maraging steel blades will be characterized, and a control system will be developed and implemented to lock the Michelson Interferometer in order to keep it at resonance.

Examining the Properties of Global Schumann Resonances and Possibilities for Subtraction Across Multiple Data Channels
Ryan Horton
Mentor: Eric Thrane

Schumann resonances are global peaks in the magnetic field of the earth, with a primary peak at 7.8Hz of a few pT and subsequent peaks every 6.5Hz. These resonances are the result of lightning storms that occur all over the world, and as such are coherent on the scales of the distance between LIGO detectors and are time variant. Because of this being able to measure these peaks in real time and remove the parts of the spectrum that are coherent across the detectors is essential to achieving the projected noise floor in aLIGO. Here I discuss the initial the magnetic field measurements made around the LIGO Livingston and Hanford Observatories (LLO and LHO) as well as the techniques used to identify and/or remove local external sources of magnetic noise from the magnetic spectra. In addition I examine the properties of the Schumann resonances near LLO and LHO and compare their strength to the noise floors of current and (potential) future magnetometers. Finally I speculate on the potential effectiveness of using subtraction and/or wiener filtering to clean the on site magnetometer channels at LLO and LHO.

Designing a Frequency Offset Locking Loop for the LIGO 40m Prototype Arm Length Stabilization System.
Sai Akhil Reddy Konakalla
Mentors: Manasadevi P Thirugnanasambandam, Eric Quintero, and Koji Arai

The primary goal of LIGO is to directly detect gravitational waves which would open doors for ground-breaking observations in the field of astrophysics and give us a better understanding about the universe. For such a huge detector, there is a dire need of automated systems to control the state of the interferometer in a very efficient and precise manner. The goal of my project is to design a digital PID loop to lock the beat frequency between the Pre-stabilized Laser(PSL) and the Auxiliary (AUX) laser, within the working range (~100 MHz) of the Arm-Length Stabilization(ALS) system. To design such a loop, it is necessary to estimate the transfer functions and noise of all the control blocks inside the loop such as the frequency counter and the temperature actuator. Also, the interfacing between the electronics and the control computers is required as a part of PID loop design and a remote frequency beat-note readout.

Cutting Edge Computing for the Extraction of Astrophysical Parameters From Gravitational-Wave Observations
Halston B. Lim
Mentors: Vivien Raymond, Rory Smith, and J. Kent Blackburn

Detecting gravitational waves emitted by compact binary coalescences can provide important astrophysical information about the progenitor through a process called parameter estimation. Because parameter estimation, which involves finding theoretical waveforms and posterior probability distributions, is computationally expensive, we aim to expedite the process by taking advantage of the Intel Many Integrated Core Architecture (MIC), which uses parallel processing to increase performance. Our results indicate that the Intel hardware compatible MKL FFT implementation runs an order of magnitude faster than the generic FFTW implementation. Thus, given this improvement, we investigated optimizing the LSC Algorithms Library parameter estimation code as it utilizes FFTs. By reducing the computational cost of parameter estimation via optimization on hardware, longer gravitational wave signals can be analyzed, with the potential of extracting more information about the progenitor. We also adapt new visualization techniques to aid in the conciseness and clarity of results in the multidimensional parameter space.
Cryogenic Silicon Cantilever Q Measurements
Marie Lu
Mentor: Nicolas Smith-Lefebvre

Cryogenic silicon is being considered as an alternate material to the current material, silica, for the test masses in future iterations of LIGO due to its potential to reduce thermal noise. For example, the thermal expansion coefficient goes to zero at 120 K. This project maps the noise spectrum of low temperature silicon. The Fluctuation Dissipation Theorem relates the amount of noise produced by a system with the system’s linear response to applied perturbations. We apply this theorem to cryogenic silicon by measuring the quality factor, Q, to observe the damping behavior. We can then calculate the noise spectrum of the system, and study the response of Q to frequency, drive amplitude, and temperature.

Orthogonal Actuators for the Xarm Auxiliary Laser and Orthogonal Sensors for the Input Mode Cleaner
Andres R. Medina
Mentors: Nicolas de Matero Smith and Gabriele Vajente

The sensitivity of the 40 meter prototype interferometer detector depends on the alignment of the optical elements with respect to the incoming laser. Because the interferometer operates in the dark fringe, it is crucial that the arms are well aligned in order for acquiring and maintaining resonance. Any misalignment decreases the signal to noise ratio by introducing inside the cavity spatial higher order TEM modes, and therefore introducing noise inside the cavity. In order to correct for any misalignment inside a cavity, orthogonal sensors and actuators are used to control the different degrees of freedom. The aims of this paper are to develop an optical setup that comprises orthogonal actuators for the current x-arm auxiliary laser and develop an optical setup for the Input Mode Cleaner, which also utilizes orthogonal sensors. We will design the optical setup in the given space that is available on the table and characterize the systems orthogonally.

Thermal Noise Reduction in Coating-Less Optical Cavities
Samuel L. Moore
Mentors: Matthew Abernathy and Koji Arai

Lasers need to have low frequency and phase noise when used in high-precision measurements (such as gravitational wave detection). The overall aim of this project is to reduce the frequency and phase noise specific to temperature fluctuations in an optical cavity. There are two forms of thermal noise, namely thermoelastic noise (associated with length fluctuations) and thermorefractive noise (associated with index of refraction fluctuations). Our optical cavity is a rectangular block, utilizing total internal reflection. Analytical and Finite element thermorefractive thermal noise calculations are presented here for this cavity. Faster methods are employed for calculating this thermal noise: the heat equation is solved using a steady-state, transient-free ansatz. Moreover, we are searching for the best mesh distribution that solves the problem quickly and accurately. In the future, these thermal noise calculations will be used to find a material that minimizes the total thermal noise.

Numerical Simulations of Superkick Binary Black Holes
Lydia Nevin
Mentor: Mark Scheel

Gravitational wave detection by LIGO depends on accurate waveform templates for comparison. The development of these templates is accomplished by numerical relativity simulations of events such as colliding black holes. Two black holes orbiting and merging, called a black hole binary, are described by seven independent parameters: the three components of spin for each black hole, and the ratio of their masses; the total mass of the system can be scaled out. Simulations can take weeks or months, and the possible cases are numerous, so a robust interpolation strategy is desired. We use the SpEC numerical relativity code to investigate cases where the masses are equal and the spins are anti-aligned and in the plane of the orbit, a situation called a Superkick, which results in unusually high radiated linear momentum. We aim to discover how significantly waveforms differ when starting conditions are slightly changed, and therefore how easily interpolation can be used between similar instances of this situation. We also describe improvements in algorithms used to specify the orbital eccentricity of binary black hole simulations.
Modeling of Optical Scattering in Advanced LIGO
Hunter Rew
Mentors: Joseph Betzwieser, David Feldbaum, and Adam Mullavey

In a quantum limited sensitivity interferometer such as LIGO, light which scatters from an optic can introduce noise in the phase measurement at the antisymmetric port, as well as become a significant source of power loss. By measuring power seen by a camera or photodiode in a well defined position, outside of the beam path, one can use the incident light in order to model the total amount of light scattered from the optic. We have used the bidirectional reflectance distribution function on data obtained from photodiodes along the beam tubes baffles to model scattering from LIGOs test masses during each alignment since the first transmission of Advanced LIGO. This data acquisition and analysis has been automated for ease of future analysis. We have also experimentally determined 8 and 12 bit monochromatic count to Watt conversion factors for the Basler Ace 100gm cameras, currently used to monitor light within the interferometer, so that archived images may be used as a data source for the model.

Automated Photodiode Frequency Response Measurement System for Caltech 40m Lab
Nichin Sreekantaswamy
Mentors: Eric Gustafson and Jameson Rollins

This project is carried out at the Caltech 40m prototype interferometer lab, which functions as an R&D facility for LIGO. The 40m houses a Dual Recycled (signal and power) Fabry-Perot Michelson Interferometer. Several photodiodes are used to sense various degrees of freedom and provide feedback signals to position the mirrors for correct operation of the apparatus and ensure that cavity resonances are acquired and maintained. The goal of this project is to treat the photodiodes and their readout electronics as systems whose performances can change with time and operating conditions and build an automatic frequency response measurement system. An amplitude modulated diode laser is used to perform frequency sweeps, while a 1x16 RF (Radio Frequency) signal multiplexer is used to choose the required photodiode. Communication to the network analyzer is done wirelessly over GPIB (General Purpose Interface Bus) and to the RF multiplexer over TCP/IP. Lab personnel can choose the required PD from a graphical interface to run the frequency sweep test, analyze the data and then bring up its current transimpedance frequency response plots. A comparison is also made between the current plots obtained and a canonical set of plots, for easy identification of errors. Finally, the transimpedance is fit to a transfer function model using vector fitting and variations of the model with respect to a standard model is monitored.

Loss Dependence on Beam Position in the Arm Cavities of aLIGO
Leo Tsukada
Mentors: Denis Martynov and Valery Frolov

High beam power in the interferometer is an essential component to realize required sensitivity to Gravitational waves. Therefore it is significant to understand main factors which cause optical loss in the arm cavities although we have not completely verified the effect of these factors on power loss. In this project we investigate the loss dependence on beam off-centering with regards to the center of the optics based on the clipping model. The loss measurement and analysis in the both of X-arm and Y-arm are conducted by the informative method which makes it possible to derive not only optical loss but also cavity mode-matching ratio and the transmissivity of the input mirror. We also explore systematic error caused by Input Mode Cleaner in order to estimate accurate loss quantities. As a result, we confirm that the optical loss strongly depends on beam spots on the cavity optics. However the specific dependence on beam off-centering is not verified only by this result. Thus more data at various spots on the optics are required to make precise maps of the mirror with optical losses.

Magnetic Dipole Near a Schwarzschild Black Hole
Farzan Vafa
Mentor: Yanbei Chen

We derive the dipole tensor for a magnetic dipole in a curved space-time, and expand the 4-current $j^\mu$ in vector harmonics assuming a spherically symmetric spacetime. We then consider the specific case of a stationary, precessing magnetic dipole in a Schwarzschild background. For this case, we set up the equations that the electromagnetic fields satisfy, and compute them on the horizon. In particular, we are interested in the Poynting flux on the horizon, and the charge separation on the horizon induced by the changing magnetic flux, which drives a current through the black hole-neutron star circuit and generates power.
Searching for Gravitational Waves From the Coalescence of High Mass Black Hole Binaries
Sophia Xiao
Mentors: Alan Weinstein, Tjonnie Li, and Surabhi Sachdev

We search for gravitational waves from the coalescence (inspiral, merger and ringdown) of binary black holes with data from the Laser Interferometer Gravitational-Wave Observatory (LIGO). Provided with well-described waveform models from General Relativity, matched filtering is employed in the GSTLAL analysis pipeline as the optimal detection technique. The GSTLAL analysis pipeline filters data with waveform template banks, identifies triggers with SNR greater than 8, forms coincident triggers between multiple detectors in the LIGO Scientific Collaboration, and attempts to optimally separate signal from detector background noise fluctuations using Chi-squared test. We run high-statistics simulations with LIGO S6 data to evaluate the search sensitivity as the analysis parameters are tuned, to arrive at optimal settings under different anticipated noise fluctuation conditions. With Advanced LIGO fully in operation by 2015 and the upgraded analysis pipelines, the expected detection rate is increased to as much as 100 events/year or more as compared to 0.01-1 events/year in Initial LIGO. We may finally be on the verge of detecting gravitational waves.

Analysis and Enhancement of Second Harmonic Generation for aLIGO
Nathan Z. Zhao
Mentors: Dick Gustafson and Daniel Sigg

Second harmonic generation is employed to increase LIGO sensitivity in the several hundred hertz range by introducing squeezed states through the dark port of the interferometer. This project characterizes the second harmonic generation of periodically poled KTP in a resonant cavity locked by a PDH servo. Measurements via oscilloscope, signal analyzer, pre-amp are interfaced via computer; cavity modifications executed electrically with a piezo-driver; and beam modifications via optics and stages. Current data suggests servo stability on the order of 10 hours. The beam in both the infrared and green contain amplitude fluctuations, but the 532 nm green shows significantly more time-averaged stability compared to the 1064 nm infrared. Initial data also show that the green beam’s energy distribution is discontinuous on short time scales, which merits further investigation before a definitive conclusion can be reached. The conversion efficiency has been maximized at around 80\% via temperature tuning (which achieves quasi-phase matching) and boosting the laser’s infrared power. Finally, a new SHG is being built to incorporate a digital temperature controller featuring Beckhoff Ethercat terminals and TwinCat PLC software. The response characteristics (set-temperature response and step function response) for this servo have been analyzed and suggest slow (on the order of minutes), albeit stable performance.
Abstracts

Student–Faculty Programs

2014