Caltech Student-Faculty Programs

Poster Session Abstracts

Behavioral and immunological consequences of excessive sugar intake
Barbara I. Ayala
Mentors: Yuki Oka and Yameng Zhang

Sugar is an essential dietary carbohydrate, fundamental for living organisms, but its overconsumption has become a major contributor to global health deterioration. Currently, the typical American adult exceeds the recommended daily sugar intake by 50%. This excess disrupts systems involved in maintaining homeostasis, such as the immune system or neural circuits. Recent studies have associated sugar-rich diets with the development of a systemic proinflammatory state and immunocompromised conditions. For this reason, this project aims to create a mouse model that mimics long-term excessive intake of three common sources of sweetness in the American diet: glucose, sucrose, and acesulfame potassium (AceK), an artificial non-caloric sweetener. Using a standardized paradigm, we trained mice with sweet solutions under deprived conditions to model sugar overconsumption. Preliminary preference results suggest that, after restriction, mice exhibit ingestive behavior that exceeds their energy needs, showing a clear bias toward higher-caloric solutions such as glucose over water or non-caloric sweeteners. To assess the long-term effects of this behavior, we will evaluate systemic inflammation and neuronal activity in satiety-related brain regions following chronic sugar exposure. Molecular analyses such as qPCR and ELISA will be used to link consumption patterns with pathological mechanisms associated with chronic disease risk.

Theoretical ellipsometer for thin films of silicon and aluminum and related compounds
Michael K. Battiest
Mentors: Austin J. Minnich and Finley Donachie

To overcome limited access to ellipsometer, we implemented a Python-based simulation spectroscopic ellipsometry for thin films. The simulator primarily uses the transfer matrix method to model ellipsometry outputs, specifically the amplitude ratio (XXXXX) and phase difference (XXXXX). The simulation outputs reveal how optical properties evolve with film thickness, including the presence of tunable XXXXX minima across different materials and layer configurations. The benefit of the model is that the theoretical experiment avoids costly fabrication and makes it possible to evaluate different films without a physical experiment This approach allows preliminary optical screening of materials prior to fabrication which bypasses intermediate steps that require plasma ALE development workflows. This research provides insight into thin film selection for semiconductor applications that require precise control of reflectance, and it enables comparison between future experimental and theoretical ellipsometry data.

Low-cost spalled GaAs (110) thin film solar cells
Bonnie Chen
Mentors: Harry A. Atwater, Jr., and Andy Nyholm

The Caltech Space Solar Power Project (SSPP) strives to harvest solar energy from space and wirelessly transmit it back to Earth using microwaves. To fulfill this goal, it is necessary to create low areal weight, high efficiency, radiation-hard, and low-cost solar cells, with costs at least similar to those of terrestrial solar cells, in order for space solar to be desirable. The vast majority of terrestrial solar cells are bulk solar cells. However, bulk solar cells exceed the efficiency to areal weight ratio required to launch solar cells into space economically. Moreover, thin-film semiconductors have been traditionally produced using epitaxy, which significantly increases manufacturing costs due to requirements for high quality substrates, high vacuum processes, and specialized equipment. In this project, we explore different configurations of GaAs thin film solar cells. We design and fabricate thin-film solar cells with EL2-annealed and diffusion-doped (110) GaAs using the method of spalling. A GaAs (110) wafer is first electroplated with a stressed nickel layer, then spalled into a thin film. Contacts are deposited using photolithography and electron-beam deposition. We investigate experimental methods to reliably produce these spalled cells, including etch rates of various GaAs substrates, adhesive removal, and nickel etching, as well as efficiency of differently sized cells (from .25mm^2 to 1cm^2). Through electromagnetic field simulations and finite element multiphysics simulations with Ansys Lumerical, we also examine the specific power of spalled GaAs (110) to spalled GaAs (100), which is a more readily available substrate material, and has a corrugated surface that may exhibit light trapping mechanisms. With these experimental and computational methods, we advance the development of low cost space solar cells.

Steering diffusion policy for controllable actions in robot manipulation
Yen-Ru Chen
Mentors: Aaron D. Ames, Albert Li, and Damiano Marsili

Learning-based control under the imitation learning paradigm offers a promising alternative to classical model-based control for robotics. Unlike model-based approaches, which require explicit and complete modeling of the robot's environment, learning-based methods can acquire complex, multimodal behaviors directly from human demonstrations—even in settings without full observability or detailed task specification. Diffusion Policy has emerged as a leading method for behavior cloning in this context. In this work, we investigate strategies to flexibly control a Diffusion Policy's behavior in robot manipulation by incorporating additional visual inputs as conditioning signals. Our experiments highlight both the challenges and opportunities of steering robot actions via enhanced sensory guidance.

Studies in calcium isotope speciation in urine
Margo T. Crothers
Mentors: John M. Eiler, Francois Tissot, Rebecca J. Ryan, and Theo J. Tacail

Background: It has been proposed that calcium (Ca) complexation with organic ligands found in urine favor the heavy isotopic species, providing a mechanistic explanation for isotopically heavy urine relative to other Ca reservoirs in the body. *Aims and Methods:* Here, we conduct a study of isotopic fractionation among Ca species in urine. First, we study the effects of solid phase precipitation on the bulk Ca isotopic composition of natural urine samples. Second, we begin development of a method with ESI Orbitrap IRMS that discretely measures isotopic composition of multiple aqueous Ca-ligand species in a single sample. *Conclusions*: Solid compositional analyses reveal variable solid phases in urine with similarly varying effects on isotopic composition. Analysis of Ca-complexes on ESI Orbitrap can produce consistent precision in simple mixtures, but the full effects of a more complex matrix on measurement precision and accuracy are yet to be rigorously tested. *Implications:* Precipitation has variable effects on calcium fractionation, depending on precipitate composition and quantity, which varies even among demographically similar individuals. ESI Orbitrap IRMS has the potential to measure complex-specific Ca isotopes, but a greater understanding of sample matrix effects is needed before measurements can be performed on natural samples on a large scale.

Converting carbon dioxide into useful chemicals and fuels
Daniel C. Darahdgian
Mentors: Harry B. Gray and Aisulu Aitbekova

Lowering carbon dioxide emissions while also reducing demand for fossil fuels is made possible through the catalytic hydrogenation of carbon dioxide into hydrocarbons. However, few catalysts are capable of hydrogenating CO_2 while not reducing the carbon-carbon double bonds characteristic of olefins or unsaturated hydrocarbons. Therefore, we studied a carbon nanotube supported iron-potassium catalyst, which has previously been reported to have high CO_2 conversion while maintaining great olefin selectivity. In our experiments, carbon monoxide and methane were our major gaseous products. However, we did not produce any liquid olefins but instead made mostly alcohols and carboxylic acids. We investigated the cause of these unexpected results with particular interest in how catalyst loading may affect what sort of products are made in the hydrogenation reaction.

Boosting generalization in neural CFD surrogates through FIGConv refinement
Yichen Di
Mentors: Anima Anandkumar and Valentin Duruisseaux

We develop methods to improve the accuracy and generalization of neural operator architectures for computational fluid dynamics (CFD) prediction. Building on the Factorized Implicit Global Convolution (FIGConv) framework, we explore architectural refinements, optimized training schedules, enhanced conditioning strategies, and the integration of geometric priors. Controlled overfitting experiments confirm strong model expressiveness, while tests on varied geometries reveal a generalization gap that motivates ongoing optimization. These advancements aim to enable scalable, reliable surrogates for complex fluid systems, supporting downstream applications such as shape optimization.

Oxygen generating smart bandage for wound management
Sofia H. Granieri
Mentors: Wei Gao and Kexin Fan

Chronic wounds such as diabetic ulcers are often oxygen-deficient, which impedes healing and increases risk of infection. To address this issue, a smart bandage device is being developed that supplies oxygen and hypochlorous acid to promote wound healing, while simultaneously monitoring wound conditions to ensure an optimal healing environment. In this study we started developing several components of this device, including hypochlorous acid sensors, hydrogels for oxygen generation, and membranes for oxygen and fluid transport. The primary focus has been on optimizing a wear resistant hydrophobic coating for a Janus membrane to facilitate oxygen delivery to the wound and fluid transport into the hydrogel. Here we present preliminary findings, with the aim of integrating these components into a functional device in the future.

Observing sleep behavior within zebrafish using clustering
Amudhan S. Gurumoorthy
Mentors: David Prober and Yun Chiu

Sleep is a very important part of everyday life, yet many of the common sleep practices behind humans remain unknown. This research paper attempts to delve further into the processes behind sleep by studying zebrafish, an organism with a sleeping pattern that resembles that of humans. With data obtained through a GCaMP imaging dataset, this study uses permutation tests to identify responsive neurons whose activity increases or decreases upon HCRT activation and factor based clustering to reveal cell populations with similar neural activity patterns. This consequently shows the neurons most correlated with sleep, which we then analyze to determine the activity of specific regions of the brain during changes in sleep. Then, we can compare this activity to behavioral activity within zebrafish, explaining the cause of certain zebrafish behaviors during sleep. By visualizing the spatial distribution of these functional clusters on the registered brain image, we confirmed these functional clusters could be real cell populations since they are spatially located together. Future work involves translating these neuronal effects to the brains of humans, determining whether particular regions of the human brain are heavily affected during sleep.

Investigation of the cancer cell resistance mechanisms to p97/VCP ATPase inhibitor via single-cell and bulk phosphoproteomics
Ying-Hsin Hsiao
Mentors: Tsui-Fen Chou and Marion Wan Rion Pang

p97 AAA ATPase is a critical regulator of protein homeostasis and a promising anticancer drug target, with inhibitors such as CB-5083 and CB-5339 advancing to phase I clinical trials. Although p97 inhibitors have demonstrated efficacy in colon cancer xenografts, prolonged exposure results in resistant cell populations acquiring resistance through p97 mutations. To elucidate the mechanisms underlying this drug resistance, we used three CB-5083 resistant HCT116 sublines (CB-R1, CB-R2, CB-R3) and performed integrated bulk and single-cell mass spectrometry–based proteomics. We incorporated phosphoproteomics on both bulk and low-analyte samples, capturing alterations in signaling activity that accompany resistance. Upregulated kinases in CB-R cells were identified through motif-enrichment analysis on phosphoproteomics data. We then performed drug combination experiments between CB-5339 and 20 kinase inhibitors to determine their combined effect with the expectation of potential synergistic cytotoxicity with CB-5339, suggesting specific vulnerabilities in resistant cells. Follow-up single-cell MS profiling after co-treatment revealed pathway reactivation, feedback signaling, and stress responses unique to certain combinations, enabling insight into compensatory survival pathways. Altogether, our study leverages deep proteomic and phosphoproteomic profiling across bulk and single-cell scales to uncover key mediators of resistance and to nominate rational combination strategies that may overcome therapeutic failure in p97-targeted cancer treatment.

SFB power spectrum emulator: Spherical Fourier-Bessel power spectrum emulation to constrain fundamental cosmology
Elizabeth Huber
Mentors: James J. Bock and James Cheshire, IV

The SFB power spectrum emulator is a spherical Fourier-Bessel (SFB) emulator which enables inference of cosmological parameters, motivated by SPHEREx's (Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer) goal to constrain primordial non-Gaussianity and model time evolving dark energy. Given a set of cosmological parameters, the SFB power spectrum emulator emulates a corresponding SFB power spectrum. The emulator is a neural network which was trained on a Latin Hypercube sampling of cosmological parameters, used to generate Cartesian matter power spectra, then subsequently transformed to SFB power spectra with primordial non-Gaussianity, f_{NL}, and bias parameter modeling. After completion, this software will provide a widely accessible rapidly iterable surrogate for classical Boltzmann solvers, and will provide increased accuracy in constraining cosmological parameters by enabling improved data isolation and mode cuts. Future applications include applying our SFB power spectrum emulator to eBOSS cosmological surveys, and applications to SPHEREx to forecast their sensitivity to dark energy parameters, namely w_0 and w_a.

Sensor fusion system for infrared-based fire detection and localization
Dami Kim
Mentors: Morteza Gharib and Julian Humml

A portable sensor fusion system integrating an infrared (IR) camera, inertial measurement unit (IMU), GPS, rangefinder, and Raspberry Pi is under development for thermal source localization in wildfire detection applications. Radiometric IR data is combined with orientation estimates from a bias-corrected IMU and timestamped sensor logs to enable multi-modal data fusion. The system is mounted on a custom three-axis gimbal that simulates aerial motion. Preliminary analysis demonstrates that angular platform movements produce corresponding shifts in hotspot pixel locations, confirming the feasibility of orientation-based coordinate transformation. Ongoing efforts focus on implementing the pinhole camera model and integrating range data to estimate the global positions of detected heat sources. Once gimbal-based testing is validated, the sensor system will be mounted on a UAV to perform fire localization while following a pre-planned autonomous flight path. This work lays the foundation for real-time, drone-based wildfire detection through onboard thermal and spatial sensing.

Design and simulation of an acoustic waveguide for quasi-point source generation in photoacoustic tomography
Jinsung Kim
Mentors: Lihong Wang and Manxiu Cui

Photoacoustic tomography (PAT) benefits from calibration using an ideal ultrasonic point source, but real transducers exhibit directional bias. We propose an acoustic waveguide to transform a 1 MHz transducer output into a quasi-point source. Using 2D axisymmetric k-Wave simulations, the spline-parameterized geometry was optimized via a genetic algorithm with a multi-term loss function. Simulations show improved angular uniformity over the baseline. Fabrication and experimental validation will assess performance for enhancing PAT system calibration.

Quantifying peak-shift style exaggeration in comic covers and its marketplace signal
Brendan D. Lee
Mentors: Colin F. Camerer and Katelyn Haly

Supernormal stimuli are exaggerated versions of stimuli that organisms have an innate tendency to respond to. Comic books, for instance, often feature hyper-exaggerated heroic physiques, explosive action, and saturated colors to captivate readers. This project investigates whether such visual exaggeration predicts commercial success by developing an automated pipeline to quantify these features and correlate them with sales data. A custom web crawler was built to harvest comic book covers and their metadata, which were then matched to a sales database. To quantify the visual elements, two parallel computer-vision models were employed: an OpenCLIP model measured the semantic similarity between covers and engineered prompts, while a GPT-4o mini vision model assigned discrete scores for the same attributes. These analyses yielded a composite Stimuli Index for each cover. Sales metrics from Comichron were then regressed against this index. A preliminary analysis revealed a modest, positive correlation with revenue, supporting the initial hypothesis. While these early results suggest a link between heightened visual stimuli and commercial performance, a larger sample is required to achieve statistical power. Ongoing work will expand the dataset across more publishers, incorporate validation from human raters, and explore the potential of using these models to predict the success of new cover designs.

Computational framework for predicting acoustic force fields in ultrasound neuromodulation

Andrea H. Li
Mentors: Mikhail G. Shapiro and Alen Pavlic

Abstract withheld from publication at mentor's request.

Synthesizing and examining the novel magnetic topological semimetals properties of $TaCoTe_2$

Xiang-Yu Li
Mentors: Linda Ye and Tao Lu

Magnetic semimetals are a new class of materials that combine time reversal symmetry breaking and topology. $TaCoTe_2$, a recently proposed van der Waals material, is a layered antiferromagnetic semimetal with a high Néel temperature (~310 K) and has type-II Dirac fermions protected by glide mirror symmetry. Upon the inclusion of SOC, this Dirac point opens a small gap, but a new type-II Dirac point emerges approximately 0.2 eV below the Fermi level. Those makes $TaCoTe_2$ a candidate system for exploring novel quantum transport phenomena, such as the in-plane anomalous Hall effect arising and investigating quantum geometry. To synthesize single crystals, we first obtained polycrystals by solid-state reaction and subsequently applied a chemical vapor transport (CVT) method using $TeCl_4$ as a transport agent. We confirmed the polycrystals matched the expected structure by powder X-ray diffraction(XRD) , but the single crystals grown by CVT unexpectedly showed a stoichiometry closer to $TaCo_2Te_2$, as revealed by energy-dispersive X-ray spectroscopy(EDS). XRD and phase diagram further supported that a more stable phase $TaCo_2Te_2$ might have formed during transport. To solve this, we attempted growth parameters optimization by adjusting the temperature gradient and transport agent concentration. Additionally, we proposed a tellurium self-flux growth method for better phase selectivity and crystal yield. If successful, we plan to perform transport measurements under rotating magnetic fields to probe the in-plane Hall effect. These measurements will provide insight into the role of magnetic symmetry and quantum geometry in antiferromagnetic topological systems.

Searching for planetary nebulae in CLU PTF Hα survey using segmentation and machine learning algorithms

Ryan X. Lin
Mentors: Shrinivas R. Kulkarni and Soumyadeep Bhattacharjee

Planetary nebulae (PNe) are ionized shells of gas ejected by intermediate-mass stars in late stellar evolution, though similar PN-like structures can also arise from binary interactions or unrelated processes such as bow shocks. A major challenge is the gap between the ~4,000 confirmed and candidate PNe in the HASH catalogue and theoretical estimates of 6,600-60,000, motivating systematic searches in new datasets. Narrow-band Hα imaging has been the primary discovery method, but past surveys have focused on the Galactic plane. The Census of the Local Universe (CLU) Hα survey, covering 26,470 deg^2 of the northern sky, offers a largely unexplored high-galactic-latitude search space. Here, we develop segmentation-based and machine learning algorithms to detect compact and extended nebulae, enabling automated, wide-field searches for new PNe and related emission-line sources. In our segmentation-based algorithm, we implement multiprocessing and memory optimisations to enhance algorithmic performance, Bayesian optimisation to find optimal hyperparameters, and temporal crosschecking to reduce the number of false detections. Our segmentation-based algorithm yielded positive results, achieving a recall of 59.8%, resulting in several new planetary nebula candidates. In our machine learning algorithm, we experiment with various convolutional neural network architectures for low-latency and wide-field searches, yielding impressive performance.

Biochemical characterization of UFD-3/PLAA intrinsically disordered regions and their role in neurodegenerative pathogenesis
Marc Moroz
Mentors: Tsui-Fen Chou and Yanping Qiu

Phospholipase A2 Activating protein (PLAA) is a co-factor of Valosin-Containing protein (VCP), a protein that is necessary for the function of the Endoplasmic Reticulum-Associated Degradation (ERAD) pathway. Through this relationship, mutations in PLAA are known to play a role in the pathogenesis of Degradation-Associated Neurodegenerative Disorders (DAND). However, *Caenorhabditis elegans* (*C. elegans*) with mutations in the intrinsically disordered region (IDR) of Ubiquitin Fusion Degradation protein 3 (UFD-3), the *C. elegans* homolog of PLAA, demonstrated inhibited formation of p-bodies—a symptom of DAND—and a direct interaction with mRNA Decapping enzyme 1 (DCAP-1) seemingly independently of Cell Division Cycle protein 48 (CDC-48.2), the VCP *C. elegans* ortholog. Investigating this mechanism may reveal a neurodegenerative role for UFD-3 independent of CDC-48.2 As a result, this study seeks to learn more about the UFD-3 recruitment of DCAP-1 by characterizing UFD-3 *in vitro*. Protein expression of UFD-3 is in progress for in vitro characterization—in the presence of CDC-48.2, which may potentially act as a stabilizing and solubilizing agent. This study will contribute to our knowledge about UFD-3 and hopefully increase our understanding of neurodegenerative diseases.

Assembly and qualification of the barrel Precision Timing detector for the high luminosity upgrade of CMS at CERN
Nabeeha W. Mubeen
Mentors: Maria Spiropulu and Soham Bhattacharya

The LHC will begin its Long Shutdown 3 (LS3) in 2026 to upgrade the accelerator for CERN's HL-LHC (High Luminosity Large Hadron Collider) era. This era will help improve the sensitivity for standard model physics studies such as the characterization of the Higgs boson and searches for physics beyond the standard model such as exploring dark matter production. This project focuses on precision timing measurement at the Compact Muon Solenoid (CMS) experiment. This will be achieved by working on the assembly of the barrel timing layer (BTL) which is one of the two components of the CMS minimum ionizing particle Timing Detector (MTD). This will be the first detector at collider experiments dedicated to precision timing with a resolution of 30-60 picoseconds. Construction of the BTL consists of assembling sensor modules (SMs) and detector modules (DMs). Rigorous quality assurance and control tests of SMs and DMs are performed to ensure optimal performance. The BTL is segmented into 72 trays where each tray contains 6 readout units (RU). Each RU contains 12 DMs, and a DM includes 2 SMs mounted on a front-end electronic card. This project involves activities in the assembly procedure, from building and testing modules, to constructing trays.

Interrogating the AtGet3a-AtGet4 interaction in the *Arabidopsis thaliana* guided entry of tail-anchored proteins (GET) pathway
Stanley A. Muñoz
Mentors: William M. Clemons, Jr., and Conner W. Wells

Tail-anchored (TA) proteins are a topologically distinct class of integral membrane proteins that require post-translational targeting by the Guided Entry Tail-anchored (GET) pathway. While this process is well characterized in fungi and metazoans, its mechanism in plants remains poorly understood. In the model organism, *Arabidopsis thaliana*, AtGet3a and AtGet4 are predicted homologs of cytosolic GET pathway components. This project investigates how AtGet4 regulates the ATPase activity of AtGet3a and which conserved residues mediate their interactions. Conserved residues in AtGet3a and AtGet4 were identified through multiple sequence alignment. Mutations were introduced by site-directed mutagenesis, constructs were expressed in *E. Coli*, and purified using Ni-NTA affinity chromatography as well as size exclusion chromatography. ATPase and qualitative chromatographic studies will be performed to assess the significance of these interactions. Understanding the molecular mechanisms between AtGet3a and AtGet4 will provide insight into the evolutionary conservation and divergence of the GET pathway and provide the basis for future structural and functional studies in plants.

Hydroacoustic analysis of the 2022-2023 Tanaga Island seismic unrest
Neha Narayan
Mentors: Gabrielle Tepp, Robert Dziak, Ross Parnell-Turner, and Vaibhav Ingale

Volcanic monitoring and hazard evaluation is difficult in remote locations like the Aleutian Islands. Tanaga Island, one of the volcanic islands in the Aleutians, experienced a period of seismic unrest, attributed to magmatic transport and recorded by a hydrophone array deployed in the Bering Sea. A preliminary study found that seismic events recorded by the array compared well with a United States Geological Survey seismic event catalog. Another recent study relocated the seismic events with greater accuracy, reducing uncertainty in source characteristics. Comparing the hydroacoustic events to this relocated catalog may help constrain trends in the event source parameters. In this study, we match the hydroacoustic and seismic catalogs by signal arrival time and back-azimuth, and use the ray-tracing based modeling software, Bellhop, to model transmission loss and determine the sound source levels. Assuming conversion points at 2.5 and 3.5 km below sea level, we estimated the transmission loss between the event locations and the hydrophone array as ~96 and 107 dB, respectively. Using the matched events, we reanalyze the relationships between event location, depth, magnitude, and rise time. These findings will characterize the seismicity near Tanaga Island to aid hazard assessment and future studies of the region’s seismic activity.

Hypervelocity impact ionisation of Europa-relevant ice grains for SUDA data interpretation of NASA's Europa Clipper Mission
Holly L. Nerurker Espinoza
Mentors: Paul D. Asimow, Bryana Henderson, and Sankhabrata Chandra

NASA’s Europa Clipper mission will investigate the chemical makeup of Europa’s surface and plumes to assess the moon’s potential habitability. One of the key instruments aboard the spacecraft, the Surface Dust Analyzer (SUDA), is a Time-of-Flight (TOF) impact ionization mass spectrometer that measures the ion fragments produced when micrometer-scale ice grains impact a target-plate at hypervelocity. However, interpreting SUDA’s data requires understanding of how variables such as pH, salinity, and impact velocity influence ionization patterns, and to-date no comprehensive laboratory database exists. To address this gap, we are conducting controlled impact experiments with salt solutions, systematically varying pH (2, 5, 8 and 11), salinity (10 mM, 100mM, 500mM, 1M and saturation), and grain velocities (3.0, 3.5, 4.0 km/s) both in cation and anion mode. The selected salts (NaCl, Na_2SO_4 and Na_2CO_3) are thought to be present on Europa’s surface based on observations by the Near Infrared Mapping Spectrometer (NIMS) on Galileo spacecraft and Hubble Space Telescope. Preliminary results reveal systematic changes in peak intensity and cluster formation; for example, integrated salt cluster peak areas increase with salinity up to 500 mM. By building a spectral database that captures these trends, this work will enable confident identification of surface composition not only for Europa, but for Enceladus and other icy or ocean worlds.

ULX marks the spot: Searching for bright UV emission around ultraluminous X-ray sources
Sophia C. Nicolella
Mentors: Fiona A. Harrison and Hannah Earnshaw

Ultraluminous X-Ray Sources (ULXs) are binary star systems exhibiting super-Eddington luminosities and are thought to be candidates for intermediate-mass black holes or magnetized neutron stars accreting matter at super-Eddington rates. However, the process that causes their ultraluminosity is not well-understood, and ULXs are not well studied in the ultraviolet regime, which may be able to tell us about the surrounding environments, formation channels, and life cycles of these types of systems. We created a catalog of bright UV sources corresponding to known ULXs. Using observational data from the Swift UVOT instrument, we analyzed their UV emission to investigate the conditions in which they reside and whether the accreting source itself is UV-bright. Since UV variability and super-Eddington UV luminosities are likely indicative of a ULUV, we generate UV light curves in order to compare them to the X-ray output, identify the best ULUV candidates in the sample, and report on their properties.

Wireless power transfer system for low power, millimeter scale implantable biomedical sensors
John I. Ogbu
Mentors: Azita Emami and Shengsheng Wang

Biomedical sensors are a vital part of many of the high-impact implantable medical devices (IMDs) used in modern healthcare to provide continuous, functional support, early disease diagnosis, and/or drug delivery in targeted tissue or organs. Recently, the Mixed-Mode Integrated Circuits and Systems (MICS) Lab demonstrated an implantable, 3D alternating current (AC) magnetic sensor design that used a magnetic gradient technique to achieve high-resolution sensing in a 65-nm CMOS process. The MICS sensor requires 14.8μW of power to operate and common powering solutions, such as discrete batteries or various energy harvesting systems, are unideal due to their ineffectiveness within the intended use cases of the MICS sensor. Here, we present a wireless power transfer (WPT) system that meets the power, size, and longevity demands of the MICS sensor. The system consists of one receiver (RX) coil fabricated in the 65-nm mode on the sensing chip and three external, orthogonal printed circuit board (PCB) spiral transmitter (TX) coils to provide 3D power transfer capabilities. A 13.56MHz AC current is passed through the TX coil(s), which allows us to model the TX coils as RLC resonator tanks using a lumped circuit model. The RX and TX coils are inductively coupled; according to Ampère's Law, the AC current in the TX coil(s) produces a time-varying magnetic field. This field produces time-dependent variations in the magnetic flux of the RX coil. By Faraday's Law, the changing magnetic flux induces a time-varying voltage across the RX coil. This induced voltage produces a current that flows in a direction that, according to Lenz's law, opposes changes in the magnetic flux produced by the TX coil(s), resulting in wireless power transfer via an AC current. The efficiency of this process is heavily dependent on the geometry of the RX and TX coils and determining the ideal geometry of the coils requires solving a multivariate optimization problem. The peripheral power electronics for the system consists of impedance matching networks on both the TX and RX sides of the system, a preamplifier on the TX side, and a rectifier and DC-DC converter on the RX side for signal shaping. The on-chip electronics use a supply voltage of 1.2V to match the constraint given by the MICS sensor.

Deep learning and coarse graining on discrete element simulation data to learn constitutive models for granular flow
Amitesh Anand Pandey
Mentors: Kaushik Bhattacharya, Harkirat Singh, and Lianghao Cao

Discrete Element Method (DEM) simulations are a high-fidelity computational technique used to model granular materials, consisting of discrete particles, to uncover the underlying physics governing various processes. However, DEM scales poorly with system size, making it computationally intractable for simulating real-world systems. Instead, these simulations can be leveraged to inform macro-scale models, which offer a more efficient approach to studying large-scale systems. In this work, we run DEM simulations across a range of cases, varying particle properties, grain-level interactions, flow geometries, and system sizes to explore their effects. We employ advanced tools to extract meaningful coarse-scale properties from grain-scale simulations, enabling the development of accurate macro-scale models and advancing the understanding of granular material behavior.

Analysis of the dimethylallyl radical using pulse laser photolysis cavity ring-down spectroscopy
Keaton A. Raney
Mentors: Mitchio Okumura and Kristen Roehling

Polyaromatic hydrocarbons are crucial in processes like combustion and soot formation, and small hydrocarbon radicals are thought to be their precursors. Therefore, species like the three-carbon allyl radical have been the subject of much research. However, the electronically excited *A* state of the allyl radical remains uncharacterized due to its short lifetime. Therefore, looking at similar species could elucidate further understanding of the proposed *A* state. In this work, spectra of dimethylallyl were recorded with a pulse laser photolysis cavity ring-down spectrometer from 410—418 nm. The experiments took place in a flow reactor at 50 torr and 293K. The influence of the two methyl groups on the excited states of the radical were studied. Complete characterization of the electronically excited *A* state of the dimethylallyl radical requires further work.

Developing a system to optimize microbial carbon fixation
Efe Sakarya
Mentors: Victoria J. Orphan and Madison Dunitz

In order to mitigate the growing climate change problem, current carbon capture and sequestration (CCS) methods are being employed; however, they are not scalable. This project investigates the use of microbial communities collected from Mono Lake, an environment with high salinity and alkalinity, for carbon capturing in an experimental set-up designed to select for the most efficient and resilient strains in terms of carbon fixation. Carbon levels inside the columns that contain water samples with algal-microbe populations were quantified using Total Organic Carbon (TOC) measurements. The additional data from DNA sequencing, as well as temperature and light from HOBO data loggers, were utilized to assess environmental and biological variables. Preliminary results show that columns populated with microbial and algal communities increased their carbon capture efficiency gradually. Correlation analysis is ongoing to identify key factors influencing carbon fixation. These findings demonstrate the viability of biological systems as sustainable carbon capture solutions and offer a starting point for improving the selection of more effective strains in future studies.

Synthesis of multimechanophore polymers for the controlled release of COS with a fluorescent reporter and for separate luminescent systems
Hanna P. Shan
Mentors: Maxwell J. Robb and Yu Ling Tseng

Polymer mechanochemistry utilizes mechanical force to drive productive chemical transformations in stress-sensitive molecules called mechanophores. The Robb group has designed a mechanophore that leverages a furan-maleimide Diels-Alder adduct. Upon activation, the mechanophore undergoes a retro-[4+2] cycloaddition, resulting in a reactive furan intermediate that decomposes in polar protic solvents to release a covalently bound cargo. Multimechanophore polymers (MMP) are especially attractive since we can trigger multi-mechanophore activation from a single polymer chain to achieve enhanced functional response. The group has developed a modular MMP platform, allowing for swapping attached cargo for diverse responses. I am leveraging this modularity to achieve two distinct functionalities, luminescence and COS release.

Mechanoluminescence is the emission of light from materials in response to force, which has potential applications such as bioimaging. A successful model reaction using pentafluorophenol as a leaving group has resulted in a viable method for attaching the chemiluminophore to the mechanophore. For the other project, COS is rapidly converted to H_2S in cellular environments and has potential therapeutic effects. Release of aminocoumarin as a fluorescent receptor with COS will provide an effective and nondestructive method of monitoring H_2S release. The synthesis of the mechanophore for COS release is underway.

cuEquivariance implementation of OrbNet-Equi for accelerated orbital learning and foundation-scale training

Erh-Wei Sheng

Mentors: Anima Anandkumar and Beom Seok Kang

Quantum mechanics-informed geometric deep learning combines physical priors with symmetry-aware neural networks to predict molecular properties efficiently. OrbNet-Equi is a leading model in this domain, using quantum mechanical matrix features as input to an SE(3)-equivariant message-passing network. This approach, known as orbital learning, enhances data efficiency and accuracy by embedding electronic structure directly into the learning process. However, the original implementation of OrbNet-Equi uses the torch-gauge backend, where Clebsch–Gordan tensor products are computed via separate CUDA kernels. This design limits GPU utilization and scalability.

In this project, we implement a new backend for OrbNet-Equi using NVIDIA's cuEquivariance library, which fuses spherical tensor operations into optimized CUDA kernels. The updated architecture removes Python-level bottlenecks, improves memory efficiency, and modularizes key components such as diagonal reduction and message passing. This enables more effective use of modern hardware for large-scale training. By accelerating core operations in OrbNet-Equi, we establish the computational foundation for future orbital-level foundation models that can generalize across diverse molecular systems while maintaining high efficiency and fidelity.

Experimental characterization of ice spheres formed through fluid fragmentation and flash freezing

Jordan L. Threat

Mentors: Xiaojing Fu and Nathan Jones

This project aims to optimize the process for creating ice spheres necessary to assemble laboratory snowpacks used in snow hydrology research. We produce ice spheres between 0.5 and 2 millimeters in diameter by flash freezing liquid droplets. To produce liquid droplets, we leverage the Rayleigh-Plateau instability of a water jet introduced by a syringe, which breaks into droplets in the air due to surface tension. These droplets then fall into a bath of liquid nitrogen below, where they freeze on impact into spherical ice and are later collected for further testing and analysis. The height and flow rate of the water jet, as well as the diameter of the syringe tip, are systematically varied in search of the desired droplet size range, which is determined by sieving the ice particles. The eventual goal of the project is to use the ice beads to perform imbibition experiments to measure the capillary retention curve of an ice bead pack. This will help to determine the hydraulic property of our laboratory snowpacks.

First light and characterization of the DSA-2000 test array
Shuyu W. van Kerkwijk
Mentor: Vikram Ravi

The 2000-dish Deep Synoptic Array (DSA-2000) will be a large leap forward in radio telescope instrumentation, operating as a ”radio camera” that produces reliable, high-resolution images. A two-dish test array has been commissioned at Owens Valley Radio Observatory ahead of construction of the full array in Nevada. Our objective was to characterize the performance of this test array, and use it to make science measurements of dark molecular gas in the outer Galaxy. We built an end-to-end control suite that automates source tracking and data recording through a graphical interface. For tracking, we fit an on-sky-calibrated 11-parameter pointing model to translate celestial targets (right ascension and declination) into local azimuth and elevation commands for the antenna drives. For recording, we convert raw digitizer output into standard measurement sets, correcting for antenna geometry and Earth's rotation to keep signals in phase. Using this system, we successfully obtained first light from the test array. We also identified and resolved several system-level issues that will inform design decisions for the full array.

Expanding the CRISPR-based toolkit for *in vivo* gene editing in mammalian systems
Wenting Ye
Mentor: David J. Anderson

Adaptation to changing environments is vital for survival. In mammals, reproductive behaviors(e.g. mating and aggression) are modulated by neuromodulators, e.g. neuropeptides. Gene editing approaches using SpCas9 have revealed the importance of Neuropeptides modulating neural activity in brain regions such as ventromedial hypothalamus (VMHvl) via G-protein-coupled receptors(GPCRs). Oxytocin receptor(Oxtr) and the arginine vasopressin receptor-1A(Avpr1A) in the VMHvl during aggression. Yet the large size of spcas9 requires a two-virus system one for enzhyme and one for the gRNAs that guide the Cas9 protein to the specic genomic loci. To overcome this, we aimed to expand the CRISPR-based toolkit for in vivo gene editing in mammalian systems. A major limitation of the use of SpCas9, requires a two-virus system due to its large size. We evaluated the smaller Staphylococcus aureus Cas9 (SaCas9), which can be efficiently packaged into a single AAV vector and allows efficient viral delivery. From biochemical approach, we validate gRNAs targeting Oxtr and Avpr1a using N2a cells. We also did functional imaging using hypothalamic-derived cell lines(GT1-7 and mHypoA1-2) expressing endogenous receptors to monitor calcium responses after peptide stimulation. We successfully cloned gRNAs, confirmed viral SaCas9 expression, and observed potential calcium acitvitity, suggesting SaCas9-based in vitro platform may support functional interrogation of neuropeptidergic signaling.

The thermoelectric measurements of ferromagnetic quantum materials
Kenneth J. Yi
Mentors: Linda Ye and Takashi Kurumaji

The thermoelectric effect is a phenomenon in which a temperature gradient generates an electric current within the material without the presence of an external electric field. Through this mechanism, heat can be directly converted into electricity. The Seebeck effect is the classic thermoelectric property described by the production of an electric field or voltage difference in the direction of the temperature gradient. This phenomenon is obtained by the equation $S_{xx} = - E_x / |-\nabla T_x| = \Delta V_x / \Delta T_x$. The Nernst signal is given similarly by $S_{xy} = E_y / |-\nabla T_x| = \Delta V_y / \Delta T_x$, transverse to the gradient, with an external magnetic field in the z direction. Additionally, the anomalous Nernst effect (ANE) is related to the nernst effect but is dependent on magnetization of the material as opposed to the external magnetic field. Various ferromagnetic materials are known to have large Berry curvatures which arise from the specific electronic arrangements and states of the atoms. An internal field allows for the conduction electrons to give rise to a large anomalous Nernst signal. Initial Seebeck measurements of Fe_4GeTe_2 yielded a clear signal with parabolic temperature dependence and symmetric magnetic field dependence, while Cr_3Te_4 showed a clear Nernst signal with an antisymmetric magnetic field dependence. This allows for the future steps of precisely characterizing the thermoelectric properties along with the ANE of these ferromagnets.

A synthetic cell platform: Development of protein expressive + payload releasing vesicles and their encapsulation in hydrogels
Pierre A. Zeineddin
Mentor: Matthew W. Thomson

During the 2025 SURF program, we have continued designing and constructing a synthetic cell platform that produces clinically relevant proteins, releases its payload into a liquid or gel environment. Concretely, we have

a) shown that our synthetic cells (Giant Lamellar vesicles, GUVS) can be stored in hydrogels (prolonging their lifespan on the order of days),

b) tested a **pore forming protein that can release clinically relevant proteins**, as well as

c) collected preliminary results on said pore forming expression alongside fluorescent proteins.

With the pore protein Listerolysin O releasing large cargo (75 kDa) from our synthetic cells, we see a very near future where the synthetic cell platform can produce proteins expressible in cell free expression media. This is grounded in an advantage of the easy to form, inducible pore forming proteins.

Continuing our work on gathering cargo expression and release data, we plan to perform flow cytometry assays with immune cell populations, producing and releasing those critically important proteins used in fighting cancers and immune system activation. Success in showing activation will show the power of a simple synthetic system. It is our hope that this design platform will enable researchers, engineers to design experiments that delve deeper into therapeutic studies, regrow damaged or previously irreparable tissues--with cartilage, even one day brain tissue being regrown.

Formal theorem proving with large language models and reinforcement learning for the Andrews–Curtis conjecture
Caroline Zhang
Mentors: Anima Anandkumar and Robert Joseph George

Automated theorem proving uses proof assistants, such as Lean, to rigorously verify mathematical proofs, leading to the development of Large Language Models (LLMs) as formal theorem provers. We explore how LLMs and reinforcement learning (RL) can be applied to the currently unproven Andrews–Curtis (AC) conjecture in combinatorial group theory. We present an evaluation of LLM capabilities on group theory problems and introduce a modular framework that supports proof decomposition and enables collaboration between multiple LLMs and solving techniques. This framework is designed to improve model performance on challenging proofs by enabling flexible and customizable handling of different components within a theorem. However, existing models continue to struggle with the long-horizon reasoning required for AC conjecture problems. To address this, we further explore fine-tuning LLMs to improve the decomposition of AC trivializations, along with implementing subgoal prioritization strategies to guide the proof-solving process more effectively.