Caltech
Student-Faculty Programs

Session O Abstracts

Developing spectral analysis tools for WISER: Spectral angle mapper and spectral feature fitting
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Imaging spectroscopy enables remote identification of materials by capturing their unique spectral signatures across hundreds of wavelength bands, but freely available tools for efficient, large-scale analysis remain limited. To address this limitation, the Ehlmann Research Group at Caltech developed WISER, a free, open-source software to help scientists analyze imaging spectroscopy data. In this project, we integrate two complementary algorithms into WISER: Spectral Angle Mapper (SAM) and Spectral Feature Fitting (SFF). These tools help scientists efficiently detect and identify materials in their images, streamlining data analysis to aid research and discovery. SAM computes angular similarity between a target spectrum, a spectral library, or image cube and a reference library and the SFF module quantifies absorption-band alignment through continuum removal and R^2 goodness-of-fit. Both tools support user-defined wavelength bounds and thresholds, batch processing of hyperspectral cubes, and dynamic result visualization via a PySide2 interface. By vectorizing core computations and enforcing data-quality controls, our plugin accelerates material matching and feature analysis, broadening access to open-source spectral mapping for planetary and geological research.

Constraints on the orbital parameters of stellar flybys of the early solar system
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The Cold Classical Kuiper Belt (CCKB) has an unexcited dynamical structure, with low inclinations and eccentricities that have persisted since its formation. The CCKB is thus a constraint on proposed perturbation events such as stellar flybys, because any perturbation must leave the CCKB undisturbed. Here, N-body simulations are carried out to explore whether different trajectories of hyperbolic stellar flybys preserve the observed Rayleigh distribution of free inclinations in the CCKBs. Using a random forest classifier, the impact parameter and inclination of the flyby were found to be the best predictors of whether Rayleigh-ness is preserved. In particular, it was found that encounters with perihelion distance $q<160$ AU and inclinations far from 0, 90, or 180 degrees almost always destroy the CCKB's structure, and are thus unlikely. These results provide a useful constraint on the Sun's birth environment, ruling out long residence times in dense clusters where such disruptive encounters would be likely.

Constraining properties of dust formed in Wolf-Rayet binary WR 112 using mid-infrared and millimeter observations
Donglin Wu
Mentors: Konstantin Batygin and Yinuo Han

Dust, tiny solid particles in interstellar space, plays an important role in the formation of stars and planets. Binaries that host a carbon-rich Wolf-Rayet (WC) star, the late stages of some of the most massive stars, have been theorized to be major dust producers. The dust production rate of WR112, a single WC binary system, is comparable to the total dust production rate of all asymptotic giant branch stars in the Small Magellanic Cloud; these stars are known to be important dust producers. While previous studies have found dust in these systems are in expanding spiral shells, there lacks accurate characterization of the properties of dust in these shells. We combined mid-infrared observations by the James Webb Space Telescope (JWST) and millimeter-wavelength observations by the Atacama Large Millimeter Array telescope (ALMA) to derive the spectral energy distribution (SED) of the dust. By fitting dust emission models to the SED, we were able to constrain the grain properties of dust in the WC binary system. We found that the SED is consistent with emission from carbonaceous dust and the dust grains have to be smaller than half a micron in size. This study leads to a better

understanding of the type of dust produced by WR systems and the sources of carbonaceous dust in the interstellar medium. The constraint on grain sizes may inform future models of dust formation in WR systems and their influence on the galactic environment.

Constraining grain size dependent dynamics in AU Mic's debris disk: A joint JWST and ALMA study of the vertical structure
Junyi Zhao
Mentors: Konstantin Batygin and Yinuo Han

We present a joint modeling of JWST NIRCam F444W coronagraphic images and ALMA Band 6 visibilities of the debris disk around AU Mic, viewed edge on. Though using a unified Bayesian MCMC framework implemented in emcee combined with parametric disk models, we derive the vertical scale height h at infrared and millimeter wavelengths under the same disk inclination and position angle. This analysis provides the first direct measurement of grain size dependent vertical stirring in AU Mic by combining high contrast scattered-light imaging and interferometric data. By quantifying how scale height differs between infrared-emitting and millimeter-emitting grains we can constrain collisional damping rates and turbulence levels, providing evidence on planetesimal assembly and the physical processes that govern disk evolution around young stars. Our unified Bayesian framework can be readily applied to other systems, offering a powerful pathway to test theories of disk dynamics and the early stages of planet formation across diverse stellar environments.

A geologic map of Isla Tortuga: A contribution to the volcanic history of the Guaymas Basin, Gulf of California (México)
Emilia R. Pelegano-Titmuss
Mentors: Joann M. Stock and Adriana Piña-Paez

Isla Tortuga is a young, basaltic volcanic island located in the Guaymas Basin (GB), which is a pull-apart basin in the Gulf of California (GOC) oblique rift system. The GOC is located at the boundary of the Pacific and North America plates and occupies part of an oblique divergent plate boundary. The International Ocean Discovery Program Expedition 385 drilled sediments in the GB and found that sills are intruding into the Quaternary sediments. After fieldwork was done by Caltech on Tortuga, petrographic comparison showed that the sills and samples collected from Tortuga have similar crystal sizes, textures, mineral compositions, and geochemistry. Thus, it was concluded that Tortuga and the sills are part of the same magmatic plumbing system in the GB. Therefore, Isla Tortuga is a key component of the volcanic and tectonic history of the GB. A geologic map of Isla Tortuga has been produced using Quantum Geographic Information System (QGIS). There is no other significant documentation for the geologic units on Isla Tortuga. There are a total of twenty one units on Isla Tortuga, and the geochemical composition of these units provides evidence for the magma recharge event that was proposed to have occurred before the last eruption.

Constraining the organic carbon properties of subsurface sediment in the Yukon Delta
Emily Q. Yu
Mentors: Michael P. Lamb and Yutian Ke

Arctic deltas function as major carbon sinks. A vast reservoir of organic carbon (OC) is stored within Arctic and sub-Arctic permafrost, which is increasingly vulnerable to release as rising temperatures and higher rainfall accelerate the thawing process. We analyzed 48 bank-sediment samples collected along a source-to-sink trajectory in the Yukon River Delta, encompassing diverse terrains of varying depositional ages. Samples were freeze-dried, decarbonated, and analyzed for grain-size distribution with laser diffraction; OC content was determined by elemental analysis of homogenized aliquots. We synthesize grain-size distributions and OC measurements to understand sedimentological controls on carbon content in the delta, thereby clarifying its role in regulating regional and global carbon cycles.

Flume experiments on cohesive riverbank width
Natalie R. Homyk
Mentors: Michael P. Lamb, Kimberly L. Miller, and Tingan Li

Understanding river width adjustment is vital for mitigating hazards and informing infrastructure development. We aim to quantify erosion of cohesive mud under controlled conditions to test if the channel reaches equilibrium width when shear stress matches bank material strength. This study presents the initial findings of flume experiments on the self-adjustment of cohesive riverbanks. We conducted flume experiments with a homogeneous mixture of clay, silt, and organic matter to isolate shear stress on muddy banks, allowing precise control and measurement of bank strength and erosion. These conditions offer an ideal platform to test if rivers stabilize at a width where flow forces balance bank resistance. We first calibrated friction and partitioned boundary shear stress using non-eroding gravel runs. In these initial experiments, we adjusted discharge and downstream base level, while taking water-surface scans to map hydraulic response to obtain normal flow conditions and define starting conditions for cohesive-bank runs. Muddy bank experiments combine time-lapse imaging to track erosion rates with scans of the water surface to quantify shear stress, enabling assessment of whether channel width stabilizes when shear stress balances bank strength.

Calcium isotopes in urine and nail as a tracer of bone health
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Mentors: François Tissot, Rebecca J. Ryan, and Theo J. Tacail

Over the past two decades, calcium isotopes ($\delta^{44}Ca$) in human serum and urine have emerged as promising biomarkers for bone mineral balance. Despite substantial inter-individual variability, $\delta^{44}Ca$ values exhibit relative stability within individuals, supporting their potential for longitudinal monitoring. In this study, we explored the feasibility of using human nails as a long-term baseline for $\delta^{44}Ca$ analysis, due to their solid phase and chemical stability. We quantified $\delta^{44}Ca$ in nail samples using Multicollector Inductively Coupled Plasma Mass Spectrometry (MC-ICP-MS) and compared these values to $\delta^{44}Ca$ measured in paired urine samples from the same individuals. Our results indicate that $\delta^{44}Ca$ values in nails provide a robust personal baseline against which changes in urinary $\delta^{44}Ca$ can be detected with greater sensitivity. Our approach paves the way for developing a practical, non-invasive biomarker system of calcium isotopes for monitoring bone mineral balance and enabling early detection of related bone diseases, a process further simplified by the ease of nail sample collection.

A critical review on variation of sweat composition and how sweat calcium affects bone health
Wenjing Zhou
Mentors: François Tissot and Theo J. Tacail

Isotopic composition of Ca in urine can reflect the bone mass change. However, significantly lower $\delta^{44/42}Ca_{urine}$ was observed after exercise. This research aims to conduct a review about how sweat calcium potentially affect bone health and discuss the variation of sweat composition due to different ages, genders, diets, exercise and diseases. Different methods on sweat collection and analysis will also be compared in terms of accuracy. Database of sweat composition and concentration was compiled from different literatures, and a synthetic sweat composition table was developed based on a critical review. A plan was made to carry out tests for wipe contamination, size of wipe to choose and Ca recovery from wipe. The synthetic sweat was also planned to be used to determine the method for analyzing sweat samples and the minimum volume of sweat needed to be collected for iCAP and MC-ICP-MS.

The influence of transport on chemistry in the middle atmosphere of Venus
Cheng-an Hsieh
Mentors: Yuk L. Yung and Ting Juan Liao

The atmospheric dynamics of Venus exhibit super-rotation in the troposphere (0 - 60 km), while the mesosphere (60 - 120 km) is characterized by complex dynamics and photochemistry. While the general chemical circulation in this layer presents a long-standing scientific challenge, a recent unexpected discovery of a significant increase in the deuterium-to-hydrogen (D/H) ratio in the mesosphere (~ 60 – 100 km), rising from 162 to 1,519 times Earth's value between 70 and 108 km altitude, suggests the existence of a powerful transport mechanism, possibly an aerosol-driven cycle and a meridional circulation (Mahieux et al., 2024). This study proposes a multi-step model to test and quantify the hypothesis that D/H stratification results from atmospheric transport and chemistry interaction. We utilize wind fields from a Venus General Circulation Model (GCM). By applying Singular Value Decomposition (SVD), we reconstruct the analytical stream function that characterizes the mean meridional circulation. The derived stream functions are used to drive a 2D Chemical Transport Model (CTM) (Yung et al., 2009). The CTM couples the Prather advection scheme (Prather, 1986) for tracer transport with the KINETIC gas-phase photochemistry model. The primary objective is to simulate the transport and photochemical evolution of the related species to determine if this coupled dynamic-photochemical system can reproduce the observation. This work aims to explain the mechanisms of chemical species in Venus's mesosphere, providing crucial insights into the planet's atmospheric evolution and water loss history (Donahue et al., 1982).

A study on the response mechanisms of solar-induced chlorophyll fluorescence (SIF) to heat stress in global ecosystems based on multi-source satellite data
Wenhao Lyu
Mentors: Yuk L. Yung, Liyin He, and Yuan Wang

Solar-Induced Chlorophyll Fluorescence (SIF) is a key indicator of vegetation photosynthesis and is highly sensitive to environmental stress. This study investigates the dynamic response of SIF to heat stress across global ecosystems. We evaluated the correlation between satellite SIF (TROPOMI/GOSIF) and ERA5-Land air temperature, focusing on identifying regions with negative correlations that signify photosynthetic inhibition. Using auxiliary data such as MODIS NDVI/Land Cover and soil moisture, we analyzed the regulatory effects of water availability and climate zones. Our results demonstrate that drought critically regulates SIF's response to high temperatures. We observed a clear decline in SIF during strong heatwave events in many regions, providing robust evidence of physiological constraints imposed by extreme heat. This study uncovers complex spatial response mechanisms, identifies regions vulnerable to heat stress, and establishes a multi-sensor framework for diagnosing vegetation health, improving ecosystem monitoring under climate change.