

Genetic analysis of complete Arctic charr mitogenomes reveals colonization and differentiation patterns in four Arctic lakes

Madison Elle C. Tongco

Mentors: Arnar Pálsson and Jonathan Kirshner

Arctic charr is widely used to study sympatric speciation, differentiating readily into morphs characterized by feeding and spawning behavior as well as morphology. Previous whole-genome studies have revealed genetic differences across and within four Arctic lakes in Iceland ($n=2$) and Norway ($n=2$). I asked whether mitogenome analysis would be able to separate lakes and morphs and if morph behavior could be inferred from gene-specific haplotypes. Firstly, we discovered 22 short nuclear-mitochondrial DNA segments (NUMTs, total 3439 bp), showing relatively low integration of mitochondrial DNA into the nuclear genome, before assembling complete mitogenomes ($n=285$). Whole mitogenome analysis found both Norwegian lakes to be genetically separable, but Icelandic lakes were more closely related, suggesting that charr colonized Icelandic lakes more recently. Morphs within lakes were generally not separable, except in Lake Sirdalsvatnet (Norway) and, to some degree, the four morphs of Lake Thingvallavatn (Iceland). Pairwise F_{st} among Thingvallavatn morphs showed strong intermixing between planktivorous and piscivorous morphs and weak intermixing between large benthic and piscivorous morphs, indicating sex biased gene flow between the morphs. Our results corroborate proposed models of single-morph colonization of lakes and further morph differentiation due to phenotypic plasticity and advantages in local environmental niches.

Investigating thresholds of boulder mobilization in post-wildfire debris flows

Kirby Fung

Mentors: Michael P. Lamb and Emily Geyman

Post-wildfire debris flows are a significant hazard in mountainous regions, where intense rainfall on steep, burned landscapes can mobilize large volumes of sediment and boulders. Existing debris-flow prediction models estimate the likelihood and magnitude of debris flows but do not explicitly account for the conditions controlling boulder entrainment. Previous studies of boulder mobility have also largely focused on clear-water or simplified flow conditions, providing limited understanding of how sediment-rich debris flows affect boulder entrainment. This study investigates the physical conditions governing boulder mobilization following the 2025 Eaton Fire in the San Gabriel Mountains. High-resolution LiDAR (Light Detection and Ranging) surveys and optical imagery are used to identify and quantify individual boulder movement before and after storm events. Meta's Segment Anything Model 3 is used to identify boulders, and movement for each boulder is manually verified between surveys. For observed boulders, Shields stress is calculated as an indicator of the balance between flow forces and the resistance to boulder motion, and its relationship with channel slope is evaluated to identify factors influencing boulder mobility. These field-based results are compared with flume experiments conducted with clear water to quantify differences in entrainment between natural debris-flow and clear-water conditions.

Recovering settling velocity distributions of mud and flocs from light sensor data

Amber G. Liu

Mentors: Michael P. Lamb and Kimberly L. Miller

Fine sediment in rivers clumps into loose, low-density clusters called flocs. How quickly they settle controls where mud and organic carbon deposit, which shapes floodplains and deltas worldwide. Because flocs break apart when sampled directly, their settling must be measured using a non-invasive method. This project recovers how fast suspended sediment settles from the way it dims light as it falls in a laboratory tank. I developed a model that predicts the light signal for any set of settling speeds, and the measurement is run backward to recover them. The recovered speeds are then checked against a second, independent method. I tested the approach in stages, using single grain sizes, then mixtures, then flocs, comparing against known grain sizes and video tracking. Across all three stages, the recovered speeds match the references within a factor of two to three, and several

independent solution methods agree. Flocs settle far slower than solid grains of the same size, and added organic matter turns about a quarter of the clay into flocs. The result is a validated, non-invasive way to link light measurements to fine-sediment settling and to how organic matter drives flocculation.

Investigating the growth characteristics and extracellular polymeric substances (EPS) of methylotrophic methanogens in AOM consortia

Wendy Wang

Mentors: Victoria J. Orphan and Yurina Takahagi

ANME-SRB live in diverse microbial communities that anaerobically oxidize methane (AOM), syntrophically consuming methane and producing sulfide. Even in long-term laboratory sediment-free incubations, other members of the microbial community, such as methanogens, persist for many years. Existing work in the lab has isolated strains CA12 and MCC4, of the genus *Methanococcoides*, from sediment free cultures dominated by ANME-2 and SEEP SRB-1. In this project we sought to characterize the growth rates strains CA12 and MCC4 using the Microbial Growth-rate Intervalometer (MAGI), develop a protocol for the efficient extraction of EPS while maintaining cell integrity, and investigate the components of the EPS. EPS is a crucial interface between microbes in natural consortia, possibly giving insight into the persistence of less common community members. We quantified nucleic acid, protein and polysaccharide content of the EPS, investigated the spatial distribution of nucleic acids in CA12 aggregates through methyl green-pyronin staining, and identified methods of CA12 disaggregation that may also apply to ANME-SRB aggregates.

Enantioselective crystallization of an RNA precursor and the origin of homochirality

Carolina Ayala-Garnica

Mentors: S. Furkan Ozturk and Kyogo Nagashima

Ribose-aminooxazoline (RAO) is a key intermediate in prebiotic ribonucleotide synthesis and is hypothesized as the origin of RNA's homochirality. RAO forms conglomerate crystals, a rare property where enantiomerically pure crystals individually form from racemic mixtures. Recent research demonstrates that RAO enantioselectively crystallizes on a magnetic, mineral surface. During enantioselective D-RAO crystallization on a magnetite surface, L-RAO remains in solution and can crystallize in a nearby environment resulting in racemic mass balance in the environment. This diminishes the enantioselectivity of the process on a macroscopic scale and makes it difficult to maintain homochirality. We offer a solution through phosphate-catalyzed hydrolysis of L-RAO in solution to ribose oxazolidinone, leaving homochiral D-RAO crystals intact. By hydrolyzing L-RAO in solution, we break the mass balance between enantiomers and maintain D-RAO homochirality for subsequent ribonucleotide synthesis.

Automated dark-field birefringence microscope for investigation of crystallization kinetics of chiral species on magnetized substrates

Alan Song

Mentors: S. Furkan Ozturk and Sean J. Chen

The two enantiomers of a chiral molecule are nonsuperimposable mirror images of each other, related by a parity transformation. Most chirally selective interactions in chemistry, biology, and pharmaceutical synthesis rely on inherently chiral materials to generate and transfer chiral information. In contrast, chirality induced spin selectivity (CISS) is a phenomenon where electron spin is coupled to handedness, allowing for the generation and transmission of chiral information through even achiral substrates.

CISS-like behavior has also been observed in enantioselective crystallization on magnetically polarized substrates, with a bias in the chirality of macroscopic crystals. The origin of the bias must lie in primary nucleation processes, as secondary nucleation of chiral molecules only serves as a means to propagate the CISS interaction of chiral molecules with the magnetized surface to macroscopic scale. Microscopy is a convenient method to investigate the rate kinetics for small systems such as primary nucleation. The stochastic nature of crystallization kinetics requires automation of the imaging over many experiments to precisely constrain rate constants of crystallization for the two enantiomers of a target species.

For this investigation, the primary target species is ribose aminooxazoline, a central RNA precursor, on a magnetite (Fe_3O_4) substrate. This system has previously shown enantiomeric excess during crystallization and is of interest in origin-of-life research. By investigating the rates of primary nucleation of this system's enantiomers, we hope to provide understanding for the propagation of CISS in macroscopic systems, as well as the origin of life's homochirality.

Binodal: Towards an n-ary phase diagram generator for geochemical and geological applications

Vedant Ganesh

Mentor: Paul D. Asimow

Phase diagrams describe the behavior of chemical systems under conditions of thermodynamic equilibrium, summarizing stability across composition, temperature, and pressure space. Their construction involves finding the lower convex hull of the Gibbs free energy surface to determine the stable phase(s); this is numerically challenging when there are potentially many complex surfaces intersecting. Existing phase diagram construction software typically uses polynomial fits (e.g., Scientific Group Thermodata Europe polynomials) rather than physically motivated forms for the Gibbs free energy surface. We present Binodal, an open-source Python thermodynamic toolkit that calculates and visualizes binary phase diagrams using explicit thermodynamic models. Binodal uses thermodynamically consistent regular-solution-type models with pressure- and temperature-dependent Margules parameter in a user-transparent manner, enabling its use as a pedagogical tool as well as for lightweight thermodynamic calculations in petrology. We use this software to reproduce several common phase diagram topologies, such as eutectic, peritectic, and solvus diagrams, and investigate their topologies and thermodynamic potential functions in various spaces (e.g., Gibbs energy–temperature–pressure or internal energy–volume–entropy space).

GPU-accelerated radiative transfer forward model for aerosol-aware greenhouse gas retrievals

Abubakr S. Nazriev

Mentor: Christian Frankenberg

Satellite observations of CO_2 and CH_4 gases in the Earth's atmosphere are retrieved by how sunlight is absorbed as it traverses the atmosphere. Atmospheric particles (dust, smoke, sea salts, etc.) change the paths of this light through scattering. Thus, satellite retrievals of gas concentrations in the presence of such aerosols require accurate modeling of particle scattering effects, which otherwise lead to biases in retrievals. This project develops a GPU-accelerated pipeline for simulations of the high-resolution polarized spectra in three spectral regions used in observations from NASA's Orbiting Carbon Observatory (OCO) based on physical optics of scattering in a realistic particle population whose optical properties have been calculated based on the global atmospheric chemistry models. Each aerosol is defined by its size distribution, chemical composition, and altitude; its optical properties are computed according to electromagnetic (EM) scattering theory with composition-specific mixing rules and verified using independent software. The pipeline provides spectra at an instrument-independent level together with full details of the atmospheric conditions in a benchmark dataset for the purpose of training machine learning (ML) models for fast and accurate retrievals. Ongoing work is addressing the representation of particle size distributions across the discrete model categories and preparation for a year-long global generation campaign.

Aerosol corrected methane retrievals from slant viewing geometries

Ellin J. Qiao

Mentors: Christian Frankenberg and Jiani Yang

Methane is a greenhouse gas that directly motivates global warming and climate change. Satellite and ground-based measurements of Earth's atmosphere have been leveraged to retrieve top-down measurements of column-averaged dry-air mole fractions of greenhouse gases. The dominant source of error for these observations is uncertainty due to light path deviations caused by aerosol scattering. One method to diminish aerosol-induced errors is to use a reference gas with a well-known dry mixing ratio as a light-path proxy to cancel out scattering effects. In this study, we investigate the effects of aerosols on greenhouse gas retrievals from slant viewing angles. A non-scattering retrieval is used to quantify errors arising from neglecting aerosols. We then determine the geometries and aerosol loadings where the N_2O light-path proxy is suitable and assess when full-physics retrievals are necessary due to non-linear aerosol effects. We report that nonlinearities due to variations in absorption strength dominate over discrepancies in aerosol effects at different wavelengths for shorter slant paths, but find that the N_2O proxy is more effective for very slant viewing geometries. We also apply the N_2O proxy to data from the California Laboratory for Atmospheric Remote Sensing-Fourier Transform Spectrometer (CLARS-FTS) and compare it against current retrievals.

Investigating groundwater-driven land deformation in the San Gabriel Valley using InSAR time series analysis

Natalia M. Hernandez

Mentor: Mark Simons

Groundwater withdrawals can cause aquifer compaction and land subsidence in groundwater basins such as the San Gabriel Valley. This project investigates the spatial and temporal patterns of land-surface deformation across the San Gabriel Valley and their relationship with groundwater variability. Interferometric synthetic aperture radar uses repeat-pass radar images to detect and map changes in the land surface over time. Satellite observations from Sentinel-1 are then processed to generate displacement time series that show how the ground has moved throughout the years of 2014-2026. These time series are then analyzed using mathematical models that capture the simplest temporal behavior supported by the observations, including long-term seasonal deformation where appropriate. Groundwater level extraction records are then compared with the observed deformation to evaluate whether changes in groundwater conditions respond to subsidence or uplift. Continued analysis will determine which temporal models best describe deformation in the San Gabriel Valley and help assess how this complicated groundwater system responds to changes in subsidence and storage

Independent orbit determination for Jupiter Trojans from Gaia astrometry as a foundation for a distant-perturber search

Isabella H. Mueller

Mentor: Michael E. Brown

Batygin & Brown (2016) proposed an undiscovered giant planet (known as Planet Nine) on a wide, eccentric orbit to explain the clustered orbits of distant trans-Neptunian objects. Such a body would exert a small differential acceleration across the Solar System, detectable in principle as a coherent signal in the orbits of many small bodies. Jupiter Trojans are an attractive probe because they span a baseline of roughly 10 au. Rice & Laughlin (2019) argued that precise positions for more than about 225 Trojans would separate a Planet Nine signature from that of the Kuiper belt, while Gomes et al. (2023) forecast the constraint from roughly 8000 Trojans observed by LSST through 2035. Establishing what existing astrometry can already constrain sets a baseline for these forecasts and exercises the methods they will require.

The Gaia Focused Product Release (FPR) already delivers Solar System astrometry on a single homogeneous reference frame, with CCD level positions accurate to better than one milliarcsecond along scan at the bright end. This astrometry spans an arc of 66 months, covering 0.46 of the 11.86 year Trojan orbital period. Gaia DR4 will refine the calibration but will not extend this arc. Gaia DR5, expected around 2030 and drawing on the full 10.5 year mission, will extend the arc, reaching 0.89 of a Trojan period.

We have built an orbit determination pipeline on OrbFit that uses FPR astrometry under the INPOP19a ephemeris, weights each observation by the delivered correlated covariance, and matches the FPR observation model, timescale, and coordinate conventions. For 672 Trojans, our semi-major axes match the published FPR values to a median fractional difference of 2.43×10^{-8} (maximum 6.04×10^{-8}), below the 10^{-7} threshold David et al. (2023) use to flag anomalous solutions. Formal uncertainties agree to within factors of 0.5 and 3.0. This validated baseline supports a grid search refitting orbits under a distant perturber's tidal acceleration, over a grid of perturbation strength and direction. Holman & Payne (2016) applied this approach to Pluto and other trans-Neptunian objects, finding that a tidal approximation reproduces a full moving-planet model across the sky. Sensitivity will be expressed as a limit on perturber mass at a given heliocentric distance, for direct comparison with constraints from planetary tracking.