EARTH & PLANETARY SCIENCES

AT HARVARD UNIVERSITY

2023 Senior Thesis Presentations

Shayna Grossman

Raisha Rahman

Serena Wurmser

Jason Jorge

Caleb Fried

Thursday, April 27th, 2023 11:00 am-1:00 pm
Haller Hall, Geological Museum 102

Please join us for an Undergraduate End-of-Year Reception beginning at 1:15 pm in the Student Lounge (4th Floor, Hoffman Labs).

Please join us for a reception honoring
all of our EPS Undergraduates
1:15 pm
Student Lounge
4th Floor, Hoffman Labs

Thank you for your support!

WELCOME

Message from the co-Head Tutors and Preceptors:

Thank you for joining us as we celebrate the accomplishments of our senior thesis writers who spent much of their senior year tackling an exciting range of scientific problems. The senior thesis provides an opportunity for students to gain firsthand experience in the full scope of research, from in-depth background study, to identification of core questions, design of a research plan, collection and analysis of data, and formation of rigorous conclusions. These theses and today's presentations reflect the academic excellence and dedication of these students. Their efforts would not be possible without the support of faculty advisors, graduate students, post docs, fellow undergraduate students, and family. We thank these mentors and friends and congratulate our seniors on their achievement.

Roger Fu and Zhiming Kuang
Co-Head Tutors

Chloe Anderson and Esther James
EPS Preceptors

James Anderson, Roger Fu, Zhiming Kuang, Marianna Linz
Undergraduate Curriculum Committee

Campbell Halligan
Academic Program Manager

Caleb Fried

Concentration: Earth and Planetary Sciences

Scale-Invarient Analysis of Paleoclimate Records - Using Bernoulli Statistics to Reconstruct a Globally Coherent Little Ice Age

Advisor: **Peter Huybers,** Professor of Earth and Planetary Sciences and Environmental Science and Engineering, Harvard University

The Little Ice Age (LIA) holds a unique position in the study of Earth's climate. Being the most recent major temperature anomaly prior to modern warming, it provides a valuable case study to learn about the inherent properties of the climate system. While historical and climatological evidence for the Little Ice Age has long been acknowledged, many of the most recent paleoclimate reconstructions have suggested that the LIA had a relatively small effect on the global scale. However, issues around the re-scaling of indirect "proxy" data sources used (tree rings, ice cores, and sediments) continue to plague estimates of the LIA's magnitude. In this thesis, I present an entirely new method of reconstructing past climate from proxy data using Bernoulli statistics. This new method bypasses the re-scaling step entirely, eliminating a key uncertainty in the climate reconstruction process, and finds a Little Ice Age up to half a degree colder than previous multiproxy reconstructions. An LIA of this magnitude is consistent with borehole records, which most previous reconstruction methods fail to explain, and holds significant implications for how we understand the causes and effects of climate events in the past, present, and future.

Jason Jorge

Concentration: Earth and Planetary Sciences

One-Dimensional Radiative-Convective Modeling of Greenhouse Gases on Early Mars

Advisor: **Robin Wordsworth**, Gordon McKay Professor of Environmental Science and Engineering and Professor of Earth and Planetary Sciences

Abundant geomorphological and geochemical evidence of liquid water on the surface of early Mars during the late Noachian and early Hesperian periods from ~3-4 Ga is difficult to reconcile with a faint young Sun. Traditional explanations of greenhouse warming in a dense CO_2 atmosphere fail and other proposed alternative warming mechanisms face significant challenges. Here, we adopt a bottom-up approach by modifying a one-dimensional radiative convective climate model to simulate the greenhouse warming of over 15 minor gas species at various mixing ratios under early Martian conditions. Our results show that gases are roughly organized into three groups based on their greenhouse warming potential (GWP): 1) H_2O_2 and HNO_3 stand out with GWPs ranging from ~37-40K when a mixing ratio of 10 ppm is added to the 1 bar model atmosphere; 2) Moderate absorbers such as SO_2, C_2H_4, NH_3 with GWPs ranging from ~10-15K; 3) and weak absorbers with GWPs ranging from ~0-5K. The five strong and moderate absorbers substantially reduce outgoing planetary radiation by absorbing in key atmospheric window regions and could act to warm the early Martian surface. Our work expands the number of theoretical warming scenarios on early Mars and highlights gases for further investigation. Deepening our understanding of the early Martian climate has implications for our understanding of the evolution of Earth's atmosphere and climate, the climates and atmospheres of other small rocky planets and their evolution, and whether Mars was ever capable of supporting a biosphere.

Shayna Grossman

Concentration: Earth and Planetary Sciences and Environmental Science and Engineering

Monitoring Submarine Glacier Melt Using Hydroacoustics: The Role of Timescale in the Signal of Bubble Release

Advisors: **Grant Deane**, Research Oceanographer, Scripps Institution of Oceanography
Eli Tziperman, Pamela and Vasco McCoy, Jr. Professor of Oceanography and Applied Physics [*nominal advisor*]

Submarine glacier melt plays a key role in determining glacier stability and significantly drives glacier mass loss. However, quantifying this melt remains challenging due to occupational hazards near glacier termini (Luckman et al., 2015; Deane et al., 2019). One method that has been proposed, though remains unproven, is to use acoustic monitoring of the ambient underwater soundscape, and specifically the energy produced from bubbles bursting from glacier ice, to study glacier melt from afar (Schultz et al., 2008). However, calculating melt rate remains complicated because bubbles produce different amounts of acoustic energy. This study advances the literature on passive acoustic monitoring by investigating the physical factors that cause bubbles to produce energy heterogeneously. This work proposes and uses a novel method to determine timescales of release and acoustic energy values for 203 bubble release events from glacier ice in Svalbard, Norway, and finds these variables to be negatively correlated. Additionally, this work determines initial internal pressures for the subset of events with high energy and shows that timescale of release is not linearly related with internal pressure. This work begins to untangle the acoustic signal of submarine glacier melt and necessitates further research into the environmental factors modulating bubble release.

Raisha Rahman

Concentration: Earth and Planetary Sciences and Chemistry and Chemical Biology

Investigating Chloropigment Nitrogen Stable Isotope Fractionation Patterns in Photosynthetic Microorganisms

Advisor: **Ann Pearson**, Murray and Martha Ross Professor of Environmental Sciences, Harvard College Professor, and Department Chair, Earth and Planetary Sciences, Harvard University

Compound-specific nitrogen isotope analyses can provide a robust proxy for nutrient cycles and community compositions in both ancient and modern marine environments. In particular, analysis of chloropigment $\delta^{15}N$ has the potential to be a powerful supplement to existing bulk $\delta^{15}N$ analyses, as the original nitrogen isotopic composition of these compounds are preserved within the core tetrapyrrole structure of their porphyrin degradation products. Accordingly, $\delta^{15}N$ measurements of porphyrins in sedimentary samples should reliably reflect the metabolic patterns of the photosynthetic organisms that produced them. Furthermore, previous laboratory studies have found that the offset between $\delta^{15}N_{porphyrin}$ and $\delta^{15}N_{bulk}$, designated as the value ε_{por}, varies taxonomically, with major photosynthetic microbial groups (eukaryotic algae, freshwater and marine cyanobacteria, α-proteobacteria) exhibiting distinct ε_{por} patterns spanning a range of over 20‰. If the biochemical or physiological basis for these observed isotopic differences can be identified, εpor can be more rigorously applied in the fields of paleoceanography and paleoecology. This work investigates the mechanism by which nitrogen isotope fractionation occurs during (bacterio)chlorophyll synthesis in relevant photosynthetic prokaryotic groups utilizing the two different chloropigment biosynthesis pathways, the glutamate-based pathway and the glycine-based pathway. Laboratory measurements of $\delta^{15}N$ made via gas chromatography combustion isotope ratio mass spectrometry (GC-C-IRMS) are used in tandem with isotope flux-balance modeling methods, in order to reconstruct the patterns of ^{15}N partitioning in the cell and to identify important flux parameters and kinetic isotope effects (KIEs) associated with key chemical steps. Experimental and model results suggest that differences in εpor between prokaryotic taxa utilizing the two different modes of chloropigment biosynthesis can be attributed to the nitrogen isotopic composition of their precursor compounds, glutamate and glycine, as well as the KIE of glutamate 1-semialdehyde aminotransferase (GSAT; ε-GSAT = 10‰) in the glutamate-based model and of aminolevulinic acid synthase (ALAS, ε-ALAS = 15‰) in the glycine-based model. Future study should focus on reliably constraining the cause of ε_{por} patterns in eukaryotic groups.

Serena Wurmser

Concentration: Astronomy and Earth and Planetary Sciences

Medium Stars with Big Attitudes: Testing the Effect of Stellar Activity in the Atmospheric Signals of Planets Transiting F-type Stars

Advisor: **Mercedes Lopez-Morales**, Lecturer, SAO Astrophysicist, Chair of the High Accuracy Radial velocity Planet Searcher for the Northern hemisphere (HARPS-N) Science Team

While our ability to observe and characterize exoplanet atmospheres has grown immensely in the past decade, stellar activity continues to present a major barrier towards a clear understanding of transmission spectra. Notably, there have been three exoplanets around Ftype stars (WASP-121 b, WASP-79 b, and WASP-103 b) with quiet photometric curves but radial velocity (RV) plots that indicate activity, revealing the potential presence of faculae. In this work, we explore how faculae. can present a source of contamination in transmission spectra of F-type stars by modifying SOAP 2.0, a code that simulates the effects of active regions on stars. We compare the activity indicators (i.e. bisector span, full width at half maximum) observed in these three F stars to the values modeled in SOAP 2.0 to determine if faculae. can cause the activity observed while not appearing in the star's photometry. We find that it is plausible for widespread, hot faculae. to be present within observations of WASP-121 b, in contrast to prior studies that have rejected significant stellar activity as a source of contamination. We then explore the wide applicability of our method to other transiting exoplanet systems, focusing specifically on the case of TOI-1266—an M-dwarf with two planetary companions. Although stellar activity is historically not considered for transmission spectra around F stars, our results highlight a potential source of contamination that must be taken into account for other observations of transmission spectra in exoplanets around F stars. Further, we present a method that future studies can use to assess the likelihood that faculae. are contaminating transit observations—which can be applied to any system with F stars or smaller.