

Session Q Abstracts

The Search for Lunar Trojans Using Non-Symplectic Integration Techniques

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Mentor: Mike Brown

The two-body problem within planetary dynamics describes the well-defined interaction between two isolated point masses affected by mutual gravitational attraction. However, once a third mass is added to the system (such as that of the Moon or of a co-orbital Lunar Trojan), the equations of motion of the N-body problem become analytically unsolvable. Fortunately, approximations using numerical integration schemes introduce an opportunity to map the trajectory of the masses at each defined time interval. Whether a symplectic, non-symplectic, or hybrid integration architecture is used depends on the dynamical structure of the system. We are particularly interested in the equilibrium solutions of the Earth-Moon-Sun System at Lagrangian points L4 and L5, as these regions, which lie co-orbital with the Moon, could be potential hosts to Lunar Trojans. In this work, we investigate the capture probabilities of Near-Earth Objects (NEOs) using a source population of 802,376 NEOs from realistic orbit and source-specific absolute magnitude distributions derived by Granvik et al 2018. Using IAS15, a non-symplectic high-order algorithm within the N-body integration package REBOUND, we perform various collections of integrations on the orbits of the synthetic population and extract both the probabilities of transformation from NEO to Trojan, as well as gain insight on the mean lifetime of NEOs as a function of their escape route. Previous studies show that objects that move in tadpole orbits about the triangular equilibrium points tend to remain in these stable orbital configurations for millions of years. Therefore, since NEOs act as invaluable dynamical and compositional tracers of both various places and time periods within the planetary system, we hope to better comprehend the origins of the system's dynamical history by quantifying the rate of NEO capture within Earth's sphere of influence.

Building a Spectral Library of Serpentinization With a Focus on Fe-rich Brucite

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Mentors: Bethany Ehlmann and Rebecca Greenberger

Serpentinization, where water interacts with ultramafic rocks, yields minerals like serpentine and brucite, fostering potential habitability in celestial bodies like Mars, volatile-rich asteroids, and outer planets' icy moons. Hydrogen gas production during this process varies due to the involvement of various Fe-bearing minerals. Our objective is to characterize the products of serpentinization with planetary mission-relevant spectroscopies in order to provide a database for interpreting mission data as well as terrestrial datasets, e.g., micro imaging spectroscopy of the Oman Drilling Project's serpentinized ophiolite sequence. We focus first on Fe-bearing brucites because of their role in enhancing H₂ production as Fe(II) in brucite oxidizes through fluid-rock reactions.

We synthesized Mg_xFe_(1-x)OH₂ samples via coprecipitation, dried them at the University of Colorado, and analyzed them under argon in a Caltech anoxic glove box. Spectral measurements on four samples (Mg#s 90, 66, 50, 33) show wavelength shifts consistent with trends in other minerals like Fe(II)-bearing smectites. We also studied natural samples of Fe-bearing serpentines and will present analyses using FTIR, UV/Vis, Mössbauer, and Raman spectra. Our new spectral library will aid in distinguishing Fe(II)-bearing brucites, key to understanding H₂ production during serpentinization.

Determining the Composition of Earth-Sized Planets in the TOI-406 System

Kendra Nguyen

Mentors: Heather Knutson and Michael Greklek-McKeon

M dwarfs are stars smaller and cooler than the Sun but are more active with more frequent flares. As such, planets orbiting M dwarfs may have properties different from planets in our solar system. By obtaining the masses and radii for M dwarf planets, we can determine their bulk composition and gain insight into the impact of M dwarf stellar activity on planetary formation, evolution, and habitability. We have obtained such measurements for two Earth-sized planet candidates, TOI-406.01 and TOI-406.02. Observations of the TOI-406 system were conducted through the Las Cumbres Observatory global telescope network, and we used the ExoWIRC photometric reduction pipeline to produce transit light curves and determine the transit times. Finding the transit time is needed for calculating masses based on transit timing variations (TTVs). TTVs are deviations from expected transit times due to gravitational interactions between planets in a multi-planet system. With inputs of planet masses and orbital parameters, the code TTVFast efficiently models transit times. Thus, by generating models that match the transit times we found, we have determined the masses. With the masses and radii, we calculated the bulk densities and placed the first direct constraints on the composition of both TOI-406.01 and TOI-406.02.

The Abundances of CO, H₂O, and OCS in Venus's Atmosphere From Observations and Modeling

Ting-Juan Liao

Mentors: Yuk. L. Yung, Eliot Young, and Mark Bullock

Scientific investigation into Venus's atmosphere has spotlighted gaps in photochemical models' ability to explain the trace gas species distribution. Key elements such as CO and OCS are essential to Venus's sulfur cycle and cloud formation. To understand the abundance and variability of these trace gases before the DaVinci probe's descent, we launched an observational study using NASA's IRTF telescope equipped with the ISHELL high-resolution spectrometer. From June 11 to June 30, 2023, we captured K, H, and J-band spectra of Venus's night side, utilizing the SMART software to calculate synthetic spectra across various gas abundances and emission angles. Our high-resolution spectral data ($R=\lambda/\Delta\lambda\sim 25,000$) enabled the successful mapping of CO, H₂O, and OCS abundances in the equatorial region, revealing daily and latitudinal variations. We specifically examined the sensitive balance between chemistry and transport, as indicated by the anti-correlation between OCS and CO abundance with cloud opacity. Through near-IR observations, this study seeks to untangle the complex interaction between atmospheric dynamics and chemical reactions in Venus's cloud formation. We contribute insights into the observed cloud patterns and the relationship between atmospheric chemistry, dynamics, and cloud creation on Venus, thereby providing vital parameters to refine photochemical models.

LunaX Moon Base Simulator - Exploring Lunar Development and Sustainability

Bo-Ruei Huang

Mentors: Yuk Yung and Jonathan Jiang

The LunaX Moon Base Simulator project exemplifies a dynamic undertaking inspired by NASA's Artemis program, which seeks to reintroduce humans to lunar landscapes and establish a self-sustaining lunar base by 2024. In response to this ambitious endeavor, we present an immersive video game experience that enables participants to delve into the intricacies of lunar development.

Leveraging the versatile Unity platform, the game offers a comprehensive simulation of lunar base operations. Core features encompass sophisticated resource management, intricate life support systems, and strategic infrastructure creation. Players have the opportunity to construct their lunar base and formulate strategic approaches for sustainable development.

The potential of this game transcends mere entertainment; it serves as an educational instrument, affording players insights into the multifaceted intricacies of lunar exploration and the challenges of establishing a habitable environment. By bridging the realms of gaming and tangible lunar endeavors, the LunaX Moon Base Simulator possesses the ability to ignite curiosity and cultivate enthusiasm for space exploration within a diverse array of audiences.

Exploring Calcium Isotopes Ratios in Urine as a Tracer of Bone Health

Dylan Cleveland

Mentors: Francois Tissot, Rosa Grigoryan, and Michael Kipp

Bone formation favours the incorporation of lighter calcium isotopes over heavier ones, leading to isotopic fractionation. If bone resorption exceeds growth, the isotope composition in bodily fluids shifts to be lighter, which is reflected in the isotopic ratio of urine. This project aims to analyse the calcium isotope ratio ($^{44}\text{Ca}/^{42}\text{Ca}$) in human urine to explore its potential for bone disease diagnosis. Low pressure chromatography is used to isolate the calcium, and the isotope ratio measurements carried out via MC-ICP-MS. The data generated over summer will allow a preliminary quantitative analysis of population-scale calcium isotope variability across various parameters of interest, including age, sex, diet, and lifestyle. This will give a significant indication of the efficacy of isotope ratios as a diagnostic tool, and guide future project work.

Calcium Isotopes as a Biomarker: Are They Effective for Diagnosing Bone Disease?

Phillip A. Vakoula

Mentors: Francois Tissot and Rosa Grigoryan

Osteoporosis is a bone disease characterized by the loss of bone mineral density. The progression of osteoporosis is typically assessed using dual-energy x-ray absorptiometry (DXA or DEXA), which, while effective at quantifying bone loss, is poorly subscribed as a screening technique due to access barriers (travel to clinic, radiation exposure, etc.). Multiple studies have shown a promising future in the use of natural calcium isotope variability as a bone turnover marker and more specifically as a diagnostic tool for osteoporosis and other similar bone diseases, with the hope that it would provide a more readily accessible screening method. However, it has been shown that healthy individuals with no net bone loss still have considerable urinary isotopic variability, which confounds the sensitivity and specificity of this diagnostic tool. To better understand this variability, we created a model of bodily calcium isotope mass balance to simulate different scenarios involving both healthy individuals and those experiencing bone loss. We find that a healthy person's calcium isotope mass balance is not constant, due to

variable dietary compositions and kidney reabsorption, and this is reflected by the isotopic composition of urinary calcium. While this complicates diagnosis of changes in bone mineral balance using urinary calcium isotopes alone, strong correlations between urinary calcium isotope ratios and calcium excretion rates allow a means of normalizing urine calcium data to improve the sensitivity and specificity with respect to diagnosing bone loss. We find that such normalizations could substantially improve the performance of this diagnostic tool, but would need to be calibrated against data from healthy individuals across various populations.

Optimizing Sample Preparation Protocols for Ca Isotope Analysis of Urine Samples

Rithika Chunduri

Mentors: Francois Tissot and Rosa Grigoryan

Calcium is a vital element for many physiological processes in the body. Decreases in bone mass density - for instance, during osteoporosis - are associated with a net loss of calcium from the body via urine and incur an increased fracture risk. To gauge bone health in populations at risk of osteoporosis (e.g., post-menopausal women), bone density is measured via dual-energy X-ray absorption. This technique requires exposure to radiation and a hospital visit, which makes the test less accessible to at-risk individuals. In contrast, measuring calcium isotopes in urine via multi-collector inductively coupled plasma-mass spectrometry (MC-ICP-MS) has shown potential as a novel tool for diagnosing changes in bone mineral balance in conditions such as osteoporosis. However, current methods for calcium isotope analysis of urine are time-consuming and present a major bottleneck in clinical-scale studies. We systematically tested two different sample preparation protocols to optimize calcium isotope analysis of urine samples. Oven baking in glass test tubes was tested alongside the current sample digestion method, acid attack in PFA beakers. The residues were then purified via ion exchange chromatography to obtain pure calcium. The calcium concentrations and their isotopic ratios were measured using an iCAP ICP-MS and an MC-ICP-MS, respectively. This data will be analyzed, and subsequently, the most efficient sample preparation method will be identified for large scale Ca isotope analysis of urine samples.