ERES IX Presentation Abstracts

Cornell University, Ithaca, New York

2024 July 10-12

Session 1: Exoplanet Observations I

1.1 **Title:** The ongoing search for radio emission from exoplanets
Presenter: Jake Turner
Abstract: Observing planetary auroral radio emission is among the most promising methods to detect exoplanetary magnetic fields, the knowledge of which will provide valuable insights into the planet's interior structure, atmospheric escape and dynamics, and habitability. Recently, we published the first possible detection of an exoplanet (τ Boo b) in the radio. In this talk, I will discuss our ongoing guaranteed Key Science Program "Exoplanets and Stars" using the NenuFAR low-frequency radio telescope in France. The main goals of the survey are to follow-up the tentative detection from τ Boo b and to search for radio waves from dozens of the most promising exoplanet candidates according to theoretical studies. NenuFAR is fully commissioned and is able to perform simultaneous beamformed and imaging observations. These observations will test theoretical models for the first time with a statistical sample with a high sensitivity at the predicted wavelengths. Preliminary results and the implications will be presented.

1.2 **Title:** Detecting Exoplanet Transits with the Next Generation of X-ray Telescopes
Presenter: Raven Cilley
Abstract: The detection of exoplanet transits at X-ray wavelengths would provide a window into the effect of high energy irradiation on the upper atmospheres of planets. However, due to the relative dimness of stars in the X-ray, only one exoplanet transit has been detected in X-rays to date. This study seeks to investigate how many currently known transiting exoplanets could be detected with the next generation of X-ray telescopes. Specifically, we examine this case for the NewAthena WFI instrument and the proposed Advanced X-ray Imaging Satellite (AXIS). We started with a list of confirmed transiting exoplanets from the NASA Exoplanet Archive, gathering X-ray flux measurements or estimates for each host star. We then calculated each hypothetical AXIS and NewAthena count rate and simulated light curves for the transits, which we used to select the best candidates for detection. We additionally examined our top candidate AXIS and NewAthena targets in the context of atmospheric escape.

1.3 **Title:** A well-aligned orbit for the very eccentric warm Jupiter TOI-4127 b
Presenter: Ismael Mireles
Abstract: The spin-orbit alignment of a planet can reveal a lot of information about a planet's evolutionary history. While this has been measured for many hot Jupiters, very few warm Jupiters have a measured spin-orbit angle due to their longer orbital periods. These warm Jupiters are key to understanding planet formation and evolution, as some of the most eccentric ones may be hot Jupiter precursors. Here, we present an analysis of the spin-orbit alignment for the highly eccentric (e=0.75) warm Jupiter TOI-4127 b. We use HARPS-N to measure the Rossiter-McLaughlin effect and derive a projected spin-orbit angle of -1 ± 16 degrees. Given the well-aligned orbit, we conclude that TOI-4127 b is almost certainly not a hot Jupiter precursor. Nonetheless, its high eccentricity remains a mystery. We discuss the possible scenarios that could have led to such an eccentric yet well-aligned planet, including prospects for an unseen outer planet in the system.

1.4 **Title:** The TESS Spotlight on Detached Binary Systems via Eclipse Timings
Presenter: Ekrem Esmer
Abstract: Although binary stars are common in our galaxy, circumbinary planets are observationally challenging to detect relative to the planets orbiting single stars. We address this discrepancy by leveraging the wide sky coverage, long temporal baselines, and high cadence offered by TESS to conduct a comprehensive search for eclipse timing variations (ETVs) indicative of potential additional bodies as well as stellar spots and magnetic interactions. We select bright detached eclipsing binaries from the TESS Eclipsing Binary Catalog and infer mid-eclipse times using allesfitter, yielding a typical timing precision of ∼10 seconds for T∼9 mag systems using two-minute cadence data. We catalog anti-correlations between the timings of primary and secondary eclipses as evidence of apsidal precession or the influence of stellar spots on the eclipse light curves. The resulting ETV catalog with robust timing uncertainties yields a database that can be used to establish mass limits for additional bodies in the system.

Session 2: Planet Formation, Interiors, and Solar System Bodies

2.1 **Title:** Water as a Potential Sculptor of the M Dwarf Radius Valley
Presenter: Bennett Skinner
Abstract: A key insight into the planet formation process is provided by the existence of the radius valley, a dearth of planets at 1.7–1.8 Earth radii between smaller super-Earths and larger sub-Neptunes. Super-Earths are believed to have terrestrial compositions dominated by silicates and iron, but the degeneracy between composition and bulk density makes it difficult to disentangle whether the sub-Neptune population is composed of planets with significant water fractions or significant H/He fractions. Around FGK stars, the radius valley shifts to larger planet radii at higher instellation, suggesting that the valley is carved by the atmospheric escape of a H/He envelope. However, this pattern may not be replicated around M dwarfs, indicating that the process forming the valley around M dwarfs may be distinct from FGK stars. We test whether a bimodal distribution in water mass fractions can explain the emergence of the M dwarf radius valley. We have built a planetary internal structure model that includes updated equations of state for H/He, silicates, iron, and most importantly water. This will allow a precise theoretical characterization of mass-radius relations for water-rich planets for comparison to the observed planet population. We also discuss plans to incorporate this model into planet population synthesis models that currently show that a significant number of sub-Neptunes migrate close to the host star from beyond the ice line and have ice fractions near 50%.

2.2 **Title:** Cosmic hydrogen and ice loss lines
Presenter: Li Zeng
Abstract: We explain the overall equilibrium-temperature-dependent trend in the exoplanet mass–radius diagram, using the escape mechanisms of hydrogen and relevant volatiles, and the chemical equilibrium calculation of molecular hydrogen (H2) break-up into atomic hydrogen (H). We identify two Cosmic Hydrogen and Ice Loss Lines (CHILLs) in the mass–radius diagram. Gas disks are well known to disperse in ten million years. However, gas-rich planets may lose some or almost all gas on a much longer timescale. We thus hypothesize that most planets that are born out of a hydrogen-gas-dominated nebular disk begin by possessing a primordial H2-envelope. This envelope is gradually lost due to escape processes caused by host-stellar radiation.

2.3 **Title:** Sub-Millimeter Observations of Asteroids Using the Atacama Cosmology Telescope
Presenter: Ricco Venterea
Abstract: Sub-millimeter (sub-mm) wave asteroid measurements can provide planetary scientists with information about the composition of asteroids since these measurements are sourced from deeper in the regolith. Using data collected by the Atacama Cosmology Telescope (ACT), we present significant detections of main belt asteroids and near-earth objects. We also generate light curves for objects with high signal to noise ratios. Flux data were collected in the 90–220 GHz frequency bands. These

fluxes were then compared to flux data collected by the Wide-field Infrared Survey Explorer (WISE) potentially allowing us to weigh in on how well asteroid models are able to model temperature or emissivity variations below small body surfaces. Additionally, we release a database containing thermal emission flux results from ACT. This research demonstrates the general utility of high cadence, high resolution observations such as those taken by ACT and the South Pole Telescope. Data from future millimeter-surveys, such as the Simons Observatory and CMB-S4, can be analyzed and applied following similar procedures and provide larger, high-fidelity data sets for planetary scientists.

2.4 **Title:** APPLE: A Python Code for Planetary Evolution
Presenter: Ankan Sur
Abstract: We introduce APPLE, a novel planetary evolution code designed specifically for the study of giant exoplanet and Jovian planet evolution in the era of Juno, Cassini, and Galileo. With APPLE, state-of-the-art equations of state for hydrogen, helium, ice, and rock are integrated with advanced features to treat ice/rock cores and metals in the gaseous envelope; models for helium rain and hydrogen/helium immiscibility; detailed atmosphere boundary tables that also provide self-consistent albedos and spectra; and options to address envelope metal gradients and stably-stratified regions. We hop that these purpose-built features of APPLE will help catalyze the development of the next generation of giant exoplanet and Jovian planet evolutionary models.

2.5 **Title:** Interior Structure and Gravity Harmonics Models for Uranus and Implications for the Uranus Orbiter and Probe
Presenter: Zifan Lin
Abstract: The interior composition and structure of Uranus are poorly known but have major implications for the planet's mechanism of formation, the planet's thermal evolution, and the origin of its dynamo magnetic field. Two interior structures are possible, namely a fully differentiated structure with >80 wt.% H2O ("ice giants") and a roughly 1:1 rock-ice mixture composition with radial compositional gradients ("rock giants"). To inform UOP orbit design, we construct interior models and simulate the zonal gravity harmonics for Uranus, assuming both structures. Our results show that it is of high value for UOP to measure J_6 and J_8, which requires polar, close-in orbits for the Uranus Orbiter and Probe.

Session 3: Atmospheres I

3.1 **Title:** The HUSTLE Program: Towards a Uniform UVIS Analysis of 13 Hot to Ultra-Hot Jupiters
Presenter: Abby Boehm
Abstract: Ultraviolet light (10 to 400 nm) is the core driver of photochemical haze formation and a powerful probe of aerosols and hydrodynamic escape processes in exoplanetary atmospheres, yet few transmission spectroscopy studies use these wavelengths, leaving these key physical processes poorly constrained. The ongoing Hubble Ultraviolet-visible Survey of Transiting Legacy Exoplanets (HUSTLE) program (HST-GO 17183, PI: Hannah Wakeford) is leveraging the HST WFC3/UVIS G280 to measure the ultraviolet-visible (200 to 800 nm) spectra of 13 hot Jupiters with temperatures spanning 960 K to 2640 K, enabling us to constrain transitions in aerosol composition and structure with temperature. Here we present the progress of the HUSTLE program. We provide an overview of the strengths and challenges of HST WFC3/UVIS G280 data collection and analysis, and present soon-to-be-public software developed to overcome these challenges. Current results from our analyses of several hot Jupiters are highlighted. Lastly, we outline a roadmap for the future of the HUSTLE program, identifying remaining obstacles and prospects in HST WFC3/UVIS G280 data analysis. Our work with HUSTLE deepens our understanding of how the structure and composition of hot Jupiter atmospheres varies with equilibrium temperature, and will bring self-consistent and easy HST WFC3/UVIS G280 transmission spectroscopy to the exoplanetary science community at large.

3.2 **Title:** Reflected Light Phase Curves with PICASO: A Kepler-7b Case Study
Presenter: Colin Hamill
Abstract: We introduce an enhanced capability of PICASO, an open-source radiative transfer model used for exoplanet atmospheres, to produce phase-resolved reflected light intensities (reflected light phase curves) from three-dimensional atmospheric models. PICASO is coupled to the cloud code Virga, allowing us to produce phase curves with different cloud condensate species and varying sedimentation efficiencies (fsed). This new functionality is applied to Kepler-7b, a hot Jupiter whose phase curve measurements are dominated by reflected light. The different cloud scenarios are then modeled for Kepler-7b: MgSiO3 only, Mg2SiO4 only, and Mg2SiO4, Al2O3, and TiO2. Our Virga clouds reproduce the cloudy region west of the substellar point expected from previous studies (e.g., Demory et al. 2013; Muñoz & Isaak 2015), though our clouds mostly disappear at latitudes greater than 45° N/S. We then compare our modeled reflected light phase curves to Kepler observations from Demory et al. (2013) and find that models with low sedimentation efficiencies (fsed = 0.03) match best. Our reflected light phase curves match well to observations of the cloudless region east of the substellar point, however all underestimate the reflected light intensities corresponding to regions west of the substellar point. We conclude that a better understanding of zonal transport, cloud radiative feedback, and particle scattering properties is needed to further explain the difference in modeled and observed reflected light albedos.

3.3 **Title:** Rotation and abundances of Low-mass Stars, Brown Dwarfs, and Exoplanets from Keck/KPIC High-resolution Spectroscopy
Presenter: Chih-Chun Hsu
Abstract: High-resolution spectroscopy enables precise measurements of rotation and abundances of low-mass stars, brown dwarfs and gas giant exoplanets, which shed light on their formation and evolution. The Keck Planet Imager and Characterizer (KPIC) is a fiber injection unit connecting the Keck/NIRSPEC spectrometer (R$\sim$35,000) to the Keck II AO system to provide high-resolution spectroscopy at high-angular resolution. KPIC is capable of following-up discoveries of directly imaged close companions, with high contrasts (Δmag = 5–15), which has detected and characterized rotation and abundances for $\sim$20 benchmark brown dwarfs and giant exoplanets, including HR 8799 planets. I will present updates on the KPIC instrument facilitization, the recent instrument upgrade, and early science with KPIC. For abundances, we conducted a survey for eight young companions and found that their C/O ratios and 12C/13C isotope ratios consistent with the local interstellar medium. For rotation, I will present the overall spin trend versus mass for >200 low-mass objects (M $\lesssim$ 0.08 Msun) by combining KPIC observations ($\sim$30 objects) with literature measurements. Our preliminary analysis shows a trend of faster rotation toward lower masses, which can be explained by angular momentum loss being less efficient for lower-mass objects. We found that rotational velocities increase toward older ages for objects less than 60 Mjup, consistent with constant angular momentum and radius evolution. Most rotational velocities are below 30% breakup velocities, with some of >50% breakup velocities. Finally, I summarize prospects for improving rotation and abundance measurements with high-resolution spectra.

3.4 **Title:** A New Atmospheric Retrieval Paradigm for Exoplanet Aerosols
Presenter: Elijah Mullens
Abstract: Aerosols are a ubiquitous feature of planetary atmospheres and leave clear spectral imprints in exoplanetary spectra. In this work new features are implemented into the open-source atmospheric retrieval code POSEIDON that account for the complex scattering, reflective, and absorptive properties of Mie scattering aerosols while cutting down on computation time. Hot Jupiter HD 189733b's dayside albedo spectrum and transmission spectrum indicate the presence of aerosols. We jointly retrieve the thermal and reflection spectra of HD 189733b in order to constrain cloud density and location, aerosol species, and particle size. We also present retrievals of the transmission spectrum of HD 189733b, as well as some JWST targets, in order to detect potential compositions of aerosols at the day-night terminator with a goal to formulate a self-consistent, multi-dimensional picture of cloud formation

processes due to thermochemical gradients across a planet.

Session 4: Habitability

4.1 **Title:** The White Dwarf Opportunity - Constraining M Dwarf Stellar Winds Using a White Dwarf Companion
Presenter: Raven Westlake
Abstract: M dwarf stars are known to have stellar winds that likely impact the habitability of their planets. Stellar winds are composed of high energy particles that cannot be directly observed with telescopes, so indirect methods must be used to place observational constraints on M dwarf wind rates. Close binary pairs containing a white dwarf and an M dwarf companion can be used to infer M dwarf wind rates via metal pollution in the white dwarf's atmosphere. Due to the high surface gravities of white dwarfs, metal lines are not long-lived in their atmospheres unless material is being continuously accreted, such as from the stellar wind of its M dwarf companion. I will present a selection of white dwarf – M dwarf binaries which are suitable for measuring the stellar wind rate and for which spectra are available through the Sloan Digital Sky Survey. For these targets, I will measure the equivalent widths of metal lines in the white dwarf atmospheres and calculate the metal abundances. When combined with known system parameters such as the binary's orbit and models of metal mixing and diffusion, I will determine the M dwarf wind rates. With this sample, we hope to establish the distribution of M dwarf wind rates to assess the impact that stellar winds have on atmospheric escape, atmospheric chemistry, and planet habitability.

4.2 **Title:** Kenneth Gordon
Presenter: Assessing the Habitability of Heterogeneous Terrestrial Exoplanets with Polarized Reflected Light
Abstract: Determining the habitability of terrestrial exoplanets is a complex problem that represents the next major step for the astrophysical community. The majority of current models treat these planets as homogeneous or contain heterogeneity that is constant in time. In reality, habitable exoplanets are expected to contain atmospheric and surface heterogeneities similar to Earth, with diurnal rotation, seasonal changes, and weather patterns resulting in complex, time-dependent signatures. Due to its sensitivity to the micro- and macro-physical properties of a planet's atmosphere and surface, polarimetry provides an important tool that, combined with traditional flux-only measurements, will enhance the characterizations of these worlds. Here we present preliminary results of the visible to near-infrared linear spectropolarimetric signatures, as functions of wavelength and planetary phase angle, of different heterogeneous terrestrial exoplanet archetypes. We have incorporated a range of T-P, composition, cloud/haze, and surface profiles from various archetypes including ocean (desert) planets with 1 to 4 randomly distributed continents (water bodies); early and modern Earth; and modern Venus. The contributions from the different atmospheric and surface parameters result in asymmetric phase curves and variable spectra that allow us to begin to resolve degeneracies between habitable and non-habitable scenarios. The polarization appears to be more sensitive than flux to heterogeneities such as patchy clouds/hazes and continents moving into and out-of-view. Our models provide important predictions of expected polarized and unpolarized signatures of terrestrial exoplanets that will help guide the designs and observing plans of future polarimeters, including those for the upcoming ELTs and Habitable Worlds Observatory.

4.3 **Title:** Marissa Tripus
Presenter: Exploring the Ocean Circulation on Archean Earth
Abstract: During part of the Archean Eon (4–2.5 billion years ago), it is likely Earth experienced near-global ocean coverage. Little is known about the ocean during this time, but it coincides with – and may have been instrumental in – the earliest development of life on our planet. It is important to understand what the ocean's physical environment could have been at this time, as it can help us

better understand the background under which life on our planet evolved. Here we use the ROCKE-3D atmosphere-ocean general circulation model configured for the Archean's environment to explore the dynamics of the ocean as well as its potential role in Earth's climate. In addition to the ocean coverage, many aspects of the planet were different, i.e., Earth's rotation rate, atmospheric composition, incoming solar radiation, and ocean salinity. Even less is known about what the ocean bathymetry was at the time, but it is well-established that bathymetry plays an important role in ocean circulation (e.g. Gille et al. 2004). A suite of simulations are performed to explore how ocean bathymetry could have impacted ocean circulation, heat transport, and the Archean climate via several sensitivity tests. Relevance to ocean-covered exoplanets is also considered.

4.4 **Title:** Continuous Habitable Zone Predictions for Potential Habitable Worlds Observatory Targets
Presenter: Austin Ware
Abstract: The future NASA direct imaging space telescope, coined the Habitable Worlds Observatory (HWO), will be the first telescope capable of both detecting and characterizing Earth-sized exoplanets in the habitable zones of nearby Sun-like stars. Searching for the signatures of life will require a significant amount of time and resources for even a single exoplanet. In order to maximize the potential to detect an Earth-like world harboring life, it will be essential to prioritize observations by those most-likely to host detectable life. To satisfy the goal laid out in the Astro2020 Decadal Report of surveying the habitable zones of 100 stars, NASA's Exoplanet Exploration Program compiled a mission star list for HWO with 164 targets whose habitable zones would be most accessible to a directing imaging survey with a 6-m-class space telescope. One method to further prioritize target selection and potential follow-up observations of newly discovered exoplanets is to estimate the likelihood that an exoplanet has remained continuously within the habitable zone long enough for life to emerge and make a detectable impact on the atmosphere. We use a Bayesian method to determine the probability that a given orbital radius around a star is currently in the 2 Gy continuous habitable zone (CHZ2), the approximate time it took life on Earth to significantly oxygenate the atmosphere. We use this method to calculate CHZ2 probability distributions for main sequence stars in the HWO mission star list and demonstrate the benefit of using flexible Bayesian frameworks for prioritizing observations of potentially habitable worlds.

Session 5: Atmospheres II

5.1 **Title:** The Effect of Stellar Features on Atmospheric Retrievals of WASP-52b's Transmission Spectrum
Presenter: Yanbo Pan
Abstract: Stellar inhomogeneities (unocculted starspots or faculae) are believed to influence exoplanet transmission spectroscopy. Therefore, modeling and retrieving stellar features is crucial for understanding the exoplanet's atmospheric properties. In this study, we apply atmospheric retrievals on the optical to infrared (0.6–2.7 μm) transmission spectrum of the hot Jupiter WASP-52b observed with JWST NIRISS/SOSS instruments. Our objective is to measure its atmospheric chemical composition and study the influence of unocculted stellar features on the transmission spectrum using POSEIDON (a Bayesian atmospheric retrieval algorithm). Since WASP-52b presents significant stellar features and starspot crossing events during the transit, we introduce unocculted starspot or facula (fraction, temperature, and surface gravity as free parameters) in the retrieval process. We will present our retrieval result on atmospheric composition and stellar feature estimates. This work allows us to establish constraints on WASP-52b's planetary atmosphere and the stellar feature of its host star.

5.2 **Title:** On the Detectability of Emission from Exoplanet Outflows
Presenter: Riley Rosener
Abstract: Exoplanets close to their host stars experience high amounts of irradiation, causing drastic atmospheric escape that can be measured as a gas outflow from the planet using certain chemical tracers. To date, exoplanet atmospheric escape has thus far only been probed using transmission

spectroscopy to measure line absorption. While it is theoretically possible to measure outflows via emission spectroscopy, the observability of these signatures may limit the practical application of this method. In this work, we investigate the viability of successfully observing Lya, Ha, and He* emissions from atmospheric outflows. We consider a variety of exoplanets with confirmed detections of the 10833 A metastable helium absorption line and other outflow tracers. We use the updated and improved PyTPCI (The-PLUTO-CLOUDY Interface) software and wrapper to run combined photochemistry, spectrum synthesis, and hydrodynamics simulations of our chosen exoplanet systems. Using these results and information about the observational facilities that are most sensitive to each diagnostic, we calculate the resultant signal-to-noise ratio, eclipse depth, optical depth, bremsstrahlung flux, and theoretical shock properties for our target systems. Ultimately, we find that these signals will not be large enough to detect and distinguish during the secondary eclipse using existing facilities. For future observational campaigns, our work suggests focusing on bright, well-characterized systems like hot Jupiters HD 189733b and HD 209458b, so that any potential emission signals are maximized. Although these emissions are not currently detectable with Keck and HST, they may be within reach of JWST and the next generation of extremely large telescopes.

5.3 **Title:** JWST Transmission Spectra of Four Rocky Worlds
Presenter: Ryan MacDonald
Abstract: A core goal of JWST is to detect and characterize the atmospheres of Earth-sized exoplanets around M-dwarf stars. The first step to understanding the atmospheric chemistry and potential habitability of M-dwarf planets is to establish which worlds possess detectable atmospheres.

Through JWST Cycle 1 Program GO 1981, we have conducted a survey of five rocky exoplanets to search for observational evidence of their atmospheres.

In this talk, I will present our results from the first JWST spectroscopic survey of rocky exoplanet atmospheres. I will also share takeway lessons for future searches for rocky planet atmospheres via transmission spectroscopy.

5.4 **Title:** High-resolution spectroscopy of ultra-hot planetary atmospheres: recent results and future prospects with KPF and GHOST
Presenter: Adam Langeveld
Abstract: Ultra-hot Jupiters (UHJs) are captivating subjects of study due to their scorching temperatures and extreme atmospheric conditions. Composed of a vast array of gaseous metallic species, UHJs are lucrative targets to probe with high-resolution transmission spectroscopy, particularly at optical wavelengths where absorption lines from metal atoms and ions are most prevalent. In 2023, two next-generation high-resolution optical spectrographs were commissioned: the Keck Planet Finder (KPF) at Keck I, and the Gemini High-resolution Optical SpecTrograph (GHOST) at Gemini South. These world-class instruments hold much promise to make significant contributions towards furthering our understanding of a broad sample of exoplanetary atmospheres. We will showcase some of the first UHJ transmission spectra observed with KPF and GHOST, reporting our findings from surveys of the selected UHJs' atmospheric chemistry, and highlighting key results that reveal important insights into the chemical and dynamical processes in their upper atmospheres. We also share Python code that will be made freely downloadable to other KPF and GHOST users, to simplify the process of performing telluric corrections with these instruments using Molecfit. Our results provide valuable context for comparative studies to investigate atmospheric trends in a broad population of UHJs with high-resolution transmission spectroscopy, especially as we prepare to exploit the full power of the ELT in the coming 5–10 years.

Session 6: Disks & Hydrodynamics

6.1 **Title:** Eccentric Protoplanetary Disks: Theory and Applications
Presenter: Jiaru Li

Abstract: High-resolution images captured by ALMA have demonstrated that substructures are common in protoplanetary disks. Understanding the origins and evolution of these substructures is a critical question in planet formation theory. In my talk, I will discuss theories related to the eccentricity of protoplanetary disks, which manifests as an m=1 azimuthal substructure. The first part of my presentation will cover our work on disk eccentric modes, employing both linear analysis and hydrodynamical simulations. I will introduce the long-lived eccentric mode exhibited in both two-dimensional and three-dimensional disk models, as well as the eccentric mode instability (EMI) in self-gravitating disks. The second part of my talk will focus on the applications of disk eccentricity to the formation and dynamical evolution of exoplanets, which include: (1) generating multiple gaps and rings in protoplanetary disks, (2) producing planetary orbital eccentricity, and (3) influencing the orbital migration of planets.

6.2 **Title:** The Formation and Structure of Circumplanetary Disks
Presenter: Aster Taylor
Abstract: Circumplanetary disks are thought to form alongside giant planets, which shape their formation history and the local environment. However, the structure of these disks are not well-understood. Motivated by contradictions in modern numerical simulations of these disks and the promise of observations in the near future, we analytically consider the formation and structure of circumplanetary disks. A primary point of disagreement in the numerical simulations is the infall geometry. Generalizing previous work, we consider a range of possible geometries for the flow entering the planetary sphere of influence. Specifically, we consider five geometries, from polar concentration to isotropic flow to concentration along the equatorial plane. For each case, we derive analytic descriptions for the density field of the infall region, the disk surface density in the absence of viscosity, and the steady-state solutions for viscous disks. These power sources, in concert with the surrounding material, collectively determine the observational appearance of the forming planet. For each inflow function, and a range of protoplanet masses, we calculate the spectral energy distributions of the planet-disk-envelope system. We also construct images for each object, which serve as predictions of future observations. We find that, with sufficient sensitivity, observations may be able to distinguish between these geometries. This would allow for significant improvement in our understanding of the late stages of giant planet formation, clarifying the nature of inflowing matter. It is also notable that the geometry of the inflow may change over the course of the planet's lifetime.

6.3 **Title:** Type II Migration in Protoplanetary Disks from Multiple Embedded Planets
Presenter: Sudat Khan
Abstract: Investigating the formation and evolution of protoplanetary disks allows us to understand the process of planet formation and migration. Specifically, planet-disk interactions shape planetary orbits through migration and produce substructures within disks such as spirals, vortices, and gaps. For planetary masses equal to or greater than $\sim 1\ M_J$ the Lindblad torque comprises of a positive torque applied to the planet by its inner wake and a negative torque generated by its outer wake. The planet gives angular momentum to the outer disk (the region beyond the planet's orbital radius) while absorbing some from the inner disk. There is also the corotational torque, which is the torque due to disk material that on average corotates with the planet. When the torque exerted by the planet on the disk exceeds the viscous torque, it results in the formation of an annular gap around the planet's orbit. This non-linear regime is called Type II migration. Singular embedded planet-disk interactions have helped us understand the foundations of planetary migration, however, the logical extension of this theory to massive multi-planet systems is still not well understood. Using Athena++, a hydrodynamics code, we do 2-D simulations of gap formation resulting in a singular Jupiter-massed planet and two Jupiter-massed planets embedded within a locally isothermal protoplanetary disk. From this, we can analyze the surface density of the gap formations, calculate the total torque of the planet-disk interaction, and determine the migrational direction of the planets. This analysis can help us understand the feasibility of proposed planetary migration models such as the Grand Tack Hypothesis.

6.4 **Title:** Migration of Accreting Planets in Disks

Presenter: Jordan Laune
Abstract: In the classic picture of Type I migration, planets lose angular momentum (AM) to the gaseous protoplanetary disk (PPD) via gravitational interactions. This process leads to inward migration of the planet and is a key ingredient in the evolution of nascent planetary systems. Due to the momentum carried by the gas, a planet can also exchange AM with the disk through accretion. In this talk, we present global 2D hydrodynamic simulations of an accreting planet in a PPD using Athena++. The planet is treated as an absorbing sphere, and we account for all AM exchange via gravity, accretion, pressure, and viscosity. In our simulations, we find outward migration, in contrast with the standard theory. Our findings suggest extra caution is needed when applying standard migration theory to accreting planets.

6.5 **Title:** Tidal Physics in Exoplanet Systems and a New Open-Source Code for Calculating Tidal Response
Presenter: Meng Sun
Abstract: The study of tidal physics is crucial for comprehending stellar interiors and exoplanet systems, as tidal strength depends on orbital configurations and stellar structures. Tides can play a role in modifying binary and exoplanet system orbits, such as synchronization, circularization, and semi-major axis changes. In this meeting, I will cover the basic physics behind tides, their damping mechanism, as well as the approximate semi-analytical treatment and the full numerical method in calculating the tidal response with a new open-source code GYRE-tides. Additionally, the comparison between theoretical models of tides and observations in exoplanet systems will also be discussed.

Session 7: Exoplanet Observations II

7.1 **Title:** Using Machine Learning and our CALM Linear Regression Method to Model Stellar Activity in RV Searches
Presenter: Zoë de Beurs
Abstract: Exoplanet detection with precise radial velocity (RV) observations is currently limited by spurious RV signals introduced by stellar activity (i.e. faculae, starspots). Here we show that machine learning techniques such as linear regression and neural networks can significantly improve RV measurements by separating the activity signals (primarily starspots/faculae) from real center-of-mass RV shifts. We introduce both our work using neural networks and our new modeling method, CCF Activity Linear Model (CALM), which we tested on a dozen stars spanning the HR diagram. We have successfully tested our methods on both solar and extrasolar observations. We find that these techniques can successfully predict and remove stellar activity and reduce the RMS by about 40% for the Sun. For other stars, our technique results in a similar RMS reduction. We also successfully applied our methods to K2-167, a sub-Neptune sized planet which was first found using the transit method in 2015 and falls at the upper edge of the radius valley. Using CALM, we measured K2-167 b's mass and paved the way towards characterizing more of these types of systems that are critical to probing the formation physics (e.g. photoevaporation, core-powered mass loss) of the radius valley. These promising results inspire us to apply CALM to a larger sample of stars, measure the masses of rocky exoplanets, and eventually help characterize habitable-zone Earth-mass exoplanets.

7.2 **Title:** Obtaining Precise and Accurate Masses of Super-Earths around M Dwarfs
Presenter: Drew Weisserman
Abstract: The radius distribution of small exoplanets is split by the radius valley, a dearth of planets between 1.6-1.9 Earth radii that separates rocky super-Earths from larger sub-Neptunes. For planets around FGK stars, this is commonly understood to be due to atmospheric escape processes, but growing empirical evidence suggests that this may not hold true for M dwarf systems. To further our understanding of planets around the M dwarf radius valley, both precise and accurate masses of the planets in this regime are required. We seek to measure the accuracy of reported masses of 27 planets around the M dwarf radius valley using radial velocity measurements from the literature. We

fit the masses of these planets using a homogeneous framework that accounts for stellar variability and perform injection-recovery tests to infer the accuracy of our retrieved planet masses. Additionally, we are conducting detailed follow-up observations to refine the masses of select hot super-Earths to place strong constraints on their iron core mass fractions (CMFs) and to assess how the planetary compositions relate to their host stars. This data is being obtained from an intensive radial velocity monitoring campaign with the newly commissioned NIRPS spectrograph for the M dwarfs GJ 1132 and GJ 1252. This data will deliver ultra-precise planet masses to 10% precision, as is needed to derive meaningful constraints on the planetary CMFs. We conclude by discussing our framework to derive precise CMFs that will enable much-needed insights into super-Earth formation processes in the M dwarf radius valley.

7.3 **Title:** A new machine learning pipeline for exoplanet search in microlensing data
Presenter: Javier Viaña
Abstract: Microlensing offers a unique advantage in detecting exoplanets by leveraging gravitational lensing effects caused by massive objects. Unlike other methods, it can detect planets regardless of their distance from their host stars and is particularly effective for identifying planets in wide orbits around distant stars. This makes it a valuable tool for discovering a broader range of exoplanets, including those that might otherwise be challenging to detect using traditional methods like radial velocity or transit observations. However, currently detecting microlensing events relies heavily on human inspection, which is slow and can be inaccurate. In this work we present a new machine learning architecture to enhance exoplanet searches in microlensing data from the Korea Microlensing Telescope Network (KMTNet) using machine learning. As an input, our algorithm takes the light curves and auxiliary measurements of candidate microlensing events from a detection algorithm specifically designed to identify 'rising' events, where the brightness increases over time, and returns a probability that each event is a genuine microlensing event. A preliminary Recurrent Neural Network architecture incorporating the light curve, as well as time-series information of the sky background, the star's full width at half maximum, the flux uncertainty, air mass, and PSF quality flags achieves accuracies above 80%. We are in the process of increasing the size of the training set by a factor of 20 and incorporating additional inputs, and expect considerable improvement in accuracy. Ultimately, this new tool could significantly increase the efficiency and sensitivity of the surveys of exoplanets detected through microlensing.

7.4 **Title:** Measuring the Spot Variability of T Tauri Stars Using Near-IR Atomic Fe and Molecular OH Lines
Presenter: Shih-Yun Tang
Abstract: To characterize the spot-induced variability of T Tauri Stars (TTSs) and to facilitate the discovery of the planets orbiting them, we have collected hundreds of high-resolution optical and NIR spectra in our Young Exoplanets Spectroscopic Survey over two decades. By analyzing Teff sensitive lines, we used M-dwarfs with interferometrically determined Teff to formulate an empirical equivalent width ratio (EWR)-Teff relationship for Teff values from 3400 to 5000 K to shed light on stellar activity nuances. Our comparative analysis of spectral models reveals broad agreement but also highlights significant disparities, indicating a pressing need for refined cool star atmospheric modeling and more accurate determination of physical parameters from observations. Our findings reveal temperature variations >150 K in individual TTSs, confirming substantial stellar activity beyond measurement scatter. Furthermore, the correlation of average surface magnetic field strengths with Teff variations stresses the dynamic interplay between magnetic field strengths and stellar surface features. Notably, a quarter-phase delay between EWR and RV phase curves signals spot-driven RV modulation. CI Tau's zero phase delay hints at more intricate dynamics, possibly a planetary origin. This study, blending observations and models, offers vital contributions to the time-domain exploration of young stars' activity cycles and magnetic field dynamics during the critical phase of planet formation.

Session 8: Exoplanet Observations III

8.1 **Title:** Thermal Emission from the First Giant Planet Transiting a White Dwarf
Presenter: Sydney Jenkins
Abstract: Most known exoplanets orbit stars which will eventually evolve into white dwarfs, but little is known about the fates of these systems after their hosts leave the main sequence. The first transiting planet candidate found orbiting a white dwarf, WD 1856 b, could therefore play an important role in our understanding of post-main-sequence planetary evolution. However, much is still unknown about its origins, including how it reached its current orbit. The best way to distinguish between possible formation scenarios is by constraining WD 1856 b's mass, as a lower ($\sim$1 Jupiter mass) mass would likely indicate the planet had migrated in at high eccentricity, while a larger (10–15 Jupiter masses) mass leaves common envelope evolution as a viable explanation. To constrain WD 1856 b's mass, we search for its thermal emission with JWST/NIRSPEC spectroscopy. Because massive planets cool more slowly than low-mass planets over time, WD 1856 b's infrared brightness, combined with our rough knowledge of the planet's age, yields its mass. The thermal emission also provides insight into the properties of the planet's atmosphere. We present our results and discuss the implications for the formation of WD 1856 b and the fate of giant planets in post-main-sequence systems.

8.2 **Title:** Super-Jupiter or Brown Dwarf? An investigation of two massive objects around low-mass stars.
Presenter: Andrew Hotnisky
Abstract: Giant Exoplanets around M-dwarf Stars (GEMS) are extremely scarce - an attribute predicted by core accretion theory. However, missions such as the Transiting Exoplanet Satellite Survey (TESS), continue to discover GEMS enabling statistical investigations into different formation mechanisms. I will present the discovery of two unusually massive objects around M-dwarf stars and discuss how their existence challenges the core-accretion formation model. Using TESS photometry and radial velocity measurements from the Habitable-zone Planet Finder, we determine the first object to be 9 M_J with an eccentric orbit while the second has a circular orbit with a mass of 7 M_J. These objects' masses are lower than the 13 M_J mass limit for deuterium burning and lower than the 4% mass ratio with their respective host stars, which by definition, would indicate that these are massive planets approaching the characteristics of a brown dwarf. If they are planetary in nature, they are >3x more massive than any other GEMS known to date. I will detail how we derived the object parameters and how they help discern whether these objects are extremely massive planets or brown dwarfs. In doing so, I will also explore how these planets impact our views on planetary formation (core accretion and gravitational instability) around small stars.

8.3 **Title:** Hiking Through the Spectral Forest: The TRAPPIST-1 System at High Resolution
Presenter: Madeleine Walkington & Mathis Bouffard
Abstract: From the InfraRed Doppler (IRD) instrument aboard the Subaru Telescope, we have obtained high resolution transit spectra of TRAPPIST-1 b, e and f. The infamous TRAPPIST-1 star system is of great interest to exoplanetary scientists as it hosts the largest batch of rocky Earth-sized habitable-zone exoplanets ever discovered. Cloud-free hydrogen-dominated atmospheres have been ruled out for all the system's planets, as expected since XUV radiation from the young red dwarf star would have driven atmospheric escape. We perform a data reduction and spectral analysis of these observations with the Spectral Transmission And Radiation Search for High resolutIon Planet Signal (STARSHIPS) open-source pipeline, aiming to quantify the atmospheric composition of TRAPPIST-1 b, e and f. In particular, an analysis of identifiable spectral features will yield upper limits on the abundance of greenhouse gases CH4, H2O and CO2. To that end, using transit spectra of TRAPPIST-1 b from the Spectro-Polarimetre Infra-Rouge (SPIRou), we modified STARSHIPS' code, which is still in development, to work with small, rocky planets, as it was originally designed for hot Jupiters. We will present these newfound constraints, as well as share our adaptation of the STARSHIPS tool. This analysis will significantly advance our ability to eliminate specific atmospheric scenarios on these planets. It will also showcase an open-source, accessible tool for performing analyses of high resolution spectroscopic observations of both hot Jupiters and Earth-like exoplanets.

8.4 **Title:** Evidence for Primordial Alignment: Insights from Stellar Obliquity Measurements for Compact Giant Systems
Presenter: Brandon Radzom
Abstract: Stellar obliquity – i.e., the angle between the spin axis of a star and the orbit normal axes of its planets – is a powerful tool to study the formation and evolution of exoplanetary systems. Yet, after decades of effort, the dominant mechanisms driving spin-orbit misalignment, commonly observed for hot Jupiters and sub-Saturns, remain unclear. It is particularly useful to distinguish whether such large obliquities are produced primarily by high-eccentricity migration, which is expected to have taken place for short-period, isolated planets, or a more universal process that affects systems with a wider array of present-day architectures. Compact multiple-planet systems are crucial to distinguish between these competing hypotheses, as their tightly-packed configurations are inconsistent with the violent dynamics inherent to high-eccentricity migration, allowing them to trace the primordial disk plane. However, relatively few stellar obliquity measurements have been made for planets in compact systems, especially hot Jupiters and sub-Saturns. In this context, we report Rossiter-McLaughlin effect measurements of the sky-projected stellar obliquity for two sub-Saturns, TOI-5126 b and TOI-5398 b, and one hot Jupiter, TOI-5143 b, all found to reside in multiple-transiting systems. We find that all three are spin-orbit aligned. When combined with archival data, our results demonstrate a strict trend of alignment for compact systems, providing strong observational support for primordial alignment and post-disk misalignment via high-eccentricity migration pathways.

Session 9: Demographics & Detectors

9.1 **Title:** Using Transiting Brown Dwarfs to Define the Planetary Mass Limit
Presenter: Noah Vowell
Abstract: In order to study planet formation in its most massive regime, we must reframe our thinking about planets, brown dwarfs, and stars away from strict partitions in mass in favor of their formation and evolution. Since brown dwarfs encompass the region where planet and stellar formation mechanisms likely overlap, they allow us to address the question: how massive can a planet be? The success of TESS has recently granted the ability to investigate this question from a new perspective since it has more than doubled the population of known transiting brown dwarf systems. I will present the discovery and characterization of 12 new transiting companions from TESS. We confirm 7 of these systems as transiting brown dwarfs, and the rest as very low mass stars ($< 120M_J$) using ground-based photometric and spectroscopic follow-up through the TESS Follow-up Observing Program (TFOP). The transiting brown dwarf population now exceeds 50 systems, a population large enough to begin performing robust statistical analyses. I will provide a first glimpse into the emerging trends from the transiting brown dwarf population, showing that the transition between planet and stellar formation may not be as clear as previously thought.

9.2 **Title:** Peas-in-a-Pod Across the Radius Valley
Presenter: Armaan Goyal
Abstract: The ubiquity of "peas-in-a-pod" architectural patterns and the existence of the radius valley each present a striking population-level trend for planets with $R_p \leq 4R_\oplus$ that serves to place powerful constraints on the formation and evolution of these subgiant worlds. As it has yet to be determined whether the strength of this peas-in-a-pod uniformity differs on either side of the radius valley, I shall present in this talk the first direct statistical comparison of intra-system planetary uniformity across compositionally distinct regimes, based upon the separate architectural evaluation of systems containing only small ($R_p \leq 1.6R_\oplus$), rocky planets from those harboring only intermediate-size ($1.6R_\oplus \leq R_p \leq 4R_\oplus$), volatile-rich worlds. We find that, compared to their volatile-rich counterparts, rocky systems are more uniform in size, less uniform in mass, and more uniform in spacing at respective significance levels of 4.0σ, 2.6σ, and 3.0σ. I shall conclude with a brief overview of additional statistical validation for these results, demonstrating that they are not substantially influenced by confounding

astrophysical factors, compositional assumptions, sample size effects, or detection biases.

9.3 **Title:** Characterizing the Radius Valley around Mid to Late M dwarfs
Presenter: Erik Gillis
Abstract: The occurrence rate of planets around Sun-like stars and early M dwarfs forms a bimodal distribution in planet radius known as the Radius Valley which features a dearth of planets between 1.6 and 1.9 Earth radii separating Super-Earths from sub-Neptunes. Around Sun-like stars, the dominant mechanism that shapes the Radius Valley appears to be a form of thermally-driven atmospheric escape; however, surveys of early M dwarfs provide tentative evidence that the Radius Valley around M dwarfs may instead originate from a distinct channel of terrestrial planet formation. As of yet, transiting exoplanet surveys have been largely insensitive to planets around mid-to-late M dwarfs. This presents a major gap in our understanding of the existence of the Radius Valley and the mechanisms which may shape it around these low-mass stars. Fortunately, NASA's Transiting Exoplanet Survey Satellite (TESS) has opened a window into the exoplanet population around mid-to-late M dwarfs. I am leading a systematic search for small transiting planets around more than 10,000 mid-to-late M dwarfs observed by TESS to characterize the Radius Valley and determine the dominant driver of planet formation around these low-mass stars. I will present my pipeline to process TESS light curves and to detect and vet signals from transiting planets, as well as the preliminary results of my transit survey around the lowest mass stars. With a false positive rate below 5%, this pipeline is sensitive to 92% of TESS Targets of Interest and 100% of confirmed planets around our sample of stars.

9.4 **Title:** Pandora Smallsat Detector Testing Progress
Presenter: Trevor Foote
Abstract: The Pandora NASA Astrophysics Pioneers SmallSat mission employs a dual-channel observational approach, simultaneously utilizing visible photometry and infrared spectroscopy to assess stellar contamination of exoplanet transmission spectra. Pandora will use a PCO Panda 4.2M sCMOS sensor for the visible-wavelength photometry, while the near-infrared spectroscopy will use a 2.5-micron cutoff Teledyne H2RG detector. Both detectors have undergone thermal-vacuum testing at Lawrence Livermore National Labs to characterize their performance under flight-like conditions. This paper provides an overview of the Pandora detector test plan and the suite of tests conducted to date, shedding light on critical detector properties derived from subsequent analyses. Key parameters include read noise, gain, saturation, and persistence, offering insights into the detectors' capabilities and paving the way for enhanced data interpretation in the pursuit of unraveling the complexities within exoplanetary atmospheres.

Session 10: Exoplanet Host Stars

10.1 **Title:** Forging a Path for Low-Mass Planetary Radial Velocity Detections Using Sunlight to Illuminate the Way for Granulation Mitigation
Presenter: Elizabeth Gonzalez
Abstract: The Doppler Radial Velocity (RV) technique is the only current method capable of discovering terrestrial planets in the Habitable Zones of nearby stars. Present day spectrographs are forging a path towards 10 cm/s precision to detect Earth-like planets; however, stellar variability induces RV variations at 1 m/s, which is difficult to model and hinders the recovery of planetary signals. Using the Sun as a benchmark, spectroscopic observations of solar eclipses were taken on October 14, 2023, and April 8, 2024, using NEID to obtain precise solar RVs and local solar line profiles. Granulation remains potentially one of the largest sources of unmodeled RV variability influencing disk-integrated line shapes. Hence, I will use GRASS, a granulation and spectrum simulator, which uses, as input, spatially resolved observations of solar absorption lines to create synthetic spectra with granulation driven variability. Use of GRASS provides insight into line profiles while modeling RV variations; therefore, aiding our understanding of how spatially dependent convective blueshift impacts spectrum line shape, which is crucial in obtaining cm/s precision RVs. This project aims to validate RV models

for line distortions and granulation variability using the eclipses as a convenient tool given the amplified stellar RV and Rossiter-Mclaughin curve, as well as with SNR that would be impossible on any other star. This harsh test will help us understand the limitations of current models and point the way to improvements.

10.2 **Title:** A Data-driven Spectral Model of Main Sequence Stars in Gaia DR3
Presenter: Isabel Angelo
Abstract: Precise spectroscopic classification of planet hosts is the backbone of exoplanet research at both the population and individual system level. Historically this classification has relied on high-resolution, ground-based follow-up of planet hosts, which is powerful but expensive. More recently, spectra have been published for thousands of exoplanet hosts in Gaia DR3, with more to come in future data releases. In this paper, we use the Cannon to train a data-driven model using spectra from the Gaia Data Release 3 Radial Velocity Spectrometer. Our model is capable of deriving stellar labels (e.g. temperature, surface gravity, metallicity) with high confidence and precision for main-sequence stars observed by Gaia DR3 by extrapolating from GALAH labels. We validate our model performance by checking its agreement with stellar labels of previous surveys. We show that our model is suitable for deriving stellar labels for planet hosts. We also find that it is useful for flagging systems that are not adequately described by a well-behaved main sequence model, which serves as a first pass for identifying objects such as evolved stars, accreting and active main sequence stars, interacting binaries, and more.

10.3 **Title:** Calibrating M Dwarf Elemental Abundances with SPIRou
Presenter: Nicole Gromek
Abstract: Measuring accurate stellar abundances of planet forming elements is critical to our understanding of exoplanet compositions and their formation processes. While these values can be reliably derived from optical spectra for FGK-type stars, the recovery of accurate abundances for M dwarfs is complicated due to persistent discrepancies between models and observed spectra, such as blended absorption features and broad molecular bands that hide the continuum. These lingering uncertainties in M dwarf chemical compositions inhibit our ability to accurately model the interiors and atmospheres of exoplanets around M dwarfs. To address this issue, we have built a custom framework to extract elemental abundances from the spectra of cool stars via the spectral synthesis method. By applying this process to spectra from 24 FGK-M wide binary systems, this work will be used as the basis for the generalized empirical calibration of M dwarf abundances measured with the SPIRou spectropolarimeter. SPIRou, with its high spectral resolution and broad near-IR wavelength (R$\sim$75,000, YJHK bands), is the ideal facility to help mitigate the difficulties present in observing M dwarfs. By combining the capabilities of SPIRou with our framework, we are well equipped to ensure the accuracy of derived elemental abundances in M dwarfs. Our results will ultimately be applied to planet-hosting M dwarfs in order to place strong constraints on the planets' refractory and volatile abundances, both of which are important diagnostics of planetary formation histories and interior compositions.

10.4 **Title:** Monitoring Stellar Activities of SPACE Program Exoplanet Hosts with Wesleyan's 0.6-m Telescope
Presenter: Qiushi (Chris) Tian
Abstract: The activity of exoplanet hosts significantly impacts the atmospheres of close-in exoplanets and the observed transmission spectra. Starspots and faculae introduce flux and spectral variation, posing challenges to precise exoplanet atmosphere measurements. Exoplanet atmospheres might also respond to the changing host stars. The Sub-Neptune Planetary Atmosphere Characterization Experiment (SPACE) is an ongoing Hubble Space Telescope program (GO 17192, 17414, PI: Kreidberg, Co-PI: Deming) that aims to study eight exoplanet atmospheres. To mitigate the contamination of stellar activities and provide further insight into their connection with exoplanet atmospheres, we photometrically monitor the SPACE targets with the 0.6-m automated telescope on the Wesleyan University campus. We created a customized photometry pipeline with Astropy to produce a series of light curves obtained around the HST visits. Investigating the periodicity in the exoplanet hosts' brightness

fluctuation may help constrain the spot structure, provide a statistical measure of stellar activity, or confirm no variability during the transit. Such knowledge could enhance the analysis of transmission spectra with greater detail and facilitate the characterization of planetary atmospheres.

Session 11: Dynamics

11.1 **Title:** The Super-Puff HIP-41378f may be a ringed planet: Dynamical Constraints
Presenter: Tiger Lu
Abstract: The planet HIP-41378f is the most puzzling of the so-called super-puff planets with anomalously low density, as its large orbital separation precludes many of the most accepted theories for super-puff formation. A theory that has gained traction in recent years is that the transit profile of a ringed planet could reproduce such an anomalous density. A transiting planet would require significant planetary obliquity for rings to have such an effect on the transit lightcurve. We show as HIP-41378f is in a resonant chain, the dynamics of the system are such that the planet can likely be in such a high obliquity state. We verify our results with N-body simulations, and show that over a wide range of parameter space rings can indeed reproduce the anomalous density measurement.

11.2 **Title:** Prevalent Spin-Orbit Alignment of Warm Jupiters in Single-Star Systems: Evident Even Around Hot Stars
Presenter: Xian-Yu Wang
Abstract: The stellar obliquity distribution of warm Jupiter systems is crucial for constraining the dynamical history of Jovian exoplanets, as their tidal detachment likely preserves their primordial stellar obliquity. However, the sample size of warm Jupiter systems with measured stellar obliquities has historically been limited. In this work, we present the Rossiter-Mclaughlin effect measurements for six warm Jupiter TOI-559, 2025, 2031, 2485, 2524, and 3972 detected by TESS, demonstrating that all of them are aligned. Combining these findings with existing data, our analysis reveals that warm Jupiters in single-star systems exhibit a distinct trend toward alignment, regardless of their stellar effective temperature. This pattern diverges from the trend observed in hot-Jupiter systems, where hot Jupiters around cool stars tend to be aligned, while a considerable proportion of those orbiting hot stars show misalignment. The current distribution of stellar obliquity for Jovian exoplanets suggests that misalignments are not universal or primordial phenomena affecting all planet types. The absence of misalignments in warm Jupiter systems further implies that many hot Jupiters, in contrast, have experienced dynamic and violent histories.

11.3 **Title:** Spin-Orbit Resonance Dynamics: How Different can Equal-Mass Planets Be?
Presenter: Yubo Su
Abstract: A planet sufficiently close to its host star is generally thought to rapidly evolve into a tidally locked configuration, where its spin period becomes synchronized to its orbital period, and its "obliquity," the angle between its axis of rotation and its orbital normal, damps to zero. Recent work has suggested that tidal locking may not be the only possible configuration in multiplanetary systems: certain secular spin-orbit resonances can counteract tidal alignment of the planet's spin axis and trap the planetary obliquity at large values nearing 90 degrees. However, these works assume a fluid planet model, where the planet's rotation state and shape are simply related. According to the latest observations, planets less massive than a few Earth masses have a wide range of compositions and interior structures. I will explore the impact of a planet's structure on its susceptibility to spin-orbit resonance in a few simple limiting cases.

11.4 **Title:** Simulating the Effects of Outer Giant Planets on Inner Super-Earths with In Situ Formation Models
Presenter: Phoebe Sandhaus
Abstract: Recent studies have found an observational correlation between the presence of outer giant planets and inner super-Earths. This relationship implies that outer giants do not suppress the

formation of super-Earths. We simulate late-stage in situ planet formation in the presence of outer giant planets. We investigate the effects of two sets of outer giants: the four Solar System giant planets and three dynamically active giant planets. Compared to systems without outer giants, we find that systems with the Solar System giant planets tend to form inner super-Earths that are more compact, coplanar, and circular; while the systems with the dynamically active giant planets form inner super-Earths that are more widely spaced, inclined, and eccentric, with lower intrinsic multiplicity.

11.5 **Title:** Most Hot Jupiters are lonely: An occurrence rate for inner companions to Hot Jupiters from Kepler, K2, and TESS
Presenter: Lizhou Sha
Abstract: Out of the >500 transiting Hot Jupiters known today, only 6 have been confirmed to have companion planets interior to their orbits. The survival of these inner companions means that these Hot Jupiters cannot have migrated to their present location via dynamically disruptive high-eccentricity migration, and must have undergone disk migration or formed in situ. An occurrence rate for these inner companions, therefore, helps us constrain the relative efficiency of different Hot Jupiter formation pathways. Here, we perform a uniform box least-squares search for inner companions to Hot Jupiters in Kepler, K2, and the first four years of TESS data. Accounting for observational completeness, we arrive at a refined posterior distribution on the occurrence rate of inner companions to Hot Jupiters. We discuss the implications of this occurrence rate and how it informs current discussions on the formation theories of Hot Jupiters.

11.6 **Title:** Accelerating terrestrial planet formation simulations with machine learning
Presenter: Caleb Lammers
Abstract: Constraining planet formation models based on the observed exoplanet population necessitates generating massive samples of synthetic planetary systems, which can be computationally prohibitive. A significant bottleneck is simulating the giant impact phase, during which planetary embryos evolve gravitationally and combine to form planets, which may themselves experience further collisions. To accelerate such simulations, we present a machine learning (ML) approach to predicting the outcomes of collisions in multiplanet systems. Trained on over 500,000 N-body simulations, we develop an ML model that can accurately predict which planets will experience a collision, along with the states of the post-collision planets. By combining with a previously-developed model for predicting long-term stability, we create an efficient giant impact emulator, which successfully predicts the outcomes of N-body planet formation simulations, providing a speedup of about four orders of magnitude. We expect this approach to enable analyses that would not otherwise be computationally feasible, and we release our model with an easy-to-use API through the SPOCK package.

Session 12: Atmospheres III

12.1 **Title:** Towards Robust Spectroscopic Analysis of Exoplanets with JWST
Presenter: Yoav Rotman
Abstract: With JWST providing unprecedented exoplanetary data, we can now look towards an age of population-level analysis across hundreds of exoplanets. However, in order to understand these populations, we have to ensure the data we have from individual planets is accurate and reliable. In particular, the science output we recover from exoatmospheric spectra must be unbiased and accurate in order to ensure accurate population-level understanding. Retrievals are a tool for analyzing these spectra, in which forward-modeled spectra are compared to the data to find a best-fit spectrum. Alongside the spectrum, we obtain estimates for physical parameters such as temperature profiles and gas abundances. These provide crucial insight into planetary formation and evolution. However, with higher-precision data from JWST, retrievals are at risk of overfitting poorly-fit regions of the spectrum, at the expense of parameter estimation. We introduce a novel method to de-bias spectra by adapting the way retrievals quantify the difference between forward models and data. By including a freely-fitting Gaussian process with both local and global free parameters, we can account for covarying noise and

features from unknown sources. These parameters locate and downweight regions of highly-covarying data, which allows us to identify any "missing physics" and avoid biasing our posterior probability distributions of crucial parameters. We implement this method into a free retrieval framework for JWST exoplanet transmission spectra and compare the results of retrievals on four reductions of the spectrum of the canonical hot Jupiter WASP-96b. We show that this methodology provides robust, debiased parameter estimations.

12.2 **Title:** The Atmospheres of Two Water Worlds Revealed by JWST
Presenter: Eshan Raul
Abstract: Small close-in exoplanets can be separated into two distinct populations: super-Earths at approximately 1.0–1.4$R_\oplus$ and sub-Neptunes at approximately 2.3–3.9$R_\oplus$ (Fulton et al. 2017; Luque & Pallé 2022). Since our Solar System lacks analogs of such worlds, we possess a fundamental lack of understanding of planets in this regime. While small super-Earths are likely rocky/iron in composition and sub-Neptunes are likely dominated by an H2/He atmosphere, planets approximately within the 1.5–2.2$R_\oplus$ regime could also be explained by a third 'water-world' scenario, with a volatile-rich envelope in a supercritical state above a rocky/iron core. To resolve the ambiguous composition of such planets, we are measuring the atmospheric compositions of 5 potential water worlds as part of a Large Cycle 2 JWST Program via transmission spectroscopy. In this talk, I will present our initial results for two of these planets, TOI-270d and GJ-9827d, from an atmospheric retrieval analysis. Based on these results, we introduce a new classification for the composition of sub-Neptunes: a "miscible envelope sub-Neptune." Finally, I will compare the atmospheric compositions of TOI-270d and GJ-9827d and discuss implications for future studies of water worlds with JWST.

12.3 **Title:** The First Confirmed Detection of a Metal Hydride in an Exoplanet
Presenter: Laura Flagg
Abstract: Because hot Jupiters span a similar temperature range to that of warmer brown dwarfs, comparisons between the two classes provide insights into the physics of the atmospheres for both hot Jupiters and brown dwarfs. In L dwarfs, molecules like FeH and CrH are ubiquitous and are used to determine their temperature or spectral type. However, these molecules have no previously confirmed detections in exoplanets, despite numerous, well-studied exoplanets having comparable temperatures to that of L dwarfs (∼1300–2400 K). In this talk, we present the first confirmed detection of any metal hydride in an exoplanet with our detection of CrH in WASP-31b using high-resolution transmission spectroscopy from GRACES and UVES. We discuss the statistical methods involved in confirming the detection. We also consider the implications of detections of metal hydrides for future hot Jupiter atmosphere research.

12.4 **Title:** Role of Planetary Radius on Atmospheric Escape of Rocky Exoplanets
Presenter: Laura Chin
Abstract: Large-scale characterization of exoplanetary atmospheres is on the horizon, thereby making it possible in the future to extract their statistical properties. In this context, by using a well validated model in the solar system, I will present results from three-dimensional magnetohydrodynamic simulations to compute nonthermal atmospheric ion escape rates of unmagnetized rocky exoplanets as a function of their radius based on fixed stellar radiation and wind conditions. We found that the atmospheric escape rate is, unexpectedly and strikingly, a nonmonotonic function of the planetary radius R and that it evinces a maximum at $R \sim 0.7R_\oplus$. This novel nonmonotonic behavior may arise from an intricate tradeoff between the cross-sectional area of a planet (which increases with size, boosting escape rates) and its associated escape velocity (which also increases with size, but diminishes escape rates). Our results could guide forthcoming observations because worlds with certain values of R (such as $R \sim 0.7R_\oplus$) might exhibit comparatively higher escape rates when all other factors are constant.

Poster Presentations

13.1 **Title:** TRAPPIST-1f Atmospheric Retrieval Analysis for JWST with Stellar Contamination
Presenter: Connor Rosenthal
Abstract: The TRAPPIST-1 system is a fantastic target for observation to study potentially habitable worlds thanks to its system of seven rocky planets. However, a retrieval study on the Earth-like TRAPPIST-1f that factors in the active stellar activity of its M star has yet to be done. We model three potentially habitable atmospheric scenarios for TRAPPIST-1f, an Earth-like atmosphere with 5, 10, and 25 bars of CO2 added to the atmosphere, using the coupled photochemistry and climate model, Exo-Prime 2. Additionally, we include a model modifying the 5 bar scenario to include the effects of stellar contamination from the star's activity. Using the stable solution generated, we create simulated spectra using the POSEIDON retrieval package, from 0.6 to 20 µm at a resolution of 10,000. Using Bayesian atmospheric retrieval analysis with the same package, we identified the temperature and molecular abundances that JWST can constrain for each scenario with different numbers of transits, for the NIRSPEC Prism and MIRI LRS instruments specifically. We find that generally for the uncontaminated models, 15 transits is enough to constrain CH4 within 5 sigma, and give upper bounds for O3 and N2O's mixing ratios. Additionally, we find that the O3, N2O, and any H2O signals are mostly eliminated by the effects of stellar contamination. Although we find that some mixing ratios are very hard to detect, including possible biosignatures, we find molecules key to gauging the existence of a potentially habitable atmosphere on TRAPPIST-1f constrainable within a reasonable amount of transits.

13.2 **Title:** A Characterization of Brown Dwarfs Around M Dwarfs: TOI-5610b
Presenter: Tera Swaby
Abstract: Characterizing brown dwarfs is an area of growing research due to the insight it presents on planet formation. In our research we are studying an eccentric Brown Dwarf surrounding TOI-5610, an M dwarf with Teff = 3577 ± 88 K at a distance of 274 ± 4 pc, originally observed by TESS in sectors 21 and 48. Through ground-based photometry with the 0.6 meter telescope at Red Buttes Observatory (RBO) we were able to narrow down the period for this transit to 7.95343 ± 0.000017 days. Also using twelve epochs of ground-based radial velocity data points taken 2022 November 14th - 2023 December 26th from the Hobby-Ebberly Telescope Habitable zone Planet Finder (HPF) spectrograph at McDonald Observatory, we have been able to model the system using EXOFASTv2. We find a radius of Rp = 0.707 ± 0.030 (Jupiter radii), impact parameter b = 0.15 ± 0.13 (stellar radii), eccentricity of 0.352 ± 0.012, and Mp = 38.2 ± 1.2 (Jupiter mass). This puts TOI-5610b in the rarest part of the brown dwarf population ($35 < M < 55$ Jupiter masses), making it a particularly interesting target.

13.3 **Title:** TOI-5389b: A rare brown dwarf around an M dwarf
Presenter: Alexander Larsen
Abstract: Brown dwarfs are officially demarcated as objects between 13 and 80 Jupiter masses. However, there is some debate on whether or not to classify them this way (by mass) or by relevant formation mechanism, which is what this work hopes to contribute to. Some even argue that we should only classify planets and stars, and not this intermediary brown dwarf phase. These objects are rare around main sequence stars (¡1% occurrence) and even rarer around M dwarfs (only 10 confirmed). The rarity and debate on classification make TOI-5389b a target of considerable interest. We use TESS sectors 22 and 48, two ground based transits from our own 0.6m Red Buttes Observatory (RBO), and ten radial velocity measurements by the Habitable-zone Planet Finder (HPF) in tandem with the EXOFASTv2 fitting program to characterize this target. We find a mass of 73.1 + 3.1 Jupiter masses, a radius of 0.91 + 0.05 Jupiter radii, an eccentricity of 0.096 + 0.044, and a period of $\sim$10.4 days orbiting around a M2V star with effective temperature 3567 + 88 K. This makes it one of the most massive brown dwarfs, nearing the edge of the hydrogen fusion limit. Therefore this target is of considerable interest in probing the nature and limits of brown dwarfs as a whole.

13.4 **Title:** Constraining the Vertical Composition of Exoplanet Atmospheres
Presenter: Sarahí Palma
Abstract: The launch and subsequent employment of JWST has made it possible to characterize exoplanet atmospheres in exquisite detail. However, when astronomers fit observations of exoplanet spectra using atmospheric retrieval (a Bayesian technique), it is common to assume that the chemical composition does not vary with pressure. Yet, in fact, myriad chemical and physical processes may cause large vertical deviations in molecular abundances.

In this poster, we explore the ability to directly measure vertical chemical gradients from exoplanet transmission spectra. We present a new parameterization for atmospheric retrievals including vertical chemical gradients and demonstrate its viability using simulated JWST observations for a warm Neptune atmosphere. Our improved retrieval model opens the prospect to measure the impact of important physical and chemical processes—such as photochemistry—from JWST spectra of exoplanets.

13.5 **Title:** Matthew Daunt
Presenter: Jabble: RV Extraction; Stellar Templates; and Normalization
Abstract: With the construction of new high resolution spectrographs like NEID, and packed archives from previous spectrographs like HARPS, and Keck HIRES, spectral data is being produced at extremely high signal-to-noise ratios with very fine spectral resolution. Maximizing the output science of this data should be as fundamental to astrophysics as their operation. Statistical methods that appropriately co-add data and measure radial velocities must be explored with the goal of maximizing the information output. In this paper, we consider a data-driven method to fitting a static stellar template, and RV simultaneously to maximize the information extracted from each observation. This data-driven method was first proposed by Bedell et al. (2019), but we expand upon this method further with the addition of using spline-like models for the spectral templates. We also adopt a method for modeling continuum normalization rather than considering normalization as a pre-process. This method outputs precise relative radial velocities at all epochs, and a high signal-to-noise tellurics-free mean spectrum.

13.6 **Title:** Midplane Temperature Profiles of Eight Protoplanetary Disks
Presenter: Jensen Lawrence
Abstract: The midplanes of protoplanetary disks are the stages upon which the planet formation process unfolds. As such, disk midplanes and the exoplanet population are directly linked. In particular, the midplane temperature structure is instrumental in controlling dust evolution, and afterwards, planetesimal growth. Observations of disk gas have historically been unable to resolve the midplane, meaning the midplane temperature profile could only be constrained indirectly through modelling. However, recent advances in observing have produced datasets with resolved midplanes, allowing the midplane temperature to be directly measured. Here, we identify eight disks from the MAPS and exoALMA surveys with midplanes resolved in 12CO and 13CO emissions. Building on the work of Dullemond et al. (2020), we extract the 12CO and 13CO midplane temperature profiles from each of these disks; comparing results between isotopologues, we seek to gain insights into disk structure. Subsequently, we identify where the midplane temperature reaches 20 K for each disk, using this as a proxy for the location of the CO snowline. Finally, we discuss the implications and future extensions of these results.

13.7 **Title:** Development of Simulation Software to Inform Exoplanet Direct Imaging with MIRI
Presenter: Rebecca Michelson
Abstract: The Mid-Infrared Imager (MIRI) on JWST has several four quadrant phase masks and Lyot coronagraphs that are beginning to open the field of space-based high-contrast imaging in the mid-IR. MIRISim is a program developed to simulate observations formatted as the raw, level 1b ramp data of real MIRI observations. These simulated data enable pipeline development prior to real data release, and also helps inform JWST proposal preparation. We present MIRISim Coronagraphy, an addition to MIRISim that provides coronagraphic imaging simulation, which is a feature missing from

the current standard release. This expands MIRISim simulating capabilities to all MIRI detectors. We validate MIRISim Coronagraphy output against real PSF reference star observations, and process the simulations through SpaceKLIP to ensure that they produce data that match on-sky observations. We present high-fidelity simulated MIRI images of companions using astrometric and photometric predictions. A recent MIRI program to directly image the brown dwarf companion GJ 758 B provides further opportunity to validate MIRISim Coronagraphy's contrast performance and recovered photometry and astrometry by comparing simulation output to real data. We also implement user-friendly tools including a function to calculate star and planet spectral flux densities in the mid-infrared by incorporating stellar atmospheric models. Finally, we document MIRISim Coronagraphy installation and simulation steps in a user guide, and discuss streamlining MIRISim's usability by optimizing its SpaceKLIP compatibility. This preliminary software release enables the public use of MIRISim Coronagraphy as a tool for ongoing programs, preparation of future JWST cycle proposals, and robust pipeline testing and development.

13.8 **Title:** Radiation hydrodynamics of protoplanetary disks with frequency-dependent dust opacities
Presenter: Stanley Baronett
Abstract: In protoplanetary disks of gas and dust, sub-micron interstellar grains must grow at least 13 orders of magnitude in size to become terrestrial planets. The frequency-dependent opacities of these silicate grains to pre-main-sequence stellar radiation affect the thermodynamic structure of the disk, which itself influences the various stages of planet formation and migration. With a reduced overall opacity skewed toward shorter wavelengths, the tenuous disk atmosphere heats up as dust preferentially absorbs ultraviolet rays from the young star, while settled grains make the disk midplane optically thick and cooler. Conventional disk and planet formation models, however, use simplified assumptions about the thermodynamic structure, including vertically isothermal temperature profiles, Planck- or Rosseland-mean dust opacities, and flux-limited-diffusion approximations to radiation transport valid only in optically thick regions. Thus, further development of more detailed and self-consistent disk profiles using multifrequency radiation hydrodynamics is warranted. We use the Athena++ finite-volume hydrodynamics code, extended with multigroup radiation transport, to develop and analyze new stellar-irradiated disk models that include the frequency-dependent opacities of silicate dust grains. As the radiation module neither assumes a diffusion-dominated limit nor treats the radiation field as another fluid, our models can better capture the full dynamic range in disk optical depths.

13.9 **Title:** Search for Young Exoplanets in Ursa Major
Presenter: Julia Sheffler
Abstract: We have a solid foundation for how life functions on Earth, but we can make only educated guesses about life on other planets. As missions such as Kepler and the Transiting Exoplanet Survey Satellite (TESS) discover more and more planets outside our solar system, we begin to study exoplanets, and the life they may support, more directly. The star HD 63433 is a bright, nearby, and young (400Myr) host to three planets, including the nearest detected Earth-sized planet (HD 63433d), within the Ursa Major comoving group (UMa). Young planetary systems such as HD63433 form critical test cases for understanding planetary and stellar evolution. Yet, of the over 5500 confirmed planets, only about 70 are known to have ages less then 500Myr, motivating a comprehensive search of UMa members for planetary companions. Further constraining the membership and age of UMa provides contextual foundation for this young Earth-sized exoplanet and any future planets discovered within the UMa system.

13.10 **Title:** Visualizing the Habitable Zone: A New Public-Facing Habitable Exoplanet Catalog
Presenter: Gillis Lowry
Abstract: With over 5500 currently discovered exoplanets, dozens of known worlds may be suitable for life. Our upcoming paper catalogs all planets that reside in the Habitable Zone (HZ) and provide HZ boundaries, orbit characterization, and the potential for spectroscopic follow-up observations. We outlines a simple approach to initially evaluate the habitability of terrestrial planets based on their

incident stellar irradiation, size, and orbital motion using Gaia DR3 data. We discuss how the uncertainties in the measurements change the number of planetary candidates in the HZ, placing the demographics of HZ planets in context with the full catalog of exoplanets. In addition, we provide stellar age estimates to identify the age distribution for candidates in the search for life in the HZ.

As an extension of this project, I am creating a public-audience visualization of habitable exoplanets across the night sky in ArcGIS and Python. Clicking on a planetary system reveals information about the planets' sizes, host star, and habitability. This visualization will be released on the Carl Sagan Institute website.

13.11 **Title:** On the Capture and Ejection Of Parabolic Orbits in a Sun-Jupiter System
Presenter: Julian Turner
Abstract: We investigate parabolic encounters in the circular restricted three-body problem through numerical simulation using the REBOUND package. We study the case with a star-to-planet mass ratio of 1000:1 and characterize the outcome statistically in terms of the test particle's final energy after the encounter. We run over 100,000 simulations of individual encounters, uniformly sampling over the initial conditions, and describe the distribution of the final energy as a function of the test particle's initial conditions. These results are used to calculate the probability of capture into a short-period orbit or ejection into interstellar space as a function of the periastron of the test particle, while averaging over other orbital elements. We apply our results by computing the rates of capture and ejection for Oort cloud comets encountering a Jupiter-like planet, which we compare with Solar System observations. We also predict the velocity distribution of newly ejected interstellar comets, which may inform future studies of objects like 1I/'Oumuamua and their origins.

13.12 **Title:** An Age-Dating for the Ursa Major Moving Group
Presenter: Adam Distler
Abstract: The Ursa Major (UMa) moving group is a young (approximately 400 Myr), nearby stellar association that the Earth is embedded in. Recently, an UMa member (HD 63433) was found to host three transiting exoplanets, including an Earth-sized planet (Capistrant et al., 2024). Given its youth, this system provides a unique environment to constrain and test current theories of exoplanet formation and evolution. In an effort to identify more exoplanets at early stages of evolution, our team is working to identify additional UMa members. Further, a more complete sample of members (particularly those at late stages of stellar evolution) would help to obtain more accurate age estimates of this system. By using the Comove package (https://github.com/adamkraus/Comove), we identified potential UMa targets using a volume-limited search with a radius of 50 pc, centered on HD 63433. These potential members include stars as low as 0.2 $M_\odot$ and up to 3.0 $M_\odot$, along with a population of white dwarfs. If confirmed as members, these sources would increase UMa membership by up to 30%. These targets exhibit proper motion tangential velocities indicative of a shared motion through space. Comove calculates the predicted radial velocity of targets, which we can compare to measurements to provide three-dimensional, kinematically-derived membership probabilities. Since radial velocity data is not publicly available for all UMa potential members, we collected and reduced spectroscopic data for Southern Hemisphere targets using the Southern African Large Telescope (SALT). To measure absolute radial velocities of these targets, I am building a Python software pipeline. This work will enable us to (a) generate an up-to-date membership catalog of the UMa moving group, (b) provide more accurate age estimates of this co-moving system, and (c) search additional UMa members for young transiting exoplanets.

13.13 **Title:** Modeling nonthermal hydrogen escape mechanisms at Mars and implications for water loss
Presenter: Bethan Gregory
Abstract: Mars' surface is a cold, dry, inhospitable environment today, but there is plenty of evidence for considerable surface liquid water earlier in its history. High deuterium to hydrogen ratios measured by spacecraft in the atmospheres of both Mars and Venus indicate that escape of hydrogen has been an important sink for water from both planets. At Mars, thermal H escape dominates, whereby the

thermospheric temperature is sufficiently high that some small fraction of particles have velocities high enough to escape the planet's gravitational pull. The larger mass of Venus means that thermal H escape is inhibited and nonthermal escape processes dominate, whereby atoms gain a boost of energy from, e.g., charge exchange mechanisms or exothermic photochemical reactions. Here we use a test particle Monte Carlo model to show that hydrogen produced by the exothermic reaction HCO+ + e- –¿ CO + H is a significant driver of nonthermal hydrogen escape at Mars. We also quantify escape rates of H produced by a number of other photochemical reactions, finding that they account for loss of up to 40% the magnitude of thermal escape. Despite such high escape rates, we predict that the Lyman alpha brightness of hydrogen produced by these mechanisms is very low compared to the background radiance at Mars, meaning that this population of escaping hydrogen atoms would be difficult to detect with ultraviolet instruments on orbiting spacecraft. As well as being important at Venus, some of these photochemical mechanisms potentially drive significant water loss at CO2-rich, Venus-sized exoplanets.

13.14 **Title:** NASA's Pandora SmallSat Mission: Multiwavelength Characterization of Exoplanets and their Host Stars
Presenter: Ben Hord
Abstract: The Pandora SmallSat is a NASA mission set to launch in 2025 and is designed to investigate the atmospheres of transiting exoplanets using transmission spectroscopy. This technique affords one of the best opportunities for studying the composition of planetary atmospheres in the coming years and features prominently in the science portfolio of flagship missions such as HST and JWST. Although a powerful tool, high-precision transmission spectroscopy measurements are easily contaminated by the presence of star spots, potentially making the origin of spectral features ambiguous. Potential water absorption signatures present in recent JWST observations of the exoplanets GJ 486 b and TRAPPIST-1 b have highlighted the difficulty this ambiguity presents. Pandora is designed to address this stellar contamination issue by observing exoplanet hosts via long-duration, visible-light photometric observations and near-IR spectra simultaneously. The simultaneous multiwavelength observations provided by Pandora will constrain spot covering fractions of exoplanet host stars, allowing for the disentangling of star and planet signals in transmission spectra to more reliably determine planetary atmosphere compositions. Pandora will observe at least 20 Earth- to Jupiter-sized exoplanets on orbits of less than 18 days around host stars spanning late G through M spectral types. A significant fraction of Pandora's science team is comprised of early-career researchers (ECRs) and the training of ECRs for future mission work is an explicit goal of Pandora. We will present an update on the mission status, as well as an overview of the science goals, target selection, observing strategy, and synergies with other observing facilities.

13.15 **Title:** TOI-4189 and Contributions to the Broader Sample of TESS Sub-Neptunes
Presenter: Katharine Hesse
Abstract: TESS has supplemented the findings of previous transit missions like Kepler, particularly contributing to the existing population of sub-Neptunes. Kepler found over 2400 sub-Neptunes but most were around fainter stars, with less than 5% having precise RV mass measurements to date. TESS has confirmed over 200 sub-Neptunes, with nearly half having precise RV masses. As the mission continues, this sample of sub-Neptunes around bright stars continues to grow, enabling mass and orbit measurements to further answer questions surrounding sub-Neptunes. Particularly, TESS is finding longer period sub-Neptunes such as the TOI-4189 system, consisting of a bright (Vmag 9.36) sun-like star with an inner non-transiting small planet (9.9 days) and an outer transiting sub-Neptune (46.9 days). Filling in the sub-Neptune parameter space with such systems will allow better understanding of the composition, formation, and evolution of these planets. We will discuss the new sub-Neptunes found by TESS, particularly the case of TOI-4189, and shared characteristics such as mass, density, and eccentricity of the existing TESS sample.

13.16 **Title:** Architecture Framework of Multiplanetary Systems with Jovian Planets: Stability and Complexity
Presenter: Nikita Saini

Abstract: Multiplanetary systems with Jupiter sized planets add complexity to their architecture and break down the 'Peas in a Pod' structure. In this scenario, each planet adds in multiple parameters and makes it harder to see the bigger picture. Descriptive measures like Gap Complexity and Mass Partitioning can give us a better idea of the system distribution, giving us a hint about a planet not yet observed, either outside the current observed system or in the large gaps between planets. We use 31 mixed-population observed multiplanetary systems with Jupiter sized planets and observe a wide range of Gap complexities and Mass partitioning. These systems also have planets in the 100-300 day period interval which seems to be missing in the 'Peas in a Pod' systems and have large gaps between planets. Adding synthetic planets to these systems and measuring their stability probabilities can help us learn more about favorable conditions needed by multiplanetary systems to host terrestrial planets in their habitable zones.

13.17 **Title:** The Migration and Evolution of giant ExoPlanets (MEEP) Survey
Presenter: Jack Schulte
Abstract: Since the discovery of 51 Pegasi b, over 550 hot Jupiters (HJs) have been confirmed. These discoveries were made by a wide variety of ground-based and space-based surveys using many different, independent, analysis techniques. While this has been useful for confirming the validity of the discovered HJs, it has produced a sample that is plagued by unquantifiable selection biases, differing assumptions, and a lack of self-consistency. To address these issues, we aim to discover and characterize all remaining detectable HJs orbiting bright (G ¡ 12.5 mag) FGK stars using the Transiting Exoplanet Survey Satellite (TESS) and homogeneous analysis techniques. This large-scale, collaborative, discovery effort will be combined with smaller-scale characterizations of benchmark systems that show signs of youth, planetary engulfment, and other features associated with dynamical instability. Armed with a complete, self-consistent, magnitude-limited sample of HJs and several critical benchmark systems, we will be able to comprehensively address the question of how HJs form and evolve. I will present the detailed characterization of the first dozen discoveries from the MEEP survey, and provide an early glimpse into the current population of hot Jupiters from TESS.

13.18 **Title:** The Effect of Unknown Planets on Mass Estimates
Presenter: Skyler Keyek
Abstract: Of the 5,602 exoplanets we have discovered, only 45% of them have mass estimates. When combined with radius, a mass estimate can tell us the bulk density of a planet and therefore its composition and habitability. Since our mass estimates are derived from gravitational perturbations, our estimates will be inaccurate if we forward model our data assuming one fewer planet in the system or if we are missing planets. To study these inaccuracies, we ran 1,600 N-body simulations of resonant and non-resonant systems with 3-5 planets and orbital periods between 5 and 105 days. We ran resonant simulations with a variety of resonant chains including 2:1, 3:2, and 4:3 resonances. After integrating the simulations for 0.5Myr, we collected the transit times and radial velocity data for each system. We forward modeled each system, fitting the artificial data to ensure that the true masses could be recovered. We then fit each dataset assuming one fewer planets than there actually are in the system. We explore the effect of unknown planets on mass estimates and how this effect depends on properties of the planets, the number of planets in the system, and whether planets are in resonance.

13.19 **Title:** Interplay of Close-in Planets with Disk Magnetospheric Accretion
Presenter: Arturo Soto
Abstract: We present a series of high resolution 3-D ideal MHD simulations of magnetospheric accretion onto a non-rotating star with planets embedded into the disk in various configurations. These planets vary in mass ratio with respect to the star, q, from 0.01 to 10^{-4} (once scaled to Solar parameters, this is equivalent to a range from $\sim$10 MJupiter to $\sim$30 MEarth). Their locations vary from 0.45 to 1.8 times the magnetospheric truncation radius R_T (10 Solar radii or $\sim$0.0465 au). "

13.20 **Title:** A first view of Planets in the Venus Zone
Presenter: Dylan Jackaway

Abstract: In this talk, I will introduce the concept of the Venus Zone as a hotter parallel to the Habitable Zone, and explore the overlap between the two. I will also compare the list of exoplanets posited to be in the Venus Zone by Ostberg et al. (2023) with the list I was able to generate using the NASA Exoplanet Archive.

13.21 **Title:** JWST Transmission Spectrum Reveals Insights into the Atmospheric Composition of Warm Sub-Neptune TOI
Presenter: Brian Davenport
Abstract: Atmospheric characterization of sub-Neptunes has so far remained an elusive pursuit, likely due to the ubiquitous formation of photochemical hazes in the relatively cool temperatures of these planets. Based on predictions that clouds should not form when equilibrium temperatures exceed about 850K, we observed TOI-421b, a high signal-to-noise, 1000K sub-Neptune, to search for observable evidence of its atmospheric composition. Observations were performed by JWST's NIRISS/SOSS and NIRSpec/G395M instrument modes to cover the 0.6-5 micron wavelength range. In this talk, I will present the results of the TOI-421b observations, including confirmation of spectral features in its atmosphere. I will also discuss the implications of these results on the predicted metallicity of the planet and the exciting prospects for probing sub-Neptune atmospheres with JWST.

13.22 **Title:** An Informed and Systematic Method to Identify Variable L and T dwarfs
Presenter: Natalia Oliveros Gomez
Abstract: The majority of brown dwarfs show some level of photometric or spectro-photometric variability in different wavelength ranges. Variability is most likely due to heterogeneous cloud structures in the atmospheres of these objects and directly-imaged exoplanets, which we can model using radiative transfer and mapping codes. Finding variable dwarfs requires extensive observing monitoring which implies at minimum a few hours per object. We create a systematic method to find the most likely variable brown dwarfs without the need to spend long hours of telescope time. To this aim, we designed our spectral indices using time-resolved NIR HST WFC3 spectra of an L6.5 (LP 261-75b), and a T6.5, (J2228-4310) variable dwarfs, that can predict variability using low-resolution near-infrared spectra.

We tested these spectral indices on 76 L4-L8 and 26 T5.5-T7.5 NIR SpeX/IRTF spectra. We estimated the variability fraction of our sample at 51 percent for L-dwarfs and 38 percent for T-dwarfs, which agrees with the variability fractions provided by some photometry surveys. We provided a list of 28 new L-variable candidates and 6 new T-variable candidates. We have a recovery rate for variables dwarfs of $\sim$92 percent and a false-negative rate of $\sim$12 percent. These spectral indices may apply to directly-imaged exoplanets of similar effective temperatures and might support the selection of those most likely variables to monitor for variability with the JWST.

13.23 **Title:** Universal Misalignments of Sub-Saturns Regardless of Stellar Temperatures and Orbital Periods
Presenter: Emma Dugan
Abstract: Stellar obliquity measurements for Jupiter-sized planets have uncovered two distinct patterns: cooler stars generally host aligned planetary orbits, whereas hotter stars tend to have misaligned orbits. Furthermore, hot Jupiters exhibit greater misalignment compared to their warmer counterparts, highlighting unresolved questions about the origins of these spin-orbit misalignments. Accurate measurements of smaller mass planets are crucial for elucidating the mechanisms that influence stellar obliquity, which varies with planetary mass. However, the detection of sub-Saturn planets, particularly warm sub-Saturns, has been constrained by their low occurrence rates and lower signal-to-noise ratios compared to larger gas giants. This challenge necessitates a high-precision survey with extensive sky coverage. Previous efforts, including ground-based transit surveys and the Kepler mission, have been inadequate due to a lack of precision, continuous observational baseline, or a sufficient number of bright stars for a meaningful sample of sub-Saturns. The TESS mission has dramatically transformed this field by providing full-sky coverage with the precision needed to assemble a substantial sample of sub-Saturn-sized planets around bright stars. This capability allows us to probe the stellar obliquity in the largely uncharted regime of warm sub-Saturns. In this study, we present two new stellar

obliquity measurements of warm sub-Saturn planets, both of which are misaligned. Integrating these results with archival data reveals that sub-Saturn planets, in contrast to Jupiters, consistently exhibit misalignment irrespective of their host star's temperature or orbital period. This finding introduces a compelling new puzzle and imposes significant constraints on our understanding of the origins and evolution of spin-orbit misalignment.

13.24 **Title:** Investigating Transiting Exoplanets in the ULTRASAT Field
Presenter: Matthew Lastovka
Abstract: ULTRASAT is an upcoming mission led by the Israel Space Agency with participation from NASA, set for launch in 2027. The mission will conduct the first wide-field survey of transient and variable ultraviolet sources, with an accessible volume more than 300 times greater than GALEX, the most sensitive UV satellite to date. ULTRASAT's continuous observations over a long observing baseline will allow for observations of transiting exoplanets. Time series data of planetary systems at UV and visible wavelength can be used to understand atmospheric processes such as escape and photoevaporation. We are conducting a program to identify known exoplanets and discover new transiting planets that fall within the ULTRASAT high cadence fields. We will search for new planets in the field of view using TESS data and vet these new planet candidates to develop a catalog of transiting exoplanets in the ULTRASAT field.

13.25 **Title:** What Can We Learn From TOI-5349 b: A Jupiter-like Planet Orbiting an M dwarf
Presenter: Angeli Sandoval
Abstract: The NASA TESS Mission has detected and confirmed hundreds of exoplanets, many consisting of small rocky planets but also massive "hot Jupiter" planets, like TOI-5349 b. The system TOI-5349 contains an M dwarf (0.59 $M_{\odot}$) with a single transiting gas giant (0.83 Jupiter Radii/0.53 Jupiter Masses) on a 3.3 day orbit. Like many "hot Jupiter" systems, the origin channels of such systems is not entirely understood, but is essential to improve our theories of planet formation, migration, and evolution. In this work, we investigate TOI-5349 through analysis of radial velocity data obtained with MAROON-X and HPF and photometry data obtained by the NASA TESS Mission and the 0.6m telescope at the Red Buttes Observatory. It joins a growing population of giant exoplanets orbiting M dwarfs that will enable comparative studies to hot Jupiter analogs orbiting Sun-like stars and demographic studies to understand how this sample forms.

13.26 **Title:** Modeling Planet Formation in the Protoplanetary Disk of the DQ Tau Binary Star System
Presenter: Ryan Corzo
Abstract: The study of Exoplanets has been an area of great interest in recent years. The first exoplanet was discovered in 1992 and since then over 5000 confirmed exoplanets have been discovered and cataloged. However, even with our broadening understanding of exoplanet systems, pivotal questions remain unanswered. Namely, what are the mechanisms behind planet formation within binary star systems? When a protostar forms, a spinning disk of dust and gas called a protoplanetary disk, is left behind. Within this disk, small particles of dust and gas collide, forming and growing as clumps, providing the ideal environment for planet formation. This project aims to investigate planet formation within the protoplanetary disk of the exoplanet system DQ Tau. The DQ Tau system contains two binary stars, each with a mass of 0.6 solar masses. The disk surrounding the stars is estimated to have a diameter of 33.6 AU and a mass of 0.002-0.02 solar masses. Using previously determined disk parameters from Atacama Large Millimeter/submillimeter Array observations, and the REBOUND N-Body integrator, this research constructs the protoplanetary disk surrounding the binary stars at the center of DQ Tau in the Python environment and models the particle collisions within this disk that give rise to simulated planets. By modeling particle collisions within the disk, this study aims to investigate key factors influencing planet formation, including the mass, size, and orbital characteristics of resultant planets and the presence of residual disk material.

13.27 **Title:** ALMA Molecular Mapping of the Candidate Class I Planet-forming Disk of GY 91
Presenter: Sally Jiang

Abstract: The ubiquitous observations of substructures in disks around Class II Young Stellar Objects (YSOs) have been instrumental in building theoretical interpretations for disk evolution and planet formation. However, substructures have also been resolved in a small population of younger, more embedded protostars (class 0/I), suggesting much earlier and faster disk evolution timescales than previously expected. One of these disks is GY91, a class I YSO in the L1688 star-forming region, whose disk contains developed ring/gap substructures. We present new ALMA Band 7 high-angular resolution (0.3”), molecular line imaging of GY91 using the ACA and 12-m array. We find strong detections of CS, N2H+, H2CO 4(0, 4)-3(0, 3), C18O, weak detections of H2CS and H2CO 4(2, 3)-3(2, 2), and tentative detection of 13C18O. We find CS and N2H+, in particular, are good tracers of the disk, despite its highly extincted nature, but we observe cloud contamination in H2CO 4(0, 4)-3(0, 3) and C18O. We use the CS observations to constrain the dynamical mass of the star, which we estimate to be 0.57 solar masses. This estimate is higher than previous estimates from evolutionary models that predicted the mass to be around 0.25 solar masses.

13.28 **Title:** The Effect of Initial Formation Conditions on Planetary System Properties
Presenter: Lucas Brefka
Abstract: The observable properties of planetary systems, such as composition, multiplicity and orbital architecture, can be strongly influenced by the initial conditions of formation. These conditions affect the early growth of planetary embryos in the gas disk phase through pebble and/or planetesimal accretion, which may affect the planets’ final growth during the giant impact stage. In this work, we explore how different limiting embryo isolation masses during earlier stages of planet formation affect the final properties of planets. We use and compare several limiting isolation masses for initial planetary embryos, including flow isolation, migration feedback isolation, classic isolation, and pebble isolation. Our simulations begin with isolated embryos placed within the gas disk just before its dissipation and continue through the giant impact stage. The properties of systems governed by each isolation mass are then compared to each other and to the observed properties of the known Kepler sample. This investigation sheds light on how planetary systems evolve and the processes that influence the wide range of system parameters we observe today, helping place our own solar system in context.

13.29 **Title:** Stars and Disks in Close Young Binary Systems
Presenter: Peter Knowlton
Abstract: Most stars are located in binary and multiple systems, therefore a complete picture of planet formation requires incorporating the impact of binary systems. Although fewer planets form around stars in multiple systems, astronomers have nonetheless discovered dozens of circumstellar exoplanets in binaries. Theoretical and observational evidence suggests that close binaries, with separations $<$50 AU, have smaller and shorter-lived disks than their single-star or wide binary counterparts. We aim to correlate well-determined stellar properties with circumstellar disk characteristics in order to understand their influence on the formation of planets. Using the Keck II and VLT telescopes, we have collected high-resolution (R=30,000), near-infrared spectra of the individual components in 100 young binary systems with separations from 10 to several hundred AU. Our analyses focus on absorption lines highly sensitive to stellar and disk parameters such as effective temperature, veiling, surface gravity, surface-averaged magnetic field strength, and projected rotational velocity. We have developed an MCMC procedure to extract these parameters by fitting our observed spectra to a comprehensive grid of synthetic models. Statistical tests will reveal how stellar properties impact circumstellar material and either permit or impede the formation of planets. Uniformly derived disk and stellar parameters and the observed spectra will be made publicly available on the Young Binary Star Database.

13.30 **Title:** Meridional circulation (molecular)-weighted
Presenter: Deepayan Banik
Abstract: Most stellar evolution models do not account for the spatio-temporal nature of hydrodynamics potentially leading to poor transport of angular momentum through their lifetime. This leads to fundamental questions about large scale fluid motion in rotating stratified environments. Such a flow called meridional circulation, driven by wind torques from the convective zones of small Sun-like

stars has recently been studied through an atmospheric science lens in Banik and Menou 2024, showing the importance of the time varying nature of meridional circulation. Here, we extend the existing framework to study the effect of mean molecular weight gradients, ubiquitous in stars, on meridional circulation. We find that, due to the inherent nonlinearity of the system, a spatial dependence is introduced in the solution. In other words, poles and the equator exhibit different behavior so far as meridional circulation is concerned. This will be an important update to stellar evolution codes which traditionally consider stars as 1D, rigidly rotating objects.

13.31 **Title:** Insights from Numerical and Theoretical Analysis: Exploring the Origin of Metastability in Multi-Planet Systems Through Angular Momentum Deficit Accumulation
Presenter: Zhixing Liu
Abstract: Numerical studies have shown that multi-planet systems on initially nearly circular, coplanar tend to auto-excite dynamically, eventually leading to systemic instability. The timescale of this instability grows exponentially with mean planet spacing and may not be reached for billions of orbits. Various competing explanations have been proposed to explain the origins of this eventual instability, and it is not known whether all multi-planet systems are metastable and will eventually destabilize or a critical spacing exists beyond which the system is expected to be perpetually stable. We present numerical simulations testing prior hypotheses for the pathway to instability: we examine the challenges faced by the two-body and three-body MMR overlap models in accurately predicting encounter times as the number of planets in a system increases. We find that although two-body MMR overlap theory traditionally favors equal spacing to minimize the optical depth of MMRs, systems with a more significant number of planets and varied planetary masses tend to destabilize more rapidly under such conditions, compared with an unequal spacing regime where planets with higher angular momentum are packed more tightly. Our results suggest that global transport of AMD facilitated by secular interactions may play a key role. We present a novel mode diffusion theory to illustrate how mild and bounded aperiodicity in planet semimajor axes can cause planet systems to accumulate global AMD. If this theory is correct, it suggests that all planet systems are only metastable but have a long instability time dispersion.

13.32 **Title:** CRISPR-cas9 Screening to Elucidate Mechanisms of Radiation Tolerance for Martian Colonization
Presenter: Manish Ravi
Abstract: Recent decades have seen increased interest in colonizing Mars, an effort likely to be hampered by adverse conditions including high levels of radiation. Understanding the mechanisms by which radiation-resistant species of bacteria survive radiation is of utmost importance in understanding how life might survive in a Martian environment. The primary radiation types emitted onto Mars are Galactic Cosmic Rays (GCRS), consisting of high-energy particles. Secondary particles, including neutrons and gamma-rays (γ-rays), are generated through interactions of these particles with Martian atmosphere CO_2 (95.3%) at pressures of 7-10 mbar. The average absorbed dose rate from GCRs is 0.210 mGy/day, with a dose equivalent rate of 0.64 mSv/day. To replicate similar Mars-like conditions, we utilize a radioactive isotope 60Co at a flux of 4.5 particles/cm^2/s with an energy of 1.1 to 1.3 MeV/nuc. Our E. Coli will be placed in the Mars atmosphere analog chamber, allowing for precise simulation of temperature, pressure, and gas composition. This enables us to have an in-depth assessment of their adaptive ability in a controlled environment. Experimentally evolved E. coli exposed to ionizing radiation exhibit decreased protein carbonylation, which implies a possible mechanism for radiation resistance. However, a full study to identify all pathways involved in withstanding radiation has yet to be performed. We plan to use a genome-wide CRISPR-dCas9 screen to identify gene hits involved in conferring radiation resistance. Analyzing the abundance of gRNAs before and after radiation exposure provides a comprehensive look at the genes responsible for radiation resistance. We expect to find correlations between altered protein carbonylation pathways as well as enhanced gene repair mechanisms and enhanced radiation resistance. The knowledge gained from understanding these mechanisms can guide us in developing organisms capable of surviving harsh Martian conditions. In

turn, this might change our perspective about habitable zones in the universe by showing that life can survive in areas previously believed inhospitable.

13.33 **Title:** Exploring the Internal Structures of Sub-Neptunes: Implications from JWST Observations of TOI-270 d
Presenter: Biruk Nardos Abebe
Abstract: Sub-Neptunes are planets with radii between that of Earth and Neptune and are intriguing since they lack any Solar System analogues. They are often characterized through comparing their observed masses and radii with internal structure models of different compositions, ranging from rocky cores with hydrogen envelopes to water-rich bodies. Recent JWST observations of sub-Neptunes suggest that many of these objects may host high-mean molecular weight miscible envelopes, consisting of H/He mixed with other chemical species. However, internal structure models of miscible-envelope sub-Neptunes have rarely been explored. In this work, we examine the parameter space of sub-Neptune interior models with a range of envelope compositions and thermal structures. We identify the key parameters that determine the mass-radius relationship for these objects and produce model grids that can be used for comparison with observed planets. We use our models to place constraints on the bulk composition and structure of TOI-270 d, a planet whose transmission spectrum was recently observed with JWST. We discuss possible caveats and avenues for future model developments.