ATMOSPHERIC ESCAPE and REPLENISHMENT in PLANETARY SYSTEMS

NOVEMBER 4–7, 2025

Event Program

STScI

Event Description

The competition between atmospheric mass-loss through escape versus replenishment by outgassing determines the formation, evolution, and ultimate fate of planetary atmospheres inside and outside the Solar System. New discoveries have been possible through space-based spectroscopy from *HST* and *JWST*, high-resolution ground-based spectroscopy in the optical and near-infrared, and *in situ* Solar System exploration. The future is promising with the public data coming out of STScI's Rocky Worlds DDT program and the development of the Habitable Worlds Observatory. In this workshop, we will discuss the theoretical aspects involved in atmospheric escape and replenishment through outgassing, as well as study the best strategies to observe them. We selected key outstanding questions related to this topic and invite the community of planetary and exoplanetary scientists to work together in exploring answers.

Main Science Questions

- What observational strategies maximize information content about the physics of atmospheric escape?
- What observational strategies maximize information content about the presence and/or properties of secondary atmospheres?
- What are the conditions necessary for outgassing a secondary atmosphere?
- Can rocky planets around M dwarfs retain detectable secondary atmospheres?
- What is the role of atmospheric chemical makeup in regulating hydrodynamic escape?
- How can we accurately describe the physics that shape exospheres?

Science Organizing Committee

- Leonardo Dos Santos (Space Telescope Science Institute, Co-Chair)
- Joshua Lothringer (Space Telescope Science Institute, Co-Chair)
- James Owen (Imperial College London)
- David Brain (University of Colorado Boulder)
- Kristina Kislyakova (University of Vienna)
- Keighley Rockcliffe (University of Maryland, Baltimore County)

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ATMOSPHERIC ESCAPE and REPLENISHMENT in PLANETARY SYSTEMS

NOVEMBER 4–7, 2025

Event Schedule

STScI

November 4 -7, 2025 at Space Telescope Science Institute

– Schedule of Events –

Tuesday, November 4, 2025 **TENTATIVE**

Time	Title	Speaker	Location
8:30am	Registration (Lobby) Breakfast (Café) Poster Session 1, time to hang posters (Auditorium)	**Speaker Tech Check for Session 1 (Auditorium)**	
9:00am	Welcome	Jen Lotz, STScI Director	Auditorium
9:10am	Workshop Logistics and Goals	Leonardo Dos Santos & Josh Lothringer, Co-Chairs	
Session 1: Impact of chemical makeup in atmospheric retention, Chair: Joshua Lothringer			
9:15am	Physical Processes by Which Atmospheric Chemical Makeup Regulates Hydrodynamic Escape	Ruth Murray-Clay (I)	Auditorium
10:00am	Mass loss, metallicity, and the mystery of HD 189733b	Madelyn Broome (C)	Auditorium
10:15am	Exploring atmospheric escape from hot-Jupiters and water-rich sub-Neptunes	Anna Ruth Taylor (C)	Auditorium
10:30am	Coffee Break	**Speaker Tech Check for Session 1, Part 2 (Auditorium)**	
Session 1, Part 2			
11:00am	The Rocky Worlds DDT: Strategy, Status, and Early Results	Hannah Diamond-Lowe (C)	Auditorium
11:15am	EUV Energy Sinks: Impacts of Radiative Cooling on Driving Hydrodynamic Outflows	Renata Frelikh (C)	Auditorium
11:30am	Atmospheric Escape and Chemical Fingerprints in Ultra-Hot Jupiters	Alexandra Lehtmets (C)	Auditorium
11:45am	Water-Cooled sub-Neptunes Get Better Gas Mileage	Eric Gaidos (C)	Auditorium
12:00pm	Lunch (Café)	**Speaker Tech Check for Session 2 (Auditorium)**	
Session 2: Observations of escaping primary atmospheres, Chair: Lakeisha Ramos Rosado			
1:15pm	Observational Strategies for Exoplanetary Atmospheric Escape	R.O. Parke Loyd (I)	Auditorium
2:00pm	Escaping helium from young mini-Neptunes in the southern sky	Michael Zhang (C)	Auditorium
2:15pm	A complex structure of escaping helium spanning more than half the orbit of an ultra-hot Jupiter	Romain Allart (C)	Auditorium
2:30pm	Results from the First Mass Loss Survey of Fstar Planets: Implications of Spectral Type on Mass Loss	Morgan Saidel (C)	Auditorium
2:45pm	Poster Pops: Froning, Falorca, Barat, Caldrioli, Leung		Auditorium
3:00pm	Break (Café)	**Speaker Tech Check for Session 2, Part 2 (Auditorium)**	
Session 2, Part 2:			
3:45pm	A Uniform Interpretation of Helium Escape in Exoplanets from Archival Spectroscopic Observations	Patrick McCreery (C)	Auditorium
4:00pm	Towards Precise Constraints on Atmospheric Evolution for 50 Sub-Neptunes	Shreyas Vissapragada (C)	Auditorium
4:15pm	From Youth to Maturity: Tracing Atmospheric Loss in Exoplanets Across Time	Jaume Orell-Miquel (C)	Auditorium
4:45pm-6:00pm	**Welcome Reception**		Café

Shuttles will be available back to the host hotel.

Wednesday, November 5, 2025 **TENTATIVE**

Time	Title	Speaker	Location
8:30am	Breakfast (Café) **Speaker Tech Check for Session 3 (Auditorium)**		
Session 3: Observations of secondary atmospheres, Chair: David Brain			
9:00am	What observational strategies maximize our knowledge of the physics of atmospheric escape in the Solar System?	Shannon Curry (I)	Auditorium
9:45am	Venus, Earth, and Mars: Laboratories for Understanding Terrestrial Planet Water Escape	Mike Chaffin (C)	Auditorium
10:00am	Stability of secondary atmospheres and observational manifestations	Leonardos Gkouvelis (C)	Auditorium
10:15am	Volcanically Sustained H_2 Atmospheres: Selection criteria for potential JWST candidates	Rahul Arora (C)	Auditorium
10:30am	Break (Café) **Speaker Tech Check for Session 3, Part 2 (Auditorium)**		
Session 3, Part 2			
11:15am	The Power of Coupling Transmission and Emission in Observing Atmospheres: The Case of GJ 1132 b	Katherine Bennett (C)	Auditorium
11:30am	The Extreme Ultraviolet Properties of Planet-hosting G, K, M Stars and Atmospheric Escape	Kevin France (C)	Auditorium
11:45am	A thick volatile atmosphere on an ultra-hot super-Earth	Johanna Teske (C)	Auditorium
12:00pm	Lunch (Café) **Speaker Tech Check for Session 4 (Auditorium)**		
Session 4: Physics of atmospheric replenishment, Chair: Munazza Alam			
1:15pm	Linking planet formation simulations and outgassing models to explore the atmospheric chemistry of M-dwarf planetary systems	Laura Schaefer (I)	Auditorium
2:00pm	Modeling the primary to secondary atmosphere transition and implications for the cosmic shoreline	Joshua Krissansen-Totton (C)	Auditorium
2:15pm	Water outgassing as a source of secondary atmospheres on the TRAPPIST-1 exoplanets	Trent Thomas (C)	Auditorium
2:30pm	A Systematic Exploration of Plausible Outgassed Secondary Atmospheres on the TRAPPIST-1 Planets	Megan Gialluca (C)	Auditorium
2:45pm	The Cosmic Shoreline Revisited: A Metric for Atmospheric Retention Informed by Hydrodynamic Escape	Xuan Ji (C)	Auditorium
3:00pm	Break (Café)		
Session 4, Part 2			
3:45pm	Poster Session 1: Froning, Schreyer, Falorca, Barat, Lastovka, Frisse, Caldiroli, Bischof, Leung, Duvvuri, Brain, Ramos Rosado		Auditorium
4:30pm-6:00pm	**Happy Hour SDAS**		Café

Poster Session 1 individuals should take their posters down at the end of the Wednesday Poster Session, before the Happy Hour SDAS.

Shuttles will be available back to the host hotel.

Thursday, November 6, 2025 **TENTATIVE**

Time	Title	Speaker	Location
8:30am	Breakfast (Café) Poster Session 2, time to hang posters (Auditorium)	**Speaker Tech Check for Session 5 (Auditorium)**	
Session 5: Physics of exospheres, Chair: Leonardo Dos Santos			
9:00am	Atmospheric escape from the perspective of different star-planet interactions	Aline Vidotto (I)	Auditorium
9:45am	Towards a Better Understanding of Lyman-alpha Transits with Radiation Hydrodynamic Simulations	Chase Funkhouser (C)	Auditorium
10:00am	Observing Planetary Exospheres and Escape: Mars, Venus and the Earth	John Clarke (C)	Auditorium
10:15am	Poster Pops 2: Feigelson, Nguyen, Kovacs (virtual poster), Chen (virtual presenter)		Auditorium
10:30am	Break (Café)	**Speaker Tech Check for Session 5, Part 2 (Auditorium)**	
Session 5, Part 2			
11:15am	New physics incorporated into atmospheric escape models solves the mystery of missing Helium transient	Matthaus Schulik (C)	Auditorium
11:30am	Time-variable Helium absorption in the exosphere of HD 189733b using NIRPS/HARPS	Georgia Mraz (C)	Auditorium
11:45am	The Surprising Leading Tail of Helium in TOI-3844b	Suvrath Mahadevan (C)	Auditorium
12:00pm	Lunch (Café)	**Speaker Tech Check for Session 6 (Auditorium)**	
Session 6: Interdisciplinary aspects, Chair: Patrick McCreery			
1:15pm	Poster Session 2: Chen, Nguyen, Feigelson, Morrissey, Perez, King, Peng, Vidaurri, Somers, Chatterjee, Dos Santos, Lothringer		Auditorium
2:00pm	The Role of Stellar Flares from Early and Late M Stars on the Atmospheric Escape of Rocky Planets	Laura Amaral (C)	Auditorium
2:15pm	Atmospheric evolution and escape on molten rocky exoplanets	Emma Postolec (C)	Auditorium
2:30pm	Uranus as an exoplanet in our backyard for strategizing atmospheric escape observations	Li-Jen Chen (C)	Auditorium
2:45pm	Characterizing Active Volcanism on Terrestrial Exoplanets Through Circumstellar Plasma Tori	V. Abby Boehm (C)	Auditorium
3:00pm	Break (Café)	**Speaker Tech Check for Session 6, Pt 2 (Auditorium)**	
Session 6, Part 2			
3:45pm	The transition between core-powered and photoevaporative mass loss with the aiolos hydrodynamic code	William Misener (C)	Auditorium
4:00pm	MUSCLES and MANTIS: Efforts to measure the extreme ultraviolet light from exoplanet host stars.	David Wilson (C)	Auditorium
4:15pm	Reassessing Atmospheric Escape in Sub-Neptunes: Three Mechanisms Coupled to Evolution Model	Yao Tang (C)	Auditorium
4:30pm	Group Picture	Please meet outside on the front stairs	

Shuttles will be available back to the host hotel.

Friday, November 7, 2025 **TENTATIVE**

Time	Title	Speaker	Location
8:30am	Breakfast (Café) **Speaker Tech Check for Session 7 (Auditorium)**		
Session 7: Earth 2.0 and planets around M dwarfs, Chair: Keighley Rockcliffe			
9:00am	Charting the Cosmic Shoreline	Kevin Stevenson (I)	Auditorium
9:45am	Helium escape from the temperate super-Earth LHS 1140b	Collin Cherubim (C)	Auditorium
10:00am	The Receding Cosmic Shoreline of Mid-to-late M Dwarfs	Emily Pass (C)	Auditorium
10:15am	Hot rocky planets through NIRSpec's eyes: what we learned from phase curves	Qiao Xue (C)	Auditorium
10:30am	Break (Café) **Speaker Tech Check for Session 7, Part 2 (Auditorium)**		
Session 7, Part 2			
11:15am	JWST insights into GJ 9827 d's atmosphere and redox state: a benchmark for rocky planet interiors	Caroline Piaulet Ghorayeb (C)	Auditorium
11:30am	A Tentative Trend in the Brightness Temperatures of M-Earths	Brandon Coy (C)	Auditorium
11:45am	Rules for Retaining an Atmosphere on M-dwarf Planets	Richard Chatterjee (C)	Auditorium
12:00pm	Lunch (Café)		
Session 8			
1:15pm	White Paper Discussion and Planning		Auditorium
3:15pm	Farewell Address		Auditorium

Shuttles will be available back to the host hotel.

ATMOSPHERIC ESCAPE and REPLENISHMENT in PLANETARY SYSTEMS

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Invited Speaker Abstracts

STScI

Shannon Curry, Invited Speaker

University of Colorado, Boulder

What observational strategies maximize our knowledge of the physics of atmospheric escape in the Solar System?

A critical aspect of understanding habitability beyond Earth is the evolution of a planetary atmosphere. Atmospheres dictate the surface pressure that ultimately determines whether water or other hydrocarbons can exist in a stable liquid form. Liquids are especially effective at transporting nutrients and other integral compounds (such as oxygen), which the evolution of life on Earth has depended on. Orbiters and landers at our terrestrial neighbors, Mars and Venus, have yielded the most observations of atmospheric escape. Analysis of these observations illuminates the physics of atmospheric escape, which we can apply to planets and moons throughout the universe. What is particularly fascinating about the atmospheres of Mars and Venus is that they represent two extremes in evolution; Mars' surface pressure is ~7 mbars while that of Venus reaches almost 90 bars, both in stark comparison to Earth's normalized 1 bar of surface pressure. How two planets that formed at similar times as the Earth can have such dramatically different paths inherently requires an interdisciplinary approach. This talk will focus on different observational strategies for different types of atmospheres and bodies. I will discuss some of the key factors that influence a planetary atmosphere, including volcanism and outgassing, as well as the processes and physics of atmospheric escape, which rely heavily on the interaction with the host star. Additionally, I will discuss past, present and future missions studying atmospheric escape in our own solar system.

R.O. Parke Loyd, Invited Speaker

Eureka Scientific

Observational Strategies for Exoplanetary Atmospheric Escape

After a trickle of observations spanning decades, observations of exoplanetary atmospheric escape are now flooding in. Connecting observations to the underlying physics of escape, however, remains a challenge. Transits in hydrogen Lyman-α and metastable helium at 10830 Å provide our primary windows into exoplanetary atmospheric escape. These transits encode information about the speeds at which outflows are launched, their subsequent interactions with stellar winds, and ultimately the rates at which planetary atmospheres lose mass. Yet degeneracies abound—for example, an increase in mass-loss rate or a decrease in stellar ionizing flux can both produce a deeper Lyman-α transit, and ionizing flux is notoriously difficult to constrain. In this talk, I will focus on observational strategies to maximize information content about escape physics, beginning with a review of how observations connect to escape physics. I will highlight observational strategies in use by the recently begun Survey of Transiting Exoplanets in Lyman-α (STELα) and evaluate how observations of hydrogen and helium escape can complement one another. Zooming out, I will explore how the exoplanetary escape we observe today fits into the broader landscape of escape and its many mechanisms that have influenced, and continue to influence, both extrasolar and Solar System planets. I will close with a look at possibilities with future observatories and observations.

Ruth Murray-Clay, Invited Speaker

University of California, Santa Cruz

Physical Processes by Which Atmospheric Chemical Makeup Regulates Hydrodynamic Escape

The composition of a planet's atmosphere can affect hydrodynamic escape by altering the radius at which an atmospheric outflow is launched, by changing the energy balance in the outflow, and/or by altering the conditions under which the outflow remains hydrodynamic. Conversely, fractionation due to hydrodynamic outflows may shape the bulk compositions of atmospheres. Most gas giant planets are metal-enhanced, and at lower planet masses, expected atmospheric metallicities are often high enough that intuition about escape developed from hydrogen atmospheres can be misleading. Metals have been tentatively detected in planetary outflows, both directly through metal lines and indirectly through X-ray absorption. In this review talk, I will discuss the physical mechanisms through which metals impact escape including (1) how mean molecular weight affects the transition between hydrodynamic and Jeans escape, (2) the ability of atmospheric components to remain well-mixed up to and within a hydrodynamic outflow, (3) how composition of the deep atmosphere affects the wind launch radius, (4) how hydrodynamic winds transition from molecular to atomic compositions, and (5) the critical role of radiative cooling in limiting atmospheric escape. I will highlight recent work on radiative cooling from atomic metals in high-gravity and high-flux giant planet environments and discuss preliminary work on radiative cooling from molecules on lower-mass planets.

Laura Schaefer, Invited Speaker

Stanford University

Linking planet formation simulations and outgassing models to explore the atmospheric chemistry of M-dwarf planetary systems

We use a model of core formation chemistry to examine the distribution of planetary redox states at the end of planet formation using terrestrial planet formation simulations of the Trappist-1 system, and discuss the behavior of volatile partitioning during this process. We also discuss the role of Fe-behavior during magma ocean crystallization and how the evolving magma ocean redox can cause changes in outgassing chemistry during the magma ocean lifetime. Models of outgassing can link planet formation simulations with later planetary evolution to explore the possible atmospheric compositions of these systems.

Kevin Stevenson, Invited Speaker

Johns Hopkins University - APL

Charting the Cosmic Shoreline

Is there a universal divide between planets with and without atmospheres? Is it determined by incident flux and escape velocity? By studying exoplanets that straddle the "cosmic shoreline," we are beginning to constrain the prevalence of atmospheres around rocky worlds and the mechanisms that drive their loss. JWST has already delivered a wealth of discoveries, from its first confirmed rocky exoplanet to intriguing results that favor secondary atmospheres. Building on the lessons from its first few years of science operations, new JWST programs are pushing the limits of atmospheric detection toward Earth-sized, habitable-zone planets. In this talk, I will summarize the current status of the field, highlight preliminary detections, and discuss promising paths forward. Although we have only begun to scratch the surface of rocky exoplanets, the years ahead hold the potential for transformative breakthroughs via increasingly precise studies.

Aline Vidotto, Invited Speaker

Leiden University

Atmospheric escape from the perspective of different star-planet interactions

There are several physical processes that mediate the interaction between an exoplanet and its host star, with the four main ones being due to magnetic, particle (stellar outflow), radiative and tidal interactions. The strength of these interactions depends on the architecture of planetary systems, as well as the age and activity level of the host stars. In particular, exoplanets in close-in orbits and/or orbiting active host stars can experience strong physical interactions, some of which are negligible or absent in the present-day Solar System planets. In this talk I will discuss how the environment surrounding exoplanets can affect the conditions for magnetic coupling in star-planet interactions. I will show that the presence or absence of magnetic coupling can modify not only atmospheric escape rates, but also the shape and structure of exoplanetary exospheres, which consequently affect spectroscopic transit signatures of escaping atmospheres.

ATMOSPHERIC ESCAPE and REPLENISHMENT in PLANETARY SYSTEMS

NOVEMBER 4–7, 2025

Contributed Speaker Abstracts

STScI

Romain Allart, Contributed Speaker

Universite de Montreal

A complex structure of escaping helium spanning more than half the orbit of an ultra-hot Jupiter

The near-infrared helium triplet has emerged as a powerful tool for studying atmospheric escape in exoplanets, offering crucial insights into their long-term evolution. Atmospheric escape is a fundamental process that sculpts the atmospheres of close-in exoplanets, gradually altering their composition and potentially leading to the complete loss of volatile layers over time. Understanding the mechanisms driving mass loss is essential for constraining the formation and evolutionary pathways of exoplanets, particularly those exposed to extreme stellar irradiation.

Modeling the helium triplet remains challenging due to uncertainties in the XUV flux received and the complex interactions of metastable helium with the surrounding stellar environment. Current approaches often overestimate mass loss rates, temperatures, and the physical extent of escaping atmospheres. Models often adopt unphysical parameter values to compensate for missing physics and chemistry.

This work presents JWST/NIRISS observations of a helium phase curve around an iconic ultra-hot Jupiter, providing evidence of the longest continuous atmospheric escape. We detect an absorption signature that persists for over 17 hours — covering 55% of the planet's orbit — leading the planet's transit by more than 5h and trailing it by over 10h. This extended absorption corresponds to an optically thick region spanning approximately 110 planetary radii (~0.1 AU). Our results show that the ultra-hot Jupiter sustains a strong outflow, separating into two tails trailing and leading the planet. The persistent absorption from these tails, together with their measured radial velocity shifts, suggests that they remain in a collisional fluid regime at large distances from the planet and display very different dynamics. While qualitatively agreeing with theoretical expectations, the observed structure of helium is not self-consistently reproducible by current models, limiting constraints on the mass loss rate.

These findings open a new, unexpected window into the study of extreme atmospheric escape processes, highlighting the necessity of refining our observational strategies for both ground—and space-based missions. Additionally, current 3D particle and hydrodynamic models fail to reproduce such an intense, extended, and asymmetric signal, emphasizing the urgent need for more sophisticated joint modeling efforts to fully capture the complex physics of atmospheric escape and its impact on exoplanetary evolution.

Rahul Arora, Contributed Speaker

University of Arizona

Volcanically Sustained H2 Atmospheres: Selection criteria for potential JWST candidates

Magmatic outgassing plays a critical role in replenishing atmospheric mass and shaping planetary climate. It is intimately linked to a planet's interior properties and influences its geological evolution, atmospheric composition, and potential habitability. With our current observation capabilities, the detection of magmatic outgassing signatures requires low mean molecular weight atmospheres (μ). However, close-in rocky exoplanets are expected to lose their primordial hydrogen envelopes due to intense atmospheric escape, leaving behind thin, high μ secondary atmospheres or no atmospheres. In this study, we investigate whether magmatic outgassing can sustain low μ atmospheres on close-in rocky exoplanets, making the detection of a hydrogen-dominated atmosphere a potential indicator of active magmatic outgassing. We propose tidal heating as a source of higher melt production and estimate the resulting outgassing fluxes for all planets in the TRAPPIST-1, L~98-59, and L~791-18 systems to identify candidates where outgassing may exceed escape. We model outgassing speciation and fluxes across a broad parameter space, varying mantle redox state and initial volatile inventories of carbon, hydrogen, and sulfur. We find that reducing mantles and higher initial H2O inventories favor H2 speciation and outgassing. Under mantle conditions more reducing than FMQ+1 and with initial water inventories exceeding 50 OM, planets such as L~98-59~b/c/d could theoretically sustain secondary H2-dominated atmospheres. We propose an "outgassing zone" as the region around a star where tidally-driven magmatic outgassing can exceed UV-powered hydrodynamic atmospheric escape for given planetary conditions. Additionally, we show that primordial H2 may act as a false positive for magmatic outgassing, and argue that precise mass–radius constraints are critical to distinguishing between primordial, and secondary H2 atmospheres. These secondary atmospheres offer promising opportunities to detect magmatic outgassing signatures with JWST. We assess their detection feasibility across a range of planetary conditions, highlighting key targets for future observations.

Katherine Bennett, Contributed Speaker

The Johns Hopkins University

The Power of Coupling Transmission and Emission in Observing Atmospheres: The Case of GJ 1132 b

In our quest to observe secondary atmospheres on rocky planets orbiting M dwarfs, we tend to focus either on transmission spectroscopy or emission photometry/spectroscopy. However, these two techniques are largely complementary. Emission studies are sensitive to thick, high mean molecular weight atmospheres that may be difficult to detect in transmission within a reasonable limit of transit observations. On the other hand, transmission studies are sensitive to more tenuous atmospheres that may be indistinguishable from bare rocks in emission studies. To avoid ambiguous results, we should therefore couple these techniques. To illustrate this, we share results from GJ 1132 b, a 580 K, 1.1 Earth radius planet in a 1.6 day orbital period, which has long remained a favored target of the rocky exoplanet community. We analyze four transits with JWST/NIRSpec and couple the resulting highly precise transmission spectrum with MIRI/LRS emission spectroscopy results from Xue et al. 2024. We show that only the thinnest of atmospheres are consistent with both datasets. Because of GJ 1132 b's age and proximity to its host star, a thin atmosphere is likely not stable, and a bare rock is the simplest explanation. This illustrates that only by combining transmission and emission studies will we be able to confidently detect or rule out atmospheres and bring clarity to the question of atmospheric retention for rocky M dwarf planets.

V. Abby Boehm, Contributed Speaker

Cornell University

Characterizing Active Volcanism on Terrestrial Exoplanets Through Circumstellar Plasma Tori

Volcanic outgassing of volatiles sequestered in the mantle is a key mechanism by which rocky worlds replace their stripped primordial envelopes with secondary atmospheres made of heavier elements. Understanding the conditions in which volcanism can effectively liberate mantle volatiles is crucial to discerning which planets may form and retain significant secondary atmospheres, yet to date active volcanism has been observed only on Earth, Venus, and Io. To expand our sample of volcanically active worlds, we propose a novel method of characterizing active volcanism on extrasolar terrestrial planets. Our method generalizes the physics of the plasma torus constructed around Jupiter by Io's volcanic activity to describe a hypothetical analogous structure created by transiting terrestrial exoplanets orbiting within the magnetospheres of their host stars. The quasi-steady mass of the torus is set by a balance between mass injection through volcanism and mass loss through magnetospheric convection, the latter of which may be estimated from stellar magnetic properties. The optical depth of perpetual absorption features imprinted upon the stellar spectrum by the occulting torus allows the quasi-steady mass to be determined, in turn yielding estimates of the volcanic mass outgassing rate and interior composition of the source exoplanet with minimal assumptions. We demonstrate our method is accessible to modern and near-future instrumentation and identify known exoplanets orbiting GKM stars which meet the conditions for building detectable tori. Our work demonstrates the rising need for additional space-based UV-optical instrumentation to detect the absorption features characteristic of the proposed circumstellar plasma tori.

Richard Chatterjee, Contributed Speaker

University of Oxford

Rules for Retaining an Atmosphere on M-dwarf Planets

Just like the ubiquitous photoevaporation of hydrogen envelopes, metal-dominated atmospheres such as those of Earth and Venus can undergo transonic hydrodynamic escape, but under a rich new set of rules still being uncovered. Drawing on the analytic framework of Chatterjee and Pierrehumbert (2024), I'll present the governing physics of escape across the size range of rocky planets. The emergent thresholds and plateaus under increasing ionizing irradiation have a marked impact on the cosmic shoreline, as explored in Ji, Chatterjee et al. (2025). Finally, I'll share results from ongoing work with Robert Johnson and Shane Carberry Mogan on simulations of exospheric kinetics.

Collin Cherubim, Contributed Speaker

Harvard University

Helium escape from the temperate super-Earth LHS 1140b

Atmospheric escape and volatile replenishment from planetary interiors compete to determine whether planets can maintain atmospheres. Understanding the conditions in which atmospheres are retained, lost, and replenished is of particular interest for exoplanets orbiting low-mass stars, which are amenable to atmospheric characterization. We present results from an atmospheric escape-magma ocean evolution model, IsoFATE/Atmodeller, which simulates volatile exchange between an escaping atmosphere and evolving molten interior for planets smaller than Neptune. Our model predicts helium enrichment in the atmosphere of LHS 1140b, a nearby super-Earth (R_p = 1.730 ± 0.025 $R_\oplus$; M_p = 5.60 ± 0.19 $M_\oplus$) orbiting a quiet mid-M dwarf in the liquid-water habitable zone (T_{eq} = 226 ± 4 K). We collected a high-resolution, near-infrared transmission spectrum for LHS 1140b and its closer-in sibling planet, LHS 1140c, to test our predictions. We measured a metastable helium absorption signal for LHS 1140b with a signal-to-noise ratio of 6.4 indicating ongoing atmospheric escape, and a null detection for LHS 1140c. This marks the first detection of a primordial atmospheric constituent on a rocky planet orbiting an M dwarf. Previous HST and JWST surveys ruled out clear-sky, hydrogen-rich atmospheres to explain the slight under-density of LHS 1140b compared to a purely terrestrial composition. Our results are consistent with a helium-dominated upper atmosphere above a water-rich layer or a metal-rich lower atmosphere depleted in non-condensing, reducing species such as CH_4 and NH_3. Our non-detection of escape on LHS 1140c is consistent with a JWST dayside emission spectrum that suggested an airless body or a very optically thin atmosphere. The LHS 1140 system represents an important benchmark for constraining atmospheric loss for planets orbiting low-mass stars, as it comprises one super-Earth on each side of the cosmic shoreline. [This work is under consideration for publication in Nature. Please keep the content confidential.]

Brandon Coy, Contributed Speaker

University of Chicago

A Tentative Trend in the Brightness Temperatures of M-Earths

The James Webb Space Telescope (JWST) has ushered in a new era for the characterization of rocky exoplanets orbiting M stars (M-Earths) through thermal emission. In particular, detecting atmospheres on M-Earths through eclipse measurements is the objective of large scale JWST General Observer (GO) surveys and the ongoing Rocky Worlds Director's Discretionary Time (DDT) program. Most targets accessible to JWST, however, orbit small host stars whose enhanced x-ray and ultraviolet (XUV) radiation may be efficient at stripping secondary atmospheres.

Therefore, it is possible that most, if not all, rocky planets accessible to JWST observations will be consistent with 'bare rocks' lacking thick atmospheres. I will describe how in this case, thermal emission measurements can be used to probe surface processes, such as space weathering, thermal beaming, and grain sintering. However, eclipse depth precisions are often too low to draw conclusive statements for individual planets, emphasizing the need for population-level study of these observations. This is especially true for temperate planets most likely to host secondary atmospheres like TRAPPIST-1 c, where observations are consistent with either thin atmospheres or shiny surfaces.

I will present a tentative trend in the observed 'brightness temperature ratios' (the measured brightness temperature compared to a zero-albedo blackbody) of M-Earths, where colder planets exhibit higher inferred albedo, including new results from the Rocky Worlds DDT and Hot Rocks surveys. I will discuss the geophysical and atmospheric implications of this trend in the context of the 'Cosmic Shoreline', and how future JWST observations will be able to further constrain the cause of this trend.

Hannah Diamond-Lowe, Contributed Speaker

Space Telescope Science Institute

The Rocky Worlds DDT: Strategy, Status, and Early Results

The Rocky Worlds DDT Program approved by the Director of STScI is using ~500 hours of JWST time and ~250 HST orbits to tackle the question of whether or not rocky planets orbiting M dwarfs can retain atmospheres, and how the high-energy contribution from their host stars contributes to that outcome. So far four targets have been selected and first data sets have been taken; by the time of the workshop a final list of targets should be announced and additional data sets in hand. Data and standard data products will become available immediately, just like any large or legacy program. Higher level products generated at STScI will also be available as soon as possible, on timescales of days to weeks after data is taken. Our rapid and open data policies aim to encourage modellers, theorists, and observers to incorporate these data in their research. Here we will provide an overview of the motivation for the program, and latest updates on target selection, scheduling, and data products. We will share the observational strategies we are adopting to mitigate the challenges of observing small secondary eclipse signals of M dwarf rocky planets, as well as what is still needed for interpretation by the scientific community. Finally, we will discuss the possible outcomes of the Rocky Worlds DDT Program and how they will touch the (exo)planetary astronomical community at large—from understanding atmospheric dynamics, interior-exterior exchange, and mass loss rates on small worlds to what types of rock surfaces they might have, all in the presence of M dwarf hosts.

Kevin France, Contributed Speaker

University of Colorado at Boulder

The Extreme Ultraviolet Properties of Planet-hosting G, K, M Stars and Atmospheric Escape

Ultraviolet and X-ray spectroscopy are the primary tools for probing the hot upper atmospheres of cool planet-hosting stars. The 10 – 320 nm ultraviolet bandpass contains key diagnostics of the full temperature range from the chromosphere to the corona (log(T) = 4 – 7) and offers high flare-to-quiescent emission ratios for stellar flares studies. UV photons from the host star are absorbed high in a planet's atmosphere where they regulate the atmospheric temperature and chemical structure, influencing the long-term stability of planetary atmospheres and driving atmospheric photochemistry.

I will present a brief overview of how the UV properties of cool stars change with stellar mass, focusing on differences between solar-type stars and M dwarfs. I will review our empirical and theoretical understanding of the extreme-ultraviolet (10 – 91 nm) region that is critical for driving multiple atmospheric escape processes, with specific discussions on EUV evolutionary history of G vs M stars and the impact of stellar flares on atmospheric escape rates.

I will also highlight the role of stellar characterization in the JWST/HST Rocky Worlds Director's Discretionary Time (RW DDT) program in the context of the ``Cosmic Shoreline'', a framework for understanding atmospheric retention around red dwarf stars as a simplified balance between planetary gravity and cumulative UV and X-ray energy input into a planet's atmosphere. I will conclude by highlighting key gaps in our understanding of cool stars, particularly stellar EUV emission and the characterization of stellar coronal mass ejections, that motivate future observational efforts.

Renata Frelikh, Contributed Speaker

University of Colorado at Boulder

EUV Energy Sinks: Impacts of Radiative Cooling on Driving Hydrodynamic Outflows

We investigate the efficiency of extreme-ultraviolet (EUV) radiation in driving hydrodynamic outflows by spectral energy bin and chemical makeup at a given altitude in a planet atmosphere. We develop a flexible one-dimensional code to model the hydrodynamic escape driven by photoionization heating from EUV radiation. We include stellar spectrum heating and ionization, radiative cooling, heat conduction, tidal gravity, and a chemical network. For a fiducial hot Jupiter corresponding to solar-composition atmosphere, we uncover a three-layer structure: an H3+ -cooled layer of molecular hydrogen at the base, where secondary ionization and excitation due to superthermal photoelectrons are important. This is enveloped by a Lyman-alpha-cooled layer of neutral hydrogen, which transitions into an ionized wind layer that is cooled by adiabatic expansion. The highest spectral energy photons are deposited in the molecular layer. We run a grid of models, varying the distance of our fiducial planet from the star. We find that heat conduction starts to have a significant effect at distances >0.2 au, decreasing the mass-loss rate by energy loss through the base. At increasing stellocentric distances, the outflow transitions from ionized to neutral. The neutral hydrogen may potentially decouple from the ionized outflow, free-streaming out. In our pure H-He mini-Neptune/super-Earth simulations, the outflows are significantly cooler, allowing molecules to survive throughout the outflow, pointing toward the importance of molecular in determining whether these planets can maintain massive atmospheres.

Chase Funkhouser, Contributed Speaker

The University of Virginia

Towards a Better Understanding of Lyman-alpha Transits with Radiation Hydrodynamic Simulations

Lyman-alpha transits probe the transition between an exoplanet's atmosphere and the stellar wind. In this boundary region heating from ionizing stellar radiation, radiation pressure, and tidal forces sculpt the hydrogen envelope. Observations of transits in Lyman-alpha have been used as a tool for inferring a planet's mass loss rate, providing insight into the planet's evolution. Some models of atmospheric escape focus on pressure-driven winds supported by heating from the stellar ionizing flux. However, Lyman-alpha line forces from both the host star and internal recombination also provide a source of momentum that could drive hydrodynamic escape. To improve on previous models, we developed 3D radiation-hydrodynamic simulations that include optical depth effects to provide realistic intensities for computation of line forces and transmission spectra. These simulations couple ionizing radiation transfer and Lyman-alpha resonant scattering via a Monte-Carlo implementation to hydrodynamics through the Athena++ code. I will present results from our 3D simulations of the upper hydrogen-dominated envelopes of close-in exoplanets and discuss how observations of Lyman-alpha transits can inform models of atmospheric escape.

Eric Gaidos, Contributed Speaker

University of Hawaii

Water-Cooled sub-Neptunes Get Better Gas Mileage

Sub-Neptune planets are a more observationally accessible ``laboratory" for the physics of atmospheric evolution and escape which can be used to test models applied to smaller rocky planets, especially during their youth when they could also have possessed thick H-He-rich atmospheres. One key chemical player in atmosphere evolution is H2O, which modulates albedo by cloud formation and affects vertical temperature structure by infrared emission and absorption. Long-term transiting planet surveys like Kepler and TESS are probing wider orbits around low-luminosity K and M dwarfs where H2O can condense, aka the "habitable zone". We used an integrated hydrodynamic-radiation-chemical network model of X-ray/UV-driven outflow from sub-Neptunes to demonstrate that escape is regulated by the abundance of water: increasing the H2O/H2 at the base of the flow induces a 1 dex decline in the escape rate, with definitive consequences for the retention of envelopes over Gyr. Saturation limits on H2O in the upper atmospheres of temperate sub-Neptunes could explain the paradoxical observation that these objects disappear (i.e., lose their envelopes and transform into super-Earths) more rapidly than their warmer counterparts closer to their host stars. The scarcity of sub-Neptunes around very low-mass, late M-type stars could also be related to the water-poor chemistry of their antecedent protoplanetary disks. We discuss prospects for improved statistics with TESS and soon PLATO, and how observations of atmospheric H2O by JWST as well as searches for atmospheric escape from younger planets using lines of H and He can test these predictions.

Megan Gialluca, Contributed Speaker

University of Washington

A Systematic Exploration of Plausible Outgassed Secondary Atmospheres on the TRAPPIST-1 Planets

With the launch of JWST, M dwarf terrestrial planet atmospheres are accessible to observation and provide an important test case of atmospheric retention under extreme conditions. In particular, the TRAPPIST-1 system has been the subject of intense community interest due to its observational favorability and the existence of 7 Earth-sized terrestrials, which allow us to study the balance of atmospheric escape and replenishment as a function of distance from the host star. Significant JWST time has already been invested in the TRAPPIST-1 system and, most notably, emission photometry of the interior planets has indicated a lack of high pressure atmospheres, ruling out their potential as Venus analogs. Due to the high expected atmospheric escape on these planets, bare rock interpretations of the data are felt to be more likely than the possibility of tenuous (0.1 bar) atmospheres, which also fit the data. However, an in-depth study is needed to determine the feasibility of outgassing as a way to maintain low pressure atmospheres for these planets. In this work, we leverage coupled photochemical-climate modeling to systemically explore a broad range of atmospheric sources and sinks to identify plausible atmospheres with balanced outgassing and escape, for all 7 planets. For the interior planets, we show that constant water outgassing can sustain steady-state tenuous oxygen-dominated atmospheres that are still consistent with JWST data and our understanding of realistic geochemical planetary evolution. For the habitable zone planets, we find there are a range of atmospheric pressures consistent with literature constraints on outgassing, surface deposition, and top-of-atmosphere escape rates. Furthermore, we use Pandexo to simulate JWST observations of these atmospheres to determine if the currently awarded time for TRAPPIST-1e will be sufficient to discriminate any of the atmospheric scenarios identified in this work. Additionally, we use JWST noise modeling to search for future discriminants that may be observed on the interior planets to distinguish between the bare rock and tenuous atmosphere cases.

Leonardos Gkouvelis, Contributed Speaker

LMU-Munich

Stability of secondary atmospheres and observational manifestations.

This work focuses on the Earth-size planet LP 791-18 d, which is estimated to receive continuous tidal heating due to the orbital configuration of the system; thus, it is expected to exhibit volcanic activity. Using a 1D radiative-convective model coupled with chemical kinetics and an outgassing scheme at the lower boundary, we simulated the planet's atmospheric composition across a range of oxygen fugacities, surface pressures, and graphite activities. We estimated the mantle temperature of ≈1680 - 1880 K, balancing the competing contributions of interior tidal heating and convective cooling. Our results show that the atmospheric mean molecular weight gradient is controlled by oxygen fugacity rather than bulk metallicity. Furthermore, we used the atmospheric steady-state solutions produced from the interior redox state versus surface pressure parameter space, and explored their atmospheric stability. We find that stability is achieved only in highly oxidized scenarios, $f\ O2 - IW \gtrsim 2$, while reduced interior states fall into the hydrodynamic escape regime with mass loss rates on the order of ≈ 105 − 108 kg/s. We argue that scenarios with reduced interior states are likely to have exhausted their volatile budget during the planet's lifetime. Furthermore, we predict the atmospheric footprint of the planet's interior based on its oxidation state and assess its detectability using current or forthcoming tools to constrain the internal and atmospheric composition. We show that the degeneracy between bare rock surfaces and thick atmospheres can be resolved by using three photometric bands to construct a color–color diagram that accounts for potential effects from photochemical hazes and clouds. For JWST/MIRI, this discrimination is possible only in the case of highly oxidized atmospheres. The case of LP 791-18 d enables the investigation of secondary atmosphere formation through outgassing, with implications for similar rocky exoplanets. Our modeling approach connects interior and atmospheric processes, providing a basis for exploring volatile evolution and potential habitability

Xuan Ji, Contributed Speaker

University of Chicago

The Cosmic Shoreline Revisited: A Metric for Atmospheric Retention Informed by Hydrodynamic Escape

The "cosmic shoreline", a semi-empirical relation that separates airless worlds from worlds with atmospheres as proposed by Zahnle & Catling (2017), is now guiding large-scale JWST surveys aimed at detecting rocky exoplanet atmospheres. We expand upon this framework by revisiting the shorelines using existing hydrodynamic escape models applied to Earth-like, Venus-like, and steam atmospheres for rocky exoplanets, and we estimate energy-limited escape rates for CH4 atmospheres. We determine the critical instellation required for atmospheric retention by calculating time-integrated atmospheric mass loss. Our analysis introduces a new metric for target selection in the Rocky Worlds DDT and refines expectations for rocky planet atmosphere searches in Cycle 4. Exploring initial volatile inventory ranging from 0.01% to 1% of planetary mass, we find that its variation prevents the definition of a unique clear-cut shoreline, though non-linear escape physics can reduce this sensitivity to initial conditions. Additionally, uncertain distributions of high-energy stellar evolution and planet age further blur the critical instellations for atmospheric retention, yielding broad shorelines. Hydrodynamic escape models find atmospheric retention is markedly more favorable for higher-mass planets orbiting higher-mass stars, with carbon-rich atmospheres remaining plausible for 55 Cancri e despite its extreme instellation. Dedicated modeling efforts are needed to better constrain the escape dynamics of secondary atmospheres, such as the role of atomic line cooling, especially for Earth-sized planets. Finally, we illustrate how density measurements can be used to statistically test the existence of the cosmic shorelines, emphasizing the need for more precise mass and radius measurements.

Joshua Krissansen-Totten, Contributed Speaker

University of Washington

Modeling the primary to secondary atmosphere transition and implications for the cosmic shoreline

James Webb Space Telescope (JWST) observations of hot rocky exoplanets have revealed that many of these objects are seemingly airless rocks. For example, JWST observations of TRAPPIST-1 b (Greene et al. 2023), GJ 1132 b (Xue et al. 2024), and GJ 486 b (Mansfield et al. 2024) disfavor substantial atmospheres containing CO2. What, if anything, does this imply for the cosmic shoreline and the atmospheric retention prospects for habitable zone planets around low mass stars? Here, we investigate this question with a self-consistent model of atmosphere-interior evolution during the transition from primary to secondary atmospheres. The model incorporates all Fe-C-O-H-bearing species and simulates magma ocean volatile partitioning + solidification, radiative-convective climate, thermal escape, and mantle redox evolution. For the illustrative example TRAPPIST-1, our model predicts a comparatively thin atmosphere for the Venus-analog TRAPPIST-1 b, which would be vulnerable to complete erosion via non-thermal escape (consistent with JWST observations). However, the same model strongly favors secondary atmosphere retention for the habitable zone planet TRAPPIST-1 e. This difference arises because the duration of hydrodynamic escape on planets exterior to the runaway greenhouse limit is limited, and because surface water inventories are readily replenished by the reduction of FeO by H2. More broadly, we suggest that habitable zone planets around M-dwarfs such as TRAPPIST-1 are highly likely to retain secondary atmospheres across a broad swath of initial compositions, a prediction that is supported by tentative atmospheric detections on other comparatively temperate rocky planets, such as LHS 1478 b (August et al. 2025) and TOI-270 b (Coulombe et al., in review). Our atmospheric retention predictions are imminently testable with ongoing JWST thermal emission and transmission observations of temperate rocky exoplanets.

Alexandra Lehtmets, Contributed Speaker

University of Tartu

Atmospheric Escape and Chemical Fingerprints in Ultra-Hot Jupiters

Ultra-hot Jupiters orbiting close to early-type stars undergo extreme irradiation, driving atmospheric escape and the formation of extended, metal-rich exospheres. Using existing spectroscopic datasets from both space- and ground-based observations, I study a sample of such planets with confirmed detections of species including Na, H, and metal oxides. These observations are used to probe the vertical structure and chemical composition of their upper atmospheres, with particular focus on escape-sensitive features. In addition, I examine whether trace signatures of stellar photospheric contamination by evaporated planetary material can be identified. While such contamination is unlikely to be long-lasting, it may provide a unique, indirect probe of the escaping atmospheric composition. I also discuss whether observed species distributions are consistent with partial atmospheric replenishment, for instance through outgassing or vertical mixing. These findings contribute to a more complete picture of atmospheric mass-loss and chemical evolution in extreme exoplanetary environments.

Suvrath Mahadevan, Contributed Speaker

The Pennsylvania State University

The Surprising Leading Tail of Helium in TOI-3844b

TOI 3884b is a super-Neptune is a short period orbit around a M dwarf that exhibits persistent spot crossing in its transit lightcurve and is likely in a polar orbit around its host star. Using the infrared Habitable-zone Planet finder (HHF) spectrometer on the 10m Hobby Eberly Telescope we detect He10830 absorption before and during the transit of the planet. Such a large leading tail has been seen in systems like HAT-P-67b, which orbits a F star, and is likely due to a planetary wind being launched from the dayside. The existence of such a leading tail in a planet around a M dwarf is unexpected, and offers opportunities to understand the interplay of stellar activity, planet orbit, and planetary properties in a unique system. We will also discuss the challenges of interpreting He10830 signatures of evaporating planets orbiting active stars like TOI-3884, and how we are addressing these challenges with HPF.

William Misener, Contributed Speaker

Carnegie Institution of Washington

The transition between core-powered and photoevaporative mass loss with the aiolos hydrodynamic code

Two mechanisms are thought to be responsible for driving atmospheric escape from small planets: photoevaporation, in which a hydrodynamic wind is driven by UV irradiation, and core-powered mass loss, in which a bolometrically heated wind is sustained by cooling from the planetary interior. While existing models usually treat one process or the other, external UV heating and the release of heat from the interior should occur simultaneously. In addition, core-powered mass loss is usually modeled analytically using an isothermal wind. But many observed exoplanets are inferred to have non-isothermal stratospheres, caused by differences in molecular absorption in the visible and infrared potentially caused by outgassed species. To determine which process dominates in sculpting the observed demographics and how the two mechanisms interact, we use aiolos, a hydrodynamic radiative transfer code, coupled to a thermal evolution scheme to model core-powered and photoevaporative escape together for the first time. We find that under core-powered mass-loss alone, non-isothermal profiles can lead to orders-of-magnitude differences in atmospheric escape rates. Hotter stratospheres lead to faster loss, and differences in escape rate are larger for smaller radius planets. In the combined model, we find that a bolometrically heated wind occurs in the most inflated planets, in which UV absorption occurs above the bolometric sonic radius. As a planet contracts, there is an extensive transitional regime where the wind is heated partly bolometrically and partly by UV radiation, keeping atmospheric mass loss rates in between those predicted by core-powered mass loss and by the photoevaporative energy limit. In this regime, the thermal profile below the UV absorption radius, dictated by the molecular species present, continues to influence the mass loss rate. At small radii, escape rates approach the purely photoevaporative energy limit. These results unify the core-powered and photo-evaporative escape models into a cohesive paradigm and demonstrate how a coupled approach to atmospheric composition, escape, and evolution is vital to understanding small exoplanets.

Georgia Mraz, Contributed Speaker

McGill University

Time-variable Helium absorption in the exosphere of HD 189733b using NIRPS/HARPS

The prototypical hot Jupiter HD 189733 b has been extensively characterized due to its bright K-type host star (V = 7.7), deep transits (~2.4%), and period of 2.2 days. The host star is known to exhibit rotational variability and time-varying H-alpha absorption. However, the star's chromospheric activity indicators, such as Ca II H&K and H-alpha, remain contested in the literature. These lines have been seen in past transmission observations and may originate from a strong star spot or the planetary atmosphere. Among the 17 planets with confirmed detections of the helium triplet, HD 189733 b stands out for exhibiting clear variability. We have investigated the properties of HD 189733 b using four transits of simultaneous near-infrared and optical data recently obtained with the Near Infrared Planet Searcher (NIRPS) and High Accuracy Radial Velocity Planet Searcher (HARPS) instruments at ESO's La Silla Observatory. NIRPS is sensitive to molecules in the planetary atmosphere and helium in its exosphere, while HARPS is sensitive to stellar activity indicators. The NIRPS data reveal well-behaved systematics, clear molecular signatures, and helium detections. The HARPS data reveal indications that stellar activity may be amplifying the planetary helium signal. The simultaneous near-infrared and optical data provide a unique opportunity to investigate the connection between stellar activity and the proposed variation in the helium triplet, putting in context the previous detections of planetary helium on HD 189733 b.

Laura Neves Ribeiro do Amaral, Contributed Speaker

Arizona State University

The Role of Stellar Flares from Early and Late M Stars on the Atmospheric Escape of Rocky Planets

JWST observations suggest that the TRAPPIST-1 planets and many other terrestrial worlds orbiting field-age M stars may lack atmospheres, likely due to intense stellar flaring. While high-energy stellar activity is known to drive atmospheric loss, its precise role in the survival of rocky-planet atmospheres remains unclear. Here we quantify how primordial atmospheres of terrestrial planets evolve under flares from early- and late-type M stars. We develop an age-dependent flare frequency distribution model, based on TESS light curves and scaled to XUV wavelengths, to track atmospheric loss over time. Our results show that extra XUV flux from flares accelerate atmospheric depletion for all types of M-stars. This process typically occurs within ~2 Gyr earlier than when only quiescent emission is considered, which the most impacted planets are located in the habitable zone. For rocky planets located at the outer edge of the habitable zone, the additional XUV from flares is necessary to fully deplete primordial atmospheres, as quiescent emission alone is insufficient. For close-in rocky planets, quiescent stellar emission alone can remove atmospheres within a few hundred Myr. These findings suggest that searches for atmospheres around active M-star planets should prioritize (1) young systems where primordial atmospheres may persist, and (2) planets at or beyond the habitable zone's outer edge.

Jaume Orell-Miquel, Contributed Speaker

University of Texas at Austin

From Youth to Maturity: Tracing Atmospheric Loss in Exoplanets Across Time

During the early stages of planetary formation, planets suffer severe changes in their physical and orbital properties due to internal and external forces, which also affect their primordial atmospheres composed mainly of hydrogen and helium. The study of planets at early stages and their comparison with the already mature planet population is crucial for a better comprehension of different processes, such as: planet formation, evaporation of primary atmospheres of rocky planets, gas accretion or inflation.

As part of a large project to study the evolution, outflow, and evaporation processes of exoplanet atmospheres across different planet types and host stars, we conducted high-resolution transmission spectroscopy of more than 30 exoplanets to explore their atmospheres through the two principal ground-accessible evaporation tracers: Halpha in the visible, and He triplet in the infrared. We focused on young planets, in particular the sub-Neptune and mini-Neptune population with well constrained ages of less than 1Gyr. We complemented our survey with (nearly) all the available literature results, building the largest dataset of evaporation observations. We compared the observational results between young and old planet populations, using a sample that covers a wide range of the Mass-Radius-Period parameter space. This broad range of studied planets allows us to obtain a general understanding of atmospheres across different ages, radii, and temperatures, while minimizing observational biases in the sample. In addition, this large sample helps to identify what the next steps should be to understand the processes and mechanisms of evaporation. This talk is based on published and new results from the MOPYS (Measuring Outflows in Planets around Young Stars) survey, complemented by the observations from the large HET/HPF helium survey and preliminary results from helium observations with the new high-resolution spectrograph NIRPS.

Emily Pass, Contributed Speaker

Massachusetts Institute of Technology

The Receding Cosmic Shoreline of Mid-to-late M Dwarfs

Can the planets of mid-to-late M dwarfs retain atmospheres within the 'cosmic shoreline' paradigm originally presented in Zahnle & Catling (2017)? Previous works modeled the historic X-ray and ultraviolet (XUV) radiation received by mid-to-late M-dwarf planets using a scaling relation calibrated using more massive stars, but fully convective M dwarfs display unique rotation/activity histories that differ from Sun-like stars and early M dwarfs. We synthesize observations of the active lifetimes of mid-to-late M dwarfs to present an updated estimate of their historic XUV fluence. For known planets of inactive, mid-to-late M dwarfs, we calculate a historic XUV fluence that is 2.1–3.1 times the canonical XUV scaling relation on average, with the larger value including corrections for the pre-main-sequence phase and energetic flares. We find that only the largest terrestrial planets known to orbit mid-to-late M dwarfs are likely to have retained atmospheres within the cosmic shoreline paradigm.

Caroline Piaulet-Ghorayeb, Contributed Speaker

University of Chicago

JWST insights into GJ 9827 d's atmosphere and redox state: a benchmark for rocky planet interiors

In recent years, JWST's sensitivity has opened a "small sub-Neptune opportunity", paving the way for atmospheric reconnaissance on rocky exo-Earths. Indeed, the atmospheres of the smallest sub-Neptunes are ideally puffy for chemical characterization, but thin enough to carry the imprints of both chemical exchanges with their interiors and atmospheric escape over Gyr timescales.

The 2-Earth-radii warm (680 K) planet GJ 9827d is the smallest sub-Neptune to be chemically characterized with JWST to date, with NIRISS/SOSS revealing its "steam world" water-rich atmosphere. We will present new results from two additional JWST NIRSpec/G395H transits, enabling constraints on major carbon-, oxygen-, and potential sulfur-bearing species. Importantly, this new window into GJ 9827 d's chemical composition enables us to constrain its mantle's present-day oxidation state, a measurement still elusive for rocky exoplanets but crucial to assess their atmospheric detectability as probed by e.g. CO2 features. We "turn back time" on the mantle composition by modeling its compositional evolution regulated by both the evolving relative solubilities of different volatile species, and fractionated atmospheric escape. Combining insights from atmospheric modeling, interior-atmosphere retrievals, atmospheric escape and stellar characterization, GJ 9827d serves as a benchmark for the study of rocky planet interiors as well as the origins of atmospheric metal enrichment on small sub-Neptunes.

Emma Postolec, Contributed Speaker

University of Groningen

Atmospheric evolution and escape on molten rocky exoplanets

The atmospheric composition of gaseous and sub-Neptune exoplanets can now be identified thanks to JWST observations, but remains challenging for rocky planets such as super-Earths. Rocky planets atmospheres are molded by several phenomena: initial volatile budget, radiation from the host star, the escape of volatile species and more. On planets with largely molten planetary mantles, magma oceans, the volatile species present in the atmosphere, such as H2O or CO2, interact strongly with the interior through various processes like in- and outgassing. Escape mechanisms strongly shape the chemical evolution of magma ocean atmospheres. We aim to estimate the mass loss rate induced by escape mechanisms for some volatile species in the atmosphere of lava planets, evolving on geologic timescales. We use a coupled interior-atmosphere model (PROTEUS) to simulate the evolution of rocky planets during the magma ocean era, focusing on the atmospheric escape induced by the interaction between volatile escape and outgassing from the planetary interior.

Morgan Saidel, Contributed Speaker

California Institute of Technology

Results from the First Mass Loss Survey of Fstar Planets: Implications of Spectral Type on Mass Loss

Close-in exoplanets experience intense irradiation from their host stars, driving atmospheric escape that can catastrophically alter planetary evolution. In order to understand how these processes shape the close-in exoplanet population, we must develop accurate forward models to predict atmospheric mass loss and validate these models against observations of present-day mass loss rates. However, most planets with published mass loss measurements orbit K star hosts, and are therefore not fully representative of all exoplanet populations. The first and only two detections of atmospheric escape on planets orbiting hotter F stars reveal significantly more extended and faster outflows than those observed for planets orbiting K stars. This is surprising, and hints at the possible presence of additional energy sources (e.g., Balmer-driven escape) that can drive outflows for planets orbiting hot stars.

We recently initiated the first dedicated mass loss survey of planets orbiting F stars in order to determine whether these first two detections are representative of the broader population, and to test competing models for the physics and origin of the fast observed outflow rates. We report two tentative (2σ) and two strong (>3σ) detections of outflows for four additional gas giants orbiting F stars. We explore several potential factors that may affect the outflow rates on planets orbiting hot stars, including XUV flux, NUV flux, and Roche lobe overflow. Our new detections underscore the importance of expanding our observational studies of atmospheric escape to a wider range of stellar environments in order to develop a more accurate population-level understanding of the expected mass loss rates and atmospheric lifetimes of exoplanets on close-in orbits.

Matthäus Schulik, Contributed Speaker

Imperial College London

New physics incorporated into atmospheric escape models solves the mystery of missing Helium transit

The first large scale Helium 10830A surveys indicate a surprising lack of transit observations in the population of Sub-Neptunes, which surely harbour Hydrogen/Helium rich atmospheres.
This is even more confounding as established models predict enormous transit depths in this important atmospheric escape tracer. Solving this tension is crucial not only for measuring mass-loss rates from Sub-Neptunes, but also needed to formulate expectations for the usefulness of the Helium line as tracer of Super-Earth atmospheric escape.
In this talk, we will present updates of the common theoretical models which are needed to explain the dearth of Sub-Neptune escape signals. This encompasses molecular outflows, so far entirely ignored in the Helium escape literature and we provide updates to the kinetic rates used to compute the Helium line populations. We will discuss the physics which controls the switch between detection and non-detection, and emphasize that Hydrogen, Helium and metals should be seen as independent components, where H/He do not necessarily co-evolve. To this end, we will further present new evolutionary models and illuminate the time scales during which a planet can be observed in Helium, as it looses its light gas inventory.

Yao Tang, Contributed Speaker

University of California - Santa Cruz

Reassessing Atmospheric Escape in Sub-Neptunes: Three Mechanisms Coupled to Evolution Model

It was first suggested over a decade ago that sub-Neptunes can lose their envelopes through atmospheric escape, becoming super-Earths. However, the relative importance of stellar XUV-driven escape, core-powered mass loss, and post-formation boil-off remains unclear.

We address these issues by incorporating all three mass loss mechanisms into a new 1D sub-Neptune thermal evolution model with real hydrodynamics for photoevaporation, realistic radiative atmospheres, detailed core energy transport, and metallicity effects. Our analysis reveals that boil-off and core-powered mass loss are not limited by core luminosity. With proper boil-off initial conditions, long-lived core-powered escape rates are orders of magnitude lower than previous estimates.

Our findings predict larger radii for a given H/He mass fraction, indicating present-day sub-Neptunes retain 50% less H/He than previously thought. Boil-off accounts for 80-90% of total mass loss, with photoevaporation contributing 10-20%. In low-gravity planets, metallicity primarily increases atmospheric mean molecular weight, reducing scale height and suppressing all escape mechanisms.

We identify a new low-gravity XUV-driven mass loss regime, important for sub-Neptunes, called thermal-energy-mediated photoevaporation (TEMP), where thermal energy conversion critically sets mass loss rates. This reveals significant mass-loss overestimation in energy-limited escape models. We provide TEMP scaling laws and validate our framework by reproducing the observed properties of super-puff exoplanets. Our work establishes a new understanding of the dominant mechanisms shaping the sub-Neptune population.

Anna Ruth Taylor, Contributed Speaker

University of Arizona

Exploring atmospheric escape from hot-Jupiters and water-rich sub-Neptunes

Understanding atmospheric escape from hot Jupiters and sub-Neptunes is critical for constraining exoplanet evolution, demographics, and star-planet interactions. Observations of escaping atmospheres increasingly probe excited states of hydrogen and helium, including the He I 1083 nm triplet and H I Balmer lines. These features provide sensitive diagnostics of mass loss, thermal structure, and non-LTE level populations but have at times proven difficult to interpret. We present results from a full-atmosphere model framework that connects results from a multi-species thermosphere-ionosphere escape code with a 1D lower atmosphere model. We apply this modeling framework to three hot Jupiters—HD 209458b, HD 189733b, and HD 149026b—and find that while their atmospheric temperature and velocity structures are broadly similar, the observed and modeled transit depths are widely varying and do not appear to follow recent scaling laws proposed in the literature. We further demonstrate that the predicted He I 1083 nm absorption is highly sensitive to multi-species transport processes, stellar activity, and the inclusion of metals in the atmosphere. These results highlight the need for detailed modeling to interpret transit observations. We extend the framework to sub-Neptunes, including new models with H2 and other molecules. This model enables investigation of how composition regulates escape structure and observables. Together, these results inform strategies for extracting physical meaning from spectroscopic data and improve our understanding of the role that composition, structure, and external forcing play in shaping exoplanet atmospheres.

Johanna Teske, Contributed Speaker

Carnegie Institution of Washington

A thick volatile atmosphere on an ultra-hot super-Earth

Ultra-short period (USP) exoplanets – with radii ≤ 2 REarth and periods ≤ 1 day – are expected to be stripped of volatile atmospheres by intense host star irradiation, which is corroborated by their bulk densities and previous eclipse observations consistent with bare rock surfaces. However, a few USP planets appear anomalously under-dense, suggesting they are enveloped by vapor, defying expectations of atmospheric loss. One proposed explanation is that volatiles locked up in the planet interior are replenishing a secondary atmosphere that experienced inhibited escape. This scenario would offer the exciting opportunity to observationally investigate the exchange of atmospheric volatiles with the interiors in rocky exoplanets. The ultra-short period exoplanet TOI-561 b is both under-dense and orbiting an old, thick disk star, making its formation environment distinct from the Solar System as well as other USP planets. In this talk, we present our JWST NIRSpec/G395H observations of TOI-561 b that are highly inconsistent with a bare-rock surface, suggesting instead a thick volatile envelope is cooling the dayside of this planet. Our findings thus contradict the hypothesis of atmospheric desiccation for highly irradiated exoplanets, and support predictions that planetary-scale magma oceans can retain substantial volatile reservoirs. Overall, studying USP planets offers important context for the low-mass exoplanet population and the optimal strategy for characterizing their atmospheres, showing that this will require coupled models of atmospheric escape and geochemical internal evolution.

Trent Thomas, Contributed Speaker

University of Washington

Water outgassing as a source of secondary atmospheres on the TRAPPIST-1 exoplanets

The TRAPPIST-1 planetary system is observationally favorable for studying the balance of atmospheric escape and replenishment on planets orbiting M stars. Recent JWST observations rule out thick CO2 atmospheres on the interior TRAPPIST-1 planets, but atmospheric water vapor and its photochemical product, oxygen, may still be present. Given the high expected atmospheric escape rates on planets orbiting M stars, maintenance of atmospheric water vapor would require a present-day water source, such as volcanic outgassing. Here, we simulate water outgassing on the TRAPPIST-1 planets over a broad phase space that is based on solar system bodies and constrained with observational and theoretical knowledge of TRAPPIST-1. For all seven TRAPPIST-1 planets, we find that the water outgassing rate is most likely ∼0.03x Earth's but has upper limits of ∼8x Earth's. We also constrain other aspects of the TRAPPIST-1 planet interiors, like the magma emplacement rate and mantle water content. We find that water outgassing rates are likely high enough to balance water escape rates, providing a theoretical pathway for the TRAPPIST-1 planets to maintain surface water or water-vapor-containing atmospheres over long timescales. The bounds on outgassing rates and interior properties can be used in atmospheric chemistry and escape models to contextualize future observations of the TRAPPIST-1 planets, and may be applicable to other terrestrial exoplanets.

Shreyas Vissapragada, Contributed Speaker

Carnegie Institution of Washington

Towards Precise Constraints on Atmospheric Evolution for 50 Sub-Neptunes

Sub-Neptunes are the most common short-period (P < 100 d) planets in the galaxy, but their evolutionary histories remain a major mystery for the field. Demographic evidence alone cannot currently distinguish the roles of photoevaporation, core-powered mass loss, and gas-poor formation in sculpting the distribution of sub-Neptune sizes and masses. Observations of atmospheric escape processes in action can help clarify the physical mechanisms responsible for sub-Neptune evolution. We have recently formed the WINERED Helium Consortium to help advance the field towards a better understanding of these processes. Using the Magellan/WINERED instrument, members of our consortium are making precise measurements of metastable helium, a tracer of atmospheric escape that can help diagnose physical conditions in the upper atmospheres of exoplanets. By measuring metastable helium absorption to at least 0.2% precision in a sample of 50 sub-Neptunes, we will help disentangle the roles of photoevaporation and core-powered mass loss in a statistical sample of small planets, all while delivering a sample of planets with known low-Z atmospheres that are suitable for targeted JWST followup. By the start of the STScI workshop, this effort will be over halfway done. We will present some of the first results from this extensive observational campaign, including a high-SNR detection of helium in a planet only three times the mass of the Earth -- the lowest-mass planet to have its atmosphere robustly detected from the ground to date.

David Wilson, Contributed Speaker

University of Colorado at Boulder

MUSCLES and MANTIS: Efforts to measure the extreme ultraviolet light from exoplanet host stars.

The extreme ultraviolet (EUV) light that exoplanets receive from their host stars is the key driver of atmospheric escape. Quantifying the EUV fluxes emitted by stars is thus vital, but is stymied by a lack of empirical data, due both to inadequate observing facilities and the difficulties of observing through heavy interstellar absorption. Fortunately, multiple techniques allow us to infer the unobservable EUV flux from the accessible ultraviolet and X-ray wavebands, albeit with considerable uncertainty.

To this end, multiple programs have collected or are collecting panchromatic data of an increasingly large sample of stars with HST and the X-ray telescopes and combining them into high-quality Spectral Energy Distributions (SEDs). I will discuss the latest results from the MUSCLES family of projects, which has obtained ultraviolet and X-ray spectroscopy for a plethora of M dwarfs and JWST planet target host stars, with a focus on the EUV and its consequences for JWST planets.

Looking to the future, I will also provide an overview of the MANTIS cubesat. Launching in 2027, this groundbreaking cubesat mission will obtain EUV spectra of exoplanet host stars, finally providing the empirical data to fill this crucial gap in our understanding of atmosphere escape processes.

Qiao Xue, Contributed Speaker

University of Chicago

Hot rocky planets through NIRSpec's eyes: what we learned from phase curves

Rocky planets orbiting M dwarfs (M-Earths) lie at the frontier of characterizing exoplanet atmospheres: they are the most common planets in the Galaxy, and their planet-to-star flux ratio makes them favorable for observation follow-ups. However, intense stellar irradiation can strip primordial volatiles, and the threshold at which atmospheres are lost in these worlds remains uncertain. Detecting atmospheres on M-Earths through secondary-eclipse measurements with JWST is a central goal of multiple GO programs and the ongoing Rocky Worlds DDT program.

In this talk, we present results for two M-Earths that probe a previously unexplored range in irradiation (Tirr) space—TOI-2445 b and TOI-1685 b. We obtained full-orbit JWST/NIRSpec phase curves with PRISM for TOI-2445 b and G395H for TOI-1685 b. The blue end of PRISM (0.5–2 μm) provides a simultaneous reference for stellar variability; a Gaussian-process model fitted to this region removes activity-induced noise from the thermal-emission band, dramatically improving sensitivity to planetary signals.

From the corrected phase curves, we retrieve dayside and nightside brightness temperatures for both planets, constraining their albedos and heat redistribution efficiencies, which are key diagnostics for the presence or absence of an atmosphere. Unlike single-eclipse measurements, these continuous phase curves can break the surface–atmosphere degeneracy.

Finally, we place these results in a population context by combining our NIRSpec phase curves with existing MIRI/LRS, imaging and the new DDT data on rocky planets. Together, the data will map out the existence or absence of atmospheres across a more complete range of temperatures, guiding future atmospheric searches on JWST and beyond.

Michael Zhang, Contributed Speaker

University of Chicago

Escaping helium from young mini-Neptunes in the southern sky

The helium line at 1083 nm is a rich probe of atmospheric physics. It constrains not only the mass loss rate, temperature, and mechanism, but also the atmospheric metallicity and magnetic field--properties that have often proven difficult to probe with other methods. To get insight into these properties, we are conducting an all-sky survey of escaping helium from young mini-Neptunes. Here, we report the progress of our southern-sky survey with Magellan/WINERED. The results are more varied than those from the northern sky, and include two strong detections of optically thin outflows, one detection of a strongly confined optically thick outflow, and one tentative detection of an episodic outflow from an unusually dense and eccentric planet. Combining these data with contemporaneous stellar X-ray spectra from XMM-Newton and eROSITA, we self-consistently model the outflows with our new open-source code, pyTPCI, and demonstrate their power in informing the nature and evolution of mini-Neptunes--as well as the substantial modelling challenges which need to be resolved.

ATMOSPHERIC ESCAPE and REPLENISHMENT in PLANETARY SYSTEMS

NOVEMBER 4–7, 2025

Poster Abstracts

STScI

Saugata Barat, Poster Presenter

Massachusetts Institute of Technology

Exoplanets through time: First glimpse of the evolving atmospheres of young transiting planets

Transiting planets younger than 100 Myr represent the earliest phase of evolution. We present the first atmospheric characterization study of a benchmark young transiting planet, V1298 Tau b (10-30 Myr old) using HST and JWST observations.

Using these observations we measure the mass of this young planet, which has been challenging to obtain from RV studies owing to extreme stellar activity. Furthermore, we precisely constrain its atmospheric composition and compare it with the mature exoplanet population, as well as with other young transiting planets to test the effect of ongoing evolution on atmospheric metallicity. We also infer the internal entropy of V1298 Tau b from its transmission spectrum and compare it with predictions from interior structure evolution model.

Ultimately, these observations, for the first time, provide observational constraints on the atmospheric properties and mass of a young sub-Neptune, which allows us to model its atmospheric mass loss and predict its subsequent evolution. We compare the predicted atmospheric mass loss rate for this planet with constraints from ground based high resolution observations of this system.

Grace Bischof, Poster Presenter

York University

Characterization of Rocky Planet Atmospheres through Lyman-alpha Transit Observations

Lyman-α transit spectroscopy has been successfully used to detect atmospheric escape from large, highly irradiated planets, aiding in the characterization of atmospheric properties including mass loss rates. To date, Lyman-α transits for rocky planets have yielded only non-detections, possibly due to limited hydrogen escape from Earth-sized planets. However, despite these non-detections, Earth's own hydrogen exosphere extends past 38-Earth radii, with modelling suggesting an Earth-like exosphere may be detectable with future space telescope technology (1).

Our work seeks to aid in diagnosing the composition of rocky exoplanet atmospheres by simulating Lyman-α transits. For example, how does the Lyman-α transit of a water-rich planet, like Earth, compare to that of a desiccated planet like Venus? Can these differences be discerned with future technology? To test this, the escape of hydrogen from a wide range of rocky exoplanets is modelled, where parameters in the upper atmosphere, such as temperature and the mixing ratio of hydrogen, are varied. We model either a Jean's-like or hydrodynamic escape based on the properties of the atmosphere, which result in a hydrogen exospheric profile from which we compute the Lyman-α transit depth. We examine trends in the transit depth to provide insight into the atmospheric characterization of rocky planets observed with future space telescope technology.

David Brain, Poster Presenter

University of Colorado at Boulder

Modeling atmospheric escape of secondary atmospheres from rocky exoplanets

Consideration of the full suite of thermal and non-thermal escape processes has proved important for understanding the history and current state of the atmospheres of rocky planets in the solar system. The importance of each process in determining atmospheric escape rates varies with the atmospheric species being considered, the time in solar system history being considered, and the properties of the planet.

In this presentation, we provide an overview of an interdisciplinary effort to model atmospheric escape from a variety of planets and host stars. The effort (RHAPS- Retention of Habitable Atmospheres in Planetary Systems) features end-to-end modeling of planetary thermospheres, ionospheres, exospheres, magnetospheres, and escape processes given inputs about the stellar EUX/Xray flux and stellar wind. It also features redundant models for many aspects of the upper atmosphere and escape, allowing coarse estimates of uncertainties. We show RHAPS results for present-day Mars if it orbited Barnard's star, and for Venus orbiting G stars of varying age. We preview upcoming modeling cases for the RHAPS team, featuring planets orbiting a variety of M stars.

Andrea Caldiroli, Poster Presenter

Como Lake Center for Astrophysics, University of Insubria, Como, Italy

The effect of M-dwarf flares on sub-Neptunes' atmospheric evaporation

M-type stars are prime targets for exoplanet searches within their habitable zones (HZs). These stars also exhibit significant flaring activity, especially during the first billion years, which can potentially accelerate the evaporation of the hydrogen-helium envelopes of close-in planets. The increased irradiation can influence the atmospheric retention of close-in Neptune-sized planets, including within the HZ. Using the time-dependent photo-ionization hydrodynamics code ATES, we investigate the impact of flares on atmospheric escape, focusing on a sub-Neptune-sized planet orbiting an early M-type star. Our results indicate that flares have a modest impact on increasing the cumulative atmospheric mass loss. The relative enhancement in mass loss between flaring and non-flaring cases depends on the orbital distance, with the greater enhancement observed at larger separations. This trend arises because, as stellar irradiation fluctuates between quiescent levels and peak flares, the proportion of time the planet spends in energy-limited versus recombination-limited mass loss regimes depends on its orbital separation. Additionally, our approach allows to demonstrate the existence of a characteristic flare energy, intermediate between the minimum and maximum values, that maximizes the fractional contribution to flare-driven mass loss. The potential occurrence of rare super-flares, which observational campaigns might be biased against, does not alter our conclusions.

Richard Chatterjee, Poster Presenter

Richard Chatterjee, Shane Carberry Mogan, and Robert E. Johnson

The Exosphere Connection: Bulk-Kinetic Outflow of Rocky Planet Atmospheres

The energetics and dynamics governing the transition from Jeans escape to transonic photoevaporation remain poorly characterized, yet this regime is crucial for understanding the irreversible loss of secondary atmospheres and the cosmic shoreline. Our ongoing work investigates this transition in the photoevaporation of exo-Earth and super-Earth atmospheres, building on the foundational study by Johnson et. Al. (2013, ApJL). This poster presents simulations of thermally simulations of thermally conductive outflow of a monatomic nitrogen atmosphere from an Earth-sized planet, spanning collisional to collisionless regimes. The absence of persistent heating up to the exobase in the preliminary setup limits the possibility of rapid escape. Nevertheless, these preliminary results highlight the influence of the exosphere on atmospheric structure and show that, for a sufficiently hot thermosphere, bulk outflow enhances escape rates above the classical Jeans rate.

Yixuan Chen, Poster Presenter

Imperial College of London

Mapping the atmospheric escape regimes of water-rich sub-Neptunes

Observations suggest that a fraction of sub-Neptunes possess water-rich atmospheres. However, the presence of clouds and hazes often obscures these atmospheres, making direct characterisation via transmission spectroscopy challenging. Atmospheric escape provides an alternative observational window into atmospheric composition and evolution. Accurate modelling of escape processes in water-rich sub-Neptunes is therefore essential for interpreting future observations and deepening our understanding of these planets' atmospheres. In this talk, I will present new results using AIOLOS—a time-dependent, radiative-transfer hydrodynamic code—to map the atmospheric escape regimes of sub-Neptunes with steam atmospheres. I will show how key properties such as mass-loss rates, atmospheric structure, and outflow composition vary across orbital distances and stellar types. Finally, I will discuss what these variations imply for sub-Neptune composition and formation, and how atmospheric escape signatures can inform demographic studies and observational strategies.

Leonardo Dos Santos, Poster Presenter

Space Telescope Science Institute

A magnetic star-planet interaction candidate signal observed during transits of a young exoplanet

Models of evaporation driven by X-ray and extreme ultraviolet irradiation predict that short-period exoplanets experience intense mass loss in their early lives, when their host stars are the most active. In this context, the 45 Myr-old gas giant DS Tucanae Ab stands out one of the best targets for observations of evaporation due to host star brightness as observed from Earth. We observed three far-ultraviolet (FUV) transits of DS Tucanae Ab with the Hubble Space Telescope aiming to detect, in Lyman-alpha, its H-rich exosphere fed by mass loss. We serendipitously observed one FUV flare that is among the most energetic events detected to date for a late-type star. In the epochs mid-2022 and early-2023 we observe a 5-sigma absorption of ~17% in the red wing of the stellar Lyman-alpha line about four hours before mid-transit and again immediately after transit egress, between Doppler velocities +100 to +400 km/s in the stellar rest frame. This signal suggests the presence of a large cloud of neutral H infalling into the host star at high velocities, possibly originating from atmospheric escape in DS Tucanae Ab. We propose that the extended planetary exosphere is being shaped by sub-Alfvenic interactions with the stellar wind and magnetic field.

Girish Duvvuri, Poster Presenter

Vanderbilt University

We Only See Fractions of Flares

We present two multiwavelength flare observations of GJ 4334, an M dwarf with an intermediate rotation period of 23.5 days, that present very differently across the observed wavelength regimes: the first was observed simultaneously with Hubble STIS G140L (1160 -- 1710 Angstroms) and the Dual Imaging Spectrograph at Apache Point Observatory (3750 -- 5050; 5800 -- 6950 Angstroms) and the second was observed simultaneously in the near ultraviolet and X-ray using the instruments aboard XMM-Newton. Both flares show a multiple-stage release of energy and an extended period of high-energy emission after the flare that could be mistaken for quiescence if we had not observed the flare first. The first flare would likely not have been detected by TESS because it did not brighten the optical continuum and most of the second flare's X-ray emission lacks a near ultraviolet counterpart. These flares highlight the limits of what we know about how different wavelength regimes vary during flares and warn us that our models of atmospheric escape during flares are largely informed by inaccurate time-dependent spectral energy distributions and inaccurate statistics at high-energy wavelengths.

Anselo Falorca, Poster Presenter

Leiden University

Influence of Stellar Winds on Photoevaporating Hot Jupiters through the HeI line (1083 nm)

Close-in exoplanets are subject to high levels of extreme ultra-violet radiation (XUV) flux - this is particularly relevant for Hot Jupiters. Such conditions make these exoplanets undergo hydrodynamic atmospheric escape by means of the photoevaporation mechanism. The metastable helium (He) triplet line at 1083 nm (HeI line) has been shown to be a good marker to detect and quantify atmospheric escape. However, most theoretical models remain limited to 1D geometries and usually neglect the role of stellar winds - which has only been thoroughly studied in 3D models with the Hydrogen (H) Ly-alpha line.

Here, I present new insights from ongoing work of realistic atmospheric escape simulations with HeI synthetic spectra. We have developed a radiation-hydrodynamic model with self-consistent population-chemistry dynamics between H and He gas particles, evolved in a 3D cartesian framework with the code BATSRUS. We use the Hot Jupiter HD209458b as case study under different stellar host environments, with irradiation flux divided into 4 wavelength bands (mid-UV, soft-EUV, hard-EUV, X-ray) and exploring 3 cases of distinct stellar wind strengths.

The results reveal distinct morphologies of planetary material interacting with different stellar winds, characterized by the overall chemistry of the escaping outflow. Consequently, the HeI line in the ray-tracing technique captures clear in-transit and out-of-transit signatures of escaping material. Interpretation of transit depth results and hydrodynamic flow components like Mass-Loss rate allow us to assess current (and future) observations, and to address key open questions regarding the interplay between stellar winds, radiation, and atmospheric escape.

Eric Feigelson, Poster Presenter

Pennsylvania State University

Chandra surveys measure X-ray irradiation of young planets

Since the beginning of its mission, NASA's Chandra X-ray Observatory has devoted months to observations of young star clusters with ages ranging from 0.5 to >500 Myr. The detection of tens of thousands of young stars, together with nondetection of cluster members, allows high-quality measure of the evolution of magnetic activity as a function stellar mass. During the pre-main sequence phase, emission is roughly constant at an extremely high level with frequent superflares orders magnitude more powerful than contemporary solar flares.

The emission decays in a mass-dependent fashion as magnetic field generation changes from an efficient distributed convective dynamo to the solar-type less-efficient tachoclinal dynamo (Getman+ 2025).

These empirical results provide inputs to XUV irradiation models of nearby molecular material, initially protoplanetary disks and later primordial and secondary atmospheres of young inner planets. Existing calculations of disk and atmospheric photoevaporative losses are often based on simplistic inputs that differ from our survey findings.

An open question is whether coronal mass ejections scaled to the X-ray luminosities also impact the young planets. If so, atmospheric escape may be considerably faster than previously thought with implications for planetary evolution and habitability.

Makayla Frisse, Poster Presenter

University of Florida

A Method for Constraining the EUV Flux Variations of Sun-Like Stars using Optical Photometry

Context: Strengthening our understanding of stellar activity in the EUV regime is a vital step toward better assessing exoplanet habitability. Ionizing radiation considerably impacts a planetary atmosphere's composition, density, temperature, and escape rates, which are integral to the planet's environmental characteristics and ability to support life. High EUV irradiance can cause extreme loss of critical species such as oxygen, carbon, and nitrogen. Such considerations will be vital for future work and missions such as the Habitable Worlds Observatory (HWO), particularly with target selection in mind. There is a dearth of direct EUV observations of stars due to a lack of integration of the required technology with space-based observatories. This contributes to a notable knowledge gap of this spectral range.

Aims: We aim to investigate the presence of trends among quiet and flare-driven flux variations between the optical and EUV regimes by studying the sun as-a-star. Thereby constraining a star's EUV flux using known values, these results will work to supplement the EUV knowledge gap.

Methods: We conduct an empirical and quantitative study of the relative photometry in the EUV (94, 131, 171, 193, 211, and 304 Å) passbands observed by SDO/AIA and integrated 1D solar spectroscopy from HARPS-N. We examine the relative flux variations over a total of ~100 hours of observations taken between 2015 and 2025, including both during solar events and periods of lower activity. These data will be examined for statistically significant correlations, accounting for the possibility of non-linear and multidimensional functional results. By convolving HARPS spectra with Tess and Kepler wavefunctions prior to the integration, we obtain simulated sun-as-a-star observations in the EUV from the perspective of currently available observations.

Results: We will determine any correlations between the relative flux in the EUV and optical regimes for a sun-like star. This would include the energy in physical units released by EUV radiation that coincides with an optical brightening. We also plan to find how this relationship may vary depending upon particular wavelength ranges or flux magnitudes.

Conclusions: We plan to determine whether or not we can utilize pre-existing and current observations from TESS and/or Kepler to indirectly measure the EUV flux of other sun-like stars. This method would be able to provide an empirically driven quantitative measurement of the prevalence and intensity of EUV radiation output of the target stars, before technology to widely observe these stars in the EUV regime becomes available.

Cynthia Froning, Poster Presenter

Southwest Research Institute

The XUV Properties of the Young Sun HIP 67522

Analysis of exoplanet atmospheres depends on a strong understanding of the properties of the host star. The X-ray/ultraviolet (XUV) emission in particular governs planetary atmospheric heating and photochemistry. XUV emission peaks in solar-type stars within the first 100 Myr, with roughly 30% of the lifetime emission being radiated during this phase. The combination of the most intense phase of XUV emission occurring at early times and the fact that recently formed plants have radii inflated by residual heat from the star formation phase results in the dominant phase of hydrodynamic escape occurring in the first few hundred Myr. Here, we will present XUV spectroscopy of the 17Myr G0V star HIP 67522. The system has two super-Earth transiting planets and JWST transmission spectroscopy of HIP 67522b shows that it is an extremely inflated sub-Neptune. We will discuss how the high energy emission and variability properties of the star affect our understanding of the evolution of close-in, gaseous planets in solar-like systems at the earliest epochs.

George King, Poster Presenter

University of Michigan

The current irradiation and future evolution of the young giant TOI-1227b

TOI-1227 is one of just a handful of mid M dwarfs known to host a giant planet. However, unlike most other systems of this type, it has only recently formed; at just 5-12 Myr, TOI-1227b is one of the youngest transiting planets known. This early age suggests the planet's current 9.6 Earth radii size represents an ephemeral state, and through cooling and mass loss processes it could shrink significantly as it ages, becoming a more typical size for a planet orbiting such a star. We present the results of a recent XMM-Newton observation of the system to constrain the escape-driving XUV environment at the current epoch. We then investigate the possible future fate of TOI-1227b using MESA to determine whether it is a progenitor of the large sub-Neptunes or super-Earth populations observed among older systems.

Grace Lai, Poster Presenter

Bullis School

Atmospheric Retention on LHS 1140 b: Insights from JWST and Comparative M Dwarf Systems

Rocky exoplanets around M dwarfs are compelling targets for atmospheric characterization due to factors including the stars' small radii, low luminosities, and high planet-to-star contrast ratios. However, high stellar activity from their host stars - such as flares and high-energy radiation - may erode their atmospheres over time. Using observations from JWST and other available observatories, we plan to evaluate whether LHS 1140 b may retain a N_2-rich atmosphere. We will further assess the role of orbital distance, eccentricity, stellar activity, and planetary mass in the atmospheric retention of LHS 1140 b compared to other rocky exoplanets around M dwarfs.

Skylar Larsen, Contributed Speaker

Cornell University

Updating the Orbital Ephemeris of Radius-Gap sub-Neptune π Men c

Exoplanet characterization observations require precise measurements of orbital and physical parameters. This is especially true for exoplanets of ambiguous atmospheric retention, as orbital and planetary parameters directly affect which chemical species are expected to escape an exoplanet's atmosphere. The first ever exoplanet discovered by the Transiting Exoplanet Survey Satellite (TESS), π Men c, is a gaseous warm sub-Neptune orbiting a bright Sun-like star. π Men c exists within the planetary radius gap and is expected to have lost its primordial hydrogen and helium, but kept heavier compounds like H2O and CO2. The TESS mission has continued to observe π Men c after its initial discovery, with six years and 21 sectors of data currently available. Here we present the first analysis of all six years' worth of TESS observations to provide an updated period and orbital ephemeris for π Men c. Preliminary results suggest that the previously derived orbital period of π Men c is inaccurate on the order of seconds, which would cause current or future observation attempts to miss the transit window. Additionally, we assess the functional differences between TESS data products and various pipeline processes in analyzing sub-Neptune transit data, and provide recommendations for further pipeline usage and transit modeling. Our updated ephemeris will improve the accuracy of future observations of π Men c, and our pipeline will continue to analyze observations of exoplanets with atmospheres affected by thermal escape in the future.

Matthew Lastovka, Poster Presenter

University of Maryland

Investigating Transiting Exoplanets in the ULTRASAT Fields

One way to characterize atmospheric escape is by comparing the planetary transit depth in visible and ultraviolet (UV) wavelengths. However, few observatories are currently capable of making UV transit measurements, and none are capable of uniformly and efficiently observing a significant number of planets. The ULTRASAT mission is an upcoming UV space telescope that will change this. The primary science case of the detection and follow-up of extragalactic transients necessitates an observing strategy that is also well-suited for measuring the transits of many exoplanets in the UV. This project aims to build a list of well-vetted planets candidates in the ULTRASAT high-cadence survey fields. We increase the size of the sample by conducting a transit search of faint stars using TESS, which extends nearly 3 magnitudes fainter than previous faint star searches. Given its mission design, ULTRASAT is likely sensitive to planets around these faint stars. This sample of well-vetted transiting planets provides a testbed for atmospheric escape studies.

Matthew Leung, Poster Presenter

Harvard University

VIPER: A high-resolution VIPA spectrograph concept for characterizing exoplanet atmospheric escape

The metastable helium 1083 nm triplet has been used as an effective probe for atmospheric escape in gaseous planets. While most studies to date have focused on detecting this feature during transits, observations outside of transits have the potential to reveal deeper insights into the velocity and density distributions of escaping atmospheres. Extended observations, covering the full orbital phase, can provide a 3D time-evolved picture of the system's dynamics, helping to constrain anisotropic mass-loss mechanisms. To address this observational gap, we are developing VIPER: a high-resolution (R>300,000), narrowband, multimode fiber-fed VIPA spectrograph specifically designed to observe the helium 1083 nm triplet. VIPER will operate on the 1.5 m Tillinghast Telescope and potentially on the 6.5 m MMT, both at the Fred Lawrence Whipple Observatory on Mount Hopkins, Arizona. VIPER's design is driven by the primary science goal of detecting anisotropic atmospheric escape. We present VIPER's design and discuss its instrument requirements, which were determined using a hypothesis testing framework involving simulated instrumental spectra of anisotropic planetary outflows.

Joshua Lothringer, Poster Presenter

Space Telescope Science Institute

The Mg II Cosmic Shoreline

The Cosmic Shoreline is a framework for understanding atmospheric escape and retention on objects inside and outside the Solar System though a comparison between the energy a planet receives versus its ability to hold onto an atmosphere. This framework has been a driving force in defining hypotheses for studies of terrestrial planets. Here, we use the Cosmic Shoreline framework to interpret detections and non-detections of escaping Mg II in high-resolution HST/STIS E230M observations of hot and ultra-hot Jupiters. We find that the five detections and three non-detections of Mg II escape observed so far can be neatly categorized based on each planet's location relative to a Mg II Cosmic Shoreline. For example, we hypothesize that the surprising non-detection in the ultra-hot Jupiter WASP-178b can be explained by a lack of high-energy irradiation from its chromospherically-inactive early-type host star. By defining a Mg II Cosmic Shoreline, we can not only gain insight into population-level behavior of escape in hot Jupiters, but we can also test the utility of the Cosmic Shoreline framework in general in a high-SNR regime.

Ava Morrissey, Poster Presenter

Carnegie Institution for Science

Constraining the Formation and Evolution History of a 120 Myr Old sub-Neptune

Observations from space and ground based telescopes allow for key constraints on the evolution of small planets. HIP94235b, a 3 Earth radii, 120 Myr old sub-Neptune orbiting a G-type star offers a unique opportunity to study atmospheric escape at a pivotal timestamp: just after its host star's ~100 Myr period of intense XUV irradiation. I present multi-wavelength observations from HST/STIS and VLT/CRIRES+, targeting both hydrogen and helium escape from the same planet. Both observations resulted in non-detections. These non-detections, combined with escape models, imply that HIP94235b could not have formed with a primordial envelope fraction greater than ~10% of its total mass. This is significantly smaller than the ~40% envelope fractions inferred for younger sub-Neptune progenitors V1298 Tau b and HIP67522b. These findings point to divergent formation and evolution pathways for sub-Neptunes: either as the stripped remnants of larger primordial envelopes or as planets that formed with inherently more volatile rich atmospheres.

Barron Nguyen, Poster Presenter

Stanford University

A Tidally-Enhanced Outgassed Secondary Atmosphere on 55 Cancri e

55 Cancri e (55 Cnc e) is a mature, ~8 Gyr-old rocky world with a radius of 1.95 R,Earth and mass of 8.8 M,Earth, orbiting a K-type star. Observations with JWST suggest it hosts a predominantly carbon-based atmosphere of CO2 and/or CO and sustains a global magma ocean, with temperatures possibly exceeding 3000 K. We suggest that any observable CO2-dominated atmosphere on 55 Cnc e, along with minor H2O and O2 species, is supplied by outgassing from its initial volatile reservoir. Significant tidal heating, combined with greenhouse warming, is expected to prolong outgassing on planets whose atmospheres are in solution-equilibrium with a magma ocean, as the ongoing solidification of the magma ocean gradually drives the system away from equilibrium. However, initial outgassing is primarily driven by rapid degassing of the volatile-saturated melt as the planet cools following its formation, creating a primordial nascent atmosphere. Without tidal heating, an initial water mass fraction (WMF) of 5 wt% or CO2 mass fraction (FCO2) of 3 wt% would be needed to delay outgassing of the nascent secondary atmosphere by at least ~10 Myr. With both volatiles present at 10 wt%, greenhouse warming alone could delay outgassing by up to ~30 Myr. Our model shows that tidal heating can reduce the volatile threshold required to maintain a high global mean temperature (~3200 K at e = 0.005), thereby sustaining a primordial magma ocean. Additionally, tidal heating may potentially delay outgassing of a >2 bar secondary atmosphere to the present-day. However, higher tidal heating rates present a tradeoff between prolonging tenuous outgassing or increasing the overall size of the secondary atmosphere due to volatile dissolution in the magma ocean. Tidally-enhanced outgassing may produce minor variations in atmospheric pressure that could contribute to the observed phase-curve variability. In addition, our model demonstrates that outgassing rates during young-to-midlife stages largely depend on tidal heating, while at mature ages may shift to depend on the size of the planetary volatile inventory. Using 55 Cnc e as a case study, we present a framework for prioritizing atmosphere detections on rocky ultra-short period (USP) and magma ocean planets, focusing on how the age-dependent interplay between tidal heating and volatile inventory size may shape secondary atmosphere formation and size.

Bo Peng, Poster Presenter

Stanford University

Graphite precipitation in carbon-rich atmospheres of lava worlds

The atmospheres of lava worlds have garnered observational interest as unique windows to their rocky interiors. The emergent detections of secondary atmospheres on irradiated rocky worlds such as 55 Cancri e point to some combination of a high initial volatile endowment and the continuous replenishment from the interior. In this context, graphite precipitation can facilitate the long-term survival of a carbon-rich secondary atmosphere in contact with a magma ocean, both via limiting the atmosphere's height and, more importantly, via forming a mantle C reservoir independent from the dissolved atmospheric species (CO, CO2, CH4, etc.). Graphite precipitation can thus drastically enhance the C storage capacity of lava world interiors. Here we utilize a coupled magma ocean - atmosphere model to probe the effects of graphite precipitation on atmospheric composition and structure, as well as volatile partitioning and storage in the magma ocean. We discuss how these effects are modulated by the mantle redox state and internal heat flux. We also discuss how graphite floatation/sinkage influences its availability to sustain/revive secondary atmospheres.

Junellie Perez, Poster Presenter

Johns Hopkins University

Using Atmosphere-Interior Exchange Models to Constrain Geological Evolution of JWST Targets

JWST has started to push the boundaries of exoplanet science and probe the atmospheres of smaller, rocky exoplanets. One of the big questions currently is whether these small, rocky exoplanets around M-dwarfs could retain their atmospheres and if so, what can we say about their composition. However, this is just the beginning in the quest to understand habitability in such planets. To be able to fully understand them, we need to understand their geological evolution and how various geological processes can affect the outgassing of different gases that make up their atmospheres. This study will help address the range of geological evolution paths that smaller exoplanet targets observed with JWST may have taken to effectively rule out different interior and surface properties based on their atmosphere observations. To do so, we use an atmosphere-interior exchange model that simulates plate tectonics and models the carbonate-silicate cycle and the deep water cycle, which are two processes that aid in recycling of volatiles within the planet's layers and stabilizing the planet's temperature in long geological timescales. This model includes both a magma ocean phase and a later stage evolution with active cycling of materials through the geochemical cycles. It tracks various gas species such as water, hydrogen, carbon dioxide and carbon monoxide. We present preliminary results for our extended study of approximately 20 smaller exoplanets that have or will be observed with JWST, which explores the parameter space given different interior and surface parameters and aims to provide constraints on the geological evolution that these planets may have undertaken.

Lakeisha Ramos Rosado, Poster Presenter

Johns Hopkins University

Hydrodynamic atmospheric escape in the benchmark ultra-hot Jupiter WASP-76b

Hydrodynamic atmospheric escape driven by X-rays and extreme-UV irradiation is thought to be one of the key determining factors of the demographics in short-period exoplanets. In this context, ultra-hot Jupiters (UHJ) are the best targets to study hydrodynamic escape because they have detectable signals of exospheric metals in transmission spectroscopy. These signatures can only be observed by the Hubble Space Telescope (HST) in the ultraviolet. The UHJ WASP-76b has been the subject of extensive studies since it was found due to its extreme conditions. We present the transmission spectrum of WASP-76b obtained with HST's STIS instrument, E230M echelle grating. Our spectra cover a range of 2275-3119Å, which gives us access to resonant lines that trace hydrodynamic escape, as well as other lines of cloud-precursor species. We report significant absorption in the NUV, comparable to that of WASP-121b and WASP-178b. Species such as Mg II, Fe II and SiO are important opacity sources in these UHJ. WASP-76b provides an opportunity to gain deeper insights into the composition and physical structure of upper atmospheres in hot exoplanets.

Ethan Schreyer, Poster Presenter

University of California - Santa Cruz

Identifying circumstellar gas generated by the extreme mass loss of close-in planets

Close-in planets orbiting near their host stars often undergo substantial mass loss. In cases where this mass loss is extreme, the gas from the planet may not be expelled from the system by the stellar wind or radiation pressure of the star. Instead, this gas can form a circumstellar disk, which may obscure the star throughout the planet's orbit. In some systems with highly irradiated, close-in exoplanets, the host star shows unusually low chromospheric emission, indicated by a low log RHK. This reduced log RHK is thought to result from absorption by the circumstellar gas, rather than an intrinsic property of the star itself. In this talk, I examine the effects of circumstellar gas on the observed helium 10830 Å line in these stars. I demonstrate that stars with circumstellar disks exhibit a diminished helium 10830 Å line compared to field stars of similar log RHK, due to absorption from the circumstellar gas. Observing both the helium 10830 Å line and log RHK in stars hosting close-in exoplanets will help us more robustly identify these systems. Identifying these unique systems will deepen our understanding of the evolution of close-in planets and provide insights into the stellar winds of stars that host them.

Sander Somers, Poster Presenter

University of Maryland, College Park

Photochemical Modelling of TOI-421 b as a Comprehensive Baseline for Hot and Haze-Free Sub-Neptunes

Recent JWST transmission spectroscopy observations of TOI-421 b, a hot sub-Neptune orbiting a G9 star, have revealed a clear atmosphere that provides a direct window into its atmospheric composition. Motivated to understand the observed atmospheric composition of TOI-421 b, its haze-free atmosphere, and the broader population of hot sub-Neptunes, we present a haze-free photochemical model grid for hot (Teq ~ 950 K) sub-Neptunes orbiting G-type stars.

As a mature planet (~10 Gyr), the atmosphere of TOI-421 b can be simulated without considering evolutionary effects, providing a basis for isolating the impacts of chemistry from that of escape and replenishment in coupled models. To establish this baseline, we run both radiative transfer and photochemical models using present-day parameters of the evolved system, also conserving the planet's atmospheric mass and reference pressure altitude throughout the simulations. In doing so, we create a comprehensive reference grid with potential to serve as a starting point for matching simulations with observations to separate out effects of chemistry on compositional evolution. Our models predict the thermal structures, abundance profiles, and transmission spectra for a TOI-421 b-like planet across bulk metallicities, C/O, sulfur enhancement (S/H) and mixing strengths. A rich sulfur photochemistry in this regime is uncovered, and we find the combination of (non-)detections of CS2 and SO2 in transmission spectra to grant a strong, novel, lever on vertical mixing strength. We further determine supplementary tracers of metallicity are necessary to draw strong constraints when it is subsolar, with CH4 being the foremost candidate, but are unable to identify a reliable single tracer species for either C/O or S/H. From our grid, we determine atmospheres of near-solar-metallicities to match the TOI-421 b observational data best, in agreement with evidence for a low mean molecular weight atmosphere from retrievals. Across our parameter space, only low abundances of hydrocarbon haze precursors are produced, consistent with both theory and observations of TOI-421 b and similarly hot sub-Neptunes, providing further evidence for constraints on haze formation pathways. We investigate directly the impact of the limited hydrocarbon haze produced on the observables in synthetic transmission spectra of TOI-421 b.

Monica Vidaurri, Poster Presenter

Stanford University

Who Run the World? (Flares) – how M-Dwarf flares impact atmospheric O2 and O3 production on early st

The majority of planets that we have observed within a system's habitable zone have an M-type host star, which are long-lived, smaller, and cooler stars compared to our Sun. Most terrestrial planets suitable for atmospheric characterization orbit M stars due to their high signal to noise ratios, short orbital periods and high occurrence rates. However, M-type stars are notorious for their frequent stellar flares, during which the star can brighten by more than 10,000 times its usual total brightness, with even greater enhancements in the FUV wavelengths that cause heating in planetary atmospheres. In addition to such flaring events, terrestrial planets residing within the habitable zones of these stars are also likely to experience an early runaway greenhouse phase, which can lead to loss of hydrogen from water vapor due to heightened XUV fluxes during the star's youth before it reaches its main sequence. While the detection of atmospheric O2 is a key item of interest in the search for life, these steam atmospheres could lead to O2 atmospheres containing up to 300 bars, although magma oceans or solid crustal layers could bring O2 levels down to a few bars. Previous models have considered the effects of M-type flares on Earth-like atmospheres. However, the effects of these flares on early steam atmospheres have not yet been considered, including their effect on O2 and O3 production in a terrestrial planet's atmosphere around these stars. Here, we present preliminary results from a photochemical model which considers the production and evolution of O2 and O3 over time, during- and post-flare event.
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