Exoclimes VII Abstract Booklet

Sophia Adams

University of Exeter

Building a framework for 3D photochemical modelling in a GCM

We present progress from a project to develop 3D modelling of the circulations, radiative transfer alongside the thermal and photochemistry for exoplanets. Recent observations from JWST have resulted in detections of photochemical products in hot Jupiters. These detections, which show the importance of photochemistry in regulate UV radiation for terrestrial planets, contextualises our updating and benchmarking of relevant schemes. In this poster, I will present our adaptation of the SOCRATES radiative transfer scheme, used in the Unified Model (UM) and several other General Circulation Models (GCMs), and collation of input data to produce accurate photolysis rates for key atmospheric species in 1D. We compare our results with the Photocomp (2011) results for overlapping species and provide results for additional species. The photolysis rates for species relevant to Hot Jupiters are tested under an archetypal pressure-temperature profile and benchmarked against the results from ATMO. Finally, we present preliminary results from full 3D calculations with the UM.

Romain Allart

Université de Montréal

JWST reveals an extended helium signature persisting over half an exoplanet's orbit

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 the ultra-hot Jupiter WASP-121b, providing evidence of the longest continuous atmospheric escape. We detect an absorption signature that persists for over 17 hours—covering 55% of WASP-121b'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). Despite the low spectral resolution of NIRISS, the detected line profile asymmetry reveals that the escaping material is shaped into a cometary-like tail, pushed away from the host star.

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.

Natalie Allen

Johns Hopkins University

Using JWST and close transits to characterize the atmosphere of TRAPPIST-1 e

The TRAPPIST-1 system is the most tantalizing system for the detection of terrestrial exoplanet atmospheres with JWST. However, early JWST observations have shown that stellar contamination from hot/cold starspots must be corrected if we want to characterize any small planet atmospheres via transmission spectroscopy, especially for the incredibly active M8 TRAPPIST-1. Unfortunately, our current understanding of the spectroscopic appearance of these surface features is lacking, and we cannot confidently remove the contamination to the level of precision needed to detect the small atmospheric features of a terrestrial planet using current models. Here, we present the motivation and first observations for our JWST program targeting the characterization of the atmosphere of TRAPPIST-1 e utilizing close transits of the airless TRAPPIST-1 b to model-independently correct for stellar contamination by taking the ratio of the two planet's transmission spectra. However, in the case that the stellar contamination signal does not perfectly transfer between the two observations, we also present other methods to correct for stellar contamination: the first builds a map of the star itself using observations of transits at similar parts of the stellar rotational phase, while the second relies on Gaussian Processes. Overcoming the problem of stellar contamination is the only way we will be able to confidently detect the atmospheres of small planets transiting M dwarfs in the JWST era, so we will present initial results utilizing these techniques and discuss the strengths of each process. Using these methods, we expect to be able to detect an Earthlike atmosphere on TRAPPIST-1 e with our multicycle observations.

Prune August

Technical University of Denmark

Don't Observe Twice, It's All Right : A shallow eclipse for Hot Rock LHS 1478 b

M dwarf systems provide a unique opportunity to study terrestrial exoplanetary atmospheres, but their extreme stellar environments pose significant challenges for atmospheric retention, at least for close-in planets. High stellar activity further complicates the detection of such atmospheres. In this talk, I will present results from the Hot Rocks Survey, which targets nine rocky exoplanets orbiting M dwarfs to investigate their atmospheric properties.

Focusing on LHS 1478 b, a close-in planet orbiting an M3-type star with an equilibrium temperature of 585 K, I will first highlight that the two secondary eclipse observations obtained using JWST MIRI at 15um do not provide consistent results. The first observation reveals an eclipse depth of 138 +/- 52 ppm, allowing us to reject the airless, zero-albedo model at 3.3 sigma confidence. The result is consistent with a range of CO_2-rich atmospheric scenarios with surface pressures from 0.1 to 10 bar. However, the second observation results in a non-detection due to unexplained systematics, preventing a consistent confirmation of these findings.

I will discuss the nuances of this intriguing result, the complexities of characterizing atmospheres of rocky exoplanets around M dwarfs, and the lessons learned from this method. Finally, I will consider the implications of these findings for the upcoming JWST DDT Rocky Worlds initiative, which aims to expand our understanding of rocky exoplanet atmospheres through similar observational techniques.

Tomás Azevedo Silva

INAF - Osservatorio Astrofisico di Arcetri

Probing the transmission spectral signatures of chemical disequilibrium in hot-Jupiters atmospheres.

Hot Jupiters, with their tidally locked nature, inflated atmospheres, and short orbital periods, are prime targets for atmospheric studies, particularly through transmission spectroscopy. However, discrepancies persist in the interpretation of atmospheric compositions, especially for well-studied exoplanets like HD 209458b, where results from different instruments (JWST, GIANO-B@TNG, CRIRES+@VLT) remain inconsistent. These contradictions suggest that current atmospheric models, which often rely on classical 1D approaches, might fail to account for critical disequilibrium processes influencing atmospheric composition.

The work to be presented leverages VULCAN 2D, a state-of-the-art photochemical transport model, and gCMCRT, a Monte Carlo radiative transfer forward model designed to generate synthetic spectra at high-resolutions, to simulate transmission spectra under varying disequilibrium regimes. Specifically, I focus on HD 209458b, simulating species-dependent changes in the observed transmission spectra over the course of a transit, examining morning-evening limb asymmetries, and investigating longitudinal chemical variations due to horizontal mixing, quenching and photochemistry.

The balance between the different dynamical and chemical timescales of these processes can alter the rates at which key molecules such as CH4 and NH3 are dissociated, leading to the formation of compounds like HCN and C2H2. These processes, driven by high-energy stellar radiation, reshape the chemical composition of the upper atmosphere. By incorporating these into high-resolution forward models, I aim to address discrepancies in the detection of species and elemental ratios observed in HD 209458b's atmosphere.

With this approach, we aim to improve the interpretation of high-resolution spectra, shedding light on the complex atmospheric dynamics and chemistry of hot Jupiters. By bridging the gap between observational data and modeling efforts, this work will provide new insights into the measurable effects of longitudinal out-of-equilibrium chemistry on the transmission spectra of close-in exoplanets.

Sam Barber
Western University
A Mid-Infrared Low Resolution Spectral Library of L and T Dwarfs with the James Webb Space Telescope
We present the results of a comprehensive mid-infrared survey of brown dwarfs using the James Webb Space Telescope. Our Mid-Infrared Instrument Low Resolution Spectroscopy (MIRI LRS) observations provide high-SNR spectra of 23 objects across the L0-T6 spectral type range. We use the Sonora Diamondback model grid to fit physical parameters to the objects in our sample and clearly expose residual silicate absorption features. These features show a remarkable diversity in profile and extend to later spectral types than previously known. We use these features to further develop existing tentative correlations between silicate absorption profile and characteristics of the host object such as gravity and inclination. Additionally, we discuss newly observed features uncovered in our high-SNR spectra and their potential origins. Our observations form a MIRI LRS spectra library which will be invaluable as a reference in future studies of brown dwarfs and giant planets.

Michael Battalio
Yale University
Internal Climate Variability Adds Complexity to Zonal-mean Winds
Zonal-mean climate variability—called annular modes—captures a large percentage of the circulation variability for Earth, Mars, and Titan. Two types of modes operate on all three worlds. Baroclinic annular modes emerge from the zonal-mean eddy kinetic energy (EKE-AM) and describe pulsation of the storm track. Barotropic modes capture shifting in the zonal-mean zonal wind (U-AM). Annular modes exhibit characteristic timescales dependent on planetary parameters. The EKE-AM varies O(10) days, and the U-AM varies O(100) days. We investigate the dependence of annular variability on rotation rate in the Isca general circulation model. The number of jets increases with increasing rotation rate, and each jet has an associated mode. These modes interact with one another to increase the complexity of the power spectra of the whole zonal-mean atmosphere. Identifying annular mode timescales is essential for interpreting observations of planetary atmospheres across the solar system, and annular variability may place the lower bound on possible observations of exoclimate for the next decades.

Thomas Beatty

University of Wisconsin

New Insights Into Planet Formation Over a Range of Masses

Understanding the processes of planet formation is one of the major goals of characterizing exoplanet atmospheres. In the past decade, much of this work has focused – conceptually – on using the C/O ratio in planetary atmospheres to constrain their initial formation locations within the protoplanetary disk. Recently, however, JWST observations have begun opening new avenues towards approaching this goal. I will describe the results from our large JWST spectroscopic survey of half a dozen exoplanet atmospheres in transit and eclipse – that spans a mass range from sub-Neptunes to Jupiters – and discuss how these data can inform how some of these planets formed. Using a combination of forward models and retrievals, we place constraints on the atmospheric pressure-temperature profiles, cloud structure, and the abundances of major carbon-, oxygen- and sulfur-bearing molecules in these atmospheres. All our target planets show evidence of disequilibrium chemistry in their atmospheres, with one or more molecular species not present at the abundances one would expect. I will discuss how this illustrates the need to detect multiple molecular species to accurately estimate the metallicity and elemental abundance ratios of exoplanets using JWST data. In some cases, we are able to reliably constrain the interior temperature of the planets, which informs us of their migration histories. I will describe how our results – for metallicities, elemental abundances, and migration histories - fit into the current understanding of planet formation. I will also briefly comment on the lessons learned from using multiple data reduction pipelines and modeling approaches and summarize our best practices for others to use.

Taylor Bell

Space Telescope Science Institute

Exploring the Multi-Dimensional Nature of Exoplanet Atmospheres with JWST

With the transformative capabilities of JWST, we can now explore exoplanet atmospheres with unprecedented detail, breaking free from traditional one-dimensional models. In this talk, I will share how JWST observations—including transits, eclipses, phase curves, and eclipse mapping observations—are uncovering the intricate, multi-dimensional nature of exoplanet atmospheres. I will present key findings from work on exoplanets such as WASP-80b, WASP-43b, and WASP-107b, revealing phenomena like horizontal and vertical mixing, cloud asymmetries, and day-night heat redistribution. These studies illuminate how

chemical and thermal processes interact to produce diverse atmospheric behaviors. I will also discuss how these discoveries are advancing our understanding of planetary atmospheres and outline the next steps toward unraveling their multi-dimensional complexities.

Hayley Beltz

University of Maryland, College Park

Magnetic Effects on Circulation in Hot/Ultrahot Jupiters

Hot and Ultrahot Jupiters are ideal candidates for studying how magnetic effects can shape circulation. On the hot dayside, atmospheric species are thermally ionized. As these ions travel through the atmosphere due to strong winds, they will resist flow over magnetic field lines. In this talk, I will present 3D numerical models of Hot and Ultrahot Jupiters and discuss the changes in circulation brought about by magnetic effects. Specifically, this model explores the effect of a dipole aligned with the planet's axis of rotation. When the dipole is applied to the model, the dayside flow pattern drastically changes and a magnetic circulation regime emerges. I will discuss observational signatures of this circulation regime in emission, transmission, and through eclipse mapping. This talk will highlight the importance of considering magnetic effects in these atmospheres and discuss the ongoing work of detecting the presence of a magnetic field in a planet outside our solar system.

Björn Benneke

UCLA (at date of Exoclimes)

A New Understanding of Water Worlds and Sub-Neptunes from a Detailed 82-hour JWST NIRSPEC+NIRISS Survey of 6 Water-World Candidates

One of the most fundamental results of the study of exoplanets has been the discovery that small planets are extremely abundant in the Universe, and that they are divided into two seemingly distinct populations: rocky super-Earths and gas-rich sub-Neptunes. Strikingly, recent studies have suggested the existence of a long-hypothesized third category of planets, often referred to as water worlds, which are larger and warmer planetary versions of the volatile-rich icy moons of the outer solar system. In this talk, we will present highlights from our dedicated 82-hour JWST/NIRSPEC+NIRISS survey of 6 water world candidates, providing a fundamentally new understanding of these intriguing worlds and their transition into the general sub-Neptune population. We will discuss the main findings on the abundance and diversity of volatile-rich water worlds, based on molecular detections on at least four planets in our survey. We will put special emphasis on the transition from hydrogen-dominated atmospheres, through miscible high-metallicity atmospheres, to true water worlds, and we will also discuss many open questions about the chemistry and formation of these planets raised by our JWST observations, which motivate substantial theoretical studies in the community in the coming years.

Siddharth Bhatnagar

University of Geneva

Diving into exo-oceans: Implications for the climate of TRAPPIST-1e

Ocean modelling is often overlooked in exoclimate studies due to the high computing cost of dynamic oceans. Yet, oceanic heat transport can impact the climate and observables of temperate M-planets like TRAPPIST-1e (e.g., Yang+2019b). As a compromise, most exoplanet General Circulation Models (GCMs) use a slab ocean model without heat transport.

We present an improved compromise: the new dynamical slab ocean model of the Generic-PCM (Forget+in-prep., previously, the LMD Generic GCM). Our parallelisable model includes sea ice/snow evolution, wind-driven Ekman transport, horizontal diffusion and convective adjustment between ocean layers. Coupled with the atmosphere, it replicates critical modern Earth features, such as the major oceanic heat flows, an average surface temperature of 13°C, planetary albedo of 0.32 and 18 million sq. km of sea ice (Bhatnagar+to be submitted).

We also explore our model's implications for TRAPPIST-1e. Despite recent JWST observations indicating the lack of a (thick) atmosphere for TRAPPIST-1b (Greene+2023) and 1c (Zieba+2023), the planets farther from the star, like 1e, may have retained moderately thick atmospheres. Assuming 1e formed with a substantial water reservoir (Tian & Ida 2015), it could sustain surface liquid water oceans (Turbet+2018). Oceanic heat transport can lead to exotic oceanic patterns, like the lobster pattern on Proxima Centauri b (Del-Genio+2019), compared to the eyeball pattern without it (Turbet+2016).

We present results from our dynamical slab ocean within the Generic-PCM for TRAPPIST-1e and compare them with Del-Genio+2019, which used ROCKE-3D (Way+2017) with a fully dynamic ocean model. Our findings show qualitatively similar results, while maintaining a high computational efficiency. Finally, we will discuss our findings in the context of habitability, emphasising the role of a dynamical ocean model in informing our understanding of habitable conditions.

Jayne Birkby

University of Oxford

Advances Towards the Exploration of Rocky Worlds with High Resolution Spectroscopy

High resolution spectroscopy (HRS) is a powerful and highly versatile technique for exoplanet atmospheric characterisation. New HRS instruments and statistical frameworks have accelerated the field dramatically in recent years, producing results on par with JWST e.g. elemental ratios for the study of planet formation, and at the same time opening new parameter space such as the 3D dynamical nature of exoplanets winds and rotation. The unique sensitivity of HRS to spectral line shape holds a wealth of information and we are only just beginning to scratch the surface. In this talk, I will showcase the most recent advances that are enabling HRS studies of rocky exoplanets with the Extremely Large Telescopes (ELTs). I will discuss the extension to M-band wavelengths with CRIRES+ and its potential for exploring the surface composition of lava planets with existing telescopes. I will further demonstrate new results that push HRS into the warm sub-Neptune regime for the first time, constraining metallicity and aerosols. Finally, I will highlight HRS in reflected light spectroscopy and its challenges, using ESPRESSO/VLT in 4UT 16.4-m mode, while underscoring its vital role in searching for biosignature and even technosignature gases in the ELT era. I will end with a discussion on the synergy needed between HRS, JWST, HWO, and LIFE to enable the fullest exploration of rocky exoplanets in the coming decades.

Jasmina Blecic

New York University Abu Dhabi

Unlocking Exoplanetary Climates: 3D Retrieval, Eclipse Mapping, and Magnetic Field Insights from JWST

With the advent of the James Webb, already providing data of exquisite quality for a wide range of planetary types and sizes, our ability to uncover the complex 3D makeup of exoplanetary atmospheres has dramatically improved. Combining already proven data analysis and modeling techniques is key to this endeavor. Eclipse and transit mapping techniques convert exoplanet light curves into flux maps, offering insights into atmospheric thermal and compositional variations as functions of latitude and longitude. 3D atmospheric retrieval, on the other hand, that utilizes a self-consistent temperature prescription with dynamical forcing, coupled with horizontal chemical quenching and clouds, is the tool that, given observations, provides the most accurate information about the planetary climate. We have developed a technique to couple these methodologies, enabling us to confidently retrieve key properties not yet obtained for exoplanets, such as planetary energy budget and dynamics, in addition to overall temperature structure, composition, and clouds. We will present this approach applied to several JWST targets, most notably WASP-18b, a highly irradiated, tidally-locked planet expected to exhibit significant atmospheric variations in longitude due to a supersonic equatorial jet. This exceptionally hot Jupiter shows particle and gas movement that challenges these theoretical expectations, suggesting the presence of a strong magnetic field. We successfully modeled this magnetically-coupled gas in our 3D retrieval framework and linked it to JWST's eclipse mapping data to spatially resolve the dayside structure of WASP-18b. Our method uncovered a unique energy transport pattern on the dayside of the planet and allowed us to also infer the nightside flux and dynamics.

Abby Boehm

Cornell University

The HUSTLE Program: The Importance of Ultraviolet Spectroscopy for Comparative Studies of Hot Jupiters

The Hubble Space Telescope's ultraviolet (UV) observing capability offers an effective probe of aerosols, atmospheric escape, and photochemistry in exoplanetary atmospheres. The ongoing Hubble Ultraviolet-optical Survey of Transiting Legacy Exoplanets (HUSTLE) (HST-GO 17183) is studying 12 hot Jupiters with UV-optical transmission spectroscopy to probe aerosol and chemical transitions as a function of temperature. Here we present transmission spectra of the low-density hot Jupiter WASP-31 b (T~1400 K) and the metal-rich ultra-hot Jupiter WASP-189 b (T~2600 K) collected as part of HUSTLE. Our observations with the HST WFC3/UVIS G280 observing mode span 200 to 800 nm, allowing us to identify alkali species and metal hydrides in the upper atmospheres of these exoplanets. We also constrain the UV-optical slope in each planet, allowing us to distinguish between cloudy, hazy, and clear atmospheric conditions. Our complete sample of 12 hot Jupiters reveals the importance of UV-optical spectroscopy in correctly interpreting the presence or absence of spectral features in these diverse worlds.

Tori Bonidie

University of Pittsburgh

Phase-Resolving the Emission Spectroscopy of the Ultra-Hot Jupiter KELT-20 b

Ultra-hot Jupiters (UHJs) are ideal laboratories for atmospheric characterization at high spectral resolution due to their large radii, hot temperatures, and short orbital periods. By resolving their emission spectra as a function of orbital phase, we can map the 3D nature of their atmospheres, revealing crucial information about their wind dynamics. In this work, we combine five nights of high-resolution optical emission spectra from the PEPSI spectrograph on the LBT, covering orbital phases between $0.35 \le \phi \le 0.65$, to probe the planetary dayside of the UHJ KELT-20 b/MASCARA-2 b at different orbital geometries. We measure the phase-dependent emission signal of Fe I in the atmosphere of KELT-20 b, which reveals a consistent redshift before and after secondary eclipse. We investigate other species to probe different altitudes and abundance patterns, and find preliminary evidence of variation of signal strength as a function of phase. We interpret these results with a comparison to a General Circulation Model (GCM). Additionally, we retrieve the dayside emission spectrum to constrain the posterior distributions of the atmospheric pressure-temperature profile and atomic abundances.

Jonathan Brande

University of Kansas

Carbon in the Atmosphere of an Ultrahot Neptune

While we know of hundreds of Hot Jupiters and hot rocky planets, there is a notable lack of Neptune-sized planets at short orbital periods. The Neptune Desert has long been known to be physical and not an observational bias, and several explanations for this dearth of Neptunes have been put forth. Both atmospheric escape and migratory processes may be at play here, and to properly distinguish these, we need to study these planets to the fullest extent possible. To do this, we present the NIRSpec G395H emission spectrum of LTT 9779 b from two eclipses during a full phase curve of the planet's orbit. We confirm earlier Spitzer observations which implied the presence of carbon-bearing species in wide-band photometric eclipse observations by spectroscopically identifying strong CO2 absorption. Consistent with earlier flat NIRISS transmission spectroscopy, we find that LTT 9779 b is likely to have a high atmospheric metallicity, and solar or subsolar C/O. We also discuss the implications of these findings for LTT 9779 b's formation and evolutionary history, including both atmospheric mass loss and migration, especially given the extreme irradiation the planet receives from its host star.

Zarah Brown

University of Arizona, Lunar & Planetary Laboratory

An Advanced Model Grid for Roman's Jovian Exoplanet Targets

The Nancy Grace Roman Space Telescope Coronagraph Instrument (RCI) will be the most advanced coronagraph to date, enabling direct imaging of cool Jovian planets in reflected light and self-luminous hot Jovians. Spectral analysis with RCI will allow for the characterization of exoplanet atmospheres, including gases, hazes, and clouds. Given the limited observing time and capabilities of RCI, predictive models are essential for optimizing target selection and observation planning.

We are constructing predictive models for known self-luminous and reflected light targets using Picaso, a 1D radiative-convective climate model that produces high-resolution reflected light and thermal spectra. This work incorporates updated opacities and includes new parameters, such as surface gravity, that were absent in previous model grids. Importantly, these models will incorporate patchy clouds and eventually hazes.

These improved models will serve as a critical tool for maximizing the scientific return of RCI observations. By simulating atmospheric conditions and spectral features across a range of plausible scenarios, our work will inform the selection of optimal targets, aiding the mission in characterizing Jovian exoplanets and advancing our understanding of their atmospheric processes.

Ben Burningham

University of Hertfordshire

Exploring the diversity of the coldest substellar atmospheres with JWST

The coolest directly observable atmospheres beyond the Solar System are those of the Y dwarfs – the latest class of objects at the end of the stellar sequence, beyond LT dwarfs. They provide a superb opportunity to explore chemistry, thermal structure and aerosols across a temperature range that is adjacent to solar system giant planets. We present the results of retrieval analysis of 14 very late T and Y dwarfs (250K < Teff < 600K) using low and moderate resolution JWST NIRSpec data. We constrain isotopologue ratios of 12CO/13CO for much of the sample, providing important context for interpreting this ratio in exoplanets. We also highlight challenges in disentangling the impact of aerosols, potentially non-adiabatic thermal profiles, and chemistry.

Beatriz Campos Estrada

Max Planck Institute for Astronomy

We don't talk enough about cloud microphysics

State-of-the-art JWST observations are unveiling unprecedented views into the atmospheres of sub-stellar objects in the infrared, further highlighting the importance of clouds. Current forward models struggle to fit the silicate clouds absorption feature at ~ 10 μm observed in sub-stellar atmospheres. In the MSG model, we have coupled the MARCS 1D radiative convective equilibrium atmosphere model with the 1D kinetic, stationary, non-equilibrium cloud formation model DRIFT, to create a new grid of self-consistent cloudy sub-stellar atmosphere models with microphysical cloud formation. We computed atmospheric structures that self-consistently account for condensate cloud opacities based on microphysical properties. Here, we present an algorithm based on control theory to help converge such self-consistent models, a long-standing problem known to the community. We computed synthetic atmosphere spectra for each model to explore the observable impact of the cloud microphysics. We additionally explored the impact of choosing different nucleation species and the effect of less efficient atmospheric mixing on these spectra. In line with other forward model grids, the MSG grid is unable to reproduce silicate features similar to the ones found in recent JWST observations and Spitzer archival data. This shows something fundamental is currently missing in atmospheric forward models. In this presentation we discuss further work that may better approximate the impact of convection in cloud-forming regions and steps that may help resolve the silicate cloud feature. We also discuss how 1+D retrieval models might help explain the observed spectroscopic variability of directly imaged planets and brown dwarfs, while also resolving the silicate cloud feature.

Sarah Casewell

University of Leicester

Irradiated brown dwarfs and the brown dwarf desert

The brown dwarf desert is a region of parameter space containing only ~50 brown dwarfs orbiting main sequence stars within 3 AU. These systems are complemented by their more evolved form, containing a white dwarf primary and close, tidally locked brown dwarf secondary. We have performed phase resolved spectroscopy with HST and WFC3 in the NIR of 6 irradiated brown dwarfs orbiting white dwarfs. These systems are tidally locked with periods ranging from 68 minutes to 10 hours, orbiting white dwarfs with effective temperatures between 25,000 K and 7,000K. This range of temperatures and orbital periods means we have been able to determine the effects of irradiation on brown dwarf atmospheres, and see the differences in the irradiated daysides and the cooler nightsides, which in the case of eclipsing systems can be directly detected. I will discuss these results and compare them to what we know about irradiated brown dwarfs orbiting main sequence stars, a subset of which will be observed by the Ariel mission. Phase curves and emission spectroscopy of these brown dwarfs and those orbiting white dwarfs can be combined to form a holistic view of the effects of irradiation on brown dwarfs including how UV irradiation affects the atmospheres, and what may be causing the radius inflation seen in many of these systems.

Yayaati Chachan

University of California, Santa Cruz

Mass-Metallicity Relation in Giant Planets: Implications for Accretion and Planet Formation

The processes governing the growth of giant planets, particularly the proportions of solids and gas they accrete, remain poorly understood. To address this, we analyze a sample of 124 warm transiting planets with well-measured masses and radii, spanning the mass range of 20 Earth masses to 20 Jupiter masses. Using thermal evolution models, we self-consistently account for the entropy and temperature contributions of metals in the equation of state and apply updated atmospheric boundary conditions that incorporate metallicity effects in the envelope. This approach allows us to robustly quantify the metal content of these planets, tripling the sample size studied in Thorngren et al. (2016).

Our results reveal that a planet's metal mass primarily depends on its total mass, but also with a weak dependence on the host star's mass. We fit both power-law and physically motivated models to explore the relationship between metal mass and planet mass. We find that the metal mass follows the relation $M_z \sim M_{core} + f_z M_p$, with $M_{core} \sim 15\ M_\oplus$, $f_z \sim 0.07$, and an astrophysical scatter of $\sim 12\ M_\oplus$, implying that the accreted material's metal enrichment is ~5x solar metallicity. The preferential accretion of metals during the gas accretion phase hints at the role of planetesimal accretion in enriching giant planets. The weak stellar mass dependence of metal mass is likely a consequence of the reduced solid surface densities in the protoplanetary disks of lower mass stars.

These results offer new insights into the heavy element content of giant planets and provide critical constraints on planet formation theories, particularly the accretion of solids and gas during the growth of massive planets. We also use our fitted physically motivated models to predict the expected atmospheric mass-metallicity relation for transiting giant exoplanets which can then be constrained by observations.

Yiwei Chai

Johns Hopkins University

Preparing for Transiting Exoplanet Atmosphere Studies with Roman

The Nancy Grace Roman Space Telescope (Roman), NASA's next flagship mission launching no earlier than late 2026, promises to revolutionise our understanding of exoplanets. Among its key science initiatives is the Galactic Bulge Time Domain Survey (GBTDS), which is projected to detect around 100,000 transiting exoplanets — increasing the number of known exoplanets by over an order of magnitude. This wealth of data will be instrumental for conducting demographic studies, offering a comprehensive view of the diverse properties of transiting exoplanets. Roman will also provide invaluable insights into exoplanet atmospheres via two-band observations of primary transits, secondary eclipses, and phase curves. These capabilities will allow Roman to identify large-scale atmospheric trends across different exoplanet populations, advancing our knowledge of how atmospheric properties vary with planetary and host star properties. In order to prepare the community for this exciting new science opportunity, we use end-to-end simulations to model realistic exoplanetary atmospheric signals and analyse their recovery from simulated Roman data. We present our efforts to constrain the properties of the transiting exoplanets that will be detected by the GBTDS, and evaluate the extent to which Roman will be able to distinguish between different atmospheric compositions.

Ryan Challener

Cornell University

JWST-TST DREAMS: The Complete JWST Emission and Transmission Spectra of a Hot Jupiter

Exoplanet atmospheric thermal structure, winds and chemistry are complex and vary substantially from the planet's day to nightside. Often time intensive phase-curve observations spanning a broad range of wavelengths are employed to probe thermochemical spatial variations in atmospheres, but this is not always a feasible approach. In this talk I will showcase the complete 0.6-12 micron limb and dayside spectrum of the hot Jupiter WASP-17b measured from paired transit and eclipse measurements across NIRISS SOSS, NIRSpec G395H, and MIRI LRS instrument modes. In combination, these observations allow us to measure the chemical composition, changing temperature structure, and dynamics of the atmosphere in detail. From the combined transmission spectrum we retrieve H2O, CO2, H-, K, SiO2 clouds, a temperature of ~1250 K, and an upper limit on the abundance of SO2. The combined emission spectrum shows dayside abundances consistent with measurements from the terminator, with confident detections of H2O and CO2. The dayside thermal profile is non-inverted from ~1700-2000K with the shortest wavelengths probing the deeper atmosphere, suggesting a potential to constrain the planet's internal temperature. Using eclipse mapping techniques, we constrain the mid-infrared hot-spot shift to 19 +11/-4 degrees east with a day-to-night temperature contrast that matches that measured in transmission. Together, these spectra are an important legacy dataset, providing the most in-depth view of an exoplanet atmosphere to date and highlighting the ability to obtain complex multi-dimensional information without the need for phase curves.

Guillaume Chaverot

IPAG

Toward a more complete definition of the habitable zone, including different atmospheric compositions

One of the objectives of studying exoplanets is to discover surface liquid water, a sine qua non condition for the existence of life as we know it. Many parameters affect a planet's surface water phase (distance from the star, stellar type, atmospheric composition, rotation, etc.).
The concept of the habitable zone (ZH) is a generic tool for globalizing this set of processes, by defining a virtual zone within which a planet can sustain liquid water. This is a very useful tool to analyse large sample of planets for selecting the best targets for a characterization with the future instruments, such as ANDES@ELT and PCS@ELT.
Community interest has so far focused on the effect of stellar type on the position of the inner and outer edges of this HZ (Selsis et al. 2007, Kopparapu et. al. 2013), assuming the

atmosphere of the Earth. Using a 3D climate model, recent works show that various atmospheric compositions induce much greater differences in the calculation of the inner edge than the stellar type (Chaverot et al. 2023, Kuzucan et al. 2025). After a brief retrospective on the state of our knowledge regarding the definition of the ZH, I will present a work in progress exploring the effect of atmospheric composition on the calculation of the inner edge, assuming different stellar type and planetary masses. This work is a required first step in building a generic understanding of habitability conditions of terrestrial planets. Such knowledge is essential for designing the HWO and LIFE mission (2040+), and to build a realistic target list.

Duncan Christie

Max Planck Institute for Astronomy

Geometric Considerations in Hot Jupiter Magnetic Drag Models

Magnetic fields are expected to shape the atmospheric dynamics of hot and ultra-hot Jupiters due to their increased ionization fractions, but our ability to model these magnetic processes is limited by the different coupling regimes between the day and night sides of the planets. To make the problem tractable, interactions with the magnetic field are often reduced to the introduction of a zonal magnetic drag. Unfortunately, sufficiently strong zonal drag results in meridional flows, requiring consideration of meridional magnetic drag, something that is otherwise ignored in existing models. In this talk, I will demonstrate the impact of vertical and meridional drag from a background dipole magnetic field on the flows in hot Jupiter atmospheres and show that the inclusion of meridional and vertical drag can limit flows over the poles and create a relatively static dayside hot spot around the substellar point, something not seen in models that only consider zonal drag.

Tereza Constantinou

Institute of Astronomy, University of Cambridge

Comparative Biosignatures

The discovery of inhabited worlds outside our solar system hinges on identifying biosignature gases. JWST is revealing potential biosignatures in exoplanet atmospheres, though their presence is yet to provide strong evidence for life. Interpreting these biosignatures is now a key challenge: how to confidently attribute them to biogenic sources, ruling out (or, ruling as unlikely) their typically numerous possible abiotic origins? Proving atmospheric biosignatures on individual planets as definitively biological in origin is challenging. We a priori know little about the systems we are investigating --- especially with regards to system-scale stochastic processes that could set atmospheric conditions. To address this, we emphasise the utility of a comparative multi-planet approach: comparing the systematics of atmospheric compositions across multiple planets within a planetary system (or of planets between systems) to define an `abiotic baseline' with respect to which biosignatures can be referenced. Abiotic baselines are calibrating, or providing a prior for, models describing the non-biological processes that have shaped and are shaping the atmospheres of planets. This is possible because planets within a system are linked by their birth in the same natal disk, having been irradiated by the same evolving star, and having a related dynamical history. Planets in agreement with the system-specific abiotic baseline then suggest a non-biological origin of their potential biosignature gases, while anomalies detected with a Bayesian leave one-out approach to outlier detection point towards a potential biogenic source. Multi-planet systems therefore have great value in defining the abiotic baseline, and so providing improved confidence in our attempts to identify extrasolar life.

Greg Cooke

University of Cambridge

Diversity of Photochemical Signatures in the Sub-Neptune Regime

The James Webb Space Telescope (JWST) is advancing the study of sub-Neptune exoplanets by pushing the limits of atmospheric detection, particularly for the smallest exoplanets observed to date. The rapid development of sub-Neptune research is driven by the lack of direct analogs in our solar system, opening diverse avenues for exploration. Sub-Neptunes are hypothesized to exhibit a range of internal structures, from rocky super-Earths to hydrogen-rich mini-Neptunes and water-dominated ocean worlds. For example, 55 Cancri e, a hot super-Earth, serves as a significant example of atmospheric variability. Additionally, recent molecular detections in the atmospheres of K2-18 b, TOI-270 d, and GJ 9827 d have provided critical observational data for sub-Neptunes. By analyzing their atmospheric compositions, we can gain insights into their surface conditions (or lack thereof) and internal structures. In this study, we employ multiple photochemical models to investigate the atmospheric gases that can distinguish between different internal structure scenarios, considering a wide range of radii, masses, and equilibrium temperatures. Additionally, we utilize the Planetary Spectrum Generator to simulate synthetic transmission and reflection spectra, estimating the detectability of molecular signatures. Our work provides theoretical benchmarks for future observational campaigns with JWST and upcoming next-generation telescopes. By identifying abundance limits for key molecules (e.g., H_2O, CH_4, NH_3, H_2S, SO_2, CO, CO_2, and HCN) in specific exoplanetary scenarios, we refine the characterization of sub-Neptunes and advance the search for potentially habitable exoplanets.

Louis-Philippe Coulombe
Université de Montréal
Hints of volatiles on the warm super-Earth TOI-270 b
A longstanding objective of exoplanetary sciences is the search for atmospheres on extrasolar rocky planets. The study of their nature and frequency is a crucial step in understanding the processes driving atmosphere formation, retention, and loss, in search of the conditions that could be hospitable to life. Due to the current limitations in the precision that can be achieved with ground- and space-based observatories, such searches have thus far been limited to rocky planets orbiting late-type stars. While the small radii of their host stars make them favorable targets for transmission spectroscopy, observations of these planets are highly sensitive to stellar contamination, which can mimic atmospheric features. In this talk, I will present the JWST NIRSpec/G395H transmission spectrum of the warm super-Earth TOI-270 b. From our updated density measurement, an earth-like composition for this planet is significantly disfavored, and we find that it is instead best explained by the presence of %-level water by mass, either atop its surface or stored in its mantle and core. The transmission spectrum shows weak preference for an H_2O-rich atmosphere model over a flat spectrum, and strongly rules out any clear, H_2/He-rich atmospheres. At the wavelengths covered by NIRSpec/G395H, atmospheric water absorption features are usually degenerate with the transit-light-source effect, but we show this scenario to be unlikely by leveraging the transit of TOI-270 d, observed within the same visit, which acts as a much better probe for stellar contamination signals given its larger size. TOI-270 b thus presents itself as a prime water world candidate which, if confirmed, would have significant implications for our understanding of atmosphere retention and the cosmic shoreline hypothesis.

Shelby Courreges
University of Texas at Austin
Enhanced Photochemical Haze Models for Sub-Neptune Atmospheres

We are developing sub-Neptune atmosphere models that incorporate photochemically produced hazes, building on the sub-Neptune simulations published in Mukherjee et al. 2024. The Mukherjee et al. 2024 models coupled a photochemical model to a 1D climate model within the open-source PICASO framework, allowing us to calculate atmospheric structures incorporating photochemistry self-consistently for the first time. The new effort we present here incorporates hazes based on the photochemical calculations. effort As part of this project, we are integrating lab-based haze optical and physical properties into the open-source virga model, allowing for a more accurate representation of how haze particles form, grow, and interact with atmospheric radiation. Rather than relying on the simplified haze parameterizations of earlier studies, we aim to use a more detailed approach that accounts for multiple haze precursors under different atmospheric conditions. By combining these improvements with the radiative transfer framework PICASO, we are generating grids of predicted transmission, thermal emission, and reflected light spectra for hazy sub-Neptunes. These models will help observers compare data with a broader set of theoretical predictions, shedding light on the diverse atmospheric processes of this planet population. Ultimately our goal is to advance our understanding of how photochemical hazes form and shape observable properties in sub-Neptune atmospheres, which remain among the most common but least well-characterized exoplanets.

Ian Crossfield
University of Kansas
Mapping the Exoplanetary Sulfur Shoreline
SO2 has been the biggest surprise from JWST's early gas-giant spectra, providing insight into atmospheric (photo)chemistry, metallicity, and formation. I will share our exciting new results regarding detailed photochemical modeling of a new atmosphere grid, ranging from 0.3-1000x solar metallicity, 250-2000 K, and across a range of internal temperature, XUV irradiation, vertical diffusion, and elemental ratios. Our models reveal the 'sulfur shoreline' that determines the key, observable sulfur-bearing species in the atmospheres of giant exoplanets. For example, we find that expected SO2 abundances depend strongly on metallicity, C/O, and overall temperature; depend somewhat on XUV irradiation; depend weakly on Kzz (except for Teq ≲ 600 K); and are essentially independent of internal temperature. We also reveal the dominant sulfur-bearing species across this wide range

parameter space. We show that despite its recent detection in a growing number of giant planets, SO2 is never the dominant sulfur-bearing molecule. These results have important implications for interpreting the growing trove of sulfur detections (and non-detections!) from JWST and for preparing for the even larger ARIEL survey.

Caitlyn Cullen

Open University

Disentangling the effects of spotty stars from exoplanet atmosphere observations

Active stars can possess surface heterogeneities such as star spots and faculae that are often hidden within atmosphere observations and can thus complicate the interpretation of transmission spectra. When a planet transits a star with surface heterogeneities the reference light source (which is regularly taken from an average of the full stellar disc) may not be representative of the light actually occulted by the planet. This discrepancy can contaminate the transmission spectrum with features from the stellar spectrum, masking or mimicking features from atmospheric components such as water vapour, and thus introducing bias to otherwise excellent targets for atmospheric characterisation.

To improve this characterisation process for exoplanets around active stars, we aim to couple the modelling of atmospheric features alongside stellar spectral features within the retrievals process. We assess the combined use of the NEMESISPY package alongside more complex stellar activity models which incorporate representations of spot umbra and penumbra as well as faculae, to maximise the accuracy of retrieving atmospheric properties and quantify the bias for specific parameters as a result of these stellar features, for example: calculating the limiting accuracy of recovering the CO abundance on HAT-P-18b in the presence of star spots.

We investigate the presence of spots and faculae on a sample of previously well-investigated systems with potentially active K- and M-type stars observed with JWST and/or Hubble, such as WASP-52b and HAT-P-18b.

Sam de Regt

Leiden Observatory

A View of Chemistry, Clouds and Gravity through High-Resolution Spectra

High-resolution spectroscopy (HRS) unlocks a rich insight into the atmospheres of planetary-mass objects. At near-infrared wavelengths, the detection of absorption lines from volatile molecules and minor isotopologues provides access to the gaseous content of C (+13C), N, O (+18O), S, and F. The measured abundances provide clues that help to reconstruct the formation history of these sub-stellar objects, but also constrain chemical dis-equilibrium driven by atmospheric mixing. Furthermore, the pressure-broadened alkali lines serve as probes sensitive to surface gravity. Measuring the line-widths, however, requires an understanding of the line-shape asymmetries revealed at high resolving powers. Using HRS, one can also study the properties of clouds, including inhomogeneities that lead to detectable surface features and atmospheric variability.

As a showcase of the capabilities of HRS, I will present an analysis of multi-wavelength CRIRES+ spectra of the nearest brown dwarfs, Luhman 16AB, as part of the ESO SupJup Survey. These results highlight the great potential of HRS in characterising sub-stellar atmospheres and underline the exciting prospects for 30m-class telescopes in the not-too-distant future.

Jean-Michel Desert

University of Amsterdam

Tracking the Atmospheric and Interior Evolution of Exoplanets Over Time

It is expected that exoplanets undergo profound transformations as they evolve, shaped by their interactions with their host stars and the processes of stellar and planetary evolution. We present high-resolution spectroscopy and JWST observations, revealing the critical influence of stellar radiation, activity, and flares on atmospheric changes across timescales ranging from hours to secular periods, including the full lifespan of these systems. We report changes on the hour timescale of the atmospheric chemical composition, temperature structures, atmospheric escape, as well as interior properties. Special attention is given to how stellar flares reshape atmospheric chemistry and structure on very short timescales (minutes to hours) and ultimately influence the diverse evolutionary pathways. We discuss some of the impact of these changes on the challenges involved in determining the atmospheric properties—such as metallicity, C/O ratios, and elemental abundances—to trace their formation and evolution for both young and mature systems. Ultimately, this presentation provides new insights into the mechanisms shaping planetary atmospheres and interiors across the ages, including of young planets transitioning into sub-Neptune or super-Earth regimes.

Maria Di Paolo

University of East Anglia

Climate Patterns of Spin-Orbit Resonant Exoplanets Around Low-Mass Stars

Identifying planets capable of hosting life requires more than just pinpointing their position in the habitable zone: a deeper understanding of a planet's climate is essential. Oceans, with their profound influence on climate dynamics, play a crucial role in shaping planetary climate, making their impact essential for modelling terrestrial exoplanets and accurately interpreting future observations.

M dwarfs are the most promising candidates for finding habitable worlds. Planets in the habitable zone of low-mass stars experience intense tidal forcings and often become tidally locked. Despite the majority of research being centered on the climate dynamics of synchronously rotating planets in this scenario, synchronous rotation is not an inevitable outcome of tidal locking. Several different circumstances can result in an asynchronous rotation, and in some instances can lead to spin-orbit resonances.

Using a coupled atmosphere-ocean general circulation model (FORTE2.0) to investigate this scenario, we explored the climates of planets with two different rotational states: an Earth-like rotation period and a spin-orbit resonance. Our findings reveal striking differences not only between the resonant case and the Earth-like rotation case, but also when contrasted with the commonly studied synchronous rotation case. Particularly fascinating were the periodic climate patterns observed in the spin-orbit resonant scenario, where climatic features such as clouds and rainfall exhibited unique behaviours relative to the substellar point. The evolution of these quantities during a planetary orbit is noteworthy from the observational point of view, as observable features are shaped differently in each rotational scenario.

Hannah Diamond-Lowe

Space Telescope Science Institute

Updates from the Rocky Worlds DDT Program

The Rocky Worlds DDT Program approved by the Director of STScI will use ~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. 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. I will provide an overview and latest updates on target selection, scheduling, and data products, likely with real data in hand by the time of the conference. I will share the challenges and our solutions to observing small secondary eclipse signals of M dwarf rocky planets, as well as what is still needed for interpretation by the scientific community. Finally, I 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.

Feng Ding

Peking University

Oscillatory Motion of Jupiter's Polar Cyclones Diagnosed by Point-Vortex Dynamics

NASA's Juno spacecraft has been observing the poles of Jupiter since 2016, revealing a distinctive symmetrical structure of storms. Each pole features a polar cyclone, with the north pole encircled by eight circumpolar cyclones and the south pole surrounded by five. These circumpolar cyclones not only co-rotate around their poles but also oscillate with respect to their equilibrium points. Here, we construct an idealized barotropic model and assume the potential vorticities of the polar cyclones all concentrate at their centers. We examine both co-rotation around the poles and oscillations of the polar cyclones and find our model cannot reconcile the oscillation frequency with their circumpolar motion speed. Our results suggest that although barotropic vortex dynamics is sufficient to explain the formation of polar vortex crystals, other physical processes, such as baroclinic effects, may play a key role in determining the oscillation frequency and circumpolar motion speed observed by Juno.

Jackie Faherty

American Museum of Natural History

Explaining the Diversity of Cold Worlds with the James Webb Space Telescope

The James Webb Space Telescope has the capability to reveal complex chemistry in worlds formed beyond our own solar system. A key class of objects that has been trailblazing our understanding of the diversity of atmosphere compositions for giant exoplanets is brown dwarfs. In this talk I will show a library of data obtained using JWST on brown dwarfs with temperatures that range from ~700K all the way down to 250K – just 100 degrees warmer than Jupiter. The spectra will highlight the key molecules we can detect in worlds beyond our own. While we initially theorized that chemistry would be primarily guided by the temperature of a given source, what JWST reveals is a far more complicated landscape where secondary parameters like age, metallicity, and gravity strongly influence what we see.

Charlotte Fairman

University of Bristol

Disentangling temperature driven atmospheric differences in two aligned hot Jupiters around F-type stars.

We present the first spectral characterisation of NGTS-2b along with observations of KELT-7b with NIRSpec/G395H, as part of the BOWIE-ALIGN program. Underpinning these observations is the goal of uncovering formation pathways from measurements of atmospheric composition, namely the metallicity and carbon to oxygen ratio. As both planets are aligned with the rotation axis of their F-type host stars, we expect them to have accreted oxygen-rich silicates, following a migration path through the protoplanetary disk.

Despite these planets sharing the same stellar environment and alignment, they occupy distinct regions of temperature space, with equilibrium temperatures at ~1470 and 2050 K respectively. Whilst clouds are expected to provide significant opacity for the cooler NGTS-2b, the presence of H- has been detected in KELT-7b (Gascon+ in review), suggesting possible H2O dissociation.

From a comprehensive set of free and equilibrium chemistry retrievals, a range of distinct solutions can fit the observations of both planets. We discuss the validity of these models, where Bayesian model comparison is unable to identify a statistically favoured solution. Furthermore, we demonstrate how greater wavelength coverage can differentiate these possible solutions and refine our compositional constraints. In the case of KELT-7b, we show how the inferred atmospheric properties change with the inclusion of optical Hubble data, highlighting the combined strength of Hubble and JWST observations in disentangling atmospheric composition.

Jonathan Fortney

University of California, Santa Cruz

JWST Transmission Spectrum of the 283-day-orbiting Giant Planet Kepler-86b/PH-2b

The rarest transiting planets are the long-period planets with low equilibrium temperatures. Kepler-86b, with a Saturn-like mass and radius, has a Teq of ~270 K due to its 0.82 AU orbit around a main sequence mid G-type star. For the first time we present our recently acquired JWST NIRSPEC transmission spectrum from 1-5 um acquired during its 11-hour transit. Given the Sunlike parent star and cold Teq, this planet is perhaps the best bridge to our own Jupiter and Saturn that JWST will ever observe. We place constraints on atmospheric abundances of equilibrium and photochemical products and the impact of clouds, via retrieval analysis. We additionally present photochemical and spectral models that investigate the transitions of C-N-O-S-bearing-molecules from warm Jupiters to temperate Jupiters to place our observations in context. We also make connections to the Y-type brown dwarfs, the coolest of which is WISE J0855, which has a very similar Teff to Kepler-86b. Additional science includes constraints on planetary oblateness and a search for exomoons.

Marylou Fournier Tondreau

University of Oxford

Crustal Controls on Seafloor Weathering and Climate Regulation

The next generation of extremely large ground-based telescopes and space observatories will significantly advance our ability to study rocky exoplanets within the habitable zones (HZ) of their stars. The HZ is traditionally defined as the circumstellar region where conditions could allow liquid water to exist on a planet's surface. A key assumption underlying this concept is that silicate weathering regulates atmospheric carbon dioxide (CO_2), providing a stabilizing feedback on climate for water-covered, tectonically active planets over geologic timescales. Probing exoplanetary carbon cycles and the habitable zone concept are research goals that rely on a deeper understanding of the carbonate–silicate cycle. While this feedback has been extensively studied for continental weathering, the role of seafloor weathering remains comparatively underexplored despite its potential to be equally significant. For instance, during Earth's Late Mesozoic hothouse climate, seafloor weathering fluxes were comparable in magnitude to those from land.

Here, I explore the potential controls on seafloor weathering by applying the model of Maher and Chamberlain (2014)—which integrates hydrological and tectonic influences and imposes a thermodynamic limit—to both modern (Cenozoic) and Late Mesozoic oceanic crust. This solute transport model captures observed trends in carbon content with crustal age, including the finding that over 80% of carbonate accumulates within the first 20 Myr of crust formation. The simulations can also reproduce the higher CO2 uptake observed in Late Mesozoic crust compared to the Cenozoic.

I find that crustal properties such as permeability, porosity, and rock reactivity are key factors impacting weathering fluxes—challenging the hypothesis that elevated temperature alone drove enhanced uptake in the Late Mesozoic. This finding underscores the complex interplay of oceanic crust properties in governing weathering rates and introduces additional pathways for climate stabilization. Overall, this work highlights seafloor weathering as a crucial component of Earth's long-term carbon cycle and a process to consider when evaluating potential habitability of rocky exoplanets.

Anna Gagnebin
University of California, Santa Cruz
Modeling the Chemistry and Spectra of Water World Atmospheres with PICASO
Water worlds, which are planets with a non-negligible fraction of water making up the planetary mass and radius, constitute an understudied category of extrasolar planets. Recent evidence for the existence of water worlds has made it clear that we need to bring our ability to quantitatively study their atmospheres in line with the study of giant and terrestrial planets. These planets do not exist in our own solar system, so we have not fully developed a theoretical understanding of their atmospheres, which makes atmospheric observations both challenging to interpret and consequential. The atmospheric makeup, and corresponding physics at play, is key to determining the thermal evolution and cooling of planets over time. A significant motivation behind this work is to understand important atmospheric absorbers in water world atmospheres beyond steam, which may be diagnostic of their atmospheres,

atmosphere-interior interactions, and evolution. The current difficulty in our ability to accurately analyze the atmospheres of water worlds when compared to more commonly observed planets is something that we are trying to rectify in this work through the creation of models for the atmospheres of water worlds. This is done through updating the chemistry and functionality of PICASO, a python-based open-source 1D radiative-convective atmospheric modeling code which is currently optimized to model atmospheres dominated by H and He, in order to model the more water-rich atmospheres of water worlds. These models are simulations of their atmospheres as well as the corresponding transmission, reflection, and thermal emission spectra. The comparison of these spectra to observations done with JWST allows for the study of their atmospheric makeup, which allows us to investigate the time evolving atmospheric chemistry of water worlds as it relates to planetary cooling.

Peter Gao

Carnegie Institution for Science

The Life and Times of the Benchmark Super-Puff Exoplanet Kepler-51b

One of the strangest discoveries of the Kepler mission is a rare class of low mass and large radius planets that has been nicknamed Super-Puffs. These objects challenge formation and evolution theories due to their inferred large gas mass fractions, which could be an order of magnitude higher than those of the smaller and much more numerous - but similar mass sub-Neptunes. Here we present and interpret the 1-5 micron transmission spectrum of Kepler-51b as observed by JWST. Through a combination of free-chemistry retrievals and atmospheric, interior, and evolutionary models, we find that Kepler-51b is a true Super-Puff, possessing a massive low mean molecular weight atmosphere largely devoid of aerosols. In addition, the atmosphere features an extremely low C/O ~ 0.1, which may indicate accretion near the water snow-line. We use these results to craft the formation and evolutionary history of this enigmatic world and how it has survived to this day.

Frédéric Genest

Université de Montréal

Constraining the atmospheric composition and structure of warm Jupiter WASP-80 b with combined NIRPS and JWST transmission spectroscopy

I present results about the puffy warm Jupiter WASP-80 b in an effort to refine and put additional constraints on its atmospheric composition and structure. The analysis includes three transits observed with the high-resolution (R ~ 80000) near-infrared spectrograph NIRPS and a previously published transit spectrum from JWST/NIRCam (R ~ 200), also in the near-infrared but at longer wavelengths. An initial cross correlation analysis was performed on the high-resolution datasets to look for molecular detections: only water yielded a significant detection. A series of atmospheric retrievals were then launched separately and jointly on the NIRPS and JWST datasets; the JWST-only retrievals serve mainly to validate the retrieval framework used against the published results. By combining both datasets, a detection of methane is recovered in addition to the water already detected at high-resolution. However, the resulting constraints for the atmosphere's temperature structure conflict significantly between the high and low-resolution datasets. Possible causes will be discussed, including how the two instruments may be probing different parts of the atmosphere and whether the high-resolution line lists (particularly for methane) are sufficiently accurate.

Neale Gibson

Trinity College Dublin

Pushing the limits of high-resolution Doppler spectroscopy for probing exoplanet atmospheres: towards 3D retrievals and temperate planets

The last few years in exoplanet science has been remarkable due to the transformative nature of JWST to obtain exoplanet spectra. Nonetheless, ground-based high-resolution Doppler-resolved spectroscopy has undergone a quieter yet important revolution. This technique uses the large Doppler-shift of a planet relative to its host star and telluric lines to disentangle the exoplanet's spectrum. For many years, this technique was only applicable to a small number of targets, a small number of species, and could only tell us about the presence or absence of atmospheric species. However, the combination of new instruments, bright targets, and the development of appropriate retrieval techniques has dramatically changed this. In fact, even in the JWST era ground-based telescopes still lead the way in the number of atmospheric species detected, and have also provided the most precise constraints on key observables such as C/O ratios. My group were one of the pioneers of high-resolution retrievals of transmission spectra using a fully Bayesian framework. I will give an overview of our retrieval framework, and discuss new developments that have enabled us to explore the 3D nature and dynamics of the ultra-hot Jupiters WASP-121b and MASCARA-1b in both emission and transmission, as well as obtain precise constraints on their atmospheric compositions. I will also introduce a new filtering technique in development that is designed to more effectively target stellar and telluric signals while preserving the planet's signal. This will be a step towards more precise and robust retrievals and towards applying these techniques to cooler planets with the ELTs.

Mark Giovinazzi

Amherst College

Metallicities and Origins of High-Surface Gravity Giant Planets

KELT-24 b is a hot super Jupiter (P = 5.55 d, m = 4.6 MJ) orbiting a bright (V = 8.3) F-type host star, making it a premier candidate for atmospheric characterization with JWST. It is unique in that its surface gravity (logg = 3.96) is among the highest of any giant (R > 1 RJ) transiting planet. High-surface gravity giant planets offer powerful laboratories to study atmospheric compositions, formation pathways, and evolutionary processes in a region of parameter space that bridges the gap between planets and brown dwarfs. This class of planet, however, is difficult to target for atmospheric studies due to their relatively small scale heights and subsequently shallow absorption features. As a result, transmission spectroscopy studies of high-surface gravity planets have ben avoided by JWST. By simulating NIRSpec G395H transmission spectroscopy, I demonstrate the potential that KELT-24 b has for atmospheric characterization with JWST. Specifically, I show that JWST observations are capable of constraining KELT-24 b's bulk metallicity content, as well as key abundance ratios like C/O that are often linked to formation pathways. Led by KELT-24 b, I present a curated sample of highly-irradiated, high-logg giant planets amenable for transmission spectroscopy study with JWST that extend into an unexplored gap in parameter space. These measurements for such a sample will assess atmospheric metallicities for high-logg planets and directly test theories related to the origins of hot Jupiters within their disks. By obtaining C/O abundances for this population, we can, for the first time, probe differences in formation pathways between high-logg planets and their lower-density counterparts.

John Lee Grenfell

German Aerospace Centre (DLR)

Responses of Climate and Atmospheric Biosignatures on Earth-like Planets and Detectability with the Large Interferometer for Exoplanets (LIFE) Mission

We investigate the detectability of atmospheric biosignatures with the LIFE mission. Starting with the modern Earth we model the climate, photochemistry and spectra of Earth-like planets over a range of insolation, gravity, humidity, albedo, atmospheric mass and carbon dioxide abundances and investigate detectability of key atmospheric species by LIFE for Earth-like planets assumed to lie at 10pc for the instrument baseline case. We find that atmospheric ozone (O_3) abundances are present over a range of conditions. The O_3 fundamental band is present for most scenarios studied but is weakened for exoplanets with cooler central stars. Additional potential biosignatures such as methane (CH_4), nitrous oxide (N_2O) and chloromethane (CH_3Cl) are favored for low UV conditions e.g. exoplanets orbiting cooler central stars or having strong atmospheric shielding. Regarding spectral signatures, CH_4 and water (H_2O) signals in the near infrared are evident in most scenarios, as is the carbon dioxide (CO_2) fundamental band, which strengthens for low-O_2 scenarios associated with upper atmosphere cooling. Regarding detectability by LIFE (20-day viewing, baseline case), H_2O was retrievable with a confidence level (CL) of up to 3-sigma for the high (90%, 0.9 vmr) CO_2 scenario, and with ~2-sigma or less for the other scenarios. CO_2 would be detectable with high significance, having a CL sigma range of (6.2-9.4) for the various scenarios. N_2O would not be observable with a CL sigma mostly in the range (1-2). CH_4 featured a CL sigma detectability range of [2.3 to 4.4]. O_3 was detectable with a CL (>3-sigma) in all scenarios (including the low -ozone Proterozoic) except for the extremely low O_3 Archaean scenario.

Mahesh Herath

McGill University

Is there air in hell? - Coupled orbital-thermal history of lava planets and their potential for atmospheres

Lava planets can maintain a permanent dayside magma ocean and may have atmospheres made of vapourized rock. These atmospheres are affected by the surface temperature of the magma ocean and the day-night pressure gradient. The existence of a global magma ocean affects the type of atmosphere present. We investigate if a lava planet can have a molten nightside (hence a global magma ocean) resulting from tidal heating during planetary migration. We simulated planets of 1.0 and 1.5 Earth-radii and had their internal structures evolve as they migrate from 0.1 AU to 0.006 AU (14 day to 14 hour orbital periods). We find that a fully molten nightside would at most last about 100 million years through tidal heating at high eccentricities ($e > 0.5$). Such high eccentricities would only be feasible if the planet began its tide induced migration at distances between 0.03 and 0.06 AU. A partially molten (mushy) nightside can be sustained for billions of years if a small eccentricity ($0.0001 < e < 0.001$) is maintained in the orbit. This would be feasible with the presence of a companion planet to supply additional energy to the orbit of the lava planet. Overall, there is uncertainty as to where lava planets begin their migration, and the possibility exists they may have started out as sub-Neptunes before their atmospheres erode away to become lava planets. Our results show that a molten dayside and a mushy nightside is the most feasible outcome through tide-induced migration. Therefore if an atmosphere exists, it may have been global in the past, before collapsing on the nightside in 100 million years or less. This is important since the observation of an atmosphere could be used to infer the internal structure of a lava planet.

Thea Hood

Observatoire de la Côte d'Azur

Linking Atmospheric Dynamics to Doppler Shifts in High-Resolution Transmission Spectroscopy

Studying the atmospheric dynamics of exoplanet atmospheres is often hindered by our inability to access dynamical quantities directly. Wind speeds of exoplanets can in theory be evaluated from the Doppler shift measurements using high-resolution transmission spectroscopy. However, different factors can bias the wind measurements obtained from the observations, including 3D thermal and chemical structure.

Here we calculate the transmission spectra of a grid of 3D global circulation models of hot and ultra-hot Jupiters. We investigate the relationship between the measured Doppler shift of iron absorption lines and the wind speed in the planetary atmosphere. We find that, for most planets, the systematic velocity shift measured during a transit should be a good approximation of the day-to-night atmospheric wind speed. This breaks down, however, for fast rotators, and we therefore propose a new metric to link wind speed and observations for these planets.

Chih-Chun Dino Hsu

Northwestern University

Atmospheric Chemistry and Physical Properties of Directly Imaged Exoplanets and Brown Dwarfs from High-resolution Spectroscopy

With 20-25 directly imaged exoplanets discovered to date and a few dozen brown dwarf companions recently discovered through direct imaging, we can now study exoplanet atmospheres as a population through spectroscopic characterizations.

The Keck Planet Imager and Characterizer (KPIC) is a high-resolution spectrometer (R~35000) at high-angular resolution (~50 mas) and high contrast (Δmag = 5-15 mag), designed to measure their abundances and spins precisely. So far, KPIC already observed >30 substellar objects, brown dwarfs and exoplanets. I will highlight the recent KPIC science results. First, KPIC enables the first detection of CO and H2O of PDS 70b. The atmospheric retrievals constrain the PDS 70b C/O ratio to <0.63, with metallicity consistent with its host star, in contrast with that of the gas-rich outer disk (for which C/O ≳ 1). I will discuss two possible scenarios for its formation history. Next, I will summarize our main findings in abundance and spin surveys. Our survey for eight young substellar companions (~10-30 MJup) indicates that their metallicities and C/O ratios are broadly consistent with the solar compositions. This can be contrasted with the tentative metal enrichment for directly imaged exoplanets and hot Jupiters, which are more likely to be formed via core accretion. Our rotation survey for ~50 low-mass companions (5 to ~50-60 MJup) shows a strong trend of faster rotation toward older ages, opposite to the trend of higher-mass objects (~50 to 100 MJup). We thus found the first evidence for spin-up and spin-down transitions slightly below the stellar/substellar boundary. The differences can be explained by angular momentum loss being less efficient for lower-mass objects due to weaker magnetic-driven winds. Finally, I will discuss the new KPIC capabilities in J and H bands that probe refractory species, and future prospects with HISPEC.

Renyu Hu

NASA Jet Propulsion Laboratory

JWST observations of the cornerstone temperate sub-Neptune K2-18 b

Earth-temperature, sub-Neptune-sized exoplanets are now within reach for detailed atmospheric characterization with JWST, with K2-18 b being one of the first to receive repeated observations. The initial observations revealed abundant CH_4 and CO_2 and the absence of NH_3. They suggested three potential atmospheric scenarios: (1) a massive H_2-dominated envelope influenced by a high internal heat flux and possibly an underlying magma ocean, (2) a massive gas envelope with near-equal abundances of H_2O and H_2, or (3) a water-dominated envelope with a liquid water layer at the surface. To resolve these possibilities, we have conducted additional JWST observations to capture four new transmission spectra of K2-18 b using NIRSpec's G235H and G395H grisms. These spectra deliver high-precision measurements between 2 and 5 μm and enable detailed probes of the planet's atmospheric metallicity, cold trap, and abundances of NH_3, HCN, and organosulfur species. This unprecedented dataset offers critical insights into K2-18 b's internal structure and informs an updated roadmap for characterizing temperate sub-Neptunes, advancing our understanding of their atmospheric properties and potential habitability.

Lori Huseby

University of Arizona

Optical Properties and Spectral Features of Sub-Neptune Water-World Hazes After UV Irradiation Through Laboratory Experiments

Temperate sub-Neptune exoplanets could contain large inventories of water in various phases, such as water--worlds with water--rich atmospheres or even oceans. Both space-based and ground-based observations have shown that many exoplanets likely also contain photochemically-generated hazes. Haze particles are a key source of organic matter and may impact the evolution or origin of life, and their optical properties are imperative in aiding interpretations of observations using theoretical atmospheric modeling. Modelers have thus far had to assume haze optical constants which may not match sub-Neptune atmospheric compositions. Often orbiting close to M-dwarf stars, these planets receive large amounts of radiation, especially during flaring events, which may strip away their atmospheres and have the potential to accelerate atmospheric escape. Critically, it remains unknown how stellar flaring affects the formation, evolution, and optical properties of exoplanet hazes. In this work, we present laboratory investigations of stellar flare energies on laboratory-produced exoplanet hazes under conditions analogous to water-world atmospheres. We subjected two water-world haze samples to varying UV irradiation environments to assess how the hazes evolve over time. We measured the transmittance and reflectance spectra and calculated the optical properties of the hazes before and after UV irradiation across a broad wavelength range (from Far Ultraviolet to mid--IR, 0.2 - 9 μm), which overlaps with HST, JWST, and the upcoming Habitable Worlds Observatory instruments. We find that simulated flares alter the transmittance and reflectance spectra of the hazes, and also reveal that the haze optical properties change during irradiation, which may change

our interpretations of exoplanet atmospheric characterization. Overall, these laboratory-made hazes show signs of degradation over the simulated flaring period. Our results provide insight into the effects that stellar flaring events have on potential exoplanet haze composition, optical properties, and the ability for water-world like exoplanets to retain their atmospheres.

Jegug Ih

Space Telescope Science Institute

Do Rocky Planets around M Stars Have Atmospheres? A Statistical Approach to the Cosmic Shoreline

Answering the question do rocky exoplanets around M stars (M-earths) have atmospheres? is a key science goal of the JWST mission, and 500 hours of Director's Discretionary Time (DDT) have been awarded to address this very question. Observationally, all thermal emission measurements of M-earths are consistent with them being bare rocks but have also revealed a tentative 1D trend that hints at the onset of tenuous atmospheres at lower instellations. Theoretically, the so-called Cosmic Shoreline may not hold around M stars due to the harsher XUV environment. This could result in most M-earths being unable to retain significant atmospheres, a hypothesis that remains to be tested via judicious target selection.

To best inform the target selection strategy, it is necessary to precisely define the aim of the DDT. We propose one of the following: (a) determining if at least one M-earth definitively has an atmosphere, (b) placing an upper limit on the occurrence rate of atmospheres, or (c) determining whether there is a trend in the insolation-escape velocity plane which M-earths seem likely to have atmospheres.

We simulate a survey of potential targets by combining planet formation/evolution and atmospheric models. We then apply a genetic algorithm to identify the optimal set of observations to answer questions (b) or (c) in a hierarchical model. We find that, if all M-earths are indeed bare rocks, JWST can efficiently constrain the occurrence rate of atmospheres to less than 1 in 6 even without careful target selection. If the Cosmic Shoreline hypothesis for M stars is true, it can be distinguishable from the null hypothesis within 500 hours of observing time, with the optimal strategy being a wide survey. We discuss the limitations of secondary eclipse observations and suggest that question (a) is best answered via phase curve observations in General Observers programs.

Julie Inglis
Caltech

Heavy Weight Planets, or Runts of the Stellar Litter: First Results from a High Resolution Spectroscopic Survey of Transiting Super Jupiters

Gas giant planets with masses over a few Jupiter masses (super Jupiters) represent a unique population of planets with nebulous origins. Direct imaging surveys have found dozens of these objects orbiting at large separations from their host stars, but their uncertain masses and radii complicate atmospheric retrievals. Transiting super Jupiters, on the other hand, have precisely determined masses and radii, and therefore make an excellent test case to study the origins of these objects. Do they represent the high mass tail of core/pebble accretion formation with atmospheric compositions that differ from their host stars, or are they instead clones of their host stars and, therefore, possibly, represent the low mass end of stellar formation processes? I will present the first results from our high resolution K-band survey with Keck/KPIC to measure the C/O and metallicity of a sample of planets in emission, including a 6σ detection of night side emission from the mildly eccentric super Jupiter WASP-14 b (7.2 MJ). By placing these measurements in context with similar measurements of transiting hot Jupiters and wide super Jupiter companions, we can begin to disentangle the origins of this critically understudied population of planets.

Haqq-Misra Jacob
Blue Marble Space Institute of Science

Technosignature Detectability in Long-term Scenarios of Earth's Future

The search for extraterrestrial life includes efforts to detect spectroscopic biosignatures in exoplanetary atmospheres, which includes the possibility of detecting evidence of extraterrestrial technology, known as technosignatures. The search for technosignatures seeks to detect any remotely observable evidence of technology, but known examples of technology are limited to the very recent history of Earth. Technosignature studies often handle this uncertainty by making linear or exponential extrapolations of technological growth as an assumption of how an extraterrestrial civilization might behave. Such extrapolations, and their rebuttals, tend to draw upon informal approaches that neglect any systematic couplings between human needs and the technosphere. In this study, we use existing methods from futures studies to develop self-consistent scenarios for Earth's

1000-year future, which can serve as examples for defining technosignature search strategies. We define a broad range of possible scenarios based on political, economic, social, and technological factors, and we eliminate scenarios that are inconsistent, to arrive at a set of ten plausible future scenarios. We then apply a novel worldbuilding pipeline that evaluates the dimensions of human needs in each scenario as a basis for defining the observable properties of the technosphere. We provide an overview of the planetary and system technosignatures in our scenario set and discuss some of the most salient implications for observations. Our scenario set provides the basis for further systematic thinking about technosignature detection as well as for imagining a broad range of possibilities for Earth's future.

Marshall Johnson
Ohio State University

The Structure and Dynamics of Ultra Hot Jupiter Atmospheres from the PIRANGA Survey on LBT/PEPSI

High-resolution spectrographs on large telescopes allow access to the structure, dynamics, and chemistry of exoplanetary atmospheres. Ultra hot Jupiters (UHJs) around bright stars are the most favorable targets, where we can obtain the highest signal-to-noise ratio data and the most comprehensive characterization of the planets. I will present results from the PIRANGA survey, which is observing a sample of ~6 UHJs in both transmission and emission spectroscopy with the PEPSI spectrograph on the LBT. We have made strong detections of Fe I emission from every planet we have observed, providing further evidence of the ubiquity of atmospheric temperature inversions among these planets; meanwhile, we have not made any detections of typically-invoked inversion agents like TiO or VO in our data. We now have a sufficient sample of planets to enable comparative planetology of the atmospheric dynamics, and I will present initial results from this effort. Using a flexible retrieval framework, we measure the strength, velocity offsets, and line profiles of the planetary spectrum, and the orbital phase variations thereof. We perform these analyses for multiple species, probing different pressure levels in the atmospheres. Overall, we characterize the three-dimensional atmospheric structures of these planets and provide data which can be used to test global circulation models and other planetary models.

Sean Jordan

Centre for Origin and Prevalence of Life, ETH Zurich

Constraining the albedo of K2-18b from its transmission spectrum

The possibility for sub-Neptune planets to host liquid water oceans beneath hydrogen-dominated atmospheres is currently under debate. The most optimistic sub-Neptune candidate whose mass and radius allow for the possibility of a liquid water ocean layer is K2-18b. K2-18b's upper atmosphere was recently characterised in a transmission spectrum obtained by JWST. The observed spectrum showed chemical signatures that could be consistent with a range of possible planetary states - from a magma ocean planet to a water ocean planet. The case for a water ocean is subject to the planet having a high bond albedo (>~0.6). If K2-18b has an albedo lower than this value, then a water ocean overlain by only >~1 bar of hydrogen would enter runaway greenhouse. Here we develop a new technique for how to constrain the albedo of a planet from its near infrared transmission spectrum, and apply this new technique to the case of K2-18b. Our results reveal that the observed transmission spectrum of K2-18b is inconsistent with the planet being able to maintain liquid water oceans, and instead provides strong evidence that K2-18b is a magma ocean world or gas dwarf. The new technique that we present can be generally applied to constrain the albedo of any planet with compositional constraints on its observable atmosphere.

Kim Angelique Kahle

Max Planck Institute for Astronomy

A surprising MIRI/LRS dayside spectrum of the ultra-hot Jupiter WASP-121b

Ultra-hot Jupiters harbor some of the most extreme climates we know of: their daysides heat up to many thousand kelvins, inflate, and show inverted temperature profiles. These conditions promise clear skies and are our only option to observe refractory species in the gas phase of planets. As new JWST observations established the presence of silicate clouds on their colder siblings, the hot Jupiters, it is now also the time to investigate the gas-phase abundances and origins of these silicates.

For this, we observed the dayside of the ultra-hot Jupiter WASP-121b with the MIRI/LRS instrument of JWST. The mid-IR band includes the strong 8-10 micrometer feature of SiO, the most abundant gas-phase carrier of Si in these planets, and a precursor of silicate clouds. The first look at this spectrum shows emission at the expected wavelengths but also a substantial departure from equilibrium chemistry predictions. This deviation from equilibrium comes as a surprise due to the high temperature of the planet's dayside. This contribution will reveal the mid-IR dayside spectrum of WASP-121b and highlight what it can teach us about silicates on Jupiter-sized planets.

Sven Kiefer

University of Texas at Austin

How heterogeneous cloud particles affect transmission spectra

With the capabilities of JWST, we can now observe the spectral features of cloud particles within exoplanet atmospheres. Interpreting these observations requires detailed modeling of cloud particle opacities. In exoplanet atmospheres, a single cloud particle can be made from multiple materials, resulting in heterogeneous cloud particles. These particles have complex optical properties that strongly depend on their morphology. The four most commonly used approximations for calculating the opacity of heterogeneous particles are Bruggeman mixing, the LLL approximation, the core-shell model, and the assumption of homogeneous cloud particle populations. In this study, we show that these approximations are not equivalent and lead to different transmission spectra. Assuming core-shell or homogeneous cloud particles results in less muting of molecular features from the gas-phase. These approximations also preserve the spectral features of the individual cloud particle materials. In contrast, when using Bruggeman or LLL, cloud spectral features become broader, and the distinct features of individual cloud materials are lost. By how much the different approximations differ also depends on the cloud particle materials present. We tested 21 different cloud particle materials and found that materials with high refractive indices, such as iron-bearing species or carbon, have the strongest effect. These materials can change the optical properties even at volume mixing ratios of less than 1 percent of the total particle volume. Therefore, depending on the materials considered and the approximations used, retrieval frameworks might predict different cloud particle properties. We studied the JWST MIRI transmission spectra of WASP-39b, WASP-76b, and HATS-6b and showed that future high-precision observations of cloud particle features have the potential to determine the morphology of cloud particles in exoplanet atmospheres. It is therefore crucial to investigate cloud particle morphology of heterogeneous cloud particles and account for it in the prediction of transmission spectra for exoplanet atmospheres.

Daniel Kitzmann

University of Bern

PRISM observations of HAT-P-65 b: Challenging cloud formation theories

HAT-P-65 b is puffy hot Jupiter with an estimated day-side equilibrium temperature of roughly 1900 K on a decaying orbit around its solar-type host star. HAT-P-65's small apparent magnitude allows the planet's atmosphere to be studied using the NIRSpec PRISM instrument aboard the James Webb Space Telescope.

We observed two transits of this target as part of the Hot Jupiter Atmospheric Forecast program with NIRSpec, resulting in a transmission spectrum spanning the entire wavelength range from 0.8 - 5 µm. Atmospheric retrieval analyses of the spectrum revealed the presence of water and titanium oxide in the atmosphere of HAT-P-65 b.

The detection of titanium oxide is particularly intriguing, as it challenges conventional expectations of simpler cloud formation theories: equilibrium condensation and rainout models predict that titanium oxide should condense out of the gas phase at the temperatures in the terminator regions of HAT-P-65 b.

Its prominent presence in the spectrum, therefore, suggests potential shortcomings of these simplified cloud treatments. In this talk, we will present our transmission spectra and the corresponding atmospheric retrieval results. We will discuss the surprising detection of titanium oxide with respect to cloud formation theories and compare our findings for HAT-P-65 b with those of comparable objects.

Zoe Ko

Johns Hopkins University

A Gaussian Process Framework for Exoplanet Atmospheric Retrievals

The small sizes and cool temperatures of M-dwarf stars make exoplanets orbiting them promising targets for detailed atmospheric studies through transmission spectroscopy. However, these observations are compromised by photospheric heterogeneities like starspots and faculae, which introduce significant contamination into the transmission spectra; this might give rise to false spectral signatures, or biases when extracting inferences from them. The dynamic and unpredictable nature of stellar heterogeneities makes them difficult to model through theoretical approaches. Gaussian Processes (GPs) provide an alternative approach, using statistical methods rather than physical frameworks to model and account for this contamination in transmission spectra. We present a GP retrieval framework that simultaneously fits for stellar contamination and the planetary atmosphere.

To demonstrate the effectiveness of our framework, we apply it to a JWST NIRspec/PRISM observation of TOI-3235b, a well-characterized giant exoplanet transiting an M dwarf which shows signatures of significant stellar contamination. Through this analysis, we not only characterize the atmospheric composition of TOI-3235 b but also highlight the ability of GPs to effectively model stellar contamination for a system of a large exoplanet around a low-mass star, where stellar contamination is most prominent. These results demonstrate that GPs provide a robust approach to mitigating stellar contamination, offering a scalable solution applicable to a wide range of exoplanet systems.

Takanori Kodama

Earth-Life Science Institute, Institute of Science Tokyo

Climate of Tidally locked exo-terrestrial planets based on a high-resolution simulation with a global cloud-resolving model

For a tidally locked exo-terrestrial planet, the cloud stabilizing feedback has been considered to maintain surface water because of a difference in the distribution of insolation, causing permanent day-night sides. Clouds pose significant uncertainties in models for exoplanetary atmosphere. Traditionally, conventical GCMs with low resolution have used cumulus parameterization and large-scale condensation schemes to evaluate cloud-related processes. These treatments cannot explicitly resolve sub-scale physical phenomena, such as cloud formation processes.

Here, we introduce NICAM(Non-hydrostatic icosahedral atmosphere model), known as a global cloud-resolving model (GCRM). Our model can explicitly resolve cloud distribution and the vertical moisture transport of water vapor. We performed climate simulation with ~10 km horizontal mesh for TRAPPIST1-e case. The assumed planet is aqua planet configuration with 50 m of the mixed layer. The simulated period is 15 years to reach an equilibrium state. Our simulation is the highest resolution, long-term simulation with GCRM for exo-terrestrial planets to investigate characteristics of potential habitable climate. Such a cloud-resolving model will open a new era of climate studies and our understanding of habitable worlds.

Daniel Koll

Peking University

Synthesizing surface and atmosphere models to interpret rocky exoplanet emission

spectra

Thermal emission data of super-Earths including LHS 3844b, GJ 1252b, and TRAPPIST-1b suggest many short-period rocky exoplanets do not have an atmosphere, and instead resemble bare rocks like the Moon or Mercury. Our ability to correctly interpret these data, however, is crucially limited by our ability to correctly model rocky exoplanet surfaces and atmospheres. Here we synthesize Solar System data, new surface models of airless exoplanets, and new 3D General Circulation Models (GCMs) to analyze the observable signatures of rocky exoplanets. We find: 1. For airless exoplanets, albedos of exposed surfaces should quickly decrease due to space weathering processes. 2. Regolith surfaces of airless exoplanets can develop strong sub-surface temperature gradients via the solid-state greenhouse effect. This leads to distinct features in emission spectra of airless exoplanets that are not found in simpler (isothermal) surface models, and could potentially allow us to distinguish exoplanets that still have thin atmospheres but only small heat redistribution from those planets that are completely airless. 3. We re-visit heat redistribution on rocky exoplanets with a cloud-free GCM that incorporates non-grey radiative transfer. Overall, rocky exoplanet surfaces and atmospheres are shaped by a diverse range of physical processes which need to be considered to correctly interpret emission spectra of rocky exoplanets.

Thaddeus Komacek

University of Oxford

The past, present, and future of hot Jupiter circulation

Over the past twenty-two years since Showman & Guillot (2002), a coherent picture has emerged of the atmospheric dynamics of hot Jupiters from a combination of three-dimensional general circulation models (GCMs) and observations. This paradigm consists of hot Jupiters being spin-synchronized due to their close-in orbit, with resulting large day-to-night irradiation gradients driving a significant day-to-night temperature contrast. This day-to-night temperature contrast in turn raises day-to-night pressure gradients that are balanced by a circulation with wind speeds on the order of several kilometers per second. The dominant feature of this circulation is a superrotating equatorial jet, maintained by eddy-mean flow interactions that pump momentum from higher latitudes toward the equator. Notably, the the standard picture of hot Jupiter atmospheric circulation broadly stands strong to date, even with advances in observational characterization with JWST secondary eclipse mapping and phase curves as well as phase-resolved ground-based high resolution transmission and emission spectroscopy. In this presentation, I will argue that the pattern of hot Jupiter atmospheric circulation is general and relatively insensitive to parameter variations. To do so, I will show results from a combination of 3D GCMs and analytic theory that demonstrate that the atmospheric circulation of hot Jupiters is broadly insensitive to initial conditions, even across predicted regime transitions. I will further describe how ground- and space-based observations in the time-domain will provide a more stringent constraint on the detailed circulation pattern of hot and ultra-hot Jupiters.

Thea Kozakis

Instituto de Astrofísica de Andalucía

Is ozone a reliable proxy for molecular oxygen?

Molecular oxygen (O2) with a reducing gas (i.e., methane) is widely regarded as a promising biosignature, but there are circumstances in which O2 will be very difficult or impossible to detect (e.g. the mid-IR). For these scenarios, it has been suggested that ozone (O3), the photochemical product of O2, could be used as a proxy to infer the presence of O2. While O3 is not directly produced by life, it plays an important role in habitability as the ozone layer is the primary source of UV shielding for surface life on Earth. However O3 production is known to have a nonlinear dependence on O2, along with being strongly influenced by the UV spectrum of the planet's host star. To evaluate the reliability of O3 as a proxy for O2 we used Atmos, a 1D coupled climate/photochemistry code, to study the O2-O3 relationship for Earth-like'' habitable zone planets around a variety of stellar hosts (G0V-M5V) for O2 abundances from 0.01%-150% of the Present Atmospheric Level (PAL) on modern Earth, along with varying other biological fluxes. Overall we found that the O2-O3 relationship differed significantly around different stellar hosts, with different trends for hotter stars (G0V-K2V) than cooler stars (K5V-M5V). Planets orbiting hotter host stars experience an increase in O3 when O2 levels are initially decreased from the present atmospheric level, with maximum O3 abundance occurring at 25-55% PAL O2, while for cooler stars O3 decreases with O2, albeit nonlinearly. We also studied how O3 emission features for these planetary atmospheres varied for different O2 and O3 abundances using the radiative transfer code PICASO, finding a strong dependence on the amount of stratospheric heating via O3 for hotter stars. Our results show that understanding atmospheric context will be crucial for interpreting O3 measurements.

Laura Kreidberg

Max Planck Institute for Astronomy

A first look at rocky exoplanets with JWST

Rocky exoplanet atmosphere characterization has been a top priority for early JWST science operations. I will give an overview of the current state of rocky planet atmosphere observations, compiled for an upcoming review paper. At the time of writing, several major milestones have been achieved, including the most precise rocky planet transmission spectra measured to date, and the first detection of thermal emission for rocky worlds below 800 Kelvin. I will discuss how close we are to robust detections of spectral features in transmission, and summarise constraints on the surface pressure and carbon dioxide abundances from thermal emission measurements. I will also share several upcoming results, including the thermal emission spectrum of a bare rocky surface and the first phase curve of a temperate rocky planet. Finally, I will suggest some goals for future rocky planet observations, include a five scale height challenge to improve the precision of transmission spectra. JWST offers an unprecedented chance to identify and characterize the atmospheres of extrasolar rocky planets, and ExoClimes is an ideal venue to discuss how we as a community should proceed to make the most of this opportunity.

Helena Kühnle

ETH Zurich

The ultra-cool climate of COCONUTS-2b observed with JWST/MIRI

COCONUTS-2b is one of the coldest directly imaged gas giants with a temperature of about 480K. Its ultra-cool atmosphere represents a rare link between brown dwarfs and solar system objects like Jupiter. Its wide separation from the host star together with its low temperature allow to study an unique and evolved atmosphere using direct imaging. So far, the near infrared has been studied thoroughly using ground- and space-based telescopes, however leaving most of the mid-infrared hidden.

For the very first time, we want to present the MIRI/MRS data obtained by JWST revealing this atmosphere's spectral signatures far into the mid-infrared in unprecedented detail. With a resolution of up to R~3750 we can now search for isotopologues in the mid-infrared. In our analysis, we use atmospheric retrievals to characterize its chemical composition reaching a deeper understanding of the dynamical processes leading to the observed chemical disequilibrium. This leads us towards possible formation paths uncovering the secret past of this cool world. Can we provide further indications for a formation within a disc with subsequent migration or is a gravitational collapse scenario more likely? Ultimately, the presented analysis will lead to a better understanding of other cold climates now accessible with JWST.

David Lafrenière
Université de Montréal
Exoplanet Atmosphere Characterization with The Near Infra-Red Planet Searcher (NIRPS)
NIRPS is a new fiber-fed, high spectral resolution (~80k) spectrograph assisted by adaptive optics that is installed on the ESO 3.6m telescope at La Silla, Chile. Operated simultaneously with HARPS, NIRPS covers the Y, J, and H bands. The commissioning phase demonstrated high stability for both radial velocity measurements and exoplanet atmosphere characterization work. The NIRPS consortium is using a third of the 725 nights of Guaranteed Time Observations it was allocated over five years to conduct in-depth atmospheric characterization of several benchmark exoplanets, through high-fidelity, high signal-to-noise transmission and emission spectra, as well as a large, comprehensive survey of more than 75 exoplanets ranging from ultra-hot Jupiters to temperate terrestrial planets, to probe their atmosphere through transmission and emission spectroscopy and measure their orbital alignment through measurement of the Rossiter-Mclaughlin effect. Our goals are to measure the atmospheric composition and evaporation rate of each planet, to constrain their orbital configuration, and to derive statistical constraints on the correlation of these with system properties, thereby informing formation and evolution models. Over the program's first two years, we have prioritized the best exoplanets, including many JWST targets. This program will offer a unique opportunity to combine low- and high-resolution datasets, unlocking a complete understanding of exoplanets' atmospheres. Here I will present the main components and objectives of this program, and the first results obtained since the operations began on April 1, 2023, including detections of escaping atmospheres and the presence of molecules and atoms in the atmospheres of warm Neptunes and hot Jupiters.

Adam Langeveld

Johns Hopkins University

A time-resolved view of the extreme upper atmospheres of ultra-hot Jupiters with KPF and GHOST

Ultra-hot Jupiters (UHJs) are captivating subjects of study due to their scorching temperatures and extreme atmospheric conditions. Composed of a vast array of gaseous metallic species, UHJs are lucrative targets to probe with high-resolution transmission spectroscopy, particularly at optical wavelengths where absorption lines from metal atoms and ions are most prevalent. Time-resolved high-resolution transmission spectroscopy, where a significant atmospheric signal is detected at multiple phases across the transit, offers unprecedented detail into 3D atmospheric composition and dynamics by probing different planetary longitudes as the tidally-locked planet rotates during the transit. Such detections are now possible thanks to the superior sensitivity of the latest state-of-the-art instrumentation at the largest ground-based observatories. Here we will showcase some of the first UHJ transmission spectra observed with the newly-commissioned Keck Planet Finder (KPF) at Keck I, and the Gemini High-resolution Optical SpecTrograph (GHOST) at Gemini South. We will report on time-resolved detections of several chemical species in their transmission spectra. In particular, we will highlight strong detections of the infrared ionized calcium triplet lines, where the time-resolved measurements can provide insight into the atmospheric processes and dynamics at different longitudes and within the terminator limbs. Comparisons to atmospheric models that incorporate effects from non-local thermodynamic equilibrium will also be shown, helping to constrain planetary masses for UHJs orbiting rapidly rotating stars which are otherwise hard to measure with radial velocities. Our results demonstrate the power of these new high-resolution spectrographs to investigate the 3D nature of UHJ atmospheres, and provide valuable context for comparative studies to investigate atmospheric trends in a broad population of UHJs, especially as we prepare to exploit the full power of the ELT in the coming 5-10 years.

Érika Le Bourdais

Université de Montréal

New Challenges in Characterizing the Bulk Composition of Planetary Material using polluted white dwarfs

Polluted white dwarfs (WDs) provide unique laboratories for studying the composition of exoplanets and the eventual fate of planetary systems. The remnants of what was once a planetary system are accreted in the once pristine atmosphere of the star, after going through a circumstellar disk phase. To this day, we have characterized in great detail the atmosphere of dozens of polluted white dwarfs. While our sample is sufficient to embark in an age of population studies, many challenges remain in properly determining the abundances of planetary material before we can get a reliable picture of the bulk composition of exoplanets. From WD-disk interactions to the wavelength dependant discrepancy in the determined abundances, this poster/talk will discuss these challenges and how they impact our conclusions.

Benjamin Liberles

The University of Texas at Austin

Open-source Modeling Tools for Terrestrial Planetary Atmospheres within PICASO

The James Webb Space Telescope (JWST) has been instrumental for probing whether rocky planets have atmospheres. Tentative atmospheric detections have been discovered around some of those rocky planets using JWST. However, our ability to definitively characterize the composition of these atmospheres is lacking. In this poster, we introduce new modeling tools for characterizing terrestrial planetary atmospheres within the PICASO open-source code. We adapt the PICASO radiative transfer code, initially designed for gas giants and brown dwarfs, to effectively model the 1D radiative–convective structure of rocky planet atmospheres. We include updated opacities for terrestrial planets, such as opacities from collision-induced absorption of CO2, N2, O2, and CH4. Additionally, we include the presence of planetary surfaces with a range of compositions. As a case study we investigate LTT 1445A b, a rocky exoplanet with a radius of Rp = 1.34 Re and a mass of Mp = 2.73 Me. LTT 1445A b is one of two known transiting planets orbiting the closest known M-dwarf to host transiting rocky exoplanets to date. The host-star, LTT 1445A, is the largest star in a triple star system. Previous work suggests that LTT 1445A b lacks a thick Venus-like CO2 atmosphere but ambiguity remains around the planet's ability to hold onto a thinner atmosphere. We explore the possibility of LTT 1445A b hosting a moderately thin atmosphere using our new models.

Matt Lodge

University of Bristol

Fractal Aggregates: How the Shape of Atmospheric Particles can change the Climate of a Planet

It has become increasingly important to consider dust/haze particles in astrophysical contexts. These particles have been shown to be significant sources of absorption in solar system planets, moons, exoplanet atmospheres, brown dwarfs and protoplanetary disks. To determine the structure and composition of these environments accurately, it is crucial to correctly model their optical properties. Models often make the assumption that dust particles are spherical (to reduce complexity/computation time), but this can result in significantly underestimated absorption, compared to precisely calculating the properties of fluffy aggregates/fractals (by factors of up to 1,000). In this talk, I discuss the effect of considering these fractal aggregates versus spheres, and the impact this can have on transmission spectra, using the VIRGA cloud code and PICASO radiative transfer framework. These models provide key insights on how fractal aggregates affect spectra, and we have discovered several important and general conclusions that can be drawn, by separating the effects of their unique optical and dynamical behaviour within the atmosphere. In addition, I discuss the progress that has been made towards reducing the computation time for calculations of optical properties of these complex shapes for use in models. More specifically, I present MANTA-Ray: a powerful new model that can calculate accurate absorption cross-sections of fractal aggregates, but 10^(13) times faster than rigorous analysis using theories such as the discrete dipole approximation.

Joshua Lothringer

Space Telescope Science Institute

New Insights into Refractory and Volatile Species in Ultra-hot Jupiters with HST and JWST

The extreme temperatures of ultra-hot Jupiters keep all elements in the gas phase, enabling measurements of their full chemical inventories, from refractory to volatile species. These constraints provide a unique window into connecting the present-day atmospheric composition of these planets to their formation and evolutionary histories. Here, we present recent results from HST and JWST measuring refractory and volatile species for a number of ultra-hot Jupiters.

First, we analyze high-resolution UV spectra of KELT-9b, MASCARA-1b, and WASP-178b from HST, doubling the number of planets with constraints on escaping Fe and Mg. While a high escape rate is found for KELT-9b, MASCARA-1b and WASP-178b show no such evidence for escape, challenging expectations of population-wide trends. Second, we describe the

UV-to-IR HST and JWST transmission spectrum of WASP-178b, measuring SiO, H2O, and CO. We measure a solar-to-super-solar [Si/H] and [O/H] alongside a sub-solar [C/H], providing new clues to the planet's formation and accretion history. We will put these observations in context with other recent ground- and space-based observations of ultra-hot Jupiters. These results highlight two lenses with which to better understand the extreme atmospheres of these planets so that we can detail the origin and evolution of giant planets.

Parke Loyd

Eureka Scientific, Inc.

A Massive Survey of Hydrogen Mass Loss from Exoplanets

Bulk hydrogen escape influences the ultimate fate of a planetary atmosphere and thereby its climate. Ongoing hydrogen loss can produce extended clouds of hydrogen observable through transits in the Lyman-α line. By the start of Exoclimes VII, the Survey of Transiting Exoplanets in Lyman-α (STELα), a multi-cycle Hubble Space Telescope (HST) observing program selected in 2024, will be well into initial reconnaissance of over 120 systems, 40-50 of which will receive subsequent transit observations. In this talk, we provide an overview of the STELa program and the science it will enable. STELa's primary goals are mapping the role of mass loss throughout the population of known exoplanets, investigating the nature of transitional worlds such as those near the radius valley, and probing the physical mechanism driving the atmospheric erosion of sub-Neptunes. A wide array of treasury science will also be enabled, including 3D mapping of hydrogen in the local interstellar medium, a survey of stellar wind strengths, developing an atlas of reconstructed host star XUV spectra in the mass-rotation (i.e. age) plane, and investigating exosphere-thermosphere-lower atmosphere connections through synergies with the He 10830 Å mass-loss diagnostic, the James Webb Space Telescope (JWST), and other HST observations.

Cindy Luu

University of Texas at San Antonio

Revealing the Interiors of Volatile-Rich Sub-Neptunes through Geochemistry

Temperate exoplanets between the sizes of Earth and Neptune, known as sub-Neptunes, have emerged as intriguing targets for astrobiology. Yet, it is unknown whether these planets resemble Earth-like terrestrial worlds with habitable surfaces, Neptune-like giant planets with no habitable surfaces, or something in between. Yu et al. (2021) proposed that the observed atmospheric composition may constrain the surface conditions of temperate sub-Neptunes. Recently, the transmission spectra of two sub-Neptunes, K2-18 b and TOI-270 d, have become available to test this idea. However, the existing proposed surface conditions have not been able to simultaneously explain the retrieved atmospheric concentrations of ~1% CH_4, ~1% CO_2, and the non-detection of CO and NH_3 for both planets. Climate models predict these sub-Neptunes may host supercritical water in their interiors, however, current photochemical models cannot yet account for this structure. In this work, we develop a methodology for modeling the ratios of dominant carbon and nitrogen species in sub-Neptune atmospheres through equilibrium aqueous geochemical calculations.

We first model the CH_4/CO_2 and CO/CO_2 ratios of sub-Neptune K2-18 b using the Deep Earth Water (DEW) model. To match with the observed CH_4/CO_2 and CO/CO_2 ratios of K2-18 b, our calculated CH_4/CO_2 ratios correspond to an ocean temperature above 710 K and our calculated CO/CO_2 ratios are consistent with ocean temperatures below ~1070 K. These findings indicate that K2-18 b could harbor a global supercritical water ocean in the temperature range of ~710-1070 K. We then calculate the NH_3/N_2 ratio, demonstrating a necessity to consider NH_3 sequestration in water clouds and the solubility of NH_3 that is dependent on ocean acidity (pH). This work represents the first step towards understanding how a global supercritical water ocean may influence observable atmospheric characteristics on volatile-rich sub-Neptunes and demonstrates how Earth-based geochemical modeling can be valuable for characterizing exoplanet interiors.

Mathilde Malin

JHU - STScI

Medium-resolution mid-infrared spectroscopy of directly imaged exoplanets with JWST.

The MIRI instrument on the James Webb Space Telescope enables medium-resolution spectroscopy of directly imaged exoplanets. Our recent observations of GJ 504 b and of the HR 8799 system show that the MIRI-MRS can be used as a powerful high-contrast imaging instrument, even if it's not equipped with a coronagraph. GJ 504 b is estimated at 500 K, it is one of the rare planetary-mass companions that bridges the gap between the population of directly imaged young exoplanets above 1000 K, and our own Jupiter at 130 K. The unique HR

8799 system hosts four giant planets with temperatures ranging from 850 to 1400 K. First, we are taking advantages of the integral-field capabilities and medium spectral resolution of the MRS to detect multiple molecules in the atmospheres of these planets using the molecular mapping method. The molecules H2O and CO have been detected, along with NH3, CH4 and CO2 in the coldest ones, highlighting the rich chemistry that correlates with the temperature and metallicity of these planets. Comparing the HR 8799 planets with GJ 504 b is already offering insights into their evolutionary history and formation pathways. These exoplanets pose significant challenges for accurate spectrum extraction due to their proximity to a bright star. However, the stability of the JWST has enabled us to adapt reference differential imaging techniques for integral-field spectrographs to estimate and remove stellar diffraction. These novel methods hold great promise for characterizing additional exoplanets, including those yet to be discovered. After carefully subtracting the stellar PSF, the spectra can be extracted, allowing for precise measurements of their atmospheric parameters : temperature, radius, and molecular abundances.

Annabella Meech

Center for Astrophysics, Harvard & Smithsonian

BOWIE-ALIGN: the intriguing combination of sub-stellar metallicity and carbon depletion in the aligned hot Jupiter TrES-4b

Studies of exoplanet atmospheres have progressed from detecting individual chemical constituents to placing precise constraints on the atmospheric metallicity and carbon-to-oxygen (C/O) ratio. The question is then how can we refine our understanding of giant planet formation using these atmospheric markers? The JWST BOWIE-ALIGN program endeavors to characterize a sample of F star-orbiting hot Jupiters, to compare the metallicity and C/O of misaligned vs aligned Jupiters, which are believed to evolve differently. I will present the results for the second BOWIE-ALIGN target, the aligned TrES-4b. Using JWST NIRSpec G395H, we obtain a near-infrared transmission spectrum, with clear H2O and CO absorption features. We infer both sub-stellar metallicity and C/O. This combination is somewhat unexpected, and could be a product of an oxygen-rich environment, or accretion of low-metallicity gas and carbon-poor solids.

Christopher Monaghan

University of Montreal

Low 4.5 μm Dayside Emission Disfavours a Dark Bare-Rock scenario for the Hot Super-Earth TOI-431 b

The full range of conditions under which rocky planets can host atmospheres remains poorly understood, especially in the regime of close-in orbits around late-type stars. One way to assess the presence of atmospheres on rocky exoplanets is to measure their dayside emission as they are eclipsed by their host stars. Here, we present Spitzer observations of the 4.5 μm secondary eclipses of the rocky super-Earth TOI-431 b, whose mass and radius indicate an Earth-like bulk composition (3.07 $M_\oplus$, 1.28 $R_\oplus$). Exposed to more than 2000 times the irradiation of Earth, dayside temperatures of up to 2400 K are expected if the planet is a dark, atmosphereless bare-rock. Intriguingly, despite the strong stellar insolation, we measure a secondary eclipse depth of only 33±22 ppm, which corresponds to a dayside brightness temperature of 1520 K. This notably low eclipse depth disagrees with the dark bare-rock scenario at the 2.5 σ level, and suggests either that the planet is surrounded by an atmosphere, or that it is a bare-rock with a highly reflective surface. In the atmosphere scenario, the low dayside emission can be explained by the efficient redistribution of heat to the nightside, or by molecular absorption in the 4–5 μm bandpass. In the bare-rock scenario, a surface composition made of a high-albedo mineral species such as ultramafic rock can lead to reduced thermal emission consistent with low eclipse depth measurement. Follow-up spectroscopic observations with the James Webb Space Telescope hold the key to constraining the nature of the planet. We further present an updated model for interpreting the dayside emissions of bare-rock exoplanets. Our model has notable implications on future JWST observations, especially in light of upcoming DDT survey on rocky worlds.

Caroline Morley

UT Austin

Sonora Diamondback: Cloudy Atmosphere and Evolution Models for Brown Dwarfs and Giant Planets

Accurate evolution models are critical for tying observable properties (e.g., luminosity) of sub-stellar objects to key properties like mass. The thermal evolution of brown dwarfs and planets is regulated by their atmospheres, which allow their heat of formation (and from the brief era of energy generation from deuterium fusion) to radiate to space for billions of years. We present a new generation of atmosphere and evolution models which include the effects of clouds for warm substellar objects. We show how silicate (plus iron and corundum) clouds change the spectra of exoplanets and brown dwarfs in objects from 900–2400 K at a range of surface gravities. We include, for the first time in our cloudy modeling framework, three metallicities including super-solar (+0.5, similar to Jupiter) and sub-solar (-0.5) and demonstrate that these can change the evolution models substantially at some ages. We show how the emergence and disappearance of clouds affects the evolution of planets, creating a new set of hybrid evolution models applicable for giant planets and brown dwarfs. Our models have key upgrades from prior generations, including updated chemistry and opacities, and we present medium-resolution spectra (applicable for JWST, and other, applications) and high-resolution spectra appropriate for echelle spectroscopy from the ground.

Georgia Mraz

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 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 will investigate the properties HD 189733 b using three transits of near-infrared and optical data recently obtained simultaneously with the Near Infra Red 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. A preliminary analysis of the NIRPS data reveals well-behaved systematics, clear molecular signatures, and a preliminary helium detection. In addition to disentangling the planetary and stellar helium signals, our pre- and post-transit observations will shed light on previously observed signatures of a bow shock, offering valuable insights into the atmospheric loss. 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.

Evert Nasedkin

Trinity College Dublin

Weather on other Worlds: Time resolved atmospheric retrievals of directly imaged atmospheres.

Directly imaged objects, both exoplanets and brown dwarfs, present unique opportunities for understanding the atmospheric composition and dynamics of giant, hydrogen-dominated atmospheres. Spectroscopic variability, observed with JWST, has been linked to distinct atmospheric processes by comparing the wavelength dependence of the variability to the pressure level from which the emission occurs. Models are then used to reveal the dominant opacity sources that contribute in that wavelength range, providing a qualitative interpretation of the lightcurve. In order to quantify this interpretation, we extend the petitRADTRANS atmospheric retrieval into the time domain. We measure which atmospheric properties are changing over time, leading to the observed spectroscopic variability. In this talk, I will present the first results of these time-domain retrievals, applied to JWST/NIRSpec and MIRI/LRS observations of the benchmark exoplanet analogue SIMP0136. We infer how the atmospheric thermal structure, cloud coverage, and chemical composition vary with time, showing that these changing atmospheric properties lead to the observed variability. These measurements provide context for the interpretation of directly imaged spectra, and are necessary steps for linking the observations to full 3D atmospheric models.

Stevanus Kristianto Nugroho

Astrobiology Center

The Transmission Spectrum of KELT-20b with HDS/Subaru and GRACES/Gemini-N: New Detections and the Fe I Double-Peak Mystery

It has been more than three decades since the first exoplanet was discovered. Since then we have identified more than 5800 exoplanets in our galaxy alone. We have learned to characterize their atmospheres by detecting various chemical species in emission and transmission constraining chemical abundances and attempting to infer their planetary formation histories. With advances in stabilized spectrographs space telescopes like JWST and upcoming extremely large telescopes (ELTs) exoplanet atmospheres are being revealed in unprecedented three-dimensional detail marking the dawn of a new era in atmospheric studies.In this poster I will present our preliminary results on the transmission spectrum of KELT-20b observed using HDS/Subaru and GRACES/Gemini-N. We report new detections of Ca

I, Cr I, K I, Sc II, and Sr II along with confirmations of previously identified species such as Fe I, Fe II, Na I, Ca II, Cr II, and Mg I. Leveraging the high spectral resolution of HDS (R~165,000) we confirmed that only Fe I exhibits a double-peak feature among the detected species. Importantly this demonstrates that the double peak is not an instrumental artefact but is intrinsic to the exoplanet's atmosphere as it is consistently observed using four different facilities and at least six separate transit epochs. This finding offers potential insights into the atmospheric dynamics or chemical structure of KELT-20b.

Paulina Palma-Bifani

LIRA, Observatoire de Paris

Atmospheric insights into the planetary - brown dwarf boundary

Emission spectra from young super-Jupiters obtained with high-contrast imaging techniques have significantly advanced our understanding of exoplanetary atmospheres over the past two decades. They also hold clues on the formation history of these objects at the frontier of the brown-dwarf mass regime, which might have formed either like stars or planets. I have conducted a homogeneous characterization of 21 young (1 - 150 Myr) free-floating objects and companions spanning the Deuterium-burning boundary observed at medium resolution (R~4000) in the K-band (1.96 - 2.45 μm) with SINFONI at the VLT. We inverted these spectra with self-consistent 1D atmospheric grids and the forward modeling tool ForMoSA. From our results, we observe that both groups exhibit stellar-consistent atmospheric parameters. Here, I will discuss the implications of these results for the origin of these objects. I will also contrast the atmosphere of these objects with a detailed analysis of the exoplanet AF Lep b, a colder, less massive young Jupiter analog near the L-T transition, which was likely formed by core accretion. Altogether, these findings provide new insights into massive gas giants' nature, in terms of their atmospheric chemistry and formation mechanisms.

Luke Parker

University of Oxford

New regimes in exoplanet atmospheric characterisation with high-resolution spectroscopy

By the end of the decade the first light of the Extremely Large Telescope (ELT) will revolutionise exoplanet science, providing unprecedented characterisation of exoplanet atmospheres at high spectral resolution (HRS; R~100,000). To date, HRS has largely been confined to the study of Jupiter-mass planets in the optical and near-infrared (0.4–3.5 microns). However, first light instrumentation on the ELTs (e.g. METIS) will observe at novel M-band wavelengths (3.5-5 microns) and will target sub-Neptunes and super-Earths with high mean molecular weight (MMW) atmospheres. Here I present two projects opening these new parameter spaces for HRS, in preparation for the imminent arrival of the ELTs. I will first present results from our CRIRES+ survey of directly imaged companions at M-band wavelengths, pioneering the wide-scale use of this spectral range. Alongside CO and H2O, the M-band also provides a unique sensitivity to gaseous SiO which acts as both a probe of condensation processes, and as a tracer of the rock/vapour accretion history of giant exoplanets for targets across a range of temperatures. Through precise measurements of SiO abundance we constrain the formation pathway of each target through novel silicate abundance ratios, and benchmark these against established formation tracers including C/O and 13C/12C. Second, I will demonstrate the sensitivity of HRS to sub-Neptune atmospheres around M-dwarf hosts. Using CRIRES+ K-band spectra I constrain the atmosphere of the transiting warm sub-Neptune GJ 3090 b to have a high MMW (>7.1 g/mol) or high-altitude aerosols, further highlighting the diversity of atmospheres within the sub-Neptune population. These results open up the study of sub-Neptune targets from the ground and show that HRS can provide complementary and competitive constraints to JWST. The exploration of new parameter spaces with HRS is vital preparation for the ELTs and yields novel scientific results.

Stefan Pelletier

Geneva Observatory

The breaking of cold-traps and ensuing chemical transitions from hot to ultra-hot Jupiters

We understand chemistry. I dare say we understand chemistry very well. Our combined knowledge of chemistry and the natural distribution of elements in the universe has allowed us to predict with a fascinating accuracy what we should expect to see when observing atmospheres of hot (Teq >1500K) giant gaseous exoplanets based primarily on their equilibrium temperatures. Which is why when our chemistry models predict we should see something, but we do not, it is intriguing, even surprising. Nowhere has this been so glaring as the case of titanium (Ti), which has long been theorized to drive thermal inversions in the atmospheres of giant exoplanets via its oxide, TiO.

Lo and behold, exoplanets with thermal inversions have been found aplenty, but TiO detections on these remain sparse at best. Moreover, inferences via neutral atomic titanium have revealed severe levels of Ti depletion in the colder portion of the ultra-hot Jupiter population, indicative of nightside cold-trapping. And yet, cold-traps can be broken, as evident by the dazzling spectral presence of Ti-bearing species strongly seen on only slightly hotter exoplanets, revealing a dichotomy in atmospheric chemistry occurring over a relatively small temperature range.

Here I will present an overview of the titanium situation on hot and ultra-hot giant exoplanets. This will be done by highlighting new results from the NIRPS GTO program as well as JWST, which show that the depletion levels of titanium species lessen smoothly rather than sharply across the population as a function of equilibrium temperature. This indicates that the breaking of nightside cold-traps in tidally locked hot and ultra-hot Jupiters, which gives rise to a gas phase enrichment from specific condensates evaporating, occurs more progressively than some studies had previously suggested.

Junellie Perez

Johns Hopkins University

Testing Atmosphere-Interior Exchange Models for Rocky Exoplanets

Thousands of exoplanets have been discovered in the last several decades and as the number of exoplanets increases, the need to characterize these exoplanets has continued to grow. JWST has pushed the boundaries of exoplanet science and has started to show that it can probe smaller, rocky planets such as the inner planets in the TRAPPIST-1 system. One of the big questions is whether these small, rocky exoplanets around M-dwarfs could have 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. In order to fully understand these exoplanets, we need to understand their geological evolution since that can directly impact their atmospheres and hence play a role in habitability. In this research, I will start to address how the atmosphere-interior exchange resulting from geochemical cycles, such as the carbonate silicate cycle and the deep water cycle, can impact the atmospheric composition of these rocky exoplanets. While previous studies have looked at late-stage geological evolution on the TRAPPIST-1 planets (Perez et al. in prep), we aim to build a full geological evolution mode including a magma ocean phase that we can use to study rocky exoplanets observed with JWST. Since most of the exoplanets observed by JWST have higher equilibrium temperatures, this can indicate that they may have or are currently undergoing that phase, which can affect the gas abundances prior to the planet solidifying and therefore the late-stage atmosphere-interior exchange. We will present the preliminary list of exoplanets that will be part of this study and preliminary results from the models that the community can use moving forward.

Caroline Piaulet-Ghorayeb
University of Chicago

Exploring Uncharted Territory: Characterization of GJ 9827d's steam world atmosphere and interior

In recent years, JWST observations have revolutionized the study of exoplanet atmospheres, enabling unprecedented insights into sub-Neptunes - a ubiquitous yet poorly understood class of planets. Small sub-Neptunes in particular are expected to exhibit a diversity of compositions shaped by formation, atmospheric escape, and interior-atmosphere interactions. Yet, the extent to which they are enriched in heavy molecules and the mechanisms driving volatile enrichment remain elusive. Recently, JWST NIRISS/SOSS observations revealed the steam world composition of GJ 9827d, a warm (680 K) small (2 Earth radii) low-density sub-Neptune, with a detection of abundant water in the atmosphere. However, the limited wavelength range precluded the identification of other key atmospheric species. I will present the first 0.6-5.2 microns spectrum of GJ 9827 d, with new NIRSpec/G395H observations that extent our sensitivity to cover all major carbon-, oxygen-, and potential sulfur-bearing species in GJ 9827d's atmosphere. By combining these observations with host star elemental characterization and interior-atmosphere modeling, we constrain GJ 9827d's full structure, including the impact of a partially molten mantle as an additional water reservoir. This study of GJ 9827d establishes it as a benchmark for understanding atmospheric metal enrichment, offering critical insights into the formation conditions and evolutionary mechanisms shaping the atmospheres of warm sub-Neptunes.

Raymond Pierrehumbert
University of Oxford

Envelope interaction with magma oceans on SubNeptunes

Though their densities require a much more massive volatile envelope than Earth or Venus, many (perhaps most) subNeptunes are primarily composed of silicate rock and iron by mass, with rock/iron mass fractions ranging up to 90% or more, or even 99% in the case of hydrogen dominated envelopes. For sufficiently strong instellation or sufficiently massive envelope the rock/envelope interface consists of a (generally supercritical) envelope in contact with a silicate magma ocean. In extreme cases, the silicate itself can become supercritical and miscible with the envelope. I will review the criteria for existence of a magma ocean, and survey the situation for the handful of subNeptunes for which adequate atmospheric characterizations are available. Silicate melts are complex fluids, and evaporate incongruently (unlike the case of a water ocean, for which H2O liquid evaporates into H2O vapour). A consequence of this property is that the rock vapours (e.g. SiO) in equilibrium with the magma ocean are very subsaturated with regard to the Clausius-Clapeyron saturation vapour pressure for the pure vapour. This has profound consequences for the nature of convection in the envelope, which we will discuss in terms of the Ledoux (noncondensing) and Guillot (condensing) criteria. Some remarks on nonideal behaviour of CO2 in mixtures will also be offered.

Lorenzo Pino
INAF - Osservatorio Astrofisico di Arcetri
High dispersion optical phase curves of ultra-hot Jupiters with SHINE ON.
Ultra-hot Jupiters (UHJs; Teq ≧ 2500 K) are the hottest gaseous giants known. They emerged as ideal laboratories to test (1) theories of atmospheric structure and climate under extreme irradiation, and (2) planet formation theories, due to the simultaneous presence of gaseous refractory (e.g. Fe) and volatile (e.g. C) elements in their atmospheres. In combination, these offer a crucial complement to traditional tracers of planet formation, like the carbon-to-oxygen ratio.

Theoretical predictions suggest that UHJs should be close to chemical equilibrium and largely cloud-free, providing a more direct link between thermal structure and composition. Their climate should differ, due to the emergence of factors such as atmospheric drag. Yet, observational support is still sparse.

The SHINE ON program aims to fill this gap of knowledge through optical high dispersion (HDS) phase curves of about 15 UHJs obtained with some of the best instruments for this purpose (VLT ESPRESSO and Gemini-N MAROON-X). By resolving the planetary emission lines in time and wavelength SHINE ON will homogeneously provide - for the first time - longitudinally resolved information on the thermal structure, chemistry, wind speed and geometry of a statistically significant UHJ sample.

I will present the first results from the SHINE ON program. I will discuss how this program is complimentary to JWST and HDS observations in the near-infrared and in transmission geometry, and the importance of HDS phase curves as precursor of future instrumentation (e.g. ELT ANDES).

Michael Plummer

United States Air Force Academy

A Harmony of Clouds and Carbon Chemistry: Vertically Mapping the Atmospheric Waves of a Planetary-Mass Object

Young planetary-mass objects and brown dwarfs near the L/T transition exhibit enhanced spectrophotometric variability over field objects. Patchy clouds, aurora, stratospheric hot spots, and complex carbon chemistry have all been shown to be potential sources of this variability. Each of these is likely to be driven or influenced by planetary-scale waves (e.g., Rossby or Kelvin). Using time-resolved, low-resolution spectroscopy collected with the JWST/NIRISS and NIRSpec instruments, as well as ground-based spectrophotometry from the Canada-France-Hawaii Telescope and Observatoire du Mont-Megantic, we apply harmonic analysis to SIMP J013656.5+093347 (SIMP0136), a highly variable, isolated planetary-mass object. Employing Bayesian inference via dynamic nested sampling, we identify fundamental and higher-order harmonics (likely corresponding to planetary-scale waves). We use these harmonics, along with substellar models, to create 1D atmospheric flux maps (pressure levels vs. time) and identify interaction between atmospheric layers. We find correlation between deep atmosphere cloud modulation and overlying carbon chemistry, clarifying the principal drivers of substellar variability and shedding light on these objects' time-varying atmospheric dynamics.

Michael Radica

University of Chicago

Atmospheric Chemistry and Dynamics Probed Through JWST and Ground-Based

Spectroscopy of a Cloud-Free Hot-Saturn

With the launch of JWST, we are now in the regime where we are able to probe the three-dimensional coupling of atmospheric dynamics and chemistry in the atmospheres of giant planets with space-based observations. In this talk, I will present the complete near-infrared NIRISS + NIRSpec transmission spectrum of the unique, inflated hot-Saturn WASP-96b -- one of the few known cloud-free planets. Given its moderate equilibrium temperature (Teq~1300K), WASP-96b lies in a sweet spot for disequilibrium atmospheric processes. The cloud-free transit spectrum, with its unimpeded spectral features, is a perfect laboratory for the study of disequilibrium chemistry: notably, the abundances of H2O, SO2, and CO2 all point to different bulk metallicities, either indicating important contributions from photochemistry or depletion of H2O. Moreover, from the extremely precise JWST light curves, we extract independent spectra for the morning and evening planet limbs. We then compare these limb spectra to a suite of GCM simulations, tailored to WASP-96b, to better understand the impacts of 3D atmospheric circulation on the observable atmospheric chemistry.
Finally, we join our space-based JWST spectra with low-resolution, ground-based transit observations to better constrain the abundances of alkalis like Na and K, and thereby construct multiple robust refractory-to-volatile ratios; strong tracers of a planet's formation history. This work is also the first to demonstrate the continued compatibility between low-resolution ground and space-based observations in the era of JWST.

Sayyed Ali Rafi

The University of Tokyo

The Power and Pitfalls of High-Resolution Spectroscopy: HD 149026 b's Atmosphere and Telluric Correction Techniques

High-resolution spectroscopy (HRS) has proven invaluable for studying exoplanetary atmospheres, enabling the detection of dozens of exoplanets through its ability to resolve thousands of individual spectral lines. Its sensitivity to Doppler shifts also allows the investigation of atmospheric dynamics in close-in planets. More recently, HRS has been used for detailed atmospheric characterization via retrieval analyses, infering various orbital and atmospheric properties. In my talk, we present our work of the atmosphere of the hot Saturn HD 149026 b using infrared transmission spectra obtained with CARMENES. We report marginal evidence for H2O in the atmosphere, detected at a signal-to-noise ratio (S/N) of

~4.8. Through a Bayesian retrieval framework, we also constrained the planet's orbital and systemic velocities, finding the latter to be significantly red-shifted by >3σ relative to its expected value, while the former is consistent within 1σ. The origin of this anomalous redshift remains unclear but could be attributed to previously unknown atmospheric dynamics or, less likely, a non-zero orbital eccentricity.
Despite the remarkable capabilities of HRS, telluric line correction remains a significant challenge. In the second part of my talk, we present our ongoing work to identify the limitations of the forward modeling technique to be used for telluric removal analyses. While forward modeling performs well in the optical regime, our analysis of the same CARMENES dataset reveals its poor performance in the infrared, particularly compared to the PCA-like technique, SysRem. We attribute this to several factors, including inaccurate assumptions about Earth's atmospheric profiles, overlapping stellar lines, and potential shape inaccuracy and/or variations in the instrumental profile.
This work not only demonstrates the capability of HRS to detect atmospheric species and constrain orbital properties but also highlights the pressing need for improved telluric correction methods, particularly in the infrared.

Vanesa Ramirez
Leiden Observatory
Probing the Interiors of Giant Exoplanets Through Light Curves
Giant exoplanets are key targets for atmospheric and interior characterization due to their favorable detectability and diverse compositions. Yet their deep interiors remain poorly constrained. Standard interior modeling techniques based on mass and radius measurements often lead to degenerate results. However, when a planet orbits close to its host star, it experiences strong tidal forces, and its response—tidal deformation—offers an additional observable to probe its internal structure. In particular, phase curves and transit light curves can be used to infer the second fluid Love number for radial deformation, h2f, which depends on the planet's internal mass distribution. Despite its significance, Love numbers have been measured for only a few gas giants, highlighting the need to extend such studies to a larger number of exoplanets.

This work explores the feasibility of measuring Love numbers in short-period giant exoplanets using current and upcoming instruments, such as Ariel. We simulate light curves of confirmed targets to assess how variations in composition and Love numbers affect transit and phase curve signatures. By identifying promising systems and quantifying the observational precision required to detect tidal deformation in light curves, this study aims to establish a roadmap for expanding Love number measurements across diverse exoplanetary systems.

Swaetha Ramkumar
Trinity College Dublin

New perspectives on MASCARA-1b: A combined analysis of pre- and post-eclipse emission data using CRIRES+

Recent advancements in ground-based high-resolution spectrographs and subsequent analyses have been instrumental in detecting individual species and constraining dynamic processes in exoplanetary atmospheres. Furthermore, resolved phase-curve observations of highly irradiated gas giants enable us to obtain spectra as the planet rotates, offering crucial insights into day-night temperature contrasts, heat redistribution, and atmospheric dynamics.

We present new high-resolution emission spectroscopy observations of MASCARA-1b, obtained with CRIRES+, focusing on the post-eclipse phases of its orbit. By combining these observations with previously published pre-eclipse data, we investigate how key atmospheric properties—such as the temperature-pressure (T-P) profile and the carbon-to-oxygen (C/O) ratio—evolve as the planet rotates. Notably, the post-eclipse data probe the planet’s atmosphere after it has rotated by ≈106 degrees relative to the pre-eclipse observations, providing a complementary perspective on the chemical composition and dynamics of MASCARA-1b's atmosphere.

Lakeisha Ramos Rosado
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.

Sukrit Ranjan

University of Arizona

Model Intercomparisons Falsify O2 False Positives and Strengthen O2 as an Exoplanet Biosignature Gas

Current and upcoming facilities (James Webb Space Telescope, JWST; Extremely Large Telescopes, ELTs; Habitable Worlds Observatory, HWO) aim to characterize habitable exoplanets in search of signs of life (biosignatures; Seager et al. 2014). The canonical biosignature, motivated by the Solar System (Sagan et al. 1993), is atmospheric O2. However, scenarios have been proposed whereby abiotic mechanisms like photochemistry can generate abundant O2 on exoplanets (false positive scenarios; Meadows et al. 2018), questioning the value of O2 as an exoplanet biosignature gas. Particularly pernicious is the M-dwarf scenario, wherein the high FUV/NUV emission ratio of M-dwarfs may drive abundant abiotic O2 accumulation on the only class of temperate planet accessible to near-term atmospheric characterization with JWST (Domagal-Goldman et al. 2014, Harman et al. 2015, 2018, Hu et al. 2020). Here, we re-examine this scenario using a model intercomparison. We show that model artifacts drive the M-dwarf scenario, which, when rectified, eliminate this false positive scenario (Ranjan et al. 2023). Coupled with our earlier work using new UV cross-section measurements to rule out the low outgassing O2 false positive scenario (Ranjan et al. 2020), 2 of the 3 proposed photochemical O2 false positives have been eliminated, dramatically strengthening the case for oxygen as an exoplanet biosignature gas. Additionally, our modelling confirms earlier suggestions that CO is a high-reliability discriminant for abiotic O2 production (Schwieterman et al. 2016). Crucially, our findings replicate across multiple independently developed photochemical models, making them highly robust. Overall, our work strengthens the biosignature gas paradigm for exoplanet life search in general and O2 as a biosignature gas in particular, with significant implications for ongoing JWST observations of temperate terrestrial planets like TRAPPIST-1e (Allen et al. 2024), in-development ELT instruments like the Fabry-Perot Instrument for Oxygen Searches in Exoplanet Atmospheres (FIOS; Rukdee et al. 2019), and design of the upcoming HWO (Clery et al. 2023).

Alexander Rathcke
Technical University of Denmark, DTU Space
Stellar Contamination Correction Using Back-to-Back Transits of TRAPPIST-1 b and c
Stellar surface heterogeneities, such as spots and faculae, often contaminate exoplanet transit spectra, hindering precise atmospheric characterization. We demonstrate a novel, epoch-based, model-independent method to mitigate stellar contamination, applicable to multi-planet systems with at least one airless planet. We apply this method using quasi-simultaneous transits of TRAPPIST-1 b and TRAPPIST-1 c observed on July 9, 2024, with JWST NIRSpec PRISM. These two planets, with nearly identical radii and impact parameters, are likely either bare rocks or possess thin, low-pressure atmospheres, making them ideal candidates for this technique, as variations in their transit spectra would be primarily attributed to stellar activity. Our observations reveal their transit spectra exhibit consistent features, indicating similar levels of stellar contamination. We use TRAPPIST-1 b to correct the transit spectrum of TRAPPIST-1 c, achieving a 2.5x reduction in stellar contamination at shorter wavelengths. At longer wavelengths, lower SNR prevents clear detection of contamination or full assessment of mitigation. Still, out-of-transit analysis reveals variations across the spectrum, suggesting contamination extends into the longer wavelengths. Based on the success of the correction at shorter wavelengths, we argue that contamination is also reduced at longer wavelengths to a similar extent. This shifts the challenge of detecting atmospheric features to a predominantly white noise issue, which can be addressed by stacking observations. This method enables epoch-specific stellar contamination corrections, allowing co-addition of planetary spectra for reliable searches of secondary atmospheres with signals of 60-250 ppm.

Emily Rickman
ESA/STScI
Breaking the degeneracy: substellar anchors for atmospheric and evolutionary models

Understanding the formation and atmospheric properties of giant planets and brown dwarfs is a major goal of modern astrophysics, but are often plagued by a lack of observational constraints. Measurements of companion brightness, atmospheric parameters, and dynamic environments require thermal emission measured through direct detection that historically has been difficult to do. High-contrast imaging has revealed a precious sample of benchmark brown dwarfs, analogous to giant exoplanets, that are ideal for comprehensively characterizing such properties through direct spectroscopy at an unprecedented level of resolution and sensitivity thanks to JWST, without relying on a coronagraph.

Through targeting observations of companions that have measured model-independent masses through radial velocity data and astrometric accelerations from ESA's Hipparcos and Gaia missions, I am leading a JWST program that goes beyond just directly imaging such companions, but comprehensively characterizing their atmospheric properties through direct spectroscopic observations in the high-contrast regime.

Here I present JWST/NIRSpec IFU spectra from a mass- and age-calibrated sample of benchmark brown dwarf companions that span spectral types, that will set the standard for studying exoplanet atmospheres and identifying physical processes missing in giant planet evolutionary and spectral models. This carefully mass- and age-calibrated sample consists of carefully measured dynamical masses from ESA's Hipparcos and Gaia missions, in addition to radial velocity and imaging data, that underpin the key parameters needed to understand the degeneracies in these models and set the basis for testing, calibrating, and identifying physical processes missing in evolutionary and spectral models.

Frances Rigby

Institute of Astronomy, University of Cambridge

Testing gas dwarf scenarios for temperate sub-Neptunes

Recent works have investigated the possibility of gas dwarfs, with rocky interiors and thick H2-rich atmospheres, to explain aspects of the sub-Neptune population. We report a coupled interior-atmosphere modelling framework for gas dwarfs to investigate the plausibility of this scenario for temperate sub-Neptunes, including both solid surfaces and magma oceans, and their observable diagnostics. The surface-atmosphere interactions and atmospheric composition are sensitive to a range of parameters, including the atmospheric and internal structure, volatile solubility and atmospheric chemistry. Using our framework, we test the viability of gas dwarf scenarios to explain the observed atmospheric compositions of some key temperate sub-Neptunes.

Felix Sainsbury-Martinez

University of Leeds

The Response and Observability of Exo-Earth Climates to Cometary Impacts

Impacts by icy bodies likely played a key role in shaping the composition of solar systems objects, including the Earth's habitability. Hence, it is likely that they play a similar role in exoplanetary systems. Here I discuss how an impact from a comet affects the atmospheric chemistry, climate, and composition of two Earth-like terrestrial exoplanets with differing orbital configurations: a short (6 days), tidally-locked, orbit and an Earth-analogue orbit with a diurnal cycle.

To investigate this, I coupled a cometary impact model, which includes thermal ablation and pressure-drive breakup, with the 3D Earth-System-Model WACCM6/CESM2, quantifying the impact of a 2.5 km radius pure water ice comet. This revealed how both the impact-delivered water and thermal energy together affect the planetary atmosphere, including changing i) the cloud greenhouse effect, ii) the planetary albedo, iii) and the overall atmospheric composition. For the latter, we generally find an increase in the abundance of oxygen-bearing molecules with one key exception: ozone, the abundance of which is highly sensitive to products of the photodissociation of water, e.g OH.

My models also revealed how the response of the planetary atmosphere to the impact is shaped by the orbital configuration, and hence circulation regime of the planet. I find that the global atmospheric circulation may play a key role in setting the potential observability of individual massive impacts in future observations of exo-Earths. On the other hand, longer term changes to atmospheric composition appear less sensitive to orbital configuration, suggesting that sustained bombardment, or multiple large impacts, have the potential to measurably change the composition, and hence the habitability, of terrestrial exo-Earths.

In summary we find that cometary impacts may play an important role in shapping terrestrial exoplanetary atmospheres, and that to fully understand their impact we must also understand the underlying atmosphere they interact with.

Andrea Salazar

Harvard University

Exploring self-consistent habitable Venus scenarios using a novel spin-climate evolution model

Venus's current slow, retrograde rotation has long been theorized as an equilibrium state of its gravitational tide (which acts to spin the planet down) and its atmospheric thermal tide (which acts to spin the planet up). Previous work has suggested that its current slow rotation rate is conducive to the formation of strong substellar cloud cover, which may have shielded the planet from a runaway greenhouse and sustained habitable conditions for billions of years. However, differences in atmospheric composition should affect the planetary rotation rate through coupling via the atmospheric thermal tide, which may spin-up the planet and preclude substellar cloud formation. In this work, we develop a novel coupled spin-climate evolution model to explore self-consistent habitable Venus scenarios. We find that habitable, Earth-like atmospheres have thermal tides nearly an order of magnitude stronger than that on modern Venus. These strong tides increase the planetary rotation rate during the habitable periods and push Venus out of the slow-rotating/cloudy regime, thus terminating habitable conditions. For planets with atmospheres similar to Earth, the habitable period does not last longer than 0.5 Gyr. This work suggests that the atmospheric thermal tide may restrict the length of habitable periods on early Venus and other Venus-like exoplanets.

Salma Salhi

Université de Montréal

Score-based models for correlated noise correction in JWST NIRISS spectral data

Transit spectroscopy for atmospheric characterization is very sensitive to various sources of noise, and this is especially true when using the Single Object Slitless Spectroscopy (SOSS) mode on the NIRISS instrument aboard the JWST. Current methods to deal with 1/f (correlated) noise, such as approximating the 1/f signal as a constant across a column, leave noise residuals that are almost double that of the expected readout noise. Deep learning models could be a way to mitigate this problem, as they have already been shown to be very efficient at a wide variety of tasks in astrophysical data reduction, including denoising. We construct a score-based generative diffusion model to learn the structure of the noise in dark images, including bad pixels, hot pixels, cosmic rays, and 1/f noise to create a noise model. We then use this noise model as the data likelihood to analyze mock spectral trace observations in a Bayesian framework, allowing us to produce noise-free posterior samples of the pixel values of the underlying trace. We are already seeing a ~36% improvement in precision of spectral extractions when applied to simulated data. We aim to apply this method to time series spectroscopic observations, which will allow for a more accurate retrieval of the underlying trace parameters, potentially reducing our error to the photon noise limit. This could substantially improve our signal-to-noise by up to a factor of 2 for some spectral regions and thus enable higher precision spectroscopy and better constraints on molecule detections.

Mariana Sastre
University of Groningen
Impact of varying redox states on crystallization and atmospheric composition of rocky exoplanets
The magma ocean phase describes the early stage of rocky planets, during which the entire planet is molten due to heat generated by accretion processes. In the case of short-period exoplanets inside the runaway greenhouse limit, this phase may last Gyrs, until the inventory of major primordial volatiles, such as H2O, CO2, and H2, is exhausted. The internal evolution of these planets is influenced by various factors, including the exchange of volatiles between the molten planetary interior and the atmosphere. This exchange significantly impacts planetary climate, exoplanet bulk densities, surface conditions, and long-term geodynamic activity by controlling greenhouse effects, surface water stability, and atmospheric composition. However, so far the evolution of the magma ocean phase and the interaction between interior and atmosphere has focused dominantly on Earth-like (oxidized) conditions, or alternatively on strongly hydrogen-rich (sub-Neptune) environments, neglecting that vast parameter space likely covered in the transition compositional regime. The work I will present here, focuses on modeling the evolving interaction of atmospheres and interiors under different redox (composition) conditions. Using a coupled computational framework of the planetary interior and atmosphere, I studied the detailed evolution of the magma ocean phase, aiming to understand the crystallization sequence and the atmospheric composition in equilibrium with long-lived magma oceans.

Arjun Savel
University of Maryland, College Park
Maximizing constraints from JWST transmission spectra with cross-correlation retrievals

JWST is already realizing a major goal by providing high-SNR, broad-wavelength measurements of giant exoplanet atmospheres. Yet the richness of these data has not been fully exploited — methodological advances promise more insights from existing spectra. Take the case of CO in WASP-39b. While initial observations in the ERS program did not detect this molecule in the planet's NIRSpec/G395H spectrum, Esparza-Borges et al. (2023) reported a strong 7.5 sigma CO detection. Their analysis rests on a technique that is not standard in JWST exoplanet analysis, yet is widely used by the ground-based atmospheric characterization community: cross-correlation at native pixel resolution. Their result, along with the detection of planetary winds in WASP-121b via cross-correlation (Sing et al. 2024), shows that existing NIRSpec/G395H datasets have more to reveal than traditional analyses can recover. While innovative, the above approach stops at detection for molecules — cross-correlation alone does not constrain gas abundance. We turn to the powerful statistical machinery of cross-correlation retrievals, which we apply for the first time to JWST spectra. We show that cross-correlation retrievals on the WASP-39b NIRSpec/G395H data provide much tighter constraints on the CO abundance than do standard retrievals. Cross-correlation retrievals with JWST's NIRSpec/G395H mode therefore appear highly fruitful: they are able to measure the major C-, S-, and O-bearing molecules in a single instrument mode, to rigorously search for potential isotope fractionation, to constrain atmospheric dynamics for a wide range of planets, and to squeeze new information from existing datasets.

Matthäus Schulik
Imperial College London

The Helium frontier - Fractionation, ionization and their implications for (non)-detections

Helium is the second lightest element, hence prone to atmospheric escape similar to hydrogen. It is now being searched in a number of large surveys as escape tracer, targeting planets young and old, large and small. To understand a number of recent trends, such as the apparent lack of vigorous escapers at a young age, and missing escapers around M-dwarf hosts (Dos Santos 2023, Orrel-Miquel+2024) we employ the new self-consistent 1-D radiation hydrodynamic simulation code AIOLOS (Schulik & Booth2023).

Specifically, our numerical technique allows every escaping species to possess their own velocity and temperature fields. This opens the possibility to study fractionation between light and heavy and ionized and neutral species. This approach also accomodates non-equal temperatures between the species. Because most of the reaction coefficients of the Helium

recombination cascade need to be evaluated at the electron temperature, which is generally hotter than the ionic and neutral gases (Johnstone+2020), dramatic changes in the radial distribution of He2^3S can occur compared to single-temperature approaches.
Using this tool, we present results for the fractionation of escaping Helium from Hot Jupiters, (Schulik & Owen, subm. MNRAS). We firstly discuss the surprisingly small role of the He2^1S population on that of He2^3S, when the electronic excitation and de-excitation rates are updated. Secondly, the onset of fractionation at larger stellar distances and its imprint in the transit depth of the Helium line is presented. Beyond that, our new results for Sub-Neptunes show markedly different behaviour of Helium fractionation compared to published work by Malsky+(2023), owing to our inclusion of photoionization and multiple temperatures. We discuss how fractionation interacts with contraction of the planetary envelope over time, and contrast this with the current dataset on (non)-detections.

Julia Seidel

ESO/Observatory of the Cote d'Azur

The origin of atmospheric winds in ultra-hot Jupiters: magnetic field strength

Given the plethora of exoplanet atmospheres observed to date, the field is moving towards the first population studies. I will present the preliminary results of zonal atmospheric winds in ultra-hot Jupiters as traced by iron for all current detections and highlight population trends. Most importantly, atmospheric zonal wind speeds seem to show trends as a function of temperature. I will show how this trend is likely driven by the magnetic field strength of the planet, providing an indirect avenue to probe magnetic fields in ultra-hot exoplanets.

Sarah Silverman

McGill University

The Fate of Ice Sheets on Chaotically Rotating Exoplanets

The majority of Earth-like exoplanets orbit red dwarf stars. Given the abundance of these red dwarf planets, determining whether they are habitable is essential for assessing the potential for life beyond our Solar System. The habitability of these planets is threatened by water being lost to space, trapped in their interiors, and frozen in ice sheets. The fate of ice sheets in particular has been minimally explored yet is critical to understand, as ice sheets not only govern the availability of liquid surface water but also interact with the climate system and the solid planet. Ice sheets have been modeled on synchronously rotating planets in 1:1

spin-orbit resonance. However, gravitational interactions between neighboring planets may sporadically induce non-synchronous spin states, resulting in slow rotation or libration of the substellar point. Such slow rotation would bring an ice sheet from the nightside into daylight, with global repercussions. We couple a 3D global climate model known as the Planetary Climate Model with a 1D ice sheet model to determine the fate of ice sheets when these near-synchronous spin states are taken into account. We present simulations showcasing the spatial distribution and thickness of these ice sheets. This work advances our understanding of the diverse environments that can sustain life beyond Earth and provides insights into how ice sheets, climate, and the solid planet evolve under varied conditions.

Peter Smith

Arizona State University

Stronger Together: Increasing Atmospheric Inference Capabilities by Combing Ground-based and JWST Spectroscopy

In just a few short years, JWST has already revolutionized our understanding of exoplanetary atmospheres. However, cutting edge characterization is still being done with ground-based facilities. Ground-based, high resolution spectroscopy and space-based, low resolution spectroscopy have complementary strengths and weaknesses, and the combination of the two can provide a more powerful probe of a planet's atmosphere than can be achieved by either method individually. I will highlight the differing capabilities of high and low resolution spectroscopy for measuring and interpreting exoplanet climates and chemistry, and I will then describe how combining the two methods can result in more precise inferences and more comprehensive pictures of a planet's atmosphere. The relevance of such a combination will be demonstrated through several real case studies in which high resolution spectra and JWST data have been combined for joint atmospheric retrieval analyses of transiting gas giants WASP-77A b, WASP-18 b, and WASP-166 b.

Zhuo-Yang Song

Peking University

Influence of Planetary Rotation on Supersonic Flow of Lava Planets: A Two-Dimensional Horizontal Model Analysis

Lava planets, characterized by their proximity to host stars, have garnered significant attention due to their enhanced detectability for atmospheric characterization. Previous research indicated that the atmospheric flow around small lava planets becomes supersonic when dominated by rocky vapor evaporated from the magma ocean near the substellar point. However, these studies often assumed axisymmetric flow, neglecting the impact of planetary rotation on climate. Given the fast spin rates of lava planets due to their close-in orbits, planetary rotation can break this symmetry, inducing an asymmetric flow component. Our study introduces a two-dimensional framework to explore the influence of planetary rotation on atmospheric dynamics for the first time. Starting from the established one-dimensional axisymmetric solution, we derived the governing equation for the asymmetric flow by expanding with respect to 1/Ro (where Ro is the Rossby number, typically exceeding unity for lava planets). Moving forward, we plan to refine the perturbation method results and investigate long-term effects that may impact observations, such as planetary shape deformation and magma ocean flow patterns. Our work aims to deepen the understanding of lava planets and provide theoretical support for future observations.

Jared Splinter

McGill University

Atmospheric Heat Transport in the Ultra-hot Jupiter WASP-121b using a NIRISS/SOSS Phase Curve

Ultra-hot Jupiters, with their extreme temperatures, serve as excellent laboratories for exploring atmospheric dynamics and heat transfer, including hydrogen dissociation and magnetic drag. The Single Object Slitless Spectroscopy (SOSS) mode of JWST's NIRISS instrument delivers medium-resolution (R ~ 700) time-series spectroscopy optimized for transiting exoplanet studies. We present an analysis of the ultra-hot Jupiter WASP-121b, using a NIRISS/SOSS phase curve spanning visible and near-infrared wavelengths sensitive to reflected light and thermal emission (~0.6–2.85 μm).

This wavelength range captures more than half of the planet's bolometric flux, allowing a precise determination of its energy budget. Our analysis of the phase-resolved emission spectra allows us to constrain WASP-121b's atmospheric temperature structure, reflected light, and updated estimates of the Bond albedo and heat recirculation efficiency. Given the planet's tidally distorted shape, we model its projected area to accurately determine the emitted flux at each orbital phase.

We convert the planet's emitted flux into an effective temperature map. We find a dayside effective temperature of 2760 K and a nightside effective temperature of 1488 K with uncertainties under 10 K. Using a 1D Energy Balance Model that incorporates molecular dissociation, we constrain the planet's mixed layer depth, wind speed, and albedo. We find a low Bond albedo of 0.19 and a low heat recirculation efficiency of 0.2, consistent with previous work. Notably, we detect larger eastward phase offsets at shorter wavelengths than at longer wavelengths.

These methods are broadly applicable to phase curve analyses of other exoplanets. They can be readily applied to future observations with JWST and ARIEL, providing deeper insights into heat transport and aerosols in extreme planetary environments.

Marie-Luise Steinmeyer

Institute for Particle Physics and Astrophysics , ETH Zurich

Evolving water distribution as sub-Neptunes age

Recent research on sub-Neptunes highlights that the atmosphere and interior of these planets are coupled and cannot be modeled as two separate systems. It is still unclear how this chemical and compositional coupling affects the evolution and contraction of sub-Neptunes.

Here, we quantify the effects of the atmosphere-interior coupling on the radius evolution as the planet ages. Our structure model takes into account that the bulk water content of a planet is distributed among the core, mantle, surface, and atmosphere. In addition, the atmosphere may be rich in H2/He. We model not only the thermal evolution of sub-Neptunes, but also the loss of atmospheric mass by photoevaporation. The mantle is treated as a long-term source of water in the atmosphere through outgassing.

Static structure models find a reduction in the total planet radius in coupled models compared to previous work without coupling. We find that the strength of the radius reduction increases with planet mass but decreases with age of the planet. The relationship between planet radius and age has been proposed as a way to break the degeneracy in the composition of sub-Neptunes. Thanks to the TESS mission, the observed population of young sub-Neptunes is growing. This makes it possible to compare our modeled age-radius relation with observations. Our new mass-radius relationships show that previous models underestimated the bulk volatile abundance of sub-Neptunes by neglecting of the interior as a volatile inventory.

Genaro Suarez

American Museum of Natural History

Cloudy Extrasolar Skies in the JWST Era and their dependence on atmospheric properties

Dust clouds in extrasolar atmospheres shape the emergent spectra of gas giant planets and brown dwarfs. Therefore, our understanding of these objects depends on our knowledge of sandy clouds, which have their main spectral signature in the mid-infrared. Spitzer archival data revealed that sandy clouds in warm extrasolar worlds are near ubiquitous, concentrate at low latitudes, and may exhibit age-dependent chemical and physical properties. We present exclusive mid-infrared observations from several JWST programs for cloudy extrasolar worlds with different properties such as temperature, metallicity, and surface gravity. We explore the relation of cloud properties, including opacity, composition, and grain size, to the properties of the objects. This analysis allows us to learn about the diversity of extrasolar worlds and interpret recent and future JWST observations of dusty atmospheres.

Lev Tal-Or

Ariel University

Potential Interior Structures and Habitability of Super-Earth Exoplanets LHS 1140 b, K2-18 b, TOI-1452 b and TOI-1468 c

We analyze four super-Earth exoplanets, LHS 1140 b, K2-18 b, TOI-1452 b, and TOI-1468 c, which orbit M-dwarf stars in the habitable zone. Their relative proximity, within 40 parsecs, makes them prime candidates for follow-up observations and atmospheric and habitability studies. We assess their internal structure and habitability, considering their tidal heating, atmospheric heating, and global transport. We model the interior structure of the planets by applying Bayesian inference to an exoplanet's interior model. A constant quality factor model is used to calculate the range of tidal heating, and a one-dimensional analytical model of tidally locked planets is used to assess their surface temperature distribution and habitability. Assuming no or only thin atmospheres, K2-18 b and TOI-1468 c are likely water worlds. However, TOI-1452 b and LHS 1140 b may have rocky surfaces. We find that tidal heating is insufficient to raise the global mean surface temperature, but greenhouse heating can effectively do so. If the considered planets have retained thick atmospheres, K2-18 b, TOI-1468 c, and TOI-1452 b may be too hot to sustain liquid water on their surface. However, the lower instellation of LHS 1140 b and the non-zero probability of it having a rocky surface give more space for habitable conditions on the planet.

Keigo Taniguchi

Earth-Life Science Institute

Effects of salinity on ocean planet climate

According to the studies of planet formation, terrestrial exoplanets around M dwarfs could sustain large amount of surface water. Due to closer orbits and tidal forces, these planets would be tidally-locked, and fully covered by ocean on planetary surface.
On the other hand, Earth's ocean circulation largely affects to the climate (e.g. meridional heat transport, water cycle). In addition, meridional overturning circulation on Earth is driven by density differences which is affected by sea water temperature and salinity, resulting from heat
exchange to atmosphere and salinity change by precipitation or sea ice formation. Although salinity has large influences on ocean behavior such as strength of ocean circulation and condition of sea ice formation, this effect on tidally-locked ocean planet has been still unknown.
In order to investigate the influence by salinity, we simulated climates of ocean covered tidallylocked planet with 1 Earth ocean mass and Earth-like/zero salinity using an atmospheric and
oceanic global climate model (AOGCM) based on MIROC. Comparing the results of between Earth-like salinity and zero salinity (pure water), we found that salinity affects to not only sea ice
distribution due to freezing-point depression, but also intensity of meridional and zonal ocean current. In this presentation, we will show the physical mechanisms of these differences by salinity.

Anna Taylor

University of Arizona

A Multi-Species Atmospheric Escape Model with Excited Hydrogen and Helium: Application to HD209458b

Understanding the atmospheric escape from Hot Jupiters/Neptunes is crucial for gaining insights into exoplanet evolution, demographics, and star-planet interactions. Recent observations of exoplanets undergoing mass loss show excited states of hydrogen and helium, which can constrain escape rates, thermal structure, and level populations in non-local thermodynamic equilibrium (NLTE). In particular, absorption by He I at 1083 nm and the H I Balmer lines have been detected on many exoplanets but have proven challenging to interpret. We demonstrate that even the archetype hot-Jupiter HD209458b likely presents a challenge in reconciling observations and upper limits of He I and H I Balmer transit depths that appear low relative to high FUV/NUV transit depths. We present a coupled full-atmosphere model that integrates a multi-species thermosphere-ionosphere hydrodynamic escape model with a detailed lower/middle atmosphere model, constrained by observations from HST, JWST, and ground-based telescopes. Our results reveal that accounting for the lower/middle atmosphere leads to higher He I and H I Balmer transit depths, making it more challenging to match observations at different wavelengths. We incorporate updated excitation/de-excitation rates and high-resolution cross-sections for metastable helium, which impact the He I transit depth but do not fully resolve the problems in explaining observations. We achieve a simultaneous fit to the He I and H I Balmer transit depths by adopting a low heating efficiency that leads to a relatively low mass loss rate and diffusive separation of helium. This suggests that the larger FUV signatures may probe the extended exosphere while the excited He and H lines probe the upper atmosphere. Finally, we explore variations in stellar activity that significantly influence the He I and H I Balmer line transit depths, emphasizing the importance of near-simultaneous observations across multiple wavelengths at different times.

Jake Taylor

University of Oxford

JWST NEAT: NIRISS/SOSS Transmission Spectrum of the Super-Earth GJ 357b

We present a JWST NIRISS/SOSS transmission spectrum of the super-Earth GJ 357 b: the first atmospheric observation of this exoplanet. Despite missing the first 40% of the transit due to using an out-of-date ephemeris, we still recover a transmission spectrum that does not display any clear signs of atmospheric features. We compare the transmission spectrum to a grid of atmosphere models and reject, to 3-sigma confidence, atmospheres with metallicities ~100x solar (~4 g/mol) with clouds at pressures down to 0.01 bar. We propose that the retention of a secondary atmosphere on GJ 357 b is plausible due to its higher escape velocity compared to an Earth-sized planet and the exceptional inactivity of its host star relative to other M2.5V stars. Finally, we model the feasibility of detecting an atmosphere on GJ 357 b with MIRI/LRS or MIRI photometry. We find that, with two eclipses, it would be possible to detect features indicative of an atmosphere or surface.

Mathilde Timmermans

University of Birmingham

First insights into the atmosphere of TOI-4336 A b

Discerning patterns and trends in the physical properties of exoplanets is now possible thanks to the growing number of planet discoveries. Super-Earths and sub-Neptunes were initially thought to be separate populations, yet evidence is now in favor of a continuous transition in density, atmospheric composition, and internal structure. In this talk, I will present the first peek into the atmosphere of TOI-4336 A b, a temperate sub-Neptune-sized planet orbiting a bright M3.5 star, ahead of JWST observations (Cycle 3, GO 4711). Owing to its Transmission Spectroscopy Metric of about 85, corresponding to twice the value for K2-18 b, this planet is particularly well suited for atmospheric characterization. It will likely be studied extensively in the coming years to figure out its nature, whether water-world, gas dwarf, or other. In addition, the presence of a newly discovered super-Earth in the system will allow the comparison between volatile-rich and volatile-poor worlds. Our exploratory program of planet b with the HST WFC3/G141 aimed at revealing whether absorption signatures are detectable in transmission by exploring the region around the 1.4micron H_2O/CH_4 feature. It represents the first piece of the puzzle towards breaking the degeneracy between density, atmospheric composition, and internal composition for TOI-4336 A b, adding to the pool of characterized temperate sub-Neptunes.

Shang-Min Tsai

ASIAA (Institute of Astronomy & Astrophysics, Academia Sinica)

An Expanded habitable zone for biosignature detection

The classic outer edge of the habitable zone (HZ) is defined by a planet's ability to maintain surface liquid water without freezing, under maximum greenhouse warming by a CO_2-dominated atmosphere. However, while the classic HZ serves as a useful guide, recent studies and observations highlight the importance of considering other greenhouse gases and the diverse conditions of habitable planets. In this study, we explore the greenhouse effects of several key biosignature gases (N_2O, C_2H_6, and DMS) using self-consistent climate-photochemical modeling. We postulate that life may emerge early in a planet's history when molecular hydrogen provides additional warming, with biosignature gases produced by microbial life sustaining surface temperatures above freezing after the depletion of H2. This study quantifies the extension of the HZ enabled by these biosignature gases and emphasizes the potential for future searches targeting these planets near the outer edge of HZ, where biogenic molecules are inherently more detectable.

Jake Turner

Cornell University

Studying the magnetic field of hot Jupiter HD 189733b using spectropolarimetry of the 1083 nm helium line

Observations of an exoplanet's magnetic field would provide valuable insights into properties that are otherwise difficult to study, such as the planet's interior structure, atmospheric dynamics and escape, and the physics of star-planet interactions. Additionally, magnetic fields may contribute to the habitability of terrestrial exoplanets. Several magnetic field detection methods have been suggested, including radio observations and star-planet interactions, with ongoing observation campaigns. However, no detections have been confirmed thus far, highlighting the need for complementary approaches. Recently, it was proposed that you could detect the magnetic fields in exoplanets by measuring the polarization in the helium line at 1083 nm while they transit.

In this talk, we will discuss our campaign to detect the magnetic field of the canonical hot Jupiter HD 189733b using spectropolarimetry of the helium line at 1083 nm observed with the SPIRou instrument on the CFHT. In total, we have observed eleven transits, which includes five transits observed in Stokes-Q and three transits observed in both Stokes-U and Stokes-V. This is the first time a transiting exoplanet has been observed in all Stokes parameters. New modeling from our group suggests that all Stokes components are needed to accurately measure the strength and orientation of the planet's magnetic field. From our analysis, we have successfully reproduced the previous Stokes-I detection of helium in HD 189733b's atmosphere and can place upper limits on the strength and orientation of the planet's magnetic field. Most importantly, we show that the data are white-noise dominated and no large scale-systematics are present. Finally, we will discuss the implications of our results for future magnetic field characterization of HD 189733b and other planets using spectropolarimetry of the helium line.

Anna Grace Ulses

University of Washington

Detecting land with the Habitable Worlds Observatory can rule out O2 biosignature false positives

Biosignature searches with the Habitable Worlds Observatory (HWO) will require an understanding of how biosignature false positives – that is non-biological processes mimicking the impact of life on a planet's atmosphere or surface – can be confidently identified and ruled out. Molecular oxygen (O2) is a widely studied biosignature because of its association with photosynthesis, and the apparent low likelihood of an O2-rich atmosphere developing on a lifeless world. However, abiotic O2 may still potentially be generated on habitable zone planets around Sun-like stars resulting in a false positive. One example of which is a waterworld. For planets with H2O inventories exceeding ~50 Earth oceans, the pressure overburden from such large oceans increases the solidus of the silicate interior and rapidly terminates crustal production. The cessation of crustal cycling eliminates geological O2 sinks, and O2 builds up in the atmosphere via H2 escape. Fortunately, this false positive would be excluded by the detection of exposed land since there is a predictable maximum limit to topography based on the crushing strength of silicate rock. To that end, we present a study of simulated reflected light retrievals of Earth-like and waterworld planets, and in doing so determine what HWO capabilities will be needed to confidently detect land and rule out this false positive. We explore the sensitivity of the detections to total land fraction, cloud fraction, SNR, and wavelength coverage. Critically, we also show that land can still be detected without any prior knowledge of what the surface is composed of. Altogether we demonstrate that given sufficient SNR and wavelength coverage, HWO will be able to identify the rising surface albedo slope associated with land surfaces and thereby rule out waterworld oxygen false positives.

Jeff Valenti

STScI

JWST legacy spectra of HAT-P-26b: A new SO2 detection and two old puzzles resolved

I will present the legacy-quality JWST transmission spectra (0.6-12 µm) and emission spectra (2.9-12 µm) of HAT-P-26b, a benchmark warm Neptune (~1000 K, ~0.6 Rjup, ~0.06 Mjup). The

transmission spectrum exhibits very prominent SO2 (4.05 μm), CO2 (4.3 μm), and H2O features. The prominent SO2 indicates strong disequilibrium photochemistry, which is thought to depend on insolation (temperature) and metallicity (mass). HAT-P-26b fills the temperature gap between WASP-39b (~1200 K) and WASP-107b (~800 K), two other planets with robust SO2 detections but has a lower mass than both. SO2 formation is still poorly understood, so every new detection is valuable. We set a strong upper limit on methane, which also implies disequilibrium chemistry.

Previous observations (Hubble, Spitzer, RVs) of HAT-P-26b suggested a surprisingly eccentric orbit (e~0.12) and surprisingly low metallicity (~solar). The new JWST data resolve these puzzling early results, definitively showing that the orbit is nearly circular and the atmospheric oxygen abundance is comparable to Neptune and hence consistent with the mass-metallicity relationship obeyed by the solar system giant planets. Broad wavelength coverage, good spectral resolution, and excellent precision allow JWST to break the degeneracy between water abundance and clouds, which affected previous analyses. With these new measurements, HAT-P-26b is now consistent with standard planet formation models, which envisage the accretion of ice-rich planetesimals during inward migration.

The JWST observations reported here were obtained as part of TST DREAMS program 1312 (NIRISS SOSS transit, NIRSpec G395H transit and eclipse, MIRI LRS eclipse) and MANATEE program 1177 (MIRI LRS transit).

Daniel Valentine
University of Bristol
Ariel's Promising Potential for Phase and Eclipse Mapping
I present a comprehensive assessment of Ariel's mapping abilities, using existing eclipse maps obtained by JWST as realistic test cases to inform the simulations, enabling direct comparison between the observatories. Eclipse mapping is currently the only method of measuring 3D (longitude-latitude-pressure) profiles of exoplanet atmospheres, which allows us to map their thermal structure and constrain their atmospheric dynamics. Only JWST data has proven to be of sufficient calibre to widely apply this method, but as an oversubscribed general observatory, it is time-limited in the numbers of planets for which it can provide in-depth characterisations. Ariel, on the other hand, is a dedicated exoplanet mission,

therefore it could map substantially more planets than JWST could in the same timeframe, and devote more time to individual targets. As such, Ariel is the only observatory capable of carrying out a large-scale, spectroscopic phase curve survey of an order of magnitude more planets (>60) than would be feasible with JWST. Such a survey, which would be the largest of its kind to date, would revolutionise our understanding of multi-dimensional atmospheric dynamics and the parameters that control them. In order to motivate such a survey, I close by analytically ranking the best mapping candidates for Ariel and provide recommendations for the target list and observational design.

Thomas Vandal

Université de Montréal

First Results of the PISCO Program: Detecting Young Giant Exoplanets via their Atmosphere

Most exoplanet detection methods are heavily biased with respect to orbital separation. On the one hand, transits and precise radial velocities (pRVs) probe short separations efficiently. On the other hand, direct imaging remains limited to separations beyond ~0.2 arcseconds. This leaves a range of intermediate separations that are challenging to explore, especially with direct detection methods. One way to alleviate these limitations is to leverage high-dispersion cross-correlation spectroscopy (HDCCS) as an exoplanet detection method where planets are detected through their atmospheric signal. With a single observation, one can use HDCCS to disentangle the signature of the host star from that of any companion hidden in the observed spectrum. Our simulations for a 4-meter class telescope predict that contrast ratios down to $3x10^{-5}$ are attainable with a single 2-hour exposure. In a blind survey, this method has the potential to unveil young gas giants with only one visit per star, and without any bias in orbital separation, hence bridging a gap in our understanding of the exoplanet population. Moreover, planets detected through HDCCS will be readily amenable to atmospheric characterization. The PISCO (Planet Inference from Spectral COrrelation) program aims to demonstrate this method on 12 known brown dwarfs and one exoplanet, Beta Pictoris c, using the Near-Infrared Planet Searcher (NIRPS) on ESO's 3.6-meter Telescope. Here, we present a first analysis of these observations. We discuss the optimal observing strategies and data reduction procedures when using HDCCS as a detection method, and how they differ from the more common case of timeseries analysis. We also report the results of our companion search and derive empirical detection limits for all PISCO targets. These results have important implications for HDCCS as a detection method, both for NIRPS and future facilities such as the ANDES instrument on the ELT.

Johanna Vos

Trinity College Dublin

Exometeorology: A Multi-Pronged Approach with JWST

We are entering the era of direct exoplanet characterisation studies. Based on the handful of directly-imaged exoplanets studied to date, it is clear that interpretation of these discoveries hinges on a thorough understanding of their complex atmospheric phenomena. With unprecedented sensitivity, wavelength range and photometric stability, the advent of JWST enables a paradigm shift in our understanding of extrasolar atmospheres. I will present first results across three JWST programs that will provide an unprecedented, multi-dimensional view of extrasolar atmospheres. Program #3486 will reveal equator-to-pole atmospheric differences beyond our solar system, Program #3548 will enable longitudinally-resolved characterisation of the detailed cloud and atmospheric properties in an isolated, planetary-mass world and Program #3496 will enable the first vertically-resolved wind speed measurements in any extrasolar atmosphere. Together, these programs will provide transformational insight into the spatial and temporal behaviour of key atmospheric processes in giant extrasolar worlds.

Joost Wardenier

Université de Montréal

A first look at the JWST/NIRSpec phase curve of WASP-76b

We present the first results of the 50-hour JWST/NIRSpec phase-curve observation of the canonical ultra-hot Jupiter WASP-76b (data taken in January 2025). WASP-76b is one of the best-characterized exoplanets to date, having been observed with at least 10 different ground-based instruments. To date, 22 different atoms and molecules have been detected in its atmosphere, while 13 optical species (refractories and alkalis) have measured abundances. While such abundance measurements provide key insights into the formation/migration history of ultra-hot Jupiters, it is well-known that the extreme day-night contrasts of these planets can bias retrievals by orders of magnitude. This makes the interpretation of transmission and emission spectra a lot more challenging.

In this contribution we will present the white-light phase curve of WASP-76b, as well as initial reductions/analyses of the transmission and dayside emission spectra.

The aim of our JWST/NIRSpec program is to characterize the 3D thermochemical structure of WASP-76b in unprecedented detail and put constraints on atmospheric dynamics and heat redistribution. Additionally, we can use this 3D information to remove potential biases from retrievals based on previous ground-based observations. By combining these updated refractory measurements with constraints on the volatile budget from JWST, we can reliably trace back the formation/migration history of WASP-76b.

Another particularly elusive aspect of WASP-76b from previous ground-based observations is its asymmetric transmission signature, which seems to hint at stark thermochemical differences between the morning and evening terminator. Our phase-dependent transmission spectra from JWST will shed light on the physical mechanisms governing this asymmetry.

Peter Wheatley

University of Warwick

Characterising stellar activity and the high-energy radiation environments of exoplanets with escaping atmospheres

I will present an analysis of 25 years of serendipitous XMM-Newton X-ray observations of stars selected to be representative of exoplanet host stars. I will show that previous studies have tended to overestimate X-ray irradiation due to contamination by close binary stars. I will also use thousands of XMM-Newton measurements to characterise stellar X-ray variability on timescales up to decades, revealing evidence that some exoplanets suffer significantly higher irradiation than others. I will then discuss the implications for population-level studies of atmospheric escape and evolution. Finally, I will describe the twelve ground-based telescopes of the Next Generation Transit Survey (NGTS), which match the photometric precision of TESS, and I will explain opportunities for the exoplanet community to request observations with NGTS in support of exoplanet atmosphere observations with large facilities. This can include long-term monitoring of stellar activity to quantify spot modulation and constrain stellar contamination at the time of transmission and secondary eclipse spectroscopy, including with JWST.

Christopher Wirth

University of Chicago

A Next-Generation Analytic Model of Tidally Locked Rocky Planet Atmospheres

Observations with JWST have reported nondetections of atmospheres around the majority of hot rocky planets orbiting M dwarfs. Potentially explained by atmospheric escape due to active host stars, lacking an atmosphere would limit habitability on the most easily observable terrestrial exoplanets.

However, most of these bare rock inferences are based on models that are ill-suited to the planets we are currently able to study, as they were developed for use on cooler, slower-rotating planets like Earth and Mars. In particular, these models rely on the weak temperature gradient assumption, in which rotation is neglected and pressure and temperature gradients can be simply related to wind speeds. We find that this assumption may not be valid for over 45% of planets observed with JWST, including TRAPPIST-1b, GJ 1132b, and GJ 486b, due to their short rotation periods. Relaxing this assumption, I will present a new first-principles analytic approach to interpreting secondary eclipses and phase curves of rocky planets. This simple new model is interpretable, physically motivated, and informed by dedicated three-dimensional hydrodynamic simulations.

We observe that the longitudinal temperature structure of tidally locked terrestrials depends strongly on the atmospheric circulation. Considering the applicable range of atmospheric dynamical regimes, we find that a given planet's nightside temperature can plausibly range by 100s of Kelvin (from detectable to undetectable). Furthermore, we find that the dayside temperature of a planet may either increase or decrease with increasing pressure, depending on atmospheric characteristics. In several cases, there exist degeneracies between surface pressure and dayside temperature, demonstrating additional complexity in interpretations of recent observations.

Beyond serving as an important tool for exploring the vast space of possible atmospheres, I will share how this model can be applied to inform work in various other aspects of terrestrial atmospheres, such as simulations, clouds, hazes, and chemistry.

Nicholas Wogan

NASA Ames Research Center

Towards a general chemical and climate model of planetary atmospheres for interpreting exoplanet observations

Deciphering the nature of exoplanet atmospheres from telescope spectra relies heavily upon atmospheric chemical and climate models. Even with the high precision of modern observatories like JWST, spectra are often compatible with a wide variety of atmospheric scenarios, so researchers use theoretical models to narrow down the possibilities and ultimately choose an interpretation consistent with both the data and the model. This mixed data and theory approach is powerful, but it also has substantial risk: If atmospheric codes are not general enough to capture the diversity of exoplanet atmospheres, then simulations will misguide our understanding of the spectra.

Here, with the goal of remedying this problem, we attempt to create a more general chemical and climate model of planetary atmospheres. Specifically, we use the open-source 1-D photochemical and climate code Photochem (https://github.com/Nicholaswogan/photochem) to reproduce the observed composition and climates of Venus, Earth, Mars, Jupiter and Titan with a single set of kinetics, thermodynamics and opacities. Furthermore, we use the same model to explain several exoplanet atmospheres with high-precision JWST datasets (e.g., WASP-39b).

As a whole, we demonstrate a description of atmospheric chemistry and physics that spans a large parameter space, which should lend some tentative confidence when interpreting future exoplanet spectra with Photochem. For example, we find that self-consistent photochemical-climate simulations of K2-18b as a gas-rich mini-Neptune readily explain recent JWST observation of the planet. Our tour of the solar system and several exoplanets has also shed light on poorly understood chemical kinetics and climate physics, highlighting the future studies needed to improve the generality of exoplanet atmosphere simulations.

Robin Wordsworth

Harvard

Stochastic models of planetary climate evolution

The processes that drive the evolution of planetary atmospheres are often highly stochastic, but most climate models are deterministic. Here the case for stochastic climate evolution modeling is presented based on a series of examples. For Mars, the record of liquid water and surface chemistry is well explained by stochastic models that incorporate episodic release of greenhouse gases, crustal alteration, and loss of H to space. For Earth, a stochastic model of the changing carbon cycle based on the Itô calculus can help explain differences in glaciation between the Proterozoic and Phanerozoic eons. In addition, treating nonlinear transitions such as Snowball events as a probability flow allows interesting analogies to be drawn with other physical processes such as quantum tunneling. Finally, I will show how stochastic modeling provides new insights into whether rocky exoplanets around M-class stars are able to retain atmospheres.

Maria Zamyatina

University of Exeter

CH4-CO pathways in hot Jupiter atmospheres

CH4 and CO are the two major C-bearing chemical species in hot Jupiter atmospheres. Deep in such atmospheres chemical equilibrium dictates the split of C between CH4 and CO. Aloft the equilibrium is broken, and chemical kinetics of CH4 and CO play a role. CH4 can be converted to CO via a number of chemical pathways. The pathway that dominates at pressures where CH4 and CO are interconverted slower than transported by the wind is critical for quenching. We calculated CH4-CO interconversion pathways in 3D using the output from the aerosol-free solar-metallicity 3D GCM simulations of HAT-P-11b, HD189733b, HD209458b and WASP-17b with coupled dynamics, radiative transfer and chemical kinetics. We find that the same CH4-CO interconversion pathway operates at the CH4 quench level in these atmospheres. This qualitatively supports the previous use of CH4-CO chemical relaxation schemes and emphases the importance of a choice of a CH4-CO interconversion pathway for determining CH4 quench level.

Yapeng Zhang

Caltech

Phase-resolved high-resolution view of the emission from the hottest exoplanet

Ultra-hot Jupiters provide unique laboratories for studying the extreme climate in exoplanet atmospheres. We obtained phase-resolved high-resolution emission spectroscopy of the hottest exoplanet, KELT-9 b, with the optical spectrometer Keck Planet Finder (KPF). Using the temporally and spectrally resolved emission from Fe, we probe the strength and velocity shift of the planetary signal as a function of orbital phases (from 0 to 0.5), which map to the temperature structure and global winds across longitudes. Further comparison to circulation models will unveil the driving mechanism of heat recirculation and the role of magnetic fields in ultra-hot Jupiters. Our new observations also led to the first detection of H-alpha emission in a hot Jupiter. The H-alpha signal shows an intriguing line shape. I will present its constraints on the thermal structure, high-altitude winds, and mass loss process in the upper atmosphere of this extremely irradiated gas giant.