'Atmospheres and interiors of exoplanets and brown dwarfs (ExoAtmInt)' Abstracts

Talks

JWST Spectroscopic Variability and Auroral Modelling of Warm Ultracool Dwarf LSR J1835+3259

Authors

Eleanor Pike (1), Stuart Littlefair (1)

(1) University of Sheffield

Abstract

Auroral variability in ultracool dwarfs (UCDs) is recognised as a key source of optical and infrared modulation, yet its physical origin remains poorly understood. We present JWST/NIRISS-SOSS time-series spectroscopy of the M8.5 auroral UCD LSR J1835+3259, obtained to probe its wavelength-dependent rotational variability and the atmospheric processes underlying its infrared variability. Principal component analysis reveals the presence of two distinct surface features: one dominated by FeH modulation near 1 μm and another introducing additional variability across the H and K bands. Forward-modelling using model atmosphere grids fails to fit the average NIRISS spectrum, whereas a blended model comprising an M-dwarf photosphere and a cooler blackbody component provides a substantially improved fit. Meanwhile, the variations in the weighting of the two components also provides a good fit to the broadband variability seen within the NIRISS data. We interpret this mixture not as a literal cool surface region but as a proxy for auroral heating and non-equilibrium chemistry. By adding perturbations to PICASO model grids, we demonstrate that a combination of atmospheric heating and non-equilibrium chemistry can successfully mimic a blend of unperturbed photosphere and a blackbody, and that the presence of these effects may explain the unusual spectrum and variability of LSR J1835+3259.

Estimates of conductance of brown dwarf atmospheres using electron beam precipitation

Authors

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Abstract

In recent years there has been increasing interest in the upper atmospheres of brown dwarfs. Observations of powerful, auroral-like radio emissions have sparked interest in the structure and chemistry of the upper atmospheres, and the mechanisms driving these emissions. In particular, the origin of the ionisation that may lead to such emissions is at present poorly understood. At Jupiter, the dominant source of ionisation in the auroral zone is the auroral current system itself, enabled by Pedersen conductivity produced by the impact of precipitating electrons on H_2. Specifically, Pedersen conductivity is generated predominantly by H_3^+ ions produced by ionisation of H_2. However, to date there have been no ab initio calculations of the Pedersen conductivity at brown dwarfs. Here, we compute the Pedersen conductivity for various configurations of brown dwarfs using (a) a Chapman function for background conductivity of irradiated BDs, and (b) an electron beam precipitation model adapted from Jupiter. Our results indicate that electron precipitation can drive significant conductance at these objects, lending support to previous arguments that auroral current systems can be responsible for the radio emissions observed.

Exploring the UV-Visible Transmission Spectrum of the Warm Super-Neptune HAT-P-26 b

Authors

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Abstract

We present the UV-visible transmission spectrum of HAT-P-26 b. Past transmission spectroscopy studies tend to focus on the NIR wavelength range, but they alone don't paint a full picture of the complicated physical and chemical processes involved in exoplanet atmospheres. The UV-visible range hosts a wealth of information on the presence of UV absorbers, scatterers, and atmospheric escape. We observed the warm super-Neptune, HAT-P-26 b, from 200-800 nm with HST's WFC3/UVIS G280 observing mode. The atmosphere was previously characterised at longer wavelengths, but UV observations remain unexplored due to high SNR requirements and the challenge of a UV-dim host star. Our study is part of the Hubble Ultraviolet-optical Survey of Transiting Legacy Exoplanets (HUSTLE) treasury program with the goal of constraining the abundances of mid-to-near-UV atmospheric absorbers. I'll compare with previous observations, discuss the extraction and reduction methods applied, and highlight additional constraints we can place on the atmospheric interpretation.

Investigating star-planet compositional ties for systems with host stars of varying composition

Authors

Daisy Turner (1)

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Abstract

Stars and their planets form from the same primordial material. A fundamental connection therefore is hypothesised to exist between a host star's elemental abundances and those of its small planets. Exploring this stellar–planetary compositional link offers a unique window into the processes that carve the radius valley and determine planetary interior composition. Both the existence and complexity of a monotonic relationship between the compositions of host stars and their planets can be investigated. I unravel these complexities with a diverse stellar sample spanning a wide range of chemical balances and a diverse planetary sample covering the super-Earth and sub-Neptune populations. I put emphasis on [α/Fe] variety, as these α-elements are present in the interiors of small exoplanets. My sample spans a wide range of iron and α-element abundances, offering an opportunity to study stars with compositions both like and unlike the Sun. By leveraging planetary interior modelling, I analysed how the elemental abundances of these stars relate to the inferred compositions of their orbiting small planets. My analysis concludes that no simple, one-to-one compositional relationship exists; establishing a robust connection will therefore require a multi-parameter approach that accounts for the broader context of the planetary system.

Dwarfs of Fire and Ice: Studying irradiated white dwarf-brown dwarf binaries

Authors

Jenni French (1)

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Abstract

Irradiated white dwarf-brown dwarf binaries are ideal laboratories for studying highly irradiated atmospheres with high SNRs. Building on a comprehensive HST program that uncovered systematic trends in atmospheric properties, we are investigating JWST NIRSpec phase curves of five such systems. Four of these systems eclipse, allowing direct observations of the brown dwarfs' nightsides when they fully occult the white dwarf. Our program targets the key processes shaping irradiated atmospheres including photochemistry, vertical transport and cloud formation across a sample spanning three orders of magnitude of external irradiation flux. This wide parameter space allows us to directly explore how irradiation flux influences heat transport efficiency and disequilibrium chemistry. Using the first JWST phase curves and phase-dependent spectra of irradiated brown dwarfs, we have developed a joint retrieval framework that maps the atmospheric 3D thermal structure and the longitudinal distribution of molecular abundances. We constrain H_2O, CO_2, and CH_4 abundances in our sample, as well as detecting evidence for potential H_3^+ fluorescence. I will present new results linking irradiation flux to atmospheric structure and chemistry and place these objects in the larger context of hot Jupiters and non-irradiated brown dwarf systems. These observations highlight the exquisite opportunity granted by white dwarf-brown dwarf spectra to probe substellar atmospheres, connect them to exoplanet atmospheres, and probe the evolution of post-main sequence planetary systems.

Comparing telluric removal methods in their capability to recover injected exoplanet atmosphere signals with high resolution emission spectroscopy

Authors

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Abstract

Correction of telluric lines beyond the use of standard stars is essential to achieve good precision and unbiased measurements of atmospheric abundances and temperatures of exoplanets via high resolution cross-correlation spectroscopy. We use our own publicly available algorithm called Astroclimes to remove telluric lines from archival CARMENES observations of tau Bootis and compare its performance to PCA in the context of exoplanet emission spectroscopy. We carry out injection and recovery tests with model planetary signals of different strengths and find that Astroclimes can recover the signal with similar SNRs as the PCA cases with a higher number of components, while being less aggressive on the injected signal. Besides assessing how PCA alters the injected planetary signal as we add more PCA components, we explored cases of different planetary orbital velocities, which should pose harder challenges on both detrending methods studied. We also combine tau Bootis observations from multiple nights to verify whether we can confirm the water detection reported in Webb et al. (2022) when employing Astroclimes or PCA.
Further development is ongoing to apply the algorithm to transmission spectroscopy as well, which is a more demanding task given the typically smaller radial velocity separation between telluric and planetary signals. The first application would be to analyse archival CARMENES data of HAT-P-11 that hasn't been used for atmospheric characterisation and carry out a full retrieval analysis to determine the atmospheric composition of HAT-P-11b. This work would provide further insights on the nature of the atmosphere of HAT-P-11 b, which has had both detections (Basilicata et al. 2024) and non-detections reported in the literature (Masson et al. 2026).

Spot the Difference: a comparison of stellar contamination modelling in NIRISS/SOSS transmission spectra for two giant planet-hosting active K-dwarfs

Authors

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Abstract

Transmission spectroscopy with JWST has brought a new era of atmospheric characterisation for exoplanets, but stellar contamination from transit light source effects (TLSE) remains a critical challenge for active host stars. Surface heterogeneities such as spots and faculae can imprint wavelength-dependent signatures onto transmission spectra, which can bias retrieved atmospheric properties if not properly accounted for.

In this work, we investigate the impact of stellar contamination modelling choices on atmospheric retrievals using NIRISS/SOSS observations of two hot Jupiters orbiting active K-dwarfs: WASP-52b and HAT-P-18b. Using the NEMESISPY retrieval framework, we perform a series of tests to explore two key assumptions commonly made in stellar contamination modelling: (1) the complexity of active region representations such as the inclusion of faculae and spot umbra-penumbra distinctions, and (2) the choice of spot coverage priors, contrasting commonly-used uniform priors with physically motivated distributions informed by stellar observations and MHD simulations.

We find that models including both spots and faculae are strongly preferred for WASP-52b and improve posterior convergence for HAT-P-18b, while increasing spot dimensionality beyond two components provides no statistical benefit. Although uniform priors are often favoured by Bayesian evidence, they can drive high spot coverage fractions, whereas informed priors yield more physically plausible stellar properties. Meaningfully, we find this to marginally impact key atmospheric parameters, particularly the retrieved H_2O abundance.

By comparing two systems with similar stellar hosts but differing retrieval behaviour, we "spot the difference" between modelling assumptions that matter and those that do not. Our results highlight the importance of adopting physically motivated stellar contamination prescriptions and provide practical guidance for future JWST transmission spectroscopy studies of active stars.

Impact of Photochemical Haze on Chemistry in Hot-Jupiters: Preparing for the Era of ELT and Ariel

Authors

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Abstract

Hazes are expected to form in the atmosphere of hot-Jupiters, with their presence inferred from observations. They can strongly impact observational data such as by muting spectral signatures, and their radiative heating can modify the atmospheric thermal structure, thereby altering both the planet's emission and the abundances of key chemical species. However, the lack of 3D studies on haze limits our ability to predict spectra, interpret chemical signatures, and robustly determine whether a given planet hosts haze. Yet, combining modelling with large-scale surveys such as planned for Ariel and ELT, will allow us to break this limit.

We present results from 3D simulations of radiatively active photochemical haze, coupled with kinetic chemistry, in the atmospheres of hot-Jupiters. We found that the global haze distribution is governed by the super-rotating jet and eddy mass flux. Whereas the detailed distribution is determined by the decomposed winds. The radiative heating introduced by the haze changes the thermal structure drastically, resulting in a different shape of transmission and emission spectra during transit observation. This heating also drives chemical disequilibrium and alters the abundance of chemical species. We conclude that neglecting the radiative heating of haze could lead to misinterpretations of observations, and highlight the importance of accounting for radiatively active photochemical haze when interpreting photometric observations of hot-Jupiters. Finally, we note that population studies, such as those provided by the Ariel and ELT, will hold the key to unlocking the major mechanisms controlling the presence and nature of this atmospheric haze. By combining this framework with the large dataset achieved by the upcoming observational campaigns, we will be able to interpret the high data volume more robustly and gain deeper insight into the atmosphere of hot-Jupiters.

The impact of hazes on Sub-Neptune interior conditions and evolution

Authors

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Abstract

Photochemical hazes have been detected and are likely common in sub-Neptune atmospheres, yet their impact on interior conditions and evolution remain largely unexplored. The optical properties of hazes affect an atmosphere's temperature profile, for example, by reflecting starlight or by potentially insulating younger, warmer planets. We use a 1D radiative-convective atmosphere model (GENESIS) coupled with an aerosol microphysics code, (CARMA), to simulate temperature profiles and assess the effects on various atmospheric properties (e.g. the chemical distribution with altitude). We investigate how different haze types and production rates impact the temperature profiles of sub-Neptunes at different evolutionary stages. We discuss the implications for sub-Neptune cooling rates, thermal evolution and interior conditions.

Detection and atmospheric characterisation of temperate Jupiters

Authors

Peter Wheatley (1)

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Abstract

Until recently, our sample of bright transiting planets was very strongly biased to short orbital periods and high temperatures. In this talk I will describe ongoing efforts to discover temperate giant planets around bright stars using single-transit events from TESS that we follow up with NGTS and radial velocities. I will show how these planets are very well suited to atmospheric characterisation with JWST and Ariel, in particular opening access to nitrogen bearing species that will provide new constraints on giant planet formation locations and migration mechanisms. I will also show how long-term monitoring of VLT, JWST and Ariel targets with NGTS can mitigate the effects of stellar activity on radial velocities and transmission spectra. I will describe how members of the UK community can request NGTS activity monitoring observations in support of their characterisation programmes on large facilities.

Diurnal, latitudinal and seasonal variability of the meteoric metal layers in the atmosphere of Venus

Authors

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Abstract

Cosmic dust, densest around the ecliptic, collides with Solar System planets in their orbit. In airless bodies, like the Moon or Mercury, these materials form part of the exosphere. In planets with an atmosphere, cosmic material interacts with it in several significant ways. Earth receives around 28 ± 16 tonnes of cosmic dust per day; some ablates, forming layers of neutral and ionized metals, observed by ground-based lidar, space-based spectroscopy, and rocket-borne mass spectrometry. Venus and Mars also receive a substantial cosmic dust input (31 ± 18 and 2 ± 1 t d^{-1} respectively), but only Mg^+ has been observed around Mars, and metallic layers around Venus have yet to be observed.

This work focuses on modelling the impact of cosmic dust in the atmosphere of Venus with the Venus Planetary Climate Model, to which a meteoric input function (MIF) of Fe, Na, Mg, SiO and their respective ions has been added, along with a detailed neutral and ion-molecule chemical network. Metal molecular diffusion is also included, since the metal layers form around the turbopause. Lastly, the MIF models latitudinal and seasonal variability, to account for Venus' 3.4° inclination with respect to the ecliptic. The model was run for two Venus years, to investigate seasonal changes in the layers.

The model results indicate cosmic dust ablation forms neutral metal layers on Venus at 95-130 km altitude and ionized layers just above. This work highlights a strong diurnal variability: the neutral layers reach their peak during the night, particularly around the dawn terminator as photo-ionization is absent on the night-side. Once photo-ionization commences on the dayside, the metal ion layers are rapidly replenished. The layers are also shaped by zonal and meridional winds, strong at the altitudes of transition between super-rotation and subsolar to antisolar regimes. Species-dependant asymmetries are generated: due to their different ablation altitudes, the Na layer peaks 10 km above the Fe layer, resulting in different global distributions. This work also examines the seasonal variability of the layers due to Venus' inclination relative to the ecliptic.

This work predicts the formation of meteoric metal layers on Venus similar to those seen on Earth. These layers – in particular Na – should be detectable; we indicate methods to observe Na spectroscopically from terrestrial telescopes. A positive detection would provide insights into planetary research: meteoric metals seem fundamental in the atmosphere of Venus (for example, for the unknown UV-absorber, and the depletion of SO_2 in the clouds). Moreover, metallic layers could be used to probe the atmospheres of Venus analogues, if it is established they exist in Venus' CO_2-rich atmosphere. While atmospheric characterization for rocky exoplanets is still challenging, Na has already been detected on Hot Jupiters and Neptunes and used as a tracer for dynamics, so this research seems particularly relevant for the future.

When Stellar Winds Collide: The Impact of Corotating Interaction Regions on Exoplanetary Atmospheres (Online)

Authors

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Abstract

Corotating interaction regions (CIRs) are persistent features of stellar winds, well studied on the Sun but largely unexplored in other solar-mass or low-mass stars. These features are formed when the fast and slow wind streams collide causing a dense wind region following an Archimedean spiral, which can compress planetary magnetospheres upon impact. CIRs can also contain shocks, capable of accelerating particles to high energies, potentially influencing atmospheric erosion and space weather conditions.

Using an isothermal wind, we model the minimum formation radius of CIRs around a solar-mass star as the location where the fast and slow wind streams collide. From this, we show that the frequency of CIR-planet impacts is determined by the stellar rotation rate, rather than planetary orbit. Thus, as the star ages and spins down, the planetary environment evolves through a range of regimes as the frequency of these impacts varies. At young ages, the magnetosphere experiences an enhanced wind, experiencing frequent impacts with little time to readjust. Later, regular magnetospheric compressions are felt over the planetary orbit, and at even later ages there may no longer be any CIR-planet interactions. Additionally, we adapt an established model of particle energy distributions for solar CIRs and show that the number of high energy particles generated in CIR shocks varies by several orders of magnitude over a star's lifetime. This could have implications for the atmospheric loss of planets, especially at early ages.

We find that CIRs are formed across a wide range of rotation rates, and at a range of planetary orbits, and thus they likely contribute to the space weather environment of many exoplanets. Our results highlight CIRs as a potentially important, and previously underappreciated, component of exoplanet space weather. In systems where coronal mass ejections may be suppressed, CIRs could represent a dominant driver of long-term atmospheric evolution and habitability.

Posters

Endogenous or Accreted? Interpreting O & C in sub-Neptune atmospheres

Authors

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Abstract

The interior compositions of sub-Neptunes remain an important question in the field. A key challenge is that atmospheric observations probe the upper atmosphere rather than the bulk composition. Detections of several chemical species have been made in a number of sub-Neptunes including H_2O, CH_4 and CO_2. However, different atmosphere-interior interactions could be responsible for this. For example, large amounts of H_2O can be produced endogenously via atmosphere-mantle interactions or could have been accreted during formation. This raises the question: can endogenous vs accreted volatiles be distinguished observationally?

To address this question, we coupled a Global Chemical Equilibrium model with a 1D radiative–convective photochemical atmosphere model to investigate how volatiles are partitioned between the core, mantle and atmosphere. In particular, we test whether accreted vs endogenous water can be distinguished with atmospheric observations.

We find that the abundance of O- and C-bearing species in the upper atmosphere is sensitive to the amount of accreted volatiles, the reactivity of the iron core, and the equilibration temperatures of the interior. For example, a reactive core can store large amounts of O, C and H, "hiding" accreted volatiles from view in the atmosphere. Population studies of sub-Neptune atmospheres may therefore have the potential to provide insights into the role of the iron core in sequestering planetary volatiles.

In this talk, I will discuss these trends as well as the implications for the interpretation of JWST observations of sub-Neptunes.

Linking general circulation models and observed limb asymmetries in giant exoplanets with transmission strings

Authors
Charlotte Fairman (1)

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Abstract
Through the measurement of ingress and egress asymmetries in transit light-curves with JWST, constraints on the 3D nature of exoplanets are accessible. Such observations of giant exoplanets have revealed the presence of morning-evening limb asymmetries driven by temperature contrasts and cloud cover. We can compute these asymmetric lightcurves with transmission strings, which map the shape of the occulting planet around the terminator as a Fourier series, allowing for complex structures beyond circles or hemispheres of differing radii to be modelled. We apply this method to the post-processing of hot-Jupiter GCM outputs to produce synthetic transmission strings and assess the impact of equilibrium chemistry, quenching and clouds on modelled asymmetries. Using these detailed strings, we quantify the potential of observations to resolve dynamical features such as the equatorial jet and mid-latitude gyres. This method provides an important tool for GCM-observation intercomparison and benchmarks our understanding of atmospheric dynamics with observable measurements.

Assessing the role of self-broadening in exoplanet atmospheres

Authors

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Abstract

Exoplanet atmosphere temperature profiles strongly depend on the optical properties of their constituent gases. An important contributor to opacity in the atmospheres of super-Earths and sub-Neptunes is pressure broadening, which can impact the deep atmosphere/surface thermodynamic conditions. However, the broadening effects caused by collisions with background gases other than H2, He or air (N2/O2), such as self-broadening, remain largely unexplored in exoplanet atmospheric characterisation efforts. In this study, we present the impact of self-broadening on super-Earth and sub-Neptune temperature profiles as a function of pressure and background gases (e.g. methane). We calculate pressure-broadened line-by-line cross sections using data from the ExoMol and HITRAN databases and the cross-section calculation code pyROX. We assess the effects within a 1D radiative-convective atmospheric model, GENESIS, and determine the regions of parameter space where it is important to consider pressure broadening by molecules other than those commonly used.

Most Rocky Sub-Neptunes are Molten: Mapping the Solidification Shoreline for Gas Dwarf Exoplanets

Authors

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Abstract

Sub-Neptunes are the most common type of detected exoplanet, yet their observed masses and radii are degenerate with several interior structures. One possibility is that sub-Neptunes have silicate/iron interiors and H2-dominated atmospheres, i.e., they are 'Gas Dwarfs'. If gas dwarfs have fully molten interiors, interactions between their magma oceans and atmospheres would produce distinct observational signatures. These signatures may break the degeneracy in interior structure. We use the coupled interior-climate evolution model, PROTEUS, to estimate the 'solidification shoreline': the instellation flux boundary that separates molten gas dwarfs from solidified ones. Our results show that 98% of detected sub-Neptunes occupy a region of parameter space consistent with their having permanent magma oceans. Therefore, most detected sub-Neptunes, if they are gas dwarfs, have permanent magma oceans. This result motivates further research into the interactions between molten interiors and overlying atmospheres.

Making Waves or Seeing Spots? Placing GJ 486b on the Cosmic Shoreline with JWST/NIRISS.

Authors

Sten Vermeiren (1), Ryan MacDonald (1)

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Abstract

Understanding if rocky planets can retain atmospheres around M-dwarf stars is crucial for determining cosmic habitability. However, untangling true atmospheric signatures from stellar contamination remains a significant challenge, since water vapour in cool starspots can mimic planetary water-rich atmospheres.

The warm super-Earth GJ 486b (1.3 R_earth, 700 K) observed by JWST NIRSpec (2.8–5.2 µm; Moran et al. 2023), revealed a water absorption feature. However, this wavelength range has not been sufficient to distinguish between a water-rich steam world or a bare rock with unocculted starspots.

Here we present the first JWST NIRISS/SOSS spectra of GJ 486b from three transit observations (0.87–2.8 µm; GO-5866, PI: MacDonald). Our transmission spectrum and atmospheric retrieval analysis using POSEIDON (MacDonald 2023) cover the combined NIRISS/NIRSpec wavelength range (0.87–5.2 µm). This resolves the true nature of GJ 486b's atmosphere, probes its host M-dwarf star, and takes us one step further in charting the cosmic shoreline.

The First Optical Transmission Spectrum of the inflated Hot Jupiter WASP-168b

Authors

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Abstract

We present the first optical transmission spectrum of the inflated hot Jupiter WASP-168b, based on four ground-based transits obtained with EFOSC2 and reduced using the Tiberius pipeline. By modelling spot occultations in one transit and applying careful detrending, limb-darkening treatment, and systematic corrections, we recover a high-precision transmission spectrum from which no strong sodium absorption is detected, indicating that clouds or hazes are muting atomic features at these altitudes. WASP-168b's grazing geometry introduces strong degeneracies, making it a valuable test case for developing robust transmission-spectroscopy techniques suited to high-impact-parameter systems. This work provides the first atmospheric constraints for WASP-168b and refines key system parameters beyond the discovery paper, demonstrating the capability of ground-based facilities to characterise challenging systems.

Exploring Isotopic Ratios in the Atmosphere of the T-Dwarf HD 19467 b

Authors

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Abstract

In the era of JWST, brown dwarf atmospheres can be characterised using spectroscopy in exquisite detail. This enables measurements of the C/O ratio and isotopologue ratios for common molecules, which can potentially be linked to formation history and pathways. We present the results of a retrieval analysis of the T-dwarf HD 19467 b using NIRSpec and SPHERE data. $\mathrm{^{13}CO}$, $\mathrm{C^{18}O}$ and $\mathrm{{H_2}^{18}O}$ are consistently detected, providing estimates for the $\mathrm{^{12}C/^{13}C}$ and $\mathrm{^{16}O/^{18}O}$ ratios. We also investigate potential indicators of vertical mixing, and the impact of degeneracies on our models.

Survival of Anyhydrobiotic Tardigrade Ramazzottius cf. varieornatus in a Martian Simulation Chamber

Authors

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Abstract

Because no exoplanet has yet been directly visited, our understanding of their environments is derived exclusively from remote observations. Many of the terrestrial-type exoplanets identified to date exhibit characteristics broadly comparable to those of Earth or Mars. By examining tardigrade (microscopic animals known to survive extreme conditions) survival and stress responses under simulated martian conditions, we can begin to evaluate the potential for these organisms to persist on exoplanets detected by space-based observatories, like the James Webb Space Telescope. This research provides a framework for assessing the limits of biological resilience and contributes to our broader understanding of planetary habitability beyond the solar system.

As a rocky exoplanet, the martian environment is harsh. The atmosphere is comprised of CO2 (95.1% CO2, 2.59% N2, 1.94% Ar, and 0.16% O2), with an atmospheric pressure of about 7 mbar. Temperature extremes on Mars range from −125 to 20°C, and ultraviolet radiation (UVB and UVC) averages around 360 kJ/m2 at the surface. The Curiosity Rover at Gale Crater recorded While at Gale Crater, ionizing radiation averages about 0.21 mGy d-1 as measured by the Curiosity rover. And of course, Mars lacks a global magnetic field which could protect life from ionizing radiation.

Tardigrades are robust animals which can survive dehydration, freezing, vacuum, extreme levels of radiation, and exposure to space. They survive such extreme conditions through entering an anhydrobiotic dormant stage known as a 'tun' state. Tardigrade tolerance to extreme conditions therefore makes them excellent model organisms for understanding habitability.

Experiments were conducted at the German Aerospace Center in Cologne, Germany, in a Martian simulation chamber and investigated tardigrade survival while in the anhydrobiotic dormant stage (i.e. tun). Survival of Ramazzottius cf. varieornatus species was evaluated following exposure to martian atmospheric conditions (95% CO_2, 2.7% N_2, 1.6% Ar, 0.15% O_2 at 6 mbar), with and without X-ray radiation (up to 6000 Gy), while the tardigrades were embedded in martian simulant regolith MGS-1 for up to 28 days in Trex-Boxes. Tardigrade survival in controls (Earth atmosphere and sand; zero radiation) remained constant from setup to completion. A generalized linear model found simulant, radiation and simulant interaction, but not atmospheric conditions, as significant ($p < 0.001$) predictors of tardigrade survival rates. The median lethal dose (LD50) of X-rays for anhydrobiotic Ramazzottius was about 650 Gy in MGS-1 and increased with washing of MGS-1 (LD50 of 2090 Gy), but was still less than in the control (LD50 of 3020 Gy). The results of our experiments support previous work concerning the survival of tardigrades; namely, the extreme hardiness of anhydrobiotic tardigrades and the high likelihood for survival of UV-shielded tuns on Mars.