

PLANETS DAY 2026

Meeting programme



- 08:45 – 09:15** Badge collection and coffee
- 09:15 – 09:30** Welcome address
- 09:30 – 10:15** **Keynote talk**
Serpentinization and H₂
production on early Earth and
Mars: What, why, where, and
when?
Chair: Marylou
Fournier-Tondreau
Speaker: Nicholas Tosca
- 10:15 – 10:45** Poster and coffee
- 10:45 – 11:30** **Theme 1**
What does a planet need to have a
stable climate?
Chair: James Bryson
Speaker: Tim Woollings
Panel: David Marshall, Bob
Hilton
- 11:30 – 12:15** **Theme 2**
What makes us live, and what
makes us die?
Chair: Grant Ritchie
Speaker: Hal Drakesmith
Panel: Ros Rickaby, Jon Wade,
Matt Hitchens, Jan
Rehwinkel
- 12:15 – 13:30** Lunch – Hall
- 13:30 – 14:15** **Theme 3**
What drives us to explore the Solar
System and beyond?
Chair: Suzanne Aigrain
Speaker: Carly Howett
Panel: Rob Iliffe, Kevin Olsen,
George Dransfield
- 14:15 – 14:45** Poster and coffee
- 14:45 – 15:30** **Theme 4**
What are the planetary causes of
evolutionary radiation?
Chair: Seb Shimeld
Speaker: Frankie Dunn
Panel: Roger Close, Julia Schwab,
Tim Coulson
- 15:30 – 17:00** Collaborative activity
- 17:00 – 19:00** Poster reception

Venue information

Cheng Kar Shun Digital Hub, Jesus College

Entrance (X) via Market Street (step free)

what3words: costs.stars.atoms

<https://www.accessguide.ox.ac.uk/jesus-college>



Talk abstracts

KEYNOTE

Serpentinization and H₂ production on early Earth and Mars: What, why, where, and when?

Nicholas J. Tosca

Professor of Mineralogy & Petrology

Department of Earth Sciences, University of Cambridge

Serpentinisation, or the aqueous alteration of Fe-Mg-rich rocks to serpentine, (hydr)oxides, and H₂, remains difficult to parameterise in models of rocky planet evolution because its outcomes vary with a small set of interlinked controls. These include the composition of olivine, set by mantle redox state and magma-ocean differentiation; the origin and chemistry of the altering fluid, which determine electron balance, permeability, and reaction pathways; and the thermal-magmatic context of water-rock interaction. New approaches that track electron balance at the crystal-chemical scale are now quantifying how Fe(III) incorporation into serpentine governs H₂ yields and their dependence on parameters such as fluid SiO₂ concentration. These insights help explain why serpentinisation of Fe-rich olivine on Mars may have produced distinct serpentine assemblages and enhanced H₂ fluxes - a picture now supported by in situ data from the Mars 2020 Perseverance rover. They also provide a foundation for exploring the first interactions between liquid water and ultramafic, post-magma-ocean crust on early Earth, where short-lived but powerful pulses of H₂ and CO₂ exchange may have reshaped early atmospheric evolution and opened transient windows for prebiotic chemistry.

The role of atmosphere-ocean dynamics in shaping a stable climate

Tim Woollings

Professor in Physical Climate Science

Department of Atmospheric, Oceanic and Planetary Physics, University of Oxford

This talk will give an overview of global atmospheric and oceanic circulation patterns, mostly on Earth. A key focus will be on how these circulations act to smooth out temperature contrasts and hence maintain readily habitable climate zones. On the flip side, we'll see how subtle changes in these circulations shape regional climate variability and lead to extreme weather events. We'll also discuss the potential for more dramatic dynamical changes, for example in distant-past or potential near-future climate states.

What makes us live, and what makes us die?

Hal Drakesmith

Professor of Iron Biology

Weatherall Institute of Molecular Medicine, University of Oxford

The French philosopher and moralist Albert Camus wrote “what is called a reason for living is also an excellent reason for dying”. He was discussing ideology, not the evolution of complex life, but here I attempt to show that a similar concept resonates for the latter. It has taken 4 billion years for a “cell-to-civilization” transition. To move from hot geology-derived simple self-replicating metabolic circuits to an organism harbouring 10^{23} chemical reactions per second that support a quadrillion networked synapses capable of reading this paragraph and having feelings about it. But does evolution really need these aeons to go from vent to vindaloo, or could different reasons for living and dying theoretically impose faster changes? The answer to this question may inform how we look for life beyond Earth. There are some aspects of medical research that are relevant here, as they illustrate in depth how variably selection pressures can operate over time on metabolism, genomes and fate, for instance in the contexts of infections and cancer. With examples of the Black Death, malaria, and treatment-induced mutagenesis in tumours, I describe some key drivers of rapid evolution that govern life or death outcomes. Stability of the genetic code, environmental apocalypses and metabolic piracy are all powerful variables that influence rate of change. Extrapolation from these concepts in turn may inform constraints on elements of the Drake equation.

How we explore our Solar System and beyond

Carly Howett

Associate Professor of Space Instrumentation

Department of Atmospheric, Oceanic and Planetary Physics, University of Oxford

Exploration is a defining human trait. Throughout history, we have sought to understand what lies beyond the next horizon—across oceans, over mountains, and ultimately beyond our own world. In the past six+ decades, we have sent robotic probes to all the major bodies in our Solar System, with some now traveling beyond its boundaries. Although not all of these missions were explicitly designed to search for life, but each has contributed—directly or indirectly—to that fundamental question. In this talk, I will review how we have explored the diverse worlds of our Solar System, what these missions have taught us about planetary processes and habitability, and what future exploration opportunities lie ahead.

What are the planetary causes of evolutionary radiation?

Frankie Dunn

Senior Researcher of Natural History

Museum of Natural History, University of Oxford

The diversity of life today is shaped by radiation and extinction events that occurred in deep time and which can be calibrated by both the molecular clock and the fossil record. While there is debate about the efficacy of the molecular clock for constraining the origin of clades, this is separate from the ecological and taxonomic diversification of clades – their radiation – which can often be tracked directly through the body, trace and molecular fossil records over hundreds of millions to billions of years. The fossil record allows us to constrain the pace and mode of evolutionary radiation (and extinction) events by recording primary information on lineages through time and, crucially, their phenotypes during times of environmental upheaval. In this way, we can calibrate the fossil and geological records to evaluate the co-evolution of life and environment through time and during formative episodes like the Cambrian Explosion.

Poster abstracts

Discovering and characterising nearby Earth Analogs with PLATO and the Terra Hunting Experiment

Suzanne Aigrain

Department of Astrophysics, University of Oxford

I will outline two major, international experiments aiming to discover planets similar to the Earth around nearby stars, which will begin in the coming year: the European Space Agency's PLATO mission, which uses the transit method, and the Terra Hunting Experiment, a ground-based radial velocity survey. I will explain how these projects will find planets, the discovery space they will open, and what properties of the planets and their host stars we will learn from them, as well as the key challenges we will face along the way. I will outline what we hope to learn from these experiments over their 10-year lifetime about the incidence and diversity of temperate rocky worlds, the architectures of the systems we find them in, and how these things evolve over the planets' lifetimes. Finally, I will discuss how this efforts fits in the broader roadmap toward detecting biosignatures on Earth-like exoplanets.

Circulation models, interior evolution, and JWST observations of WASP-76b

John Allen

Department of Atmospheric, Oceanic and Planetary Physics, University of Oxford

In the new era of JWST observations, it is crucial to understand whether we can determine the interior properties of exoplanets with atmospheric information. In this work, we present a suite of General Circulation Models (GCMs) and interior evolution models of the ultra-hot Jupiter WASP-76b using the SPARC framework of ADAM, comparing simulated observations to JWST NIRSpec/G395H phase-curve and emission data. We choose WASP-76b as it is a highly inflated case, making it an optimal target for understanding any connection between interior and atmospheric processes. We use a grid of MESA models to predict heating strengths required to inflate the planet to its observed radius. We find which heating strengths and depths are suitable to match the present-day inflated radius of WASP-76b and use the output temperature profiles to fix the bottom atmosphere temperature for the GCM runs. We compare modelled evolution outcomes for various core-density scenarios, including a planet with no core. Effects such as Ohmic dissipation, turbulent mixing, shocks, and hydrodynamic instabilities, are thought to suppress the atmospheric flow within the atmospheres of ultra-hot Jupiters; in our parallel GCM runs we vary a spatially independent atmospheric drag term to simulate these effects. We present five scenarios, representing weak to strong atmospheric drag. In addition, we run models with and without the cloud species enstatite and corundum, which are allowed to circulate through the atmosphere and feed back into the radiative transfer calculations. We also account for the effect of hydrogen dissociation on the hot dayside of WASP-76b. We post-process the GCM outputs using the gCMCART radiative transfer code. We find that the atmospheres with moderately strong drag and clouds provide the best fit to the James Webb phase-curve data. This reinforces prior suggestions that ultra-hot Jupiter phase-curve observations can only be explained through drag physics and dynamics (WASP-18b, WASP-103b, WASP-121b), from both Spitzer and JWST phase-curves. We find that this widely adopted drag treatment doesn't capture the complexity of the circulation around the limbs of the planet; east-west asymmetries are clear in the JWST emission data. The requirement of relatively strong atmospheric drag to match the phase curve data results in near-identical simulated emission spectra in our model limbs. Upcoming research should explore the physics driving this important dynamical drag effect; e.g. via MHD simulations. We find that interior heating has little effect on the observational properties of the planet, with the main observational effects being from the varying atmospheric drag. We show that with this approach vastly different interior structures of these ultra-hot planets do not greatly affect the simulated atmospheric observations, when compared to the effects of varying atmospheric drag forces. This motivates further consideration into how to treat atmospheric and interior evolution models, and further couple them.

Comparative emissivity analysis of proposed sample sites on asteroid (101955) Benu

Emma Belhadfa, Neil Bowles and Katherine Shirley

Department of Atmospheric, Oceanic and Planetary Physics, University of Oxford

Introduction: Asteroid (101955) Benu, the focus of NASA's Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) mission, represents a crucial target for studying primitive materials from the early solar system. This study investigates archive data from the OSIRIS-REx Thermal Emission Spectrometer (OTES) to analyze the emissivity spectrum of Benu's surface, integrating global averages and site-specific spectra from key sampling site candidates. By exploring these datasets, we aim to characterize the composition and physical properties of Benu's regolith, with an emphasis on understanding surface heterogeneity and its implications for planetary formation processes. Methods: The study uses calibrated emissivity data from the OTES to analyze the thermal infrared properties of Benu's surface. I averaged the spectral data across the asteroid to obtain a global emissivity profile, while site-specific spectra were isolated for prospective sample sites: Sandpiper, Osprey, Kingfisher, and Nightingale. Outliers were removed and the spectral data was normalized for emissivity between 0.95 and 0.99 to focus on key spectral features, such as silicate vibrational bands, and differences between sites were assessed for their implications on mineralogy, grain size, and surface texture. Spectral observations were connected to high-resolution camera images taken by the OSIRIS-REx Camera Suite to inform discussions on boulder distributions at each prospective site. Results–Global Spectral Data: The averaged global spectrum, derived from detailed survey data, shows emissivity features typical of a hydrated carbonaceous chondrite, with a dominant silicate vibrational band near 1200 cm^{-1} and a broad absorption trough around 500 cm^{-1} . These features confirm Benu's composition is consistent with phyllosilicates, highlighting its history of aqueous alteration. Results –Proposed Sample Site Data: Focusing on site-specific data, spectral differences between sampling sites provide additional insights into Benu's surface diversity. Sandpiper demonstrates slightly higher emissivity around 1200 cm^{-1} , suggesting larger overall particle size. Osprey and Kingfisher exhibit subdued features, possibly associated with coarser grain sizes or increased surface porosity. Nightingale, selected as the sample collection site, displays a smoother spectrum with minimal heterogeneity, consistent with fresh or relatively homogeneous regolith. Conclusion: These findings, supported by spectral and thermal modelling, deepen our understanding of Benu's surface properties and processes. The integration of global and localized emissivity data establishes a framework for linking remote sensing observations to the analysis of returned samples.

Exploring the structural and electronic evolution of Fe₂O₃ at Earth's mantle and outer core conditions via density functional theory calculations

Ana Coutinho Dutra

Department of Atomic and Laser Physics, University of Oxford

The behaviour of hematite (α -Fe₂O₃) under extreme conditions has attracted significant attention due to its relevance to geophysical processes. While α -Fe₂O₃ has been studied under static compression up to approximately 113 GPa, laser-driven dynamic compression experiments have allowed analyses at higher pressures that mirror planetary interiors. Phase transformations in such set-ups, however, occur under much shorter timescales than those under planetary conditions and different phases have been observed under dynamic and static compressions, leaving the behaviour of α -Fe₂O₃ still not fully understood. Here, density functional theory and ab initio molecular dynamics are used to explore the dynamics of α -Fe₂O₃ under 70–330 GPa, mirroring the Earth's mantle and outer core. Calculations use the Perdew-Burke-Ernzerhof functional and the constant-volume, constant-pressure ensemble (NVT) with a Nose-Hoover thermostat for a temperature range of 2,250–11,000 K. Results are compared to experimental laser-driven shock compression data.

Tectonic controls on seafloor weathering: evidence from a mechanistic model and oceanic drill cores

Marylou Fournier-Tondreau

Department of Atmospheric, Oceanic and Planetary Physics, University of Oxford

Earth's climate has remained relatively stable over geological timescales, largely regulated by the silicate weathering feedback. Seafloor weathering may contribute to this feedback, but its primary controls and overall climatic role remain uncertain. Here we extend the Maher-Chamberlain weathering framework to the upper oceanic crust by coupling crustal cooling and hydrothermal circulation in a time-dependent box model constrained by Pacific drill-core data. The model reproduces the observed age-CO₂ relationship in Cenozoic crust, with plate-cooling-induced cracking maintaining reactive pathways in young crust and capturing the timing of carbon sequestration. Our results indicate that seafloor weathering transitions rapidly from a kinetically limited regime during the first ~10 Myr after crust formation to a predominantly supply-limited regime thereafter. Plausible Late Mesozoic variations in bottom-water temperature and carbonate chemistry increase weathering rates by at most ~3x, insufficient to explain the nearly 5x higher upper-crustal CO₂ content observed in Late Mesozoic crust. Reproducing these inventories requires enhanced exposure of reactive basalt in young crust, corresponding to ~2x greater strain-driven

fracturing and fluid pathways. Combined with younger Late Mesozoic seafloor age distributions, this implies global seafloor weathering rates were $\sim 8x$ higher than today ($\sim 4 \text{ Tmol C yr}^{-1}$ versus $\sim 0.5 \text{ Tmol C yr}^{-1}$). These results suggest that the direct climate sensitivity of seafloor weathering is limited, with its long-term capacity primarily governed by tectonic processes that generate and maintain permeable, reactive oceanic crust.

Energy-limited outgassing of rocky exoplanets

Claire Marie Guimond

Department of Atmospheric, Oceanic and Planetary Physics, University of Oxford

Whether or not an atmosphere is present on a planet represents a balance of sources and sinks. The main source of secondary atmospheres on lifeless planets is outgassing from the interior. For potentially-rocky planets observed with current facilities, the main sink is atmospheric escape. These planets – on close-in orbits around M-dwarfs, systematically – experience very high rates of atmospheric loss. So to explain any atmosphere detection, similarly high rates of outgassing must be invoked, to overcome the loss rate. However, for planets with solid surfaces, there is an energy limit on how efficiently volcanism can transport volatiles from mantle to atmosphere. I provide a convenient initial assessment of whether an implied outgassing rate would be physically reasonable. The upper limit on a planet's volcanic outgassing rate can be estimated from a maximum rate of melting and a maximum volatile content of magma. I show that, considering current escape rate estimates, some tentative atmosphere detections on potentially-rocky exoplanets are near the limit of plausibility.

PANDOR-I experimental set-up design: lunar dust-layered water-ice analogues in the 1.8–20 μm range.

Fiona H.M. Henderson, Neil Bowles and Katherine Shirley

Department of Atmospheric, Oceanic and Planetary Physics, University of Oxford

Hydration on the Moon's surface has been widely detected in orbital datasets, yet its abundance and physical form (-OH, H₂O, frost, or ice) remain poorly constrained. The lunar surface is covered in regolith fines, impacting local thermophysical conditions, obscuring underlying volatiles and modifying detectable hydration bands. This is driven, in part, by limited experimental constraints on water-ice spectral behaviour at the regolith interface and by the historical restriction of orbital datasets to the near-infrared ($< \sim 3 \mu\text{m}$ O-H stretching mode). To address this gap, we have developed a laboratory approach to quantify how dust layering, regolith maturity, grain size, composition, and ice abundance control the spectral expression of water-ice across the

near- and mid-infrared (1.8–20 μm), with emphasis on the ~ 3 and 6 μm diagnostic regions. The design and preliminary experimental protocols for the Polar Analogue of Dust Overlying Regolith–Ice (PANDOR-I), intended to simulate airless-body and cryogenic polar conditions are detailed below. In this initial laboratory set-up, the sample compartment of a Bruker 70V Fourier Transform Infrared (FTIR) spectrometer is isolated with PANDOR-I using potassium bromide (KBr) windows to enable controlled, cryogenic ($\sim <120$ K), low pressure ($\sim 10^{-6}$ mbar) reflectance measurements of anhydrous and hydrated analogue configurations to (i) characterise the spectral expression of hydration-related structure in the ~ 3 and ~ 6 μm regions under regolith simulant fines, and (ii) provide benchmark spectra for direct comparison with a Mie–Hapke forward model (band shape/depth, and mixing trends) prior to cryogenic and airless body analogue laboratory experiments. This experimental design pre-empts the operation of PANDOR-I and outlines the experimental plan for future cryogenic experiments.

Using atmospheric types of rocky exoplanets to constrain planetary surfaces

Oliver Herbort

Department of Astrophysics, University of Vienna

Rocky exoplanets are expected to show a large diversity of planetary interiors, surface conditions, and atmospheric compositions. While all of these are connected through geological processes, direct observations are challenging even with current and upcoming ground and space based instruments, showing the importance of models combining planetary atmospheres, surfaces, and interiors. Our modelling approach for rocky exoplanets provides a bottom-to-top surface-atmosphere model. The crust-atmosphere interaction layer is the basis of the 1D atmospheric model which includes the effects of element depletion due to cloud formation. The atmospheric and cloud composition are therefore a result of the surface composition and the pressure-temperature structure. Modelling the variety of different gas-phase compositions reveals the existence of three distinct atmospheric types (H_2 -rich, O_2 -rich, coexistence of CH_4 and CO_2), defined by their atmospheric composition. The presence of some cloud condensates (e.g. H_2SO_4 or H_2S) provides constraints on the temperature and pressure conditions at the planetary surface. The mineralogical composition of the planetary surface in contact and equilibrium with the atmosphere provides distinct transitions linked to the atmospheric types. Investigations of various elemental compositions based on different rock compositions reveal links of surface minerals to the atmospheric types. In particular, the sulphur chemistry can be constrained. While the sulphur cloud condensates of H_2S and H_2SO_4 only form for planets with high surface pressures and/or temperatures, the sulphur-bearing condensates at the planetary surface (including especially FeS , FeS_2 , and CaSO_4) are directly linked to the

atmospheric type. This work shows that in principle, spectroscopic investigations of rocky exoplanet atmospheres can constrain the atmospheric composition to a specific atmospheric type and therefore put some constraints on the expected surface mineralogy.

Thermal inertia & bolometric albedo measurements of Europa's surface using Galileo PPR

Sarah Howes

Department of Atmospheric, Oceanic and Planetary Physics, University of Oxford

Introduction: The presence of endogenic hotspots provides a measure of the level of geologic activity on icy moons, since they are indicative of ongoing resurfacing processes. However, to avoid misinterpreting thermal abnormalities, it is first necessary to understand passive thermal emission that is governed by the physical structure of materials. Two important thermophysical properties in such analysis are bolometric albedo and thermal inertia: if diurnal temperature variations can be accurately modeled by adjusting these two parameters, a passive rather than endogenic origin cannot be ruled out. **Aims & Methods:** We investigate the diurnal temperature variations and passive thermophysical properties of Europa's surface using the brightness temperatures recorded by the Galileo Photopolarimeter-Radiometer (PPR) instrument. By translating the observed radiance into brightness temperatures, the variation in temperature with local time is determined. These diurnal curves are compared to those predicted by TEMPEST, a thermophysical model that simulates surface temperature variations for airless bodies, to determine what thermal inertias and albedos can fit the data. **Results:** We map the albedo and thermal inertia for 29% and 23% of Europa's surface area, respectively, ranging 0.4-0.75 for albedo and 20-120 J m⁻² K⁻¹ s^{-1/2} for thermal inertia – a slight improvement in surface coverage over previous analyses and with comparable ranges. When averaged across ten different geological areas, categorized into four feature-based regions, no distinct correlation between geological region and either thermophysical property is found. In addition, no endogenic anomalies were detected that could not be explained by thermophysical surface property variation. Because of this we set upper limits for our sensitivity of hotspot detection using these data for three synthetic hotspot sizes: 50, 100, and 200 km². We find that hotspots of these sizes could exist to temperatures up to 291±117 K, 229±70 K, and 186±45 K, respectively, and still not be detected. These results aid in preparing for the upcoming missions to Europa by improving the surface coverage of Europa's passive thermal properties.

Enabling lunar infrastructure through microwave processing of regolith: sintering and melting pathways

Eugene Kim

Department of Earth Sciences, University of Oxford

Future lunar missions require durable surface infrastructure capable of withstanding plume-induced erosion during repeated landing and launch operations. Microwave processing of regolith has emerged as a promising in-situ resource utilization strategy; however, a fundamental question remains unresolved: should infrastructure be produced through sintering or melting? Microwave sintering promotes particle bonding through diffusion below the melting temperature, offering lower energy demand and the potential for structurally robust infrastructure. In contrast, melting generates glassy phases with superior local stiffness and hardness but typically requires substantially higher power input and can induce volatile-driven foaming that increases porosity. Existing studies report Young's modulus values ranging from ~13–16 GPa in predominantly sintered materials to ~26 GPa in molten products, yet bubble fractions exceeding 80% have been observed in melt-derived structures. Conversely, hybrid and susceptor-assisted sintering approaches have demonstrated dense blocks with porosities below ~12% and compressive strengths exceeding 40 MPa, suggesting a potentially more energy-efficient pathway toward mechanically robust infrastructure. This study investigates microwave-induced sintering and melting pathways in lunar regolith simulants to establish the processing–structure–property relationships governing material performance. Emphasis is directed toward identifying the transition regime between sintering and melting and determining how input power, thermal response, and microstructural evolution influence density, stiffness, and hardness. The study also identifies pad thickness and thermal penetration limits during plume impingement as a critical unresolved challenge for microwave-fabricated infrastructure. By clarifying this trade-off, the work aims to inform scalable manufacturing strategies for lunar infrastructure and advance the engineering foundations required for sustained extraterrestrial operations.

Tropical cyclones on temperate rocky planets: from Earth to TRAPPIST-1e

Tad Komacek

Department of Atmospheric, Oceanic and Planetary Physics, University of Oxford

Tropical cyclones occur seasonally on Earth, with typical genesis regions overlying the warm tropical oceans and tracks that follow regions of warm sea surface temperatures that provide the energy driving these storms. The long-baseline datasets of tropical cyclone genesis points and resulting tracking of tropical cyclone paths has led to the development of a variety of metrics that can predict the potential strength of tropical

cyclones from the background climate. Previous work has applied these environmental favourability metrics developed for Earth to low-resolution rocky exoplanet general circulation models (GCMs), predicting that tropical cyclones will occur on tidally locked rocky exoplanets orbiting M dwarfs with intermediate rotation periods. In this work, we present results from ExoCAM GCM simulations of tidally locked rocky exoplanets with sufficient horizontal spatial resolution to permit tropical cyclogenesis. We conduct simulations both for idealised tidally locked aquaplanets with varying rotation period, as well as for the specific test case of the well-simulated rocky exoplanet TRAPPIST-1e. We find that tropical cyclones can occur in all cases considered, though we find a peak in the number and intensity of storms at intermediate rotation periods, as expected from environmental favourability metrics. We find that tropical cyclones can occur on TRAPPIST-1e, but their maximum wind speeds are lower than that of hurricanes on Earth. Finally, we demonstrate the applicability of the novel ventilation-reduced potential intensity to predict tropical cyclone genesis regions on exoplanets, as well as how this metric can be used to postdict tropical cyclone genesis locations on Earth.

Thermophysical modelling using albedo mapping and DEMs improves interpretation of thermal signatures of icy moons

Duncan Lyster

Department of Atmospheric, Oceanic and Planetary Physics, University of Oxford

Background: Accurate characterisation of the endogenic thermal signatures of icy moons required a good understanding of their insolation driven surface heating. The scarred and craggy terrains of Enceladus and Europa feature sunlit slopes and shaded fractures that feature dramatic variation in exposure to sunlight, affecting how much heat they absorb. Europa is particularly notable for variation in albedo across its surface; darker regions absorb more heat, so accurately representing albedo in thermal models is essential. This work demonstrates the importance of considering terrain and albedo when interpreting remote sensing measurements of icy moons, and refining tools ahead of the arrival of Juice at Jupiter. Methods: This investigation was performed using TEMPEST, a modular python based thermophysical model written during the first two years of my PhD. TEMPEST has previously been applied to targets of NASA's Lucy mission – asteroids Dinkinesh and Donaldjohanson. Icy moons require the additional consideration of seasonal insolation cycles and radiative heating from their parent planet. Detailed digital elevation models of the South Polar Terrain of Enceladus derived from Cassini data are available as SPICE Kernels, providing a perfect test case for this investigation into remote sensing derived surface temperatures. Results: Initial findings show that models considering terrain have substantial deviations from smooth spheres. Non-uniform distribution of the same mean insolation across features within a

field-of-view due to terrain features leads to surface temperature variations that could lead to overestimation of mean surface temperatures. This must be well understood before attempting to characterise endogenic heating, particularly at the poles where this effect is most pronounced. As albedo strongly influences surface temperatures, over the next six months, I plan to build on this work by mapping visible-image albedo onto TEMPEST models to improve simulations and better understand its influence on surface temperatures.

Role of haze in determining habitability in exoplanets

Mei Ting Mak

Department of Atmospheric, Oceanic and Planetary Physics, University of Oxford

The first evidence for life on Earth dates back to the Archean (2.5-3.8 billion years ago). The atmosphere during the Archean was temperate and reducing, which suggests a low likelihood of oxygen-based metabolisms but a prevalence of methanogens instead. Since the Earth's atmosphere has spent most of its time in the Archean, it is reasonable to expect that other Earth-like planets in the habitable zone to possess an Archean-like atmosphere, characterised by high concentration of CH₄. CH₄ as a greenhouse gas would warm up the planet but laboratory data have shown that when CH₄/CO₂ exceeds approximately 0.1, hydrocarbon haze would start forming which would cool down the planet due to its antigreenhouse effect. We therefore need a comprehensive study of haze when modelling CH₄ in the Archean or exoplanets. By varying the CH₄/CO₂ ratio, we prescribe different profiles of haze into a rapidly-rotating planet and a tidally-locked planet with an Archean-like atmosphere within a 3D general circulation model (GCM) - the Met Office Unified Model. We find that a thin haze layer, formed when CH₄/CO₂ \approx 0.1, leads to global warming of up to \sim 10.6 K due to the change of water vapour distribution and cloud feedback. However, a thicker haze layer, formed when CH₄/CO₂ $>$ 0.1, leads to global cooling of up to \sim 65 K as the extinction effect of haze dominates in the upper atmosphere, reducing the shortwave radiation from reaching the planetary surface. We therefore conclude that an atmosphere with a high concentration of CO₂, a low concentration of CH₄ and a thin layer of haze is most conducive to maintaining surface liquid water. This study has important implications for the habitability of exoplanets, particularly for M-dwarf hosted planets where atmospheric methane absorption of the stellar radiation is large.

Water mass transformation in the Arctic Ocean

Charlotte Marris

Department of Earth Sciences, University of Oxford

Within the Arctic Ocean, warm and saline water of Atlantic origin is transformed by air-sea exchanges and interior mixing into two distinct outflow components: cold and fresh Polar Water, and a dense, saline, deep-water mass. These water masses play a key role in large-scale ocean circulation and climate through the transport of heat, freshwater, and carbon. However, it is unclear how a projected increase in surface ocean warming and freshening will alter Arctic water mass transformation (WMT), and what the broader implications will be for the global climate system. Despite sustained ocean monitoring programmes, Arctic Ocean observations are sparse, and the temporal and spatial variability of Arctic WMT is poorly constrained. Quantifying WMT is further complicated by the challenge of disentangling the contributions from surface-forcing and interior mixing to total transformation rates. To address this, we analyse Arctic WMT in a pre-industrial control run (constant CO₂) of the UK's CMIP6 coupled-climate model, HadGEM3-GC3.1. We consider the time-mean state as well as variations over seasonal to multi-decadal timescales. By separating density changes into temperature and salinity space, we quantify a baseline for the relative contributions of surface heat loss, freshwater fluxes, and interior mixing processes to the total transformation rate, and thus identify the dominant processes and regions important for Arctic WMT. Future work will consider how these change under projected warming scenarios.

JWST Phase curve observations of TOI 561b – cloudy with a chance of silicates

Alex McGinty

Department of Atmospheric, Oceanic and Planetary Physics, University of Oxford

Over the last few years, missions like Kepler and later TESS have discovered many rocky planets that orbit their host stars in less than a day. These ultra-short-period planets (USPs) are expected to be stripped of their volatile atmospheres by intense host star irradiation, which is corroborated by their bulk densities and eclipse observations, consistent with bare rock surfaces. However, some USPs planets have anonymous low densities, suggesting the presence of an atmosphere defying conventional atmospheric loss theory. Once such USP is TOI-561b, an under dense planet with an equilibrium temperature of 2300K. This high equilibrium temperature is hot enough to vaporise the planet's mantle, leading to the formation of a dayside magma ocean. This magma ocean could allow for volatile exchange between the planet's interior and atmosphere. We present global circulation model (GCM) simulations of TOI-561b with Isca for a range of possible atmospheric compositions. We apply our models to the recent JWST NIRSpec/G395H phase curve of TOI-561b. Our results show that a bare rock case can't explain the observed phase curve. For the atmospheric cases considered, assuming efficient heat redistribution and zero Bond albedo isn't sufficient to explain the observed phase curve, suggesting the presence of a reflective atmosphere.

A bare rock or a terrestrial world with a substantial secondary atmosphere? An exploration of TOI-1468 b within the JWST Hot Rocks Survey

Erik Meier Valdés

Department of Astrophysics, University of Oxford

The abundance of low-mass stars in the Milky Way and the high occurrence rate of rocky planets to orbit such a star makes exoplanets orbiting M dwarfs tempting targets for atmospheric characterisation. It is likely these planets have lost their primordial H/He-atmosphere. However, they could still harbour a secondary atmosphere. As of today, an unambiguous detection has yet to occur. This motivated the Hot Rocks Survey, a large JWST programme to measure the thermal emission of 9 terrestrial planets around M dwarfs and test whether they have a substantial atmosphere or instead are hot barren rocks. In some instances, slightly different models in the data analysis lead to vastly different interpretations regarding the atmosphere. Thus, often it is unclear which model describes best the observation. Here we present the observations of TOI-1468 b in the Hot Rocks Survey sample, using an exhaustive and systematic approach to robustly analyse photometric time-series.

Broad Horizons: high-cadence, low-cost security from space

Kevin Olsen

Department of Atmospheric, Oceanic and Planetary Physics, University of Oxford

What can low-cost, lightweight, affordable tech do for us? Broad Horizons is an Earth-observing version of an advanced filter-radiometer technology developed in the Space Instrumentation group at the University of Oxford. Current systems are monolithic, ageing, and extremely expensive. For less than ten percent of the cost of contemporary systems, we could instead build a network of these versatile imaging systems. The key benefit is a high repeat time for observations by other satellites in the constellation, providing a higher cadence of data. This will improve our ability to monitor wildfires, smoke, dust, and emissions - better security, climate resilience, and compliance.

Retention of surface water on tidally locked rocky planets in the Venus zone around M Dwarfs

Yueyun Ouyang

Department of Atmospheric, Oceanic and Planetary Physics, University of Oxford

Terrestrial planets within the Venus zone surrounding M-dwarf stars can retain surface ice caps on the perpetual dark side if atmospheric heat transport is inefficient, as

suggested by previous global climate simulations. This condition is proposed to play a role in the potential regional habitability of these planets. However, the amount of surface ice may be limited by considering the water condensed from the steam atmosphere in a runaway greenhouse state, and the physical mechanism for triggering the condensation process is not clear. Here, we use a two-column moist radiative–convective–subsiding model to investigate the water condensation process on tidally locked planets from the runaway greenhouse state. We find that the water condensation process is characterized by two distinct equilibrium states under the same incoming stellar flux. The initiation of condensation corresponds to a warm, unstable state exhibiting positive Planck feedback, whereas the termination phase corresponds to a cold, stable state exhibiting negative Planck feedback. We further show that the surface water mass in the collapsed state decreases with the incoming stellar flux, background surface pressure, and optical thickness of noncondensable greenhouse gases, with a global equivalent depth of less than ~ 20 cm. Our two-column approach provides a straightforward way to understand the water evolution on Venus zone planets around M dwarfs.

A weak case for abiotic DMS on sub-Neptune worlds

Annika Salmi

Department of Earth and Planetary Sciences, ETH Zürich

While sub-Neptune planets are commonly detected in exoplanet surveys, their internal composition remains poorly constrained; the leading models are gas-rich dwarfs and water-dominated worlds (Hyceans). Atmospheric interpretations depend on the assumed sub-Neptune type; sulfur-bearing species such as DMS have been reported when planets are interpreted as Hyceans (Madhusudhan et al. 2023). Regardless of the type of sub-Neptune, models of sulfur behavior in either sub-Neptune type remain unresolved. In this work, we examine sulfur partitioning in temperate sub-Neptunes and super-Earths with varying amounts of accreted water and hydrogen. We do this by adopting the chemical equilibrium network first described by Schlichting & Young (2022), which models equilibrium chemistry on planets with a molten metal core, silicate mantle, and a hydrogen-rich envelope. Starting from a chondritic composition, we incorporate accreted gases and water into a chemical equilibrium model to track sulfur partitioning among the core, mantle, and atmosphere and its effects on bulk planetary properties. We then use this alongside an atmospheric chemistry model to find that abiotic production of DMS is unlikely.

Prospects for including atmospheric technosignatures in the high-resolution near-infrared search for biosignatures with the ELT: a simulated search for the artificial greenhouse gas SF₆

Mitchell Yzer

Department of Atmospheric, Oceanic and Planetary Physics, University of Oxford

With the Extremely Large Telescope (ELT) on the horizon, exoplanetary science is entering a new era: characterising terrestrial exoplanets in the habitable zone. Searching for technosignature gases on these planets is a natural extension to the broader search for biosignatures. High-resolution cross-correlation spectroscopy (HRCCS) is particularly adept at disentangling faint spectral signatures like these from more significant atmospheric constituents. Here, I present the results of a simulated search for sulphur hexafluoride (SF₆) with the mid-infrared high-resolution spectrograph METIS on the ELT. SF₆ is an industrial pollutant on Earth, but may also be deliberately released as an artificial greenhouse agent on planets with insufficient natural CO₂ production. It is non-toxic and long-lived, is not produced biologically and only at low rates abiotically, and has unique spectral features, making it an ideal technosignature candidate. Our preliminary results of idealised simulations show that only high abundances corresponding to significant terraforming efforts are detectable. To bring down the detection limit for technosignatures, improved line lists are required. An important next step is to assess through atmospheric modelling whether the planet could be habitable at the detectable abundances, and what other signatures would be expected.

List of participants

Department of Physics

Alex Bedford

Nick Dight

Delina Gabriel

Clara Gonsalves

Yasmine Tazi

Henry Xu

Astrophysics

Suzanne Aigrain

Alex Andersson

Oscar Barragán

Jayne Birkby

David DeBoer

George Dransfield

Baptiste Klein

Erik Meier Valdés

Luke Parker

Valentina Tardugno

Jake Taylor

Mitchell Yzer

Atmospheric, Oceanic, and Planetary Physics

John Allen
Asier Anguiano
Emma Belhadfa
Ofer Cohen
Michelle Colantoni
Leonardo Costa Lesage
Robert Doane-Solomon
Marylou Fournier Tondreau
Claire Guimond
Namrah Habib
Fiona Henderson
Sarah Howes
Carly Howett
Xinmiao Hu

Tad Komacek
Duncan Lyster
Mei Ting Mak
David Marshall
Alex McGinty
Kevin Olsen
Yueyun Ouyang
Joe Penn
Wei Qiang
Katherine Shirley
Kya Sorli
Rebecca Tichford
Colin Wilson
Hannah Wood
Tim Woollings

Atomic and Laser Physics

Ana Coutinho Dutra

Condensed Matter Physics

Jon Bath

Napan Phuphathanaphong

Department of Earth Sciences

Tom Barrett
Katherine Bormann
James Bryson
Roger Close
Brandon Fish
Aryaman Gupta
Alex Halliday
Jessica Hawthorne
Eugene Kim
Alasdair Knight
Paula Koelemeijer
Yiming Lai
Adam Lindholm
Charlotte Marris

Matthew McKinnon-Bell
Tin Tin Naing
Konstantin Nazarov
Claire Nichols
Richard Palin
Luke Parry
Ros Rickaby
Stuart Robinson
Charlotte Simpson
Jason Terry
Richard Thomas
Vaishvi Tyagi
Jon Wade
Andrew Walker

Department of Biology

Tim Coulson

Clive Hambler

Stephen Kearsey
Tyler Murray-Ramcharan

Sebastian Shimeld

Weatherall Institute of Molecular Medicine

Dana Costigan
Hal Drakesmith
Ewa Gogola

Hannah Murray
Maria Obregon Comino
Jan Rehwinkel

Museum of Natural History

Ross Anderson
Frankie Dunn

Łukasz Kowalski
Julia Schwab

Other

Andrew Davidson (*Faculty of Theology and Religion*)
Robert Hilton (*School of Geography and the Environment*)
Matt Hitchens (*Faculty of Philosophy*)
Robert Iliffe (*Faculty of History*)
Dominic Martin (*School of Anthropology & Museum Ethnography*)
Jessica Matthew (*Mathematical, Physical and Life Sciences Division*)
Grant Ritchie (*Department of Chemistry*)
Max Wang (*Department of Engineering Science*)

Michael Gross (*Independent science writer*)
Oliver Herbort (*Department of Astrophysics, University of Vienna*)
Annika Salmi (*Department of Earth and Planetary Sciences, ETH Zürich*)
Nicholas Tosca (*Department of Earth Sciences, University of Cambridge*)
Daniel Valentine (*School of Physics, University of Bristol*)

Scientific Organising Committee

Marylou Fournier Tondreau (chair), Claire Guimond, Ross Anderson, Claire Nichols, Suzanne Aigrain, Jayne Birkby, James Bryson, Tim Coulson, Hal Drakesmith, Carly Howett, Tad Komacek

Local Organising Committee

Marylou Fournier Tondreau (chair), Claire Guimond, Fiona Henderson, Tad Komacek, John Allen, Namrah Habib, Martha Mak, Alex McGinty, Mitchell Yzer