Abstracts from the conference

Are we a Unique Species on a Unique Planet?

- or are we just the ordinary Galactic standard?

Copenhagen, 2024

Support from the following foundations and institutions made this conference possible and is gratefully acknowledged:

CELS
CENTRE FOR EXOLIFE SCIENCES

UNIVERSITY OF COPENHAGEN

Niels Bohr Institute Foundation

CARLSBERG FOUNDATION

CHAMELEON
Curie Innovative Training Network for European Joint Doctorates

novo nordisk foundation
Benefitting people and society

Time slots Tuesday	Tuesday (2024-07-30): Exoplanets
08:30 - 09:00	Arrival for morning snacks / coffee
09:00 - 09:10	Formal Welcome by Uffe Graae Jørgensen
09:10 - 09:55	i1, Anne-Marie Lagrange: Exoplanet discovery and evolution.
09:55 - 10:40	i2, Nikku Madhusudhan: Chemical diversity of temperate exoplanets and implications for life elsewhere.
10:40 - 11:15	Coffee break
11:15 - 12:00	i3, Lena Noack: Planetary interior and habitability.
12:00 - 12:20	c1, Haiyang Wang: Cosmochemically constrained M-R diagrams for rocky worlds.
12:20 - 12:40	c2, Marrick Braam: Habitable environments and 3D atmospheric chemistry on rocky exoplanets in spin-orbit resonances.
12:40 - 14:05	Lunch break (Gumle Canteen)

Time slots Tuesday	Tuesday (2024-07-30): Exoplanets
12:40 - 14:05	Lunch break (Gumle Canteen)
14:05 - 14:50	i4, Helmut Lammer: The evolution of Earth-like habitats.
14:50 - 15:10	c3, Gergely Friss: How good are rocky exoplanets as cradles of life?
15:10 - 15:30	c4, Sven Kiefer: The cloudy climate of warm Saturns around M-dwarfs: A synergistic modeling approach and observational implications.
15:30 - 16:00	Coffee break
16:00 - 16:30	Pop-up poster presentations of 30 posters
16:30 - 17:00	Panel discussion 1
17:00 - 20:00	After day-1 sandwich & wine

Anne-Marie Lagrange: Exoplanet discovery and evolution

Exoplanetary systems represent a vibrant domain in today astronomy. Intriguing questions are how they form, how diverse they are, how unique our Solar System is, and whether life could be found in these distant worlds. I will describe how we find these extrasolar worlds, what they tell us about their diversity and their formation pathways. I will also describe the projects aiming at detecting Earth twins and possible signatures of life.

Nikku Madhusudhan: Chemical diversity of temperate exoplanets and implications for life elsewhere

The search for life elsewhere is one of the major frontiers in modern astronomy. In this talk, we will discuss observational and theoretical developments in the atmospheric characterisation of temperate low-mass exoplanets, and habitable exoplanets in particular. Considering a few case studies, we will present inferences of the atmospheric chemical composition and constraints on the temperature structure, clouds/hazes, chemical disequilibrium and interior/surface conditions. We will discuss the chemical diversity of temperate sub-Neptunes and future prospects in the search for habitable environments and biosignatures in exoplanets over the next decade.

Lena Noack: Planetary interior and habitability

The possible evolution paths of a rocky planet and its surface can be very diverse, and depend on several different interior and exterior processes. These are related for example to the planet's mass and composition, or the stellar activity and orbital configuration of the planetary system. Theoretical models studying the accretion and later evolution of rocky planets, including the initiation of plate tectonics or the build-up capacity of a secondary atmosphere, can help us to understand the range of potential habitable surface conditions. In addition, we can aim to map the possible range of abiotic background atmospheres, in which then to search for life e.g. by combinations of gases that would not be (easily) explained by geophysical processes alone. Here I will give an overview of our current understanding and theoretical predictions of the range of atmospheres that we may expect when only considering volcanic outgassing.

Haiyang Wang: Cosmochemically constrained M-R diagrams for rocky worlds

In this talk, I'll present and discuss how the variance in stellar compositions will influence nebular condensation outcome and by sampling condensates in different regions of the protoplanetary discs how planetary bulk compositions may be constrained. With such constrained bulk compositions and a consideration of the 'rocky' regime with $M < 5M\bigoplus$ and $R \sim [0.5,1.5]R\bigoplus$, the M-R diagrams under various scenarios are modelled, to guide the first-order interpretation of the compositional and interior properties of discovered rocky exoplanets. This forward modelling process may also be inverted to retrieve key formation parameters, e.g., feeding zone and its width, of a rocky planet, given its measured mass and radius.

Marrick Braam: Habitable environments and 3D atmospheric chemistry on rocky exoplanets in spin-orbit resonances

The observed diversity in stellar and exoplanetary environments leads to various 3D physical and chemical effects in planetary atmospheres. We need comprehensive numerical simulations describing these effects to understand the potential planetary habitability and interpret spectroscopic observations. Here, we focus on exoplanets orbiting relatively cool stars (M and K type) or residing in multi-planet systems that are likely tidally locked in spin-orbit resonances. We use a 3-D coupled climate-chemistry model to study how spin-orbit resonances impact spatial and temporal variations in atmospheric chemistry and thus affect planetary habitability. We simulate Proxima Centauri b residing in a 1:1 and 3:2 spin-orbit resonance around its host star and assume Earth-like atmospheric composition. First, we find that an ozone layer forms in both cases driven by the incoming stellar radiation. For a 1:1 and 3:2 resonance, the spatial distribution of ozone shows zonal or meridional variations, respectively. We report the dominant circulation mechanism driving these ozone distributions. Second, Proxima Centauri b in a 3:2 resonance orbit exhibits a warmer mean climate due to its eccentric orbit, with habitable regions extended to both hemispheres. We identify associated apoastron-periastron and daytime-nighttime cycles in incoming radiation, temperature, water vapour, and ozone that may be crucial for life on other planets. Finally, using the Planetary Spectrum Generator, we report how these contrasting 3D chemical distributions would be observed by future telescope concepts such as the Large Interferometer For Exoplanets.

Helmut Lammer: The evolution of Earth-like habitats

The talk will address the most important astrophysical and geophysical factors necessary for Earth-like Habitats (EH) with N_2/O_2-dominated atmospheres inside the habitable zone for complex life (HZCL). It will be explained that the lifetime of the disk and accretion processes of the growing protoplanets set the initial parameter stages for terrestrial planets so that they can end up as EHs. A competition between the time scales of the gas disk and the planetary accretion will determine if an accreting terrestrial planet may end inside the HZCL as a planet with an H_2/He dominated atmosphere, or not. Other relevant factors like a planet's thermal evolution and hence the right tectonic regime that is necessary for aerobic lifeforms as we know it will also be addressed. One can expect that many terrestrial planets inside the HZCL will have internal heat budgets and tectonic regimes that are different than those of Earth. Nitrogen is a necessary element in the building blocks of life; therefore, the geobiological N_2-cycle and a functioning C-cycle are fundamental factors in the long-term evolution of EHs. Thus, terrestrial planets with N_2/O_2-dominated atmospheres will have a tectonic regime and will be a strong indication for an aerobic biosphere. Tectonic regimes that do not allow or maintain N_2/O_2-dominated atmospheres for billions of years are very likely to produce Venus- or Mars-like CO_2-dominated atmospheres which will be not be life-friendly for aerobic complex lifeforms. Finally, a newly derived formula that can be used to estimate the potential numbers of EHs in the galaxy, will also be discussed.

Gergely Friss and Paul I. Palmer: How good are rocky exoplanets as cradles of life?

So far we only know of one location in the observable universe that hosts life as we know it: Earth. But how can life emerge on a rocky planet and what conditions are beneficial for it? A possible answer to that is warm little ponds that experience wet and dry cycles that could be vital for the polymerisation of organics. In this work, we couple a 1D atmospheric chemistry and a warm little pond model via rain-out processes to explore the physical parameter space of rocky planets. Parameters tested include meteoritic bombardment rate, initial atmospheric composition, temperature-pressure profile and stellar radiation profile. We study how they influence the prebiotic chemistry and conditions for the origins of life first on an Early Earth and then on an Earth as a tidally locked exoplanet setting.

Sven Kiefer: The cloudy climate of warm Saturns around M-dwarfs: A Synergistic Modelling Approach and Observational Implications

The comprehensive modelling of 3D atmospheres of exoplanets often encounters computational constraints due to extensive processing times. Here, we present the results from our synergistic modelling approach of a 3D cloudy atmosphere model, applied to the case of HATS-6b orbiting an M-dwarf star. Our methodology involves a series of iterative interactions between the full 3D General Circulation model expert/MITgcm and a detailed kinetic cloud formation model. Through this integrated effort we achieve a predictive understanding of HATS-6b's atmospheric properties, aligning with the observational capabilities of the James Webb Space Telescope (JWST), including NIRspec Prism and MIRI LRS instruments.

Our findings highlight the profound impact of global cloud coverage on HATS-6b's temperature and wind patterns. The presence of clouds induces a temperature inversion on the planet's illuminated hemisphere, resulting in cooler temperatures at greater atmospheric depths. While these clouds contribute to a flattened transmission spectrum for wavelengths below 1 micron, longer wavelengths offer promising prospects for the detection of molecular features, such as H_2O and CH_4, as well as potential signatures from cloud materials. Our approach offers a multifaceted perspective on the complex interplay of atmospheric dynamics and chemical process, and on observational potential in the study of exoplanets.

Time slots Wednesday	Wednesday (2024-07-31): Disks & pre-biology
08:30 - 09:00	Morning snacks / coffee
09:00 - 09:45	i5, Bengt Gustafsson: Is the Sun and oddball and if so, why? Interpretations and implications.
09:45 - 10:05	c5, Åke Nordlund: Disk outflows and abundance differences.
10:05 - 10:50	i6, Michiel Lambrechts: Understanding the formation of our Solar System in an exoplanet context.
10:50 - 11:25	Coffee break
11:25 - 12:10	i7, Paola Caselli: Chemistry from ISM to disks to pre-biology to planets.
12:10 - 12:30	c6, Hans Zinnecker: What if the Moon did not exist?
12:30 - 13:55	Lunch break (Gumle Canteen) **incl. group photo**

Time slots Wednesday	Wednesday (2024-07-31): Disks & pre-biology
12:30 - 13:55	Lunch break (Gumle Canteen) **incl. group photo**
13:55 - 14:15	c7, Inga Kamp: The chemical composition of planet-forming disks with JWST: a new view into terrestrial planet composition.
14:15 - 14:35	c8, Peter Woitke: The chemistry in the inner disk of T-Tauri stars.
14:35 - 14:55	c9, Pooneh Nazari: ALMA, Disk-Planet connection.
14:55 - 15:15	c10, Helene Rousseau: Advancing exo-zodiacal dust research through improved thermal background subtraction.
15:15 - 15:45	Coffee break
15:45 - 16:30	i8, Pascale Ehrenfreund: Prebiotic reservoirs available to the early Earth and Mars
16:30 - 17:00	Panel discussion 2
17:00 - 20:00	After day-2 sandwich & wine
18:30 - 22:00	Conference dinner, Frue Plads 4, 1168 Copenhagen K

Bengt Gustafsson: Is the Sun an oddball and if so why? Interpretations and implications

The atomic chemical composition of the Sun departs systematically from that of most other solar-type stars in that its ratio of volatiles (like the biogenic elements) to the refractories is higher by about 10%. What does this tell about the formation and evolution of the Solar System? Scenarios in terms of different nucleosynthesis, early formation of the pre-solar nebula, of the evolution of the proto-planetary disk, of the engulfing of planets, and of other processes within the system will be considered. Implications, if any, on the habitability of the Solar System will commented on.

Åke Nordlund: Disk outflows and abundance differences

Observations of young stellar objects, as well as recent high-resolution adaptive-mesh-refinement numerical simulations of star formation, have shown that massive outflows are always associated with star formation. Protoplanetary disks channel the accretion flows from the surroundings of newly formed star down to the star. Mass can only reach the star by shedding angular momentum and potential energy; a process that relies mainly on transporting away the excess angular momentum and energy via the strong magnetic fields that are dragged in along with the gas and dust. The magnetic fields connect the disks with the surrounding interstellar medium, and transport angular momentum and energy via Maxwell and Reynolds stresses; i.e., both directly, via electromagnetic Poynting flux, and indirectly, via the systematic outflows (disk winds and jets) driven by the magnetic field and assisted by the dissipation of magnetic energy into heat. The outflows that allow accretion of a fraction of the mass to occur return the rest of the gas and dust to the interstellar medium. Volatile elements are more likely to become part of the ejected material, and hence this process may be expected to leave an abundance imprint on the accreted material, with a general underabundance of volatile elements. As also shown by both observations and simulations, no two stars are subjected to exactly the same conditions when they form; important properties such as upstream specific angular momentum and average magnetic flux density vary from case to case, including between stars that form binaries. This process is therefore an excellent candidate to explain the systematic chemical abundance differences between CI-chondrites, the Sun, and stars very similar to the Sun (‘solar twins’). Correlations with condensation temperatures are a natural consequence of ‘thermal processing’ of pristine dust into on the one hand gas that escapes the system, and on the other hand solids dominated by refractories that largely remain in the system.

Michiel Lambrechts: Understanding the formation of our Solar System in an exoplanet context.

This talk will cover our current view on how planets, like Earth, grow large in protoplanetary discs. These discs, composed of gas and dust, surround young stars for a few million years after their formation. Starting with microscopic dust particles, solids efficiently grow through coagulation to larger mm-sized particles for which fragmentation becomes important. These pebbles then radially drift inwards, through gas drag, within the disc lifetime. During their radial trek inwards, a significant fraction of the tens to hundreds of Earth-masses of pebbles gets either trapped in dense pebble swarms that get converted to planetesimals, or directly accreted by large planetesimals that act as planetary embryos. Depending on the available mass budget in pebbles, these cores then grow into Earth-like, super-Earths or even gas-giant planets. Putting this all together, we will compare the outcome of this theoretical model to the currently-known exoplanet census, our Solar System, and discuss implications - specifically with respect to volatile delivery - to the composition of habitable-zone planets.

Paola Caselli: Chemistry from ISM to disks to pre-biology to planets

All ingredients to make stars like our Sun and planets like our Earth are present in dense cold interstellar clouds. In these "stellar-system progenitors" active chemistry is already at work, as demonstrated by the presence of a rich variety of organic molecules (including precursors of pre-biotic molecules) in the gas phase and water-rich icy mantles surrounding the sub-micrometer dust grains, the building blocks of planets. Here, I’ll present a journey from the earliest phases of star formation to protoplanetary disks, with links to our Solar System, highlighting the crucial role of astrochemistry as a powerful diagnostic tool of the various steps, needed to unveil our astrochemical origins.

Jan Hendrik Bredehöft: The Universality of Prebiotic Chemistry

Prebiotic Chemistry encompasses the whole evolution of the necessary building blocks and ingredients for the origin of life. It starts with the elements C, H, O, N, S and P and ends with the first cell. This evolutionary process is characterized by a simultaneous increase in complexity as well as order of the system. Starting with Miller and Urey in the 1950s, a large number of lab experiments have shown that many of the organic building blocks of modern biology, like amino acids, sugars, lipid-like amphiphiles, nucleobases, etc. can be formed abiotically by radiation-driven chemistry.

The surprising commonality between the experimental results, regardless of the exact starting conditions and of the exact type of radiation has led to the realization that there must a common chemical driving force in these reactions. This driving force exists in the form of the secondary electrons that are liberated by interaction of with ionizing radiation. These electrons are extremely potent at driving chemical change. By directly using these low-energy electrons in the lab, not only can we understand the universality of the chemical reactions occurring, but we can actually work out reaction paths and cross sections for many reactions that are of great relevance in prebiotic chemistry.

The production of secondary electrons and the reactions that they trigger in chemical mixtures, are governed by very basic physical and chemical principles that make them very universal as long as physics keeps working the way it does here.

Inga Kamp: The chemical composition of planet forming disks with JWST: A new view into terrestrial planet composition?

JWST mid-IR spectra provide a new window into the terrestrial planet forming zone around young stars. Its unprecedented sensitivity and spectral resolution allow us for the first time to study the chemical inventory across spectral types down to Very Low Mass Stars and also to push down to minor species beyond CO_2, HCN, C_2H_2 and water. Most rocky exoplanets to date are detected around such Very Low Mass Stars including the famous TRAPPIST-1 system. I present here results from the MINDS Guaranteed Time program (MIRI mid-INfrared Disk Survey, PI: Th. Henning). I will discuss the diversity in observed molecular emission across stellar spectral type and present the results from retrieval and forward 2D thermochemical modeling of those spectra. Based on that, I will summarize the current ideas to explain those differences from a physical and chemical point of view and put this into the context of disk evolutionary processes and planet formation theories.

Peter Woitke: The Chemistry in the Inner Discs of T-Tauri Stars

JWST observations of protoplanetary discs probe the chemistry in the planet−forming inner disc < 1au, with new, spectacular evidence for very strong oxygen depletions in some cases (Arabhavi+2024). I will report on the challenges and recent successes in understanding the chemistry in the inner discs of T-Tauri stars. For the ordinary T-Tauri star EX Lupi, we were able to devise a 2D thermo-chemical disc model with a slowly increasing surface density profile around the inner rim that can simultaneously fit the spectral energy distribution (SED), the overall shape of the JWST spectrum, and the main characteristics of H_2O, CO, CO_2, C_2H_2, HCN and OH in terms of their column densities, emitting areas, and molecular emission temperatures (Woitke 2024). All these observables are derived from a single disc model with consistently calculated 2D dust and gas temperature structures and chemical concentrations. High abundances of HCN and C_2H2 are caused in the model by stellar X-ray irradiation of the gas around the inner rim. For the discs around low-mass stars, JWST has collected striking evidence for the existence of highly oxygen-depleted inner discs, with C/O as large as 100. Simplified disc models using radial powerlaws for molecular column densities and emission temperatures combined with full Bayesian analysis (Kaeufer 2024) can simultaneously fit the continuum and the molecular properties. For the case of the low−mass T-Tauri star Sz 28, we fit the emissions of C_2H_2, HCN, C_6H_6, CO_2, HC_3N, C_2H_6, C_3H_4, C_4H_2, and CH_4, with additional tentative detections of CH_3 and NH_3, but no water and no CO. The work of Kanwar (2024), using 2D thermo-chemical disc models, shows that strong constraints about high C/O ratios in the inner disk can be deduced from the non-detection of CO.

Pooneh Nazari: The Dawn of Planets: Tracing Early Planet Formation in Protostellar Disks

Recent observations by ALMA suggest that planets begin forming much earlier in the lifecycle of stellar systems than previously thought, challenging our standard models that assume most of planet formation occurs in mature protoplanetary disks. This talk explores the implications of these recent findings for understanding planet formation and its chemical evolution. By integrating models with observational data, I will examine the connection between the early chemical compositions found in protostellar environments and the atmospheric makeup of emerging planets. Our discussion will shed light on how planet formation in early stages influence the observable properties of disks and planets.

Hélène Rousseau: Advancing exozodiacal dust research through improved thermal-background subtraction

Exozodiacal dust is warm and hot dust in the inner regions of mature planetary systems, around the habitable zone and closer in, and is an analogue of the zodiacal dust in our Solar system. This dust must be delivered to the inner regions from further out in the system, e.g., through cometary activity. Volatiles, water, and building blocks of life may be delivered to potential rocky planets in the habitable zone through this same process. Hence, the study of exozodiacal dust can provide clues about whether and why such planets are Earth-like, barren or water worlds. At the same time, large amounts of exozodiacal dust will add noise and confusion to the data from future exo-Earth imaging missions and potentially prevent detection. While the dust can be the most luminous component of a planetary system after the star, it predominantly emits at near- to mid-infrared wavelengths, where it is outshone by the star. Hence, their detection requires the high spatial resolving power of precision infrared interferometry. We will introduce the topic of exozodiacal dust and summarize the current knowledge in the field, and then focus on mid-infrared observations, which are particularly important as they specifically probe habitable-zone dust. The main sensitivity limitation of such observations is currently the quality of thermal-background subtraction. Improving the sensitivity by a factor of 2-3 is a critical step towards completing the design of an exo-Earth imaging mission such as the Habitable Worlds Observatory. We address this issue using a new approach based on principal component analysis and show that this can improve the sensitivity by the required factors.

Pascale Ehrenfreund: Prebiotic reservoirs available to the early Earth and Mars

One of the most compelling questions in planetary science revolves around the origins of life on Earth and the possibility of extraterrestrial life. Key environments conducive to the formation of organic molecules, crucial in the genesis of life, include deep-sea hydrothermal vents, volcanic regions, and primordial oceans. Additionally, the early Earth's chemical raw material may have been enriched by small Solar System bodies that deposited carbon-rich molecules and volatile compounds onto the young planets.

Recent space missions focused on comets and asteroids have markedly enriched our understanding of the prebiotic materials available to the early Earth and Mars. This enhanced comprehension of Earth's primordial biochemical conditions assists in the identification of similar environments on Mars, furthering our quest to unravel the mysteries of life beyond our planet.

Time slots Thursday	Thursday (2024-08-01): Terrestrial contra alien biology
08:30 - 09:00	Morning snacks / coffee
09:00 - 09:45	i9, Kate Adamala: Synthetic life.
09:45 - 10:30	i10, David Catling: The rise of oxygen and its importance for complex life.
10:30 - 11:00	Coffee break
11:00 - 11:45	i11, Dirk Schulze-Makuch & Ian Crawford: Expectations about Alien Life Forms and their Existence
11:45 - 12:05	c11, Felix Leo Arens: The hyper-arid Atacama desert as a standard for terrestrial desert planets.
12:05 - 12:25	c12, Miguel Á. Salinas-García: Extreme smells: Compounds from Greenlandic bacteria as biomarker.
12:25 - 13:50	Lunch break (Gumle Canteen)

Time slots Thursday	Thursday (2024-08-01): Terrestrial contra alien biology
12:25 - 13:50	Lunch break (Gumle Canteen)
13:50 - 14:35	i12, Kai Finster: The interaction between micro-organisms and cloud formation.
14:35 - 14:55	c13, Helena Lecoq-Molinos: Quantum chemical insights into metal oxide nucleation in substellar environments.
14:55 - 15:25	Coffee break
15:25 - 16:10	i13, Donald Canfield: The evolution of Eukaryote ecosystems.
16:10 - 16:30	c14, Johan Rahnberg-Andersen: Identification and characterization of the chlorophyll c synthase and the evolutionary implications for marine algae
16:30 - 17:00	Panel discussion 3
17:00 - 20:00	After day-3 sandwich & wine

Kate Adamala: Synthetic life

The earliest history of life on any planet includes a series of transitions from non-living matter, through prebiotic synthesis, towards the first living cell. Those transitions leave no witnesses or fossil records. With modern biology representing only a single sample of possible life, it is difficult to speculate how those earliest stages of evolution looked like, and what other possible life forms could have existed on ours and other planets. The emerging field of synthetic cell engineering allows us, for the first time, to directly interrogate those questions. We now have the opportunity to interrogate other possible trees of life, elucidating other ways in which chemistry can become biology.

David Catling: The rise of oxygen and its importance for complex life

A very oxygen-rich atmosphere sustains multicellular life on Earth, including us, yet Earth’s early history is marked by a lengthy anoxic period. The evolution of Earth's atmospheric oxygen is of interest when we consider other Earth-like planets, and their potential for supporting complex life. Life comparable to advanced metazoans arguably required high partial pressures of oxygen. The multi-billion-year geological timescale for Earth to acquire an oxygen-rich atmosphere, or “oxygenation time”, was thus a limiting step in the evolution of complex life.

Here, I will discuss the dependence of complex life on atmospheric oxygen, what caused atmospheric oxygen to rise on the Earth, and whether oxygen-rich atmospheres might evolve on Earth-like exoplanets. I contend that complex animal-like life elsewhere that can move, jump, and think, will breathe oxygen and so biogeochemical conditions for sufficient oxygen in exoplanet atmospheres will limit the distribution of complex life in the universe.

Dirk Schulze-Makuch & Ian Crawford: Expectations about Alien Life Forms and their Existence

We have only one example of life as we know it, yet it surprises us with an incredible diversity. When expanding our viewpoint to other forms of life that may exist in the Universe, that diversity is expected to be even larger, because that life has originated and evolved under very different environmental conditions and circumstances.

Life as we don´t know (yet) may utilize different energy sources like magnetic energy or osmotic gradients, and to us puzzling ways of transmitting information from one generation to the next. However, there are constraints as any life form will be intrinsically linked to the environment in which it thrives, and in principle knowing the environment will let us deduce properties about the type of life within it, and vice versa. Also, in a rich biosphere, evolution will drive life to more complexity and complex organisms, some of which will have functional capabilities similar to animal and plant life on Earth.

Felix Arens, Jacob Heinz & Dirk Schulze-Makuch: The hyper-arid Atacama desert as a standard for terrestrial desert planets

Liquid water is essential for life as we know it. Understanding how organisms cope with water scarcity is crucial, particularly as these extreme conditions are commonly found on Mars and expected on many exoplanets. Therefore, we investigate soils in the hyperarid Atacama Desert to study the dry limits of life. The focus is on exploring survival strategies and potential niches for life along a gradient of decreasing water availability. As these stresses intensify, only certain microbial life forms manage to persist, becoming dormant and being forced to retreat to subsurface shelters that offer protection against the harsh surface conditions. In the driest regions of the desert, deliquescent salts play a vital role. Their porous texture and ability to attract water from the atmosphere during elevated relative humidity extend the last refuges of microbial habitability in dryland ecosystems. However, hypersaline conditions also pose significant challenges for life such as osmotic stresses. These insights from extreme ecosystems on Earth are essential for assessing the habitability of Mars and other celestial bodies.

Miguel Á. Salinas-García: Extreme smells: Volatile compounds from Greenlandic bacteria as biomarkers

Microbial Volatile Organic Compounds (MVOCs) are small organic molecules produced by microorganisms that evaporate at low temperatures. They function as waste products, modulate stress responses, are involved in intra- and interspecies communication, and are influenced by environmental changes. These molecules can be used as biomarkers in extreme environments and may contribute to global element cycles, such as the sulphur cycle. This study investigates MVOCs in the High Arctic deserts of Northern Greenland, an analogue of Mars-like planets. We isolated three novel bacterial strains: *Oceanobacillus sp.* and *Nesterenkonia aurantiaca* from dry crust soil, and *Arthrobacter sp.* from permafrost. The strains were grown at 0, 5, and 10% w/v NaCl. In the late exponential phase, the MVOCs produced were analysed with GC-MS. In addition, we used PTR-MS to monitor MVOC production over 60 hours. *N. aurantiaca* emitted mainly oxygenated compounds, *Oceanobacillus sp*. produced methanethiol and dimethyl disulphide, and *Arthrobacter sp*. produced oxygenated and nitrogen-containing volatiles. Suboptimal salinities delayed MVOC production, and further effects on the production of MVOCs were observed. These results highlight the potential of MVOCs as biomarkers in extreme environments, with applications in taxonomy, ecology, biotechnology, and astrobiology.

Thursday, 5: Terrestrial contra alien biology

Kai Finster: The interaction between micro-organisms and cloud formation

Clouds are crucial for regulating Earth's temperature and climate by affecting the planet's radiation balance. Despite their importance, clouds are the least understood components of the Earth's climate system, as indicated by recent IPCC reports. Clouds are made up of different-sized droplets, which determine their reflectivity (albedo). Cloud droplets form around tiny particles called cloud condensation nuclei (CCN), which can be either inorganic or organic. The size of a droplet affects whether it remains suspended in the air or falls as precipitation. One important process in cloud formation is the Bergeron process, where ice crystals grow in mixed-phase clouds. This process occurs in regions where the air is supersaturated with respect to ice but subsaturated with respect to liquid water, leading to rapid ice crystal growth. If the density of ice is relatively low compared to liquid water, ice crystals can grow large enough to fall out of the cloud, melting into raindrops if temperatures at lower levels are sufficiently high. The initial formation of ice necessitates the presence of ice nucleating particles (INPs), which can be either mineral or biological. Mineral INPs are active at temperatures below -15°C, whereas biological INPs are active at temperatures above -15°C. Notably, proteins produced by plant pathogenic bacteria, such as those belonging to the genera Pseudomonas, Xanthomonas, and Pantoea, are among the most efficient INPs. In this presentation, we will discuss our research on the role of bacteria in ice formation within clouds and precipitation, and explore the potential of cloud formation as a biosignature in the quest for life on exoplanets.

H. Lecoq-Molinos, D. Gobrecht, J.P. Sindel, Ch. Helling and L. Decin: Quantum Chemical Insights into Metal Oxide Nucleation in Substellar Environments

Observations of numerous gaseous exoplanets have revealed the presence of clouds in their atmospheres. These clouds form from a complex set of physical and chemical processes which are not fully understood. In this work, we study the first steps of cloud formation, nucleation, in gaseous atmospheres using quantum chemistry calculations of metal oxide clusters, including vanadium oxide, titanium oxide and silicon oxide. Nucleation occurs when gas-phase molecules cluster together to form nanometer-sized particles (i.e. nanoclusters), which can further coagulate into macroscopic dust grains that provide a surface for the cloud materials to condense on. The process is highly dependent on the characteristics of the clusters such as their potential energies, geometries and spectral properties, all of which are not well known. We apply a bottom-up approach to obtain the geometries and thermochemical energies of global minima candidate structures for the different metal oxides. Each structure has been calculated by applying Density Functional Theory at the B3LYP/cc-pVTZ level of theory.
We present thermochemical results for VO, V2O5, TiO and SiO that are in accordance with the experimental energies listed in the JANAF-NIST tables. Further, we provide updated values for VO2, as well as results for larger structures that are not currently available in the literature. We use a chemical equilibrium code to explore astrophysical environments for which each metal oxide nucleation will be important, with a focus on exoplanet atmospheres. With our revised cluster data, we calculate non-classical nucleation rates which are up to 15 orders of magnitude higher than classical nucleation rates. We compute the vibrational spectra of all clusters and found that the strongest emission peaks lie within the JWST-MIRI wavelength range.

Don Canfield: The evolution of Eukaryote ecosystems

The fossil record suggests that eukaryotes were part of the marine ecosystem by about 1700 million years ago. However, the accepted biomarker record of steranes, derived from eukaryotic sterols, do not appear in the rock record until about 780 Ma in what is known the “Rise of Algae”. To explain this time gap, it is variably argued that either eukaryotes were minor shadow members of marine ecosystems for almost 1 billion years after they first appeared, or that the early fossils represent “stem group” organisms that first evolved into “crown group” eukaryotes capable of “modern”-style sterol production around 800 million ago. In this view, complex eukaryote ecosystems with both photosynthesis and grazing also emerged with this relatively late evolution of crown group organisms. We challenge these views. First, using high temperature pyrolysis techniques, we find “modern” steranes in rocks from 1400 and 1000 million years ago, demonstrating that crown-group Eukaryotes evolved before 1400 million years ago. Next, we use a size-based ecosystem model to show that the size distribution of preserved eukaryotic microfossils from 1700 Ma and onwards required an active and complex eukaryote ecosystem complete with photosynthesis and grazing. This result is robust over a wide range of nutrient concentrations. Furthermore, our model results suggest that these ancient eukaryote ecosystems could have provided from one third to one half of the marine primary production. Thus, complex eukaryote ecosystems were likely active from 1700 million years ago and onwards. In this view, the general lack of steranes in the pre-780 Ma rock record could be a result of poor preservation.

Thursday, 8: Terrestrial contra alien biology

Johan Rahnberg-Andersen: Identification and characterization of the chlorophyll c synthase and the evolutionary implications for marine algae

Photosynthesis has shaped Earth and the conditions for life throughout eons. Pigments are molecules that captures light and tranduce the energy used in photosynthesis for splitting water and capturing CO_2. Oxygenic photosynthesis emerged in cyanobacteria ~ 3000 million years ago (Mya), and caused the great oxidation event. Following this event, photosynthetic lifestyles has adapted and evolved in eukaryotic organisms producing O_2 via water splitting leading to the oxygen rich atmosphere on present Earth. Eukaryotic photosynthesis has been enabled by the evolution of pigment biosynthetic enzymes establishing new pigments with novel spectral properties adopted by the eukaryotic photosynthetic machinery. This has supported the succes of phototrophic eukaryotes and their acclimation to ecosystems across the globe.

Time slots Friday	Friday (2024-08-02): Future of life and humanity
08:30 - 09:00	Morning snacks / coffee
09:00 - 09:45	i14, Steven Dick: Transforming our worldviews in a biological (or post-biological) Universe.
09:45 - 10:20	c15, Hans Zinnecker: What if the Moon did not exist?
10:20 - 11:00	Coffee break
11:00 - 11:20	c16, Hans Rickman: The fate of giant planets in embedded clusters - consequences for life?
11:20 - 12:05	i15, Edward Schwieterman: Challenges for advanced life in the habitable zone - and implications for the search for life in the Universe.
12:05 - 12:25	c17, Katrien Kolenberg: Bridging science results to society through art and education.
12:25 - 14:00	Lunch break (Gumle Canteen)

Time slots Friday	Friday (2024-08-02): Future of life and humanity
12:25 - 14:00	Lunch break (Gumle Canteen)
14:00 - 14:20	c18, Ian Crawford: Who speaks for Earth? - Some political implications of a human future in space.
14:20 - 15:05	i16, Robert Zubrin: The future of humanity in the colonization of space
15:05 - 15:45	Coffee break
15:45 - 16:30	Panel discussion 4 and Scientific Outlook, Presentation of poster prizes and Farewell
16:30 - 18:00	After day-4 sandwich & wine

Steven Dick: Transforming our worldviews in a biological (or post-biological) Universe

The discovery of what I have called a "Biological Universe" full of life would have substantial effects not only on science, but also on society at large, including philosophical, theological, and ethical impacts (Dick, 1996; Dick, 2018). This presentation discusses systematic approaches to those questions from the point of view of history, the nature of discovery, and the promise and pitfalls of analogy, and surmises what the impacts might be under differing scenarios. We also argue based on what I call the Intelligence Principle, "the central principle of cultural evolution" that it is highly likely we live in a post-biological universe full of artificial intelligence. The implications of that scenario are as yet unexplored.

Dick, Steven J. The Biological Universe: The Twentieth Century Extraterrestrial Life Debate and the Limits of Science (Cambridge University Press, 1996).

Dick, Steven J. Astrobiology, Discovery, and Societal Impact (Springer, 2018).

Hans Zinnecker: What if the Moon did not exist?

I hope to discuss several key aspects of how the Moon relates to the possibly unique life on Earth. Starting with the moon's origin and mass and the original rotation speed of the Earth, then touching upon its role to stabilize the Earth's obliquity (and seasons), and thirdly recalling the Moon's gravity causing the tides on the surface of the Earth and differential rotation in the Earth's partially liquid iron core, I would like to raise 3 issues: (1) whether the grazing collision of a Mars-sized object (Theia) with the proto-Earth has bestowed the Earth's lithosphere with plate tectonics and the associated CO_2 cycle (unlike on Venus with no moon and slow rotation), (2) whether the precession of the Earth's spin axis caused by the moon's torque contributes to the generation of the geodynamo which is key to provide complex life on Earth with a magnetic shield protecting it against the lethal cosmic rays and also solar storms (note that Venus, in the habitable zone but without a moon, has but a feeble magnetic field), and (3) whether the to and fro of the Earth's ocean tides due to the moon have swept initial life out of the water and onto land where it could evolve to a higher complexity and ultimately to homo sapiens. Note that ocean life (whales) cannot build space rockets!
These ideas build on a 2012 book by Andre Maeder, written in French (L'unique terre habitee'?) who gives a balanced thorough astronomical, climatic, biological and even sociological analysis about the conditions and dangers of life in the universe, between the Ward & Brownlee (2000) "Rare Earth" hypothesis and Kasting's (2010) more optimistic view how to find a habitable planet in the Galaxy.

Hans Rickman, T. Wisniowski, P. Wajer & R. Przyluski: The fate of giant planets in embedded clusters – consequences for life?

It is now realised that a dense stellar environment may trigger the breakdown of a newly formed planetary system and that such environments are normal for the birth of solar type stars. This raises the issue of the consequences of such breakdowns for the formation of terrestrial planets, including implications for the origin and evolution of life.

Here, we report on the first simulations of planetary system dynamics as affected by an embedded cluster environment. By studying a giant planet system that could reasonably represent the precursor of our solar system, we find that this runs a significant risk of being destroyed by the effects of such a cluster.

When breakdown occurs, all planets, except the innermost giant, suffer a large risk of being ejected from the system or extracted into distant orbits with semi-major axes of hundreds or thousands of astronomical units. Moreover, we have demonstrated a possibility for inner giants to evolve into "hot Jupiter" orbits by tidal circularisation during the chaotic evolution.

The mentioned events take place at a very early time, when only Earth precursors may have existed in the form of large planetesimals or embryos. In most cases, we find no evidence that a planet like the Earth could not have formed at about 1 au from the Sun, and even a series of brief passages by an ice giant may not have prevented the growth of such a planet. However, there is a non-negligible risk for destruction of the commonly accepted source of the Earth's water in and beyond the outer asteroid belt, since Jupiter's orbit may have evolved into this region. This might leave Earth and its neighbours as essentially dry planets with much reduced chances for the origin and development of life.

Edward Schwieterman: Challenges for advanced life in the habitable zone – and implications for the search for life in the Universe

The habitable zone is typically defined as the circumstellar region where a planet with a CO_2-H_2O greenhouse could maintain stable surface liquid water, an essential requirement for all known life. However, substantially more CO_2 than in Earth's modern atmosphere is required to maintain clement conditions in most of the habitable zone (HZ), up to over 10,000 times more at the HZ's outer edge. At these high concentrations, CO_2 is known to be a toxic gas for many large O_2-respiring organisms (humans and other animals) and would have a substantial impact on ocean chemistry (pH). Coupled with differences in atmospheric chemistry predicted for planets orbiting M dwarf stars, which would facilitate the accumulation of biosignature and toxic gases, the habitable zone real estate where technological civilizations could originate and thrive may be more limited than commonly assumed. I will present modeling results that illuminate these challenges, which also suggest the appearance of intelligent life is not necessarily dependent on random evolutionary steps but – at least in part – related to the co-evolution of the planet and its host star. I will close by discussing the implications of this work for the search for biosignatures and technosignatures beyond the solar system.

K. Kolenberg, A.C. Andersen, J. Bruun, P. van Petegem, O. Marshall & P. Steyaert: Bridging science results to society through art and education

Are we a unique species on a unique planet?
Astrophysics is a STEM discipline par excellence, making use of expertise from various fields (physics, maths, chemistry, biology, geography, high-tech, engineering, …). Moreover, as a subject triggering the imagination – and even raising philosophical questions – it has the potential to raise interest in STEM disciplines. Therefore, the development of STE(A)M projects linked to topics in Astrophysics is a useful endeavour, both for school education and for reaching a larger segment of society through public outreach.
More and more, the value of integrated STEM projects is put into practice and even investigated. However, the question in what way the A (Arts) in **STEAM** also brings benefit is largely unexplored.
Science communication and education have played a key role in our Curie Innovative Training Network for European Joint Doctorates, CHAMELEON, both for the school context and for the public. What makes CHAMELEON unique is that we have gone beyond the regular ways of communicating the project's results by developing STE(A)M lesson modules for the classroom and through dedicated **artwork** triggering reflection and conversation.
In this presentation, we highlight the efforts made to bridge the CHAMELEON research topics to a much wider audience, which were the subject of pioneering and interdisciplinary research done within the CHAMELEON consortium.

Ian Crawford: Who speaks for Earth? – Some political implications of a human future in space

Future astrobiological activities and discoveries, along with other human activities in the transnational domains of outer space, will require the development of political institutions able legitimately to speak for humanity as a whole. Examples include:

• Regulation of space resources so that competition for them doesn't exacerbate geopolitical tensions on Earth or in space.

• Decisions on the preservation of alien environments, whether inhabited or not.

• Management of interactions with lifeforms that may be discovered elsewhere in the Solar System.

• Decisions on what to do should a SETI signal be detected, and on whether METI is to be permitted.

• If we find no evidence for life elsewhere (or even if we do), would it be desirable (or not) to artificially spread Earth-life to locations elsewhere in the Solar System or even to planets orbiting other stars?

Currently, the world lacks global political institutions capable of legitimately making these kinds of decisions. Here, I identify a range of possibilities, including the formation of a world space agency and strengthening the United Nation's oversight of space activities. I argue that ultimately the logic points towards bringing space exploration within the remit of much stronger institutions of global governance (which will in any case be required to deal effectively with other pressing transnational problems in the twenty-first century, e.g., climate change, biodiversity loss, pandemics, nuclear disarmament, etc). Although, at present, humanity appears to lack a sufficiently strong sense of global community for the formation of strong global political institutions, I argue that the cosmic and evolutionary perspectives provided by space exploration and astrobiology can help lay the psychological foundations on which such institutions may be built.

Robert Zubrin: The future of humanity in the colonization of space

Founder and president of the Mars Society and Pioneer Astronautics. Zubrin's career includes being a driving force first in Lockheed Martin's development of strategies for space exploration, and later also in Martin Marietta Astronautics and in Pioneer Astronautics, designing concepts for interplanetary space missions. The Mars Society is an international organization advocating human exploration and colonization of Mars, while Pioneer Astronautics, which Zubrin led from its founding in 1996 until selling it in 2023, does research and development on aerospace technologies. Zubrin is the author of a large number of scientific reports, papers and books on the development of space missions and methods, including a strong promotion of the Mars-direct concept designed to take advantage of the Martian atmosphere to produce in-situ oxygen, water and fuel, as a necessary basis for making long term human presence on Mars and beyond possible. His classic book "The Case for Mars", was re-issued in 2021 in an extended and widely updated 5th anniversary edition. There and elsewhere Zubrin argues for the ethics of human colonization and how becoming a spacefaring species will benefit the future of humanity also back on Earth. The Mars Society Webpage

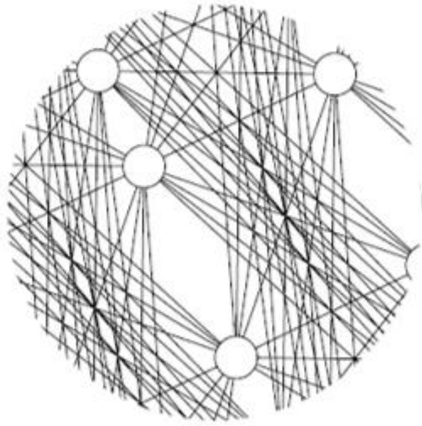
Exploring Exoplanets

SPACE ECOLOGIES ART AND DESIGN

Opening Night
Monday July 29, 20.00 - ...

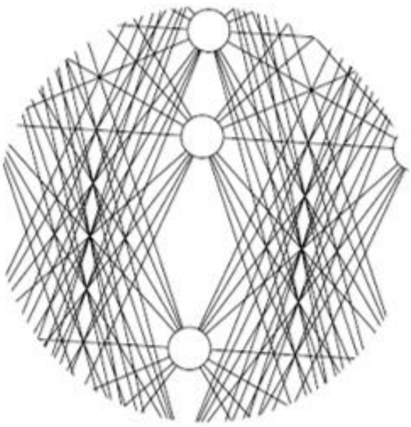
Astro Bodies - Kinesthetic Exercises
Tuesday 30 July, 10.00 - 12.00

Exoplanet Data Visualization Workshop
Tuesday 30 July, 13.00 - 16.30



SciFi and the cosmos:
Exoplanets, Games and Cinema
Tuesday 30 July, 19.00 - 20.30

Exoplanet Explorers: Hands-On Learning
Wednesday 31 July, 10.00 - 12.00



Galactic Games:
A Space-Themed Board Game Experience
Wednesday 31 July, 14.00 - 17.00

Habitat in Peril - A Role Playing Game
Thursday 01 August, 13.00 - 18.00

Improv Comedy Copenhagen
Thursday 01 August, 19.00 - 20.30

CARLSBERG FOUNDATION

MARIE CURIE ACTIONS

The whole week: Exploring Exoplanets

You are warmly invited to join us at ***Huset Copenhagen****, just a few minutes away from the conference venue, for an exhibition and activities supporting the conference.

The exhibition includes portraits, textile designs, photographs, and video installations related to exoplanet research. Engage in guided meditation sessions, Improv Comedy Copenhagen, data visualization workshops, an interactive role-playing afternoon, and educational activities for kids on Wednesday morning.

The exhibition and interventions feature researchers from the CHAMELEON network alongside Danish astronomer-artist Jo Verwohlt, space biologist and artist Angelo Vermeulen, and others, developed with support from the SEADS (Space Ecologies Art and Design) network and Theater Neumarkt.

This event showcases the transdisciplinary research of the CHAMELEON network, with a significant focus on the art and science research by Pieter Steyaert. It also includes contributions inspired by the educational research of Oriel Marshall. Organized by Pieter Steyaert, with help from Supervisors Anja Andersen, Jesper Bruun, Katrien Kolenberg, and PhD candidates Oriel Marshall and Sven Kiefer.

We look forward to welcoming you to this inspiring event. All activities are free but require reservation via this website.

www.exploringexoplanets.eu

***Huset, Xenon,**
Rådhusstræde 13, 1466 KBH K

Abstracts of Posters on Display the Whole Week:

Amy Bonsor: Cosmochemical-style insights for exoplanetary systems

Beatriz C. Estrada, J.E. Owen, M. Jankovic, A. Wilson & Ch. Helling: Constraining small planet compositions with catastrophically evaporating rocky planets

Brian Thorsbro: Using C/O ratio of WASP-121 b to investigate planet formation theories

Christiane Helling, H. Lecoq-Molinos, N. Bach-Møller, S. Kiefer & L. Carone: From high- to low-energy chemistry in exoplanet atmospheres

Eftychia Symeonidou, U.G. Jørgensen, M.B. Madsen & A. Priemé: Effects of temperature, chloride and perchlorate salts on the metabolic activity of *Deinococcus radiodurans*

Flavia Amadio, A. D'Alessandro, U.G. Jørgensen, L. Decin: WASP-43 b dayside: a case study with MSG + syntos

Hideaki Fujiwara: Mid-Infrared Observations of Warm Debris Disks

Jhon Y. Galarza, T. Ferreira, D. Lorenzo-Oliveira and H. Reggiani: Exploring the Origin of the Solar Chemical Anomalies with Planet-Hosting Solar-Type Stars

Johan Rahnberg-Andersen: Identification and characterization of the chlorophyll c synthase and the evolutionary implications for marine algae

Jonas M. Fernbach: Genetic Linguistics: Deciphering the Genetic Code through Natural Language Paradigms

Josefine E. Melchior: The ESA ExoMars Rover Mission

Julie N. Nováková & Peter Vickers: Testing Uncertainty in Astrobiology Communication: An Experimental Approach

Linus Heinke: Fully Leveraging Current Space-based Transmission Spectroscopy - Characterization of the Warm Sub-Saturn HAT-P-12b Using HST and JWST

Ludmilla Carone: From CO_2- to H_2O-dominated atmospheres and back - Mixed outgassing on the TRAPPIST-1 planets

Nanna Bach-Møller et al.: Stellar Storms and Cosmic Rays: Exploring Exoplanet Chemistry in Extreme Environments

Nicholas Borsato: The Limi1ng Factor: Decoding the Extreme Atmospheric Dynamics of the Ultra-hot Jupiter KELT-9b

Oliver Herbort: Nutrient availability constraining habitability in atmospheres of rocky exoplanets

Ruth-Sophie Taubner, C. Helling & CHAMELEON: Virtual Laboratories for Exoplanets and Planet-Forming Disk

Ryun-Young Kwon: An Introduction to Solar Flares and Coronal Mass Ejections: Their Influence on the Habitable Zone

Silja Rebecka Grentoft: Extraterrestrial life and how it has been affected by its environment

Sungwook E. Hong, R. Gobat, O. Snaith & S. Hong: Panspermia in a Milky Way-like Galaxy

Thorsten Balduin et al.: Dust grain charging in protoplanetary disks

Till Kaeufer: DuCKLinG: Interpreting JWST/MIRI spectra of protoplanetary disks

Uffe Graae Jørgensen et al.: Self-consistent MSG (sub-)stellar and exoplanetary model atmospheres

Varuna Deopersad: Estimating detectability of phosphine in the Venusian atmosphere using spectral modeling

Viktor Sparrman, M.J. Way & S. Bladh: Multiple Habitable Phases on Outer Exosolar Worlds

Amy Bonsor: Cosmochemical-style insights for exoplanetary systems

We live in an epoch of rocky exoplanet discovery. Yet characterising the interior of these planets remains hard. If we are to truly know what it is like on the surface of these planets or understand their habitability, we need to know what they are made from. The composition of host-stars provides crucial insights - but how does planet formation alter the compositions of exoplanets? By characterising the abundances of planetary material in the atmosphere of a white dwarf with a main-sequence companion, this work provides observations of both planet and host-star compositions. Cosmochemical-style insights are possible for exoplanetary systems. These observations tell us how planet formation altered planetary abundances, in particular quantifying the loss of volatiles. Insights from white dwarf - main-sequence wide binary systems will aid future characterisation of rocky planet interiors based on host-star compositions.

Beatriz C. Estrada, J.E. Owen, M. Jankovic, A. Wilson & Ch. Helling: Constraining small planet compositions with catastrophically evaporating rocky planets

The nature and composition of small planets' interiors remain uncertain. Catastrophically evaporating rocky planets provide a unique opportunity to study the composition of small planets. The surface composition of these planets can be constrained via modelling their comet-like tails of dust. In this work we present a new self-consistent model of the dusty tails. We model two catastrophically evaporating planets: KIC 1255 b and K2-22 b. For both planets we find the dust is likely composed of magnesium-iron silicates (olivine and pyroxene), consistent with an Earth-like composition.

Brian Thorsbro: Using C/O ratio of WASP-121 b to investigate planet formation theories

The carbon-to-oxygen (C/O) ratio of exoplanet atmospheres is considered an important diagnostic for constraining planet formation theories and has been the focus of theoretical investigations. Based on standard core accretion models of planet formation, gas giants that sweep up most of their atmospheres from disk gas outside of the water snowline will have a C/O ~ 1, while atmospheres significantly contaminated by evaporating planetesimals will have a stellar or substellar C/O ~ 0.5 when formed at the same disk radius. The C/O ratio qualitatively changes the appearance of exoplanet spectra, with high C/O ratios (> 1.0) leading to atmospheres richer in methane, HCN and hydrocarbons, while intermediate to low (< 0.8) C/O ratios result in atmospheres richer in oxides, including H_2O as well as TiO/VO. Ultra-hot Jupiters (UHJs) with dayside temperatures above 2500K, like WASP-121 b, are well-suited for the exploration of the C/O as the high temperatures simplify the chemistry, limiting the vast majority of the gas phase inventory to atoms and simple molecules.

We observed WASP-121 b with the CRIRES+ spectrograph on VLT and here shows our investigation using the diatomic molecular features available in the infrared H-band, which opens up possibilities not previously reported on.

Christiane Helling, H. Lecoq-Molinos, N. Bach-Møller, S. Kiefer & L. Carone: From high- to low-energy chemistry in exoplanet atmospheres

The chemical inventory of exoplanet atmospheres is driven by the host stars’ high-energy radiation, the stellar or galactic high-energy particles, and the local temperature gradients. Interpreting observational data from e.g. JWST, TESS, CHEOPS, and future missions like ARIEL, NEWATHENA, and HWO for planets that orbit different host stars necessitates a clear understanding of which chemical processes characterise which atmospheric regimes. Exoplanets are exposed to their host star's irradiation that affects in particular the upper atmosphere through photochemical and charge processes. High-energy galactic particles penetrate into the deeper atmosphere where they may trigger the formation of complex hydrocarbons. In the same atmosphere regions, metal oxide clusters like $(TiO_2)N$ or $(V_xO_y)N$ form increasingly more complex structures that may be detectable. Exoplanets, therefore, exhibit at least two chemically distinct ensembles of complex molecules, hydrocarbons and metal oxides. Both may trigger the formation of cloud particles. Surface processes then cause an efficient growth to macroscopic sizes in the intermediate atmosphere. This almost canonical picture of atmosphere chemistry regimes has only emerged very recently based on a combination of in-depth physical models and 3D GCMs. The validation of these models through observations requires spectral and chemical rate data which are only sparsely available from measurements.

Eftychia Symeonidou, U.G. Jørgensen, M.B. Madsen & A. Priemé: Effects of temperature, chloride and perchlorate salts on the metabolic activity of *Deinococcus radiodurans*

In the present work, we studied the combined effects of temperature and chlorine-containing salts on the extremophile bacterium *Deinococcus radiodurans* which can survive and sustain its activity at high levels of radiation and thus is considered an organism that might persist in extraterrestrial environments. Focus was given on the effects perchlorate salts which have been detected at high concentrations in Martian regolith. The metabolic activity (CO_2 production rates) and viability of *D. radiodura*ns were assessed after incubation in liquid cultures for up to 30 days. Reduced metabolic capacity and low viability was observed at high perchlorate concentrations (up to 10 % w/v) during incubation at 0 or 25°C while higher tolerance was observed for chlorides at the same temperatures. Both the metabolic activity and viability were reduced as the perchlorate and chloride salt concentration increased and temperature decreased, and an interactive effect of temperature and salt concentration on the metabolic activity was found.

Flavia Amadio, A. D'Alessandro, U.G. Jørgensen, L. Decin: WASP-43 b dayside: a case study with MSG + syntos

We present a case study of the hot Jupiter WASP-43b with a combination of the self-consistent 1D atmospheric code MSG (Jørgensen et al. 2024, submitted to A&A; arXiv 2407.09397)) and the synthetic spectrum generator *syntos*. We expand the work on the basic grid of MSG models through a detailed investigation of WASP-43b dayside properties and effects of irradiation. We work under the assumptions of equilibrium chemistry and no cloud coverage, including up to 50 line opacity sources from the ExoMol database (Tennyson et al., 2020). We study how the atmospheric structure and emergent spectrum are affected by different parameters: metallicity, C/O-ratio and TiO and VO opacities. Our simulations span a range of scenarios: we run models with and without TiO and VO; we explore metallicity values, from sub- to super-solar. We run models for C/O-ratio values in the interval 0.54 – 2.0 and discuss the possible degeneracies between the C/O ratio value and the presence of TiO and VO in the atmosphere. We discuss the possibility of a thermal inversion and how it relates to TiO, VO and C/O ratio. We compare our predicted spectra against observational data from HST/WFC3 (Kreidberg et al., 2014, Changeat et al. 2022) and JWST/MIRI (Bell et al. 2024). We find the observation to be in agreement with different models in different wavelength ranges.

Hideaki Fujiwara: Mid-Infrared Observations of Warm Debris Disks

Debris disks around main-sequence stars are expected to be related to the stability of minor bodies and potentially to the presence of planets around stars. Recent high-sensitivity observations in the midinfrared allow us to investigate the properties of warm dust grains in the inner regions of debris disks, which should have a more direct link to the formation of terrestrial planets than the low-temperature dust that has been previously studied. Here, we review the results of our mid-infrared survey of warm debris disks conducted with AKARI and follow-up spectroscopic observations of the AKARI-identified disks. We particularly focus on the mineralogical nature of these debris disks.

Jhon Y. Galarza, T. Ferreira, D. Lorenzo-Oliveira and H. Reggiani: Exploring the Origin of the Solar Chemical Anomalies with Planet-Hosting Solar-Type Stars

When comparing the Sun with the majority of solar-type stars, it exhibits a deficit of refractory elements (visualized as a negative slope in the condensation temperature of elements Tc versus abundance). The Sun is also unusually depleted in lithium (Li) relative to solar-type stars of the same age. These findings argue for the idea that the Sun is an oddball. One explanation is that the negative Tc-slope in the Sun arises as a result of planet formation in the solar system, as the refractory elements would be locked within them. Another possibility is that most solar-type stars may have engulfed their exoplanets, leading to an increase in refractory elements (positive Tc-slope). In this study, we determine the chemical composition of 200 planet-hosting solar-type stars using high-resolution (R=83,000-115,000) and signal-to-noise ratio (>300) spectra to understand the origin of the chemical anomalies observed in the Sun. We applied the differential technique to infer stellar parameters and chemical abundances of up to 30 elements, with a precision as high as 0.01 dex. In our preliminary results, we find that the Sun is deficient in refractory elements (negative Tc-slope) compared to ~70% of planet-hosting solar-type stars, which was already observed in stars without exoplanets. We found no correlation between the Tc-slopes and exoplanetary masses in the systems (from super Earths to super Jupiters). Instead, we observed that metal-poor stars ([Fe/H]~-0.3 dex) exhibit positive refractory slopes, while metal-rich stars ([Fe/H]~+0.3 dex) exhibit negative slopes, indicating a correlation with metallicity. Our results also indicate that the Sun is similarly depleted in Li compared to solar-type stars, both with and without exoplanets. Therefore, exoplanets would not influence the Li content of stars as previously suggested. Additionally, recent studies suggest that the Sun is typical compared to other solar-type stars in terms of rotation and activity. With our findings on Li, it seems that the Sun is not entirely an oddball.

Johan Rahnberg-Andersen: Identification and characterization of the chlorophyll c synthase and the evolutionary implications for marine algae

Photosynthesis has shaped Earth and the conditions for life throughout eons. Pigments are molecules that captures light and tranduce the energy used in photosynthesis for splitting water and capturing CO_2. Oxygenic photosynthesis emerged in cyanobacteria ~ 3000 million years ago (Mya), and caused the great oxidation event. Following this event, photosynthetic lifestyles has adapted and evolved in eukaryotic organisms producing O_2 via water splitting leading to the oxygen rich atmosphere on present Earth. Eukaryotic photosynthesis has been enabled by the evolution of pigment biosynthetic enzymes establishing new pigments with novel spectral properties adopted by the eukaryotic photosynthetic machinery. This has supported the succes of phototrophic eukaryotes and their acclimation to ecosystems across the globe.

Jonas M. Fernbach: Genetic Linguistics: Deciphering the Genetic Code through Natural Language Paradigms

The Genetic Linguistics project tests the hypothesis that life’s genetic code may contain inherent grammatical and syntactical structures analogous to human language, aiming to decode and ‘communicate’ with genetics. We seek to uncover basic patterns in the genetic code to better understand and predict life’s complexity, and to investigate whether it is an emergent property of the genetic code or is influenced by additional, unknown factors. Our objective is to achieve comprehensive insights into genetic sequences, enabling holistic genome analysis and accurate phenotype predictions. This endeavour could significantly enhance our ability to predict genomic functions, phenotype outcomes, and facilitate the engineering of organisms with specific attributes, potentially transforming our predictive capabilities in genomic sciences.

Josefine E. Melchior: The ESA ExoMars Rover Mission – *Using chirality of molecules as a proxy to detect the onset of life on Mars*

The concept of chirality of a molecule can be used to determine if the molecule's origin is based on a biological process that we call life. One of the current endeavours to search for life is happening right now on the surface of Mars. Whether life or life-like biology was present on Mars is still subject to intensive current research. In the near future, ESA's ExoMars-Franklin rover is planned to carry the MOMA instrument suitable to detect the chiral property of molecules and thus contribute to the question of whether Mars once hosted life early on in its history. This review poster will describe ESA's ExoMars program, the MOMA instrument and what chirality means for life on Earth.

Julie N. Nováková & Peter Vickers: Testing Uncertainty in Astrobiology Communication: An Experimental Approach

Any discovery of extraterrestrial life, be it suspected microfossils, atmospheric biosignatures or other possible signs of life, will likely contain a lot of uncertainty that may persist for many years. How do we communicate this uncertainty in astrobiology to the publics and policy-makers without undermining the significance of the discovery? Evidence-based answers to this question and communication strategies stemming from them are sorely needed, but almost non-existent. Risk and uncertainty communication strategies do exist for various fields, but it's not clear to what extent their results are applicable to astrobiology with its specific timescales and types of evidence. This, together with recent calls for this type of work in astrobiology and ongoing analyses of existing astrobiology communication in the media, may serve as a strong basis upon which to build astrobiology-specific, evidence-backed recommendations. We are going to introduce an experimental approach to testing the effectiveness of different uncertainty communication strategies and the usefulness of several proposed astrobiological uncertainty evaluation frameworks in communication towards the publics and policy-makers. This work is important for making sure that astrobiology is perceived as serious science and for ensuring that potential ill-advised communication doesn't preclude support for projects that may carry a high risk of negative results, but also a potentially high gain in terms of science.

Linus Heinke: Fully Leveraging Current Space-based Transmission Spectroscopy - Characterization of the Warm Sub-Saturn HAT-P-12b Using HST and JWST

Transmission spectroscopy is a method for studying the composition and structure of exoplanetary atmospheres through the modification of their host star's light during transit. The resulting spectrum can be used to constrain the temperature structure, abundance of chemical species, and presence and properties of clouds and hazes. We can then use this information to make further deductions about the underlying processes that led to the observed spectrum, like the governing physical and chemical processes or even the formation conditions of the planet observed. To obtain reliable constraints we need precise and stable measurements over a broad wavelength range, including the near-and mid-infrared. Conditions not easily achievable from the ground, but only from space through the use of instruments like the Hubble Space Telescope (HST) and James Webb Space Telescope (JWST). HAT-P-12b is a warm sub-Saturn mass planet that could prove to be an important component in answering the question to which degree disequilibrium effects, i.e. mixing and photodissociation, govern the atmospheric chemistry within the wider exoplanet population. Transmission spectra using all feasible instrument modes of both HST and JWST have been obtained. This means we have a continuous transmission spectrum spanning from ~0.3-12 μm, the entire range currently accessible from space. We have conducted a detailed analysis of how the inclusion of the different transmission spectra affects the derived atmospheric properties. This does not only allow for the most precise atmospheric characterization of our target to date, but also provides a useful reference for optimizing observing strategies for future targets.

Ludmilla Carone: From CO_2- to H_2O-dominated atmospheres and back - Mixed outgassing on the TRAPPIST-1 planets

We investigated H_2O and CO_2 outgassing during the magma ocean stage on TRAPPIST-1 e, f and g that were subject to strong XUV flux during the first 100 Myrs of their evolution. We performed with VPLANET/MagmOc2.0 simulations with 1-100 terrestrial oceans (TO) H_2O with and without CO_2. The CO_2 mass was scaled with initial H_2O by a constant factor between 0.1 and 1. The magma ocean begins with a CO_2 -dominated atmosphere and evolves into an H_2O dominated atmosphere. For less than 10~TO initial H_2O, the atmosphere desiccates and the evolution ends with a CO_2 dominated atmosphere. Otherwise, the final state is a thick >1000 bar H_2O - CO_2 atmosphere. Feedback between H_2O and CO_2 increases H_2O outgassing and reduces CO_2 outgassing. Consequently, abiotic O2 build-up and H_2O partitioning in the mantle are increased by 10\% to 50\%. Eventually, 3% to 6 % of the initial water is retained. The magma ocean lifetime is only significantly extended with CO_2 for TRAPPIST-1e with 10~TO initial H_2O. Here, atmospheric escape alters the atmosphere's composition and consequently its radiative properties slowly enough to delay solidification. The prolongation of the magma ocean stage results in higher O_2 sequestration in the mantle, suppressing atmospheric O_2 accumulation, and culminates in a minimum relative water fraction in the mantle. Our compositional model adjusted for the measured metallicity of TRAPPIST-1 yields for the dry inner planets (b, c, d) an iron fraction of 25 wt%. For TRAPPIST-e, this iron fraction would be compatible with a desiccated evolution scenario and a CO_2 atmosphere with surface pressures > 100 bar. Thus, a comparative study between TRAPPIST-1e and g and the inner planets may yield the most insights about formation and evolution scenarios by confronting, respectively, a scenario with desiccated evolution to a volatile-rich scenario to a scenario with volatile-poor formation.

Nanna Bach-Møller et al.: Stellar Storms and Cosmic Rays: Exploring Exoplanet Chemistry in Extreme Environments

Since the discovery of exoplanets, we have been aware that planets can exist in environments dramatically different from the Solar System. One such difference is the amount and type of high-energy radiation reaching the planet. On Earth we know that high-energy radiation can have significant, and sometimes unforeseen, eifects on the atmosphere through processes such as photo-chemical reactions, and ionisation of the upper atmosphere. In order to understand and analyse the chemistry of exoplanet atmospheres, it is therefore crucial to understand the eifect of the radiative environment on the atmosphere. In this talk, I address some of the eifects high-energy radiative environments can have on the complex chemistry of exoplanet atmospheres. This study focuses on two sources of high-energy radiation: 1) the host star, through XUV radiation and stellar energetic particles (SEPs), and 2) the galactic environment through galactic cosmic rays (GCRs). We model the eifect of these radiation sources on the disequilibrium chemistry of a hot-Jupiter using the 1D photo-chemistry and diifusion code, ARGO, in combination with the chemical kinetic network, STAND2020. STAND2020 excels by its complexity in H/C/N/O chemistry, which allows us to study the eifect of the irradiation on larger complex molecules. We present a grid of models run for host stars of the seven main sequence spectral types, under influxes of GCRs ranging from highly shielded systems with no GCRs, to highly exposed systems with GCR fluxes estimated for high-energy environments in the galaxy. This grid over radiative environments allows us an insight into the eifects of high-energy radiation on atmospheric chemistry, and can help guide our analysis of exoplanet atmosphere observations based on the host star and the environment the system is located in. This might be especially interesting for future missions such as PLATO, that focuses on diiferent exoplanet host stars, and HWO, that will study the habitability of exoplanets, and it might also be interesting in relation to missions such as Athena, that is set to focus on the high-energy environments in galaxies and our universe as a whole.

Nicholas Borsato: The Limi1ng Factor: Decoding the Extreme Atmospheric Dynamics of the Ultra-hot Jupiter KELT-9b

Ultra-hot Jupiters (UHJs) are an extreme form of exoplanet with equilibrium temperatures over 2000 K and are completely inhospitable to life as we know it. KELT-9b, the hottest of this class, maintains a temperature higher than most stars (Eq ~ 4000 K). The extreme nature of UHJs rules them out as targets for habitability studies; their atmospheres are largely atomic, and their proximity to their host stars drives wind speeds to the order of tens of km/s. However, their characteritics do hold one distinct advantage: they are easier to observe and characterise than other exoplanets. Ultra-hot Jupiters, like KELT-9b, can act as laboratories for observtional techniques, enabling us to hone our observational abilities, while also providing insights into planetary evolution, formation, and characterisation. Our research focuses on characterising the atmospheric dynamics of KELT-9b using the crosscorrelation technique. With 13 transits observed using high-resolution spectrographs across 7 observing facilities, we detected 38 atomic and ionised species in the planet's atmosphere. We found a large diversity in the measured velocities of these detections, with considerable offsets from the true planetary velocity. We use these results, in conjunction with theoretical predictions about UHJ atmospheres, to infer that each detection occurs in different regions of the atmosphere. In effect, each species becomes a probe to map the dynamical characteristics of KELT-9b’s inflated and extensive atmosphere. Our findings demonstrate that the cross-correlation technique can probe different regions of an exoplanet's atmosphere and decode the dynamic mechanisms at play. The refined methods and subsequent successes we have achieved in this study are highly transferable in observing the more challenging habitability candidates.

Oliver Herbort: Nutrient availability constraining habitability in atmospheres of rocky exoplanets

The diversity of exoplanets provides a vast range of potential environments in which liquid water can exist: atmospheres, surfaces, sub-surfaces. Therefore, many environments provide the most fundamental requirement for life as we know it from Earth and could in principle be habitable. However, the presence of water is not the only necessity for life to form, especially the presence of nutrients (C, H, N, O, P, and S) is crucial for the formation of life as we know it. In order to further understand and constrain potentially habitable environments of diverse planets, we introduce the concept of nutrient availability to constrain the habitability of a planet. This framework is based on the concentrations of nutrient bearing molecules in the condensate and gas phase in the presence of liquid water.

Applying this concept to a diverse set of atmospheres allows to provide constraints on the potential of surface and aerial biospheres. The atmospheric model used is a bottom-to-top equilibrium chemistry model, which includes cloud formation. In order to cover the range of different atmospheric compositions, we investigate various different sets of element abundances and surface conditions.

We find that reduced forms of C, N, and S are commonly found at the water cloud base for a range of different compositions of the planetary surface and atmosphere - even in overall oxidised atmospheres. In our model atmospheres, the only non-CHNOS elements in the atmosphere in the surrounding of liquid water clouds are F and Cl, which are present in the form of HF and HCl. Although the CHNOS elements are present, the absence of P and metals in the atmospheres could be a limiting factor on the formation and evolution of life in aerial biospheres.

Ruth-Sophie Taubner, Ch. Helling & CHAMELEON: Virtual Laboratories for Exoplanets and Planet-Forming Disk

CHAMELEON was a Marie Curie Innovative Training Network (MC-ITN) focusing on the development of so-called virtual laboratories for the field of exoplanet atmospheres and protoplanetary disks. These virtual laboratories play a key role in simulating so far unexplored physico-chemical environments and help to analyse in detail current and future disk and exoplanet observations. A main aim was also the knowledge transfer from the planet to the disk community concerning the simulation of chemical processes in warm and dense environments, electrification, and lightning. Further, the CHAMELEON scientific topics have been included as scientific hook for the artworks by artists using various media and translated into teaching materials. The three major objectives of this network were:

• **Scientific**: Retrieve and predict the chemical composition of planet-forming disks and exoplanet atmospheres.

• **Technological**: Knowledge transfer between planet and disk community by the exchange of state-of-the-art codes. Apply and develop models of different complexity as link between big observational and numerical modelling data. Explore models as Virtual Laboratories for parameter spaces that cannot be reached by observations nor by (laboratory) experiments.

• **Educational**: Train complex modelling and big-data interpretation. Use fascination for exoplanets and their birthplaces to promote science in the society and in the local and wider communities due to dedicated art & education and art & science projects.

We will give a short overview of different projects and activities realised within the CHAMELEON network, and highlight the main outcomes. CHAMELEON MC-ITN was funded by the European Union’s Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant No 860470. The project started in June 2020 and was finished in May 2024. CHAMELEON included 15 PhD students and more than eleven supervisors from seven European research institutions under the lead of the University of St. Andrews and the Austrian Academy of Sciences.

Ryun-Young Kwon: An Introduction to Solar Flares and Coronal Mass Ejections: Their Influence on the Habitable Zone

In the exploration of habitable worlds and astrobiology, we often encounter terminologies related to solar activities, such as flares and coronal mass ejections. The host start's long- and short-term variations inherently create diverse near-planet space environments. In particular, explosive activities of the host star, such as flares and coronal mass ejections, are responsible for the short-term changes in the near-planet space environment and thus lead to alteration in determining the habitable zone in the planetary system. The Sun, the only star known to harbor life and the closest to us, allows for direct observation and study of stellar explosive phenomena and their interactions with planetary atmospheres. This presentation aims to impart knowledge on the solar explosive events and their role in changes in the space environment to the extraterrestrial life communities. We will present remote-sensing and in-situ observations of solar flares, coronal mass ejections, and related phenomena and introduce debates and changes in the interpretations. Through this presentation, we hope to contribute to a better understanding of solar explosive phenomena and related terminology when studying habitable zones and the origin and evolution of life within our communities.

Silja Rebecka Grentoft: Extraterrestrial life and how it has been affected by its environment

This is a review-poster focusing on the question “What kind of life would be shaped under different circumstances than those on Earth?”

Evolution on Earth has been shaped by the history of the planet and impacted the evolution of life on Earth. Extraterrestrial life could evolve and be affected similarly, though in different ways, by the environment and events on the exoplanets in question. One possibility of exploring this is looking at the extremophiles on Earth, as they thrive in environments considered unhospitable, just like the exoplanets. Environmental factors such as oceans, availability of certain chemicals, and light all have a profound effect on which microbial life can exist there and which adaptations or effects these could lead to when larger organisms have adapted under these circumstances.

Sungwook E. Hong, R. Gobat, O. Snaith & S. Hong: Panspermia in a Milky Way-like Galaxy

We study the process of panspermia in Milky Way-like galaxies by modeling the probability of successful travel of organic compounds between stars harboring potentially habitable planets. To this end, we apply the modified habitability recipe of Gobat & Hong (2016) to a model galaxy from the MUGS suite of zoom-in cosmological simulations. We find that, unlike habitability, which only occupies narrow dynamic range over the entire galaxy, the panspermia probability can vary be orders of magnitude between the inner (R, b = 1~4 kpc) and outer disk. However, only a small fraction of star particles has very large values of panspermia probability and, consequently, the fraction of star particles where the panspermia process is more effective than prebiotic evolution is much lower than from naïve expectations based on the ratio between panspermia probability and natural habitability.

Thorsten Balduin, P. Woitke, U. G. Jørgensen, W.-F. Thi and Y. Narita: Dust grain charging in protoplanetary disks

Lightning can have a profound impact on the chemistry of planetary atmospheres. In a similar manner, the emergence of lightning in protoplanetary disks can substantially alter their chemistry.

We aim to study under which conditions lightning could emerge within protoplanetary disks.

We employed the PRODIMO code to make 2D thermo-chemical models of protoplanetary disks. We included a new way of how the code handles dust grains, which allows the consideration of dust grains of different sizes.

We identify six regions within the disks where the charge balance is dominated by different radiation processes and find that the emergence of lightning is most probable in the lower and warmer regions of the midplane. We developed a method of inducing electric fields via turbulence within this mix of dust grains and NH_4+. The electric fields generated with this mechanism are however several orders of magnitude weaker than required to overcome the critical electric field.

We also show some first findings on a preliminary implementation of triboelectric charging into the PRODIMO code.

Till Kaeufer: DuCKLinG: Interpreting JWST/MIRI spectra of protoplanetary disks

The MIRI instrument on board JWST probes the chemistry of the inner regions of protoplanetary disks. Recent efforts to analyse these data used manual continuum subtraction and an iterative fitting of simple 0D slab models, which makes the interpretation of the retrieved properties challenging. We created a 1D protoplanetary disk model called DuCKLinG (Dust Continuum Kit with Line emission from Gas) that describes the molecular line emission and the dust continuum simultaneously without large computational cost. This allows for a full Bayesian analysis of the data without the need for a continuum subtraction or iterative fitting procedures. In this talk, I introduce the model and show analyses of the JWST/MIRI spectra for a T-Tauri disk and a very low-mass star to showcase the strength of this modelling approach.

U.G. Jørgensen, F. Amadio, B. Campos Estrada, K.H. Møller, A.D. Schneider, T. Balduin, A. D'Alessandro, E. Symeonidou, Ch. Helling, Å. Nordlund, P. Woitke: Self-consistent MSG (sub-)stellar and exoplanetary model atmospheres

We present an extension of the classical MARCS grid (Gustafsson et al. 2008, A&A 486, 951) of stellar atmosphere models to temperatures from T_{eff} = 3000 K down to 300 K, hereby including the temperature range of the coolest stars, sub-stellar objects of type M, L, T, and Y, as well as exoplanets in the temperature range from ultra-hot jupiters to Earth-like exoplanets.

The new code is a self-consistent merging of an update version of the classical MARCS code with updated input data and iterative calls to the cloud formation code Static-Weather (Helling & Woitke 2006, A&A 455, 325) and the chemical equilibrium code GGchem (Woitke et al. 2018, A&A 614, A1), hence the name MSG.

The basic grid of MSG models is described in Jørgensen et al. (2024; submitted to A&A; arXiv 2407.09397). Details about the cloud formation part of the code can be found in the paper by Campos Estrada et al (2024; submitted to A&A), and further work on the irradiated MSG models are presented in the poster by Amadio et al. at the present conference. Work on the non-equilibrium part of the code, as well as several other improvements and applications, are in progress.

Varuna Deopersad: Estimating detectability of phosphine in the Venusian atmosphere using spectral modeling

This study aims to determine if phosphine is detectable in the atmosphere of Venus and at what spectral wavelengths this may be possible. Phosphine is considered a biosignature, and its presence may imply the existence of life on Venus. The quantity of phosphine present in the atmosphere of Venus is a controversial subject and has been investigated using various in situ and Earth-based measuring devices. Due to disagreement in past research concerning detected concentrations of phosphine, further research into the possible detectability of phosphine on Venus is warranted. In this project, version 19 of the PHOENIX spectra modeling software is used to create synthetic spectra of the Venusian atmosphere. Physical parameters (temperature stratification, pressure stratification, atomic lines, molecular lines, continuum cross-section and irradiation) of the Venusian atmosphere and its environment are input into the model. The concentration of phosphine is manipulated and the synthetic spectral output produced is observed. In a synthetic atmosphere with 20ppb of phosphine the chemical can be detected at ~1.123045×107 Å (~266.95 GHz) which agrees with empirical telescopic observations. Phosphine may also be detected at ~1.134055×107 Å (~264.35 GHz) and ~ 1.367335×107 Å (~219.25GHz). The latter will potentially provide the strongest signal and can be investigated further by telescopes assuming that there are not many sources of noise at this wavelength.

Viktor Sparrman, M.J. Way & S. Bladh: Multiple Habitable Phases on Outer Exosolar Worlds

As stars evolve to higher luminosities during first ascension of the giant branch, previously frozen terrestrial worlds may thaw and host liquid water on their surfaces. Eventually these outer worlds again become uninhabitable due to receiving too much incident light and their water inventory evaporating. Solar-mass stars experience a sudden decrease in luminosity entering the horizontal branch which could result in a secondary habitable phase for their outer worlds. The outer worlds' time with habitable surface climates is key in evaluating the possibility of extra-terrestrial life arising. The times inside the habitable zone are calculated for outer worlds orbiting between 5 and 45 AU around a Sun-like star. By comparing the time inside the habitable zone to time estimates for life to arise on Earth we evaluate whether such outer worlds are promising candidates in the search for extra-terrestrial life. We use two different solar evolution models (PARSEC and Dartmouth) and both optimistic and conservative habitable zone definitions. Multiple habitable phases are found for each outer world. Outer worlds with orbits as large as Saturn are found to have a secondary habitable phase which exceeds the first in duration. Generally, the time inside the habitable zone is found to decrease almost monotonically with orbiting distance. Water-loss is calculated after the first habitable phase to determine whether a secondary habitable phase is possible. For all orbiting distances the water-loss is insufficient to deplete a water inventory equivalent to that of many moons in the outer solar system.

Support from the following foundations and institutions made this conference possible and is gratefully acknowledged:

CELS
CENTRE FOR EXOLIFE SCIENCES

UNIVERSITY OF COPENHAGEN

Niels Bohr Institute Foundation

CARLSBERG FOUNDATION

CHAMELEON
Curie Innovative Training Network for European Joint Doctorates

novo nordisk foundation
Benefitting people and society