LEVERHULME CENTRE FOR LIFE IN THE UNIVERSE

LCLU Annual Science Day 2025

Robinson College
Crausaz Wordsworth Building, Cambridge
Friday, 21 March

All talks and presentations will take place at Robinson College, Crausaz Wordsworth Building

Programme

UNIVERSITY OF CAMBRIDGE

LEVERHULME TRUST

PROGRAMME

Venue: *Robinson College, Crausaz Wordsworth Building*

9:00 - 10:00 Registration & Coffee
Welcome to Annual Science Day 2025

10:05 - 10:35 Keynote speech by **Tim Lewens**
Universal Darwinism Revisited

Session I: Significance of life (10:35 – 10:50)

10:35 - 10:50 **Frederick Simmons (Divinity)**
The Scientific and Metaphysical Significance of Abiogenetic Bias

Session II: Chasing life from afar (10:50 – 11:05 / 12:00 - 12:45)

10:50 - 11:05 **Clark Baker (Cavendish Astrophysics)**
HARVY: A Highly-repeatable Autonomous extreme-precision Radial Velocity facilitY

11:05 – 12:00 **Break:** Coffee, poster presentations

12:00 - 12:15 **Edouard Barrier (Institute of Astronomy)**
Atmospheric dynamics and climates of sub-Neptunes

12:15 - 12:30 **Tereza Constantinou (Institute of Astronomy)**
Comparative Biosignatures

12:30 - 12:45 **William McMahon (Department of Earth Sciences)**
Terrestrial silicate weathering and the emergence of land plants

12:45 - 14:00 **Break:** Lunch, poster presentations

14:00 – 14:30 Keynote speech by **Alex Archibald**
What can we learn from bio-signatures on Earth about life in the Universe?

Session III: Boom Boom Pow! Seeding and melting worlds (14:30– 15:30)

14:30 - 14:45 **Joshua Shea (Department of Earth Sciences)**
Mantle melting on Mars with applications for sample return

14:45 - 15:00 **Tuhin Ghosh (Institute of Astronomy)**
Giant impact ejecta driving enhanced atmospheric loss

15:00 - 15:15 **Ross Findlay (Department of Earth Sciences)**
Is there a comet hiding in our meteorite collections?

15:15 - 15:30 **Catriona McDonald (Institute of Astronomy)**
Determining the efficiency of volatile delivery via cometary impacts

15:30 - 16:00 **Break:** Coffee, poster presentations

Session IV: From Atoms to Organisms (16:00 - 18:00)

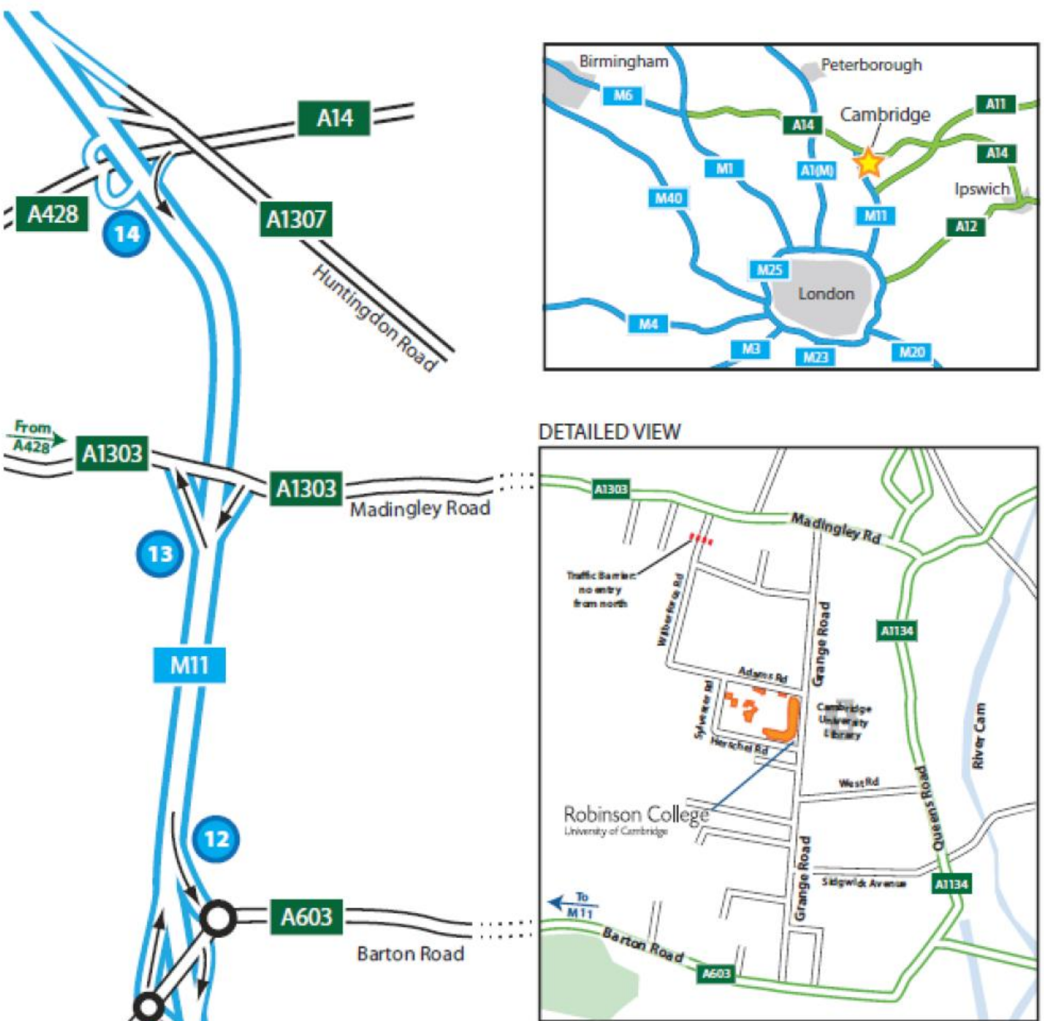
16:00 - 16:15	**Princess Buma-at (Zoology)** Morphometric analyses of Charniodiscus from the Ediacaran of Newfoundland, Canada
16:15 - 16:30	**Sai Shruthi Murali (Institute of Astronomy)** Investigation of Stability of HCN Under Wide Range of Geochemical Conditions
16:30 - 16:45	**Ziwei Liu (Department of Earth Sciences)** Fractionation of Carbon Isotopes in Carboxysulfitic Chemistry
16:45 - 17:00	**Euan Furness (Zoology)** Invaders in the Garden of Ediacara: the evolution of the first predatory ecologies
17:00 - 17:15	**S. Furkan Ozturk (Physics)** Origin of Life's Homochirality: From Magnetic Minerals to a Homochiral Genome
17:15 - 17:30	**Jose Devienne (Physics)** You spin me round – Exchange-driven reorientation of magnetic states in magnetite by chiral molecules and (potential) implications for the origin of life

17:30 - 17:45	**Summary EGM**
17:45 - 18:00	Closing remarks, prizes, followed by reception

*For any questions and enquiries, please contact LCLU Admin: admin@lclu.cam.ac.uk

Directions to venue

Please ensure that you enter the Robinson College Campus from **Adams Road Entry Point** and **not** the Porter’s lodge.



How to find us - by road from the M11

1. Exit at Junction 12 onto the A603 Barton Road
2. Follow signs for Cambridge along Barton Rd
3. Less than half a mile after entering the city turn left onto Grange Road
4. Half a mile on the left is the College
(distinctive red brick building, opposite the library tower)

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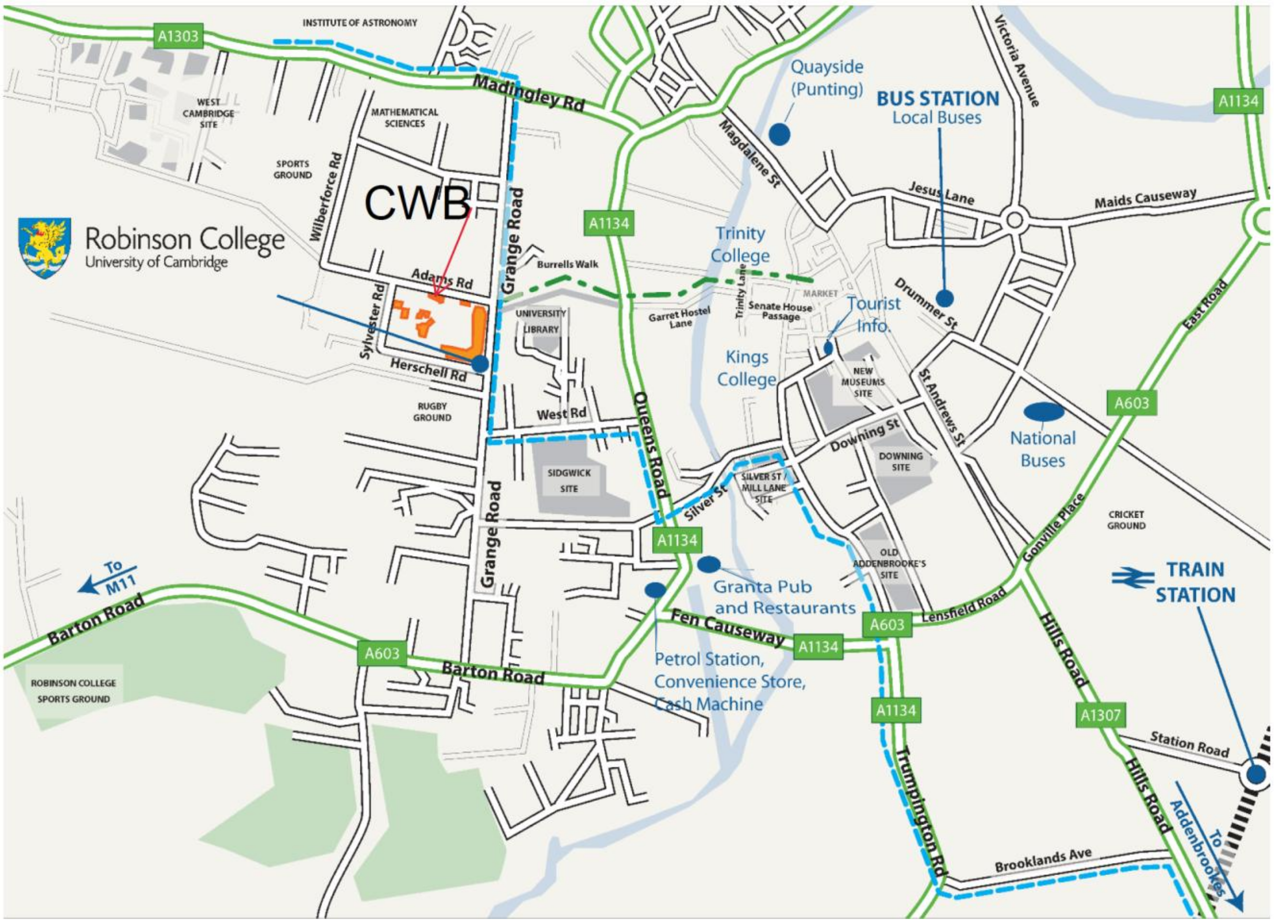
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MARKET
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College
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Downing St
DOWNING SITE
Silver St
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OLD ADDENBROOKE'S SITE
BUS STATION
Local Buses
Victoria Avenue
Jesus Lane
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Drummer St
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Buses
A1134
East Road
A603
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CRICKET GROUND
TRAIN
STATION
Lensfield Road
Hills Road
A1307
Station Road
To Addenbrookes
Brooklands Ave
Trumpington Rd
A1134
A603
Fen Causeway
Granta Pub
and Restaurants
Petrol Station,
Convenience Store,
Cash Machine
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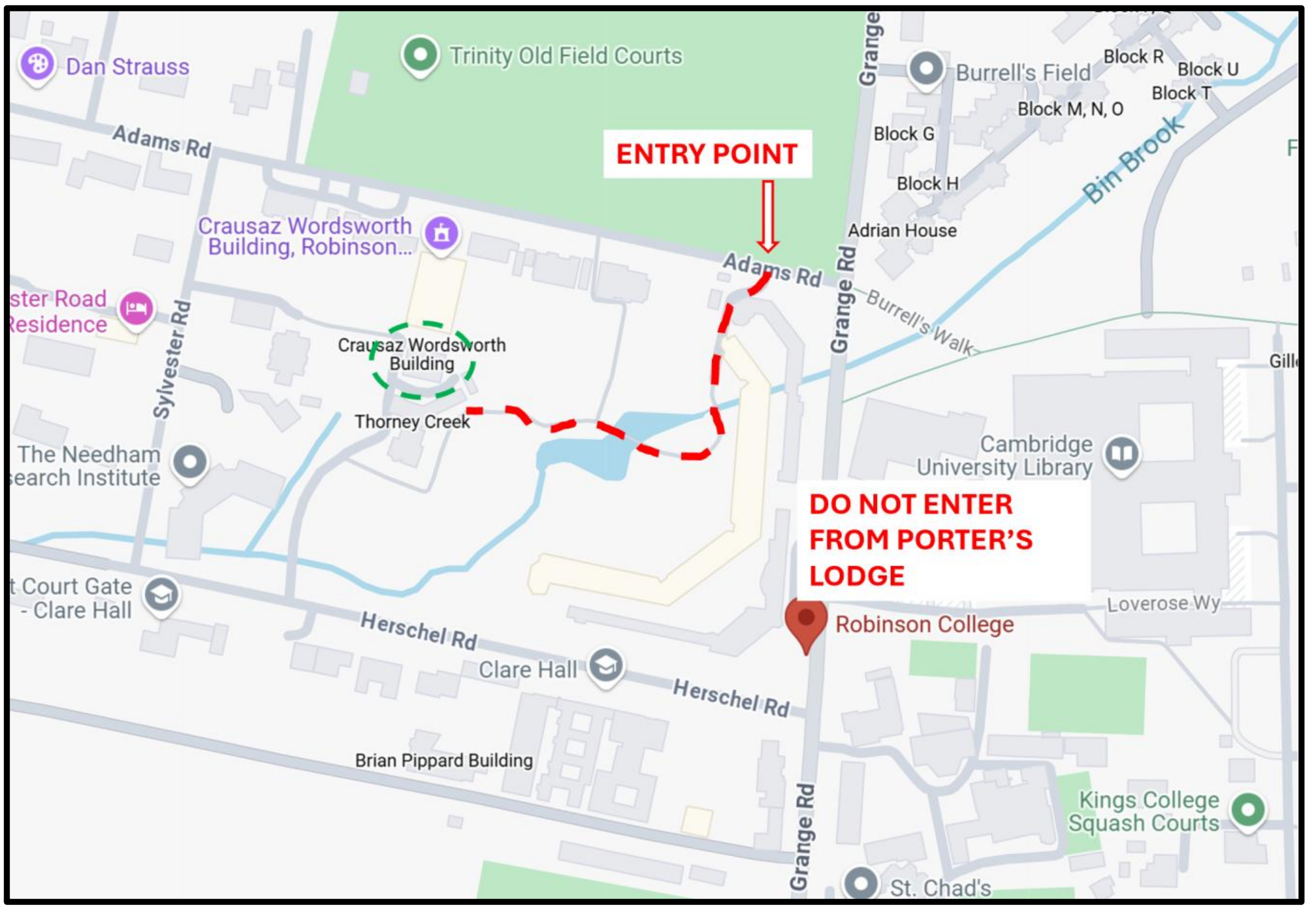
To M11
ROBINSON COLLEGE SPORTS GROUND



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Crausaz Wordsworth Building, Robinson...
Trinity Old Field Courts
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Burrell's Field
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Block U
Block T
Block M, N, O
Block G
Block H
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ABSTRACTS SUBMITTED FOR TALKS

(In order of presentation)

1. **The Scientific and Metaphysical Significance of Abiogenetic Bias**

Frederick Simmons

Abstract

If life arose simply by chance, there would be no reason to undertake origins of life research. Yet life's extraordinary complexity is not a sufficient reason to doubt that life arose simply by chance, since the extraordinary complexity of many things provides no reason to doubt that they arose simply by chance. Instead, other reasons are necessary, perhaps that life is self-constructing, self-maintaining, and self-replicating; has low entropy; diversifies and complexifies; has well-being; and contributes to the well-being of other life through the loss of its own. However, if there is no merely naturalistic reason to think that nature is biased towards the emergence of any of these features—and there seems to be no such reason—then a merely naturalistic reason to doubt that life arose simply by chance remains to be found. Conversely, there are obvious supernatural reasons to think that nature is biased towards the emergence of life's special features, namely, that a supernatural agent values these features and so biased nature abiogenetically. Hence, if origins of life research finds that nature is abiogenetically biased, it will support the teleological argument that the existence of something special that seems unlikely to arise simply by chance is evidence of purpose. Admittedly, science has undercut teleological arguments that insert a supernatural cause among natural causes. Nevertheless, teleological arguments that attribute the character of natural causes to a supernatural cause can support science. Still, because teleological arguments are inductive, they cannot demonstrate purpose—whatever origins of life research may find.

2. **HARVY. A Highly-repeatable Autonomous extreme-precision Radial Velocity facility** concept for RV follow-up and intensive search for ‘Earth-twin’, low-mass, long-period planets around main-sequence stars

Clark Baker

Abstract

The radial velocity technique is currently the only method mature enough to aim to detect Earth-like planets around nearby stars (without relying on the uncommon geometry of a transit). However, a systematic survey for Earth-twin planets will need to account for the limitation in measurement accuracy arising from the stellar variability of the stars around which the planets orbit; often an order of magnitude larger than the signals of small temperate rocky planets.

The Terra Hunting Experiment survey, led by Cambridge, is addressing this problem at face value by combining continual access to an observing facility and comprehensive analysis of the long series of observations (over a decade) with a spectrograph optimised for high precision radial velocity measurements (HARPS3). The drawback for such an intensive operation, is that the survey is limited to ~30 stars.

The HARVY instrument concept is a new development, building on 30 years of development in stabilised spectrographs, but designed to be deployed at low-cost, in series and installed on a network of 1.5m telescopes (approximately 10) enabling systematic survey of hundreds of Sun-like stars.

HARVY’s design relies on the high throughput of the entire system, with its efficiency tuned for optimised observation of Sun-like stars, enabling observations comparable to 2.5m telescope facilities through the use of newly developed components and design approaches.

Here we present our work towards the final HARVY optical design as we investigate the performances of new component approaches.

3. **Atmospheric Characterisation of Temperate Exoplanets using Ground-based High-resolution Spectroscopy**

Connor Cheverall

Abstract

Exoplanetary science has entered an exciting new age of studying lower-mass exoplanets, with atmospheric characterization emerging as the frontier of this revolution. Whilst JWST has dominated the spotlight in recent years, high-resolution spectrographs on large ground-based telescopes are powerful tools with significant scientific potential. Ground-based high-resolution spectroscopy is the natural complement to lower-resolution space-based observations, with the ability to resolve transmission spectra into individual spectral lines and break the degeneracy associated with broad and overlapping molecular bands. This allows for chemical detections with increased confidence, and offers unparalleled opportunities to probe the atmospheres of temperate, cloudy planets in the habitable zones of their host stars. However, ground-based observations have been complicated and limited by the Earth's own atmospheric absorption, particularly in the near-infrared. Despite this, in this work we demonstrate the feasibility of using ground-based high-resolution transmission spectroscopy to characterise the atmospheres of small and temperate exoplanets. Using simulations of temperate sub-Neptunes, we show that planetary signals may be recovered, allowing us to place precise constraints on the atmospheric chemical abundances of various molecular species, the cloud/haze deck pressure of the atmosphere, and the atmospheric temperature and dynamics for small and temperate planets. This work therefore ignites a new era in the characterisation of potentially habitable sub-Neptune worlds with ground-based facilities.

4. **Atmospheric dynamics and climates of sub-Neptunes**

Edouard Barrier

Abstract

Atmospheric characterisation of temperate sub-Neptunes is the new frontier of exoplanetary science with recent JWST observations of K2-18 b. Accurate modelling of atmospheric processes is essential to interpreting high-precision spectroscopic data given the wide range of possible conditions in the sub-Neptune regime, including on potentially habitable planets. 3D General Circulation Models (GCMs) can provide the sophistication to model fully self-consistent atmospheres, but care needs to be taken with their modelling of complex physical effects. Notably, convection is an important process which can operate in several very different modes across sub-Neptune conditions. We develop a new mass-flux scheme which can capture these variations and simulate convection over a wide range of parameter space for use in 3D general circulation models (GCMs). We first perform an initial validation where we show that the convection model performs near-identically to Earth-tuned models in an Earth-like TRAPPIST-1 e convection case. We then perform simulations of a mini-Neptune atmosphere. Assuming the bulk properties of K2-18 b with a deep H2 - rich atmosphere, we demonstrate the capability of the scheme to reproduce non-condensing convection. We find convection occurring at pressures above 0.3 bar and the dynamical structure shows high-latitude prograde jets. We discuss the dynamical structure and the effect of convection on the wider climate state. Next, we assume that K2-18 b has a shallow H2 – rich atmosphere with a liquid water ocean underneath. We discuss the general climate, dynamical climate and convective behaviour present for a range of albedos and surface pressures.

5. **Comparative Biosignatures**

Tereza Constantinou

Abstract

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

6. Terrestrial silicate weathering and the emergence of land plants

William J. McMahon[1], Neil S. Davies[1], Stefan C. Löhr[2], Cassandra Wheeler[3], Mohd Tarique[4], Edward T. Tipper[1], David Wilson[5], Emily P. Stevenson[6], Sean T. Murray[3]

[1]*Department of Earth Sciences, University of Cambridge, U.K*
[2]*Discipline of Earth Sciences, University of Adelaide, Australia*
[3]*School of Natural Sciences, Macquarie University, Australia*
[4]*National Centre for Polar and Ocean Research, Goa, India*
[5]*Department of Earth Sciences, University College London, London, United Kingdom*
[6]*GFZ German Research Centre for Geosciences, Potsdam, Germany*

Abstract

The existence of stabilizing feedbacks within Earth's climate system is generally thought to be necessary for the persistence of liquid water and life. The precise mechanisms which underpin this stability, including how they may adjust in tandem with evolving life, are uncertain. Moving toward a robust understanding of the factors that have enabled Earth to remain persistently inhabited for billion-year timescales is an important step toward understanding how terrestrial planets evolve and could guide views on planetary habitability beyond our solar system. We link apparent changes in terrestrial weathering processes with physical stabilizing effects caused by expanding Paleozoic plants. We have utilized novel clay mineral mapping techniques to couple mineral identification and textures at the micron-scale to differentiate clay minerals of apparent neoformed versus physically eroded origin. Applying consistent petrographic criteria to a series of selected Proterozoic and Paleozoic continental mudrocks, we measured the ratio of physically eroded to reworked neoformed clays and found an increase in neoformed content coincident with expanding land plants. We hypothesize that Paleozoic plants both chemically increased the weathering potential of terrestrial landmasses and physically stabilized the weathering environment, prolonging the time-interval over which repeated weathering reactions could occur. Shifts in weatherability (carbon sinks) on Earth are tied to the terrestrial biomass, a fundamental separator from other rocky worlds.

7. Mantle melting on Mars with applications for sample return

Joshua Shea[1], Caroline Soderman[1], Bronwyn Teece[2], Owen Weller[1], Laura Barge[2], and Oliver Shorttle[1,3]

[1]Department of Earth Sciences, University of Cambridge, United Kingdom
[2]Nasa Jet Propulsion Laboratory, California Institute of Technology, United States of America.
[3]Institute of Astronomy, University of Cambridge, United Kingdom

Abstract

Upcoming Mars sample return missions aim to collect igneous samples to understand martian geodynamics, mantle melting, and crustal formation. Constraining these processes requires obtaining primitive mantle-derived martian melts that record mantle composition and melting conditions. Primitive martian melt compositions remain poorly understood and differences from Earth's mantle limit the use of terrestrial analogues. To facilitate confidence in primitive basalt sample selection, we present an *a priori* phase equilibria modelling approach to constrain the entire martian melting regime, connecting known martian basalts with mantle mineralogy and chemistry for the first time. Our models reproduce martian meteorite and basalt compostiions between $T_p = 1450 - 1570$ ℃ via plausible variations in melt fraction, segregation depth, and crystallisation. We show melting on Mars begins earlier and rapidly increases in melt fraction compared to Earth, with melt compositions produced encompassing shergottites, and, with olivine or clinopyroxene accumulation, nakhlites and chassignites, indicating a common mantle source. This results in primitive martian basaltic chemistry distinct from Earth; for instance, solidus melts at $T_p = 1450$ ℃ yield liquidus olivine compositions of Fo_{82} on Mars versus Fo_{92} on Earth during 1 bar crystallisation. Our results provide quantitative targets for identifying primitive martian basalts, thereby informing and optimising sample return.

8. **Giant Impact Ejecta Driving Enhanced Atmospheric Loss**

Tuhin Ghosh

Abstract

The final stage of planet formation is marked by a chaotic phase of instabilities when the newly formed planetary embryos collide among themselves. Commonly referred to as giant impacts, these events play a crucial role in sculpting the planets and their orbital architectures. The outcomes of these giant impacts are studied extensively via numerical simulations, thanks to which we can now estimate the mass and atmosphere lost during the collisions. However, the high computational cost of these simulations has largely restricted investigations to the immediate aftermath of the impacts, typically spanning only a few days. This limited timespan restricts our understanding of the longer-term consequences of giant impacts, particularly the fate of their ejected debris. In this study, we investigate the importance of re-accretion of giant impact debris, a process overlooked in previous studies, on the atmospheres of Earth-like terrestrial planets. Following the collisional and dynamical evolution of the debris ejected during the giant impacts, we find that a substantial amount of the debris would be re-accreted by the planet remaining after the impact. Over a prolonged period, the re-accretion of the giant-impact-ejecta drives enhanced atmospheric loss. We find that this secondary atmospheric loss from debris accretion can exceed that of the primary giant impact event itself, often leading to complete atmospheric erosion for low-pressure Earth-like atmospheres. Our results highlight the crucial role of the secondary impacts from the giant-impact-ejecta in driving the long-term atmospheric evolution of Earth-like planets.

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9. Is there a comet hiding in our meteorite collections?

Ross Findlay, Mikey Slaney, Helen Williams

Abstract

Comets and C / D- complex asteroids accreted in the outer solar system beyond the snow line where water ice, carbon monoxide and organic molecules could condense, and as such possess a large volatile budget [1]. Impacts may send fragments of these bodies and their life-giving molecules on an Earth-crossing orbit where they are recovered as meteorites, though linking these objects to their parent bodies is a very difficult task [2]. This is particularly true for comets and fragile asteroids that may disintegrate during atmospheric entry. While there is abundant evidence for pervasive aqueous alteration in the meteorite record [3] there are sparse textural signs for the original ice crystals that melted to produce the water [4]. Furthermore, there is little evidence for an interconnected network in which fluid could flow within or sublimate from these bodies, which may be expected on an ice-rich object [1, 3, 5]. Recently, two unusual C2 carbonaceous chondrites have been recovered from Northwest Africa that contain a high level of porosity [6] which may be a fossil remnant of an initial water ice budget, or a feature produced by the mobilisation of water on the asteroid / comet during aqueous alteration. Here, we report an initial petrographic and isotopic assessment of these meteorites. Ultimately, did these meteorites come from an asteroid or a comet, and what are the implications of this conclusion for the distribution of volatiles on these bodies?

[1] Cochran, A. L. et al., (2015) The composition of comets. Space Science Reviews, 197, 9-46
[2] Greenwood, R. C. et al., (2020) Linking asteroids and meteorites to the primordial planetesimal population. GCA 227, 377-406.
[3] Suttle, M. et al., (2021) The aqueous alteration of CM chondrites, a review. GCA, 299, 219-256.
[4] Matsumoto, M. et al., (2019) Discovery of fossil asteroidal ice in primitive meteorite Acfer 094. Science Advances, 5, 11.
[5] Altwegg et al., (2014) 67P/Churymov-Gerasimensko, a Jupiter family comet with a high D/H ratio. Science, 347.
[6] The official classification documents for these two unusual meteorites
NWA 13969: https://www.lpi.usra.edu/meteor/metbull.php?code=74424
NWA 13456: https://www.lpi.usra.edu/meteor/metbull.php?code=73570

10. Determining the efficiency of volatile delivery via cometary impacts

Catriona McDonald & Richard Anslow

Abstract

The origins of life on Earth remain elusive due to the significant uncertainties surrounding the environment of the early Earth, including its atmospheric conditions, subaerial landmass distribution, and prebiotic chemical inventory. To mitigate some of these uncertainties, an exogenous origin for vital prebiotic chemicals has been suggested, through the delivery of organic molecules during cometary impacts. In this talk, we aim to paint a holistic picture of cometary delivery, considering passage through the atmosphere, direct impact onto the planetary surface, and the population of cometary impactors that may have bombarded Earth across its history. We present atmosentry, a new open-source numerical model, which describes the evolution of a comet passing through an atmosphere as strongly dependent on the comet's size and density, and the atmospheric surface density. Additionally, new impact simulations identify that in order for hydrogen cyanide, a particularly hardy prebiotic feedstock, to survive impact onto a rocky surface within a comet, extremely low impact velocities and angles are required. By coupling these two numerical modelling attempts, we emphasise the extremely narrow range of conditions under which a comet can appreciably deliver chemical feedstocks. Finally, we present preliminary results considering the likelihood of these conditions being achieved, thus constraining the efficiency of hydrogen cyanide delivery across the history of the Earth, and elucidating further the role of comets in the origins of life.

11. Morphometric analyses of *Charniodiscus* from the Ediacaran of Newfoundland, Canada

Princess Aira Buma-at[1,2], Nile Stephenson[1,2], Neil Mitchell[3], Jason Head[1,2] Charlotte Kenchington[4], Emily Mitchell[1,2]

[1]*University of Cambridge, Department of Zoology, Cambridge, UK*
[2]*University of Cambridge, University Museum of Zoology, Cambridge, UK*
[3]*Independent*
[4]*University of Cambridge, Department of Earth Sciences, Cambridge, UK*

Abstract

Ediacaran macrofossils (580-539 Ma) represent the earliest-known complex animals, revealing critical insight into the evolution of life. This study focuses on Charniodiscus, an upright, sessile, frondose organism morphologically simpler than the iconic rangeomorphs, enabling the refinement of new quantitative techniques. One of the largest in situ Charniodiscus populations occurs within the Main E Surface community in the UNESCO Mistaken Point Ecological Reserve (Newfoundland, Canada). This population can be utilized to explore physical variation across specimens, as well as the spatial distributions of variations within a community. We generated a photogrammetric map of the Main E Surface and obtained morphological traits by marking up the branching architecture of 116 well-preserved Charniodiscus specimens. We then used multivariate cluster techniques to identify different morphogroups and to constrain defining physical traits. Principal component analyses (PCA) showed that C. spinosus was mostly constrained to a singular discrete morphospace, whereas C. procerus displayed more trait variability, potentially indicating increased phenotypic plasticity. Therefore, this novel approach is the first step in elucidating which morphological traits, or combinations of traits, are key drivers of Ediacaran evolutionary dynamics.

12. Investigation of Stability of HCN Under Wide Range of Geochemical Conditions

Sai Shruthi Murali, Paul. B. Rimmer

Abstract

Understanding the origin of life on Early Earth is challenging, as it requires unification of different fields like astrophysics, astrobiology, chemistry, geology etc.[1] Despite these complexities, the research in this field is progressing steadily. Several chemical pathways have been proposed to understand the formation of biologically significant molecules on primitive Earth. One such pathway is cyanosulfidic protometabolism, which demonstrated that the four major building blocks of life-lipids, sugars, nucleotides and nucleobases-can be synthesised using hydrogen cyanide (HCN) as the primary precursor. [2-4] However, the feasibility of these reactions under prebiotic conditions and the physical factors influencing their efficiency remains less explored[5].

In this work, we investigate the stability of HCN- under different geochemical conditions. Specifically, we study the hydrolysis of HCN, a key process in determining its availability for polymerization leading to subsequent biomolecule formation. We estimate the hydrolysis rates at different temperature, pH and in the presence of salts like sulphate, sulphite, sulphide and phosphate. Our results show that the hydrolysis rates are significantly influenced by pH and temperature with variations observed depending on the nature of salts. The projected lifetime of HCN in the alkaline environment at 100 ℃ and 0 ℃ was estimated to be 6 and 270 days respectively in the absence of salts. The preliminary results suggest that the lifetime was shortened in the presence of sulphide salt. These observations provide new insights into the effect of physical parameters on HCN stability, providing a better understanding of the early Earth’s local geochemical conditions.

References

1. Sutherland, J.D., The Origin of Life—Out of the Blue. Angewandte Chemie International Edition, 2016. 55(1): p. 104-121.

2. Xu, J., et al., Photochemical reductive homologation of hydrogen cyanide using sulfite and ferrocyanide. Chemical Communications, 2018. 54(44): p. 5566-5569.

3. Xu, J., et al., A prebiotically plausible synthesis of pyrimidine β-ribonucleosides and their phosphate derivatives involving photoanomerization. Nat Chem, 2017. 9(4): p. 303-309.

4. Patel, B.H., et al., Common origins of RNA, protein and lipid precursors in a cyanosulfidic protometabolism. Nat Chem, 2015. 7(4): p. 301-7.

5. Miyakawa, S., H. James Cleaves, and S.L. Miller, The Cold Origin of Life: A. Implications Based On The Hydrolytic Stabilities Of Hydrogen Cyanide And Formamide. Origins of life and evolution of the biosphere, 2002. 32(3): p. 195-208

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13. Fractionation of Carbon Isotopes in Carboxysulfitic Chemistry

Ziwei Liu[1,2]

[1]*Department of Earth Sciences, University of Cambridge, Downing Street, CB2 3EQ, United Kingdom*
[2]*MRC – Laboratory of Molecular Biology, Francis Crick Avenue, Cambridge Biomedical Campus, Cambridge, CB2 0QH, United Kingdom*

Abstract

In modern biology, the isotopic $\delta^{13}C$ value of the photosynthetic pathway ranges from -10‰ to -37‰, reflecting enzymatic carbon fixation mechanisms that lead to varying degrees of isotopic fractionation. Carboxysulfitic chemistry [1], an efficient abiotic carbon dioxide photoreduction process, has been proposed as a plausible prebiotic pathway for organic compound formation. This reaction facilitates the reduction of carbon dioxide to formate, glycolate, malonate, and other carboxylic acids under ultraviolet irradiation, suggesting a potential non-biological source of reduced carbon compounds on early Earth. However, despite the growing interest in abiotic carbon fixation, there are no studies on the carbon isotopic fractionation ($\delta^{13}C$ values) of products derived from carboxysulfitic chemistry. Understanding the extent of isotopic fractionation in such reactions is crucial for distinguishing abiotic versus biotic signatures in the geochemical record. Here, we demonstrate the analysis of carbon isotopic fractionation across different products of carboxysulfitic chemistry. Our findings reveal significant variability in $\delta^{13}C$ values among reaction products, with some compounds exhibiting substantial depletion relative to the starting CO_2. This suggests that carboxysulfitic chemistry follows distinct isotopic fractionation patterns compared to biological carbon fixation. These results provide valuable insights into prebiotic chemistry and may contribute to the interpretation of ancient carbon reservoirs in the context of Earth's early environment and extraterrestrial systems.

References

[1] Liu, Z.; Wu, L.-F.; Kufner, C.; Sasselov, D. D.; Fischer, W.; Sutherland, J. Nature Chemistry 2021, 13, 1126–1132.

LEVERHULME CENTRE FOR LIFE IN THE UNIVERSE

14. Invaders in the Garden of Ediacara: the evolutuion of the first predatory ecologies

Euan Furness

Abstract

Most of the history of life on Earth is a history of unicellular organisms, limited in their activity by their environment. However, in the late Ediacaran (575 Ma), the first animal ecosystems arose. This represented a step change in the history of life, as life gradually changed to become limited by ecological interactions between organisms, rather than by their environments. However, these first ecosystems lacked many of the ecological groups present in modern marine ecosystems, such as predators, burrowers, and zooplankton. These groups have substantial impacts on ecology and evolution in the modern day, and it is unclear how these first animal ecosystems would have changed as these critical groups evolved. We employ biomass-based ecological network modelling techniques, designed using modern ecosystems and parameterised using data from the fossil record, to assess the ecological stability of Ediacaran ecosystems, and to determine how this stability may have changed in response to the evolution of predators and zooplankton. We find that introducing predators to these naive ecosystems tends to destabilise them, but the exact effect is dependent upon the state of the ecosystem prior to perturbation. Zooplankton, on the other hand, can stabilise ecosystems if they increase the speed of ecological feedback loops. These results demonstrate that interactions between organisms, resulting from evolutionary innovation, have the potential to fundamentally restructure ecosystems on a global scale.

15. **Origin of Life's Homochirality: From Magnetic Minerals to a Homochiral Genome**

Furkan Ozturk

Abstract

Essential molecules of life are chiral; they exist in mirror-symmetrical pairs. However, biological systems exclusively only use one form of these pairs: right-handed sugars, along with left-handed amino acids. This phenomenon characterizes life as homochiral. The origins of this molecular asymmetry, however, remain elusive, and it is this long-standing mystery that I will address in my presentation. The chiral-induced spin selectivity (CISS) effect has established a strong coupling between electron spin and molecular chirality. This coupling paves the way for breaking the chiral molecular symmetry via spin-selective processes. Achiral magnetic surfaces, when spin-polarised, can function as chiral agents due to the CISS effect, serving as templates for the asymmetric crystallization of chiral molecules. We studied the spin-selective crystallization of racemic ribo-aminooxazoline (RAO), a central precursor of RNA and DNA, on magnetite surfaces—achieving homochirality in two crystallization steps. We also demonstrated the chirality induced avalanche magnetization of magnetite by RAO molecules. Moreover, we studied the prebiotic synthesis and magnetic properties of magnetite minerals in fresh water lakes, providing a plausible environmental setting for our scenario. Finally, we proposed a pathway through which the achieved homochirality in a single compound, RAO, can efficiently propagate throughout the entire prebiotic network—from *D*-nucleic acids to *L*-peptides and then to homochiral metabolites. Our findings provide a prebiotically plausible model for achieving systems-level homochirality from racemic starting materials and highlight the importance of magnetic minerals in addressing this age-old mystery.

16. You spin me round – Exchange driven reorientation of magnetic states in magnetite by chiral molecules and (potential) implication for the origin of life

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Abstract

The origin of homochirality – the preference for one of the two mirror-image (or enantiomer) versions of chiral biological molecules – remains a pivotal question in understanding the emergence of life. Homochirality is fundamental to life's chemistry: RNA exclusively contains right-handed D-ribose, proteins are composed of left-handed L-amino acids, and metabolites adopt specific chiral configurations. Recent studies revealed that enantiomeric selectivity in ribose-aminooxazoline (RAO) – a key RNA precursor – can be induced and propagated through interactions with magnetized materials. Spin alignment biases, linked to remanent magnetization in natural materials like magnetite, serve as effective symmetry-breaking agents for enantioselective molecular formation. Experiments demonstrate that RAO crystallizes with high chiral selectivity on magnetized multi-domain (MD) magnetite thin films. Once homochirality is achieved, it can induce domain transformation, creating a uniform surface magnetization, which spreads across the magnetic surface akin to an avalanche. However, early Earth conditions were certainly distinct to those achieved in the laboratory; in evaporative lake settings, magnetite formation likely involved authigenic precipitation, leading to individual and/or cluster of nanoparticles (NP) in the single-domain (SD) and pseudo-single-domain (PSD) range. It remains to be seen, therefore, if domain transformation on SP, SD and PSD magnetite grains takes place in the presence of homochiral crystals, akin to the magnetization avalanche observed in MD thin films. To explore this, we developed a phenomenological model coupling micromagnetics, machine-learning and analytical models to examine how homochiral crystals drive magnetization changes in SP and SD magnetite. Our model quantitatively predicts coercivity and thermal stability changes in magnetite NPs due to exchange interactions, offering insights into feedback mechanisms critical for propagating homochirality in prebiotic systems and its potential role in the origin of life's homochirality.

ABSTRACTS SUBMITTED FOR POSTERS

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17. **Habitability of exoplanets around M dwarfs**

Annika Salmi, Akhil Kumar, Michael Kreuziger, Viktoria Ellmies, and Imre Kisvardai.

Abstract

Exoplanets around M dwarfs have emerged as prime candidates in the search for life in the universe. The increased planet-to-star radius ratio in these systems has facilitated the study of smaller transiting exoplanets. This marks a new era in exoplanet characterization and allows for the exploration of potentially habitable worlds. However, the low mass and differing emission spectra of these stars, along with common tidal locking of their exoplanets, create planetary environments markedly different to those in our solar system. Therefore, it is imperative to continue studying the habitability of these systems. This poster describes research performed by five MPhil students in Planetary Sciences and Life in the Universe on various aspects of exoplanet habitability in these unusual environments. We first assess the potential of M dwarf exoplanets as targets for future detection missions. Next, we investigate promising exoplanet candidates for habitability, focusing on those within the abiogenesis zones of their host stars, and analyze the detectability of pre-biosignatures in their atmospheres. We then leverage experimental approaches to investigate potential prebiotic chemistry on these exoplanets, evaluating the impact of stellar radiation on the plausibility of a urea-based warm-pond scenario for the emergence of life. Subsequently, we study the effectiveness of silicate weathering on wet, rocky exoplanets, using stellar composition to constrain climate stability. Finally, we perform a case study on TOI-700 – a M-dwarf with two Earth-sized habitable zone planets, and investigate the observability of atmospheric features on these planets with current and future observational facilities.

LEVERHULME CENTRE FOR LIFE IN THE UNIVERSE

18. Investigating the impact of Stellar Flaring on Nitroprusside formation

Lukas Rossmanith, Paul Rimmer, Sofia K. Platymesi, Samantha Thompson

Abstract

Nitroprusside is an important prebiotic molecule, thought to contribute to reaction pathways that lead to the production of amino acid chains (Mariani et al. [2018]). Nitroprusside can be made from Ferrocyanide photochemically. It has been found that the timescales for this reaction on Early Earth would have been between an order of days to months , making this route of abiotic production very useful in further prebiotic reaction networks and an important factor to consider when discussing the viability of life to evolve on a planet (Rimmer et al. [2021]). Here we investigate this reaction with a focus on constant and time varied radiation, meaning experimental runs involving the sample being subjected to a constant flux of UV light and runs with UV flux changing over time. FlareLab makes use of a broad band UV-Vis Laser Driven Light Source (LDLS), to experimentally simulate stellar irradiation and stellar flaring activity. The reasoning behind investigating flares is based on recent findings that have shown that M-dwarves are prone to flaring (G¨unther et al. [2020]). Flaring for M-dwarves is also shown to be the best way to get enough UV to an exoplanet's surface for good yield of photochemical products (Ranjan et al. [2017]). With M-dwarves seen as the best stars to look at to detect small rocky planets, it is important to consider how flaring could effect the production of Nitroprusside and if there's a discrepancy between assuming a constant irradiation of the surface or taking into account flaring. We show that FlareLab can be used as a means of detecting the production of Nitroprusside in-situ during the irradiation period. We also compare the constant flux and variable flux regimes, and discuss the implications of these findings.

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19. **Abiotic Ozone in the Atmospheres of Venus and Venus-like Exoplanets**

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Abstract

Ozone is a potential exoplanet biosignature and disambiguator between Earth-like and Venus-like exoplanets due to its association with photosynthetically produced oxygen and strong absorption in the mid-infrared. However, the existence of ozone in Venus's observable atmosphere, a planet with no known life, raises the possibility of ozone biosignature false-positives on Venus-like exoplanets. We use a photochemical model of Venus's atmosphere to investigate the origin of its mesospheric ozone layer, and how similar ozone layers would manifest for Venus-like exoplanets. Our model shows that the hypothesis that Venus's ozone forms on the nightside due to a flux of O radicals from the dayside, cannot generate enough ozone to match observed levels of 1 ppm at altitudes of 90-105 km [1] without also producing oxygen in excess of observational upper limit of 3 ppm at altitudes of 60-80 km [2]. Nor do our ozone and molecular oxygen predictions match observations by varying the lower-atmosphere trace-gas concentrations, atmospheric thermal structure, or stellar flux in our model of Venus's atmosphere. These results imply that a presently unknown chemical pathway is responsible for the ozone in Venus's mesosphere. Until the origin of Venus's ozone is understood, we cannot rule out that ozone production will be common on abiotic Venus-like worlds, a possibility that limits the usefulness of ozone as a biosignature.

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20. Chemical Kinetics as a Window into Prebiotic Plausibility

S. B. White[1], P. B. Rimmer[1]

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Abstract

Origin of Life research has gained significant momentum in recent years as an endeavour requiring interdisciplinary collaboration [1]. Despite this, many groups work in isolation, leading to an ongoing disconnect between the geochemistry and prebiotic chemistry communities. This lack of cohesion stems from the absence of effective tools to assess the likelihood of specific synthetic pathways occurring within proposed geochemical environments. How can we bridge the gap between laboratory experiments and geochemical environments? We believe that chemical kinetics is key to answering this question [2], making the measurement of rate constants for prebiotic reactions a priority [3]. We propose that an aqueous chemical kinetics model, informed by experimental data, could serve as a foundation for linking laboratory chemistry to realistic geochemical settings. Such a model would enhance our understanding of the requisite conditions for prebiotic syntheses and reveal how evolving aqueous environments influence the progression of a reaction network. Moreover, this model could elucidate how different proposed prebiotic pathways might interact, providing insights into their potential synergy or competition. Here we present a preliminary aqueous chemical kinetics model alongside a nascent database for prebiotic chemical reaction networks. Development and implementation of this tool will require overcoming major gaps in experimental data, as well as the obstacles inherent in interdisciplinary collaboration. Despite these challenges, we believe that the development of a predictive prebiotic kinetics model would spark a paradigm shift in how we study life's emergence.

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21. **Ultraviolet Light as an Energy Source for Amino Acid Synthesis**

Reductive Amination of Pyruvate

Theresa Drobnik

Abstract

Amino acids are essential for life, synthesised in modern organisms from tricarboxylic acid cycle intermediates via reductive amination. Lactate, a structurally similarmetabolite, plays a key role in cellular energy metabolism, making its prebiotic formation significant not only as an intermediate in the conversion of pyruvate to alanine but also for a prebiotic reaction network in general.

Understanding amino acid formation before life emerged remains a key question in prebiotic chemistry. Proposed mechanisms include synthesis via lightning (Miller, 1953), delivery of organic precursors through meteorites (Chyba & Sagan, 1992), Strecker synthesis (Patel et al., 2015), and metal-catalyzed reductive amination in hydrothermal vents (Barge et al., 2019).

In this research, we investigated whether ultraviolet (UV) light could serve as an energy source for amino acid formation via reductive amination. UV irradiation of sulfur species in aqueous environments generates solvated electrons, which act as reductants. We tested this by irradiating pyruvate, sodium sulfite, and ammonium chloride under UV light with ferrocyanide included in some reactions to explore alternative electron sources.

Preliminary NMR analysis identified lactate and formate formation. The detection of lactate strongly suggests that key metabolic precursors could have formed through photochemical processes. This discovery opens exciting new avenues for exploring how life's biochemical foundations could have originated in surface-level ponds on early Earth. Future experiments will refine reaction conditions to maximize yields and drive amino acid synthesis.

22. **Assessing the habitability of icy moons and their detection elsewhere in the galaxy**

Walker, Andrews, Yang, Hawkins

Abstract

The subsurface oceans of icy moons are potentially habitable environments. This work investigates the formation of oceans using a melting depth model and estimates the occurrence rate of cryovolcanism. Cryovolcanic plumes allow us to study ocean composition by sampling the atmosphere. The detection of formaldehyde on icy moons has implications for prebiotic chemistry and habitability. As a precursor to key biomolecules, its presence on Europa and Enceladus is promising for eventual chemical evolution. The lifetimes of aldehydes and ketones in icy moon oceans are determined by modelling their destruction pathways and estimating their rate constants. A Bayesian statistical approach is used to quantify the probability that methanogenesis (biotic methane production) explains the H_2-to-CH_4 ratio and CH_4/H_2 fluxes in Europa's plumes. Simulated plume data is produced for three habitability scenarios—biotic, abiotic-habitable, and uninhabitable—using models of Europa's geophysics and ocean biogeochemistry. To date there have been no confirmed exomoon detections. This work examines the feasibility of icy exomoon detection via transit photometry as a function of noise and observation cadence. Synthetic planet-moon transit light curves are generated with a photodynamical model, with parameters recovered through nested sampling algorithms. This work extends the search for habitable environments beyond the typical circumstellar habitable zone to include icy moons with subsurface oceans sustained by tidal heating.

23. Can we find habitable zone planets around white dwarfs, and could life emerge and persist there?

Yuanjin Wang

Abstract

White dwarfs are star remnants accounting for ~97% of the stars in the Milky Way. During cooling, they emit strong radiation that heats up nearby planets, making them intriguing targets in the search for extraterrestrial life. Our research aims to investigate the habitability of planets around white dwarfs. We begin with estimating the number of HZ planets around white dwarfs by generating a population of main-sequence stars and their planets of various sizes and orbital distances. As the stars evolve to white dwarfs, we use various functions to study how planet numbers and orbital radius change under different evolutionary scenarios. This is followed by examining how stellar and planetary properties influence their detectability using transit surveys, as well as the impact of PLUTO instrument parameters on detection efficiency. It will help determine what HZ planets we can expect to detect around white dwarfs and estimate their potential occurrence rates. By studying potential prebiotic chemistry in the planet's atmosphere driven by radiation, we expect to suggest if life can emerge on white dwarf planets. A computational modelling of atmospheric chemical networks and a series of laboratory experiments of degradation chemistry under UV-light will complement each other to resolve this aspect. Finally, we will investigate how white dwarf cooling affects the habitability of hydrogenous methanogens, which might have significant climate impact on the early Earth. By evaluating its biomass production and climate feedback over time, we aim to determine whether life could persist on white dwarf HZ planets and shape planetary habitability.

24. **High-eccentricity tidal evolution of planetesimals around white dwarfs: volcanism and transits**

Yuqi Li

Abstract

White dwarf pollutants uniquely probe the composition of exoplanets. Open questions, however, remain regarding how planetary material is delivered to white dwarfs. Periodic transits seen for a handful of white dwarfs reveal the rich dynamics of close-in planetary material over a wide range of orbits before/undergoing accretion. We model the tidal evolution of planetesimals gravitationally perturbed onto highly eccentric orbits around white dwarfs. Planetesimals undergoing tidal evolution tend to pile-up at long-period highlyeccentric orbits (~ 100 day) and short-period near circular orbits (~ 10 hr-1 day), generally in agreement with the observed transits. Meanwhile, tidal heating accompanied with orbital decay may trigger volcanism over a wide range of orbits, with the erupted dust causing transits. We model the evolution of volcanic dust leaving planetesimals, showing that tidally induced volcanism may explain the transit features around WD1145+017.