



# LEVERHULME CENTRE FOR LIFE IN THE UNIVERSE

## **LCLU Annual Science Day 2026**

Robinson College

Crausaz Wordsworth Building, Cambridge

Friday, 20<sup>th</sup> March 2026

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

Programme

## **PROGRAMME**

Venue: *Robinson College, Crausaz Wordsworth Building*

**9:00 - 10:00** Registration & Coffee  
Welcome to Annual Science Day 2026

### **Keynote I: Exoplanet Composition and Habitability**

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**10:00 - 11:00** Keynote talk by **Amy Bonsor**

### **Session I: Hidden Oceans (11:00 – 12:50)**

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**11:00 - 11:15** **Lorenzo Pica Ciamarra (Institute of Astronomy)**  
A Systematic Search for Trace Molecules in Exoplanet K2-18 b

**11:15 - 11:30** **Robb Calder (Institute of Astronomy)**  
Most Rocky Sub Neptunes are Molten: Mapping the Solidification Shoreline for Gas Dwarf Exoplanets

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**11:30-12:00** **Break:** Coffee, poster presentations

### **Session II: The Rocky History of Planets Cracked Open (12:00 - 13:00/14:00-15:00)**

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**12:00 - 12:15** **Harrison Nicholls (Institute of Astronomy)**  
The billion-year history of L 98-59 d: photochemistry, deep magma oceans, and a volatile-rich formation

**12:15 -12:30** **Craig Walton (Institute of Astronomy)**  
U-Pb Records of an “Early Heavy Bombardment” of the Inner Solar System

**12:30-12:45** **Richard Anslow (Institute of Astronomy)**  
What highly siderophile elements reveal about the final stages of Earth’s formation

**12:45-13:00** **Tuhin Ghosh (Institute of Astronomy)**  
Atmospheric Erosion from Re-accretion of Giant Impact Ejecta

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**13:00-14:00** **Break:** Lunch, poster presentations

### **Keynote II: Lost in Translation, the Origins of Life’s Peptides**

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**14:00 -14:45** Keynote talk by **Matthew Powner**

### **Session III: How Chemistry Became Biology (15:00– 16:00)**

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**15:00 - 15:15** **Bruno Marinič (MRC Laboratory of Molecular Biology)**  
Prebiotically Plausible Synthesis of N-Cyanoimidazole for Phosphate Activation and Templated RNA Ligation

**15:15-15:30** **Edoardo Gianni (MRC Laboratory of Molecular Biology)**  
Development of RNA-Based Self-Replicating Systems

**15:30-15:45** **Bence Csakany (Yusuf Hamied Department of Chemistry)**  
Chirality Induced Spin-Selectivity as a Collective Phenomenon

**15:45-16:00** **Sai Shruthi Murali (Department of Physics)**  
Confronting the Water Problem: The Lifetime of Aqueous Cyanide and its Role in Origins of Life

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

## **Session IV: Conditions for Life on Earth and Beyond (16:30 - 18:00)**

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- 16:30 - 16:45** **Jose Devienne (Department of Earth Sciences)**  
Prebiotic Magnetite Enables Chirality-Magnetic Surface Feedback
- 16:45-17:00** **William McMahon (Department of Earth Sciences)**  
Clay minerals reveal a global intensification of continental weathering after the evolution of land plants
- 17:00-17:15** **Joshua Shea (Department of Earth Sciences)**  
Mantle Carbon Isotopes as a Record of Biosphere-Planet Redox Evolution
- 17:15-17:30** **Jules Macome (History and Philosophy of Science)**  
From the Chance Scenario to the Origins Contingency Hypothesis
- 17:30-17:45** **Gregory Cooke (Institute of Astronomy)**  
Ecological Modelling of Hycean Worlds

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

\*For any questions and enquiries, please contact LCLU Admin: [admin@lclu.cam.ac.uk](mailto:admin@lclu.cam.ac.uk)

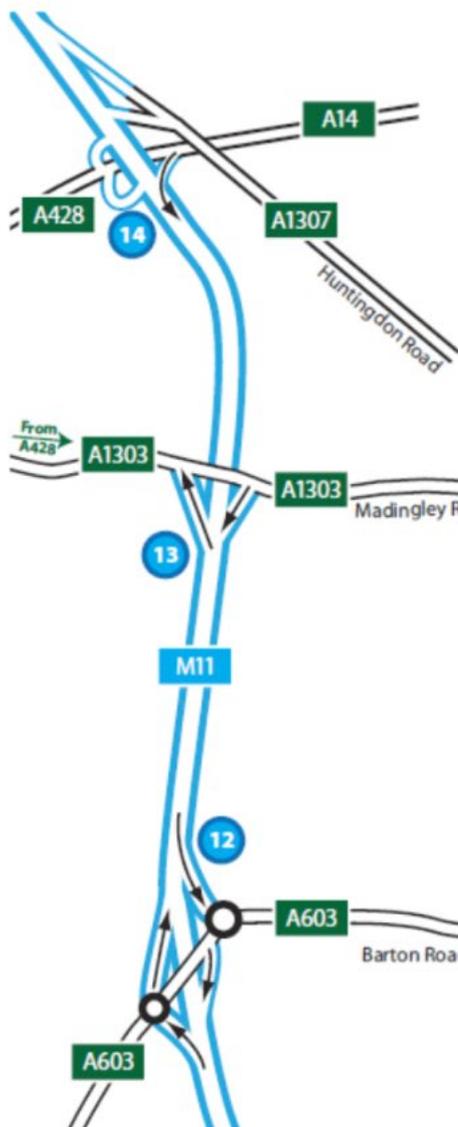
# Directions to venue

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



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Robinson College  
University of Cambridge



DETAILED VIEW



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)

**Robinson College**  
Grange Road  
Cambridge  
CB3 9AN

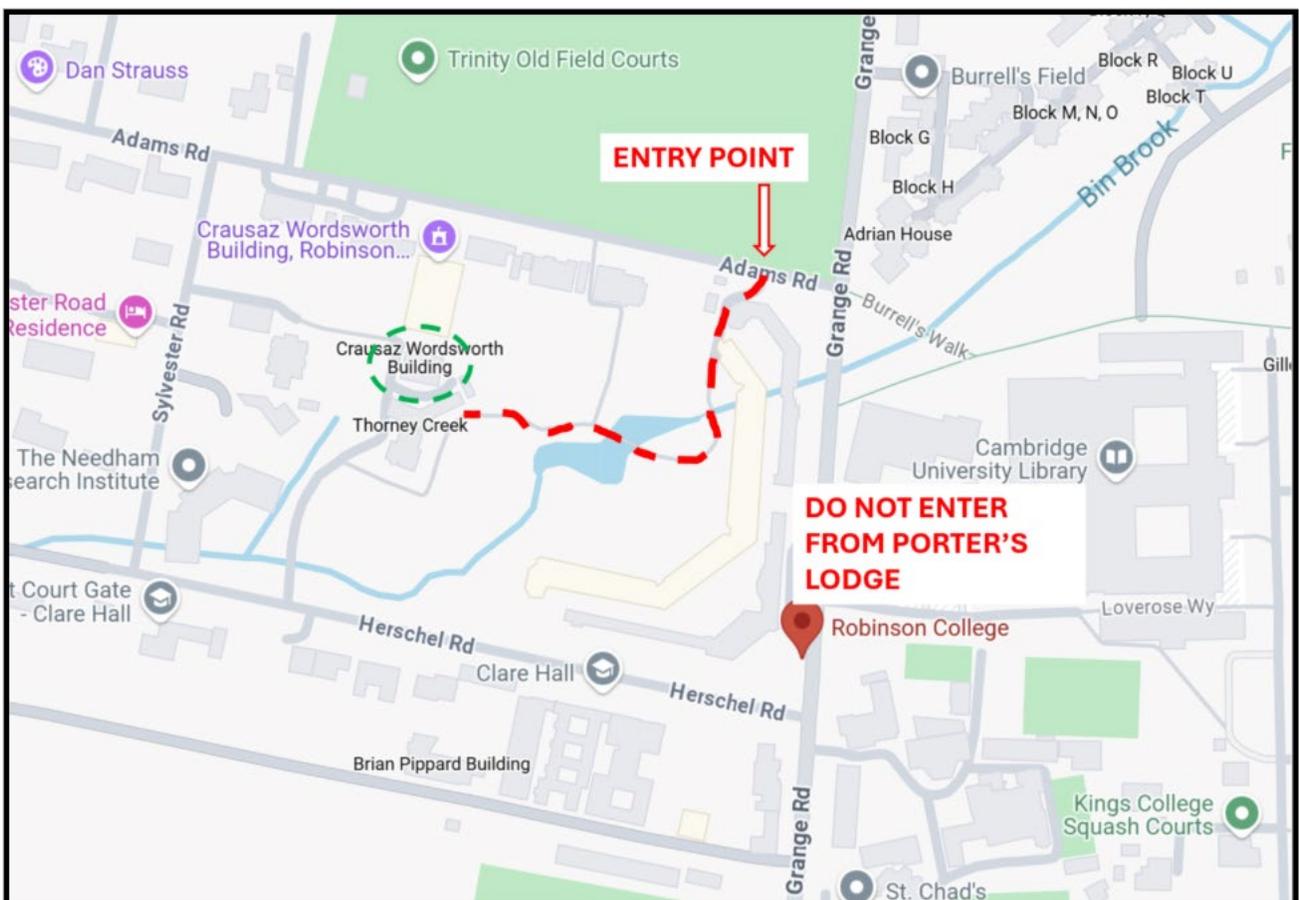
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## KEYNOTE TALKS

**Amy Bonsor**

**Institute of Astronomy**

### **Exoplanet Composition and Habitability**

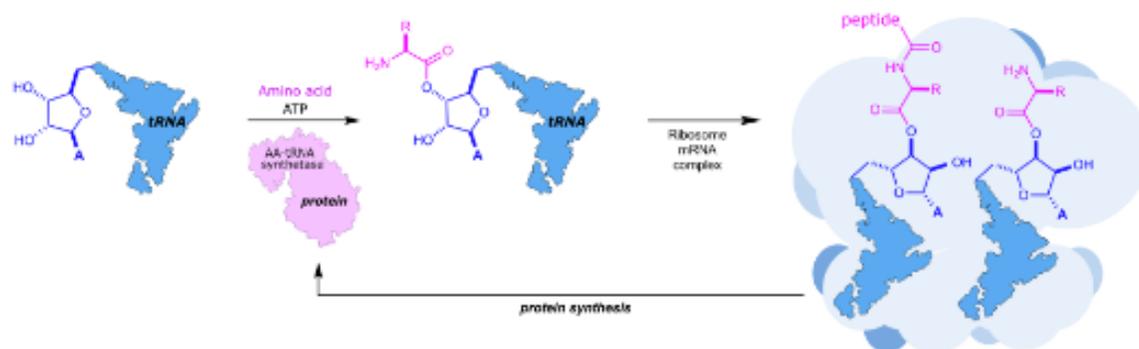
As we move towards an epoch of rocky exoplanet discovery, composition is key to assessing potential habitability. I will discuss how the bulk composition of planets influences their habitability, as well as the potential for late delivery to provide material crucial to prebiotic pathways. Observations of planetary material in the atmospheres of white dwarfs can inform us about planetary composition and geology. This talk will probe the link between host star and planet compositions, as well as the journey of volatiles, crucial for habitability, from planet forming discs into rocky planets.

**Matthew Powner**

**UCL, Department of Chemistry**

### **Lost in translation, the origins of life's peptides**

Ribosomal peptide synthesis (RPS) is orchestrated through the aminoacylation of RNAs by aminoacyl-tRNA synthetase enzymes that are produced by RPS. This causal paradox, which was established prior to the evolution of life's last universal common ancestor, obscures the origins of protein biosynthesis. To break this paradox, we set out to build a deterministic model of the minimum reactivity required to initiate peptide biosynthesis.



The chemical unity and antiquity of life's central metabolites provide compelling evidence that a simple set of chemical reactions predicated the appearance of life on Earth,<sup>1-2</sup> and we reasoned that rediscovering such a reaction network, and the rules that control it, would be the key to uncovering the origins of peptide biosynthesis.

In this talk recent advances that suggest life's nucleotides [1,3], peptides [3-7], and cofactors [8] are predisposed structures will be presented. These results indicate that (biological) thioester activation can direct RNA to intercept peptide synthesis [9], which is an essential step towards establishing life's central dogma.

### **Selected references**

- [1] Powner + *Nature* **2009**, 459, 239–242.
- [2] Coggins + *Nat. Chem.* **2017**, 9, 310–317.
- [3] Islam + *Nat. Chem.* **2017**, 9, 584–589.
- [4] Canavelli + *Nature* **2019**, 571, 546–549.
- [5] Foden + *Science* **2020**, 370, 865–869.
- [6] Singh + *J. Am. Chem. Soc.* **2022**, 144, 10151–10155.
- [7] Thoma + *J. Am. Chem. Soc.* **2023**, 145, 3121–3130.
- [8] Fairchild + *Science* **2024**, 383, 911–918.
- [9] Singh + *Nature* **2025**, 644, 933–944.

## ABSTRACTS SUBMITTED FOR TALKS (In order of presentation)

**Lorenzo Pica Ciamarra**  
**Institute of Astronomy**

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### **A Systematic Search for Trace Molecules in Exoplanet K2-18 b**

The search for life in the Universe has found fertile ground in the hypothesis that some temperate sub-Neptunes may be habitable 'hycean' worlds. Recent JWST observations of the habitable-zone sub-Neptune K2-18 b have revealed an atmospheric composition consistent with predictions for a hycean scenario. Most tantalising of all has been the tentative inference, in this planet's spectrum, of spectral features attributed to dimethyl sulfide (DMS), a chemical species with no known significant abiotic sources. In the search for biosignatures, however, it is essential to ensure any signal has been properly identified and attributed to the correct species. Following the recent inference of DMS on K2-18 b, a natural question is whether the signal may have been due to other chemical absorbers. We present the most comprehensive retrieval analysis of an exoplanet spectrum conducted to date. We use the available JWST spectra of K2-18 b to search for potential absorption from any of over 600 species for which molecular cross-sections are available, and verify which of them are supported by independent lines of evidence. For promising species, we also assess the physical plausibility of their presence in the atmosphere of K2-18 b, considering both potential abiotic and biological sources. We discuss our findings, and how they affect the inference of DMS in K2-18 b

**Robb Calder**  
**Institute of Astronomy**

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

Sub-Neptunes are the most common type of detected exoplanet, yet their observed masses and radii are degenerate with several interior structures. One possibility is that sub-Neptunes have silicate/iron interiors and H<sub>2</sub>-dominated atmospheres, i.e., they are 'gas dwarfs'. If gas dwarfs have molten interiors, interactions between their magma oceans and atmospheres will produce distinct observational signatures. These signatures may break the degeneracy in interior structure, while providing insight into their interior processes, history, and population trends. We expect all such planets are born molten, but under what conditions do they remain molten today? We use the coupled interior-climate evolution model, PROTEUS, to estimate the 'solidification shoreline': the instellation flux boundary (as a function of stellar eff) that separates molten gas dwarfs from solidified ones. Our results show that 98% of detected sub-Neptunes occupy a region of parameter space consistent with their having permanent magma oceans, if they are gas dwarfs. While mantle O<sub>2</sub> and bulk volatile C/H ratio both influence magma ocean lifetimes, planets with oxidising mantles and carbon-rich atmospheres are unlikely to have radii consistent with the sub-Neptune classification. Therefore, most detected sub-Neptunes (if they are gas dwarfs) have permanent magma oceans. This result motivates further research into the interactions between molten interiors and overlying atmospheres, and campaigns to identify unambiguous signatures of these Interactions.

**Harrison Nicholls**  
**Institute of Astronomy**

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### **The billion-year history of L 98-59 d: photochemistry, deep magma oceans, and a volatile-rich formation**

*Harrison Nicholls, Tim Lichtenberg, Richard D. Chatterjee, Claire Marie Guimond, Emma Postolec, Raymond T. Pierrehumbert*

Sub-Neptune and super-Earth exoplanets are often proposed to be composed of rocky interiors with hydrogen envelopes ('gas-dwarfs'), or alternatively with various water phases ('waterworlds'). Observations of super-Earth L 98-59 d have revealed its uniquely low bulk-density, consistent with a volatile atmosphere above a rocky interior; furthermore, recent JWST (2025) and ground-based (2026) spectroscopy provide evidence that its metal-rich atmosphere contains sulfur species. In this work, we directly simulate the possible evolution pathways for L 98-59 d from its birth, up to the present, using the PROTEUS interior-atmosphere evolutionary modelling framework. Our coupled numerical modelling shows that L 98-59 d has maintained a deep magma ocean over Gyr timescales, enabled by a thick greenhouse atmosphere. This planet formed with a large amount (>1.8 mass%) of sulfur and hydrogen, while retaining a chemically-reducing mantle.

Its permanent magma ocean allows the retention of volatiles within its deep interior. Furthermore, in-situ photochemical production of SO<sub>2</sub> in an H<sub>2</sub>-H<sub>2</sub>S background atmosphere explains the JWST transmission features. We demonstrate that multiple physical interactions between planetary interiors and their atmospheres shape exoplanet observables over billions of years. Our physically self-consistent explanation for L 98-59 d does not fit into either of the two popular gas-dwarf/water-world scenarios, suggesting that the small exoplanet population encompasses a continuum of outcomes which arise from the physics of planet formation and evolution.

**Craig Walton**

**Institute of Astronomy**

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### **U-Pb Records of an “Early Heavy Bombardment” of the Inner Solar System**

The orbital elements of the Solar System's ancient asteroid families are highly dispersed, recording the last dynamical chaos in its history. However, dynamics alone cannot precisely date this when this terminal chaos occurred. Instead, we can precisely date the collisions triggered by such dynamical rearrangement to constrain this event. We measured in-situ ordinary chondrite meteorite apatite U-Pb ages to trace collisions that induce parent body break-up events. We show that the U-Pb records of strongly shocked and weakly shocked meteorites are distinct. The U-Pb ages of weakly shocked meteorites record the decline of radiogenic heating in asteroidal bodies. Meanwhile, shocked meteorite ages record major collisions. All sampled ordinary chondrite bodies record collisions that occurred 4480 ± 20 Ma million years ago. These ages constrain that the last date of major dynamical chaos to modify the orbital elements of asteroids occurred at around 4480 Ma. This date is relatively late in Solar System history, possibly representing the timing of a major collisional pulse — an ‘Early Heavy Bombardment’ of the inner Solar System.

**Richard Anslow**

**Institute of Astronomy**

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### **What highly siderophile elements reveal about the final stages of Earth's formation**

*Richard Anslow [1], Maylis Landeau[2], Amy Bonsor[1], Oliver Shorttle [1,3]*

[1] Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK

[2] Université de Paris, Institut de Physique du Globe de Paris, CNRS, Paris, France

[3] Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge, CB3 9ET, UK

Highly siderophile elements (HSEs) – metal-loving elements such as platinum and gold – are unexpectedly abundant in Earth's mantle, expected to have been removed during core formation. Their presence is therefore widely interpreted as evidence for a ‘late veneer’ of impacts after Earth's core formed. Assuming that all material delivered during the late veneer remained entrained in the mantle, excess mantle HSEs are thought to record the final ~ 0.5 wt% of Earth's accretion. These impacts are thought to have potentially played an important role in the origins of life, generating transient reducing atmospheres favourable for prebiotic chemistry. I will discuss recent work investigating the fate of impactor metal in both local magma oceans and the solid mantle, showing that metals from impactors larger than approximately 1 km will sink to Earth's core, leaving no HSE signature in the mantle. By considering realistic impactor size distributions, we show that sub-km impactors cannot be the dominant source of Earth's HSEs, highlighting a contradiction between the observed concentration of HSEs in Earth's mantle, and estimates of total mass accretion during the late veneer. I will finish by discussing potential resolutions to this paradox – including (i) the delivery of oxidised (carbonaceous chondrite-like) material, (ii) the vaporisation of late accreted material, and (iii) the possibility that a substantial fraction of HSEs pre-date Moon formation – and the potential implications for the frequency of reducing post-impact atmospheres on the early Earth.

**Tuhin Ghosh**

**Institute of Astronomy**

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### **Atmospheric Erosion from Re-accretion of Giant Impact Ejecta**

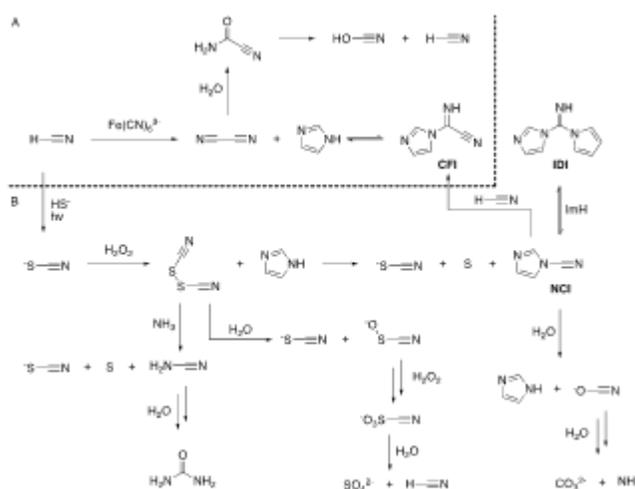
Understanding why some planets lose their atmospheres while others retain them is central to determining whether rocky planets can sustain habitable conditions. The evolution of planetary atmospheres is closely tied to their dynamical histories, and the formation of terrestrial planets concludes with a dynamically active phase of instabilities during which newly formed planetary embryos collide with one another. While advanced numerical simulations have provided important insights into the immediate atmospheric loss during these collisions, their high computational cost has largely limited studies to the immediate aftermath. As a result, the longer-term consequences of giant impacts, particularly the fate of the debris they produce, remain poorly

understood. In this study, we investigate the importance of re-accretion of giant impact debris on the atmospheres of Earth-like terrestrial planets, a process that has been overlooked in previous studies. 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 prolonged timescales, the re-accretion of this ejecta drives sustained atmospheric loss through numerous secondary impacts. In many cases, the cumulative atmospheric erosion caused by debris re-accretion can exceed that from the primary giant impact itself, often leading to the complete loss of Earth-like atmospheres. Our results highlight the crucial role of secondary impacts from giant-impact ejecta in driving the long-term atmospheric evolution, and potential habitability, of terrestrial planets.

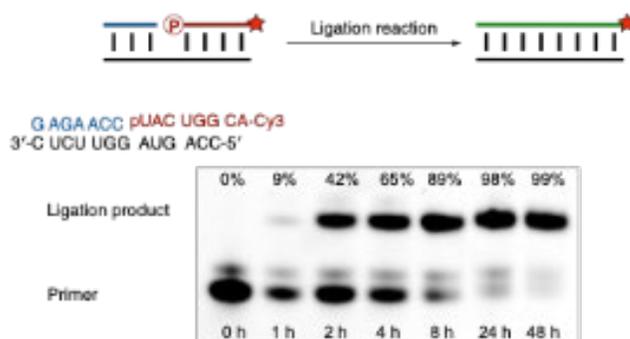
**Bruno Marinič**  
**MRC Laboratory of Molecular Biology**

### Prebiotically Plausible Synthesis of N-Cyanoimidazole for Phosphate Activation and Templated RNA Ligation

The formation of oligonucleotides from nucleotide building blocks through phosphate activation and O-P bond formation represents a key step in the synthesis of the first functional biopolymers. Prebiotically plausible phosphate activating reagents have remained elusive, with potential candidates limited by either poor reactivity or uncertain prebiotic provenance. We have proposed a prebiotically plausible synthesis of *N*-cyanoimidazole (NCI), a known and efficient phosphate activating reagent, from the reaction of imidazole with thiocyanogen, which is produced by oxidation of NCS<sup>-</sup>, and this in turn is consistent with the cyanosulfidic system we have previously reported.



We have demonstrated NCI's potential for mononucleotide activation by the formation of phosphorimidazolides, as well as RNA ligation in a nicked duplex. This work represents the RNA counterpart to the DNA ligation elucidated by Asanuma and Murayama, and a protecting group free alternative to our previous work on 5'-OH and 3'-phosphate RNA ligation. We optimized conditions for the RNA nicked duplex ligation system, demonstrated high yielding RNA ligation with oligonucleotides as short as trimers and performed the ligation with NCI derived from a prebiotically plausible mixture in good yield.



**Edoardo Gianni**

**MRC Laboratory of Molecular Biology**

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### **Development of RNA-Based Self-Replicating Systems**

The emergence of a chemical system capable of self-replication and evolution represents a critical transition in the origins of life. We are interested in establishing such a system experimentally to better understand the chemical and environmental constraints governing this transition. Our focus has been on studying RNA sequences that catalyse RNA copying, as these have the potential of driving their own self-replication. The large size (~200 nucleotides) and complexity of existing examples hinder their self-replication and suggests that such molecules would be extremely rare in sequence space. In my talk, I will describe QT45, a 45-nucleotide long RNA polymerase ribozyme, discovered from random sequence pools, that can catalyse general RNA copying using trinucleotide substrates. Thanks to its small size, QT45 can synthesise both itself and its complementary strand, the two constituent reactions of self-replication. These results indicate that RNA copying is much more abundant in RNA sequence space than anticipated, suggesting that self-replicating systems could more readily emerge both in nature and in the laboratory.

**Bence Csakany**

**Yusuf Hamied Department of Chemistry**

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### **Chirality Induced Spin-Selectivity as a Collective Phenomenon**

Many molecules essential to life are chiral, they exist in left and right-handed forms. Yet biology uses almost exclusively one handedness. This preference is yet unexplained. One proposed explanation (Ozturk 2023) relies on chirality-induced spin selectivity (CISS).

CISS is the surprising observation that chiral molecules can preferentially interact with electrons of a particular spin orientation. Electron spin can be thought of as a tiny magnet, and experiments have shown that when chiral molecules, such as DNA or small organic compounds, are placed on metal surfaces, measurable spin polarisation can result. This raises the possibility that weak magnetic environments on the early Earth might have biased chemical selection.

The difficulty in CISS explanations is in its magnitude. The fundamental relativistic effects that link molecular structure to electron spin are extremely small, too small to explain the relatively large spin polarisations observed in a multitude of molecules. We show that this gap can be resolved by considering electron-electron interactions.

Using standard Hartree–Fock molecular orbital theory, we demonstrate that a small initial spin imbalance can be amplified through Coulomb exchange interactions between electrons. In this picture, CISS is not a large fundamental interaction by itself, but an emergent, collective effect of many interacting electrons.

This provides a simple explanation for experimentally observed spin polarisations and suggests that small asymmetries could be amplified into chemically significant biases.

S. Furkan Ozturk et al. , *Origin of biological homochirality by crystallization of an RNA precursor on a magnetic surface*. *Sci.Adv.*9, eadg8274(2023).

DOI:10.1126/sciadv.adg8274

**Sai Shruthi Murali**

**Department of Physics**

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### **Confronting the Water Problem: The Lifetime of Aqueous Cyanide and its Role in Origins of Life**

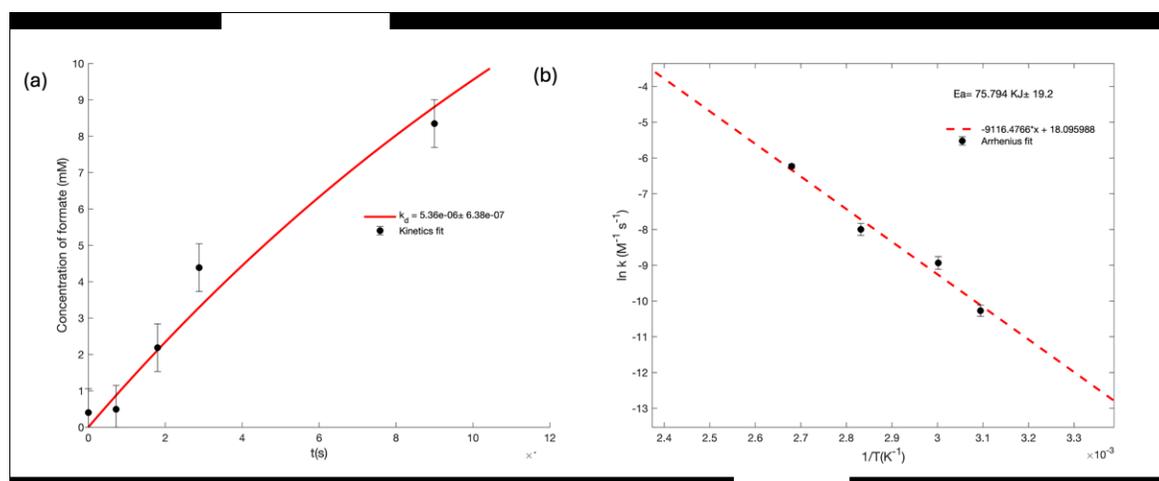
Several chemical routes are proposed to understand the synthesis of biologically significant molecules on early earth.[1] However, the research has just began to discover the feasibility of these reactions under prebiotic conditions and the physical factors influencing their efficiency in a planetary context.[2-4] Hydrogen cyanide (HCN) has emerged one of the key molecules for the synthesis of major building blocks of life – lipids, sugars and nucleotides – through a series of chemical reactions, some mediated by ultraviolet light along with other scenarios.[5, 6] The amount of cyanide available in a natural environment can be predicted from the rate at which it is produced in an environment plus the rate it is introduced to the environment, versus the rates it is destroyed and leaves the environment. One of the most important mechanisms of HCN loss is hydrolysis. The rate of hydrolysis is known to depend on the physical and chemical conditions of the environment. I will present the most comprehensive study thus far of the hydrolysis of HCN. I explore hydrolysis across a range of temperatures, pH and in the presence of salts like sulphite, sulphide and phosphate (for two example measurements, see Figure 1 (a,b)). We determine the degradation rate for this range of conditions and predict

the rate constants for acid-catalyzed hydrolysis and base-catalyzed hydrolysis of cyanide, along with uncertainties.

These uncertainties are critical for comparing our results to similar studies[ ], and applying our results to environmental conditions. We find that the hydrolysis rates are significantly influenced by pH and temperature with significant variations observed with salts. The activation energy for acid-catalyzed and base-catalyzed hydrolysis of HCN is found to be  $75.7 \pm 6.7$  KJ/mol and  $49.7 \pm 4.0$  KJ/mol, respectively. This result is consistent within the errors to the literature but are systematically faster than the literature values and favours maximum lifetime around pH-7 rather than pH-4.[4] We apply our results, in comparison to a variety of cyanide sources found in the literature to provide new predictions of cyanide availability in natural waters. Our results are critical for constraining the prebiotic environment where the prebiotic synthesis of amino acids, nucleotides and phospholipids could have occurred.

#### References:

1. Ruiz-Mirazo, K., C. Briones, and A. de la Escosura, *Prebiotic Systems Chemistry: New Perspectives for the Origins of Life*. Chemical Reviews, 2014. **114**(1): p. 285-366.
2. Sutherland, J.D., *The Origin of Life—Out of the Blue*. Angewandte Chemie International Edition, 2016. **55**(1): p. 104-121.
3. 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.
4. 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.
5. Benner, S.A., *Paradoxes in the Origin of Life*. Origins of Life and Evolution of Biospheres, 2014. **44**(4): p. 339-343.
6. Müller, F., et al., *A prebiotically plausible scenario of an RNA-peptide world*. Nature, 2022. **605**(7909): p. 279-284.



**Fig 1:** Hydrolysis of HCN at pH-12 (a) Kinetics of formation of formate ion fitted to a kinetic model to estimate the rate of formation of formate ion and (b) Arrhenius plot for HCN hydrolysis.  $E_a = 75.7 \pm 6.7$  KJ/mol

**Jose Devienne**

**Department of Earth Sciences**

**Prebiotic Magnetite Enables Chirality-Magnetic Surface Feedback**

José A. P. M. Devienne<sup>1</sup>, Ziwei Liu<sup>1</sup>, Clancy Jiang<sup>1</sup>, Nicholas J. Tosca<sup>1</sup>, Thomas Ginnis<sup>1,2</sup>,  
Dimitar D. Sasselov<sup>3</sup>, Richard J. Harrison<sup>1</sup>, S. Furkan Ozturk<sup>4</sup>

<sup>1</sup> Department of Earth Sciences, University of Cambridge, Cambridge CB2 3EQ, UK

<sup>2</sup> Department of Materials Science and Metallurgy, University of Cambridge, Cambridge CB3 0FS, UK

<sup>3</sup> Department of Astronomy, Harvard University, Cambridge, MA 02138, USA

<sup>4</sup> Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, USA

The emergence of biomolecular homochirality requires both an initial symmetry-breaking event and a mechanism to amplify and preserve a chiral imbalance. Magnetic minerals have been shown to function as chiral agents through the chiral-induced spin selectivity (CISS) effect and may have enabled homochirality on early Earth, yet the magnetic properties of magnetite formed under realistic prebiotic conditions remain unexplored. Here we show that magnetite synthesized through two geochemically plausible

pathways – UV-driven photo-oxidation and nitrite-mediated oxidation of Fe(II) – produces particles dominated by single-vortex and multi-vortex magnetic domain states. Magnetic measurements and electron microscopy confirm that these populations differ markedly from the nano-fabricated thin-film substrates conventionally used in previous CISS experiments. Using 3D micromagnetic simulations, we demonstrate that single-domain and vortex-state grains undergo irreversible, exchange-driven re-magnetization when interacting with spin-polarized homochiral compounds. This magnetic irreversibility provides a robust mechanism for storing and reinforcing weak chiral bias, suggesting that prebiotic magnetite could have contributed to the emergence and stabilization of persistent chiral bias on the early Earth.

**William McMahon**

**Department of Earth Sciences**

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### **Clay minerals reveal a global intensification of continental weathering after the evolution of land plants**

William J. McMahon, Neil S. Davies, Stefan C. Löhner, Mohd Tarique, Yorick P. Veenma, Hamilton A. Allport, James A. Craig, Cassandra Wheeler, Edward T. Tipper, David J. Wilson, Emily I. Stevenson, Sean T. Murray

Terrestrial vegetation plays a fundamental role in the operation of Earth's critical zone. Yet how the initial evolution of land plants altered global chemical weathering patterns and the long-term carbon cycle remains debated. Here we show increases in the abundance and diversity of terrigenous clay minerals that closely track major steps in plant evolution, using >25,000 individual clay grains from 120 Proterozoic and Paleozoic continental mudrocks. The proportion of terrigenous mudrocks composed of detrital pedogenic clays rises from 0.6% in pre-Silurian rocks to 24% in Middle Devonian–Permian rocks and is coeval with a decline in  $\delta^7\text{Li}$  values. We link these coupled unidirectional shifts in clay mineralogy and isotopic composition to intensified continental weathering, mediated by both plant-induced chemical weathering and enhanced landscape stability that prolonged sediment residence and soil formation. The increased longevity and abundance of clay-forming environments demonstrate the interdependence of mud retention and production, explaining the previously identified increase in continental mudrock through the Palaeozoic and reconciling longstanding contradictions between biogeochemical models and empirical evidence from the rock record.

**Joshua Shea**

**Department of Earth Sciences**

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### **Mantle Carbon Isotopes as a Record of Biosphere-Planet Redox Evolution**

Joshua Shea[1], John Maclennan[1], Marie Edmonds[1], Ery Hughes[2], Margaret Hartley[3], Sami Mikhail[4], Michael Perfit[5], Oliver Shorttle[1,6]\*

[1] Department of Earth Sciences, University of Cambridge, UK

[2] Department of Earth Sciences, University College London, UK

[3] Department of Earth and Environmental Sciences, University of Manchester, UK

[4] School of Earth and Environmental Sciences, University of St Andrews, UK

[5] Department of Geological Sciences, University of Florida, USA

[6] Institute of Astronomy, University of Cambridge, UK

The oxidation of planetary atmospheres is one of the largest consequences of life. On Earth, molecular oxygen is generated by oxygenic photosynthesis, but atmospheric oxygen accumulates only when biologically produced organic carbon is buried rather than re-oxidised. The efficiency of this process, expressed as the fraction of carbon buried as organic matter ( $f_{org}$ ), determines the long-term oxidising power of the biosphere and plays a central role in planetary redox evolution. Organic carbon is isotopically depleted in  $^{13}\text{C}$  relative to carbonate carbon, the burial and recycling of these reservoirs leaves a measurable imprint on the carbon isotope composition of the mantle. Subducted sediments transport surface carbon into the deep Earth, where it mixes with mantle carbon and is eventually returned through volcanism, allowing mantle-derived magmas to record the long-term balance between organic and carbonate carbon burial. High-precision measurements of carbon isotopes in olivine-hosted melt inclusions constrain the carbon isotope composition of the convecting upper mantle and provide new estimates of  $f_{org}$ . These results imply  $f_{org} = 0.13 \pm 0.02$ , consistent with independent constraints from sedimentary carbon inventories. For modern carbon burial rates, this corresponds to a biospheric oxygen source flux of order  $10^{12}$  mol  $\text{O}_2$  yr $^{-1}$ , sufficient to oxygenate a planetary atmosphere on geological timescales in the absence of large reductant sinks. Mantle carbon isotopes therefore provide a

geological archive of biosphere–planet interactions and a quantitative framework linking the deep carbon cycle to atmospheric oxygen evolution and planetary habitability.

**Jules Macome**

**History and Philosophy of Science**

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### **From the Chance Scenario to the Origins Contingency Hypothesis**

The chance scenario for the origin of life holds that life emerged through a series of fortuitous events rather than through processes strongly biased toward producing life. Fry (1995; 2019) has argued that such a view effectively treats the origin of life as a miracle and renders the problem scientifically intractable, because science cannot explain unique, fortuitous occurrences in the past. In this talk, I argue that this interpretation mischaracterizes what the chance scenario actually entails. Rather than appealing to inexplicable accidents, the chance scenario can be reconstructed as a scientifically meaningful hypothesis about the causal structure of life's emergence.

My key contribution is conceptual. The language of chance is often vague and misleading, conflating several different ideas: improbability, randomness, and lack of explanation. I propose instead that the underlying claim is better understood in terms of contingency, presenting the origins contingency hypothesis. Given this interpretation, the origin of life was not necessitated by chemical or physical laws in the context of early earth; rather, it depended sensitively on a specific sequence of historical events and conditions.

To succeed, the origins contingency hypothesis must (i) draw on empirical evidence about early earth chemistry and prebiotic evolution to support contingency claims, and (ii) articulate how contingent events in the deep past can nonetheless be investigated and explained. Crucially, a contingent origin of life does not undermine the scientific project of explaining life's emergence. Instead, it reframes the task as reconstructing a historically path-dependent process rather than understanding life as an outcome of natural laws.

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### **Ecological Modelling of Hycean Worlds**

The Lotka–Volterra equations have been used to model numerous coupled populations within various ecosystems on Earth. For the first time, we apply the Lotka–Volterra equations to the ecology of habitable exoplanets, specifically anoxic hycean worlds. We simulate scenarios in a vertical water column with between 1-5 bacterial species that thrive on Earth. In our modelled scenarios, we find that a range of ecological diversity is possible for microbial populations under assumed hycean conditions. For instance, fast-growing phototrophic bacteria at the top of a water column can dominate in a situation analogous to a bacterial bloom. Additionally, incorporating microbial viruses can cause ecosystem collapse but may also be beneficial to ecological diversity. Finally, our results show that the constant illumination of tidally locked oceans may increase the stability of bacterial populations. This work is an initial step towards understanding the possible ecological diversity on habitable worlds beyond Earth.