RAS Specialist Discussion Meeting: **Abiotic baselines in astrobiology**
13th January 2023, Burlington House, London

This meeting builds on the idea that we cannot expect to detect a robust “signal” of life in extraterrestrial environments unless we have properly characterised the “baseline”, i.e., the abiotic processes present in the environment of interest. Both false-positive and false-negative results in the search for life may result from a failure to discriminate correctly between the signal and the baseline. However, astrobiologists have focused almost all their research efforts on anticipating the signal and almost no effort on anticipating the baseline, which significantly hampers progress in the field. In most contexts in astrobiology, the abiotic baseline is not just noise; it may well contain signals of rather complex disequilibrium processes that are difficult to disentangle from life. This applies equally whether we are searching for evidence of life in exoplanet atmospheres, on Mars, Venus, and the icy moons, or in the oldest rocks on Earth. This interdisciplinary meeting will bring together astronomers, astrobiologists to discuss how abiotic processes can be distinguished from evidence of life in these challenging environments.

10-10.30	**Registration and coffee**
10.30-10.45	Sean McMahon, University of Edinburgh
10.45-11.00	Paul Rimmer, University of Cambridge
11.00-11.15	Sean Jordan, University of Cambridge
11.15-11.30	Tereza Constantinou, University of Cambridge
11.30-11.45	**Discussion/break**
11.45-12.00	Fabian Klenner, Freie Universität, Berlin
12.00-12.15	Mark Fox Powell, Open University
12.15-12.30	Electra Kotoupoulou, Université Paris-Saclay / CNRS, Orsay
12.30-12.45	Pamela Knoll, University of Edinburgh
12.45-13.00	Julie Cosmidis, University of Oxford
13.00-14.00	**Lunch**
14.00-14.30	*Jennifer Eigenbrode, NASA Goddard Space Flight Centre **(keynote)**
14.30-14.45	*Lena Noack, Freie Universität Berlin
14.45-15.00	Giovanna Tinetti, University College London
15.00-15.15	Kevin Heng, Ludwig-Maximilians Universität München / University of Warwick
15.15-15.30	Cat Gillen, Durham University
15.30-15.35	**Close**

***These speakers are joining us remotely. All others will be present in-person.**

10.00–10.30 Registration and coffee

10.30–10.45 Sean McMahon
Ambiguity in astrobiology

We do not know if extraterrestrial life exists or not. But we do know that non-biological patterns and processes can resemble biology in interesting ways: there are many life-like things other than life itself, particularly in disequilibrium conditions conducive to self-organisation and complex chemistry. On the early Earth such phenomena ultimately crossed the fuzzy divide from non-life to life. On other planets they may never have done so, but may still look misleadingly like "biosignatures". To open our discussion meeting, I will summarise a few examples of this problem in the context of Mars exploration. I will argue that "biogenicity criteria", "confidence scales", machine learning algorithms, etc., do not solve the problem unless grounded in extensive empirical study of abiotic complexity in planetary environments. In this connection I will highlight some recent work by the philosopher of science Peter Vickers on "the problem of unconceived alternatives" and its significance for astrobiology.

10.45–11.00 Paul Rimmer
Disequilibrium as a Biosignature, vs. Disequilibrium in the Abiotic Baseline

Disequilibrium has long been identified as a potential biosignature, but it can be difficult to constrain the degree of disequilibrium without a holistic model incorporating the planet and its host star. Abiotic processes can also produce disequilibrium chemistry in planetary atmospheres. Finally, observational biases can introduce the appearance of disequilibrium chemistry where none exists. I will discuss each of these cases using the claimed biosignature set of $CO2$ and $CH4$.

11.00–11.15 Sean Jordan
Metabolic signatures of an aerial biosphere in the clouds of Venus.

One possible explanation to chemical anomalies observed in the atmosphere of Venus is the presence of an aerial biosphere in the temperate cloud layer. We investigate the hypothesis of life in the clouds of Venus from the perspective of atmospheric chemistry by employing the principle that life, if present, will likely be consuming chemicals from it's environment for use in an energy-metabolism. We present a coupled photo-bio-chemical model of Venus's atmosphere in order to test whether the proposed energy-metabolisms of a biosphere in the cloud layer could explain the observed atmospheric chemistry of Venus.

11.15–11.30 Tereza Constantinou
Venus as Candidate for Constraining Volcanism and Surface Conditions

We look at volcanism on Venus as a component of the abiotic baseline. We identify the atmospheric chemistry that can be explained by volcanism, and use that chemistry to constrain the magma geochemistry. We then make predictions about the mineralogy that would be expected if the atmosphere is at equilibrium with the surface on Venus.

11.30–11.45 Discussion/Break

11.45–12.00 Fabian Klenner, Nozair Khawaja, Jon Hillier, Frank Postberg
Discriminating between abiotic and biotic fingerprints of biologically-relevant organics in ice grains emitted from icy moons

The analysis of mass spectra of ice grains emitted by Saturn's moon Enceladus rendered the moon's subsurface water ocean to be habitable. Laboratory analogue experiments can be used to predict the mass spectral appearances and detection limits of biologically-relevant organics, if these compounds are embedded in the ice grains and encountered during a future spacecraft flyby. We here present experiments with amino acids, fatty acids, DNA and lipids and demonstrate that instruments on board future space missions will be capable of detecting these molecules down to the ppm or ppb level in ice grains emitted from ocean worlds. While amino acids and fatty can be formed through abiotic or biotic processes, building blocks of DNA and lipids unite terrestrial life forms. Understanding the appearances of organics in ice grain mass spectra is particularly relevant for NASA's future Europa Clipper mission, scheduled for launch in October 2024 to investigate the habitability of Jupiter's ocean moon Europa.

12.00–12.15 Mark Fox Powell

Title and abstract T.B.C.

12.15–12.30 Electra Kotopoulou

Mind the biomorphs: lessons from lab and field studies in the search for traces of Life

The unequivocal recognition of remnants of Life/biosignatures in the rocky record of Earth and other planets/moons is the "holy grail" of Astrobiology. Yet, the origin of putative Life traces preserved in rocks is much debated owing to two main reasons. Firstly, abiotic, far-from-equilibrium precipitation reactions can produce morphologically, structurally and chemically similar footprints to those produced by biologic processes. Such structures are called 'biomorphs' *sensu lato* and include a plethora of inorganic and organic features. Secondly, geological processes such as diagenesis, deformation, metamorphosis and volcanism alter and may overprint the presence of biosignatures. In this communication I will provide an overview of: i) filamentous and vesicular, iron-silica biomorphs that mimic iron microfossils found in Precambrian formations of Earth, and ii) different inorganic biomorphs and pseudosignatures found in modern mineral precipitates from a terrestrial Martian analogue-site. The aim of this talk is not only to raise awareness about the existence of biomorphs and how these are implicated in Life detection studies, but also to bring forward analytical limitations that hinder their differentiation from true Life traces.

12.30–12.45 Pamela Knoll

Self-organization of Metal Carbonate-Silica Nanocrystals into Biomorph Microstructures

Biomorphs are abiotically formed polycrystalline microstructures composed of metal carbonates that coprecipitate with small amounts of silica. The result is hierarchically ordered biomimetic forms such as leaf-like sheets, double helices, funnels, "worms", and coral-like shapes created by the self-organization of thousands of coaligned metal carbonate nanorods. Early stages of growth reveal the nanorods are formed from a nonclassical crystallization pathway with even smaller nanodot units that attach at the active growth front to form the elongated rods. At the micrometer level, simulations based on nonlinear wave dynamics in sub-excitable media are able to reproduce the experimental pseudo two-dimensional sheet structures.

12.45–13.00 Julie Cosmidis

Carbon-sulfur biomorphs as potential false positives in the search for life

The rock record of early Earth contains numerous examples of microscopic organic filaments and spheres, commonly interpreted as fossil microorganisms. Microfossils are among the oldest traces of life on our planet, making their correct identification crucial to our understanding of early evolution. They are furthermore potential targets for astrobiological investigations on rocky planets. Yet, spherical and filamentous microscopic objects composed of organic carbon and sulfur can form in the abiogenic reaction of sulfide with organic compounds. These objects, called carbon-sulfur biomorphs, spontaneously form by self-assembly under geochemical conditions relevant to sulfidic Precambrian environments, as well as some environments of early Mars. These biomorphs adopt a diversity of morphologies that closely mimic a number of microfossil examples from the ancient rock record. Here, I will present results on the formation conditions of the C-S biomorphs and preservation potential in rocks. I will also propose some hypotheses regarding their self-assembly mechanism, and possible implications on biosignature research on early Earth and other planets.

13.00–14.00 Lunch break

14.00–14.30 Jennifer Eigenbrode
A Systems Perspective on Organic Chemical Evolution

The search for extraterrestrial life in the Solar System aims to detect a “signal” of life, which is one endmember of the abiotic-to-biotic continuum of chemical possibilities. Ideally, missions will sample and measure materials that reflect a single point within this binary spectrum. However, planetary bodies and their environments are complex systems driven by a wide range of processes over time. Organic chemicals can be altered, mixed, partitioned, condensed, recycled, or lost to volatiles that escape the planetary body; and these changes can be compounded over time. Conversely, organic chemicals might get locked into a steady state and preserved, or encountered in their native source state. The same possibilities apply to other physical and chemical records that define the context for organic chemical measurements. To improve the probability of mission success where the aim is to characterize the evolutionary status within the abiotic-to-biotic continuum, a more comprehensive framework for understanding organic chemical evolution—one that embraces this systems perspective—will be presented.

14.30–14.45 Lena Noack
Abiotic atmosphere diversity: Can we avoid false-positive biosignatures?

The possible evolution paths of a rocky planet can be very diverse, and depend on several different interior and exterior processes, that are related to for example 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 build-up capacity of a secondary atmosphere, can help us to understand the range of 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.

14.45–15.00 Giovanna Tinetti
Prospects to identify habitable environments in our Galaxy through remote sensing spectroscopy

The acquisition of spectroscopic data of the Earth’s atmosphere from artificial satellites has changed our perception of terrestrial life and has provided, for the first time, a rigorous scientific framework to search for life elsewhere in our Galaxy. Seen from the outside, our planet appears to be similar, for some aspects, to other planets, yet it shows distinctive signatures of a life-hosting planet, which cannot be found elsewhere in the Solar System. Lovelock (1965) suggested to search for the presence of compounds in the planet’s atmosphere which are incompatible on a longterm basis, i.e. in chemical disequilibrium – for example, oxygen and hydrocarbons co-exist in the Earth’s atmosphere. While being the only recipe of biosignature currently available, is that a robust one?

The discovery of planets around other stars will offer in the next decades the chance to test this hypothesis outside the boundaries of our Solar System. While the number of discovered planets located at the right distance to the star to host some liquid water is increasing by the day, are those objects really habitable or inhabited?

From the little we know about these alien worlds, it appears we need to progress further in the understanding of galactic planetary science before we can commit to a conclusive answer concerning habitability. In this talk I will review the current knowledge about exoplanets and what are, in my view, the necessary steps to be taken in the future to address the question of planetary habitability.

15.00–15.15 Kevin Heng
The secondary (outgassed) and hybrid atmospheres of exoplanets

The Solar System misleads us: it shows a dichotomy of four gas/ice giants with primary (hydrogen-dominated) atmospheres that reflect the composition of the primordial solar nebula versus four rocky planets with secondary atmospheres sourced by geochemical outgassing. By contrast, exoplanets exist in a continuum between being Earth- and Neptune-sized, implying that there should be a continuum between primary and secondary atmospheres. I will show highlights of recent work that attempts to treat both primary and secondary atmospheres within a common theoretical framework. A specific highlight is that methane-dominated atmospheres are particularly difficult to make (theoretically).

15.15–15.30 Cat Gillen
The call for a new definition of biosignatures

The term ‘biosignature’ has become increasingly prevalent in the astrobiological literature as our ability to search for life advances. Although this term is evidently useful to the community, its definition is not settled. Existing definitions conflict sharply over the balance of evidence needed to establish a biosignature, leading to misunderstanding and confusion about what is being claimed when biosignatures are purportedly detected. To resolve this, we offer a new definition of a biosignature as *any phenomenon which is known can result from biological processes and whose known potential abiotic causes have been reasonably ruled out*. This definition is strong enough to do the work required of it in multiple contexts, whilst addressing the problem of unconceived abiotic mimics that is central and pernicious to biosignature research. We show that the new definition yields intuitively satisfying judgments when applied to historical biosignature claims. We also reaffirm the importance of multidisciplinary work on abiotic mimics to narrow the gap between the detection of a biosignature and a confirmed discovery of life.

15.35 End