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Bioverse: Origins of Life

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ABSTRACT

tbd.

1. INTRODUCTION

Introduce OOL, the importance of planetary contexts

2. ORIGINS OF LIFE SCENARIOS AND THEIR PREDICTIONS

Present widely discussed OOL scenarios and their predictions on exoplanet observables; derive testable hypotheses.

In this section, we present some of the most prominent origins of life scenarios and their observational predictions. We focus on the necessary environmental conditions for the processes and reactions inherent to each scenario, and aim to identify distinct observables that are accessible via present and near-future remote sensing techniques.

2.1. *Hydrothermal vents*

e.g., Russell+2010 ... The hydrothermal vents scenario requires a direct contact of an ocean and the planetary mantle/crust. This requirement is not met on an ocean world with large amounts of water, where the water pressure on the ocean floor is high enough to form high-pressure ices (Noack+2016).

see discussion in Kite & Ford 2018 Sect. 6.4

Prediction: Planets with high-pressure ices do not show biosignatures.

2.2. *Subaerial ponds*

... By its nature, the subaerial ponds scenario relies on rock surfaces exposed to the planetary atmosphere. Water worlds that have their entire planetary surface covered with water contradict this requirement and do not allow for the wet-dry cycling inherent to this origin of life scenario. The competition of tectonic stress with gravitational crustal spreading (Melosh 2011) sets the maximum possible height of mountains, which in the solar system does not exceed $\sim 20\,\mathrm{km}$. Such mountains will be permanently under water on water worlds. Another impediment to wet-dry cycles is tidal locking of the planet as it stalls stellar tide-induced water movement and diurnal irradiation variability.

Prediction: Biosignatures occur outside the tidal locking zone and at bulk densities consistent with exposed rock..

2.3. *UV light*

... A strong requirement for the cyanosulfidic scenario is a sufficient Ultraviolet (UV) flux incident on the planet. On planets that have never received significant UV fluxes, the relevant photochemistry is limited.

Prediction: Past UV flux and the occurrence of biosignatures are correlated.

2.4. *Other Processes related to the Origins of Life*

2.4.1. *Planetary redox state and evolution*

The synthesis of prebiotic compounds requires moderately to highly reduced chemical environments (Kitadai & Maruyama 2018, Benner+2020, Sasselov+2020, Lichtenberg & Clement 2022). ... Surficial origins of life chemistries are dependent on the redox state of a planet being ∼neutral (not too reduced or oxidized) to allow the presence of precursor molecules like HCN. The planetary redox state leaves an imprint on its atmospheric composition and thus planet size (very reduced atmospheres are large) and spectral signatures. Connected to the cyanosulfidic scenario, the pond scenario, and the impact trigger.

2.4.2. *Impact trigger*

Iron-rich impactors have been suggested to intermittently provide the reduced environments favored by prebiotic chemistry (e.g., Sekine+2003, Hashimoto+2007, Kuwahara & Sugita 2015, Genda+2017, Wogan+2023). ... Prebiotic synthesis triggered through reduced impactors that stochastically create transiently reducing or neutral atmospheres requires a certain composition of the impactors, the planet to not be in a magma ocean state (???) (Lichtenberg & Clement 2022), and, related to this requirement, occurrence of impact events during early planetary evolution. Suggested observables are stochastic increases in brightness temperature, transient increases of planet size, and change of planet composition (decreasing with decreasing impact rate, i.e., stellar age).

2.4.3. *Origins of Life Hypotheses*

... Figure 1 lists the hypotheses derived from the predictions of each OOL scenario. ...

3. HYPOTHESIS TESTS

Briefly introduce Bayesian model comparison, then present the particular hypotheses in their mathematical form.

3.1. *Bayesian hypothesis testing with* `Bioverse`

3.2. *H1: Life only originates in hydrothermal vents*

The hydrothermal vent scenario does not allow oceans deep enough to form an impenetrable layer of high-pressure ice on its floor. The resulting allowed parameter space is described by a lower limit on the bulk density.

+ exclude atmospheric signature for water worlds?

...

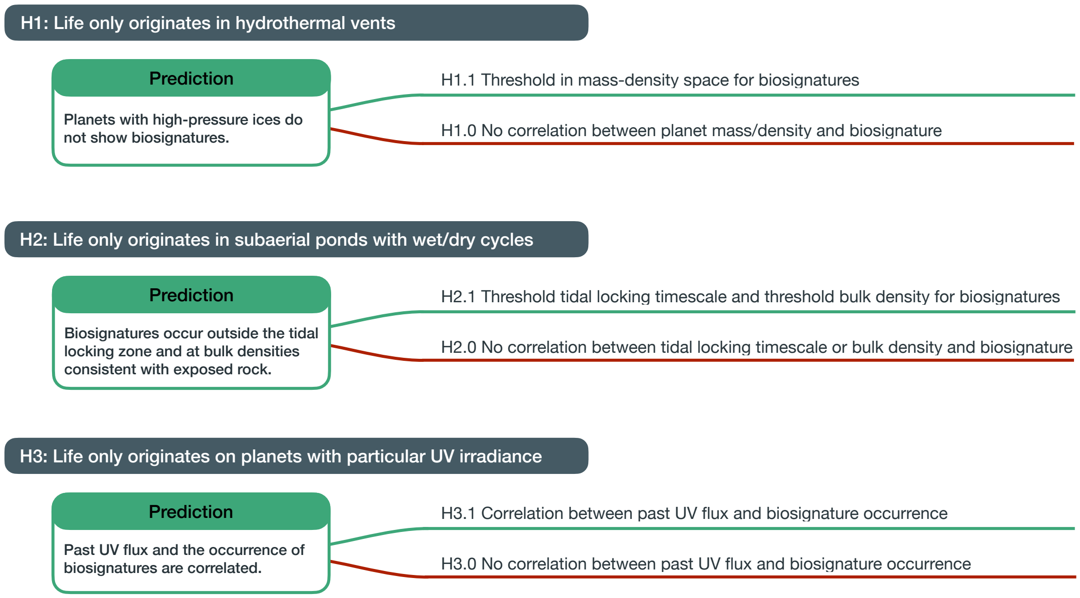

Figure 1. Origins of Life scenarios, their predictions on exoplanet observables, and derived population-level hypotheses.

3.3. *H2: Life only originates in subaerial ponds with wet/dry cycles*

We parametrize the required exposed land surface in this scenario as a lower limit in bulk density that is higher than for H1. Further, the tidal locking timescale of the planet may not be smaller than the age of the system. ...

3.4. *H3: Life only originates on planets with particular UV irradiance*

We test a UV irradiance requirement by relating the occurrence of life on a planet with a minimum past UV flux, which is a function of ...?

SUKRIT

OPTIONAL: "We further test the scenario of a linear correlation of past UV flux and biosignature occurrence rate. This test requires the detection of multiple biosignatures."
Test for negative correlations as well?

4. EXOPLANET SURVEY SIMULATIONS

Focus on molecular Oxygen as a biomarker(?)

A commonly discussed biomarker is molecular Oxygen (O_2), which on Earth emerged as a byproduct of photosynthesis during the Proterozoic era. While not the only atmospheric species discussed as a signature for planetary life CITE, we focused on O_2 as a representative biomarker for our spectroscopic survey simulations.

4.1. *Habitable Worlds Observatory*

4.1.1. *target list*

Provisional stellar target List for the habitable Worlds Observatory: (Mamajek & Stapelfeldt 2023)

4.2. *Nautilus*

4.3. *LIFE*

5. RESULTS

5.1. *Information content in mass-density space*

5.2. *Information content in tidal locking timescale-density space*

5.3. *Correlation of past UV flux and biosignature occurrence*

6. DISCUSSION AND CONCLUSIONS

6.1. *What do we learn from a single biosignature detection?*

discuss constraining power on OOL of a convincing biosignature detection on a single planet, depending on the position of the planet in the parameter space we explored.

6.2. *Constraining power for the origins of life as a function of biosignature location*

How does the location of biosignature detections impact the credibility of OOL scenarios?

biosignature on M dwarf planet vs. FGK: Impact on UV flux requirement?

6.3. *Conclusions and future work*

REFERENCES

Mamajek, E., & Stapelfeldt, K. 2023, 55, 116.07