National Aeronautics and Space Administration

FY23 Strategic Initiatives Research and Technology Development (SRTD)

Assessing Origin of Life (OOL) Scenarios for Exoplanet Studies

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Strategic Focus Area: Developing tools for scientific optimization of missions | **Strategic Initiative Leader:** Charles Lawrence

Objectives:

- Identify general origin-of-life (OOL) requirements for a habitable exoplanet (e.g., chemical nutrients, physical/energetic conditions, time duration). Identify conditions that would be most likely support prebiotic chemistry on exoplanets.
  - We define OOL as a **transcription and translation** (DNA -> RNA -> proteins) system, with enzyme-driven metabolic networks contained within a cellular membrane
- Assess planet system types (as a function of system age, atmospheric composition, size, mass, stellar type) that might be able to support prebiotic or OOL processes using a suite of theoretical models and lab experiments.
- Determine what observables can support evidence of OOL conditions at various points in a planet's geologic history.

Background:

- Current/future missions to determine exoplanet "habitability" aim to detect certain molecules (e.g., H_2O, CO_2, CH_4) in the planet's atmosphere
- To determine whether life exists on a planet, it must not just be habitable, it must also have facilitated an OOL event
- We have Earth as our only example of a 'successful' OOL, and from Earth we know that geological and mineral conditions are important

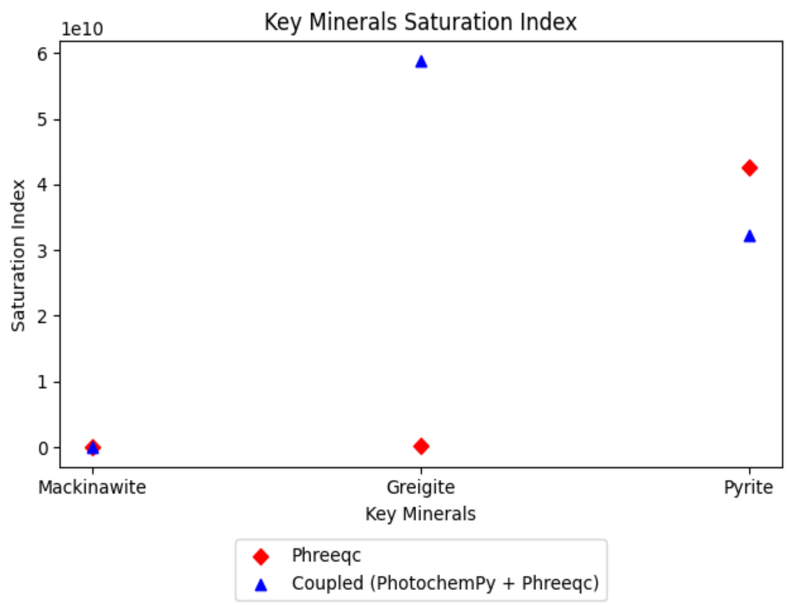

Figure 1: Simulations from the Atmosphere-Rock-Ocean (AROC) model show that the saturation index of iron-bearing minerals important for OOL differs widely with the inclusion of photochemistry.

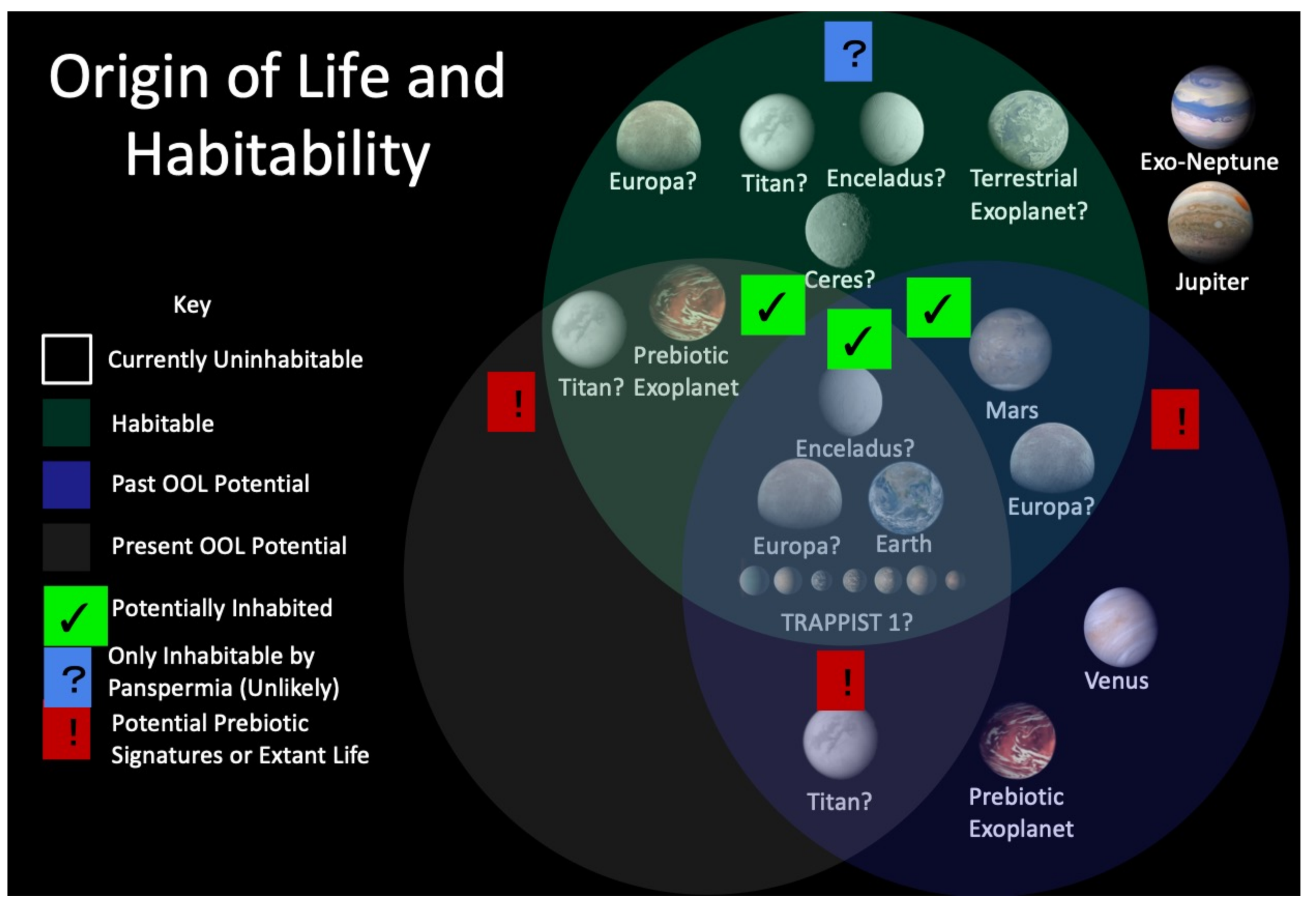

Figure 2: Venn diagram depicting the OOL and habitability potential for bodies inside and outside the solar system (Keller et al., in prep).

Approach and Results:

We focus on **mineral/enzyme transitions** associated with three bioessential elements relevant to exoplanet environments and OOL on Earth: Iron (Fe), Nitrogen (N) and Sulfur (S).

- We have begun work investigating Fe-bearing minerals
  - Fe is highly redox active / reactive
  - Fe is abundant on terrestrial planets
  - Redox behavior is known (Eh/pH diagrams) for input into models
  - There is a substantial literature about Fe minerals as catalysts / reactants in OOL reactions
- Janet Teng (MIT), investigated the importance of Fe mineral chemistry and photochemistry on OOL (Fig. 1, Table 1)
- Summer intern Finnegan Keller (Brown) conducted lit review synthesizing recommendations and findings from the Astro2020 and Planetary Decadal Surveys, alongside current research literature, to create a roadmap for determining OOL on exoplanets (Fig. 2, Table 2). This will result in a manuscript to be submitted to PNAS.

Significance/Benefits to JPL and NASA:

- This research fills a crucial gap in infusing astrobiology and life detection into future exoplanet missions, including the Habitable Worlds Observatory (HWO).

Table 1: The inclusion of photochemistry dramatically changes the pH and the pE of a terrestrial exoplanet. Simulation results from AROC by intern Janet Teng.

	Temp (°C)	pH	pE
Equilibrium aqueous chemistry	55	6.5	4
Coupled (Photochemistry + Equilibrium Aqueous Chemistry)	55	8.590	-5.694

Table 2: Fundamental ingredients for evaluating OOL potential (Keller et al., in prep).

	Energy	Building blocks	Solvent	Time
Why does life need it?	To trigger prebiotic synthesis and power life	To make up life itself	To house life	To enable the formation and evolution of life
How does life get it?	Redox reactions	Accretion, migration, impacts	Ocean, freshwater pool	Sustained energy, building blocks, and solvent
How can we detect it?	Stellar classification, mean planet star distance, magnetic field, ocean glint	Atmospheric spectroscopy, planetary disk and formation studies	Ocean glint, atmospheric water signatures	Stellar age dating

Publications:

Keller et al., in prep
Ruby et al. 2006

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