RPC 2020

Virtual Research Presentation Conference

Prebiotic and Microbial Bioindicators for Exoplanet Discovery

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Program: Topic RTD

Assigned Presentation # RPC-031

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Tutorial Introduction

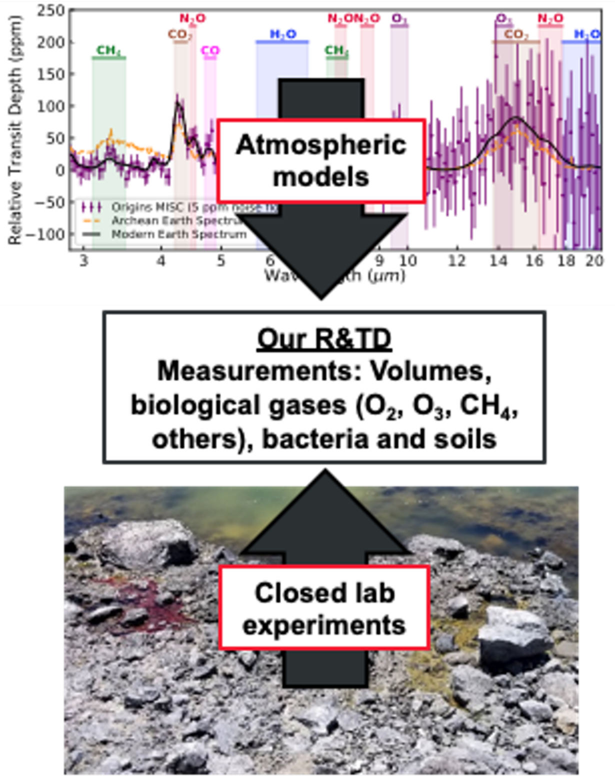
Abstract

The aim of this TRTD is to assess the habitability of potentially habitable exoplanets using a laboratory-to-model approach, with real microbial gas outputs from laboratory experiments that will serve as inputs to a surface-to-atmosphere theoretical model. In this way, we can link our theoretical understanding of atmospheric chemistry on potentially habitable exoplanets (whose atmospheres can be characterized by remote telescopes) to the very biology and metabolisms found in nature.

Problem Description

- a) Context
  - a) The assessment of exoplanet habitability is predominantly based on the measurement of biosignature gases such as methane, oxygen, carbon dioxide, and ozone
  - b) Because exoplanets are distant, this is predicated on an ability to detect these molecules on a global scale by remote telescopes
  - c) Requires an investigation that links detections of biosignature gases to the potentially biogenic sources that emit these gases at the planetary surface
- b) Advancement of the state of the art
  - a) Previous exoplanet modeling efforts (e.g., Seager et al. 2013) linking biosignature gas detections with biomass estimates were based on thermodynamic models and not direct measurement of laboratory samples
  - b) This work quantifies these processes through gas measurements of actual microbial communities, and trace their evolution through a surface-to-atmosphere model including aqueous geochemistry and photochemistry.
- c) Relevance to NASA and JPL
  - a) Results will enable recommendations for abundances, wavelength coverage and detection sensitivity of biosignatures in terrestrial HZ exoplanet atmospheres
  - b) Strengthens JPL's broad expertise in exoplanetary science. Leverages cross-disciplinary expertise across laboratory and campus.
  - c) Provides NASA with more comprehensive understanding of atmospheric biosignatures; complementary to previous model-driven efforts

*Exoplanet atmospheric bioindicators**



Atmospheric models

Our R&TD
Measurements: Volumes, biological gases (O_2, O_3, CH_4, others), bacteria and soils

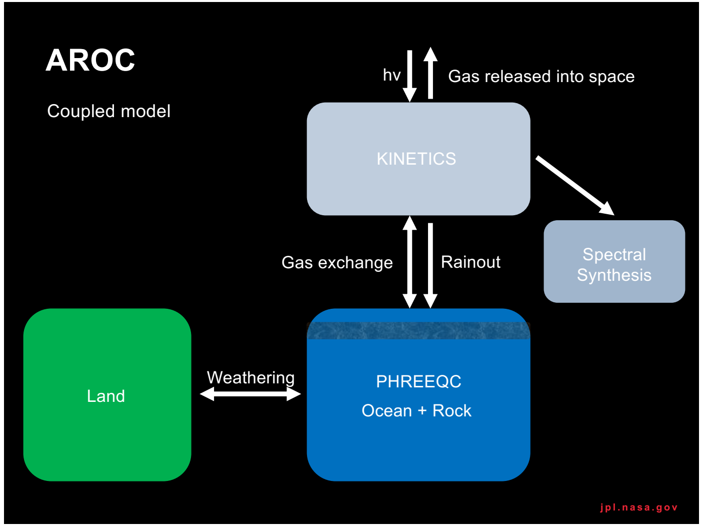
Closed lab experiments

Two distinct microbial communities

Methodology

- a) Laboratory Work
  - a) We selected three bacteria who represent different terrestrial exoplanet climates, are known to produce biogenic gases (e.g. CO_2, CH_4), and have doubling times that are on the order of 4-5 hours (so that experimental repeatability and control groups are built with confidence).
  - b) Bacteria are cultured in a closed system to allow for significant growth, which will increase our yield of gas measurements such that we can measure gaseous release and gas production over time
  - c) Measurements made using Mark Anderson's Analytical Chemistry Lab
- b) Modeling Work
  - a) Atmosphere-Rock-Ocean-Chemistry (AROC) model couples an aqueous geochemistry code and KINETICS (photochemistry code) to trace surface-to-atmosphere chemistry
  - b) Focus on studying Earth’s Great Oxidation Event (GOE), the bulk geochemical and driving forces for which are still poorly understood on Earth, and will help inform how a exoplanetary habitability may evolve on an global scale

Bacterial Species	Exoplanet Climate Analog	Doubling Time (Optimal conditions)
Vibrio	Water-dominated	49 minutes
Bacillus Subtilis	Rocky	72 minutes
E. coli	General / multi-environmental	26 minutes



AROC

Coupled model

Laboratory Results

a) All bacteria were cultured overnight to grow to 10^4 cell concentration (and hence viable for measurements)

b) While the initial plan was to make measurements after the doubling period was reached for each bacteria, we instead chose to take measurements at the beginning and at the end followed eventually by single measurements if we needed finer time resolution

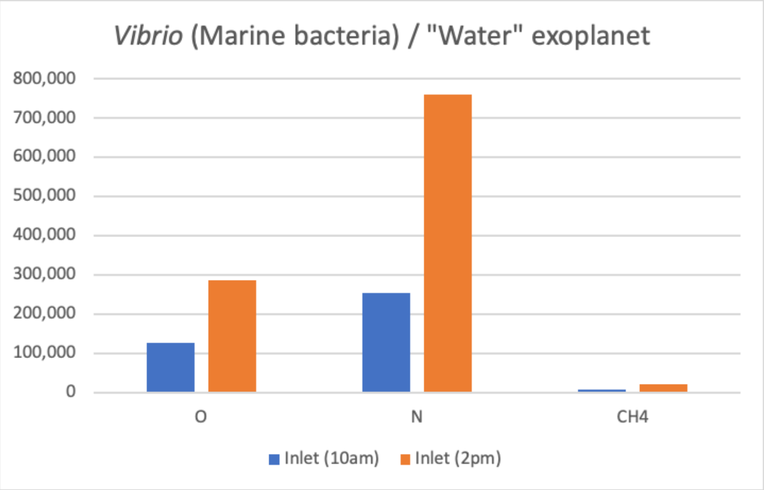
c) The clear cumulative change in oxygen, nitrogen, and methane for each bacteria shows the experiment process and standard operating procedure for this type of gas measurement was successful

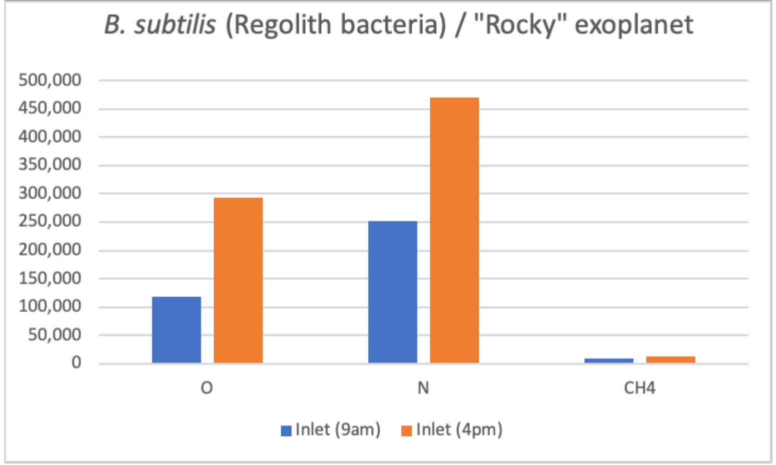
  a) The rate of increase per gas species depends on the individual bacteria and its metabolism

d) Next steps

  a) Measure gas outputs for different types of bacteria using the new Origins and Habitability Lab (OHL) gas injected gas chromatograph (GC), which allows for higher sensitivity and temporal resolution

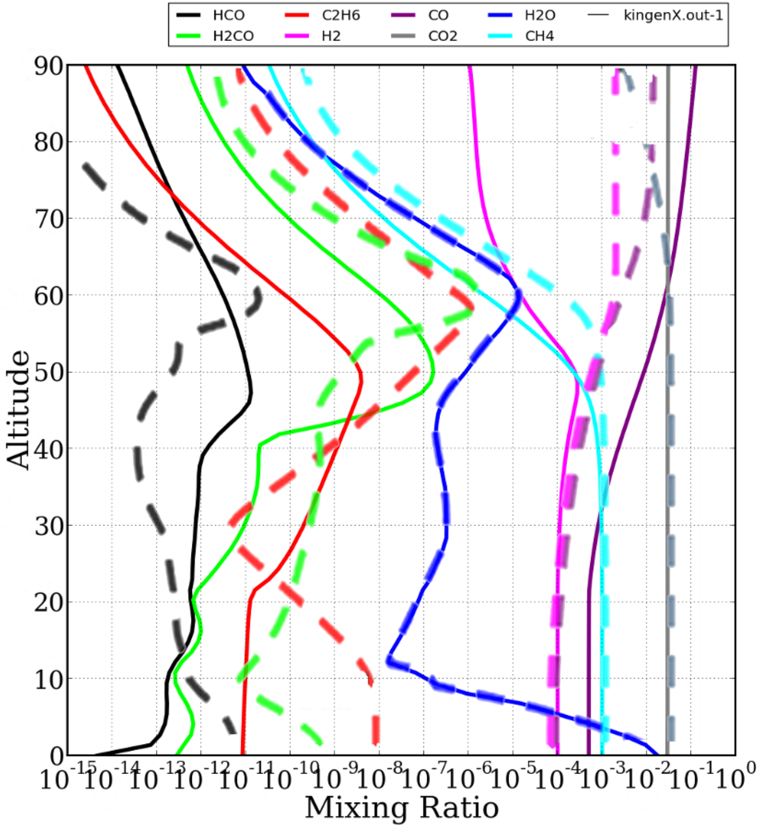
  b) We could not complete the soil experiments that were originally proposed due to COVID-19, but these are planned for future R&TD and NASA R&A proposals





Modeling Results

- a) **Theoretical modeling has continued apace with significant progress, even in the midst of remote work**
- b) Last year, we constructed an aqueous chemistry model for the Archean ocean and rocks, and this year, we concentrated efforts in developing an Archean photochemical model
- c) Preliminary Archean photochemical model incorporates hydrogen, oxygen, carbon, nitrogen, and sulfur chemistry
- d) Currently benchmarking model against the state-of-the-art (Liu et al. 2019)
  - a) Discrepancies do exist between our model and the Liu+ model due to different inputs and assumptions (different assumed spectral age; different O2 photolysis rates)
  - b) We are currently communicating with the lead author, Dr. Liu, to resolve model differences
- e) Next steps
  - a) After benchmarking is complete, we will fully couple the atmospheric chemistry model with rest of AROC
  - b) First apply AROC to simulate hydrogen escape and investigate interactions of atmospheric-ocean-rock chemistry that alter the atmospheric oxidation state



Publications and References

Liu, P., Harman, C. E., Kasting, J. F., et al. 2019, Earth and Planetary Science Letters, 526, 115767