National Aeronautics and Space Administration

Prebiotic and Microbial Bioindicators for Exoplanet Discovery

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Program: Topical R&TD

Project Objective:

Assess the habitability of Earth-like exoplanets using real microbial gas outputs from laboratory experiments as inputs to a surface-to-atmosphere theoretical model.

Benefits to NASA and JPL (or significance of results):

- Being able to associate our microbial in-situ samples with biogenic spectra associated with potential metabolisms would improve on the initial studies that previous exoplanet groups have conducted, but do not directly relate to life processes.
- Ultimately, the search for biosignatures and bioindicators in terrestrial exoplanet atmospheres is a main objective of future astrophysics large mission concepts LUVOIR, HabEx, and Origins, all of which have JPL involvement.

Laboratory Work: Measures surface biology, gas release from biogenic sources

Bacterial Species	Expected Gas Outputs	Doubling Time (min, hrs)
Clostridium	H, CO_2, N, O	8-10 min
Colwellia	O	2-4 hrs
Staphylococcus	CO_2	27-30 min
Methanobacterium	CH_4	2.3 hrs

Table 1: *List of the four chosen bacteria for our microbial measurements, their expected gas outputs, and their growth rate over time. We explicitly choose those that will have short doubling times, so that we may yield appreciable gas for our measurements.*

Figure 2: *Closed bottles resembling our experiments that will release biotic gas over time in headspace sections of the bottles.*

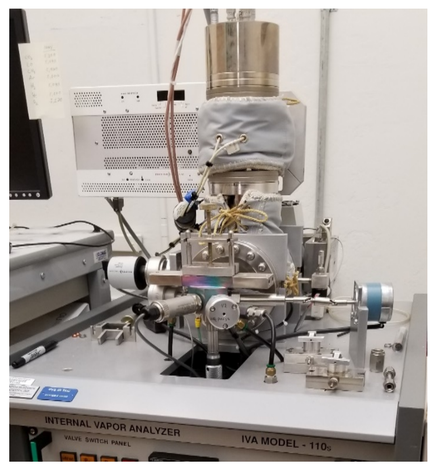
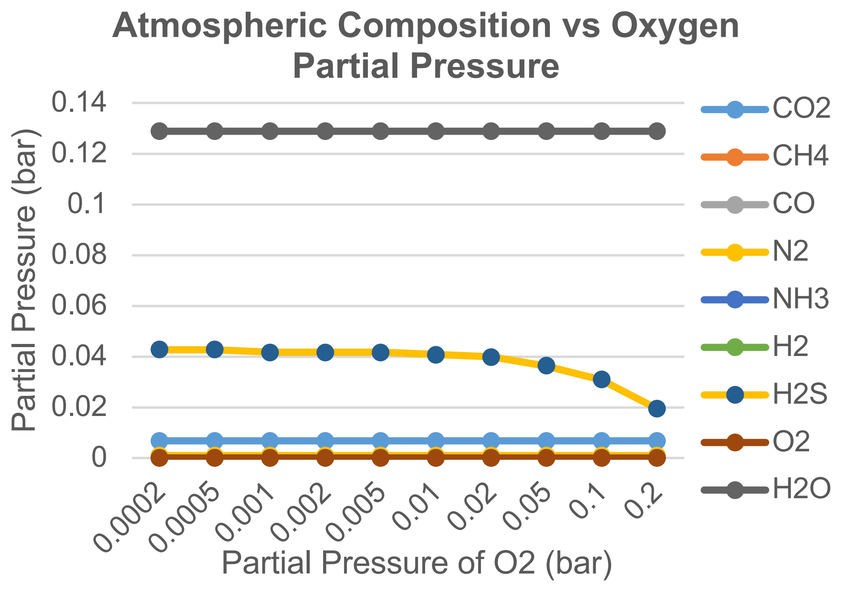


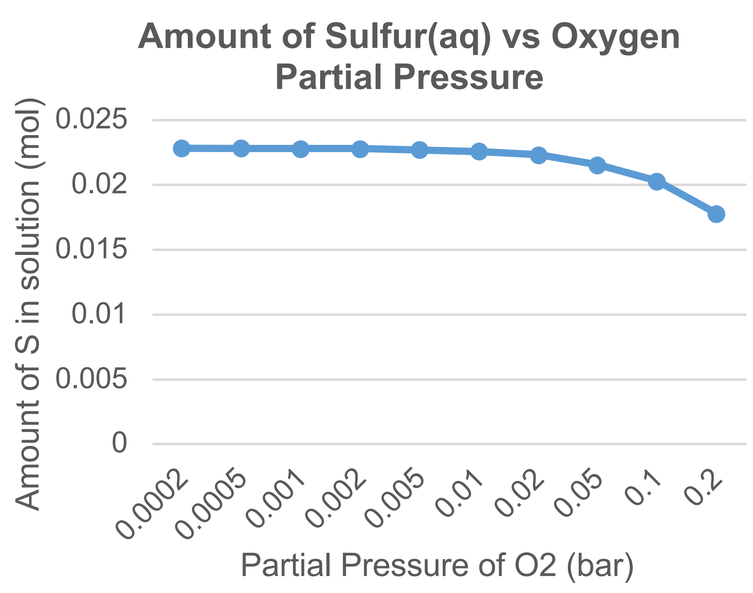
Figure 3: *Preliminary setup of our gas analysis prior to GC analyses. This gas analyzer has the temporal resolution to measure gases in-between doubling time periods – allowing for a high fidelity to the amount of gases produced by the bacteria.*

Our investigation seeks to quantify the spectra of gases produced by single-bacteria species (*Table 1*). The number of experimental runs depends on the control measurements and how often we expect to see changes in gas buildup in the closed bottle systems. These spectra will be analyzed using a "blank" bottle as a reference such that gas production can be measured as a function of time. We will use our gas chromatograph (GC) to isolate minor gas products from amino acids and other fatty acids, which could be used to quantify the longevity of some of the "surface" biomarkers well after the biology within the closed-system bottles has died.

Modeling Work: Link surface sources to chemical evolution of atmosphere

Figure 4: Results from a test AROC simulation showing atmospheric abundances (left) and elemental sulfur in solution (right) for an Archean-Earth system subject to cumulative incremental amounts of O_2 to the atmosphere *as a proxy for a biological gas emission. Because of the added amounts of O_2, S was removed from the atmosphere and solution and shown to be sequestered into minerals, mainly barite ($BaSO_4$). Note also the decrease in partial pressure of H_2S in the atmosphere. Although oversimplified,* ***this example demonstrates AROC's ability to simulate how gas emissions interact with geochemistry on a planetary scale, and suggests important insights on the impact of a large biosphere on planetary atmospheric composition.***





We will use the gas yields from our microbial experiments as inputs to the Atmospheric--Rock-Ocean-Chemistry (AROC) model, which couples an aqueous geochemistry model as a surface lower boundary (PHREEQC; Parkhurst & Appelo 2013, USGS Techniques and Methods, book 6, chap. A43, 497) with an atmospheric photochemical model (KINETICS; Yung et al. 1984, ApJS, 55, 465). In this way, **we can use real laboratory inputs (*Fig. 3*) to quantitatively determine how chemistry in the atmospheres of terrestrial exoplanets evolve when interacting with biogenic sources on the surface (*Fig. 4*)**. Moreover, this approach can be used to simulate major microbial events on Earth and Earth-like planets, where the forced outputs of cyanobacteria and other evolving species had an impact on the atmosphere such that its composition was changed due environmental equilibration and nutrient cycling.

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Poster No. RPC-031