Atmospheric Biosignatures

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A planetary biosignature is a way that life has modified its environment in a potentially detectable way.
Biosignatures need to be:
1. Reliable
2. Survivable
3. Detectable
What does life produce?

Can a dead planet fool us?

How do we interpret limited data?

How do we quantify our certainties?

Figure by Aaron Gronstal
NExSS Biosignatures Workshop/SAG16
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At the simplest level, chromatin is a double-stranded helical structure of DNA.

DNA is complexed with histones to form nucleosomes.

Each nucleosome consists of eight histone proteins around which the DNA wraps 1.66 times.

A chromatid consists of a nucleosome plus the H1 histone.

The nucleosomes fold up to produce a 30-nm fiber.

The 300-nm fibers are compressed and folded to produce a 250-nm-wide fiber.

Tight coiling of the 250-nm fiber produces the chromatid of a chromosome.
Searching for the things life does is easy.

Eliminating abiotic processes is hard.

To eliminate abiotic processes, you need to understand environmental context.
# Features of Potentially Habitable Planets

<table>
<thead>
<tr>
<th>Gas</th>
<th>Disk-integrated Light &amp; Transmission</th>
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<tbody>
<tr>
<td>H$_2$O (gas)</td>
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<td>CO$_2$</td>
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<td>CH$_4$</td>
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<tr>
<td>CO</td>
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<tr>
<td>Organic Gas</td>
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<td>(haze)</td>
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Fujii+ submitted
Features of Potentially Habitable Planets

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<tr>
<th>gaseous species</th>
<th>HabEx/LUVOIR</th>
<th>OST</th>
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For exoplanets, the environmental context is beyond global.
Exoplanet biosignatures assessment

1. Characterize key stellar parameters and “external” exoplanetary system properties for astrophysical context
2. Characterize key “internal” exoplanet properties of the atmosphere, climate, and surface for further context
3. Search for biosignatures
4. Check for false positives

Likelihoods

\[ P(\text{data} | \text{context, life}) \]
\[ P(\text{data} | \text{context, no life}) \]

Exo-Earth models
simulate data

Catling+ 2017
LUVOIR interim report

(HabEx and OST have similar step-wise observation sequences)
Atmospheric Models, driven by host star and biology or geology

Global Climate Models and Planet Systems Models, driven by host star, that have biogeochemistry and photochemical modules

Intermodel and intermodule comparisons of Global Climate Models, and Planet Systems Models

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| Confidence level for detection of life | Posterior Probability $P(\text{life}|\text{data, context})$ | Evidence |
|---------------------------------------|----------------------------------------------------------|----------|
| **Level 1:** Very likely inhabited    | 90-100%                                                  | Multiple lines of evidence for life. Given current understanding of planetary processes, no known abiotic process can plausibly explain all observed features. |
| **Level 2:** Likely inhabited         | 66-100%                                                  | The body of evidence is consistent with the presence of life. |
| **Level 3:** About as likely as not inhabited (inconclusive) | 33–66%                                                   | Some evidence for life, but insufficient contextual information to draw a definitive conclusion because plausible alternative abiotic explanations cannot be ruled out. |
vegetation detection w/30-m space telescope

Simulations and figure from Jacob Lustig-Yaeger
whereas other planetary atmospheres, including Mars, Venus, Titan, the Jovian planets, are structured more like... contained in Earth's atmosphere may require a more complex network to fully explain them. The fundamental reason...
The diagram illustrates various redox reactions with their corresponding oxidation potentials (E°). The reactions are divided into two categories: oxidizing half-reactions and reducing half-reactions. The chart highlights specific reactions such as:

- **H₂ → 2H⁺**
- **CO₂ → CH₄**

These reactions are part of a larger system known as the electron tower, which orchestrates the flow of electrons through different chemical processes. Each reaction is accompanied by a numerical identifier for reference:

- **13**, **16**, **10a**, **3**, **5a**, **7a**, **8b2**

The diagram emphasizes the interconnectedness of these reactions, suggesting a dynamic equilibrium in natural systems.
Required number of habitable planet candidates

Percentage of candidates with water:
- 61 candidates with 5% water
- 30 candidates with 10% water
- 9 candidates with 30% water
- 5 candidates with 50% water
- 3 candidates with 70% water
- 1 candidate with 90% water

LUVOIR interim report
An abbreviated wish-list

• More complete incorporation of biological understanding into the field
• Models of abiotic processes under not-Earth-like conditions
• Evaluation of potential new biosignatures, and their false positives
• Sustained support of lab measurements of known and potential biosignatures
• Development/support for 3-D general circulation models, including chemistry
• Expansion of 1D models to include subsurface, surface (ocean, biology, geochemistry), atmospheric, and escape processes
• More accounting of model uncertainties, in general
• Quantitative biosignatures, and the adoption of statistical frameworks (e.g., Bayesian) to utilize them.
• *The interdisciplinary “glue” to make the above possible.*