Direct Imaging Wavelength Range Implications for Biosignatures

Shawn Domagal-Goldman, Aki Roberge, Victoria Meadows, Eddie Schwieterman, Giada Arney, Chris Stark, Avi Mandell, Matt Bolcar, Karl Stapelfeldt, Mark Clampin, Sonny Harman, Harley Thronson, and years of insights from colleagues at the Virtual Planetary Laboratory and the ATLAST team

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Fig. 1. Plot of LR data from first sample analysis on VL1. An active sequence was used on a fresh surface sample. Radioactivity was measured at 16-minute intervals throughout the cycle except for the first 2 hours after the first nutrient injection when readings were taken every 4 minutes. Radioactivity data include a background count of 490 cpm prior to the onset of the cycle. Detector and test cell temperatures were monitored every 16 minutes.
Take home point #1: Everywhere and every way we have looked finding biosignatures has been easy. Eliminating false positives (abiotic sources) is the difficult part.
Robinson et al. 2011

Reflectance vs. Wavelength (μm)

- O₃
- O₂
- H₂O

R = 120
<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Star Type</th>
<th>False Positive</th>
<th>Identifiers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photochemistry</td>
<td>F, M, K</td>
<td>O$_3$, potentially O$_2$</td>
<td>High CO$_2$, high CO, low CH$_4$</td>
</tr>
<tr>
<td>(Domagal-Goldman et al., 2014; Gao et al., 2015, Hu and Seager, 2014, Tian et al., 2014, Harman et al., in prep.)</td>
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<tr>
<td>Atmospheric Loss</td>
<td>M</td>
<td>Extremely high (&gt;90%) O$_2$ and O$_3$, &gt;10 bars total pressure, ~pure O$_2$</td>
<td>Low CH$_4$, low CH$_4$</td>
</tr>
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<td>(Luger and Barnes, 2014)</td>
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<tr>
<td>No cold trap</td>
<td>All?</td>
<td>Extremely high (&gt;90%) O$_2$ and O$_3$.</td>
<td>Low pressure, low CH$_4$</td>
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<td>(Wordsworth, 2014)</td>
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Figure courtesy Sonny Harman, from Harman, et al., in prep.
Degraded Modern Earth Spectra R=200

(PAL = “Present Atmospheric Level”)
Impact of Telescope Temperature on Characterization Time (8-m, 20% throughput)

Take home point #2: 
CH$_4$ detection would be a strong confirmation of a biogenic O$_2$ source...

... but CH$_4$ is hard to detect for "modern Earth twins."
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Take home point #3:
There are a number of features that would indicate a false positive.

All currently known abiotic O$_2$ & O$_3$ sources would be identifiable with a 0.3-1.8 μm wavelength range.
What we could say

• For a mission that goes out to 1.0 μm (any Temp.): “We found the presence of biosignature gases (O$_2$ and O$_3$) on that planet, but did not comprehensively search for abiotic sources of those gases.”

• For a mission that goes out to 1.8 μm (T ≤ 275 K) “We found the presence of biosignature gases (O$_2$ and O$_3$) on that planet, and searched for but did not find signs (CO$_2$, CO, O4, pressure) that these gases were created by abiotic processes.”

• For a mission that goes out to 2.5 μm (T ≤ 250 K) “We found the presence of biosignature gases (O$_2$ and O$_3$) on that planet, and secondary features (CH$_4$) inconsistent with abiotic processes.”
Implications for LUVOIR and HabEx

Getting to ~2 μm would be strongly preferred

Might not be necessary if we obtain high spectral resolution and time-dependent spectra.

This is a trade against telescope temperature and associated cost.

However, viewing planets in habitable zones at longer wavelengths is a challenge.

For coronagraphs, longer wavelength requires better coronagraph and/or larger telescope diameter, since \( \text{IWA} = C \times \left( \frac{\lambda}{D} \right) \).

For starshades, longer wavelength requires larger starshade diameter and greater telescope/starshade separation = longer retargeting times.

At 2 μm, both types of missions limited by collecting area and telescope thermal background.
Slide courtesy Eddie Schwieterman, figures from Schwieterman et al., 2015
R = 70, SNR = 10, Earth-Sun-1 Zodi 10 pc. Away.

**Figure from Giada Arney and Ty Robinson**

- 4 m telescope w/ 20% Throughput
- 4 m telescope w/ 50% Throughput
- 8 m telescope w/ 20% Throughput

Preliminary work - feedback welcome!
Figure from Giada Arney and Ty Robinson

R = 70, SNR = 10, Earth-Sun-1 Zodi 10 pc. Away.

4 m telescope w/ 20% Throughput, T = 274 K

4 m telescope w/ 50% Throughput, T = 274 K

8 m telescope w/ 20% Throughput, T = 274 K

integration time [days]

Preliminary work - feedback welcome!