Detecting False Positives with Oxygen: A Feasibility Study

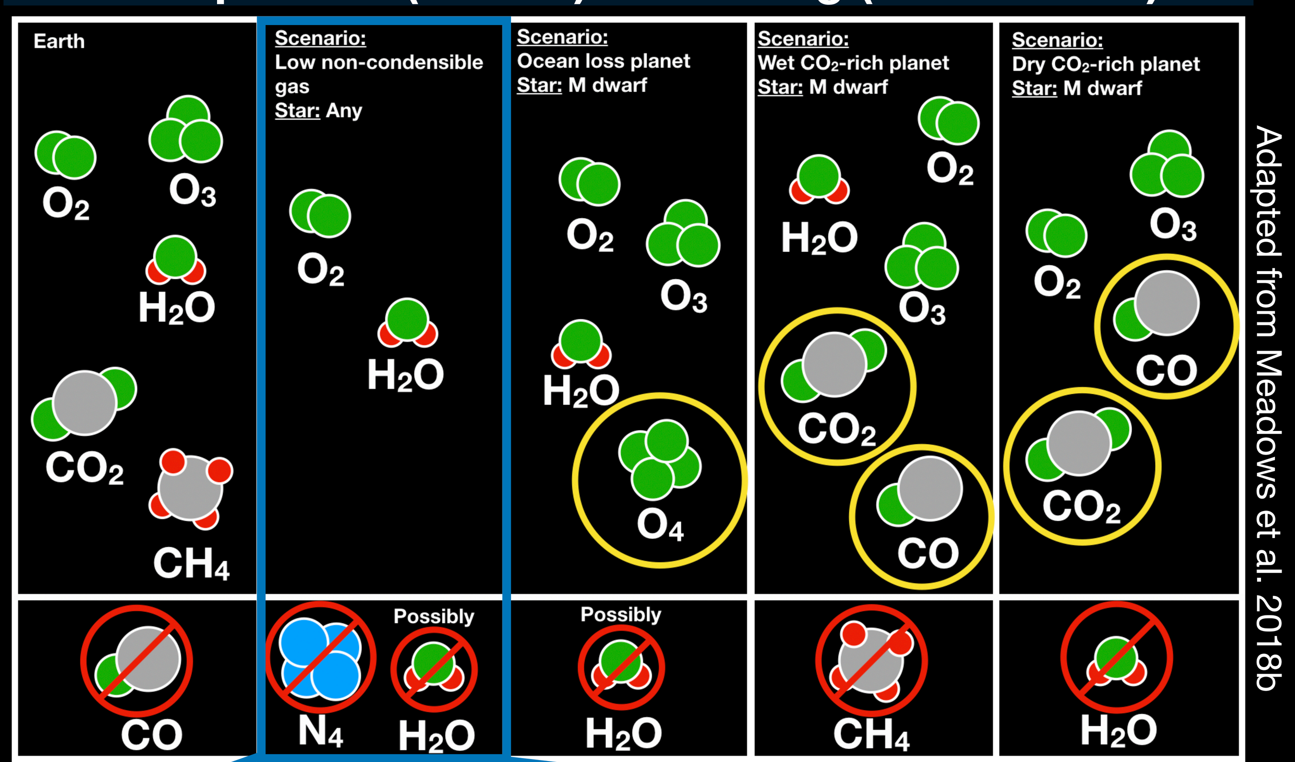
Miles Currie, Victoria Meadows
University of Washington, Virtual Planetary Laboratory

We are exploring how to use ground-based high-resolution spectroscopy to distinguish between abiotic O_2 formed from H_2O photolysis in the upper atmosphere, and well-mixed biological O_2.

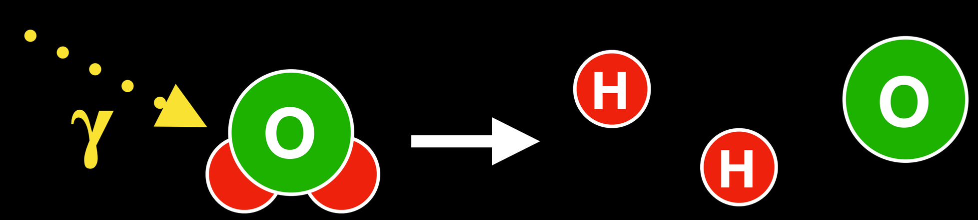
O_2 as a Biosignature

- Oxygen is a strong biosignature
- However, there are several abiotic mechanisms which can produce O_2
- The abiotic production of O_2 via H_2O photolysis may be particularly difficult to distinguish from biological O_2
- We present the prospects for using ground-based high-resolution spectroscopy to reconcile this **false positive** (below) mechanism

Many false positives for biological O_2 are known, but most reveal their presence via additional molecules that are present (circled) or missing (crossed out).



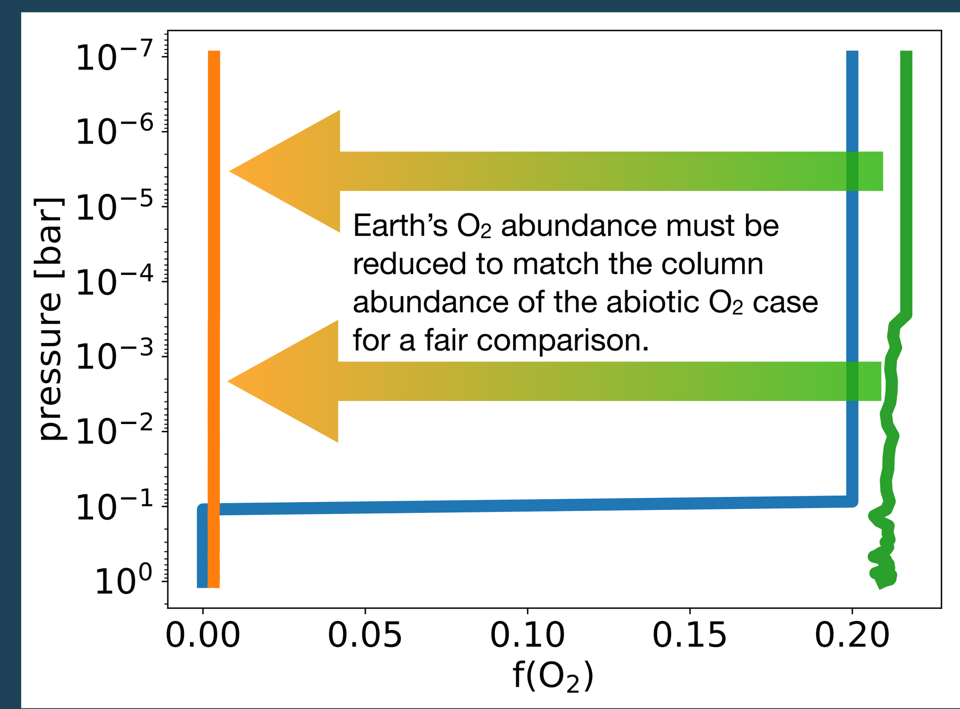
Abiotic O_2 Production



- Lowering the non-condensible gas (e.g. N_2) inventory allows more H_2O into the upper atmosphere (Wordsworth and Pierrehumbert 2014)
- H_2O is photolyzed and H escapes to space
- **O_2 builds up in the upper atmosphere**
- Possible for planets around all stellar types

O_2 Profiles

To compare the spectrum of a photochemically produced oxygen profile to the spectrum of a well-mixed biologically produced oxygen profile, we must ensure that the column abundances of these two profiles are equal. This requires a well-mixed profile with $f(O_2) = 0.33\%$.



Test Cases:

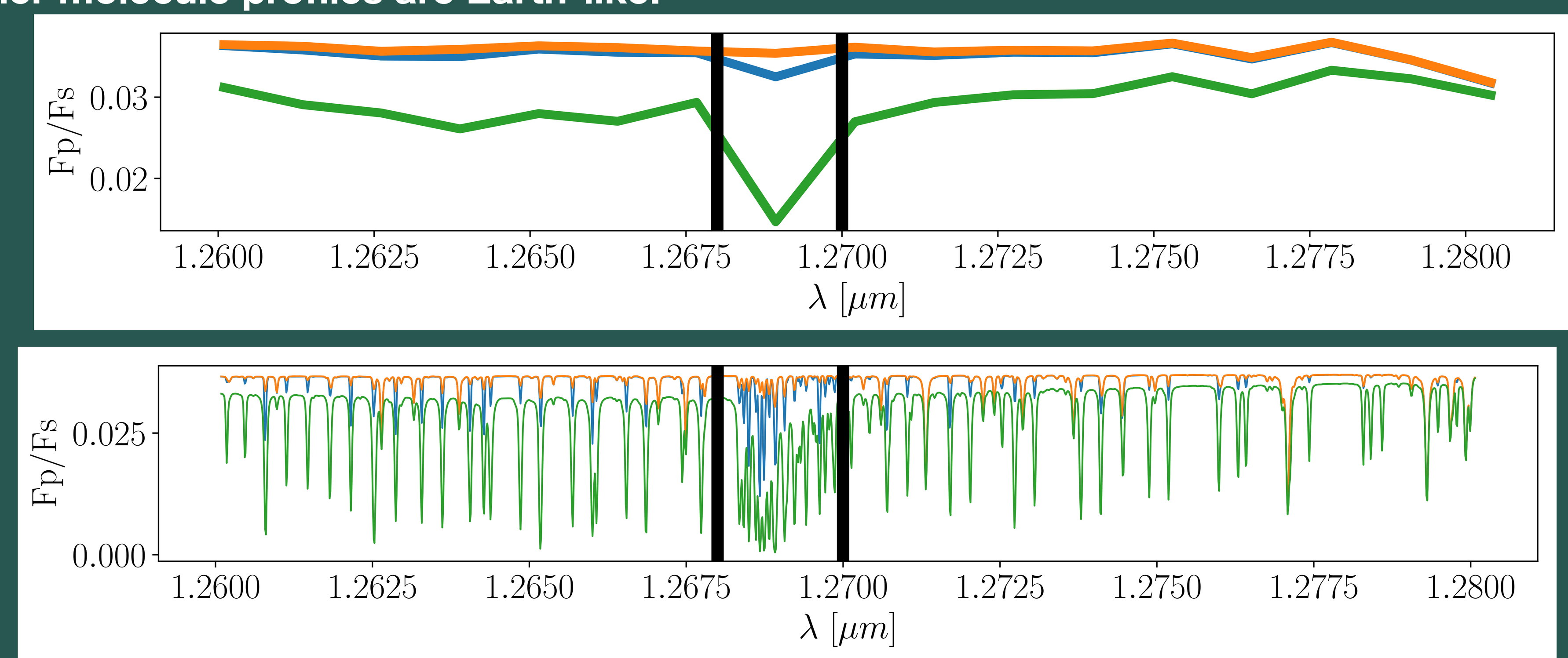
Abiotic O_2 (Photochemistry)

Biological O_2 With same column abundance as abiotic case (Photosynthetic Life)

Earth

1.27 μm O_2 Band

We create low (R=1,000) and high (R=100,000) resolution spectra from these oxygen profiles using SMART, our one-dimensional, multi-scattering, multi-stream line-by-line atmospheric modeling algorithm. Below is the result of simulating TRAPPIST-1e around TRAPPIST-1. All other molecule profiles are Earth-like.



Branch Ratios

Because the Q branch of this spectroscopic band is more sensitive to changes in the oxygen profile than the P and R branches, we hypothesize that the Q branch flux will saturate before the others. Thus, the ratio of the fluxes in the Q branch to the P and R branches may be sufficient for probing the distribution of oxygen in the atmosphere. Below we show the calculated ratios for each of the above scenarios.

$$\text{Ratio} = \frac{Q_{flux}}{P_{flux} + R_{flux}}$$

	Abiotic O_2	Biological O_2	Earth
Low-res	0.054	0.058	0.030
High-res	0.096	0.101	0.068

Ground-Based High-Res Spectroscopy

- Potential solution for solving one of the trickiest false positives
- Current space-based instruments are not capable of the resolution needed to distinguish this false positive (R≳100,000)
- The upcoming extremely large (30-40m) ground-based observatories will carry the high-resolution instruments needed for using this method for distinguishing this false positive

Conclusions

- We may be able to distinguish evenly mixed biological O_2 from the abiotic production and buildup of oxygen in the upper atmosphere by analyzing the P, Q, and R branches of the 1.27 μm O_2 band
- This false positive remains very challenging to discriminate, but this method is a promising start

Future Work

- Use a coupled climate-photochem model to better understand the atmospheric distribution of photochemically produced O_2
- Investigate the detectability and retrieval of these types of atmospheres
- Investigate the use of atmospheric pressure indicators as another method to distinguish this false positive

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