Detecting False Positives with O_2 : A Feasibility Study

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Introduction: In the coming decade, a new class of ground-based observatories will begin to come online, capable of delivering unprecedented high-resolution spectra of exoplanetary atmospheres (Crossfield, 2016). Among the atmospheric gases these telescopes will be able to detect, O_2 is one of the best candidates for the search for biosignatures (Meadows et al., 2018a). However, O_2 could be generated via non-biological planetary processes, and techniques to discriminate these "false positives" in high-resolution spectra have yet to be explored.

Wordsworth & Pierrehumbert (2014) introduced the idea that O_2 may build up in the upper atmosphere via water photolysis on potentially habitable planets, orbiting any type of star, due to a low inventory of non-condensable gases making the cold trap mechanism ineffective for protecting the planet's H_2O. Learning how to discriminate this false positive for O_2 detection is critical to being able to interpret whether O_2 seen in a planetary atmosphere is biological or abiotic.

In the near term, ground-based telescopes will preferentially observe M dwarf terrestrial planets because of their favorable star/planet contrast and size/mass ratio, making them prime targets for the search for biosignatures. M dwarfs are known to be common and nearby (Kroupa et al., 1993) and have a promising occurrence rate of small, rocky bodies in the habitable zone (Dressing & Charbonneau, 2015), well studied examples of which include the TRAPPIST-1 (Gillon et al., 2017) and Proxima Centauri b (Meadows et al., 2018b) planets.

Approach: We address the feasibility of using high-resolution spectroscopy, or direct imaging, to determine the vertical distribution of O_2 in a planetary atmosphere as a discriminant between biological and abiotic sources.

We assume photochemically produced O_2 will build up in the upper atmosphere, as in Wordsworth & Pierrehumbert (2014), whereas biologically produced oxygen will either be found near the surface or evenly mixed through the atmospheric column. At high spectral resolution, different O_2 lines within a single band probe different pressures in a planetary atmosphere in accordance with the line intensities. We take advantage of this phenomenon to discriminate false positives, and explore other possible observational mechanisms to discriminate the vertical distribution of O_2 in the planetary atmosphere.

Modeling Spectra with SMART. All spectra are generated using the spectral mapping atmospheric radiative transfer (SMART) model (Meadows & Crisp, 1996). SMART is a one-dimensional, multi-scattering, multi-stream line-by-line atmospheric modeling algorithm that is capable of generating high- and low-resolution spectra for given mixing ratio profiles of atmospheric species. In Figure 1, we show the capabilities of SMART by producing a reflected light planetary spectrum of the 0.76μm O_2 band simulated with an Earth-like O_2 abundance and atmosphere. High resolution is needed to resolve the individual line shapes within the oxygen band. The ability of SMART to have a flexible and user-defined vertical atmospheric structure as well as its line-by-line approach for resolving line shapes is crucial for this analysis.

Conclusion: We will show the prospects for discriminating biological O_2 production at a planetary surface from the abiotic photochemical production of O_2 in the upper atmosphere with high-resolution detectors on the upcoming generation of large, ground-based observatories, and potentially for direct imaging capabilities.

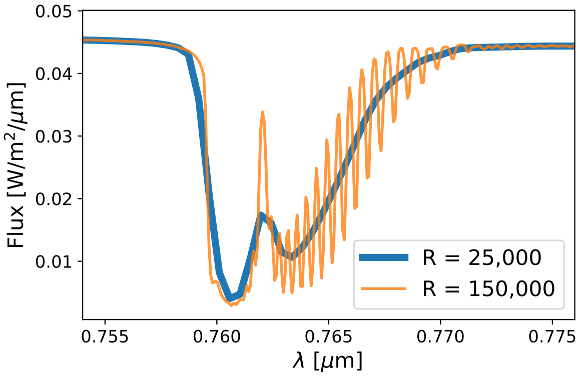

Figure 1: O_2 A-band as a function of resolution with an Earth-like O_2 abundance.

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