

USING DIMERS TO CONSTRAIN PLANETARY HABITABILITY AND DISCRIMINATE AGAINST FALSE POSITIVES FOR LIFE. E. W. Schwieterman^{1,2,3}, V. S. Meadows^{1,2,3}, T. D. Robinson^{2,4}, A. Misra^{1,2,3}, S. D. Domagal-Goldman^{2,5}, R. Luger^{1,2,3}, R. Barnes^{1,2,3}, and D. Crisp^{2,6}, ¹Astronomy Department, University of Washington, Box 351580, Seattle, WA 98115 (eschwiet@uw.edu), ²NAI Virtual Planetary Laboratory, Seattle, WA 98115, ³University of Washington Astrobiology Program, Seattle, WA 98115, ⁴NASA Ames Research Center, Moffett Field, CA 94035, ⁵NASA Goddard Space Flight Center, Greenbelt, MD 20771, ⁶Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

Introduction: One of the key factors contributing to planetary habitability is atmospheric mass. An atmosphere must maintain sufficient surface pressure for the stability of liquid water, but atmospheres that are too massive may indicate post-runaway conditions inhospitable to life. Additionally, measurements of atmospheric mass could be used to discriminate between true biosignatures and recently proposed mechanisms for generating false O₂ biosignatures [1,2]. Dimer molecules such as (O₂)₂ and (N₂)₂ are produced preferentially at higher gas densities and create observable spectral features. Quantifying the effect of these dimers could provide a useful probe for constraining the bulk characteristics of planetary atmospheres [3,4] and therefore habitability and the potential for false positives for life. We use photochemical, climate, and spectral models to examine Earth as an exoplanet and demonstrate the spectral influence of (N₂)₂ and (O₂)₂ dimers on terrestrial planet spectra through comparisons of observational and simulated data. We also model and analyze the spectral detectability of (O₂)₂ and (N₂)₂ dimers assuming planetary conditions that produce abiotic O₂.

Confirming habitability: Molecular nitrogen (N₂) comprises the largest fraction of Earth's atmosphere and is likely to be an important component of many terrestrial exoplanet atmospheres. While N₂ is largely spectrally inactive, and therefore difficult to detect remotely, at sufficient densities (N₂)₂ dimers form that absorb in the near-infrared. Figure 1 shows the spectral effect of (N₂)₂ in Earth's disk-integrated spectrum near 4 μm by comparing data from NASA's EPOXI mission [5] to synthetic spectra from the Virtual Planetary Laboratory (VPL) Earth model [6]. Through additional modeling, we find that (N₂)₂ only produces a significant spectral feature when N₂ abundances are large enough to guarantee sufficient pressures for surface liquid water. Detection of (N₂)₂ would also confirm the presence of a bioessential element (N) and potentially the presence of plate tectonics [7].

Constraining O₂ false positives for life:

Rarefied atmosphere scenario: It has been hypothesized that abiotic O₂ could accumulate in the atmospheres of planets with sufficiently low abundances of non-condensable gases such as N₂ [1]. A thin, predominantly water vapor atmosphere ($P_{\text{surf}} < 0.2$ bar) lacks an effective tropospheric cold trap, allowing H₂O to

diffuse into the stratosphere and become photo-dissociated, leading to H loss and atmospheric oxidation. We show that the detection of (O₂)₂ or (N₂)₂ in radiance or transmission spectra would set a lower limit on surface pressure that would rule out this false positive mechanism.

Post-runaway O₂-dominated atmospheres: Planets in the habitable zones of late-type stars may possess significant amounts of abiotic O₂ [2]. These planets most likely spent tens to hundreds of millions of years in a runaway greenhouse state due to the extended super-luminous phase of low-mass stars. Extreme ultraviolet radiation from the host star could have efficiently photo-dissociated H₂O in these atmospheres, facilitating H escape and consequent O₂ buildup once surface sinks for O were exhausted. The O₂ abundances of these atmospheres are likely to be large [2] and could be identified spectrally using (O₂)₂ absorption as an abundance metric [3,8].

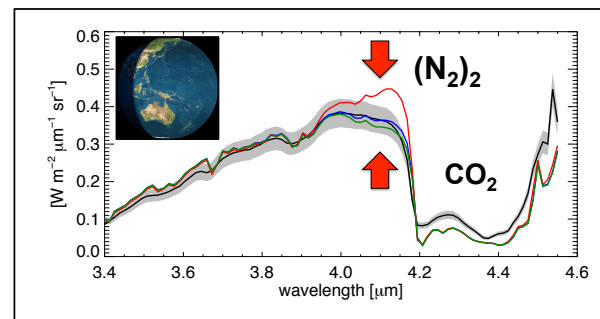


Fig. 1 - Detection of (N₂)₂ dimer absorption in Earth's NIR spectrum. Spectral radiance of Earth as measured by the EPOXI near-infrared spectrograph on 2008-March-18 at 22:39 UT (black), as generated by the VPL three-dimensional Earth Model without (N₂)₂ absorption (red), with (N₂)₂ absorption (blue), and with both (N₂)₂ and N₂-O₂ absorption (green). The inset diagram shows Earth as seen by EPOXI.

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