ORGANIC HAZE AS A BIOSIGNATURE IN THE PRESENCE OF BIOGENIC SULFUR GASES.

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Introduction: The Archean (3.8 – 2.5 billion years ago) eon may have experienced several intervals when a transient organic haze globally veiled our planet [1,2]. This haze would have dramatically altered our planet's climate, spectral appearance, and photochemistry [e.g. 3,4,5]. Despite the haze's cooling effects, we have previously shown that habitable surface temperatures are possible on hazy Archean Earth. Organic haze formation is driven by methane (CH_4) photochemistry, and haze thickness is controlled by the ratio of atmospheric CH_4 relative to carbon dioxide (CO_2).

Biological Mediation: The Archean haze was likely biologically-mediated because methane-producing metabolisms likely dominated early Earth's methane production [6], as they do today. Organic hazes on Earthlike exoplanets may likewise be a sign of biological activity. Using a 1D photochemical-climate model, we find organic haze formation at Archean-like CO_2 levels (~0.1-1% of the atmosphere [7]) requires methane fluxes consistent with known and theoretical biological production rates, ~1×10^{11} molecules/cm^2/s. However, abiotic methane can be produced by a number of different processes [8]. Therefore, additional information is needed to establish the biogenecity of organic haze on an Earthlike planet.

Biogenic organic sulfur gases (S_{org}, CS_2, OCS, CH_3SH, and CH_3SCH_3) can contribute to the atmospheric hydrocarbon budget through photochemistry that liberates organic molecules [9]. S_{org} gases can drive haze formation at lower CH_4/CO_2 ratios than methane photochemistry alone would predict. For a planet orbiting a solar-type star, at 30x the modern S_{org} flux, haze forms at a CH_4/CO_2 ratio 20% lower than at 1x modern S_{org} flux. For a planet orbiting the M4V dwarf GJ 876, this effect is more pronounced: at 1x the modern Earth S_{org} flux, a substantial haze forms at CH_4/CO_2 ~ 0.2, but at 30x the S_{org} flux, a substantial haze forms at CH_4/CO_2 ~ 0.02, an order of magnitude lower. Detection of haze at an anomalously low CH_4/CO_2 ratio could suggest the influence of biogenic sulfur gases.

Detection: Organic sulfur gases themselves are not readily detectable in the spectrum of an Earthlike exoplanet, but organic haze produces strong spectral features. Arguing for the involvement of S_{org} in haze formation will require measurement of the CH_4/CO_2 level in the atmosphere.

Potential future direct imaging telescopes such as the Large UV Visible Infrared surveyor (LUVOIR) and the Habitable Exoplanet Imaging Mission (HabEx) may provide direct observations of Earthlike exoplanets in the 2030s and beyond. Organic haze is a novel biosignature with a very strong absorption feature at UV-blue wavelengths in reflected light (Fig. 1). This haze absorption feature is stronger than absorption features from CH_4 itself and could be detected at spectral resolutions ($R=\lambda/\Delta\lambda$) as low as 10. CH_4 absorbs near 1.1 and 1.4 μm, and there are CO_2 bands near 1.5 and 2 μm (although 2 μm will be difficult to reach if the telescope is not cryogenically cooled). At pCO_2 = 2%, resolving the narrow multi-peaked structures of the 1.5 μm CO_2 feature requires R > 100, and R > 170 will be required to correctly resolve the depths of the bands of this feature to provide accurate constraints on the atmospheric CO_2 abundance.

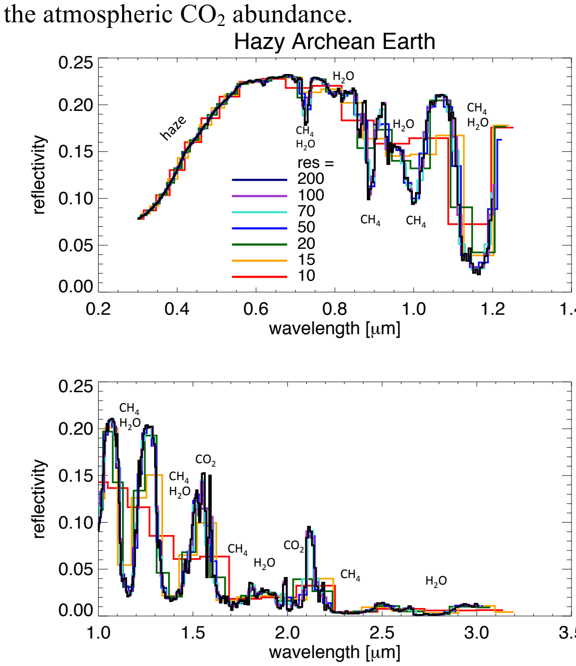

Figure 1. Reflected light spectra of hazy Archean Earth at different spectral resolutions.

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