National Aeronautics and Space Administration

FY24 Strategic University Research Partnership (SURP)

Haze Evolution in Sub-Neptune Exoplanets

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Objectives:

1. Explore the effect of UV radiation, representative of various stellar irradiation processes, on photochemical hazes in the atmospheres of sub-Neptune exoplanets
2. Understand the destruction or alteration of photochemical hazes in diverse atmospheres by measuring laboratory haze samples subjected to UV radiation, including their chemical, optical, and physical properties before and after UV-evolution.
3. Evaluate the effect of UV-evolved hazes in theoretical spectra of sub-Neptunes.

Background:

- Photochemically-produced exoplanet hazes have particle sizes of 10s-100s nm and can initiate from a range of gases, such as O- and S-rich precursors (e.g., He et al., 2020)
- Exoplanet hazes can produce larger-than-Rayleigh scattering slopes in exoplanet transmission spectra at optical wavelengths (Ohno et al., 2020) and/or dampen spectral features in the IR (Morley et al., 2013)
- However, the formation and evolution of exoplanet hazes are only beginning to be understood through laboratory and theoretical experiments
- Exoplanet systems can have different stellar types with different UV fluxes, which can also dramatically influence the pathways and persistence of photochemical hazes.

Approach and Results:

- We conduct laboratory and theoretical investigations to determine the effect of stellar type on the haze evolution of sub- Neptune exoplanets, planets <3R_{Earth}.
- UA graduate student Lori Huseby is leading this work as part of her PhD, and has been trained in both the radiative transfer (RT) modeling (with PICASO, an open-source RT code) and the use of the spectroscopy suite, vacuum systems, and UV lamp with Co-I Moran
- Co-Is Huseby and Moran completed irradiation in full for two samples over August 2023. Samples were one “water world” atmosphere with trace methane and one with “water world” with trace carbon monoxide. (**Fig 1**)
- Co-I Huseby performed microscopy of the 2 samples post-irradiation, showing the influence of the irradiation and composition differences.

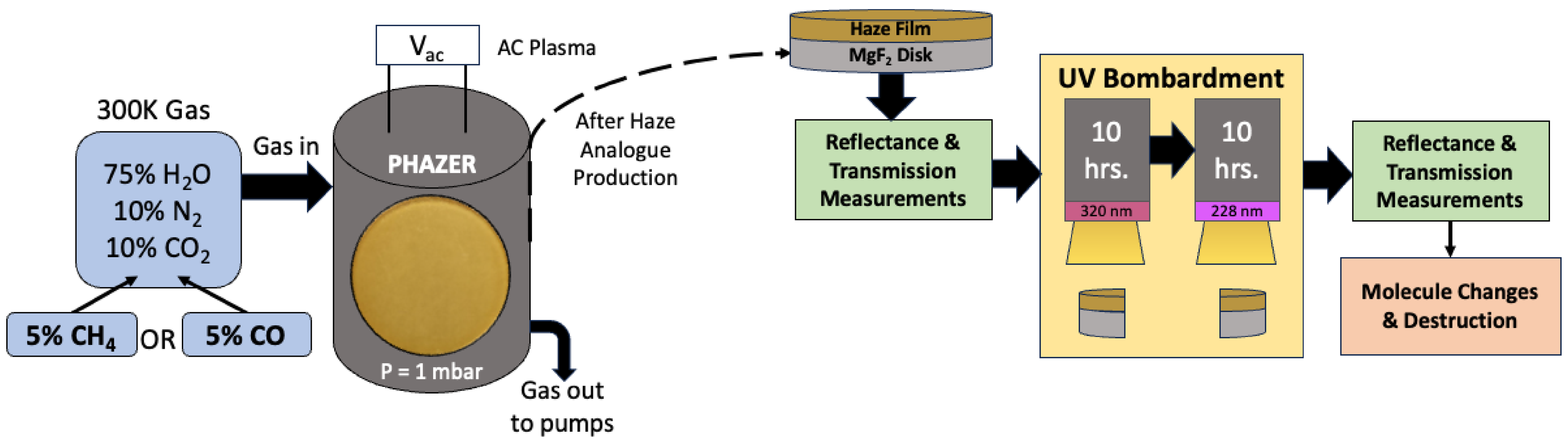

Figure 1: Streamlined schematic of the experimental setup, simulated atmospheric compositions and conditions, UV bombardment process, measurements, and experimental outcomes. Two laboratory hazes were produced (the initial conditions varying only in the minor carbon source) in the PHAZER chamber (He et al. 2017) by exposing the gas mixture at room temperature to an AC plasma source. After the hazes were produced, each half of the films were exposed to UV irradiation under two different filters. The transmittance and reflectance spectra pre– and post–UV irradiation of both samples were measured using a FTIR spectrometer in order to quantify molecular changes and destruction during the irradiation process.

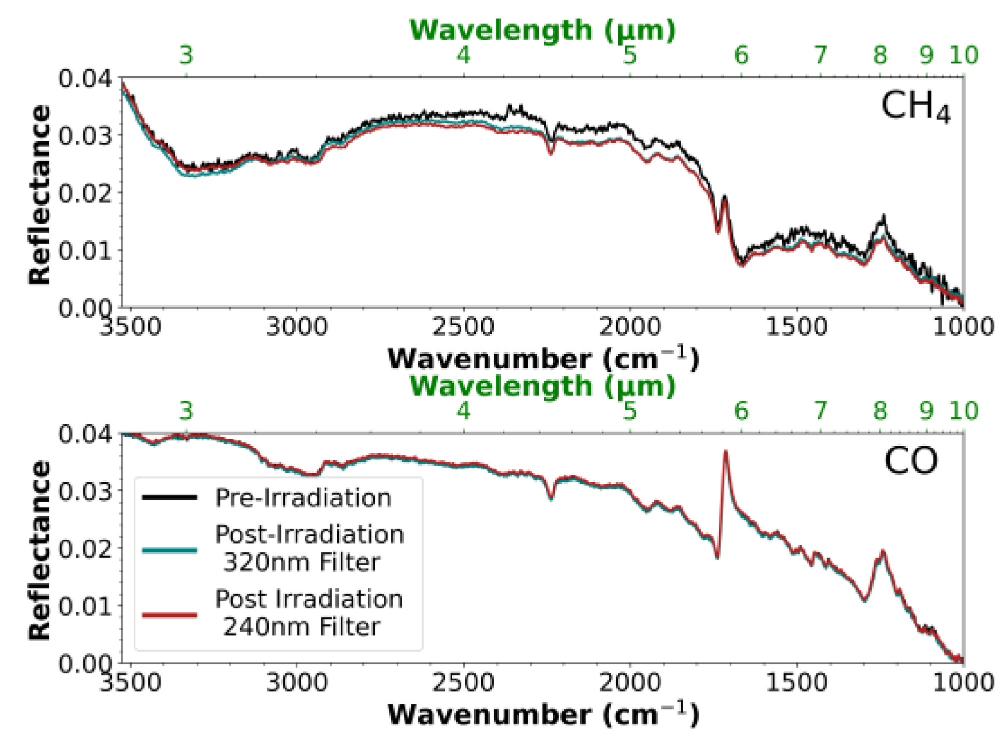

Figure 2: Enlarged spectrum between 3500 - 1000 cm-1 of the 5% CH4 (top) and 5% CO (bottom) sample haze as a function of wavelength. Between pre and post-bombardment, there are larger changes in the 5% CH4 spectrum compared to the 5% CO sample.

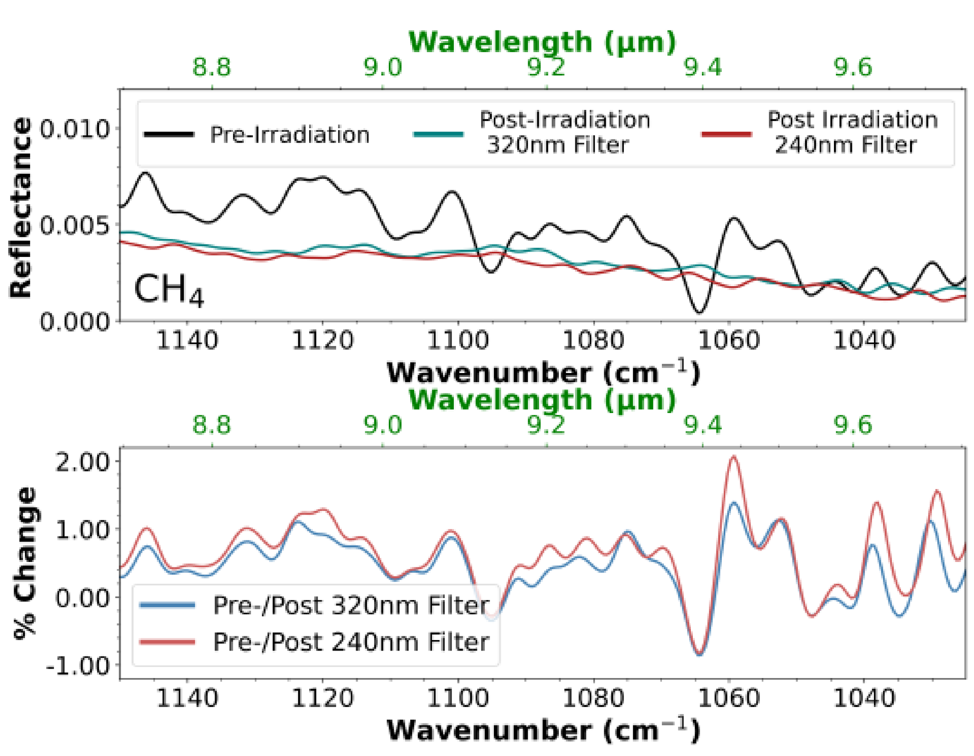

Figure 3: C-O stretching features of the 5% CH4 sample seen pre- and post-irradiation in reflectance (top) with percent change (bottom) between the pre-irradiation filter and each irradiation filter respectively. The irradiation process degraded the spectral features by large percentages.

- The 5% CH4 sample degraded more during the irradiation process compared to the 5% CO sample (**Fig 2**)
- Higher energy flares (240nm filter) cause more degradation through the haze spectra than lower energy flares (320nm filter) (**Fig 3**)
- Results were submitted to AAS Journals in Sept 2024
- Future work for Y3: Use PICASO to model the experimental haze results in comparison to atmospheric observations.

Significance/Benefits to JPL and NASA:

- This project will lead to the development of first of their kind laboratory exoplanet hazes that have been subjected to UV radiation, as representative of stellar flux by diverse host stars, with a particular focus on M dwarfs
    - M-dwarf stellar hosts are extremely common, yet the influence of this UV radiation regime on haze is unknown
- Results from this effort will have applications for future transit observations of sub-Neptunes with JWST.

Publications:
He et al. 2017
He et al. 2020
Gavilan et al. 2011
Gavilan et al. 2018
Morley et al. 2013
Ohno et al. 2020
Huseby et al. 2024, submitted

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