FY23 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 (**Fig 1**).

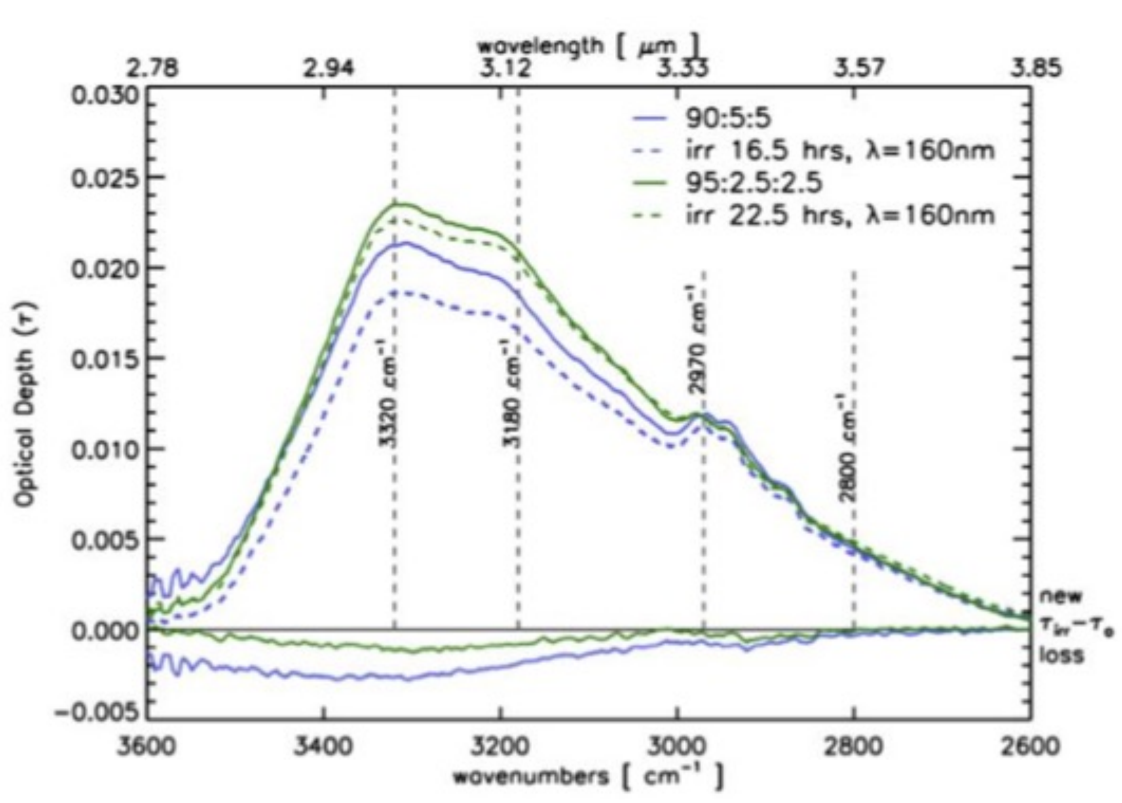

Figure 1: Mid-infrared spectra of Titan-like tholins showing the evolution of the amine (3600–2600 cm−1) bands, adapted from Gavilan et al., 2018. As tholins are subjected to VUV radiation, prominent spectral features decrease in strength. We will obtain similar measurements for exoplanet tholins and use the results to produce synthetic atmospheric transmission spectra to compare to observations of sub-Neptunes.

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
- Laboratory experiments began this summer
  - The experiments we have designed here naturally build off and expand upon previous work (e.g., Gavilan et al. 2011, 2018) into a critical regime relevant to exoplanet atmospheres.
  - Exoplanet haze samples (made from H_2O-rich atmospheres) have been produced by collaborators from JHU and deposited on Mg_2F substrates.
  - Preliminary results shown in **Fig 2**
- Future work for Y2: Use PICASO to model the experimental haze results in comparison to atmospheric observations.

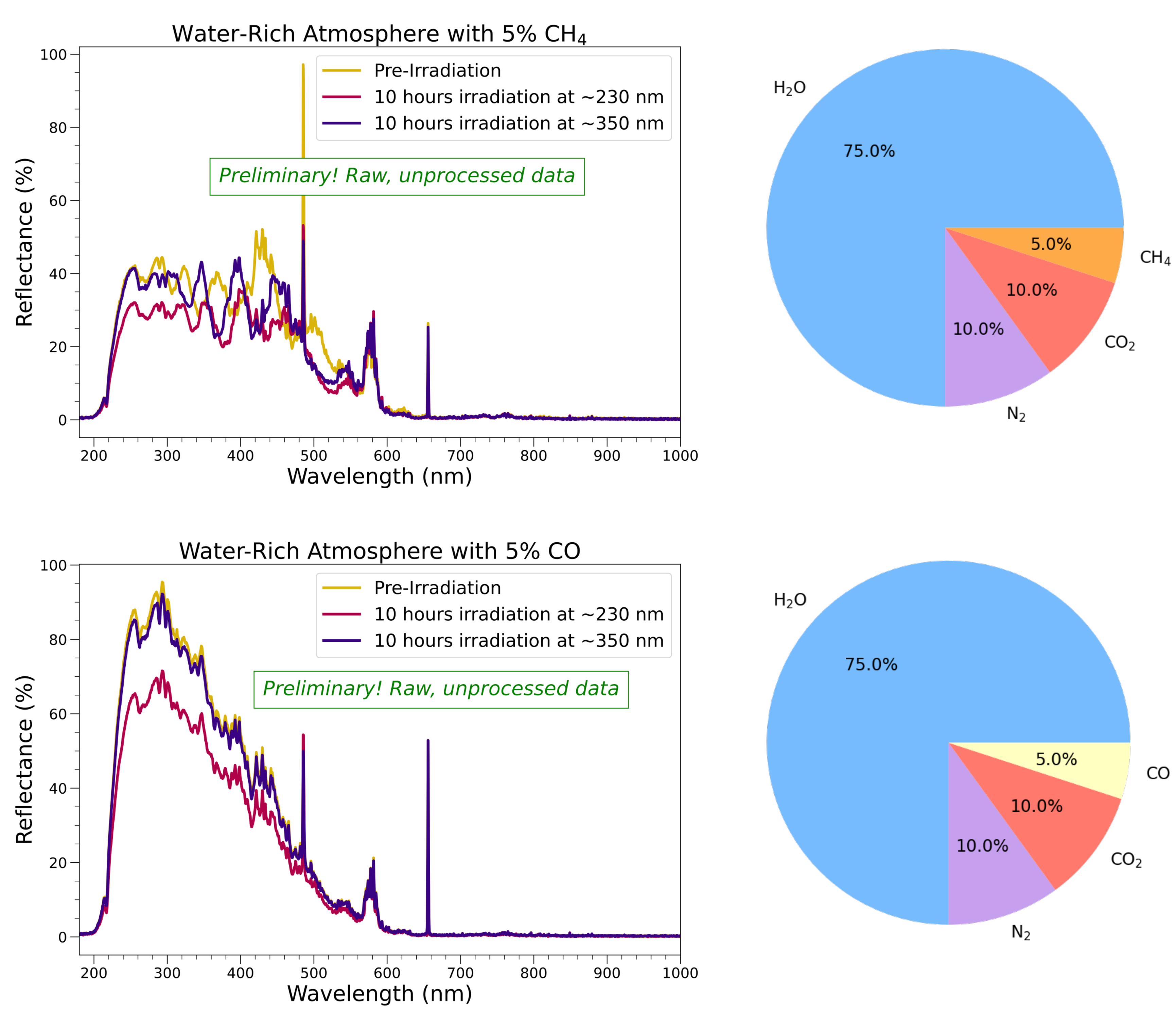

Figure 2: Preliminary reflectance spectra for a haze samples made from a water-rich atmosphere with 5% CH_4 (top row) and 5% CO (bottom row) when subjected to UV radiation at different wavelengths. These preliminary results already show that changes in irradiation effect the reflectance with wavelength, especially for the high energy filter.

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. 2020
Gavilan et al. 2011
Gavilan et al. 2018
Morley et al. 2013
Ohno et al. 2020

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