National Aeronautics and Space Administration

FY25 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:

- Our team has conducted laboratory and theoretical investigations to determine the effect of stellar type on the haze evolution of sub- Neptune exoplanets, planets <3R$_{Earth}$.
- UA PhD candidate Lori Huseby led this work as part of her dissertation, 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-I Huseby completed laboratory investigations of UV radiation effects simulating two different stellar flare energies on laboratory-produced exoplanet hazes made under conditions analogous to water-world Atmospheres (Huseby et al. 2025, PSJ). Samples were one “water world” atmosphere with trace methane and one with “water world” with trace carbon monoxide. (**Fig 1**)
- We find that both simulated flares altered the overall transmittance and reflectance of the hazes, and higher-energy "flares" make those alterations more pronounced (**Fig 2**).

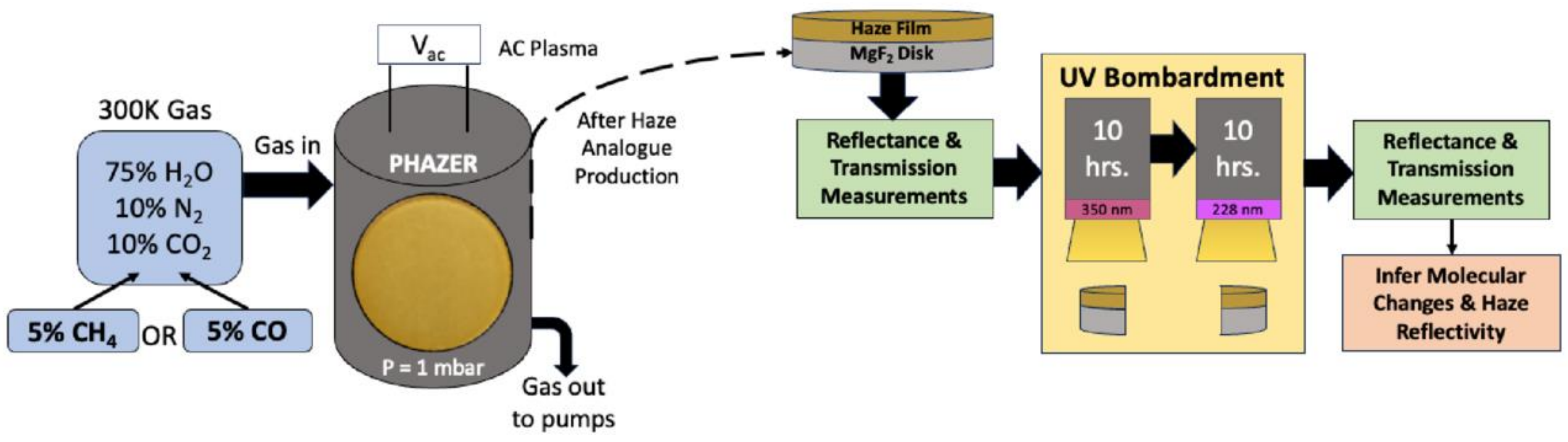

Figure 1: Streamlined schematic of the experimental setup, simulated atmospheric compositions and conditions, UV bombardment process, measurements, and experimental outcomes. Two laboratory hazes were produced (the initial conditions varying only in the minor carbon source) in the PHAZER chamber (C. 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 radiation under two different filters.The transmittance and reflectance spectra pre- and post-UV irradiation of both samples were measured using a Fourier transform IR (FTIR) spectrometer to quantify molecular changes and destruction during the irradiation process.

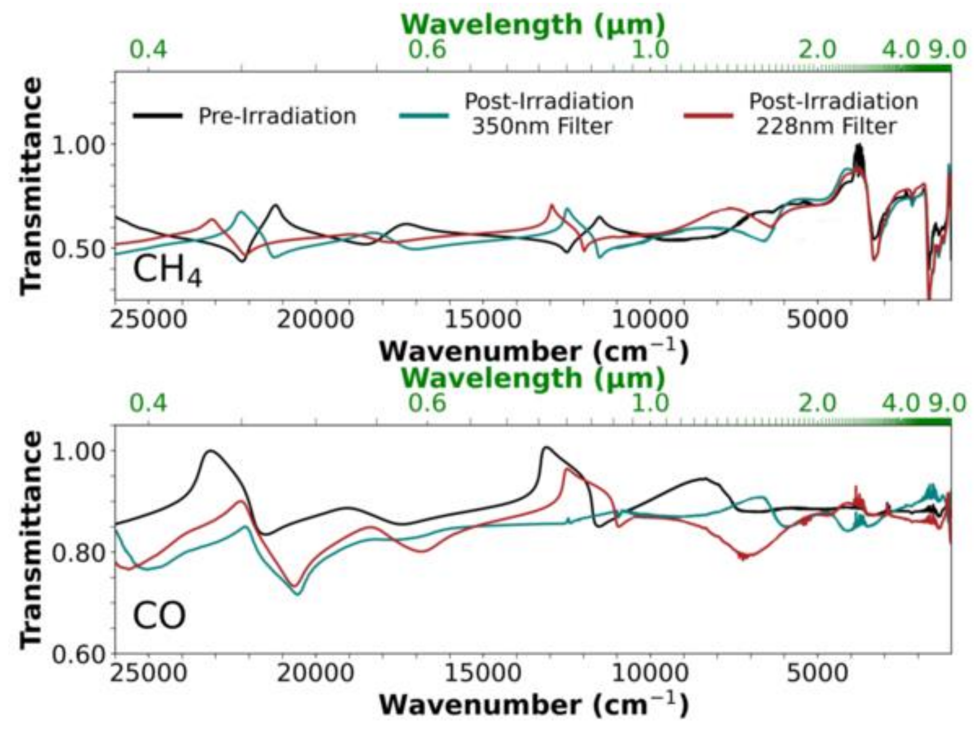

Figure 2: Transmittance spectra of our 5% CH_4 atmosphere haze sample (top) and 5% CO atmosphere haze sample (bottom) in the visible to mid-IR wavelength region (26,000–1100 cm^{-1}, 0.4–9 μm). The black line represents the samples before the irradiation process began, and the teal and red lines represent the postirradiation spectrum using the 350 nm and 228 nm filters, respectively.

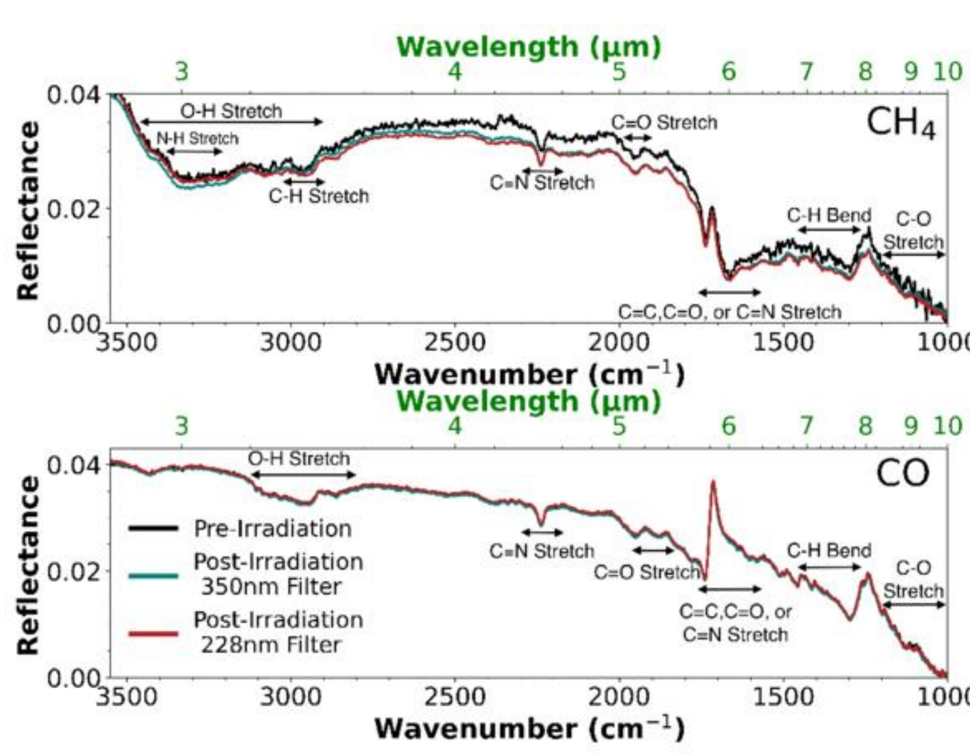

Figure 3: Enlarged spectrum between 3500 and 1000 cm^{-1} (2.5–10μm) of the 5% CH_4 (top) and 5% CO (bottom) atmosphere generated hazes as a function of wavelength in reflectance with major spectral features labeled. Between pre- and postirradiation, there are larger changes in the 5% CH_4-derived haze spectrum in comparison to the 5% CO-derived haze spectrum, where the differences are not obvious.

- On a larger scale, these laboratory-made hazes show potential signs of degradation over the simulated flaring period. Our results provide insight into the effects that stellar flaring events have on potential exoplanet haze composition and the ability for water-world-like exoplanets to retain their atmospheres.
- Co-I Huseby is preparing a second publication using the results of the experiments to compute optical constants and put them into atmospheric models to explore the effects of the UV-irradiated hazes on observations.

Significance/Benefits to JPL and NASA:

- This project led 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 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 L., Moran S.E., Pearson N., Kataria T., He C., Pesciotta C., Horst S.M., et al., 2025, PSJ 6. doi:10.3847/PSJ/adda4a

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