LUNAR & PLANETARY LABORATORY

ULTRAVIOLET RADIATION EFFECTS ON WATER-WORLD EXOPLANET HAZES THROUGH LABORATORY EXPERIMENTS

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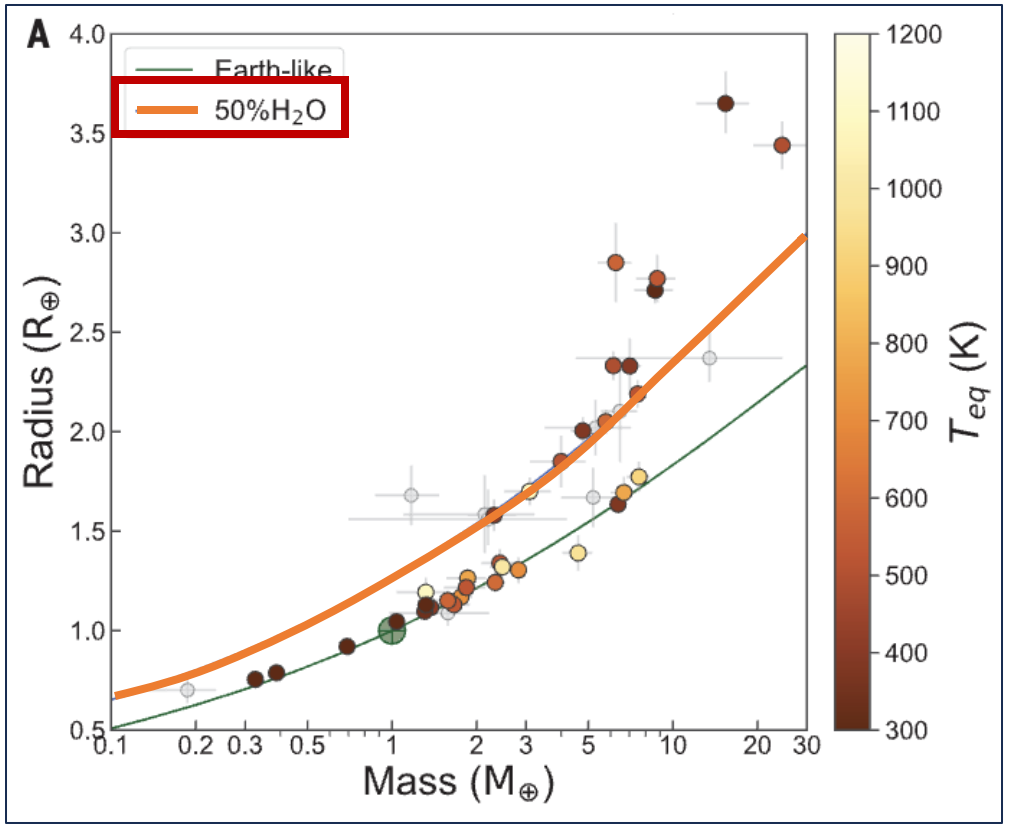
Water Worlds Introduction

We are focusing on:

- Exoplanet atmospheres composed mostly of water vapor.

- It is an active area of research how stellar irradiation, specifically flaring events, affects the atmospheric composition and chemistry of these planets.

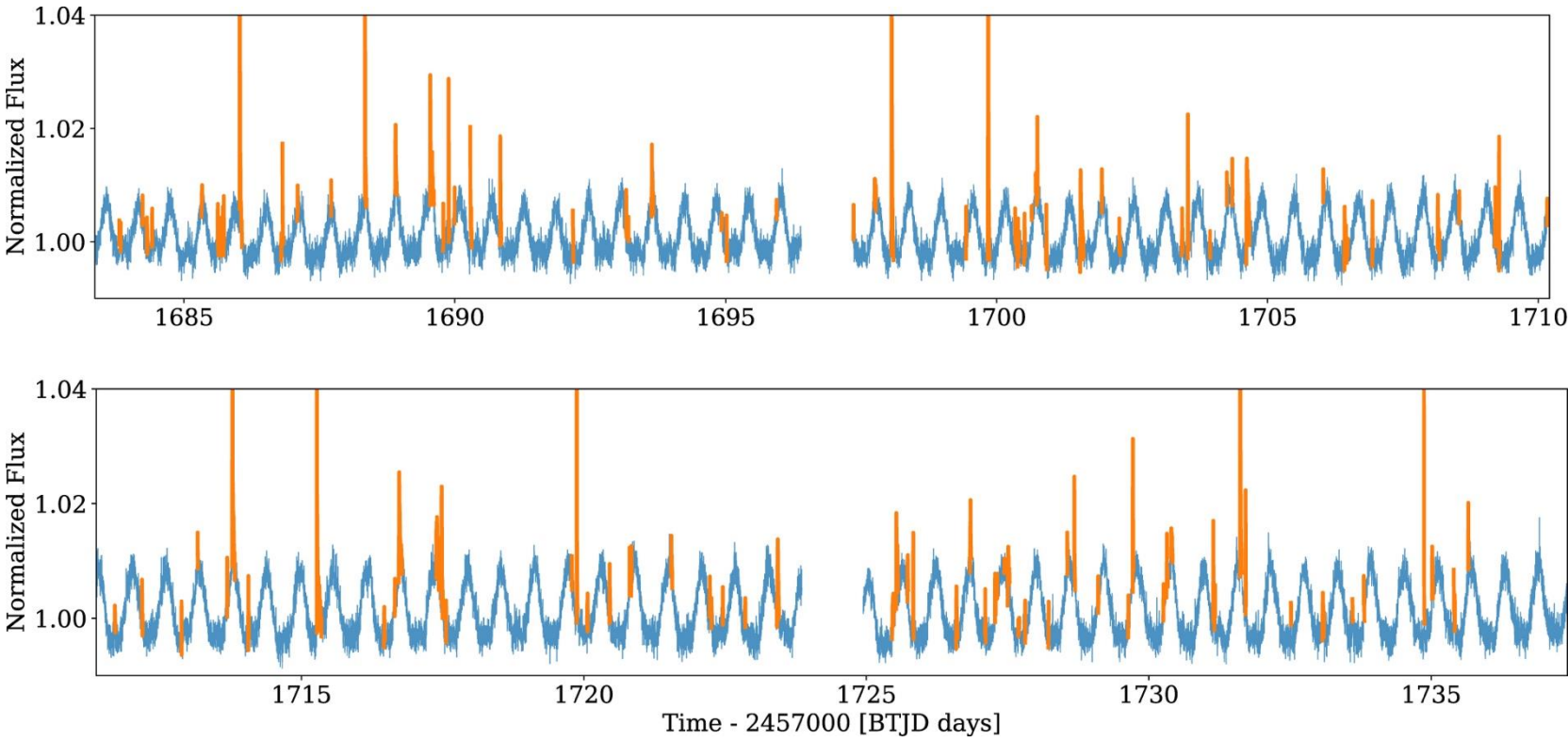
Luque & Palle 2022



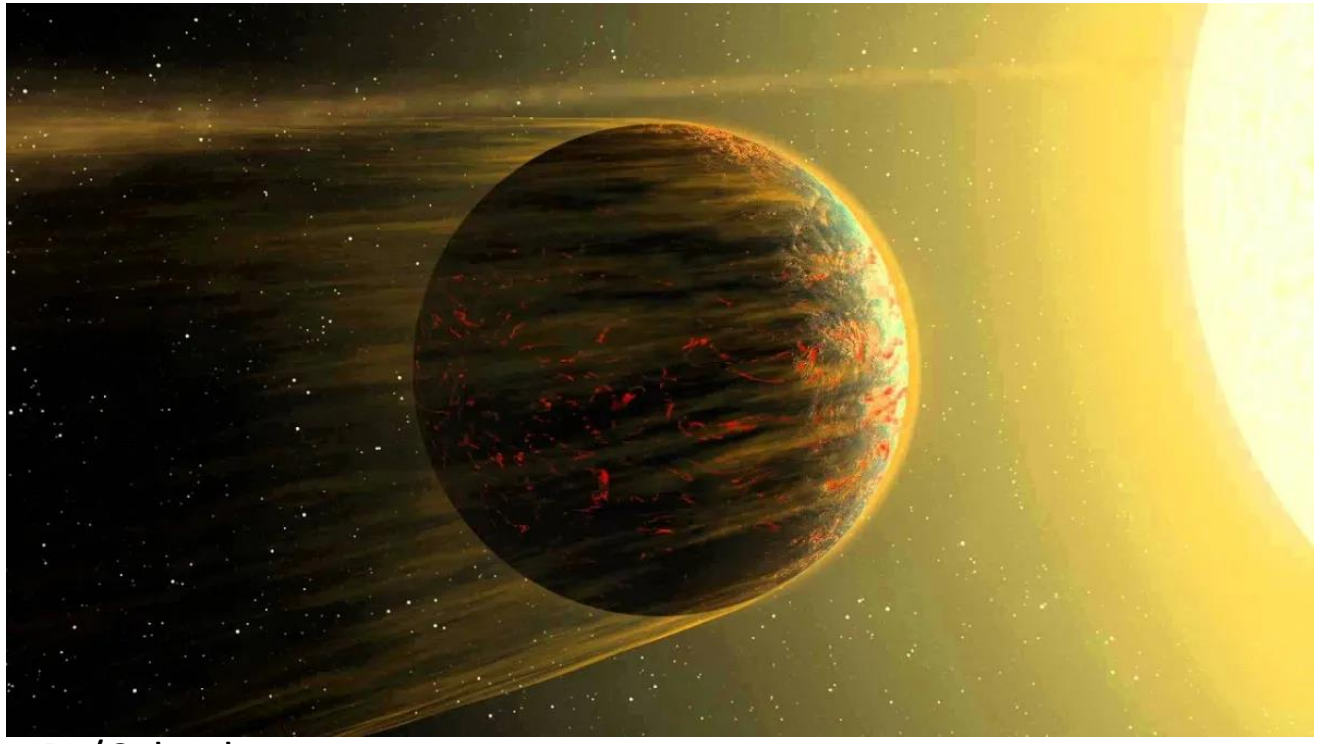
M-Dwarf Flares

- All stars produce a background energy flux towards the planets orbiting them
- Flares increase the incoming radiation for close-in orbiting planets
- M dwarf stars produce many flares over a large time and energy space
- How do these planets respond?

Davenport et al. 2020



Water Worlds & Stellar Activity

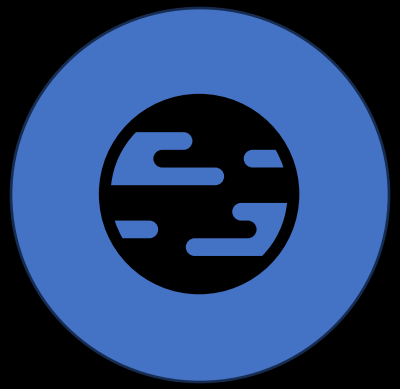


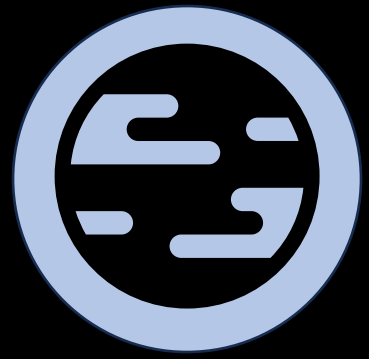
JPL/Caltech

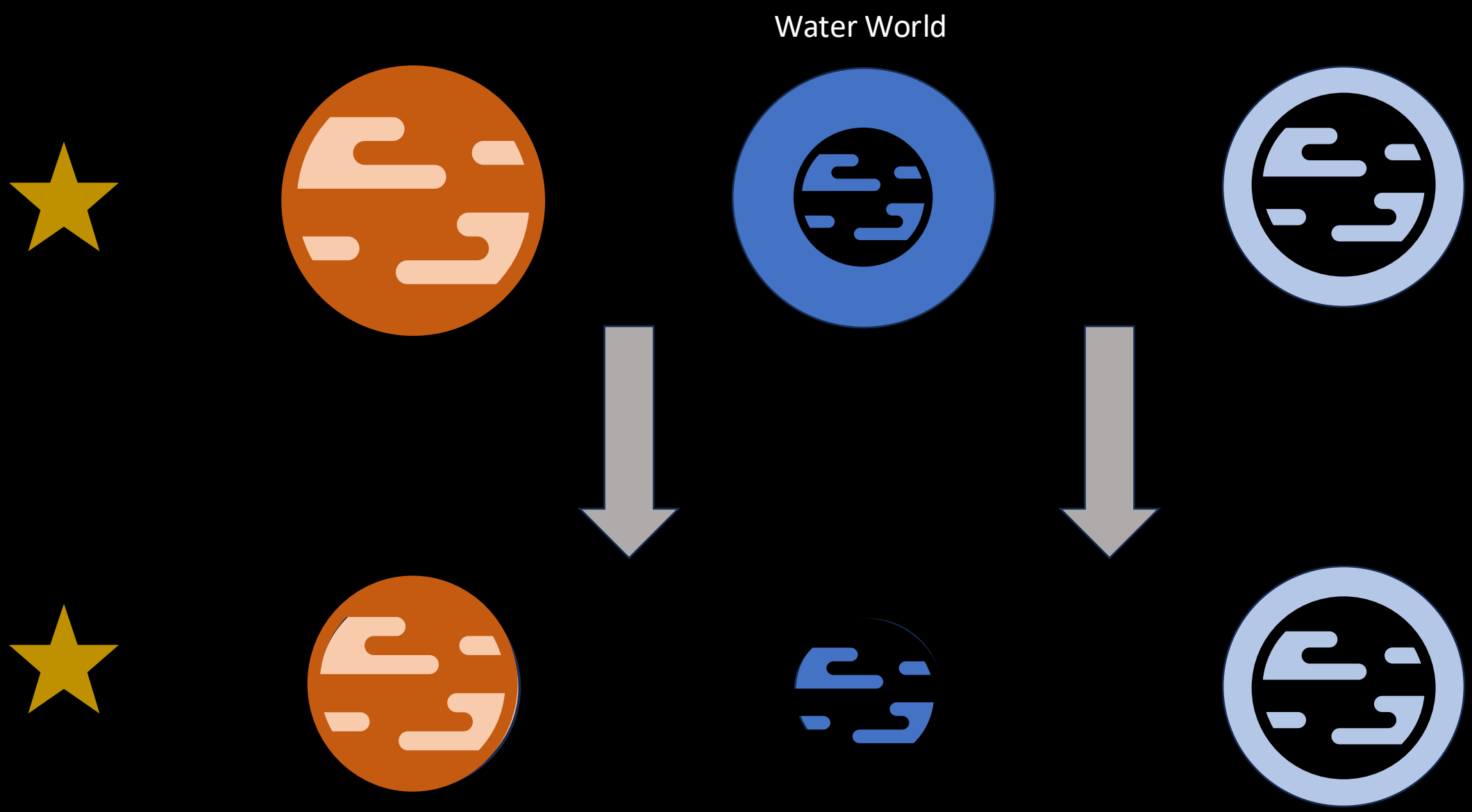
Temperate sub-Neptune water worlds exoplanets orbiting close to their star can be significantly affected by stellar flaring events.

- Stellar flares trigger photochemistry, which can affect the habitability of the surrounding planets
  - Can drive water loss and atmospheric escape

Water World



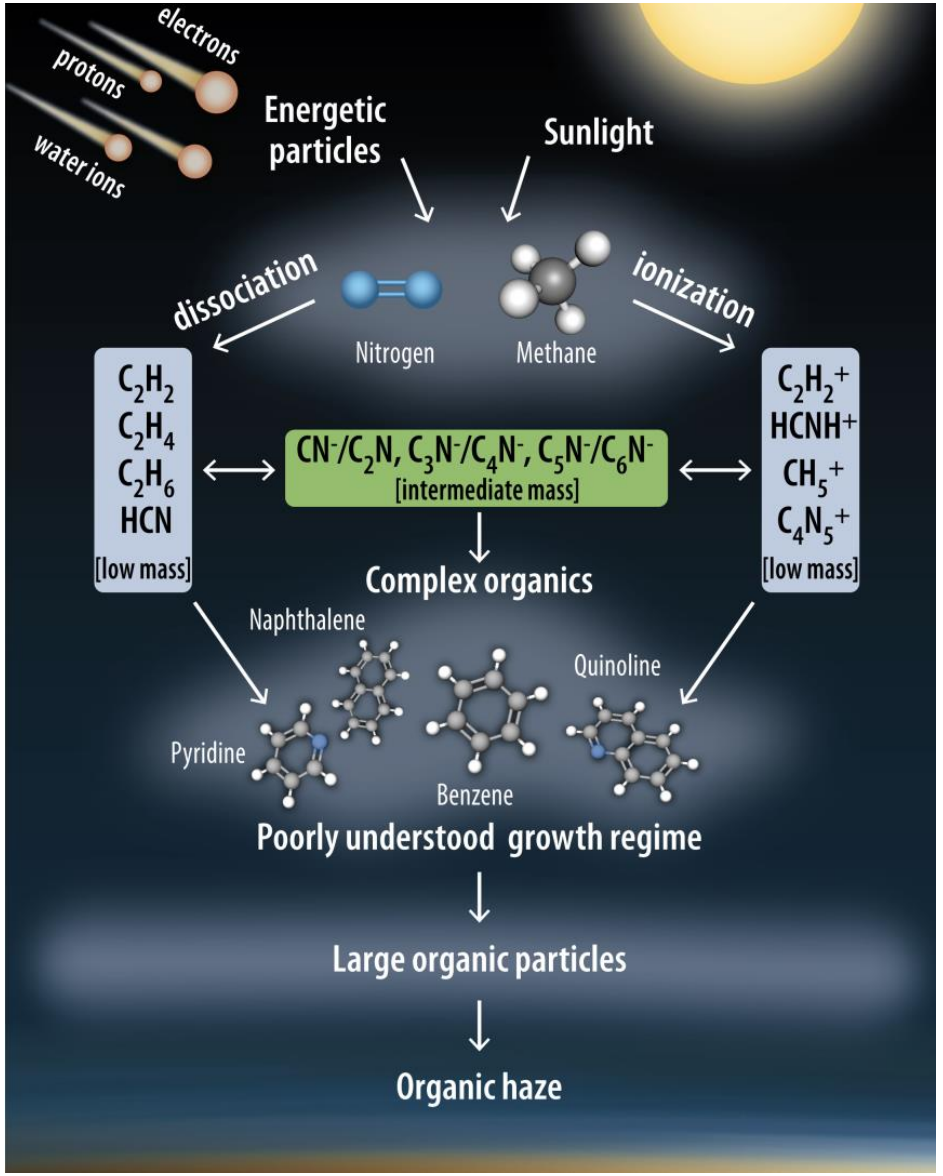


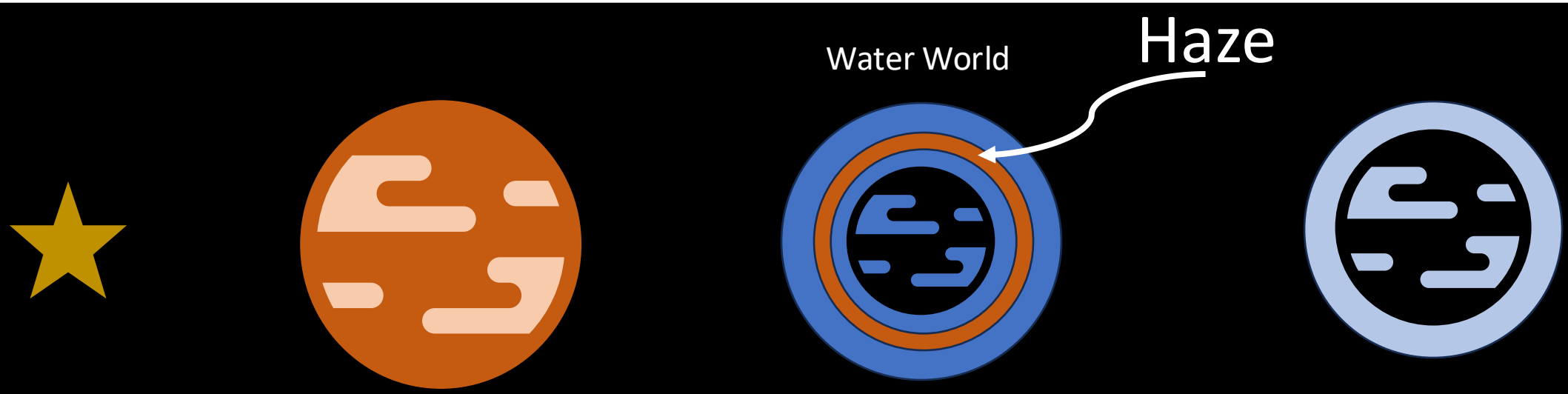

Water World

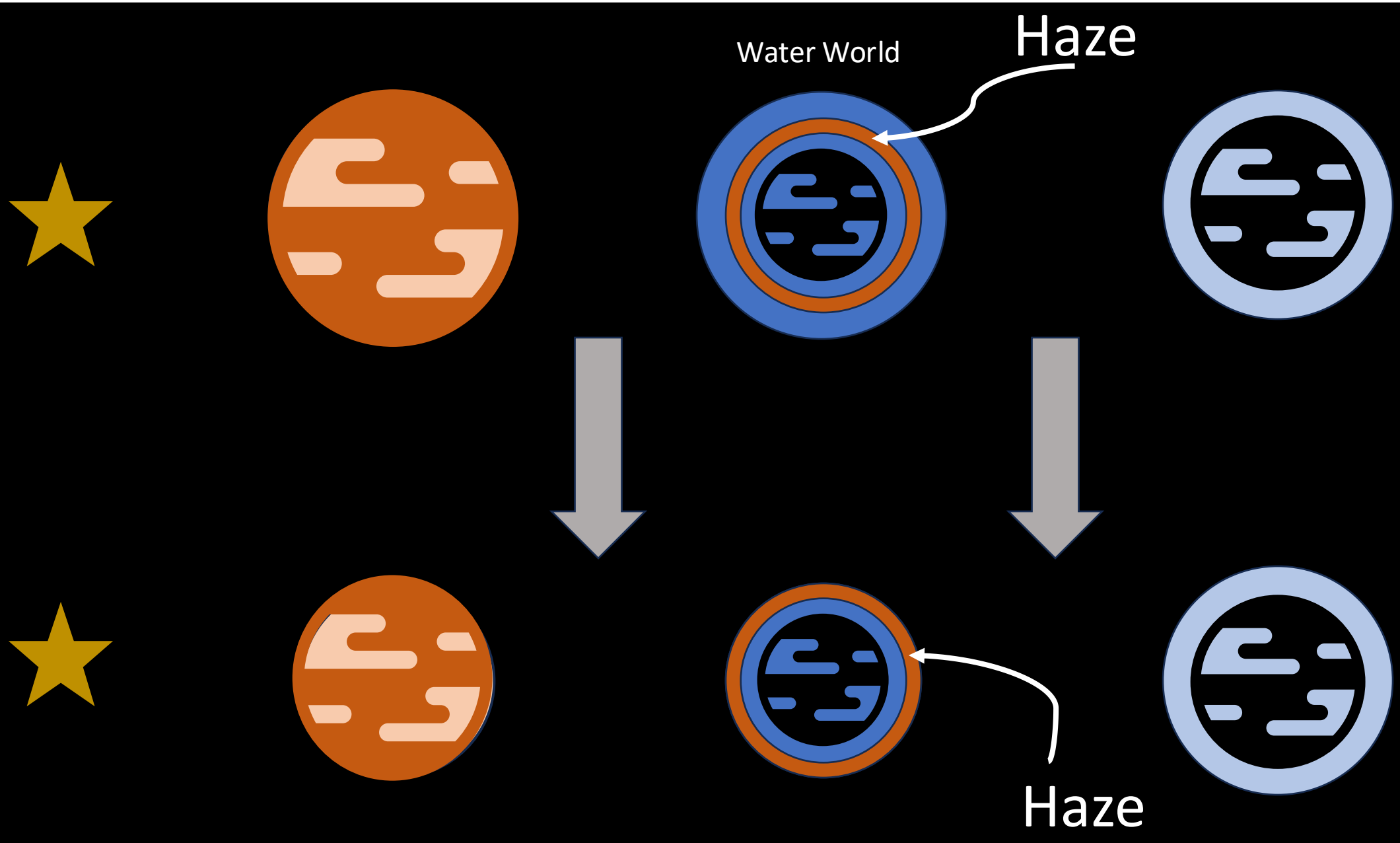
Hazes Play a Huge Part

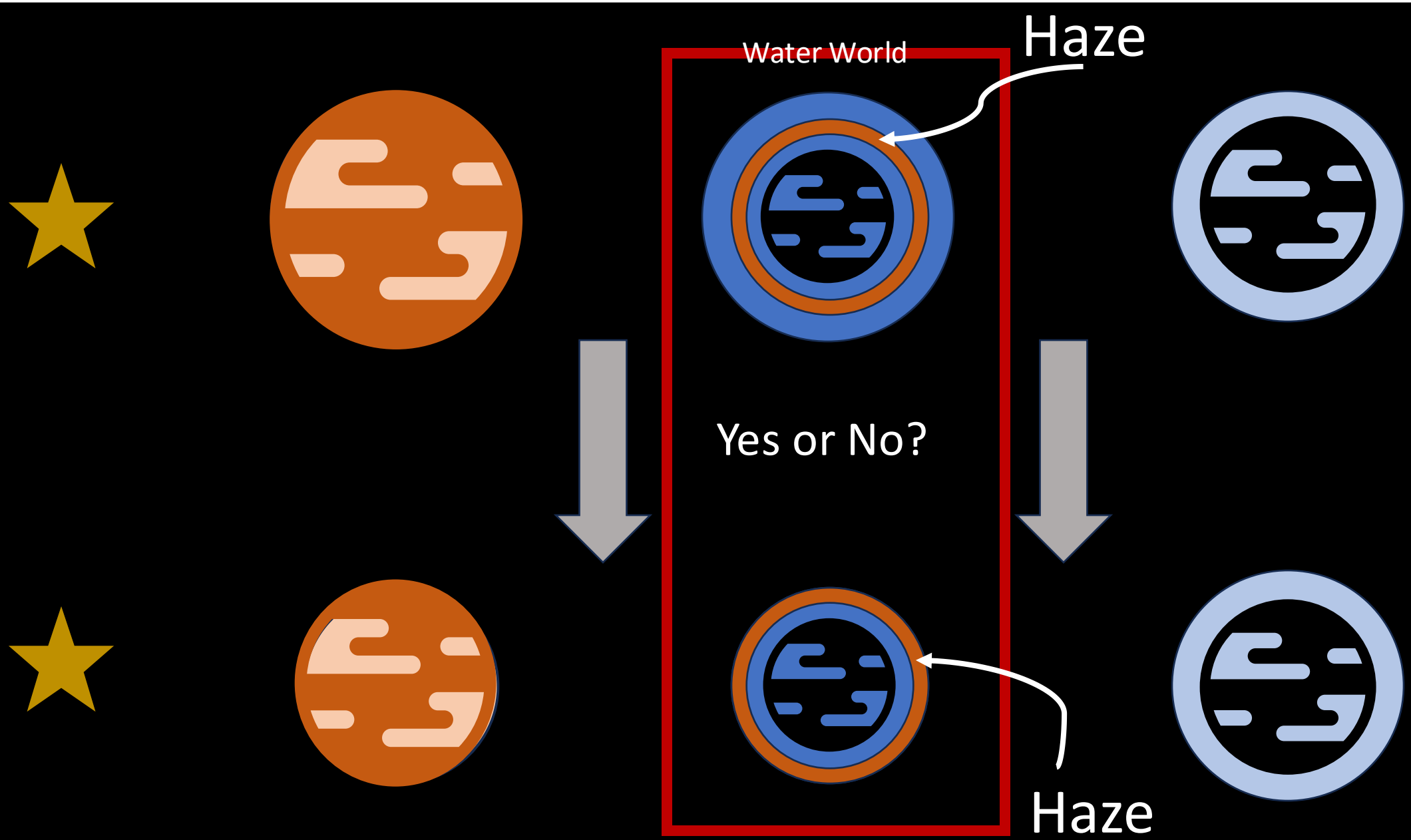
- Both space--based and ground--based observations have shown that many cooler sub--Neptune exoplanets contain clouds and hazes in their atmospheres
- Create tricky observations
- Formation and growth is not well understood yet

Nixon et al. 2024 / ESA




Water World
Haze

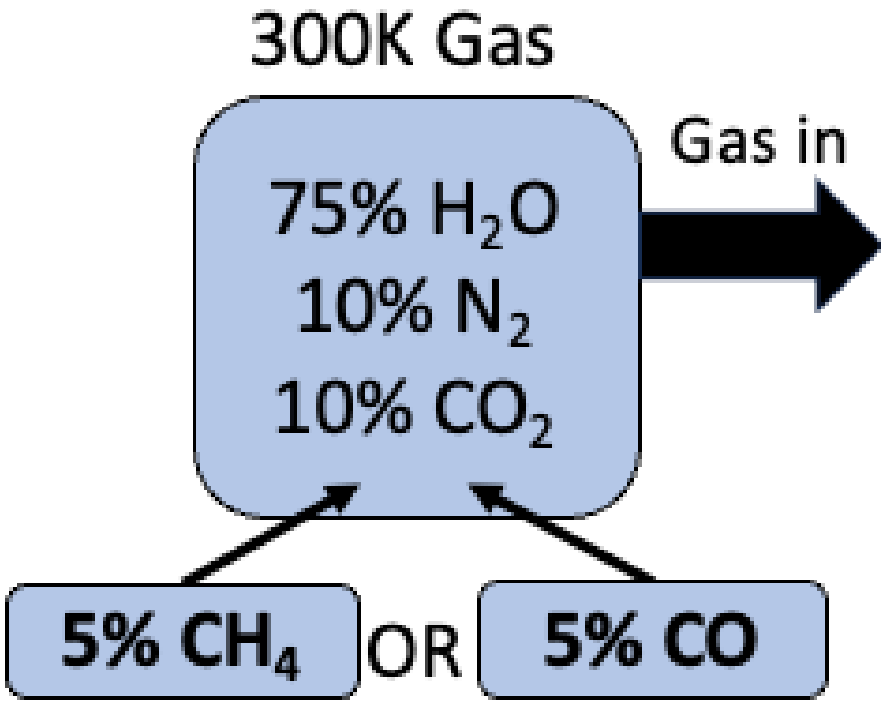

Water World
Haze
Haze


Water World
Haze
Yes or No?
Haze

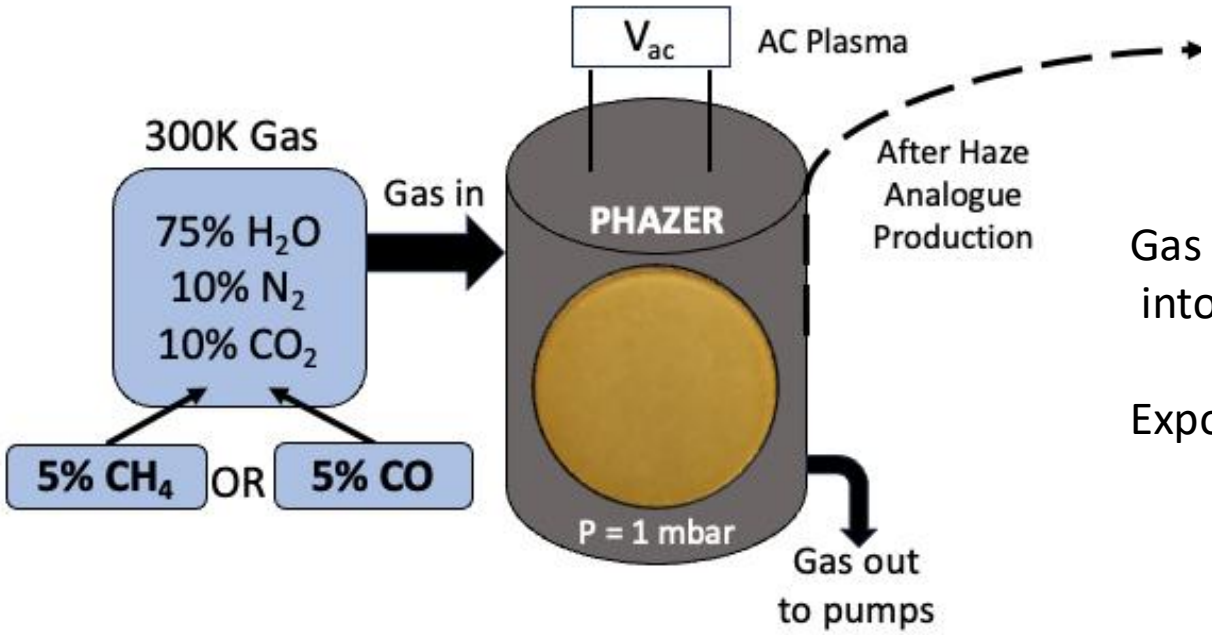
How does Stellar Flaring Affect Water-World Exoplanet Hazes?

Our work helps to quantify spectral changes to laboratory made exoplanet hazes across a broad wavelength range (0.2-9 µm) to:

- Improve our understanding of haze evolution and how stellar flares can impact exoplanet atmospheric compositions
- Assess if water worlds would be able to retain their atmospheres after a multitude of flaring events

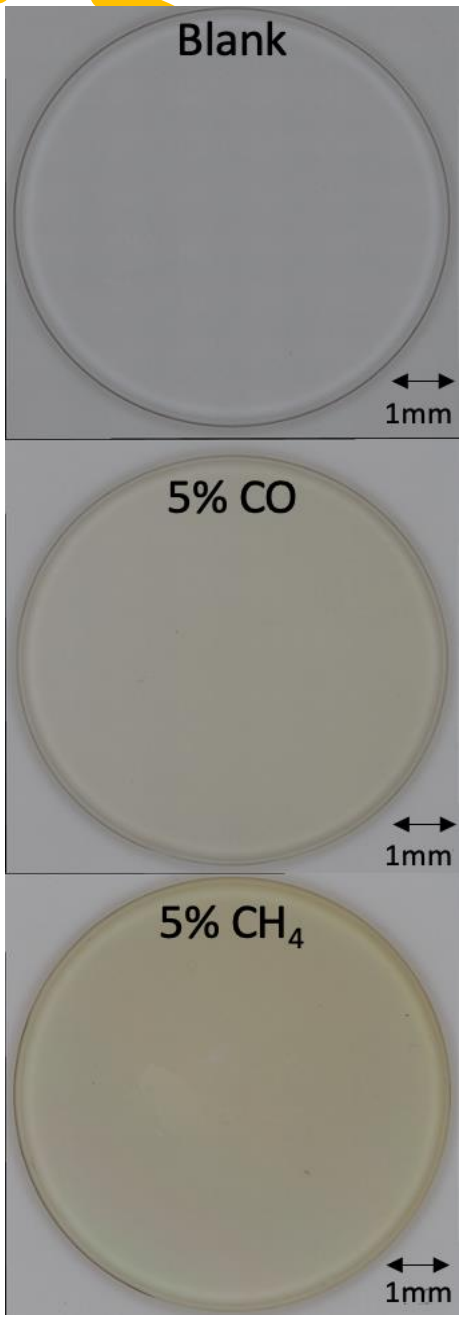


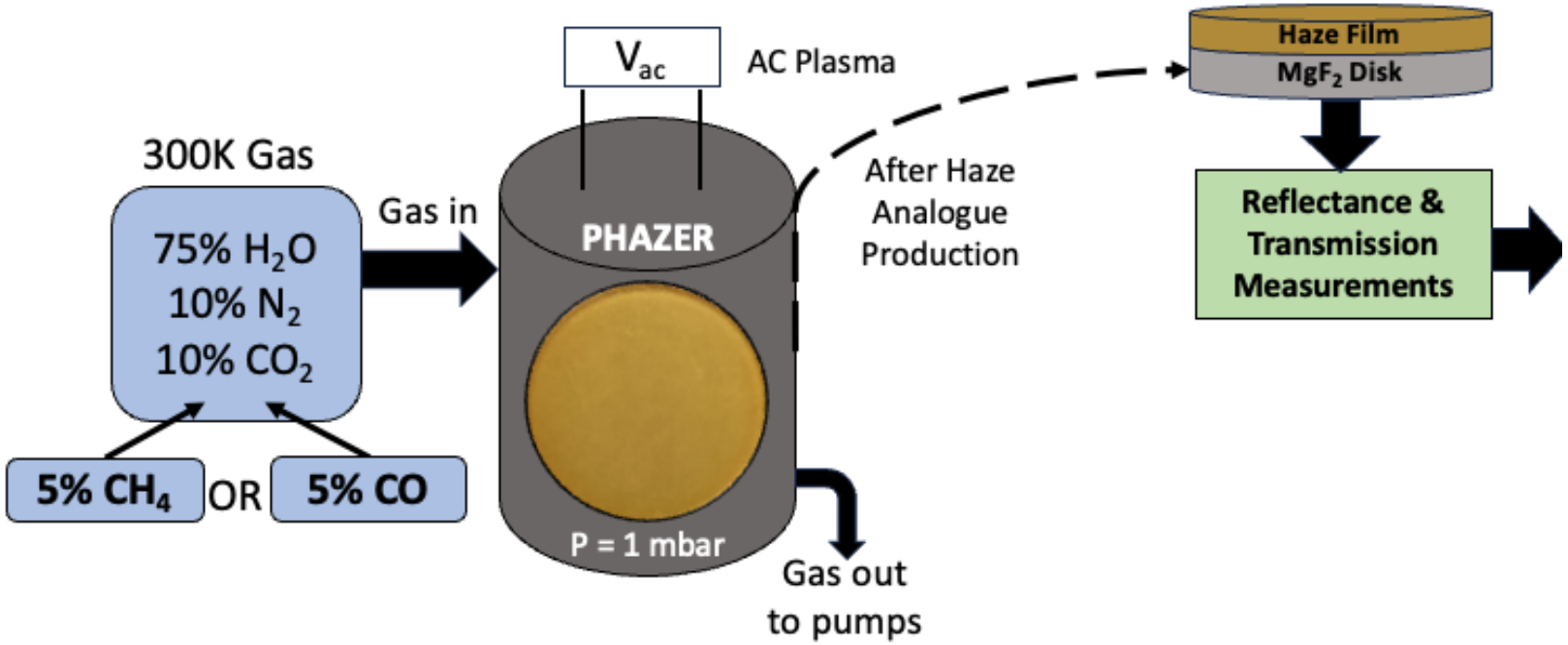
- Guided by 1000x Solar metallicity chemical equilibrium calculations (Moses et al. 2013, Hörst et al, 2018)
- Starting atmosphere varies by minor carbon source
- Produced to mimic potential sub-Neptune water-world atmospheric compositions



Gas mixture pumped in at room temperature into PHAZER reaction chamber

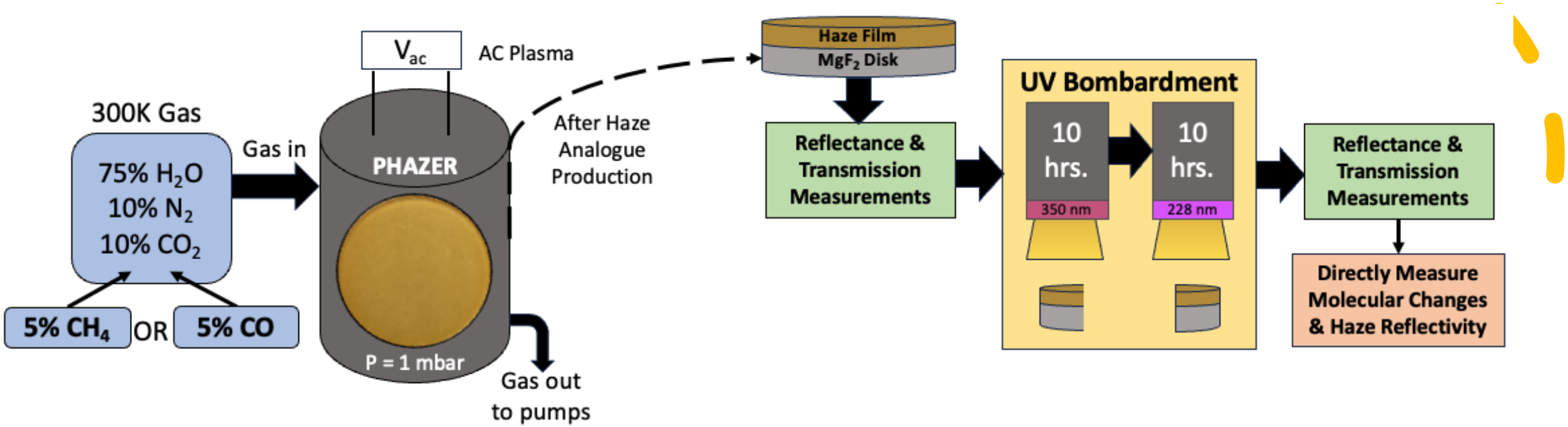
Exposed to AC Plasma for 72 hours





Haze particles deposited onto thin disks in PHAZER chamber

Pre-Irradiation measurements taken



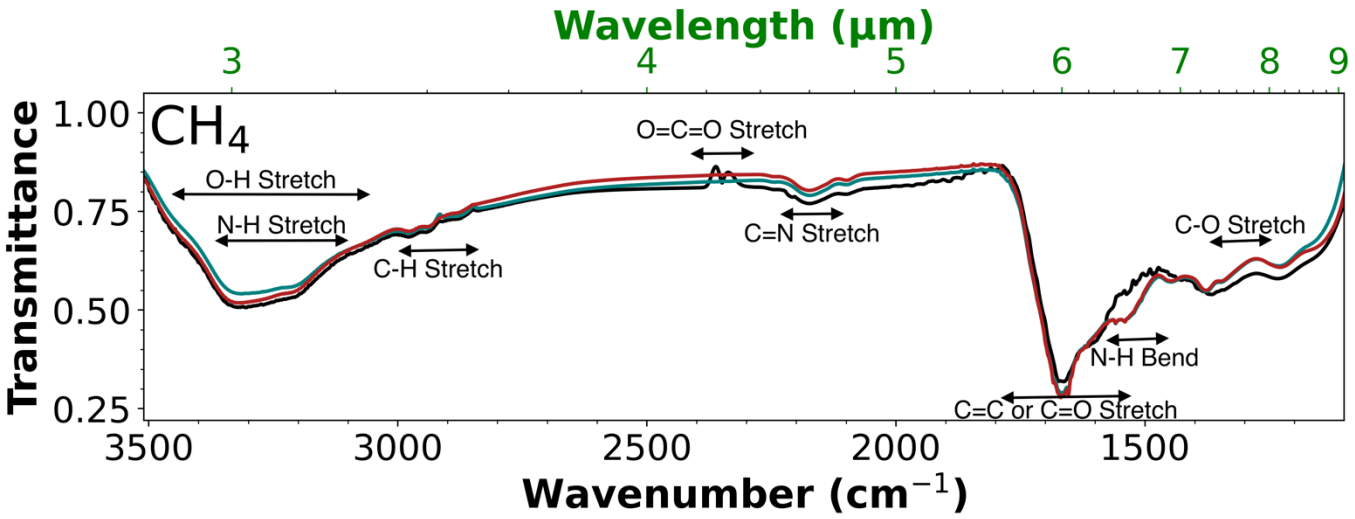
½ sample bombarded with UV light through 350 nm filter for 10 hours

Then rotated and other ½ bombarded with light through 228 nm filter for 10 hours

Post-Irradiation reflectance and transmittance measurements

Huseby et al. 2025 (In Review)

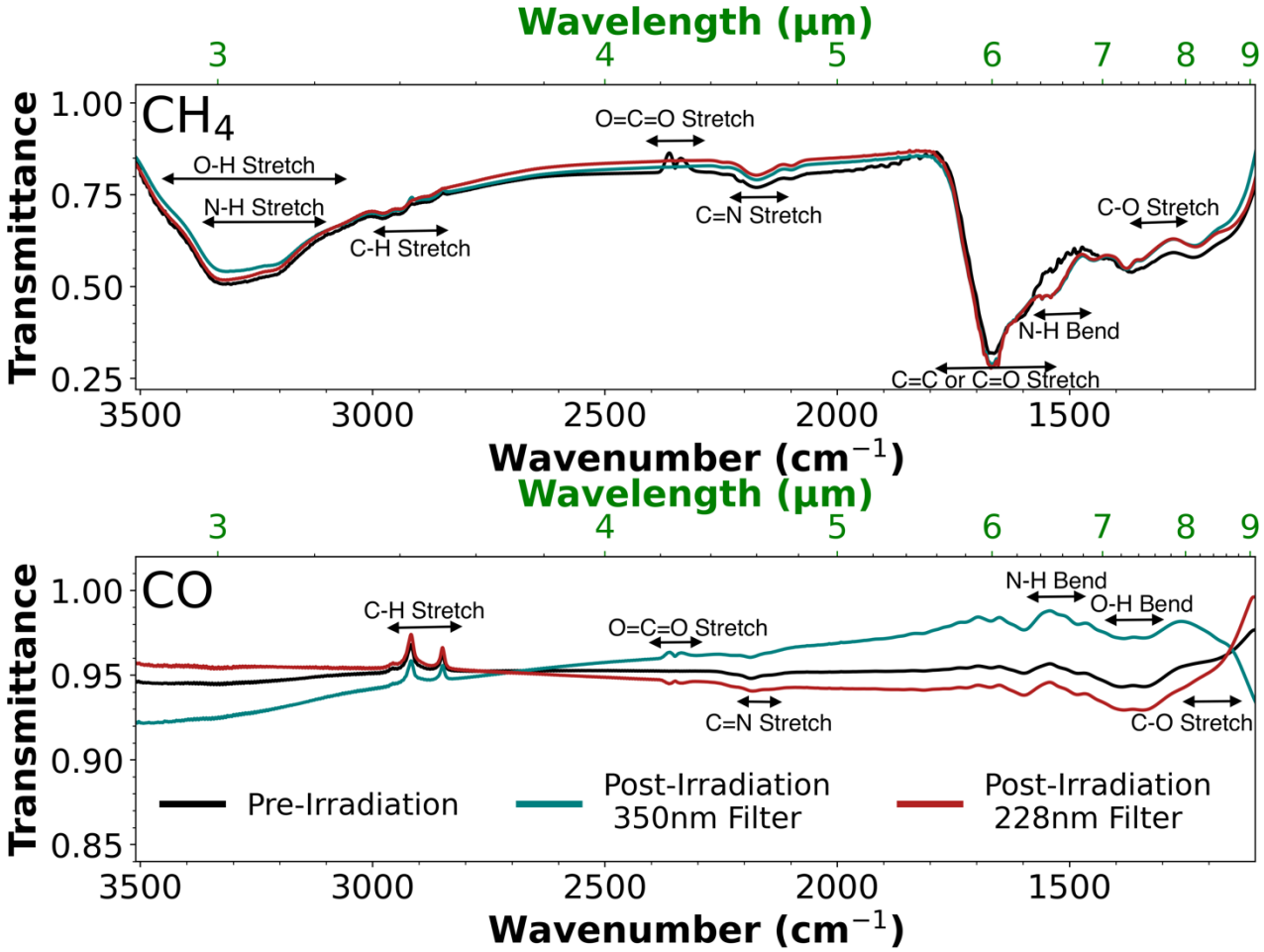
Transmittance Spectra



- 3% - 12% wavelength dependent change between pre- and post- UV irradiation in CH_4 sample

- Enlarged spectrum between 3500 - 1100 cm^{-1} (2.5 - 9 μm) of the 5% CH_4 haze sample as a function of wavelength in transmittance with major spectral features labeled.

Huseby et al. 2025 (In Review)



- Enlarged spectrum between 3500 - 1100 cm^{-1} (2.5 - 9 μm) of the 5% CH_4 (top) and 5% CO (bottom) haze samples as a function of wavelength in transmittance with major spectral features labeled.

Transmittance Spectra

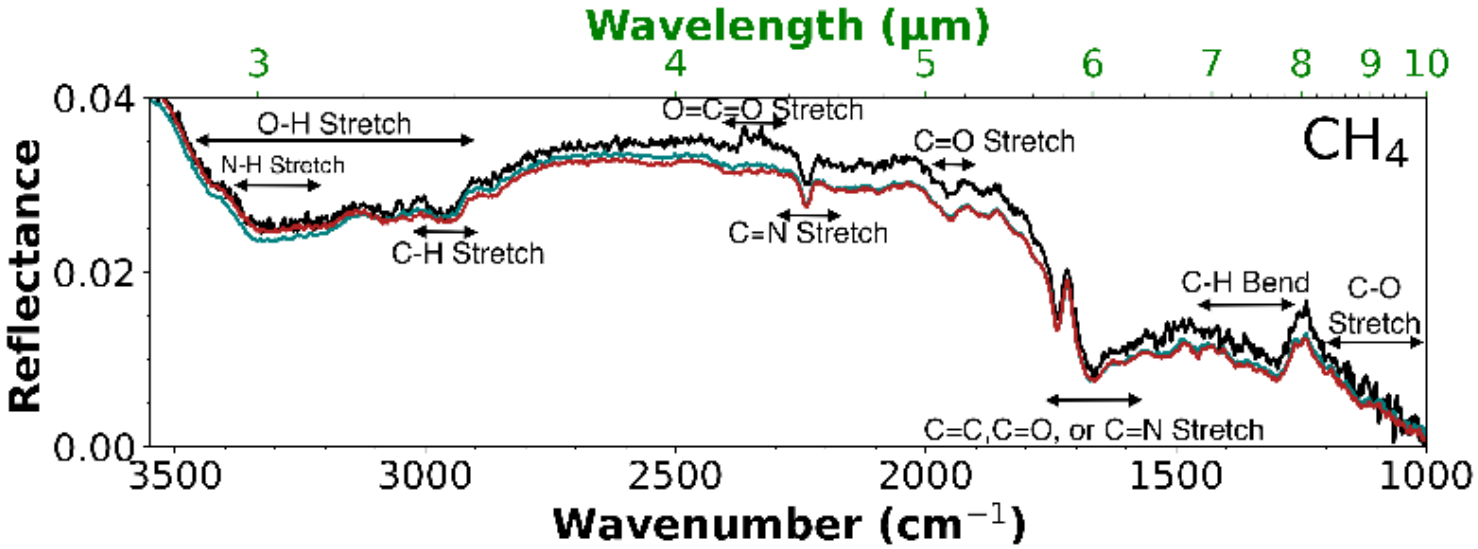
- 3% - 12% wavelength dependent change between pre- and post- UV irradiation in CH_4 sample
- 2% - 5% wavelength dependent change between pre- and post- UV irradiation in CO sample

More spectral features seen in the CH_4 sample as compared to the CO sample

Huseby et al. 2025 (In Review)

Reflectance Spectra

- 30% - 220% wavelength dependent change between pre- and post- UV irradiation in CH_4 sample

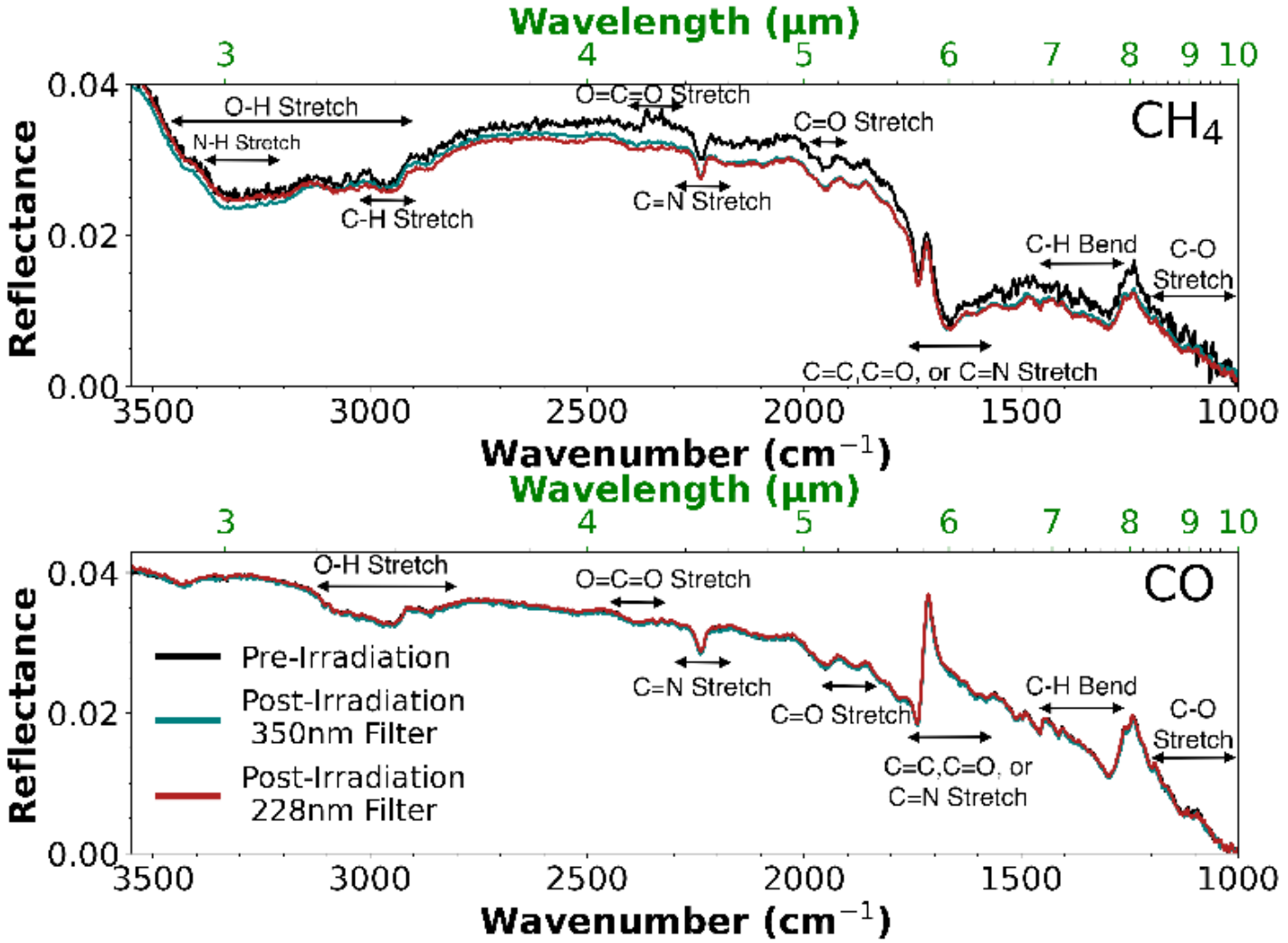


- Enlarged spectrum between 3500 - 1100 cm^{-1} (2.5 - 9 μm) of the 5% CH_4 atmosphere generated hazes as a function of wavelength in reflectance with major spectral features labeled.

Huseby et al. 2025 (In Review)

Reflectance Spectra

- 30% - 220% wavelength dependent change between pre- and post- UV irradiation in CH_4 sample
- 2% - 7% wavelength dependent change between pre- and post- UV irradiation in CO sample



- Enlarged spectrum between 3500 - 1100 cm^{-1} (2.5 - 9 μm) of the 5% CH_4 (top) and 5% CO (bottom) haze samples as a function of wavelength in reflectance with major spectral features labeled.

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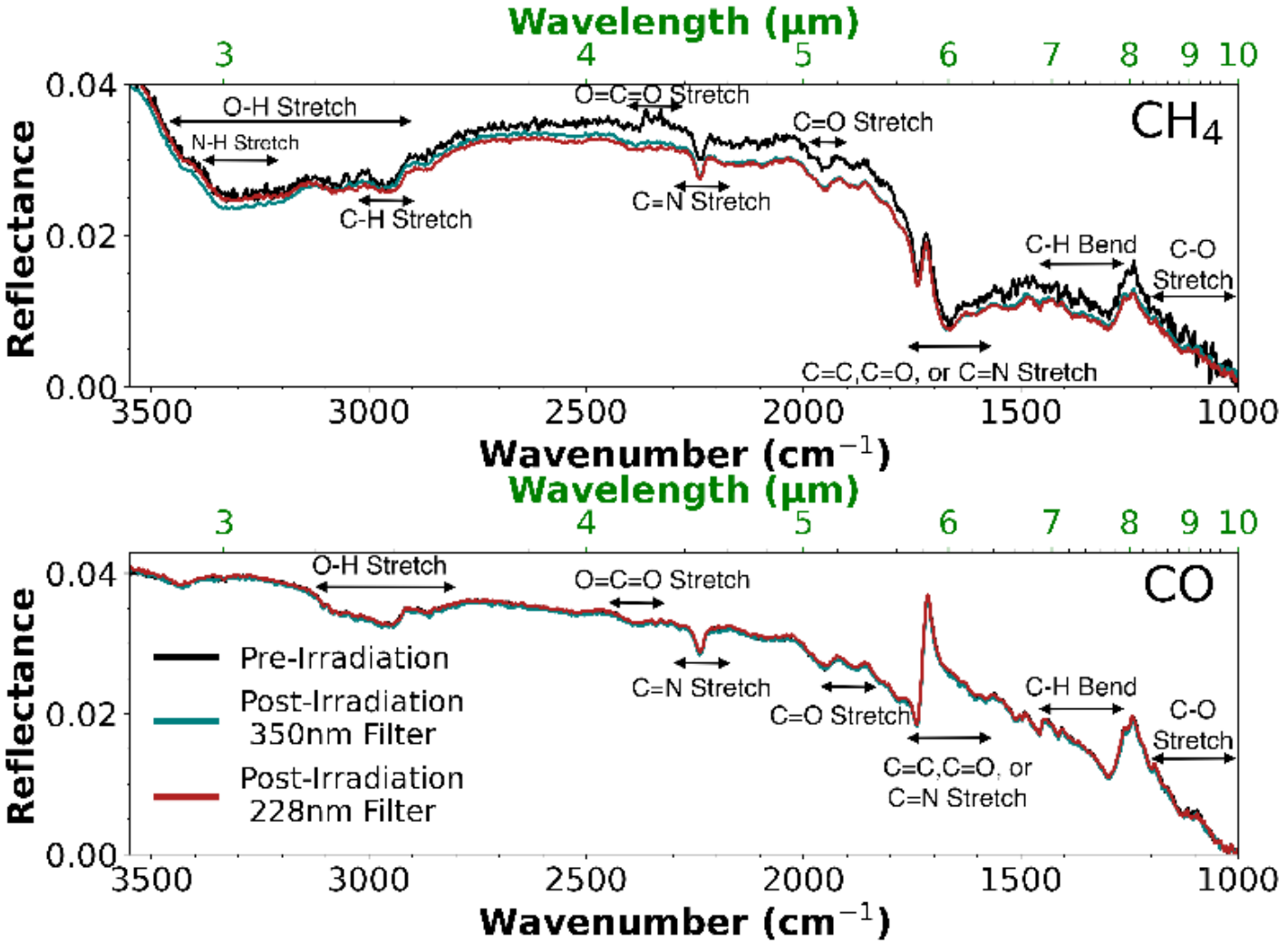
Reflectance Spectra

- 30% - 220% change between pre- and post-UV irradiation in CH_4 haze derived sample
- 2% - 7% change between pre- and post- UV irradiation in CO haze derived sample

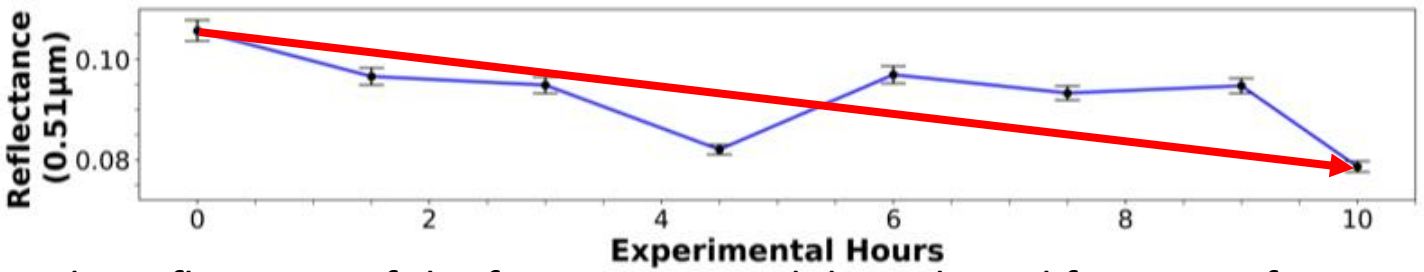
The laboratory haze samples are compositionally different not only between the two haze derived samples, but also pre- and post-irradiation.

This has key implications for the lifetime of water world exoplanet hazes and how UV energy can change the compositions of the hazes over short timescales.



- Enlarged spectrum between 3500 - 1100 cm^{-1} (2.5 - 9 μm) 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.

CH_4 Sample Reflectance – 350 nm Filter



The reflectance of the fringe-corrected data plotted for a specific wavelength (0.51 µm) over the duration of the irradiation process.

- We find that the measured reflectance decreases over time, from 10.6% to 7.9% reflective.
- Sample became less reflective over the irradiation process, leading to an increase in transmittance.

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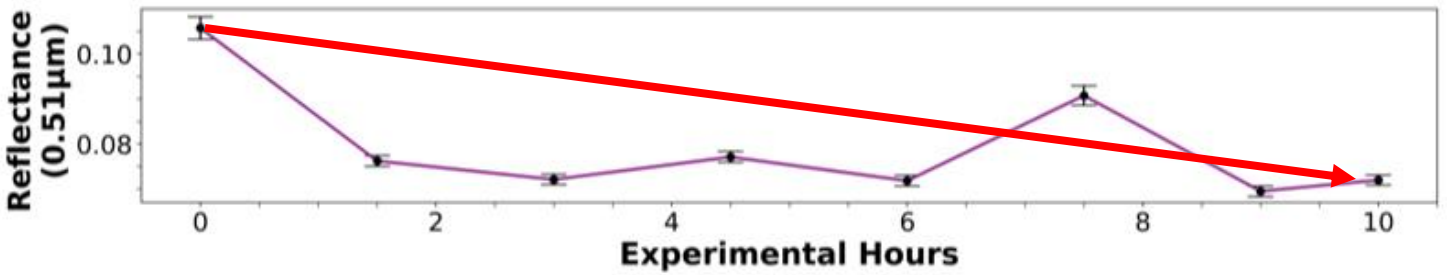
CH_4 Sample Reflectance – 228 nm Filter

- We find that the measured reflectance decreases over time, from 10.6% to 7.2% reflective.
- The higher energy UV bombardment made the haze slightly less reflective than the 350 nm filter



The reflectance of the fringe-corrected data plotted for a specific wavelength (0.51 µm) over the duration of the irradiation process.

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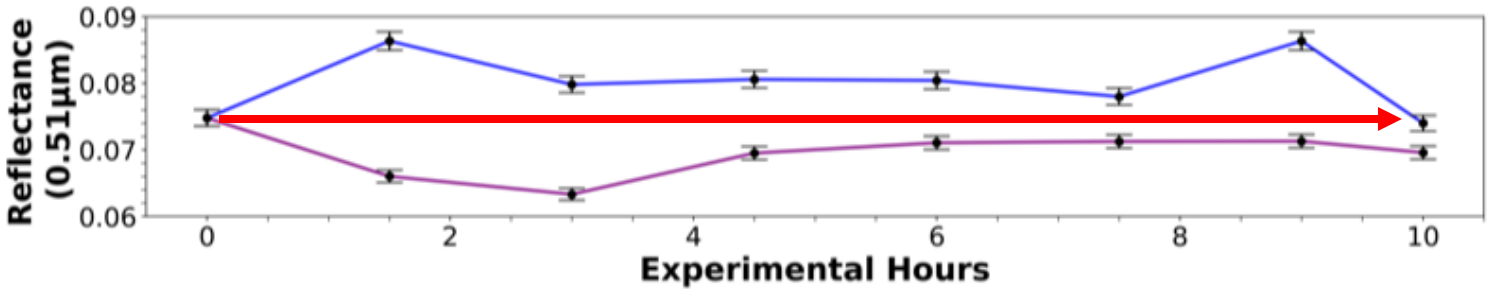
CO Sample Reflectance



Top: UV-visible spectrum between 46000 - 18000 cm-1 (0.22 - 0.54 µm) spectrum for the 5% CO atmosphere haze sample corrected for interference fringe effects. Bottom: The reflectance of the fringe-corrected data plotted for a specific wavelength (0.51 µm) over the duration of the irradiation process.

- No detectable changes during the irradiation process for the 5% CO-derived haze sample.
- This may be because the film was too thin initially to see any observed change in reflectance
- Potentially the CO sample was more resistant to UV bombardment

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Summary

Our laboratory-generated hazes change compositionally after UV irradiation

We find that the measured reflectance of the CH_4 samples slightly decreases over time

More broadly, our results suggest that stellar flaring may affect the overall thickness of the haze present in the water-world exoplanet atmosphere, if no mechanism for production is present.

This increased atmospheric loss will affect the climate and ultimately potential habitability of water world exoplanets. Future work will determine if the amplitude of these changes will be observable when they are included in models of resulting exoplanetary transmission spectra.

Huseby et al. 2025 (In Review)

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