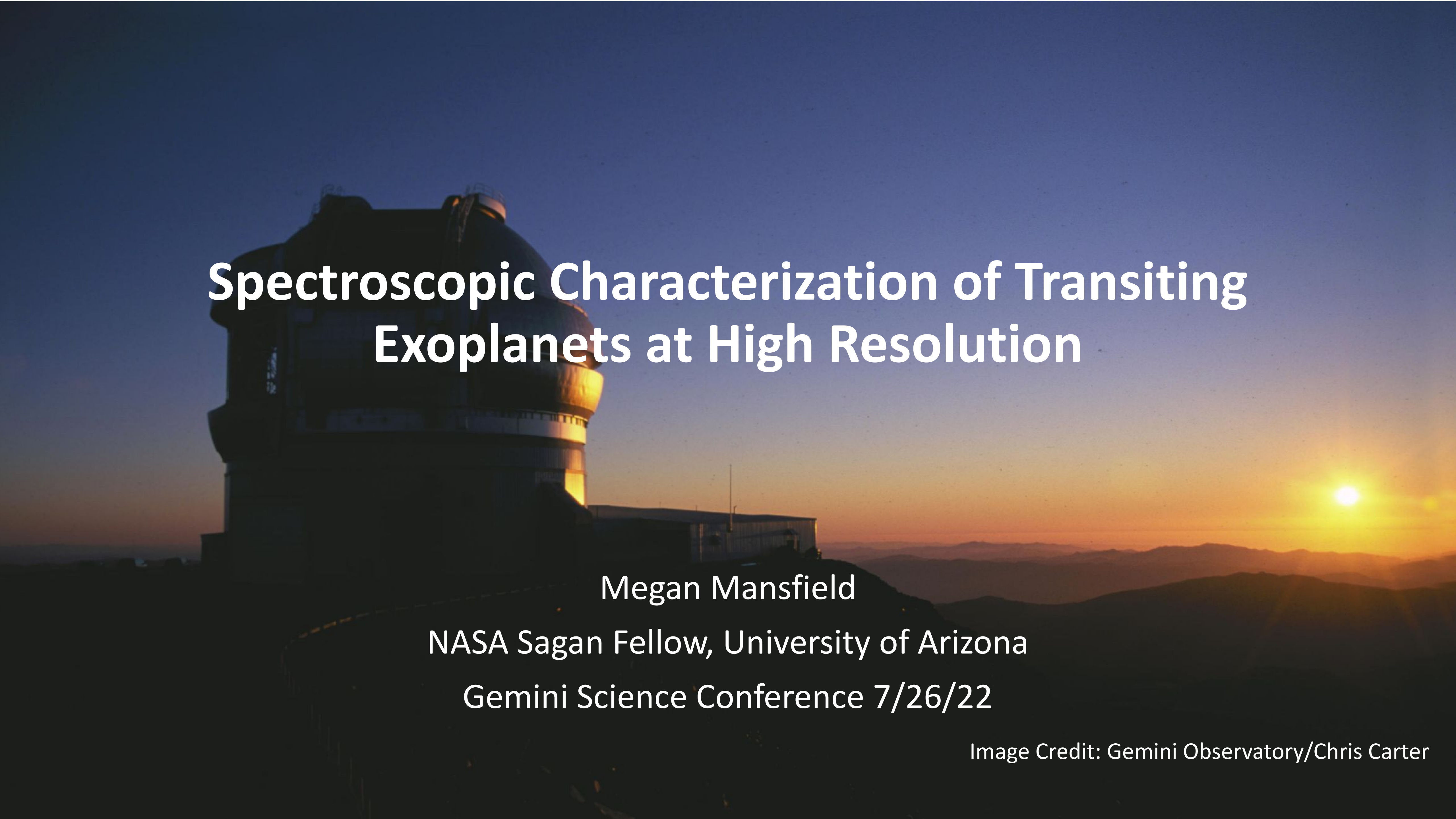


Spectroscopic Characterization of Transiting Exoplanets at High Resolution

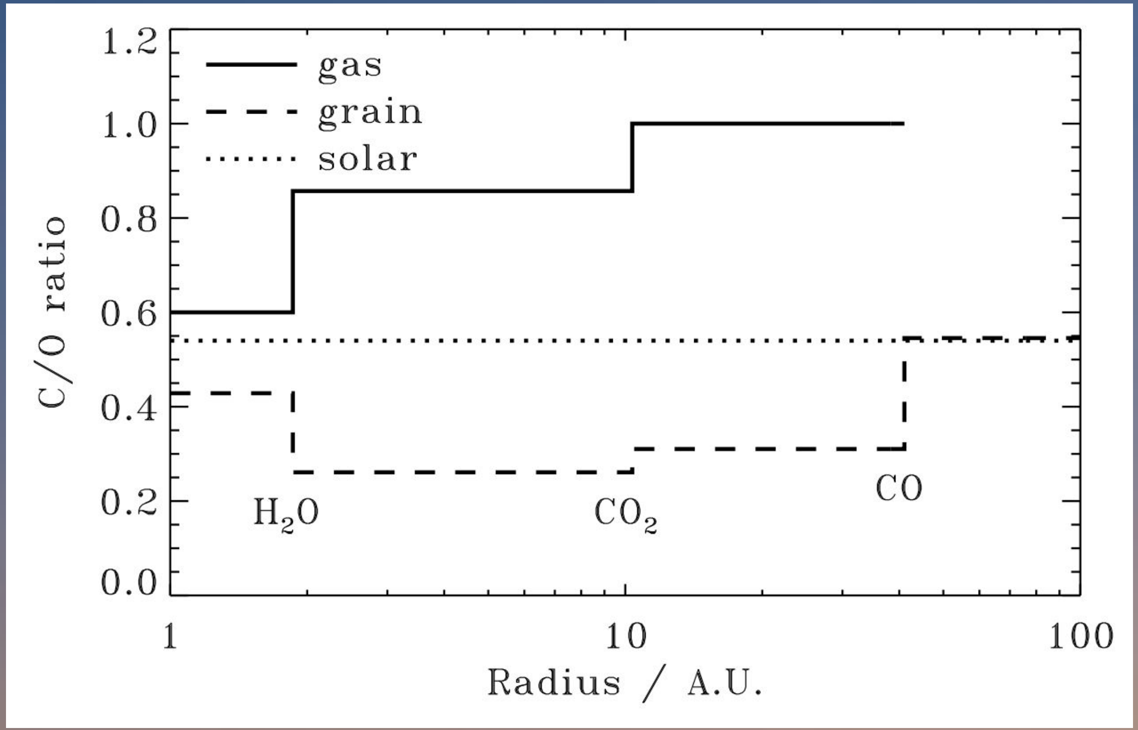
Megan Mansfield

NASA Sagan Fellow, University of Arizona

Gemini Science Conference 7/26/22

Image Credit: Gemini Observatory/Chris Carter

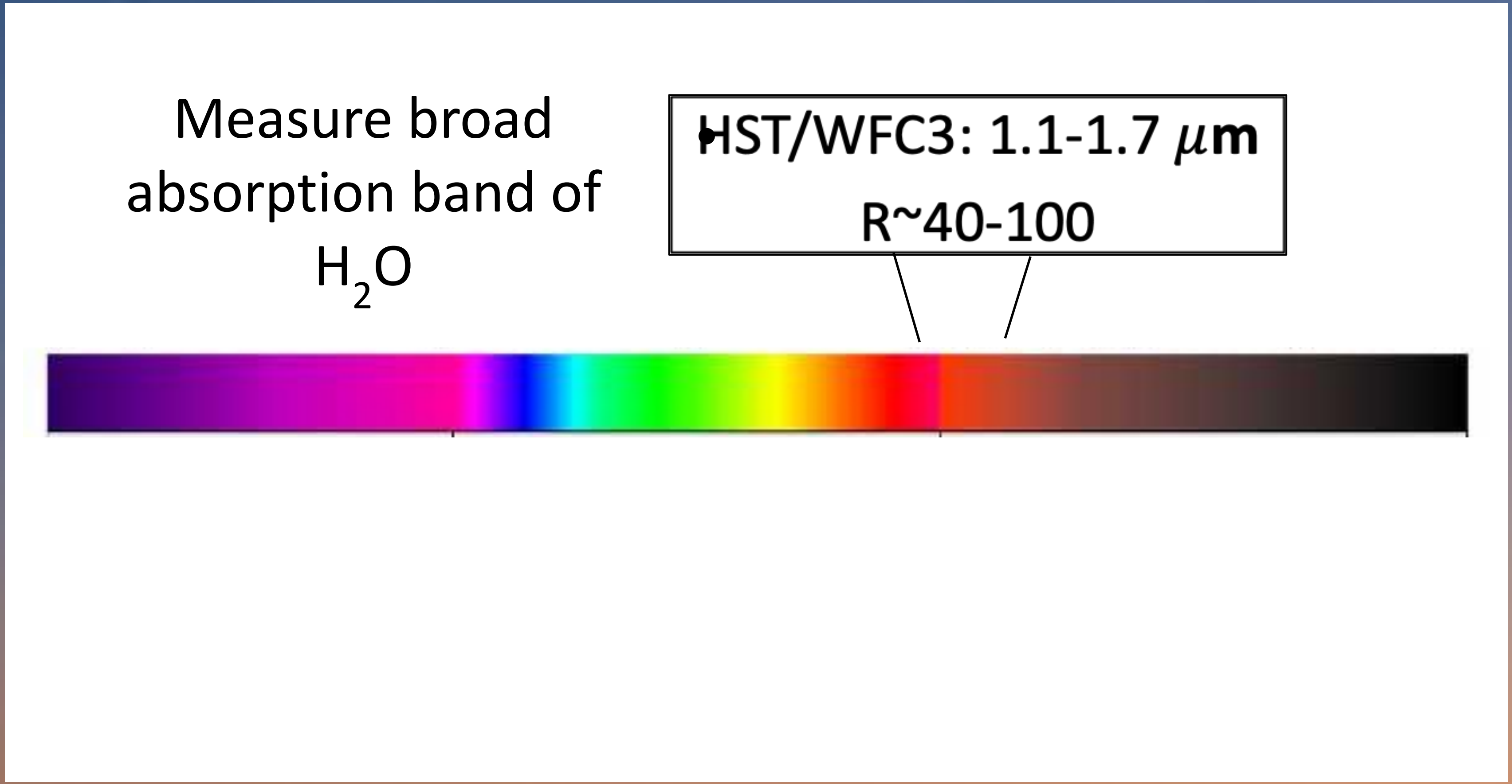
What can we learn from the compositions of exoplanet atmospheres?



Track conditions of planet formation and evolution

Figure from Öberg et al. (2011)

Previous measurements of composition and C/O ratio have been limited by low resolution + low wavelength coverage



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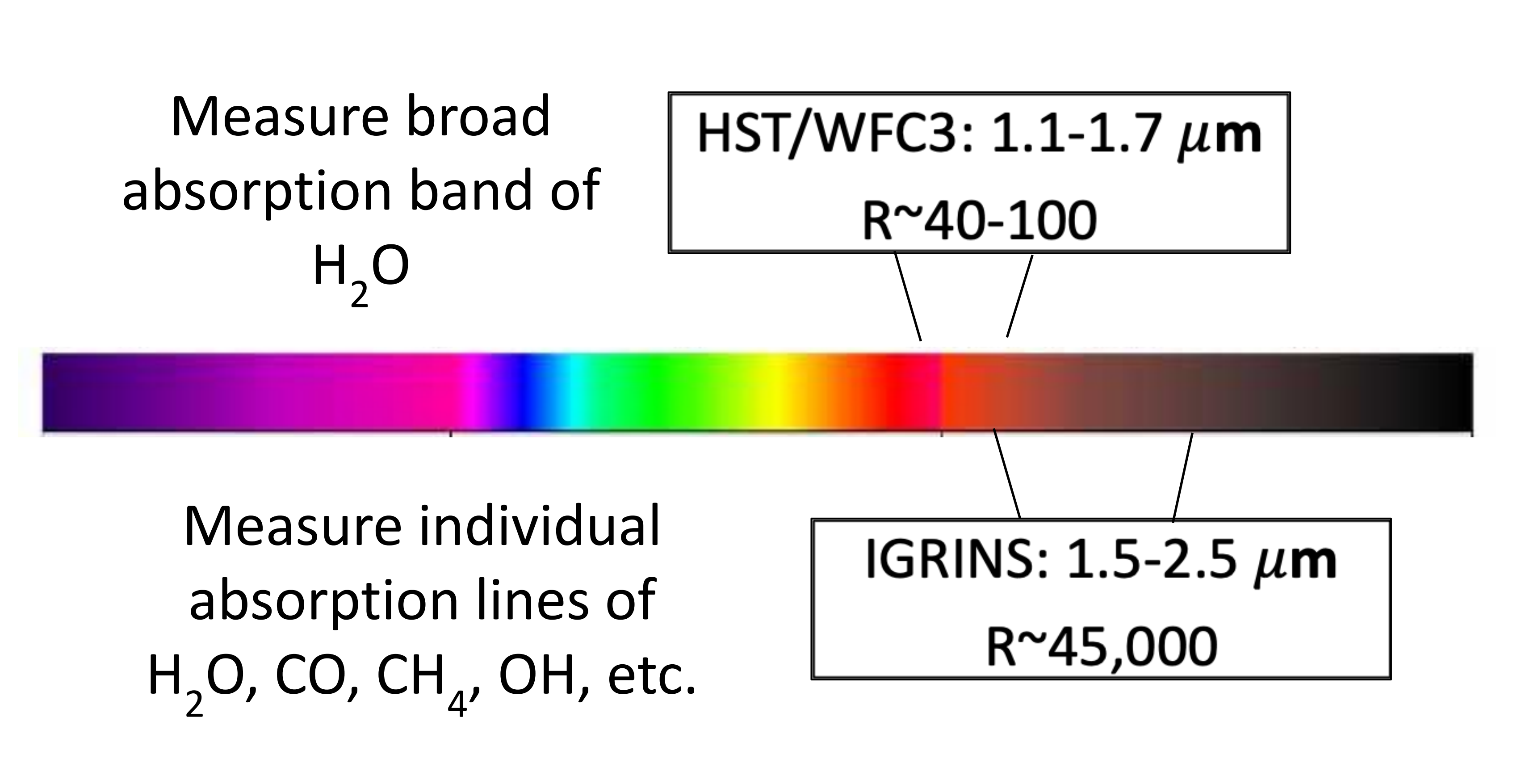
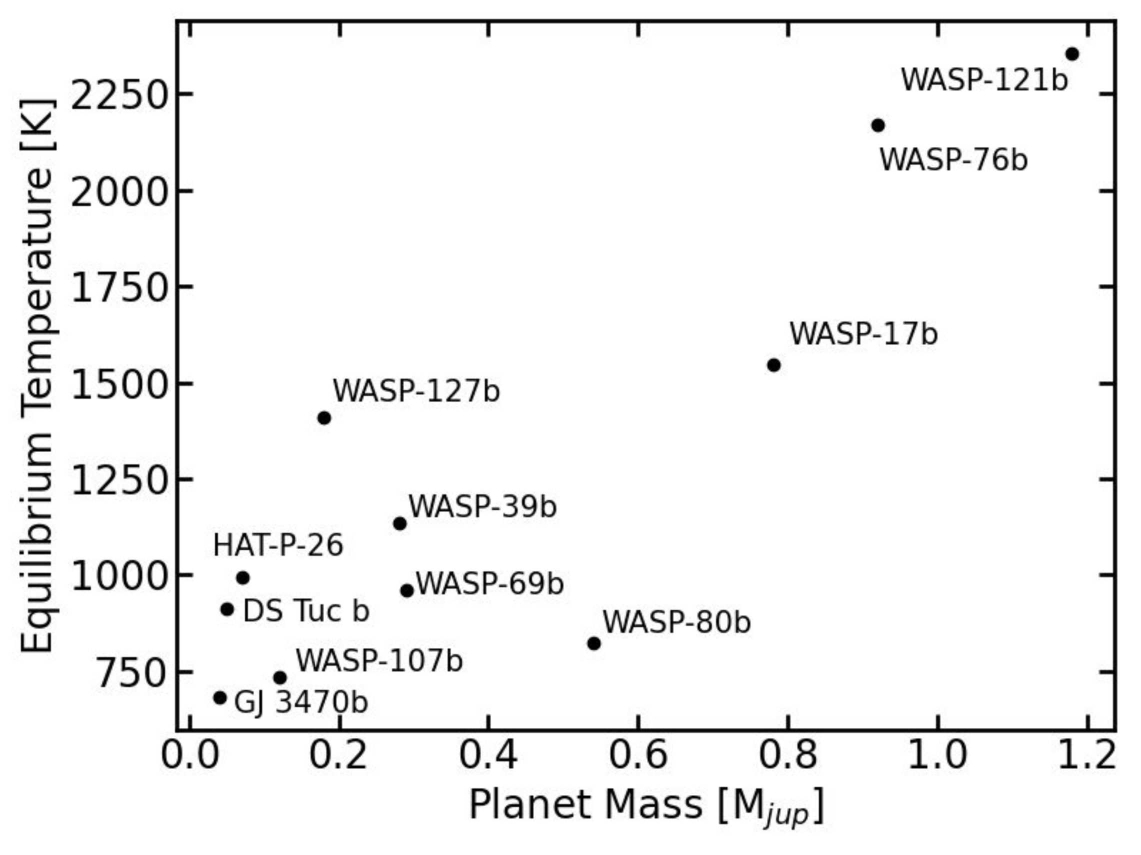


A high-resolution transit survey to measure transmission spectra of 11 exoplanets with Gemini-S/IGRINS (R~45,000 from 1.5–2.5 μm)

- Covers features of all primary C- and O-bearing molecules (e.g., H_2O, CO) look for chemical trends with mass, temperature, and age
- Combine with other data sets (Hubble, Spitzer, optical data) to get fuller picture of atmospheric abundances



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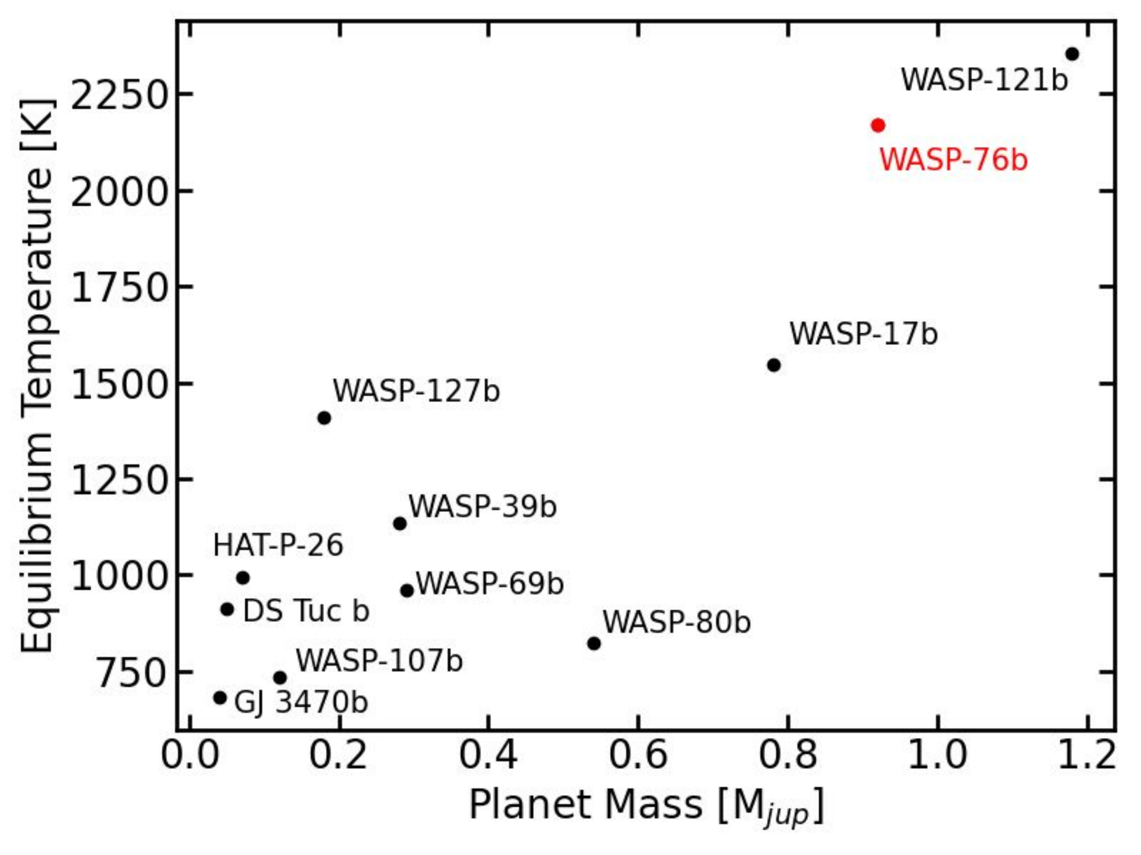
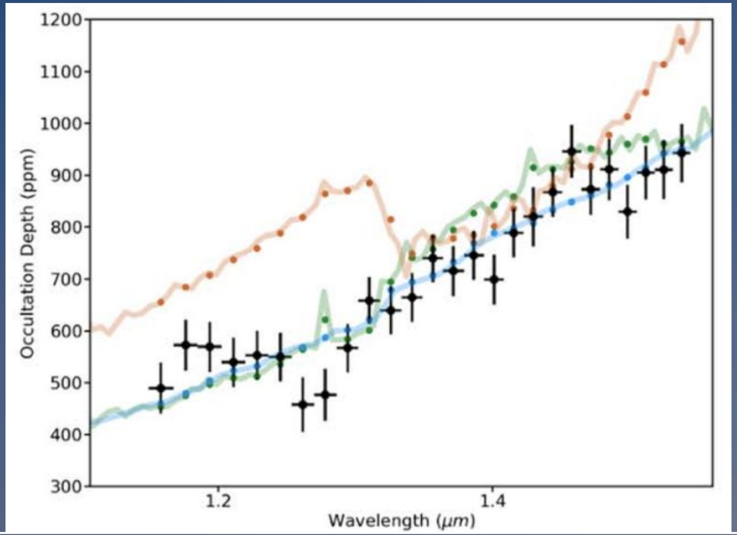


WASP-76b: ultra-hot Jupiter (T_{eq}=2170 K)



Blackbody-like *HST* spectrum; likely due to water dissociation (Edwards+2020; Fu+2021; Mansfield+2021)

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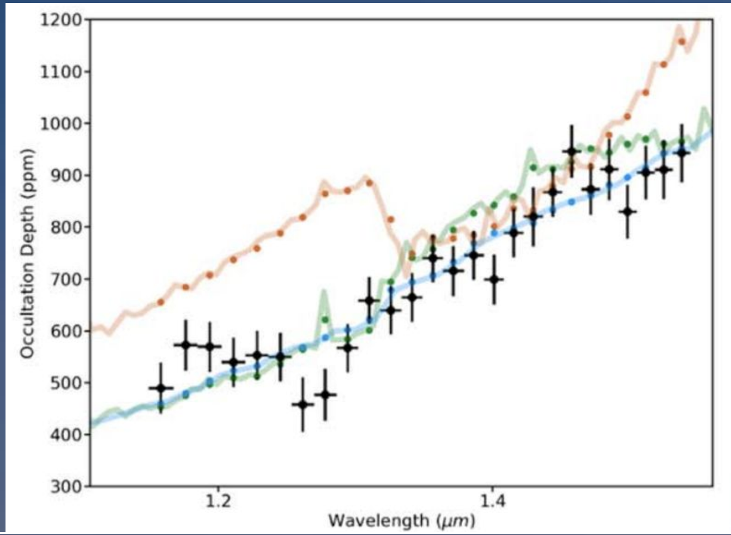

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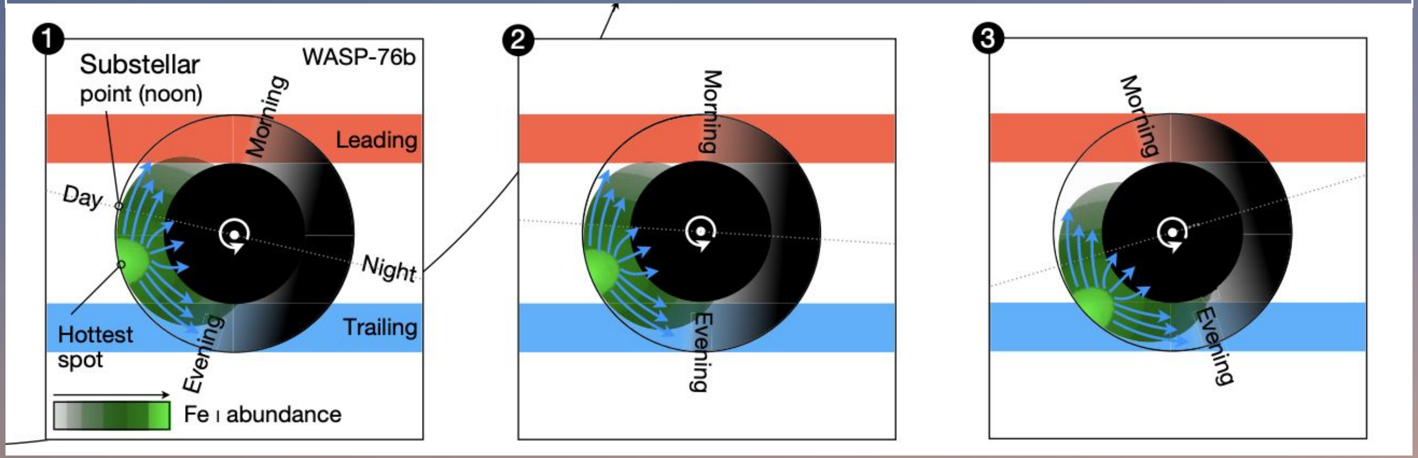
Asymmetric Fe absorption at high resolution; potential sign of nightside condensation (Ehrenreich+2020; Kesseli+2021; Wardenier+2021; Savel+2022)



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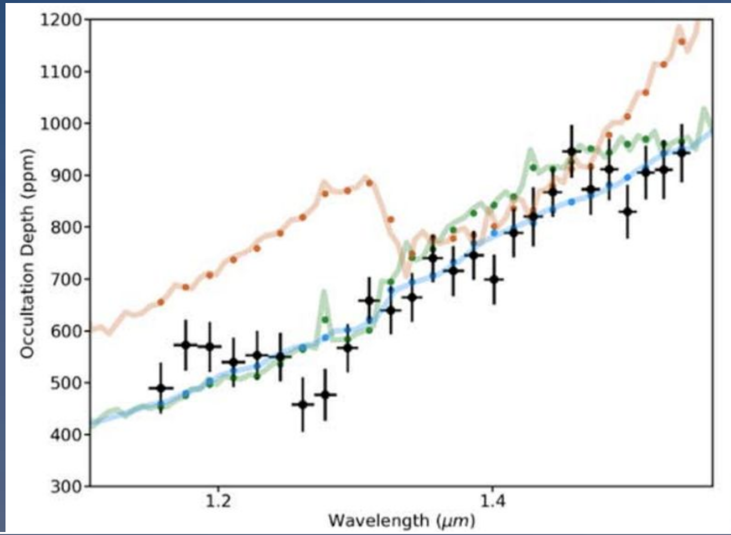

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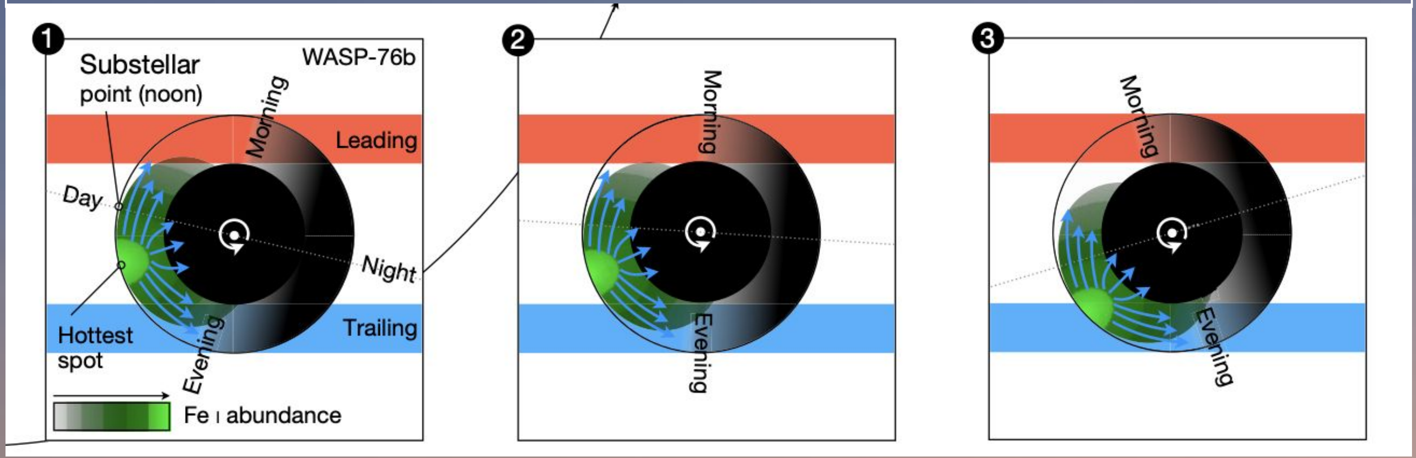
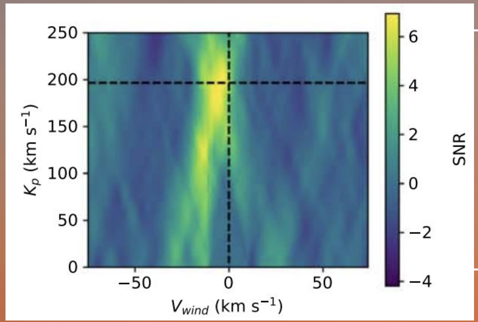
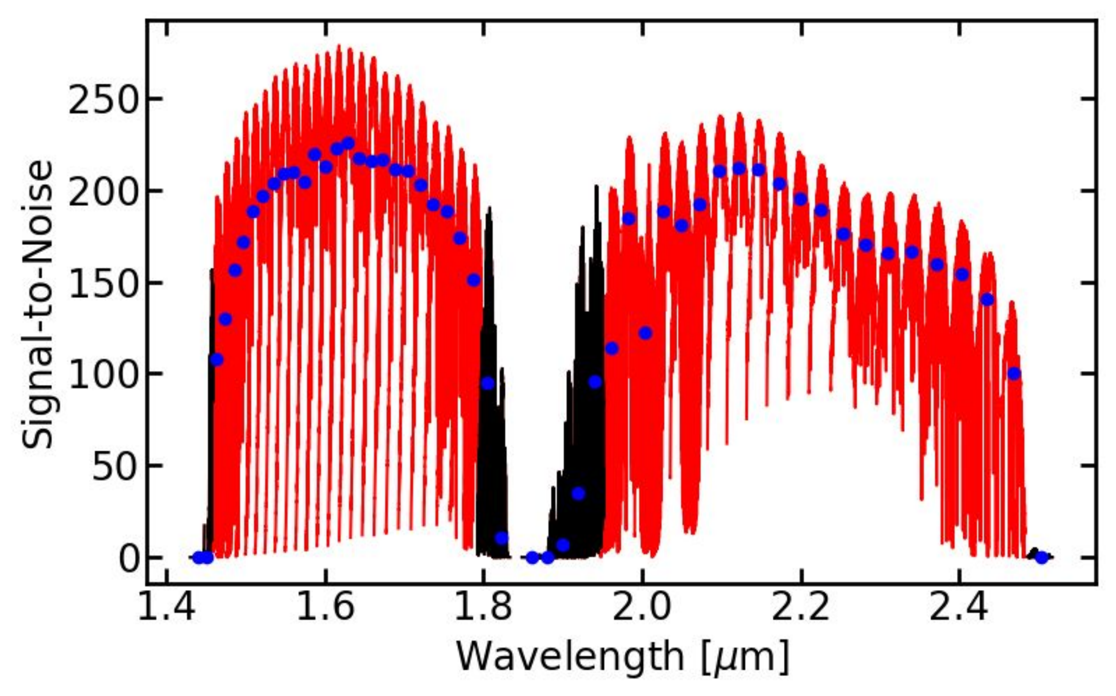




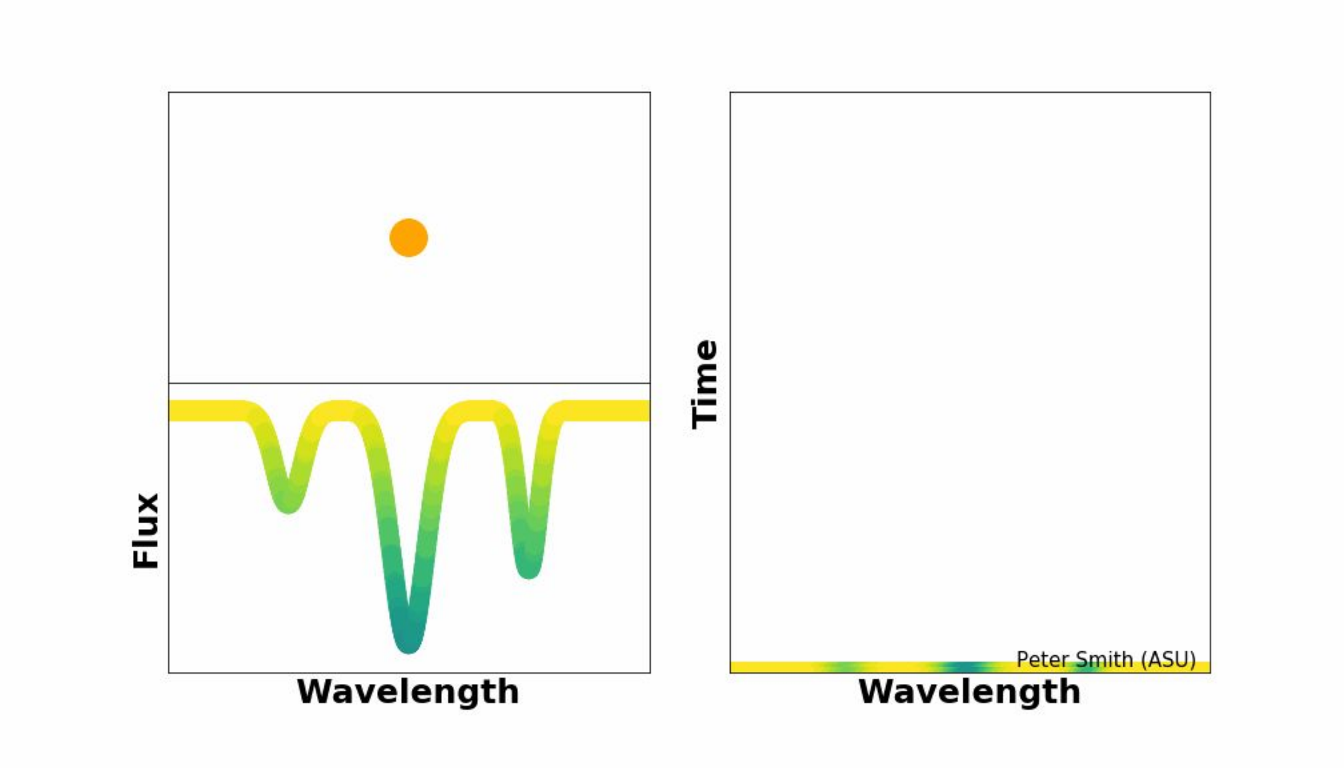
Many other species detected at high resolution (e.g., OH, Landman+2021; Mg, Fe, Na, etc., Kesseli+2022)

Gemini-S/IGRINS transit observations of WASP-76b

- Single transit observed on 10/29/21; signal-to-noise~200 per AB pair
- Remove orders with median SNR<100, then use principal component analysis to clean data

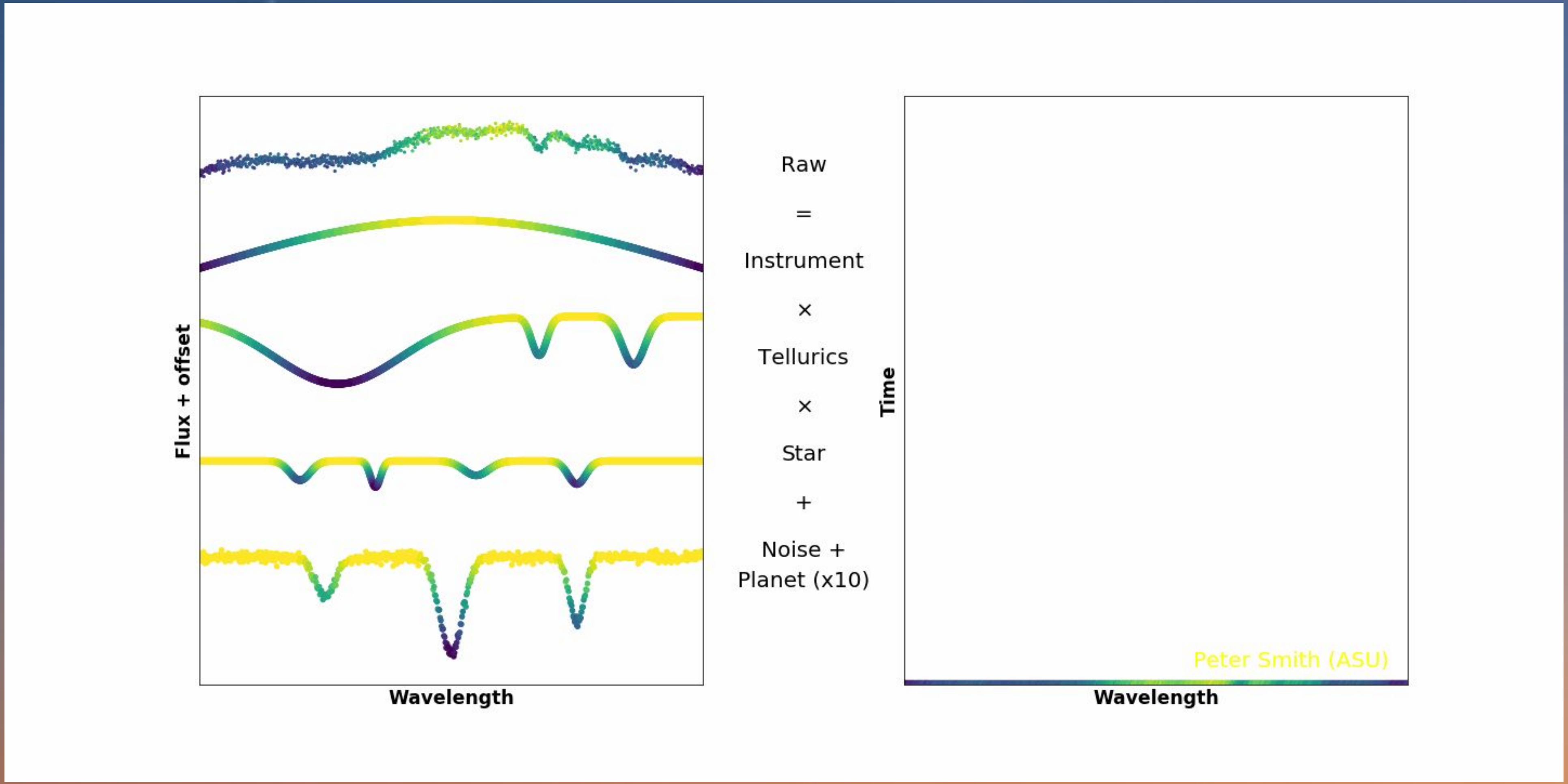


Goal: detect signal of planet as it orbits around star



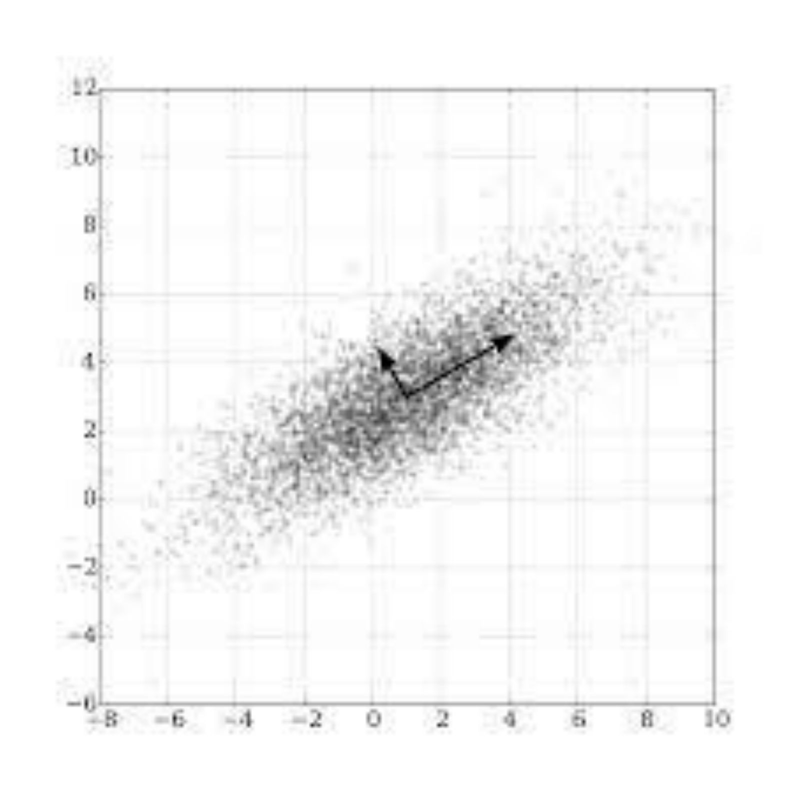
Video from Peter Smith

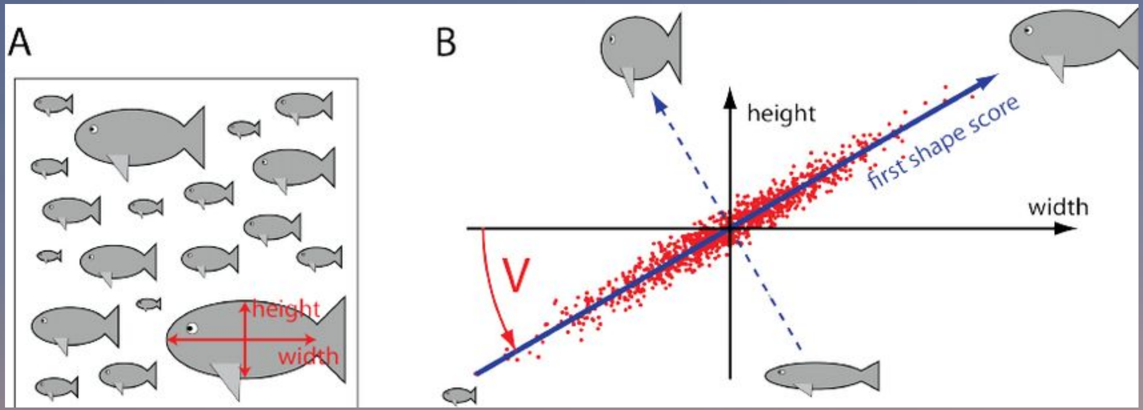
Problem: planetary signal is overwhelmed by star, tellurics, and instrument throughput



Video from Peter Smith

Solution: use principal component analysis to remove stationary signals (tellurics, star, and instrument response)

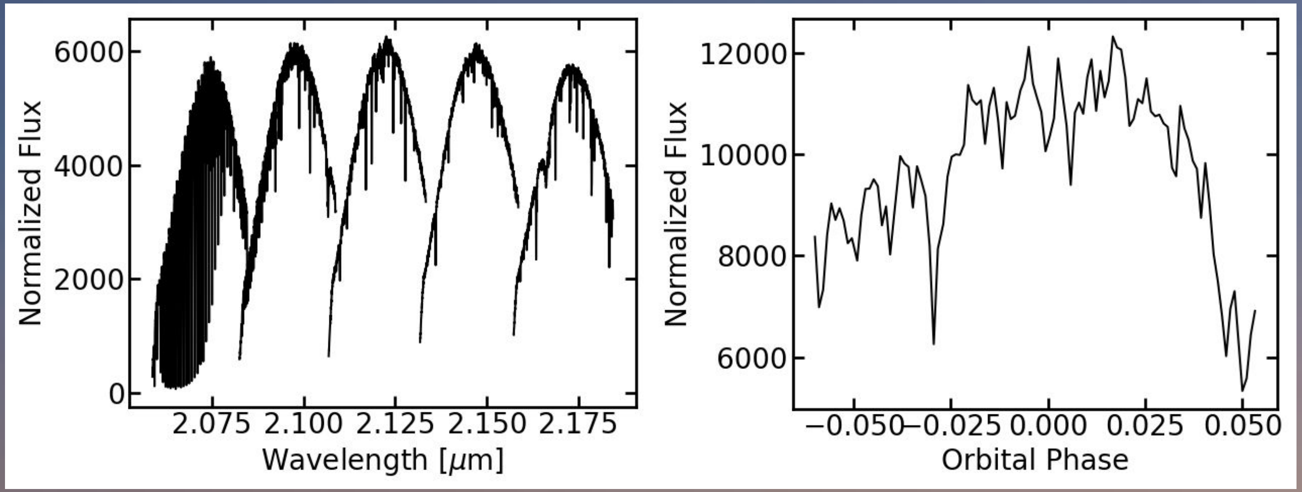




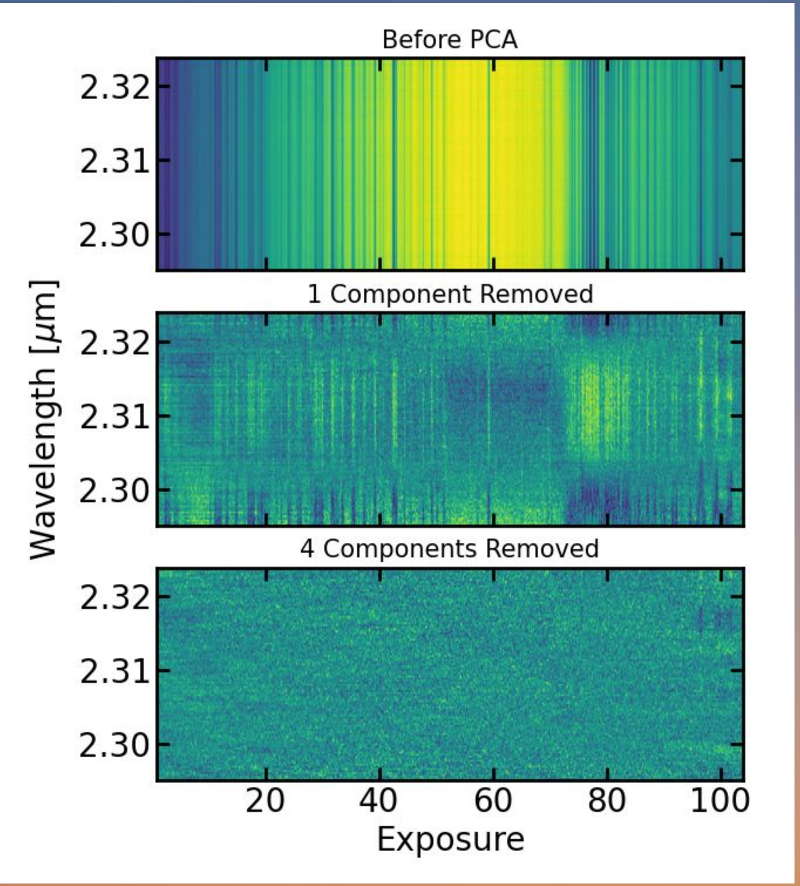
Basic idea: identify axes along which the largest amounts of the data lie

Solution: use principal component analysis to remove stationary signals (tellurics, star, and instrument response)

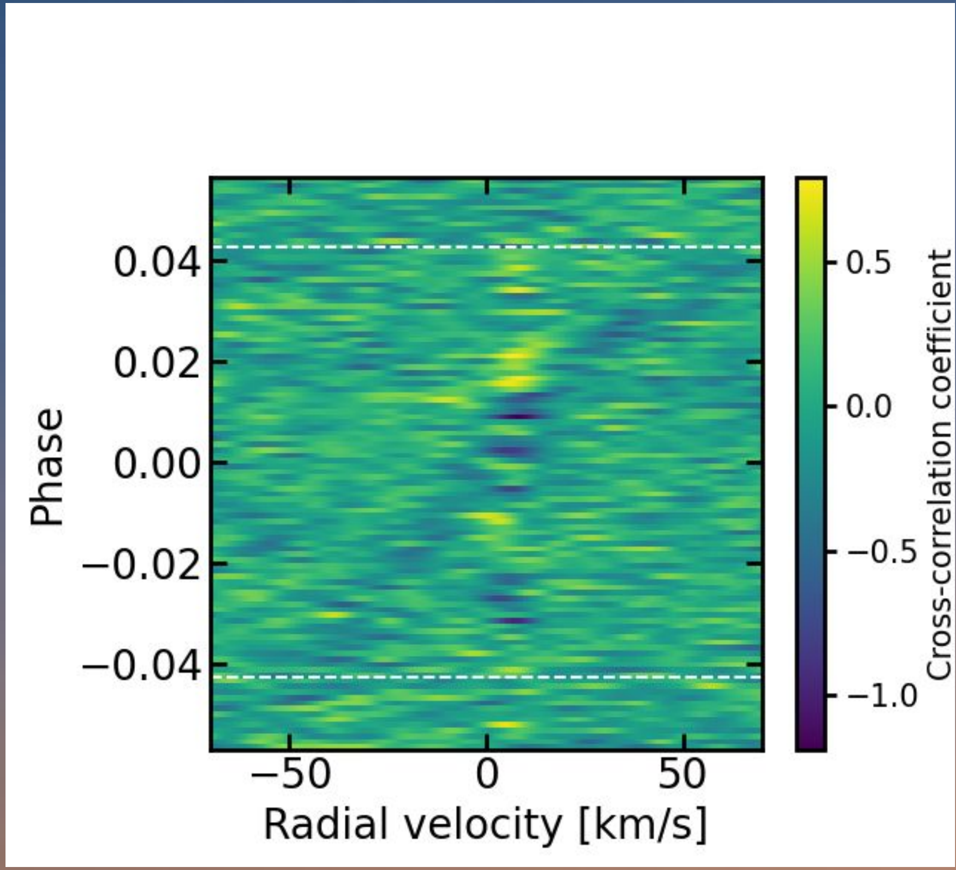
Raw data



Cleaning with PCA



Cross-correlation with model template (including H_2O, OH, and CO) to detect the atmosphere of WASP-76b



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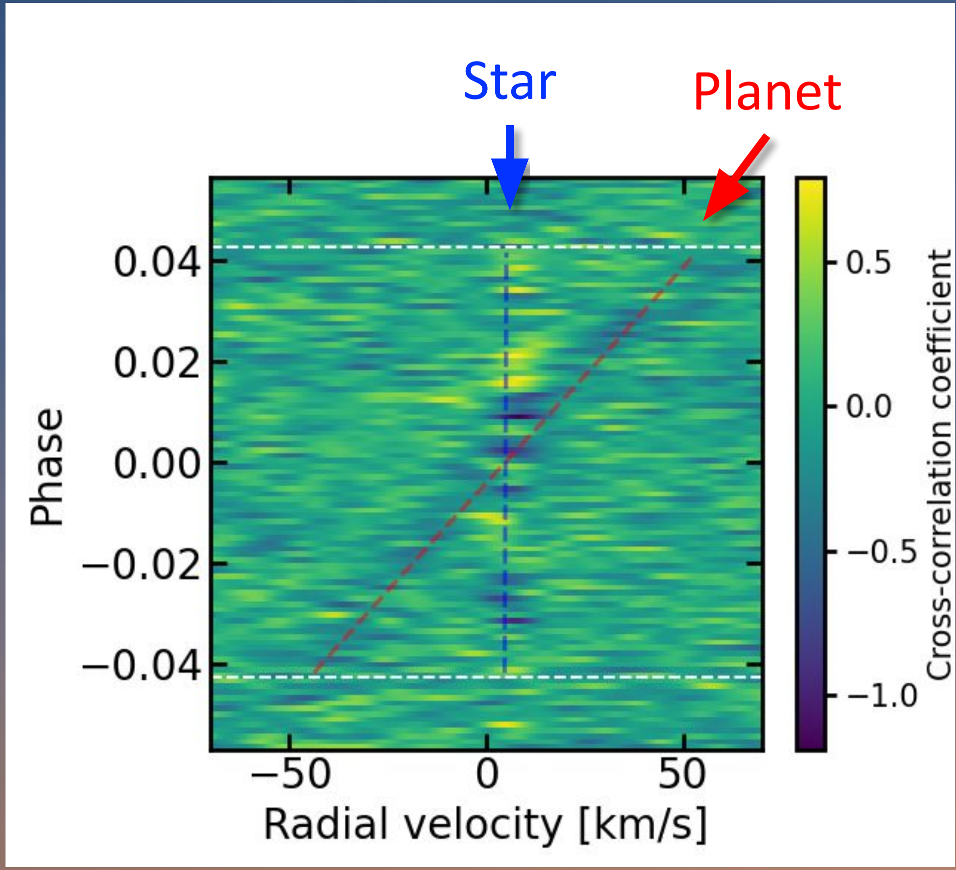

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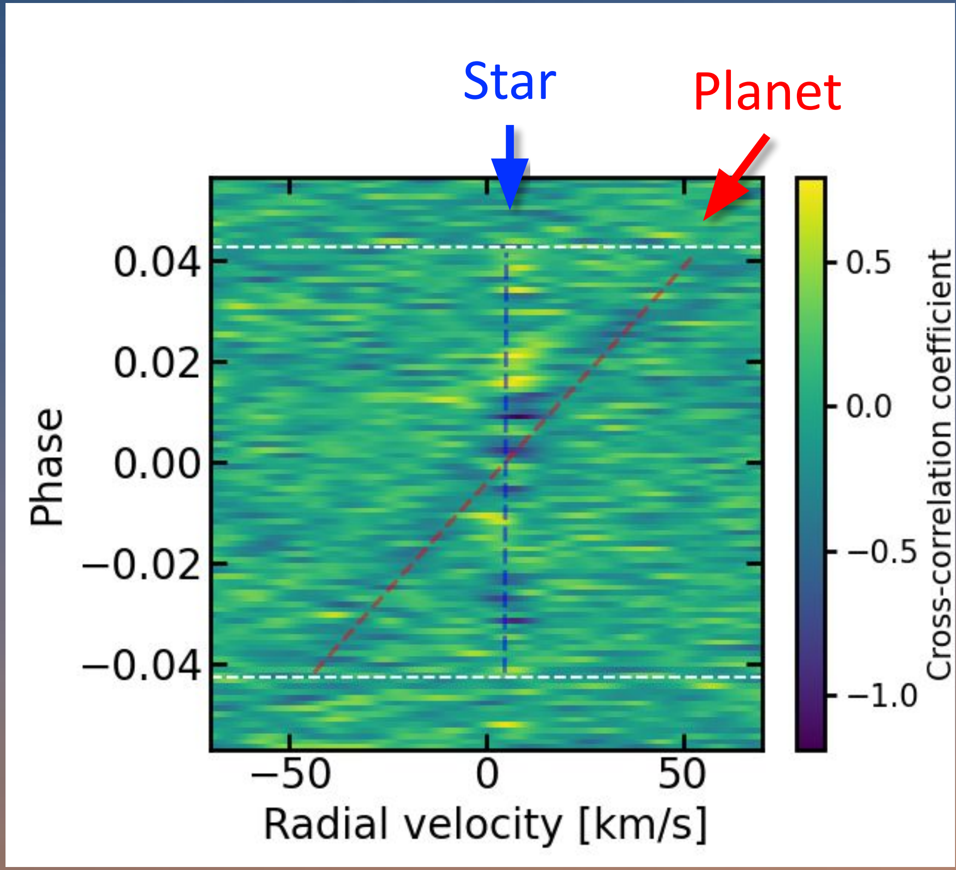
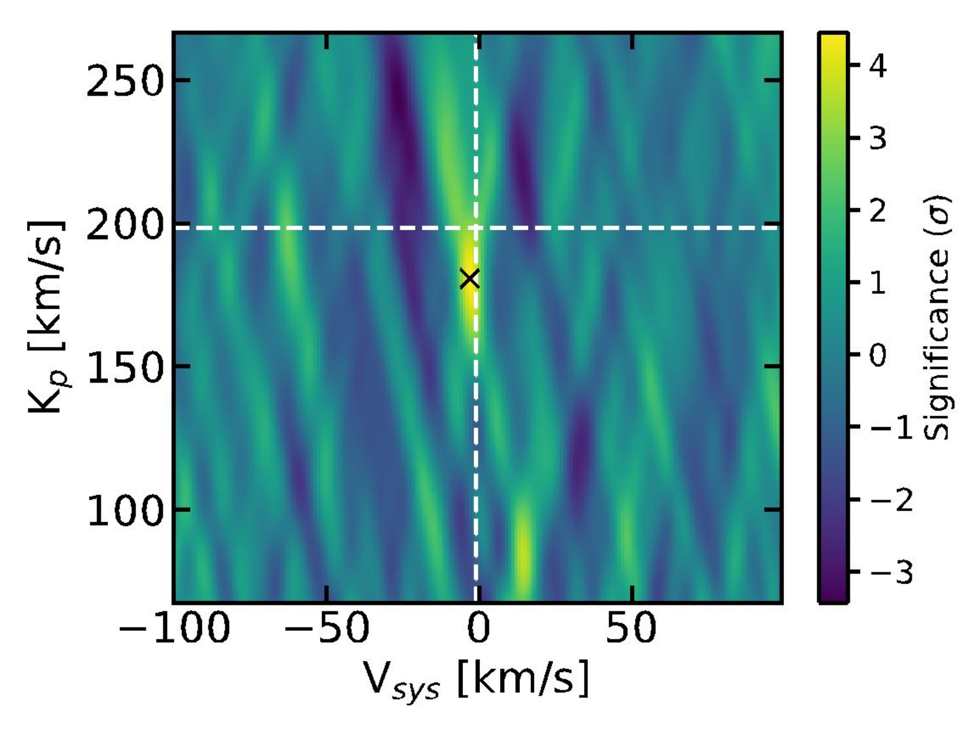
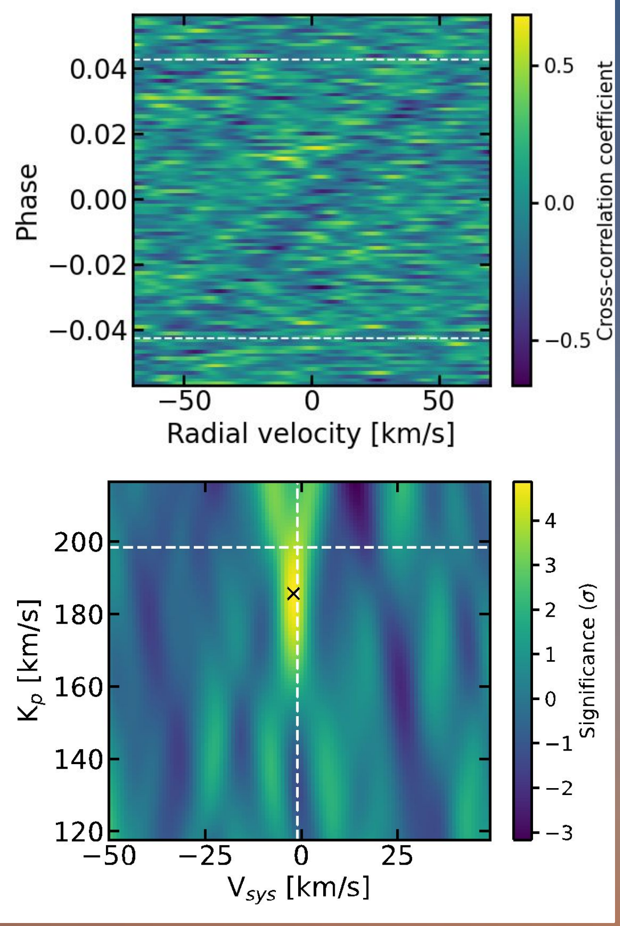


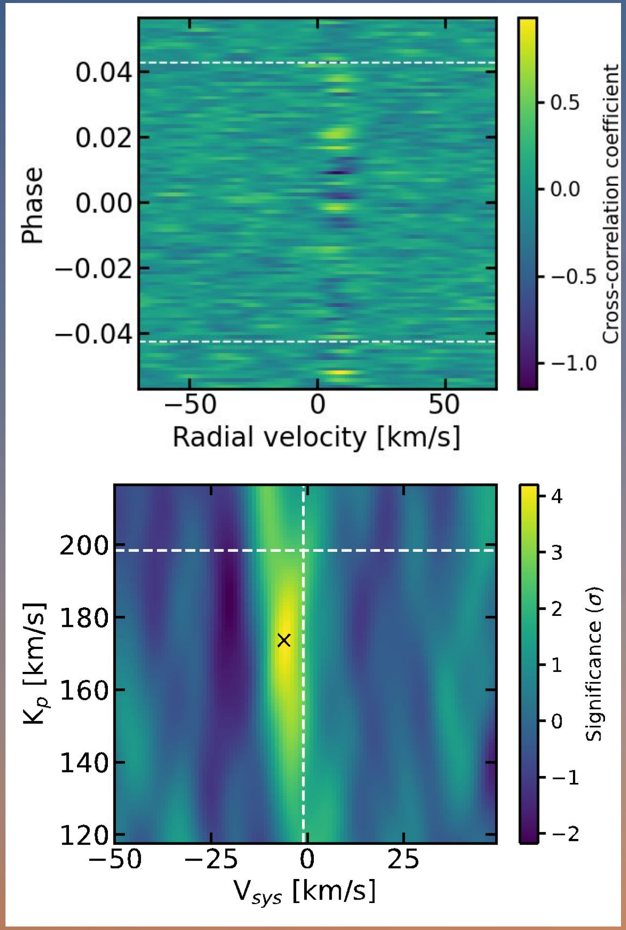


H_2O, CO, and OH detected in WASP-76b

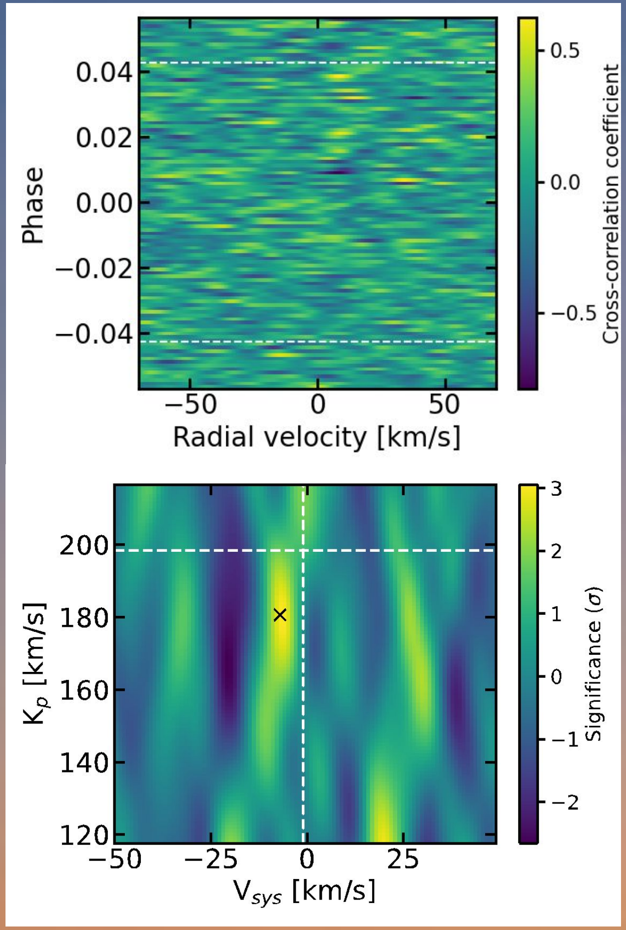
H_2O



CO

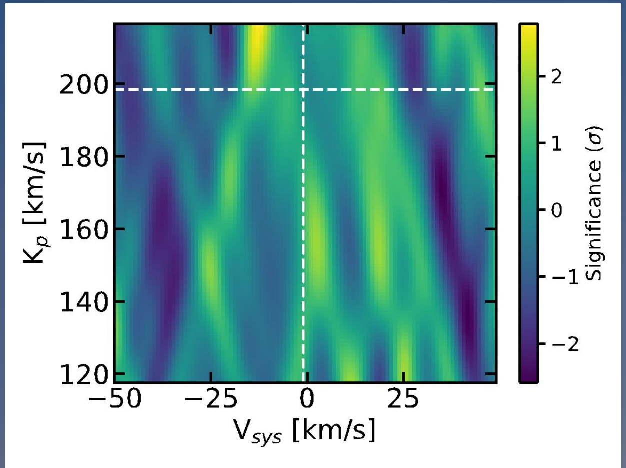


OH

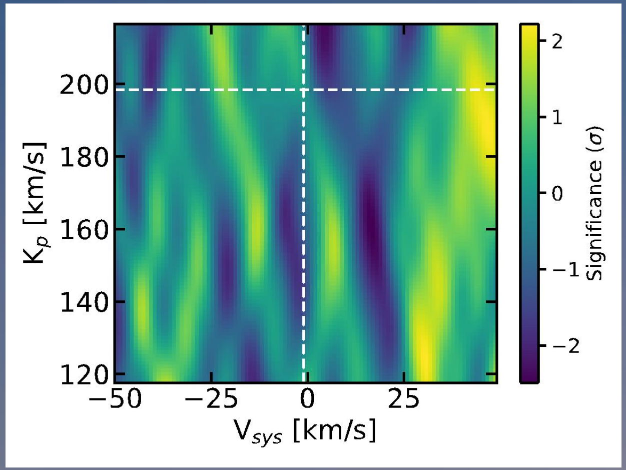


Non-detections of several other molecules

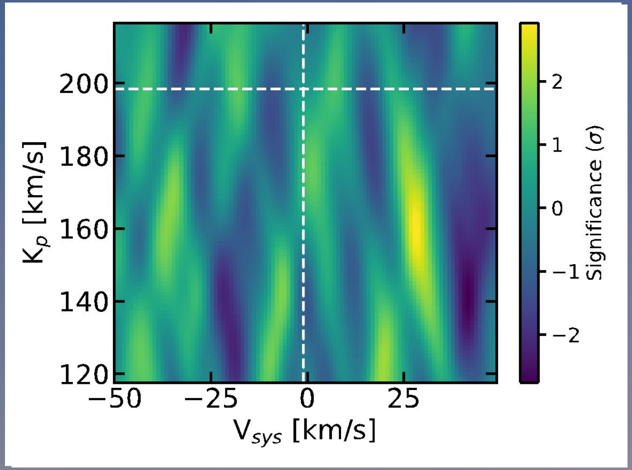
FeH



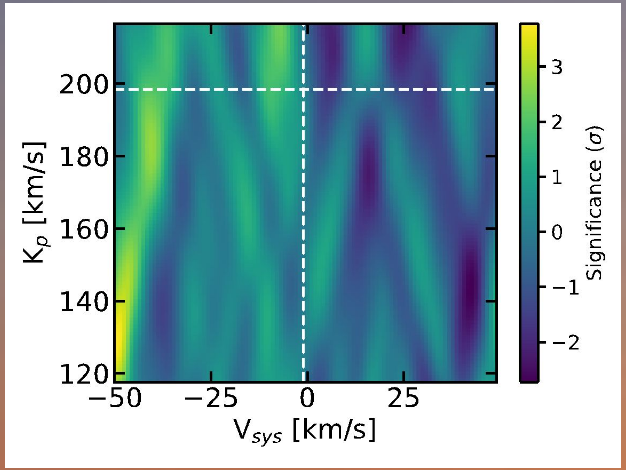
CH_4



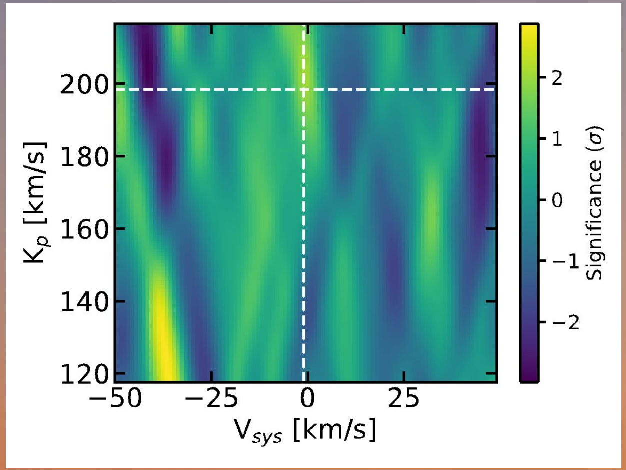
SiO



TiO

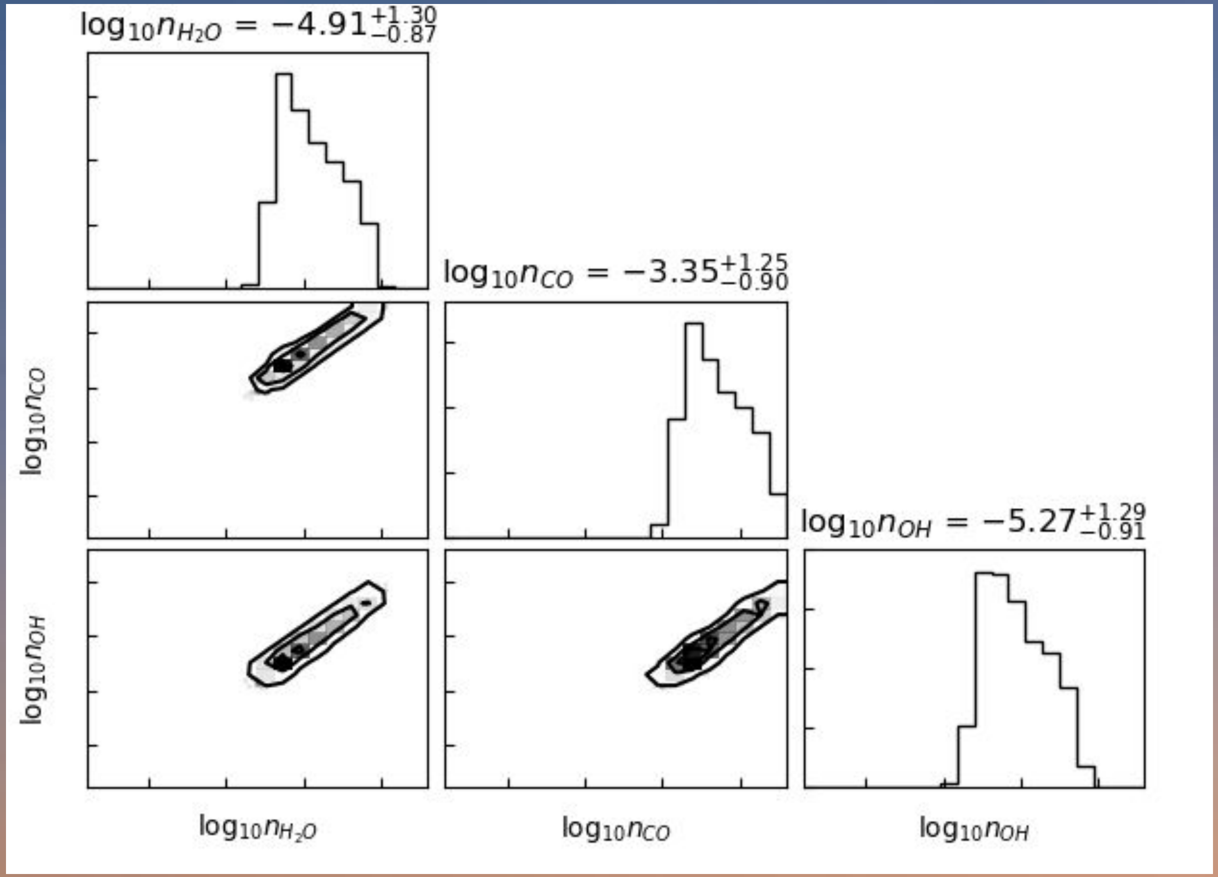


VO



Initial (not finalized!) constraints on the atmospheric composition of WASP-76b from retrieval

- Constraints on CO, H_2O, OH
- $[C/H] = -0.05^{+1.25}_{-0.90}$
- $[O/H] = -0.30^{+1.25}_{-0.90}$
- Suggests $[M/H] = -0.19^{+1.19}_{-0.90}$ (consistent with solar) and superstellar $C/O = 0.96^{+0.01}_{-0.02}$



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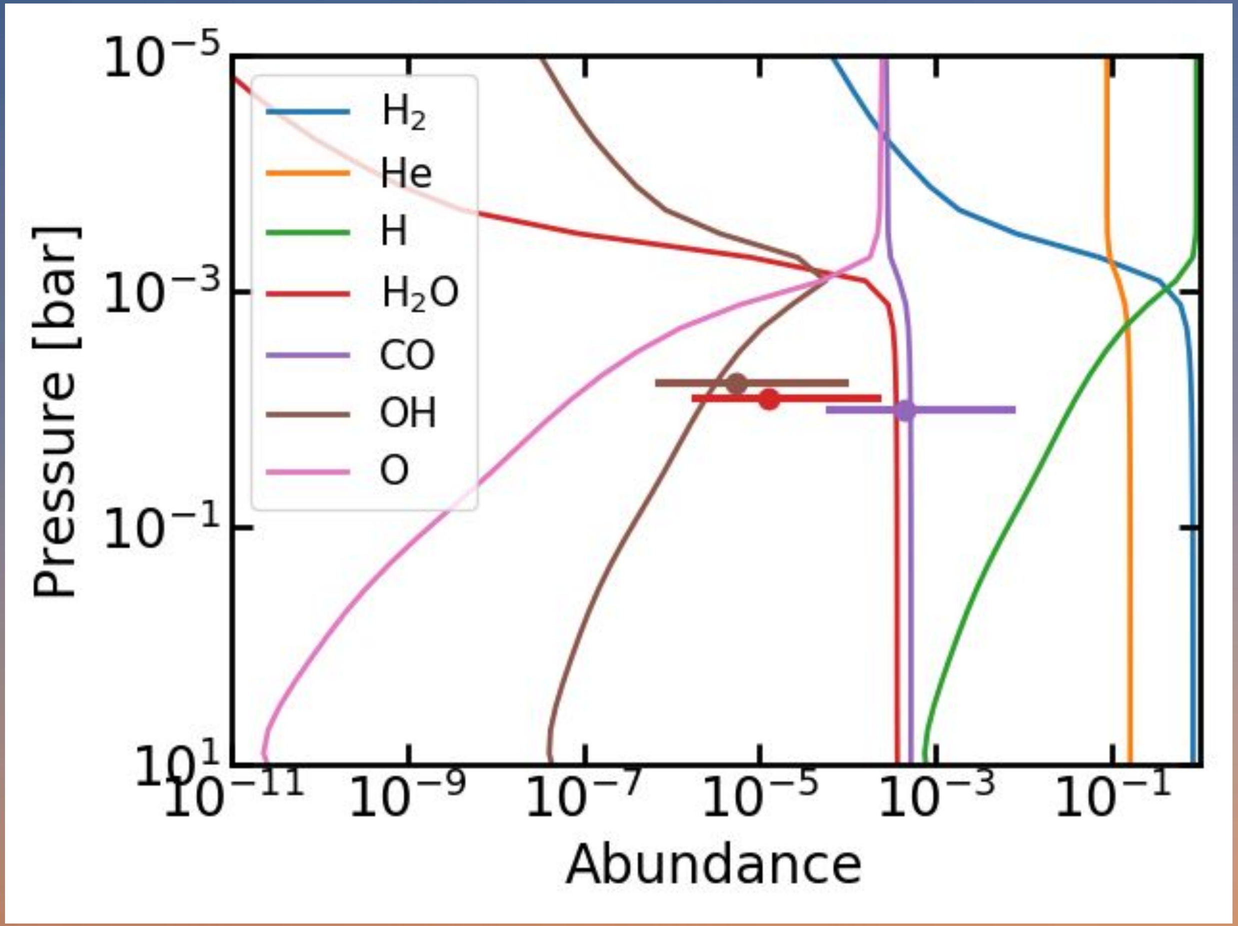
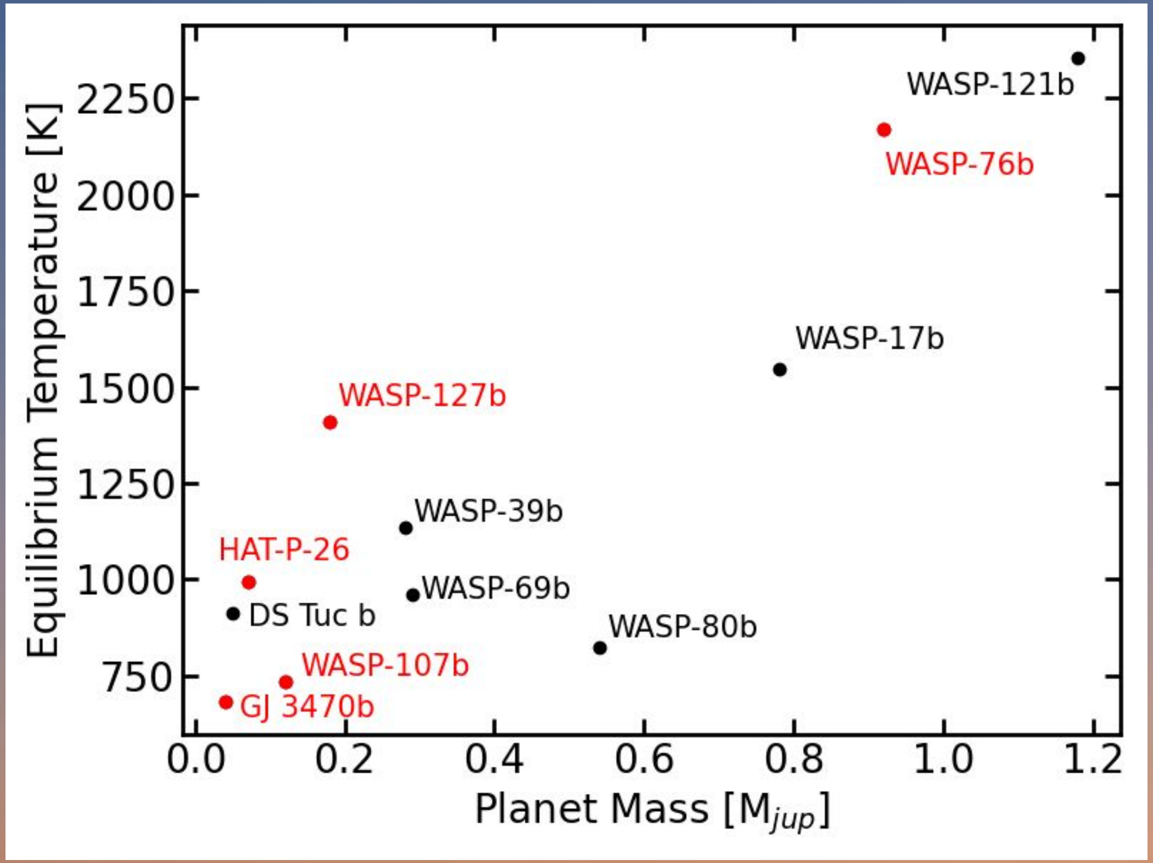
- Suggests $[M/H] = -0.19^{+1.19}_{-0.90}$ (consistent with solar) and superstellar $C/O = 0.96^{+0.01}_{-0.02}$
- Apparent H_2O depletion compared to equilibrium – ongoing work to understand

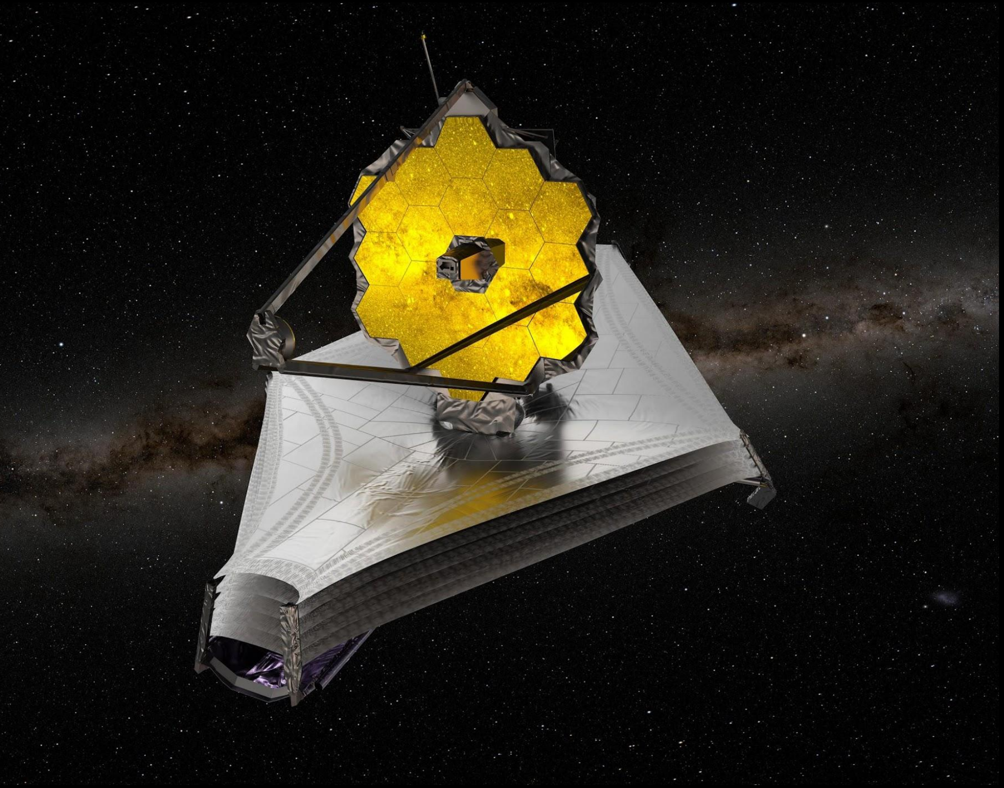


Ongoing observations of other planets in survey will reveal trends in composition

- 5/11 targets observed so far
- Survey continuing through July 2023



Synergies with JWST observations of hot Jupiters



Ground-based: lose continuum, but more lines
Space-based: preserve continuum

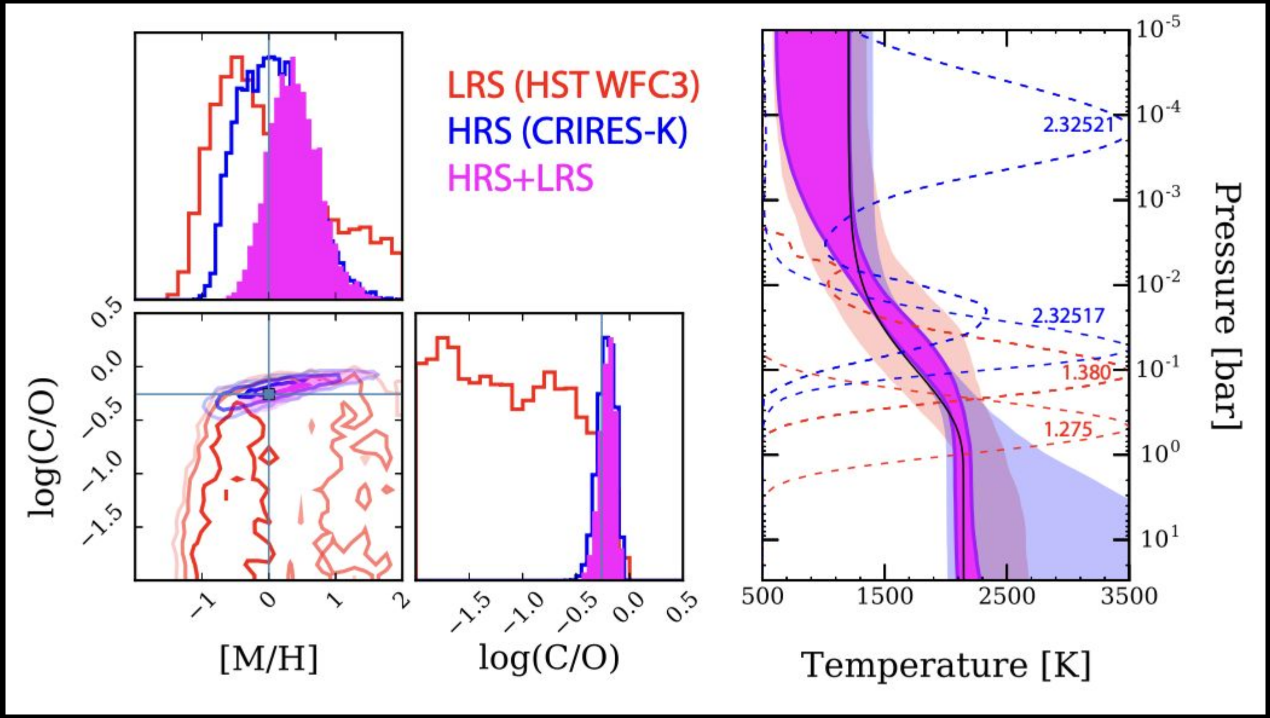
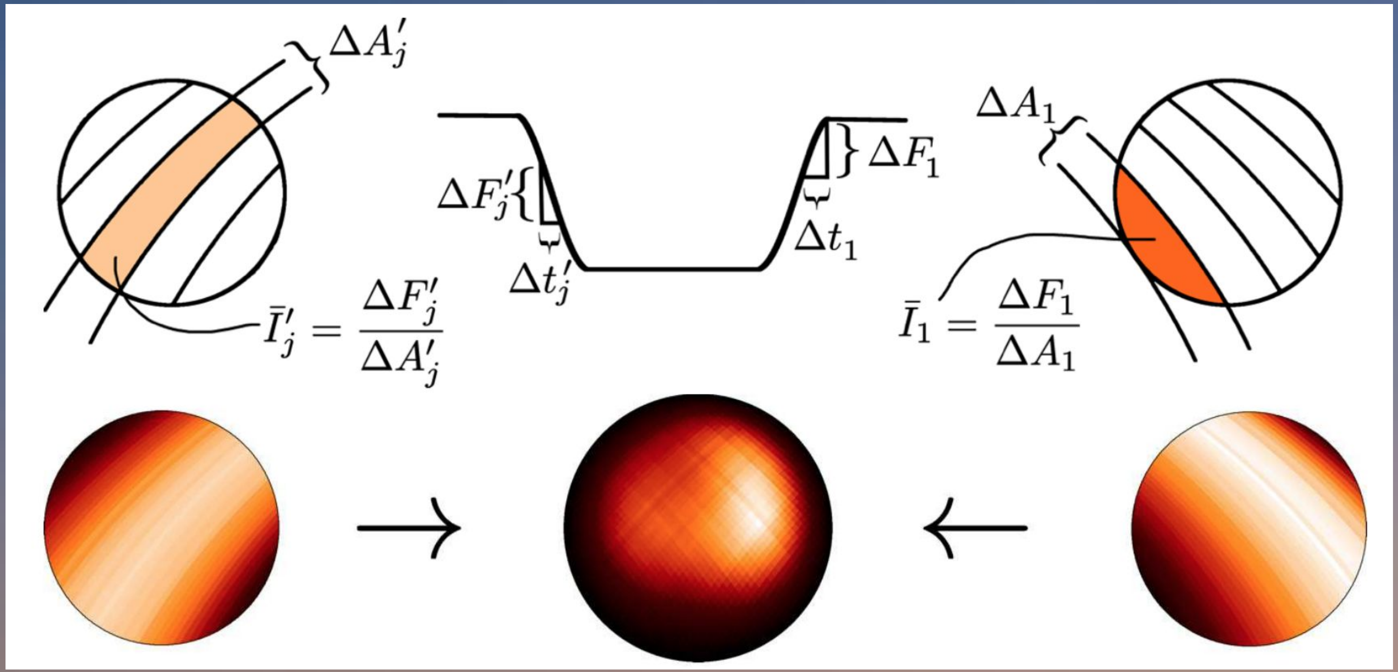


Figure from Brogi & Line (2019)

Synergies with JWST observations of hot Jupiters

Ground-based: measure wind speeds to probe dynamics



Space-based: use eclipse mapping to measure temperature structure resulting from winds

Figure from Majeau et al. (2012)

Acknowledgements

- Program Co-Is: Michael Line, Matteo Brogi, Jacob Bean, Eliza Kempton, Emily Rauscher, Joseph Zalesky, James Owen, Natasha Batalha, Ben Montet, Peter Plavchan
- Gemini-S and IGRINS science support staff (especially Gregory Mace, Hwiyun Kim)
- Funding from NASA Sagan Fellowship

NASA Hubble Fellowship Program

The University of Arizona

I respectfully acknowledge that Gemini-S is located on Cerro Pachon, in the traditional territory of the Diaguita people.

Conclusions and future work

- H_2O, CO, and OH detected in WASP-76b with Gemini-S/IGRINS
- Initial retrieval results indicate metallicity consistent with solar, but significantly supersolar C/O ratio
- Ongoing work: Non-isothermal T-P profile; varying abundances with altitude; difference between morning and evening terminators
- First results from an upcoming IGRINS survey of 11 transiting planets
- Exciting opportunities for synergies between Gemini telescopes and JWST

Questions? meganmansfield@arizona.edu @cornerof_thesky

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