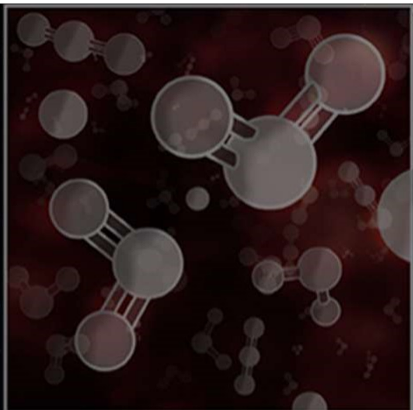


# What do exoplanet atmospheres tell us about planet diversity?


Sarah E. Moran

Director’s Postdoctoral Fellow



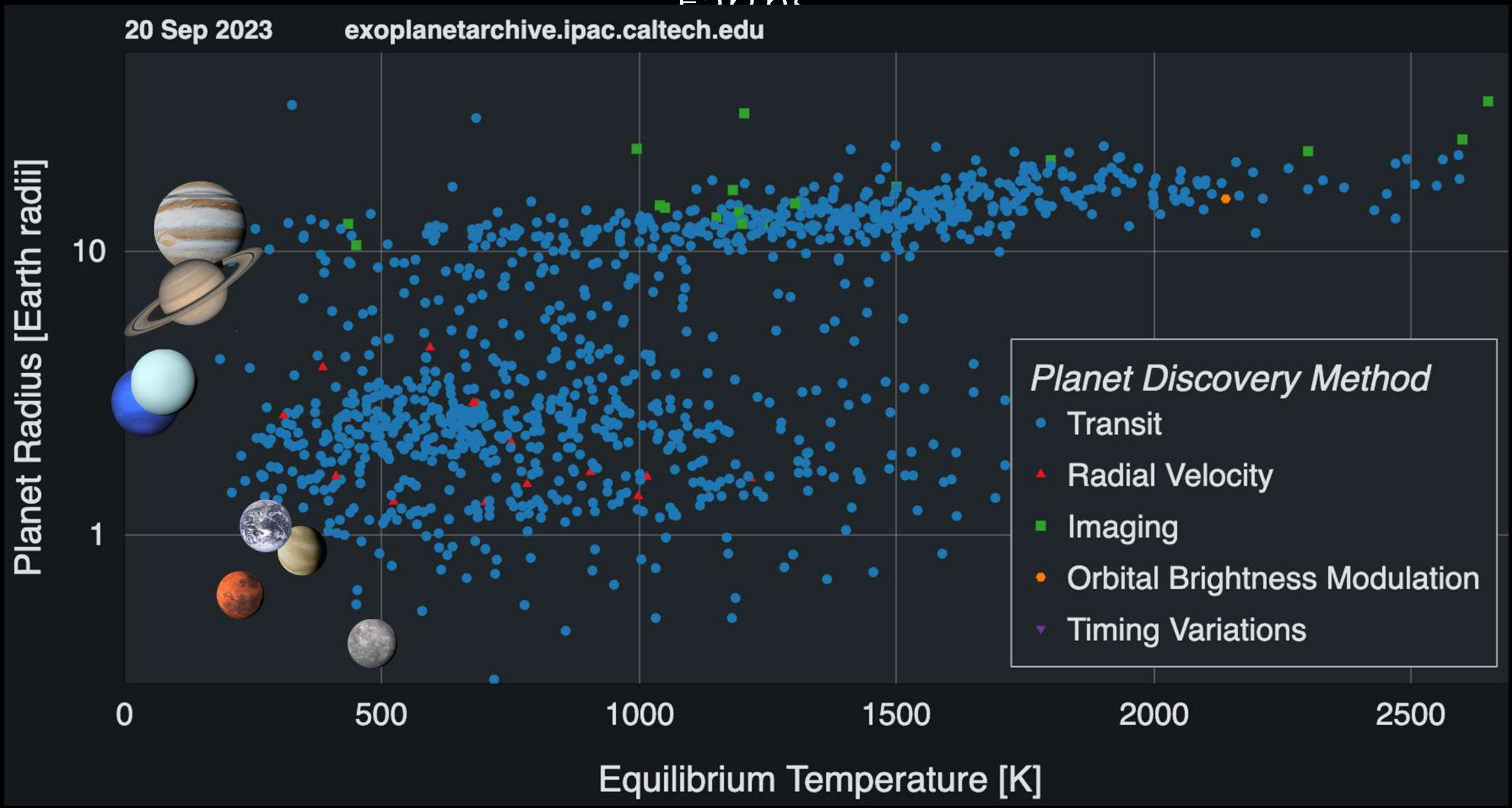
ExoPAG 28

1 October 2023

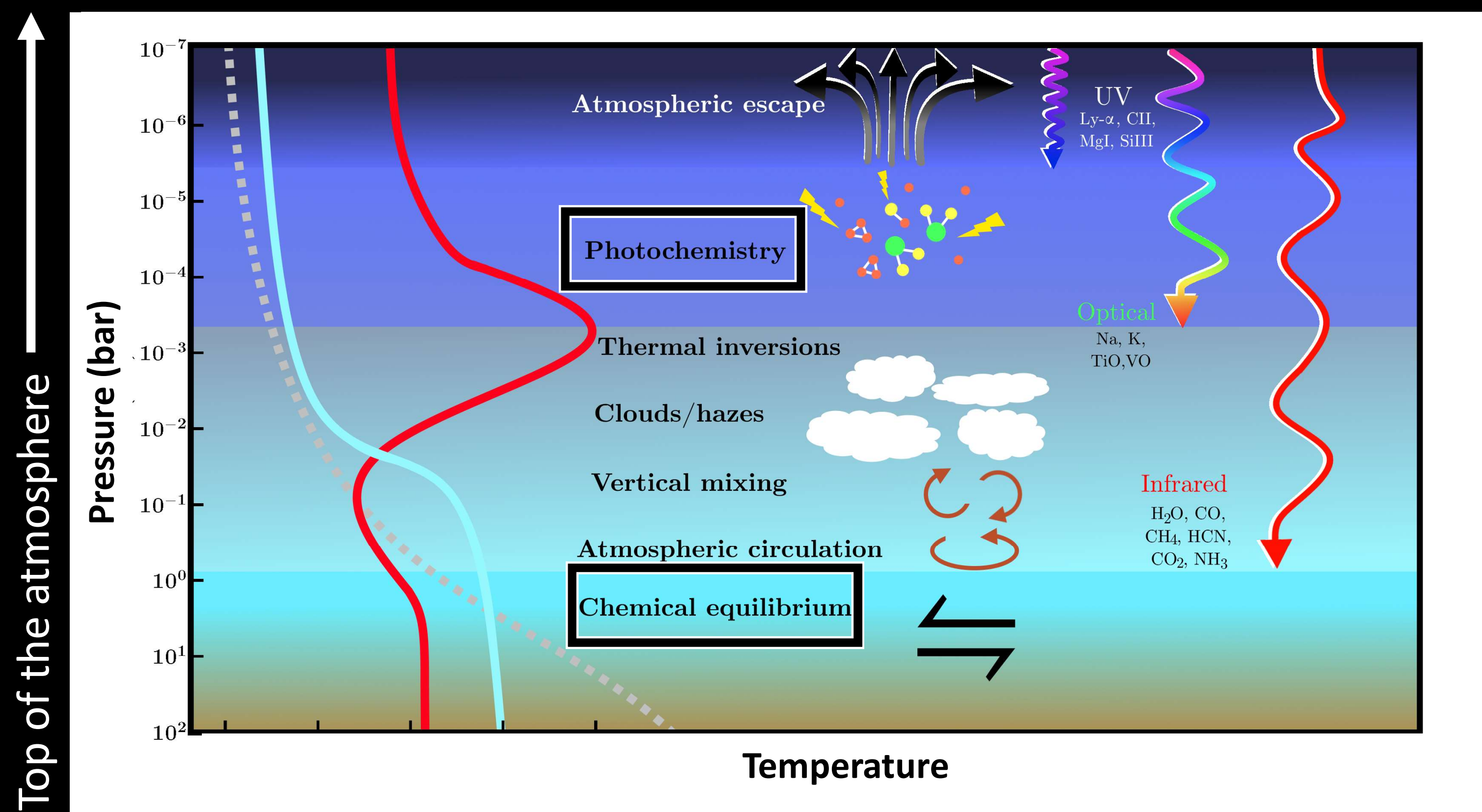


THE UNIVERSITY OF ARIZONA. LPL Lunar & Planetary Laboratory

# Two big gaps in the Solar System: hot planets and sub-Neptunes/super-Earths



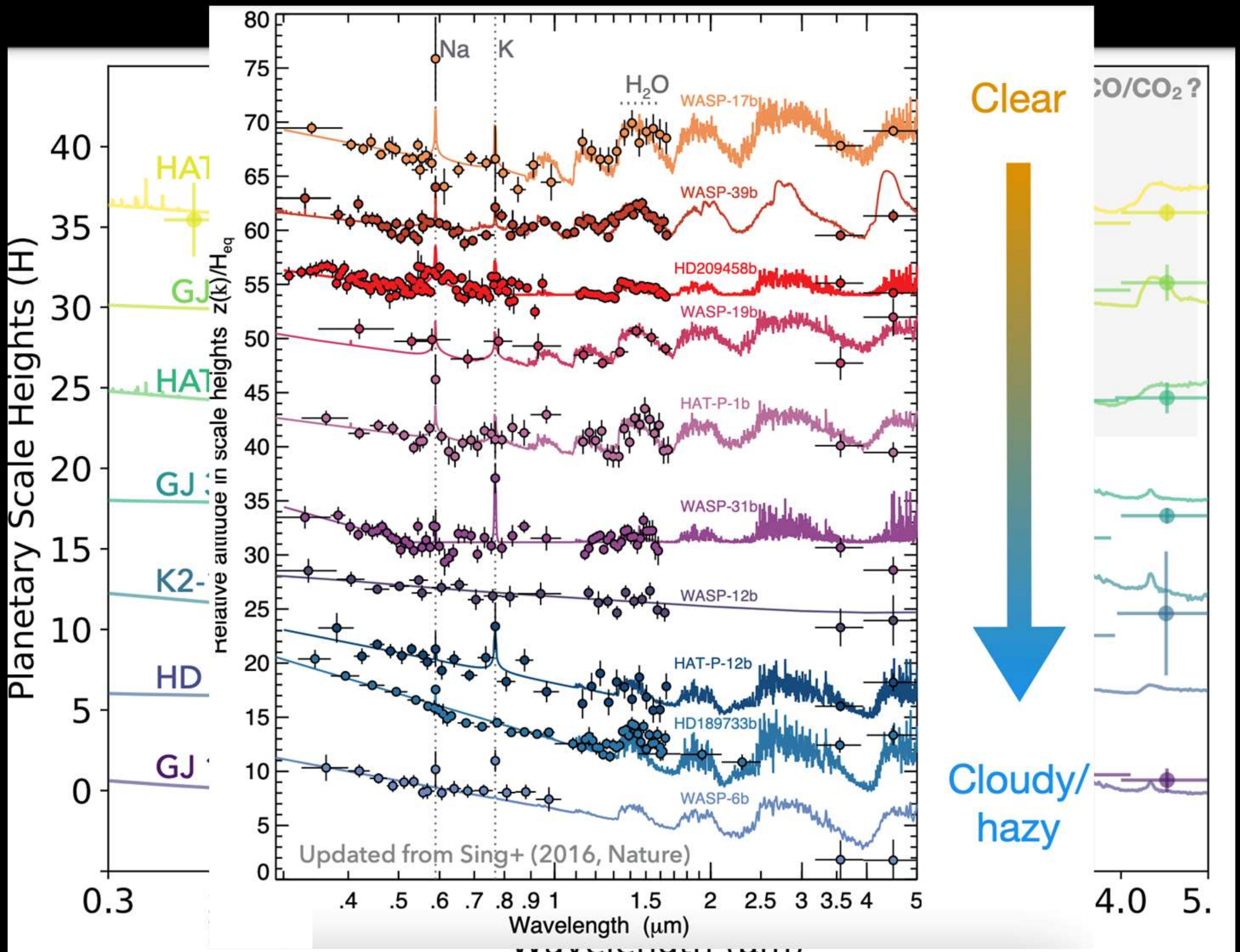
Transmission spectroscopy probes different layers of the atmosphere –> meaning we're often probing different chemical and dynamical regimes compared to the information we have from Solar System atmospheres




Madhusudhan, An.Rev. of A&A, 2019

# The Hubble and Spitzer Era → Lots of water, some alkalis, and ¿"clouds”?

(sub)-Neptune Planets




Wakeford & Dalba, 2020

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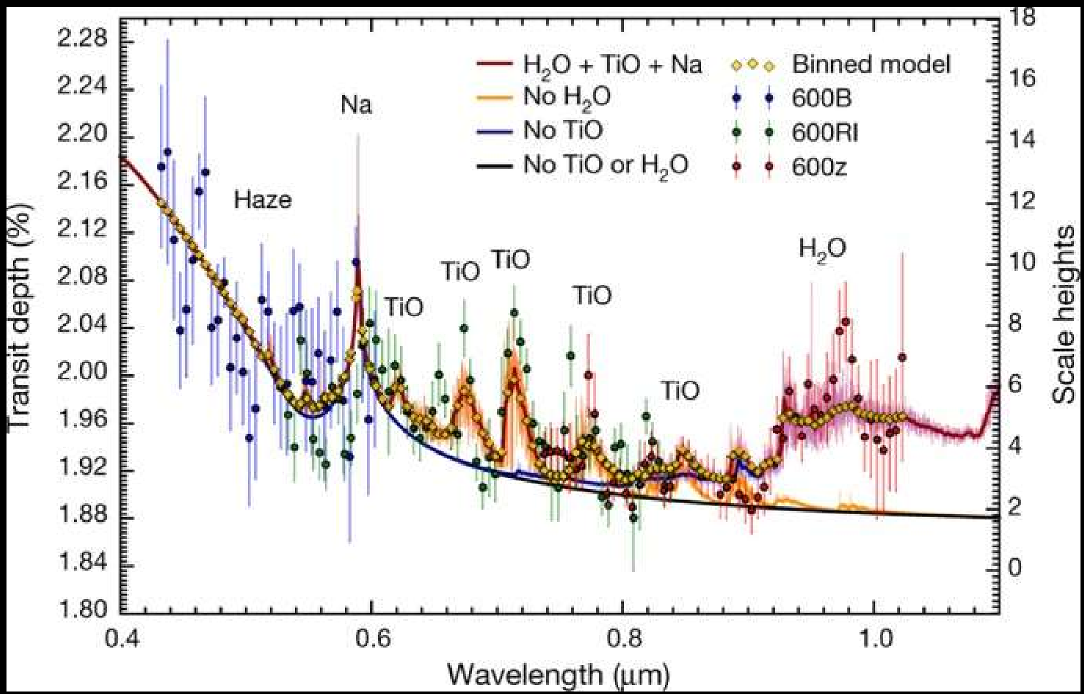
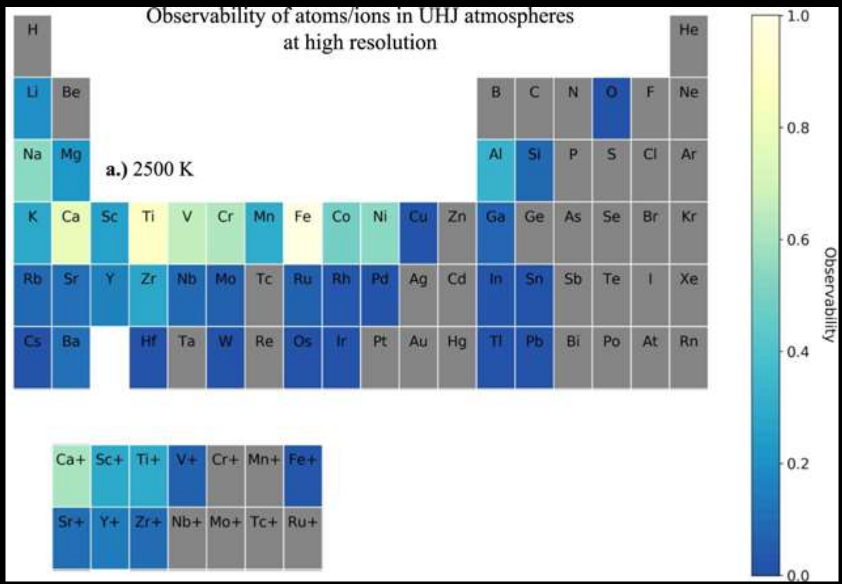
# High-res + ground-based Era → alkalis and metals and "scattering" + ultra-hot Jupiters full of metals and ions




Sedaghati et al., 2017

VLT/FORS2




Kesseli et al., 2022

ESPRESSO

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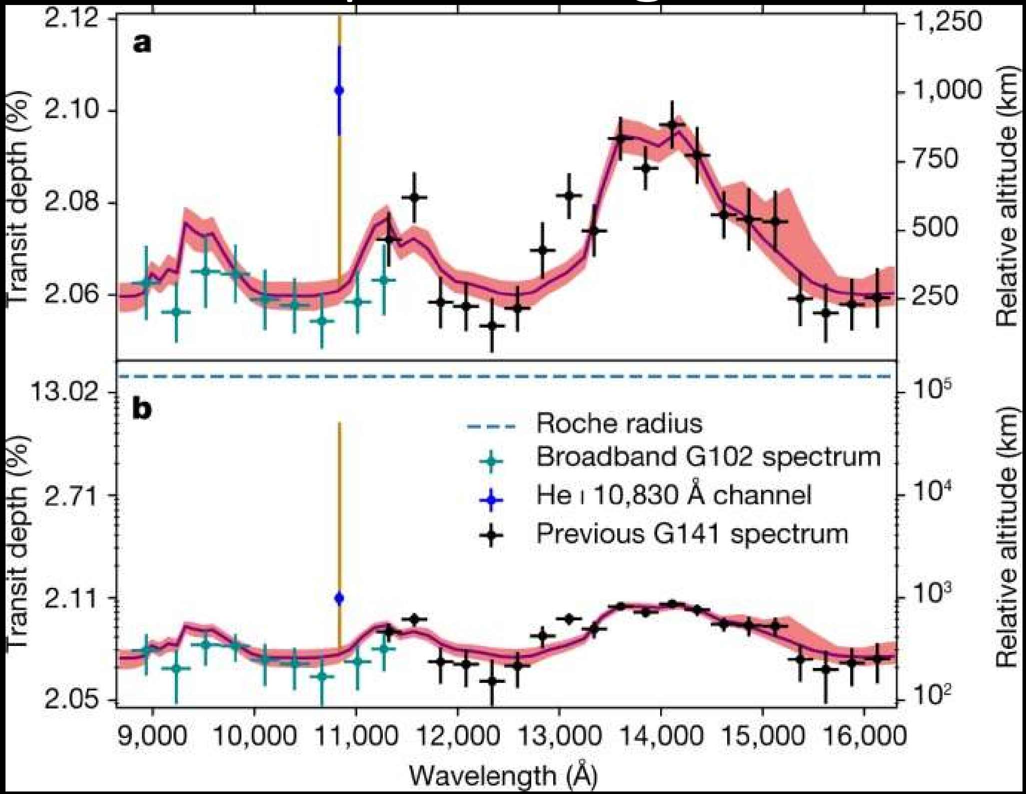
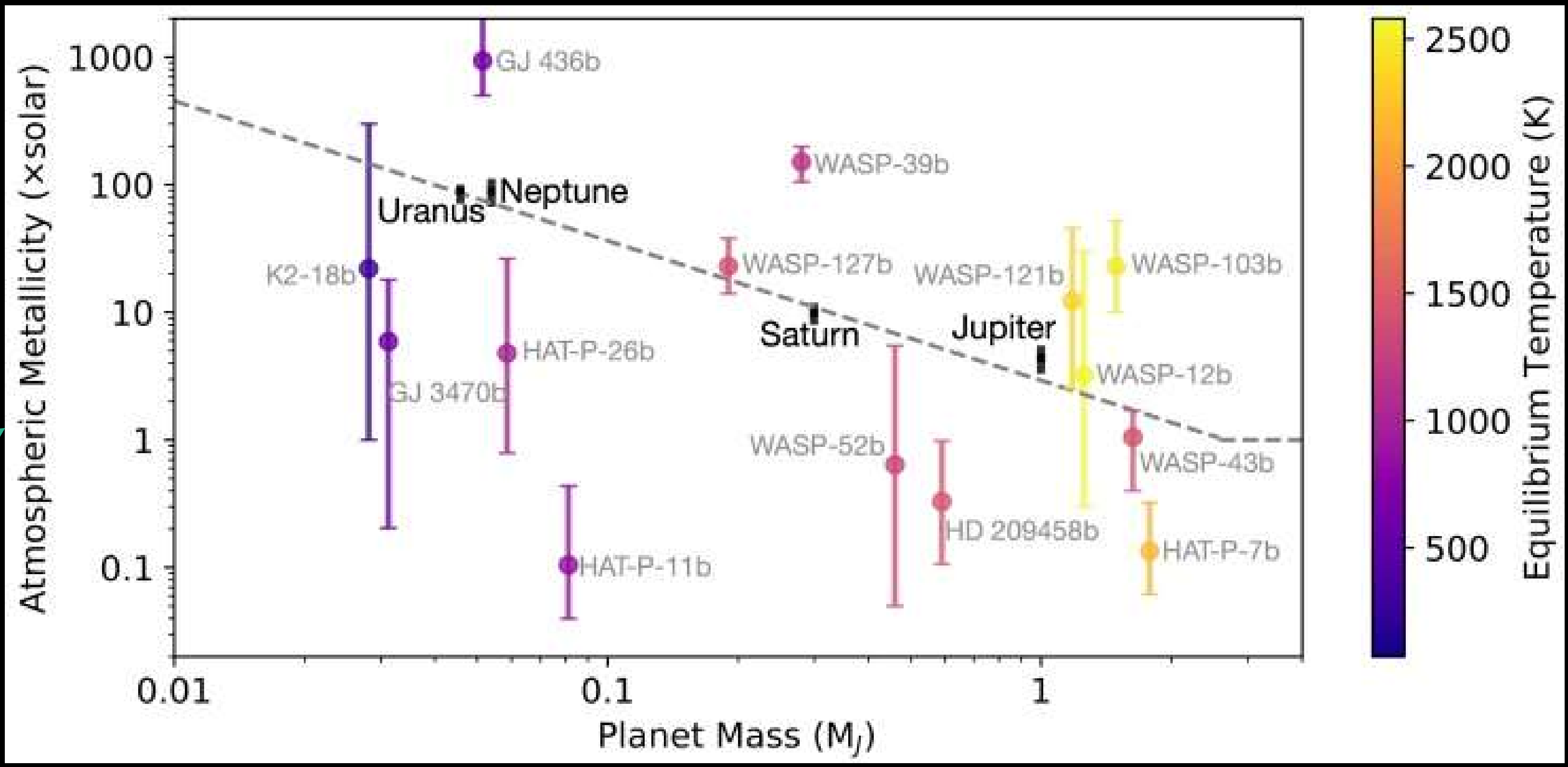
# Direct signs of escape – atmospheric composition sculpted over time as traced by HST and ground-based telescopes using helium

He escape in WASP 107b, a very puffy warm Neptune




Spake et al, Nature, 2018

# The view as of July 11th, 2022



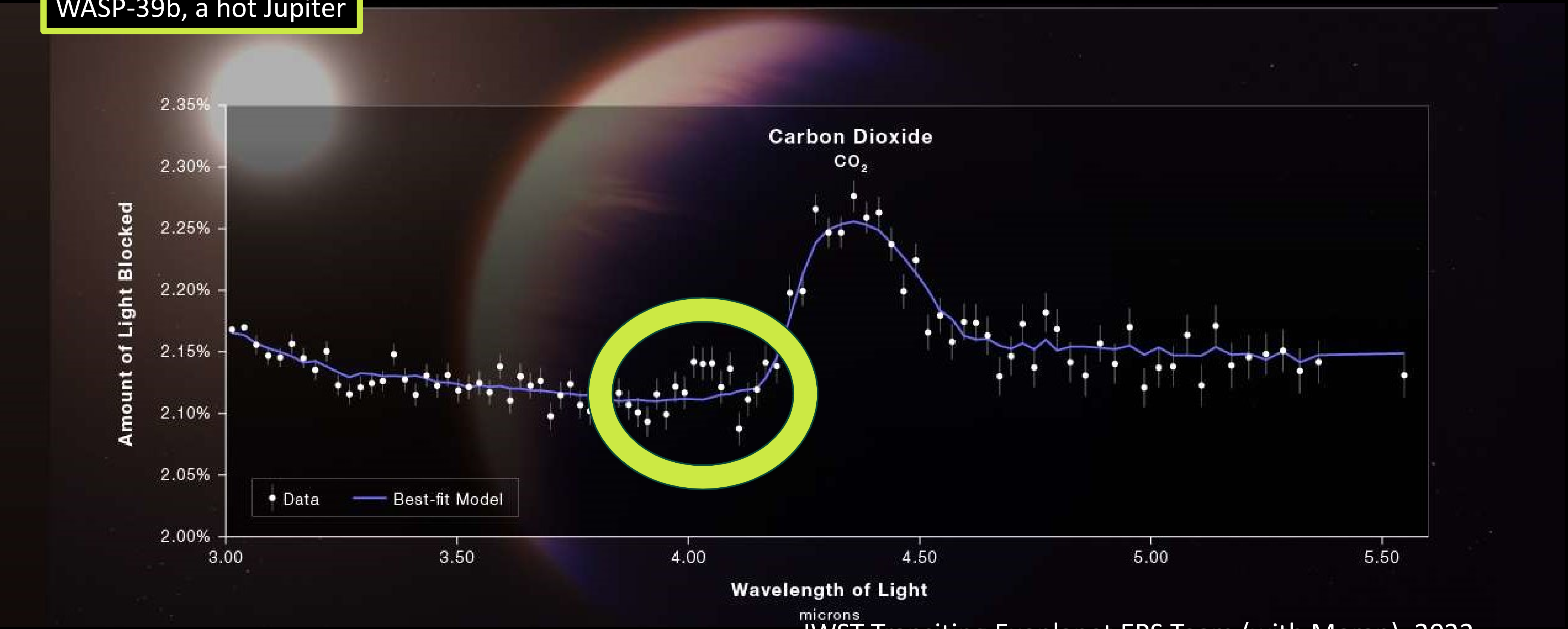

A mixed metric

Wakeford & Dalba, 2020

# Into the JWST Era (i.e., July 15th, 2022)

# Detection of $CO_2$– first time outside the solar system!*

WASP-39b, a hot Jupiter

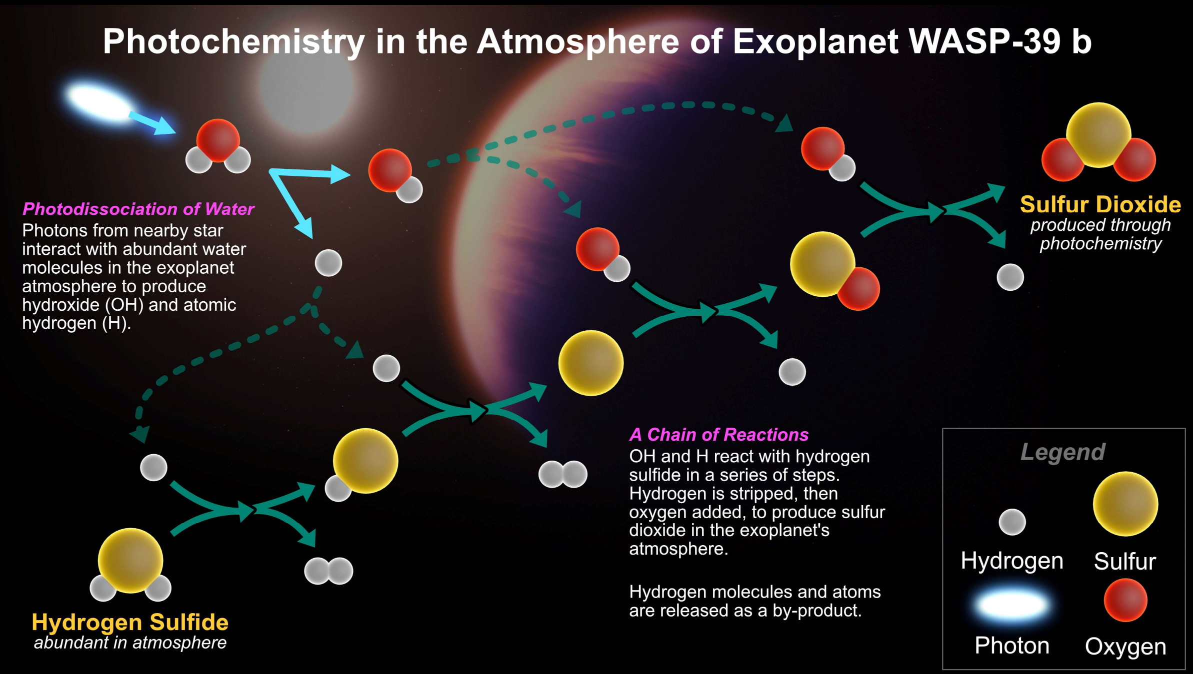



JWST Transiting Exoplanet ERS Team (with Moran), 2022

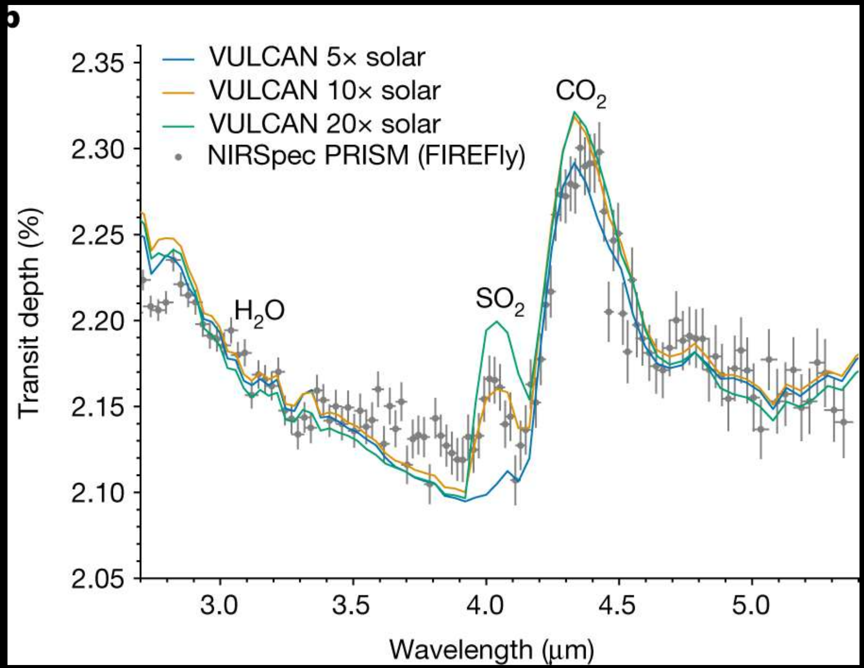
(*in a planet)

# Sulfur dioxide is the first signature of *photochemistry* on an exoplanet

WASP-39b, a hot Jupiter

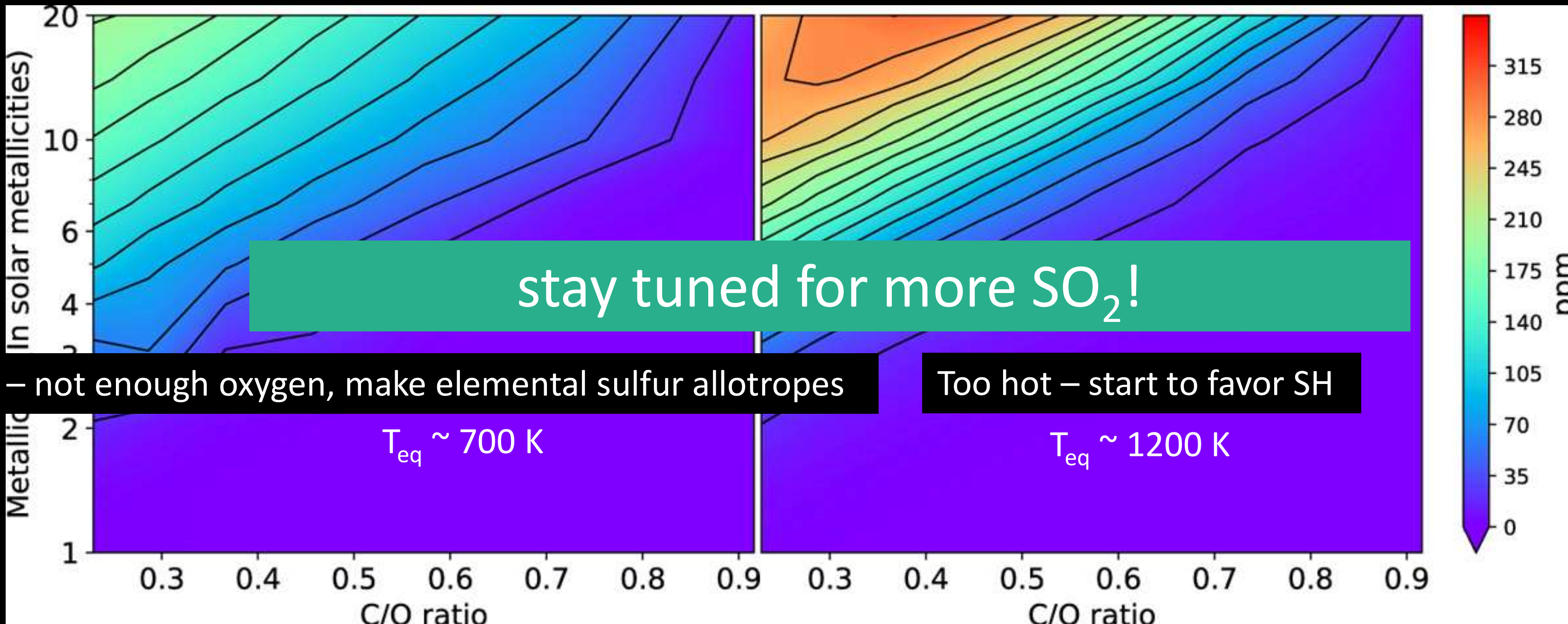



NASA/JPL-Caltech/Robert Hurt; Center for Astrophysics-Harvard & Smithsonian/Melissa Weiss



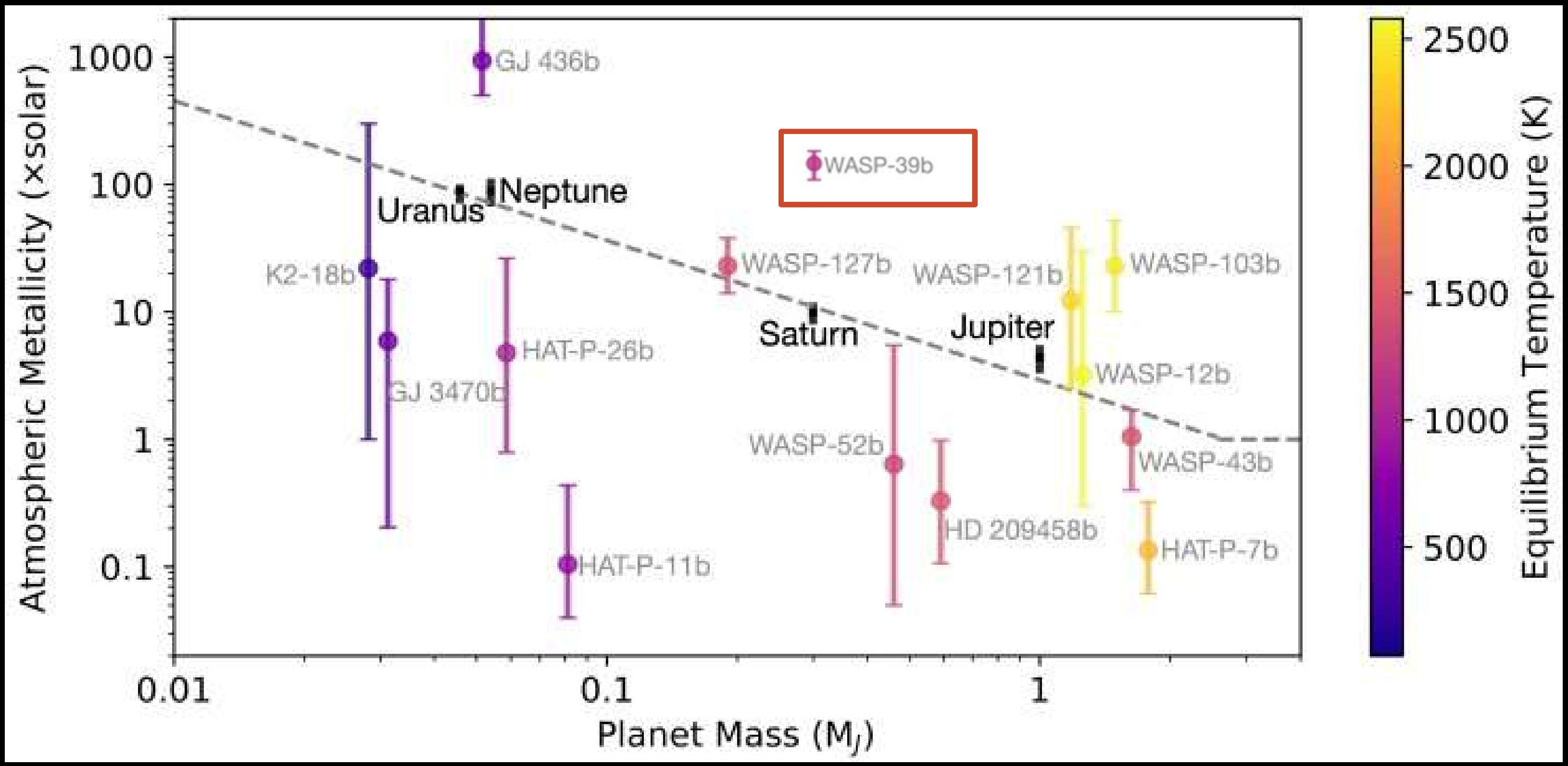

Tsai et al. (with Moran), Nature, 2023

# As a product of photochemistry, $SO_2$ very effectively traces metallicity, C/O ratio, and temperature




Polman et al., A&A, 2022; see also Tsai et al., Nature, 2023

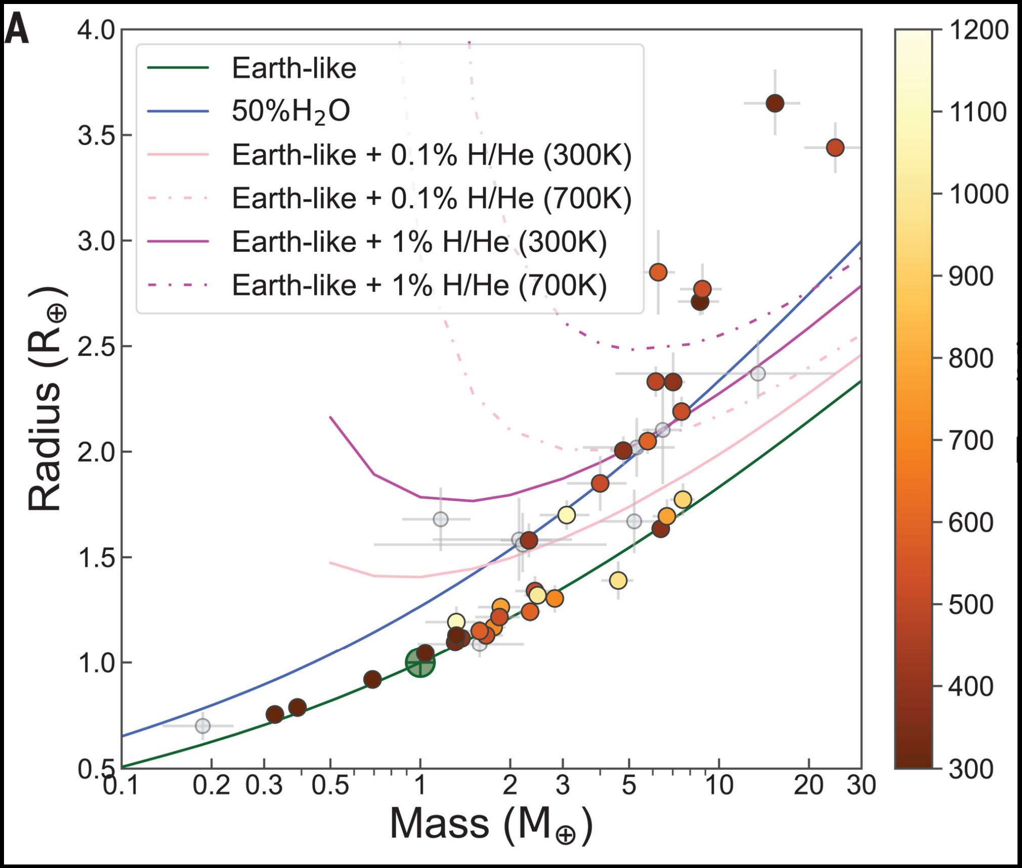
# The view as of ~~July 11th, 2022~~ today




~~Wakeford & Dalba, 2020~~

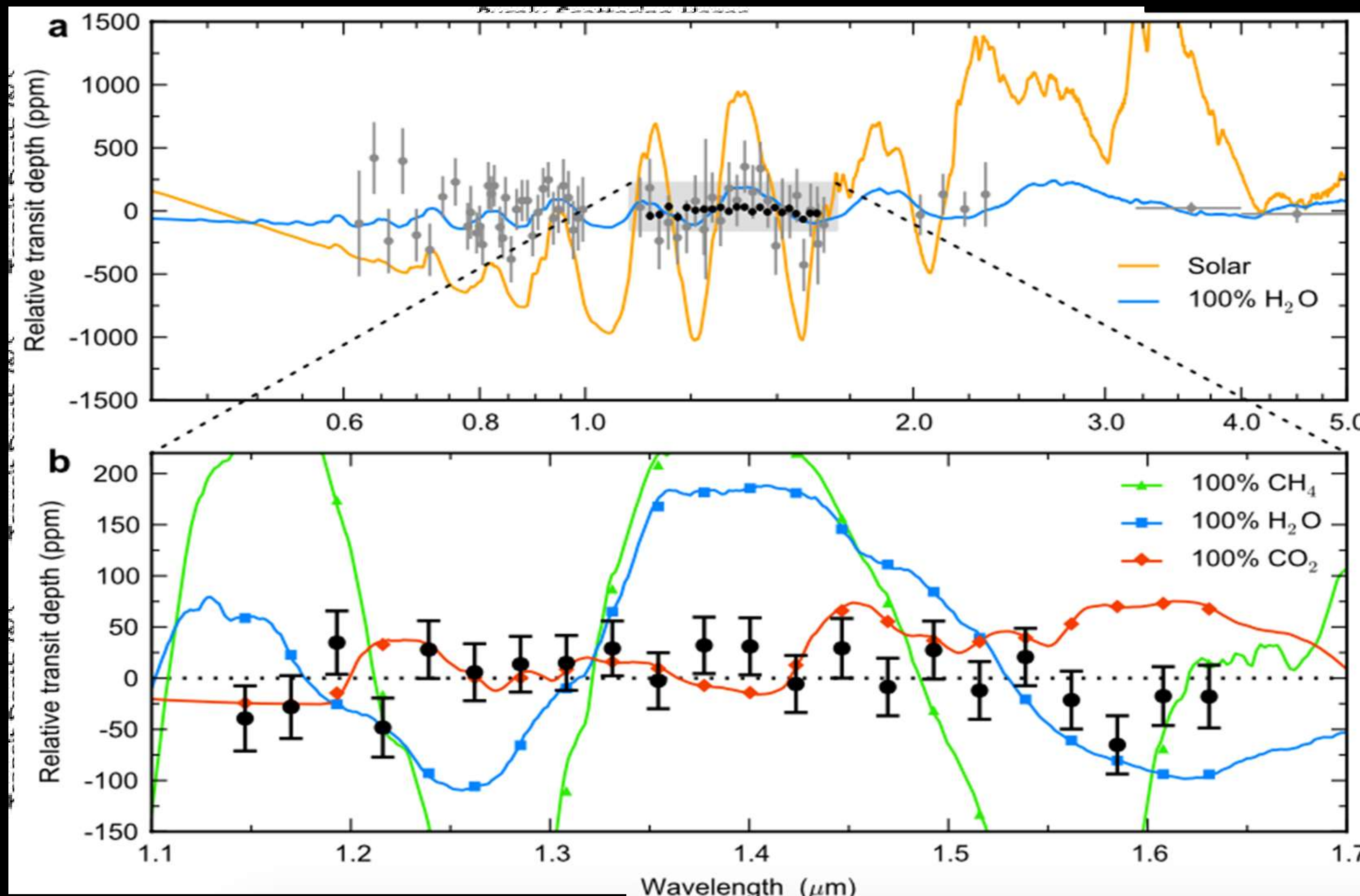
JWST Transiting ERS Team, Ahrer+ 2023, Alderson+ 2023, Feinstein+ 2023, Rustamkulov+ 2023, Tsai+ 2023

# A new thought on sub-Neptunes: water-worlds?




Luque & Pallé, Science, 2022

# Everyone's favorite* sub-Neptune GJ 1214b – haze still obscures the composition



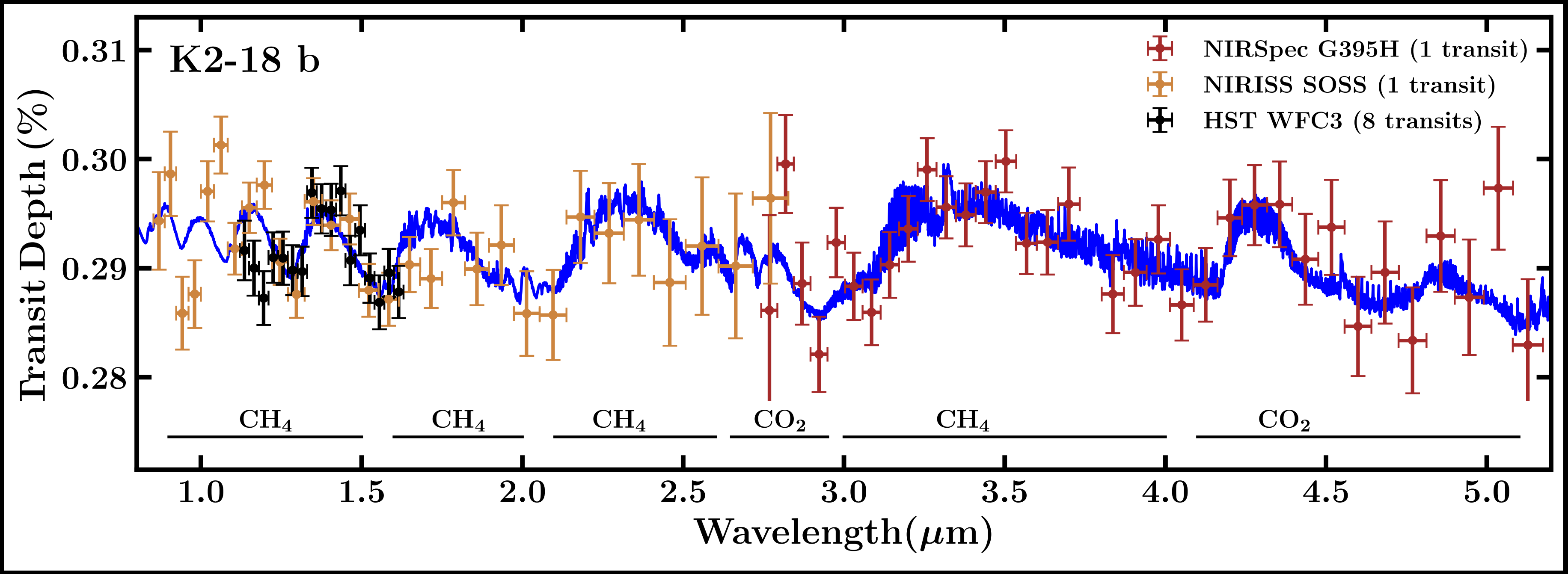

GJ 1214b – a warm sub-Neptune (500K; 2.7 $R_\oplus$)

also Kempton et al., Nature, 2023

Kreidberg et al., Nature, 2014

*mine, but I might be alone in this

# K2-18b – what HST saw as $H_2O$ is actually $CH_4$! Could be a "hy-cean" world, could be something else

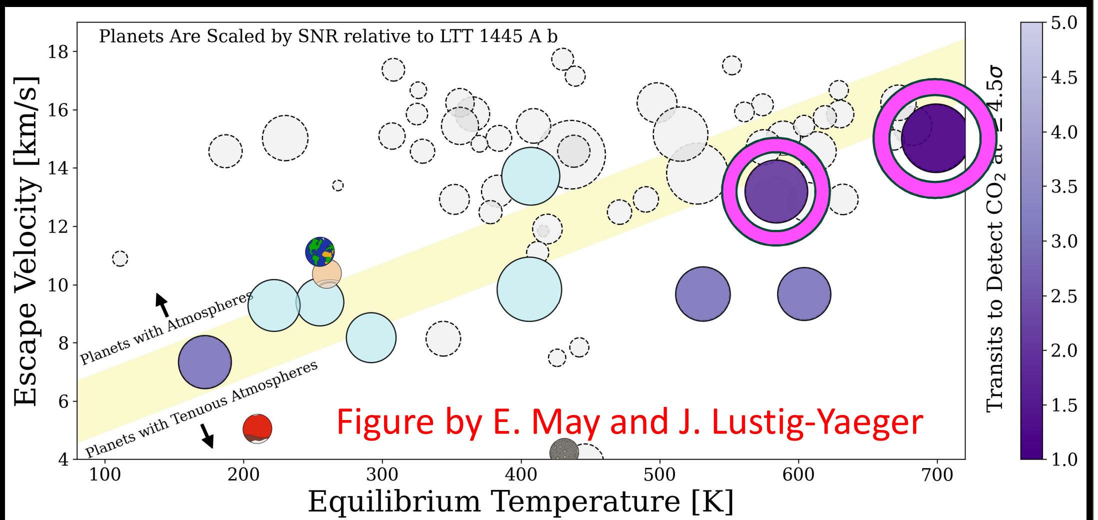



adapted from Madhusudhan et al., ApJL, in press

K2-18b– a temperate sub-Neptune ($250K$; $2.6\ R_{\oplus}$)

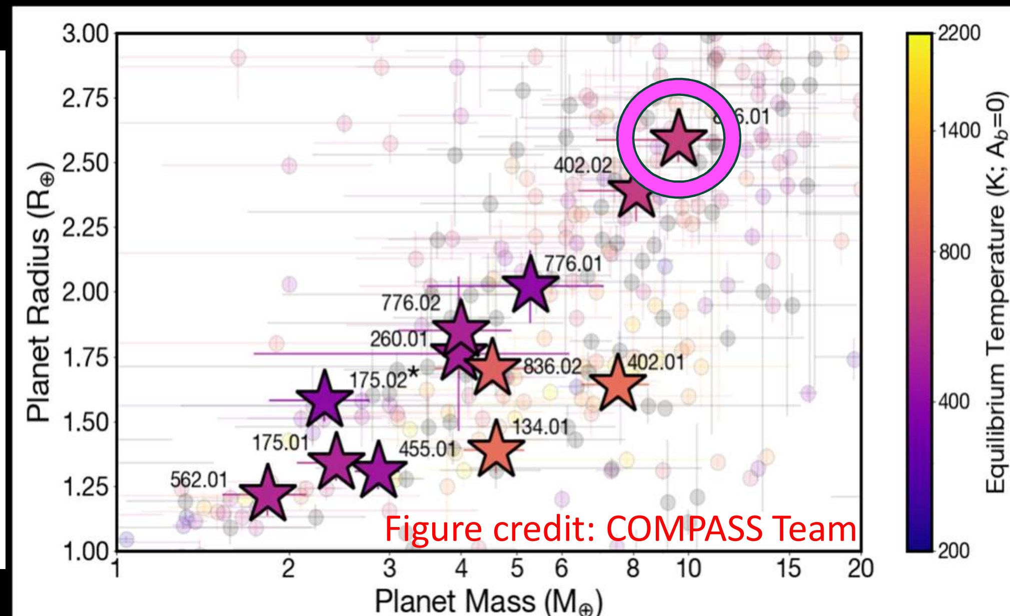
# JWST Cycle 1 Super-Earth and Sub-Neptune Surveys

Program 1981, PIs K.B. Stevenson and J. Lustig-Yaeger: No Air




Which M-dwarf planets have atmospheres?

Program 2512, PIs N. E. Batalha and J. Teske: COMPASS




Reconnaissance of super-Earths and sub-Neptunes

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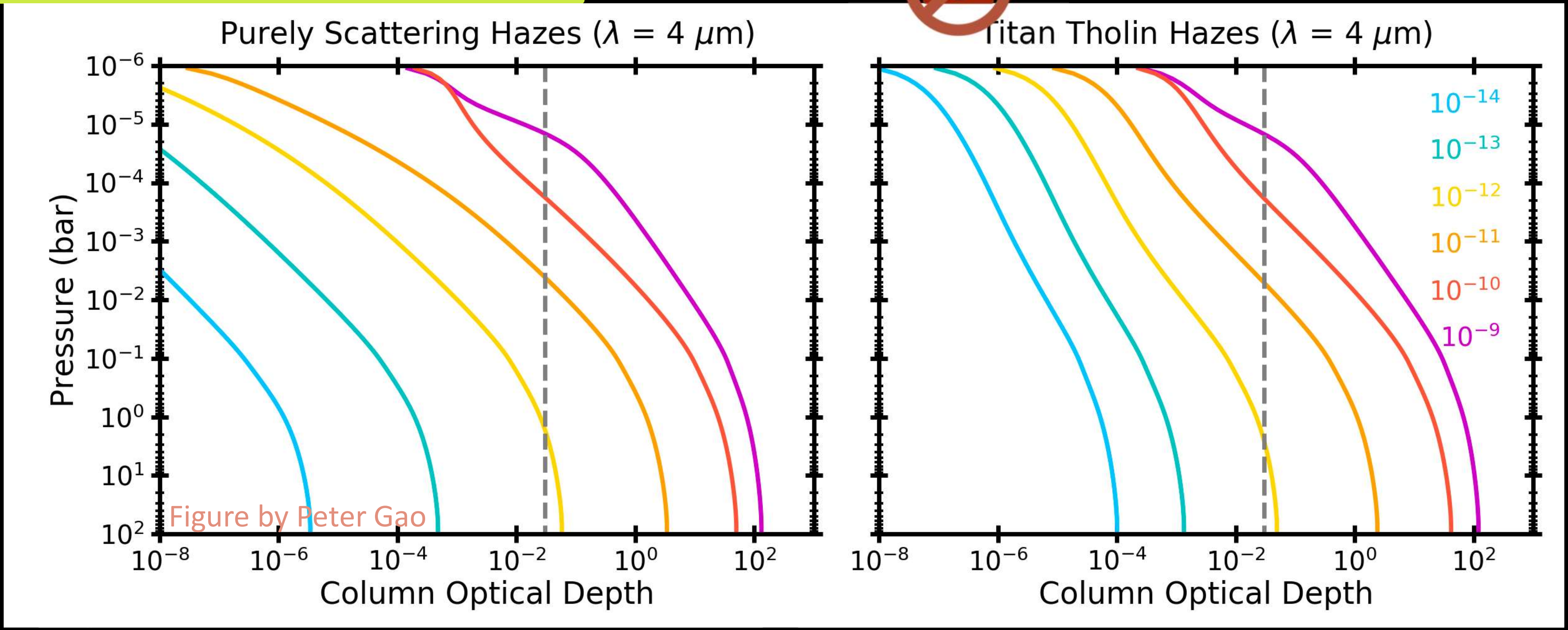
# TOI 836 c: a sub-Neptune with a flat spectrum – either >175x solar, aerosol-laden, or both

TOI 836 c, a warm sub-Neptune (670 K; 2.59 $R_{\oplus}$)

in prep, no photos/social media please




Wallack, Scarsdale, et al. (with Moran), in prep --- COMPASS Team

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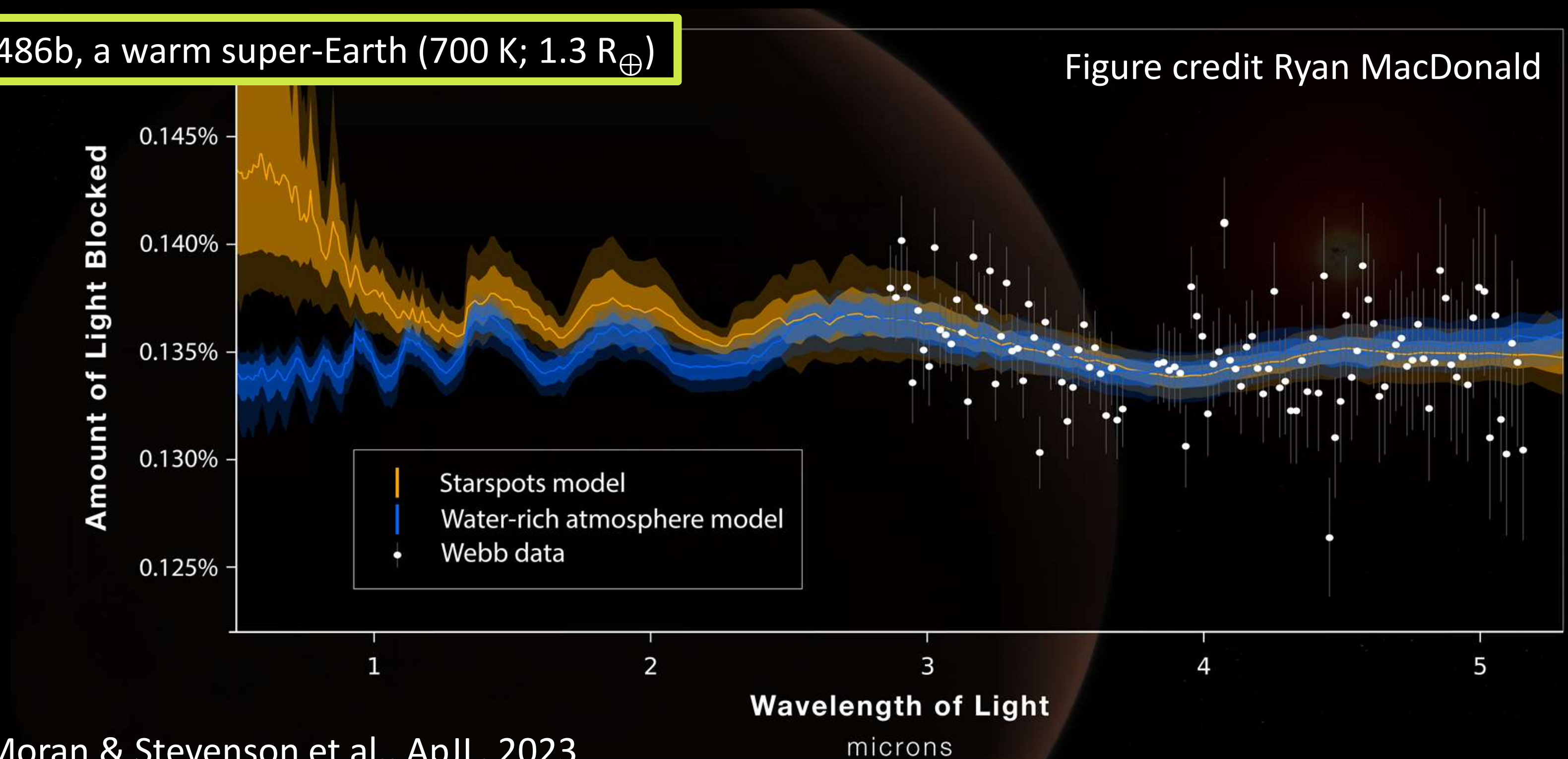
# Signs of water in a super-Earth – but could also be stellar contamination

GJ 486b, a warm super-Earth (700 K; 1.3 $R_\oplus$)

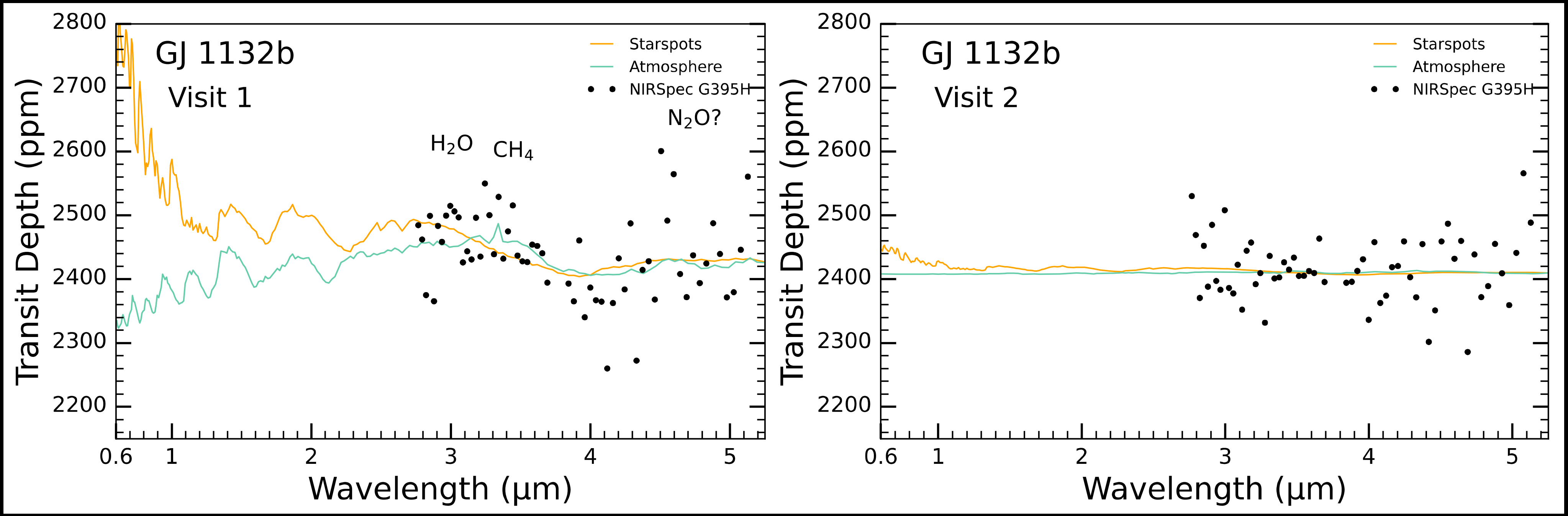



Moran & Stevenson et al., ApJL, 2023
No Air Team

# And some super-Earths look different visit to visit!

resubmitted, under review, no photos or social media please

GJ 1132b, a warm super-Earth (500 K; 1.13 $R_\oplus$ )




May & Macdonald, Bennett, Moran, et al., resubmitted
No Air Team

# Much more to come from JWST → compositional and temperature transitions hopefully to reveal trends for both hot giants AND sub-Neptunes

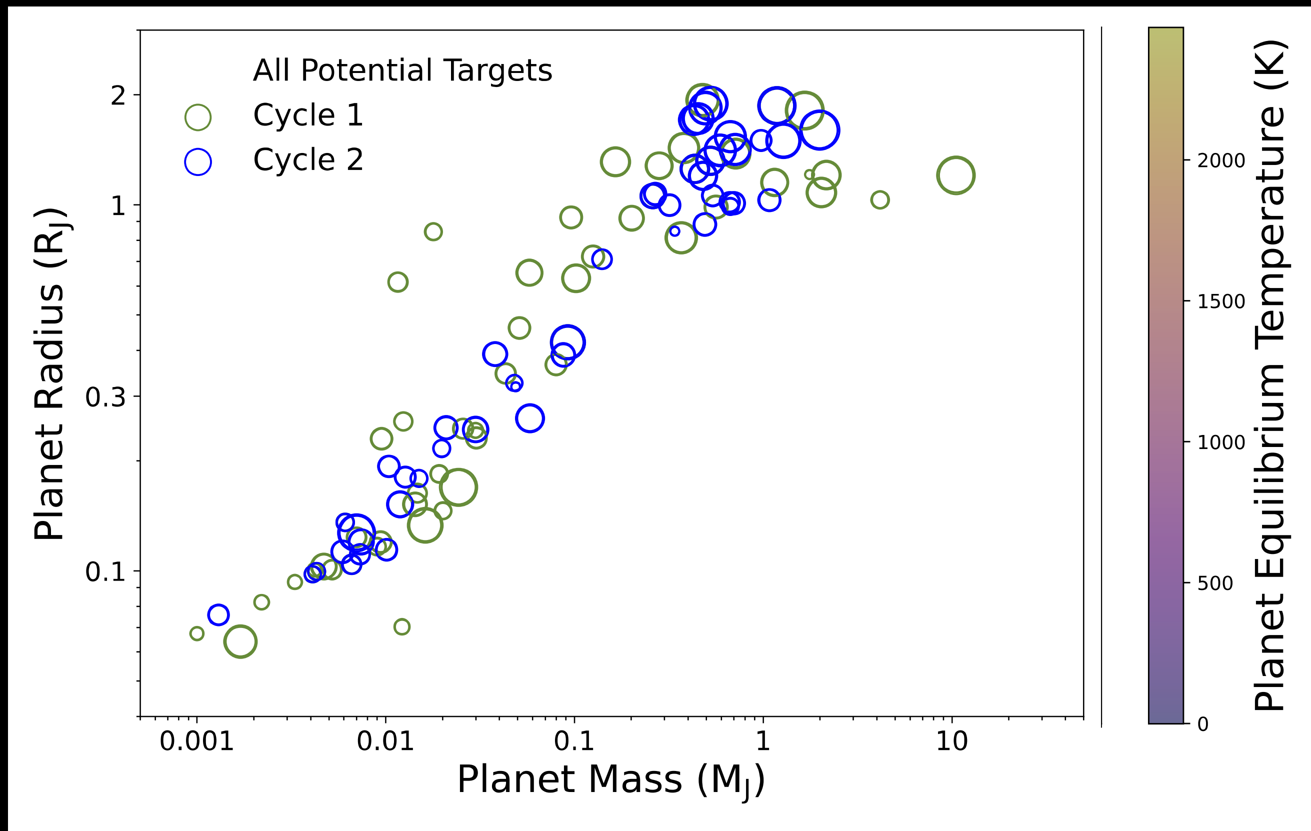



Figure plotting script: Hannah Wakeford

I’m on the job market! Let’s chat :)

# Takeaways

**Warm** exoplanets let us measure major atmospheric species – like **oxygen** – that have condensed out from the observable regions of our own solar system giants, so we can build a comprehensive understanding of planet **formation** & **evolution**

With JWST, we’re in a new era of giant planet characterization – so far mainly of **carbon** species (expected) and **sulfur** species (more surprising!) that let us probe **disequilibrium** chemical processes in these atmospheres better than we could in the era of HST alone – and actually link Solar System and exoplanet processes!

Aerosols, active host stars, and elusive atmospheres complicate our quest to measure sub-Neptune planetary atmosphere compositions, but there’s lots more to come from JWST