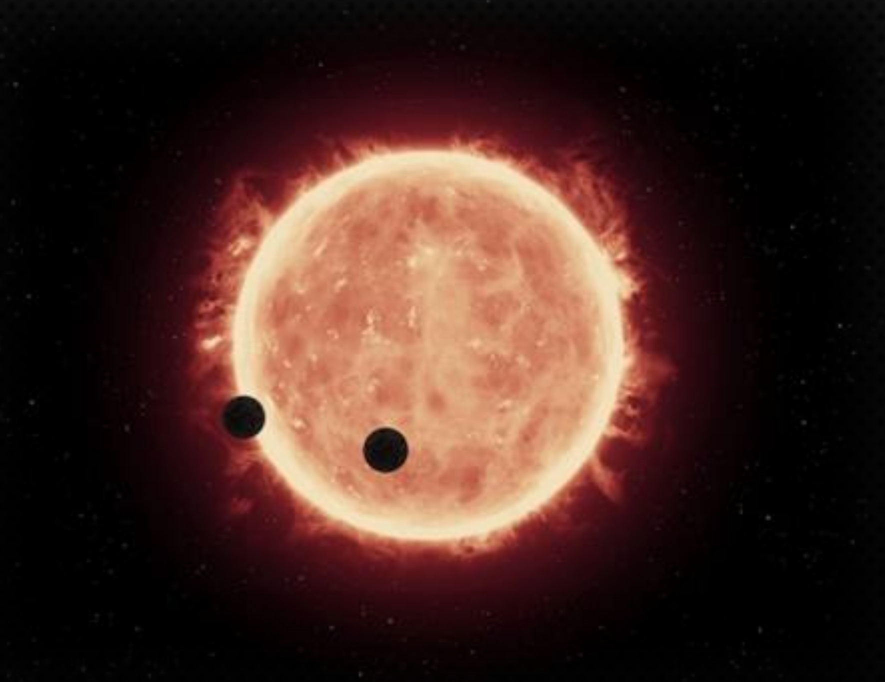
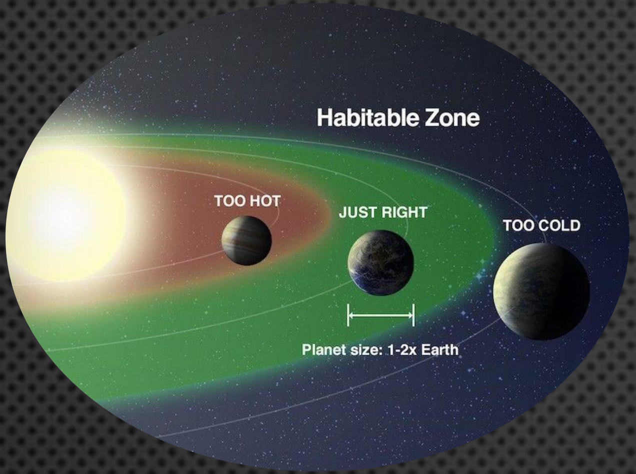
Promise & **Peril**: Stellar Contamination and Strict Limits on the Atmosphere Composition of TRAPPIST-1c from JWST NIRISS Transmission Spectra

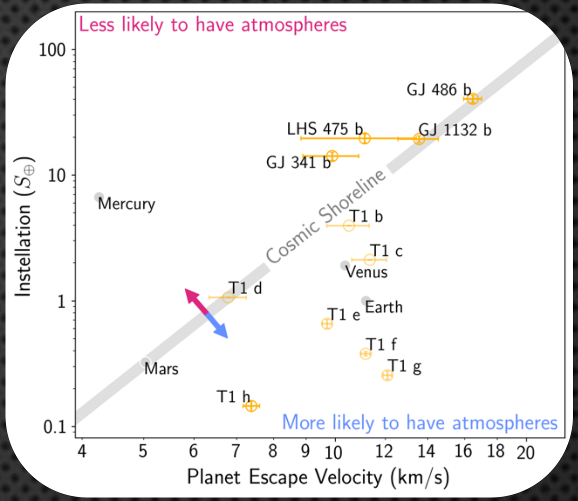


Michael Radica
NSERC Postdoctoral Fellow
University of Chicago

Know Thy Star 2
Feb 6, 2025

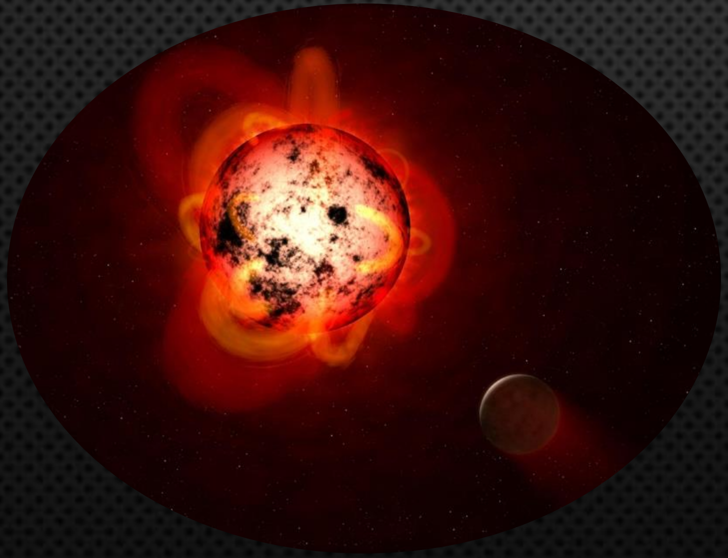
Promise →

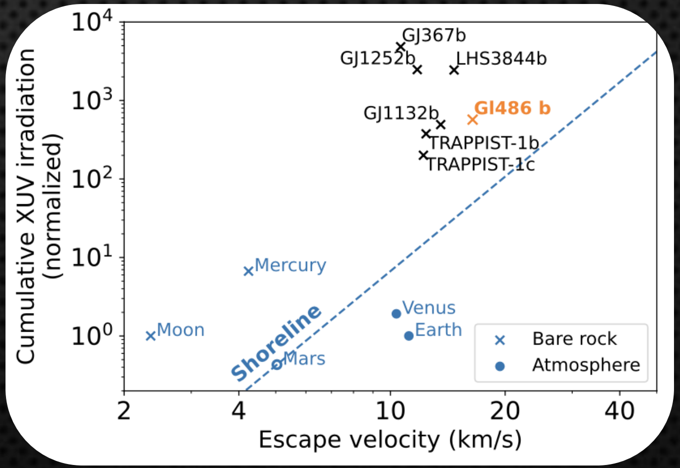




Kirk+ 24

Peril →





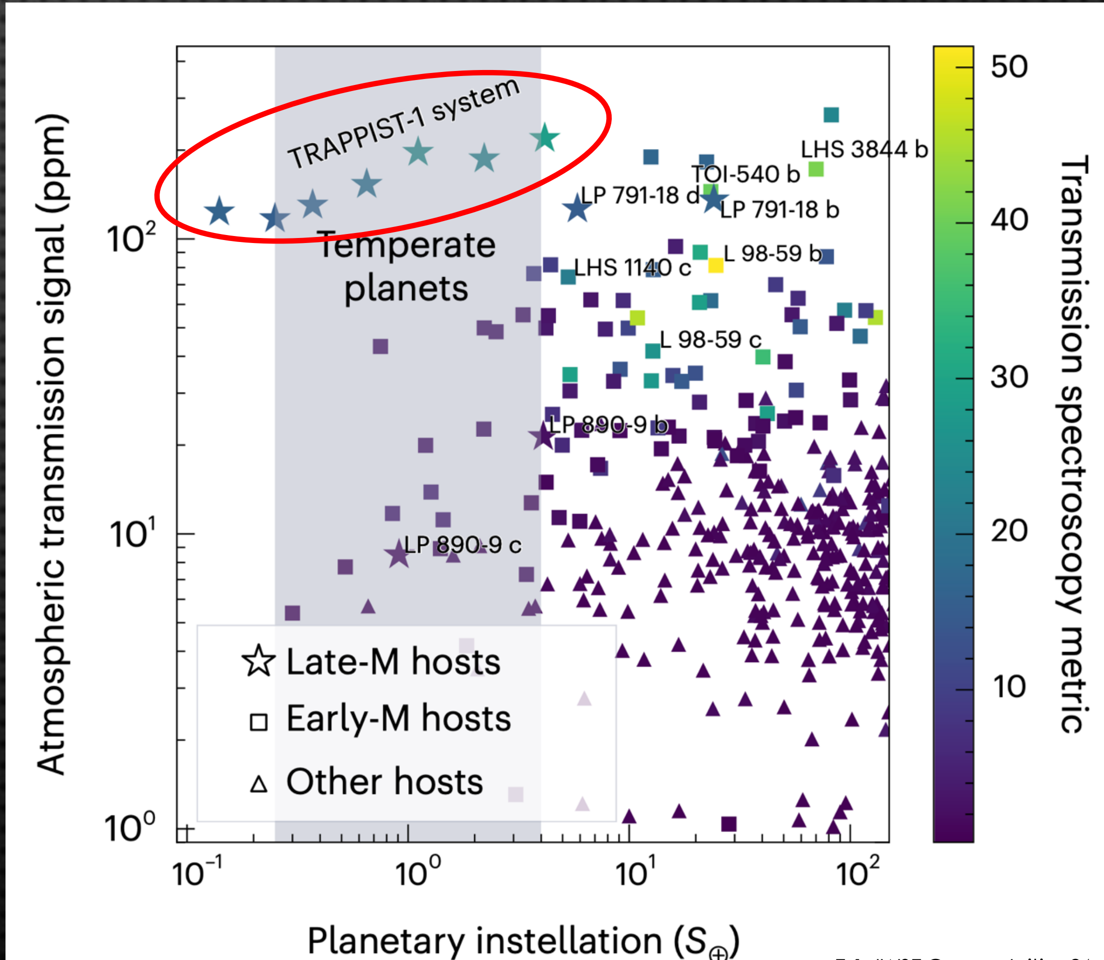
Weiner Mansfield+ 24

TRAPPIST-1 The ~~M Dwarf~~ Opportunity

~1000 hrs of JWST time on rocky M Dwarf planets

~40% on one system: TRAPPIST-1

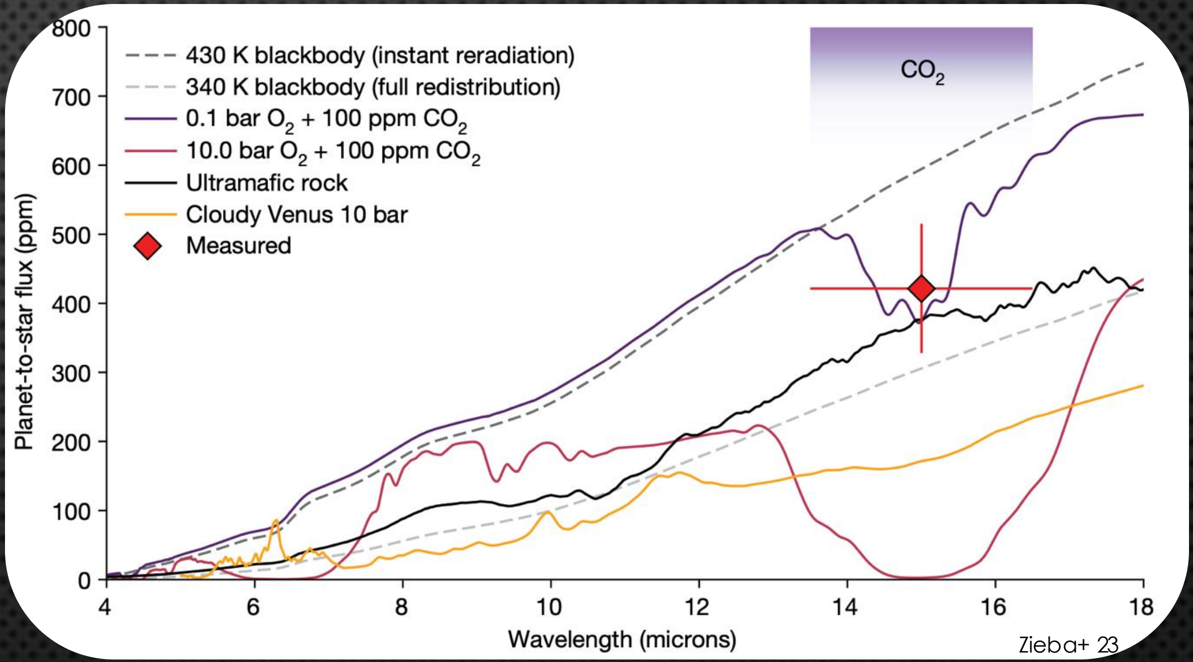
ESO



T-1 JWST Comm. Initi.+ 24

The ~~M Dwarf~~ TRAPPIST-1 Opportunity

ESO



MIRI emission photometry at 15μm (Zieba+23)

15μm primarily sensitive to CO_2 and degeneracies exist! (Lincowski+23)

Transit spectroscopy is the best way to probe for atmospheres of temperate worlds

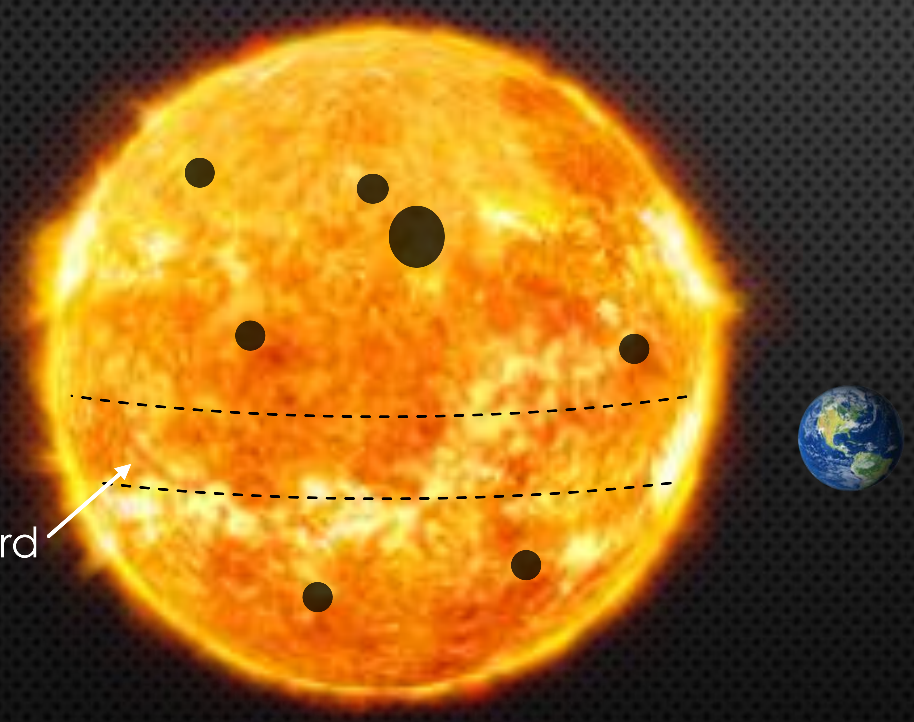
MIRI emission photometry at 12.8 and 15μm (Greene+23, Ih+23, Ducrot+24)

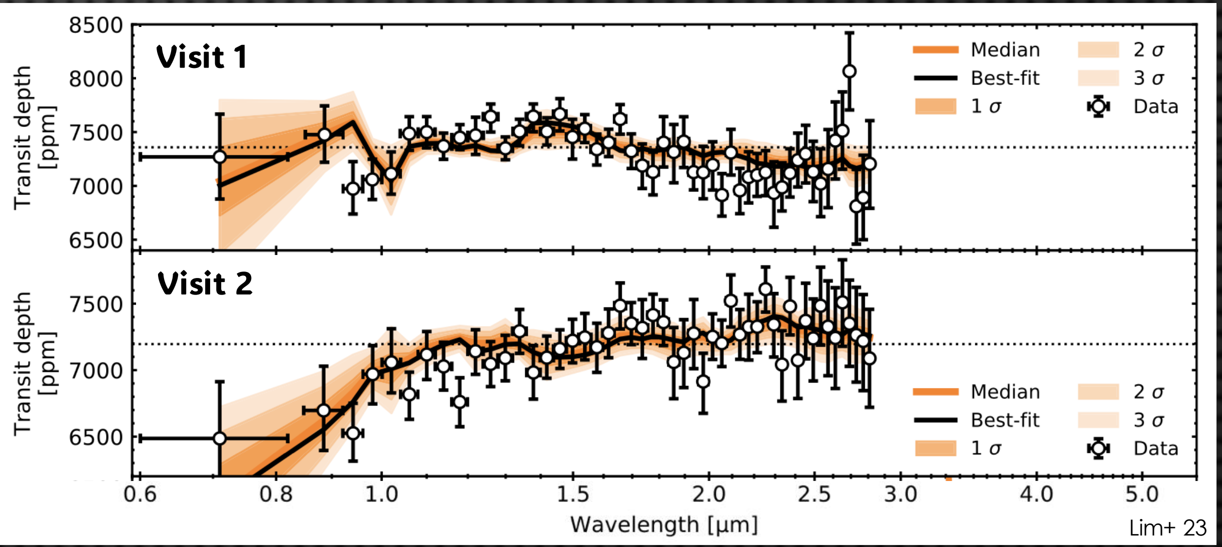
Transit spectroscopy from with **NIRISS** (0.6 – 2.8μm; Lim+ 23) and **NIRSpec** (0.6 – 5μm; Rathcke+ 24)

~~TRAPPIST-1~~

The ~~M Dwarf~~ Opportunity

TLS Effect

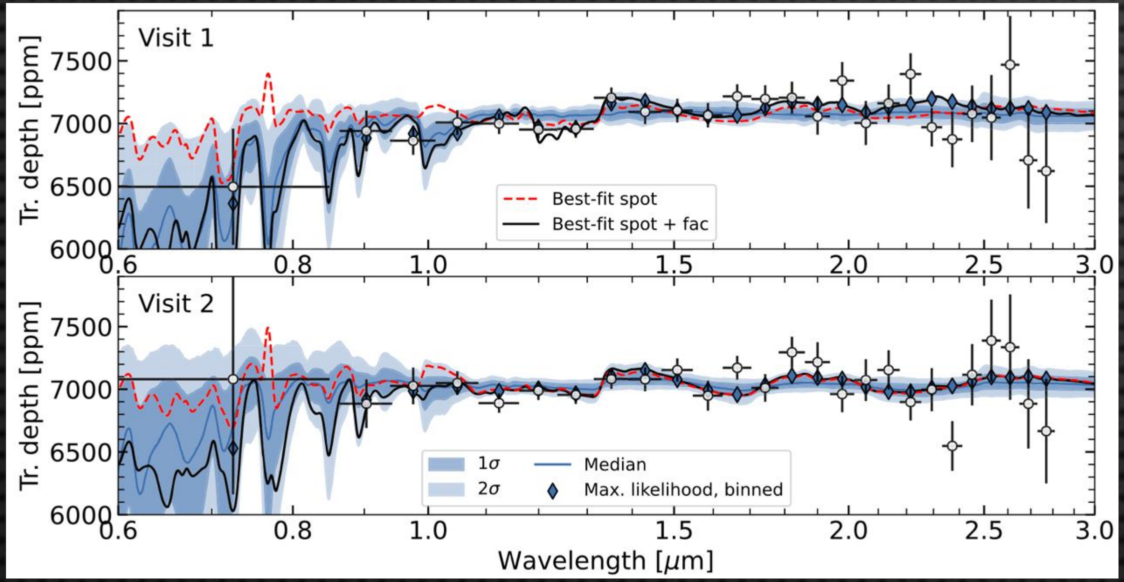




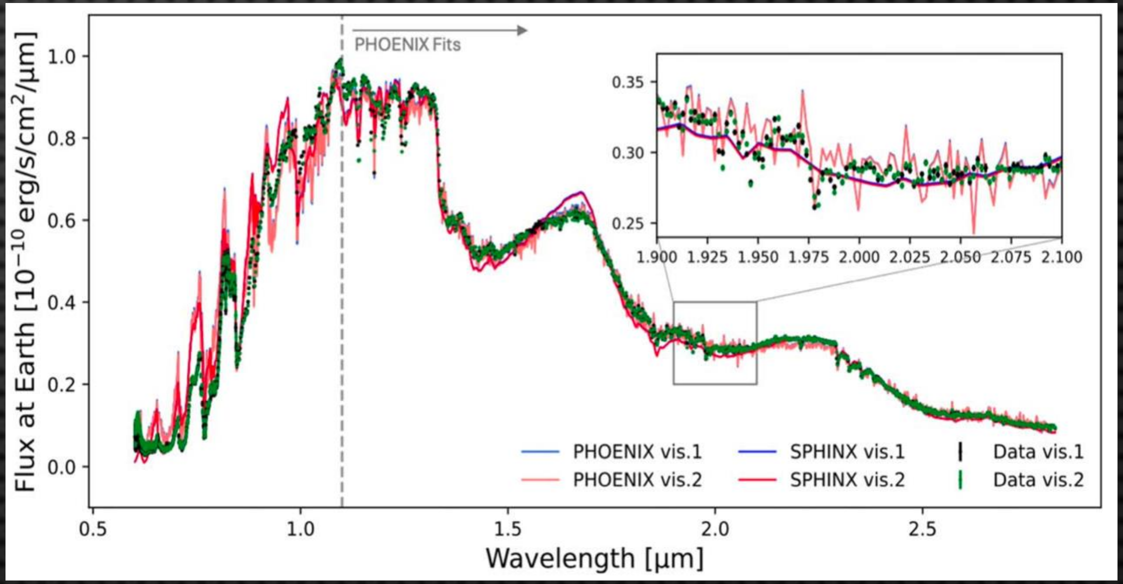
Transit light source effect can impart slopes and even spurious features onto transmission spectra of rocky planets

Not a new …or infrequent… problem
e.g., Pont+08, Sing+11, Pinhas+18, Rackham+ 18,19, Wakeford+ 19, Garcia+ 22, Lim+ 23, May & MacDonald+ 23, Moran & Stevenson+ 23, Cadieux+ 24, …

Stellar Contamination – Leveraging In- and Out-of-Transit Spectra



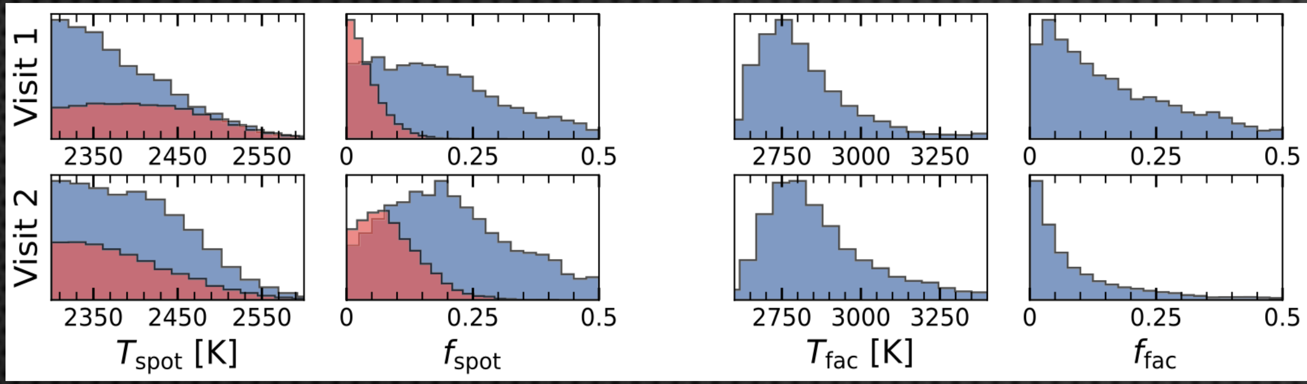
Transit light source effect fits to transmission spectra

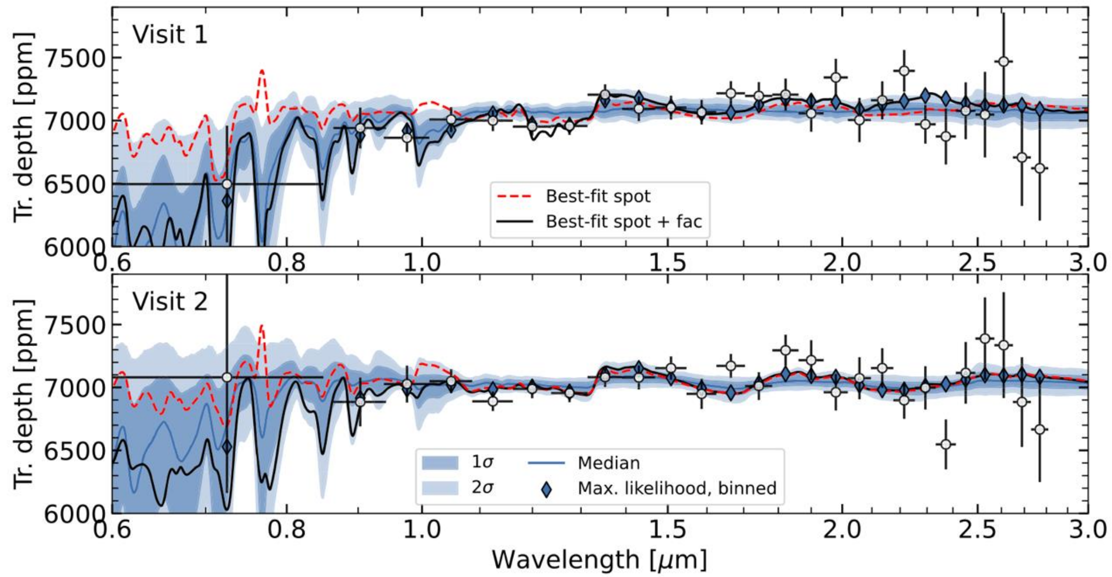


Direct fits of inhomogeneous stellar photospheres to out-of-transit stellar spectra

Consistent transmission and stellar spectra despite visits being separated by ~1 year!

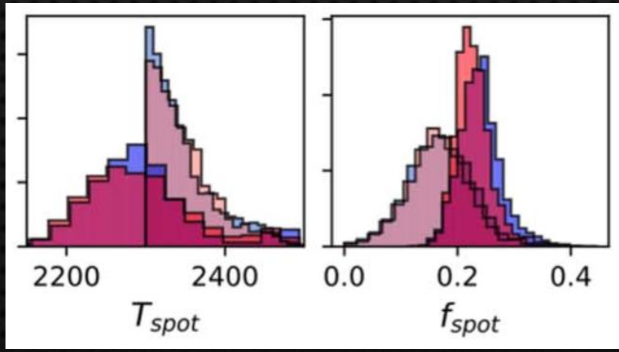
Stellar Contamination – Leveraging In- and Out-of-Transit Spectra

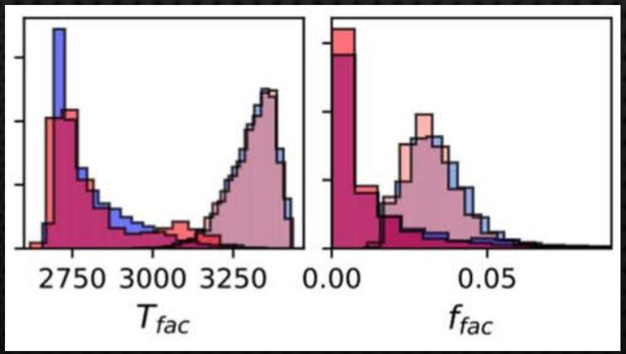


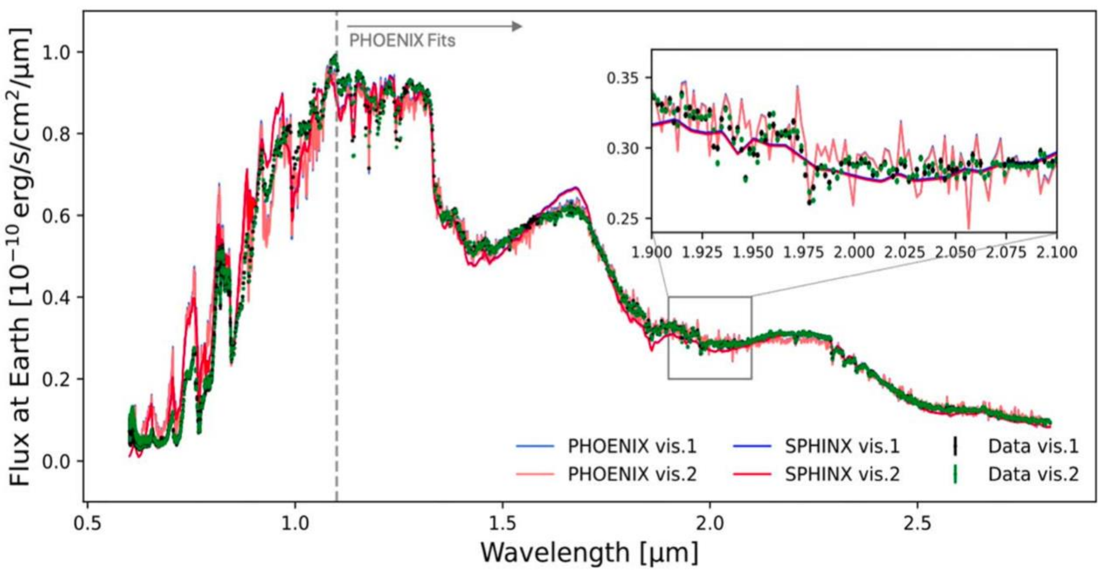


Dominated by "spots"

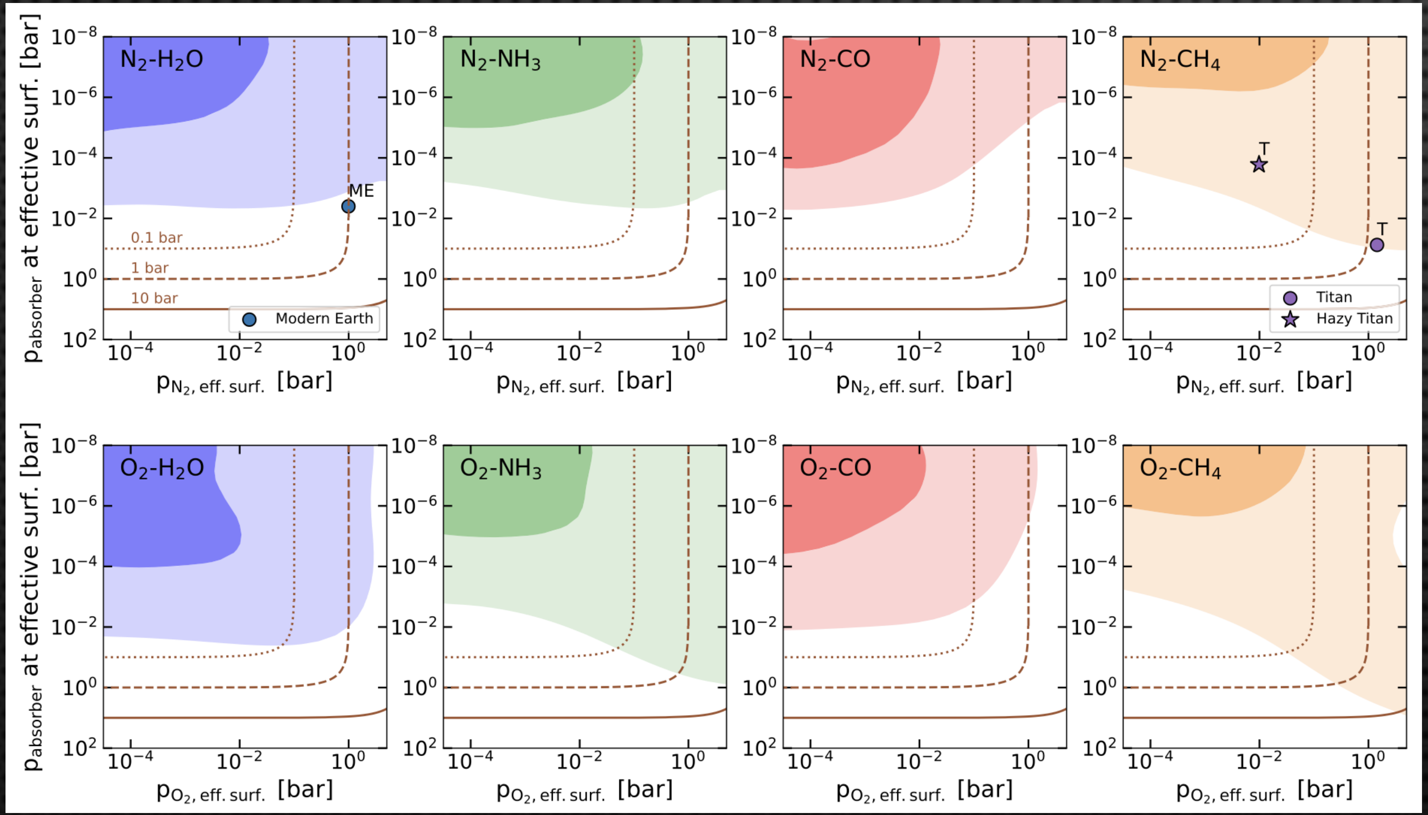
Minor "facular" contribution







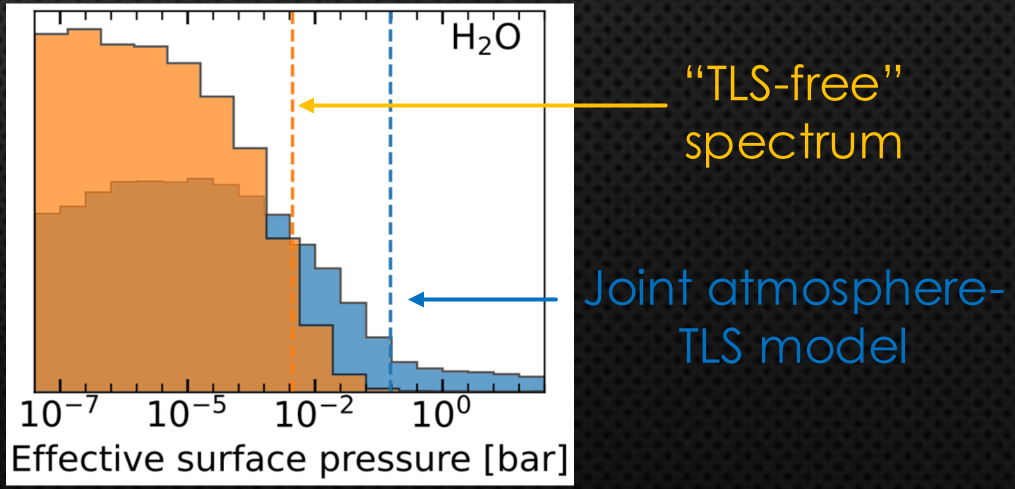
Limits on Atmosphere Composition in the Face of the TLS Effect



Modern Earth-like atmospheres disfavoured at >2σ

Thin O_2-H_2O atmospheres proposed by Lincowski+ 23 not ruled out

Bare rock scenario a strong possibility



TLS "bottleneck" decreases sensitivity by ~2 orders of magnitude!

Conclusions

Transmission spectroscopy remains the best route for probing atmospheres around temperate planets around M dwarfs

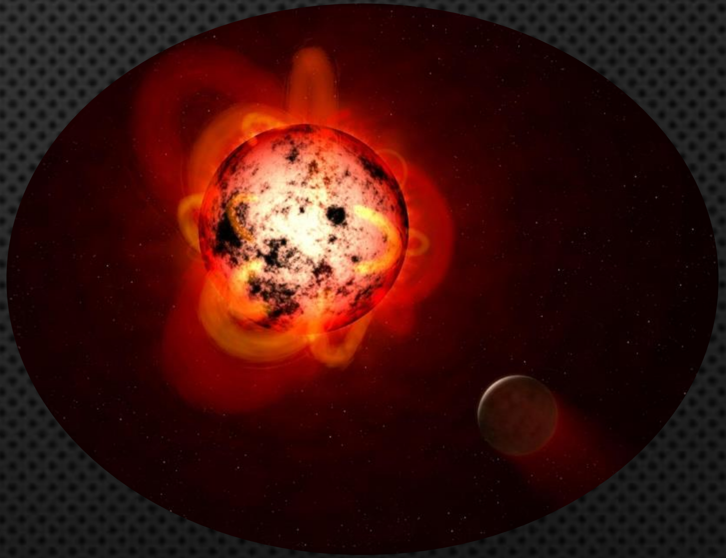
The transit light source effect remains a stubborn bottleneck

Leveraging both in- and out-of-transit data is important to constrain stellar (and therefore planetary) properties

Jointly modelling stellar heterogeneities and planet atmospheres critical to obtain accurate, unbiased inferences

NIRISS transmission spectra disfavour Earth-like compositions, or thick atmospheres of any kind

Thin O_2-CO_2 and O_2-H_2O atmospheres remain a possibility



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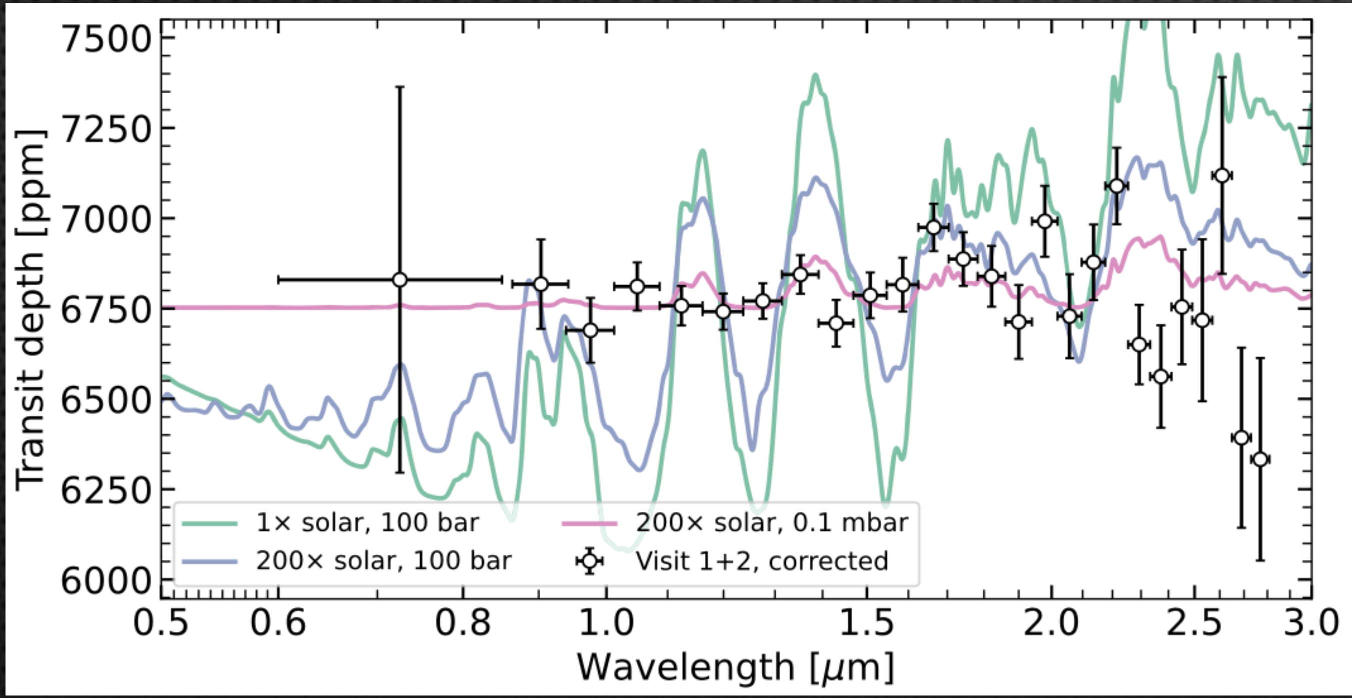
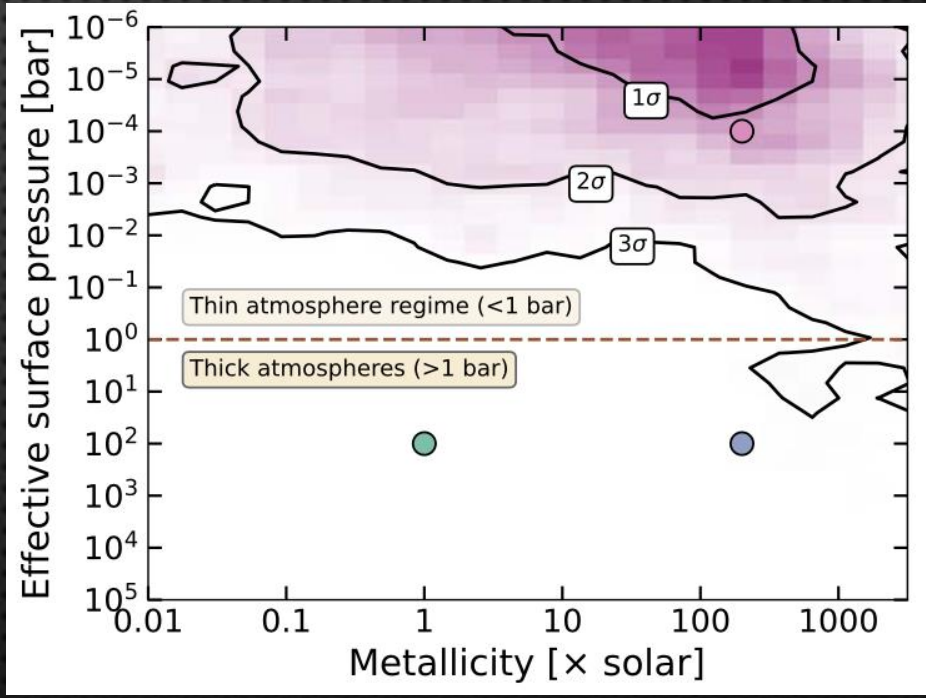
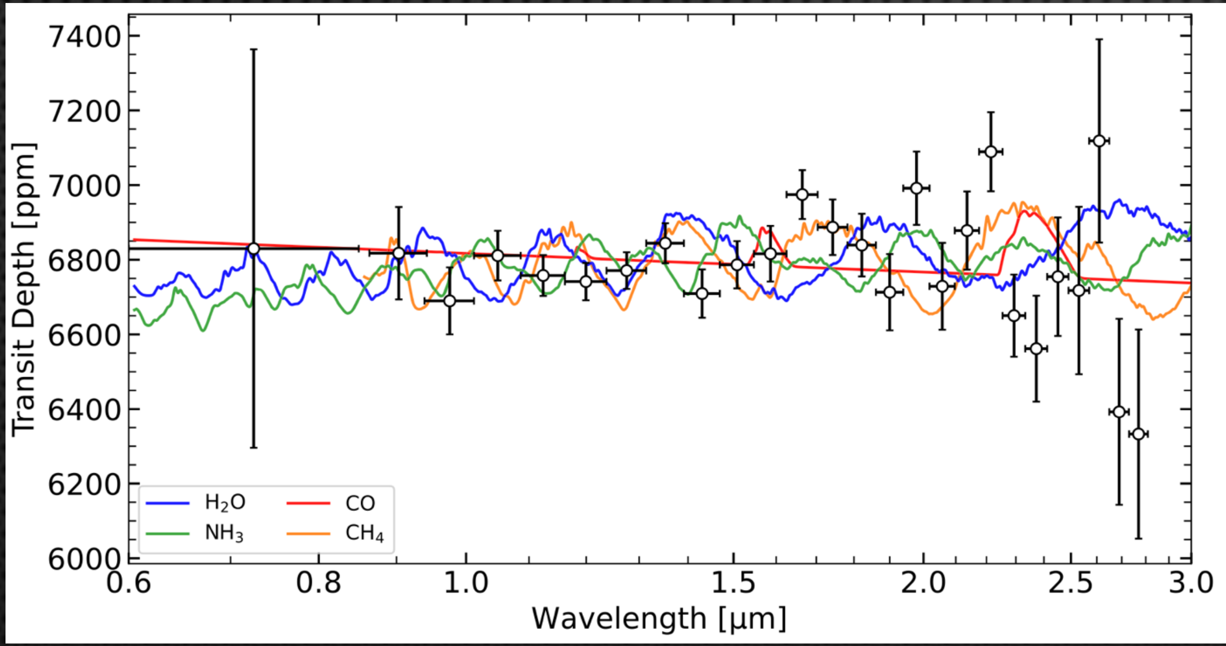


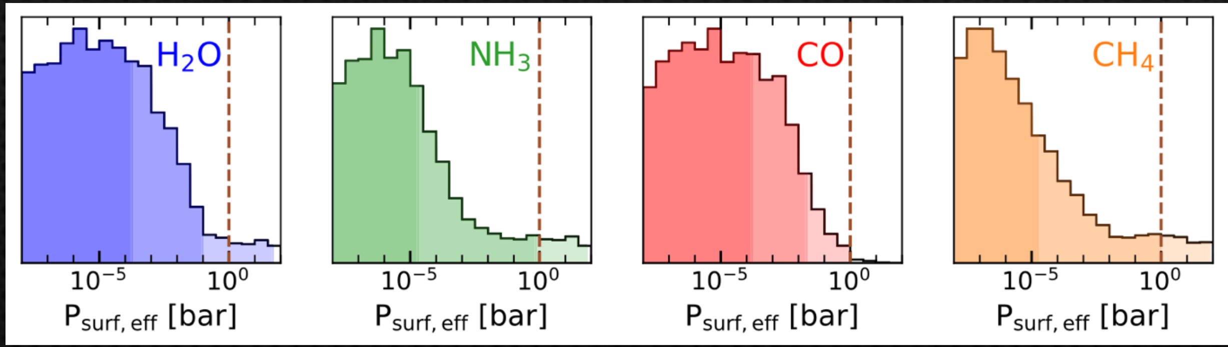


Jointly model a planetary atmosphere and the TLS effect to **marginalize over the impacts of stellar heterogeneities**

Assume a single TLS model for both visits

Limits on Atmosphere Composition in the Face of the TLS Effect





Thick, single absorber atmospheres generally disfavoured at ≥2σ

Data does not rule out thin "steam world" atmospheres (e.g., Lincowski+ 23).

Thick, H_2-dominated atmospheres ruled out at high confidence