Measuring the Atmospheres of (the best!) Earth-sized Planets with JWST

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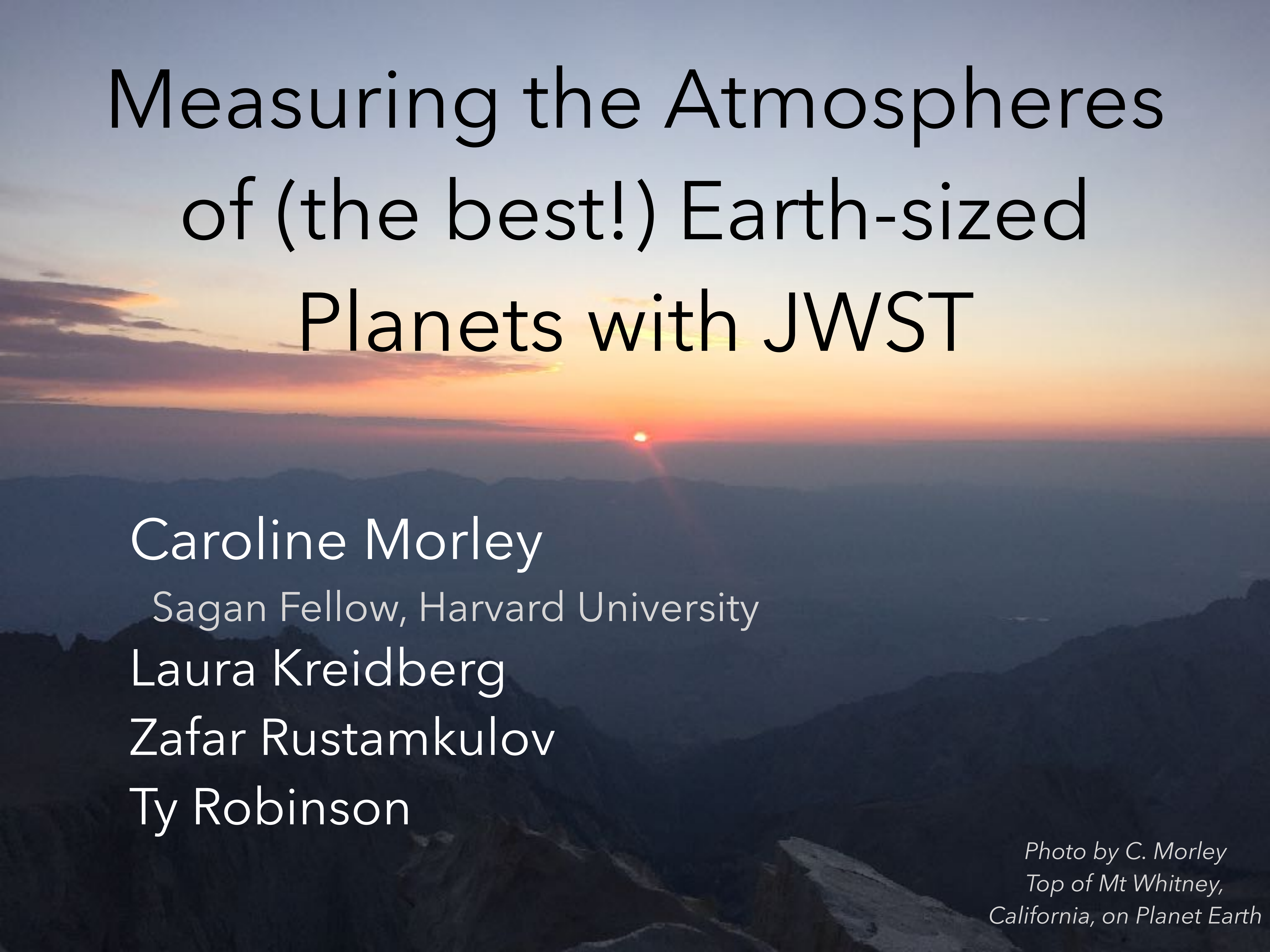
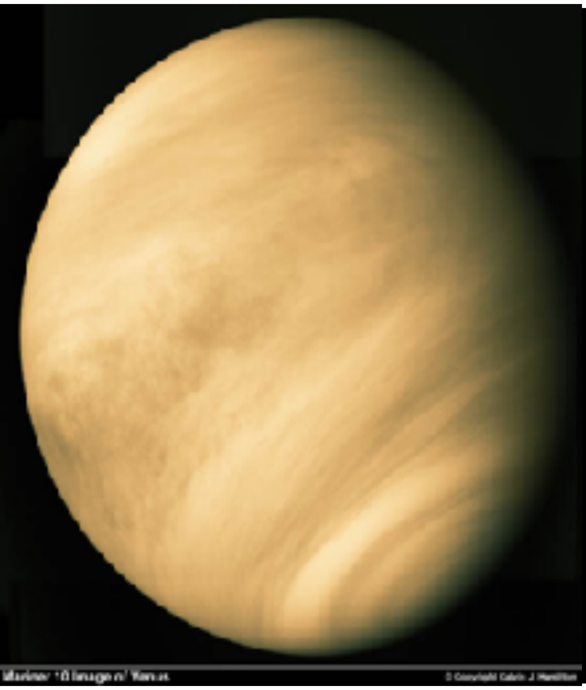


Photo by C. Morley
Top of Mt Whitney, California, on Planet Earth

Terrestrial planet atmospheres in the solar system are **diverse** and controlled by **many physical processes**

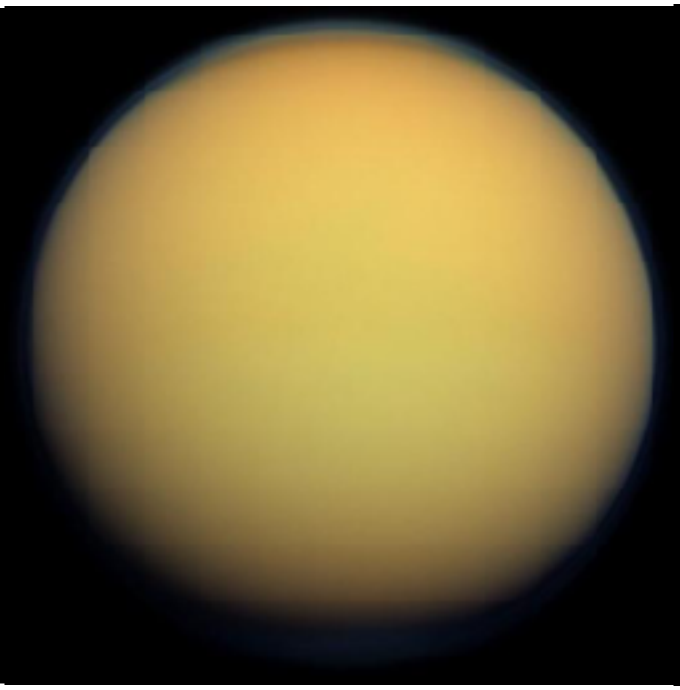


Venus

100 bar CO_2
sulfuric acid clouds
no oceans
surface is hellscape

Earth

1 bar N_2/O_2
oceans & hydro cycle
surface is nice



Titan

1 bar N_2
methane lakes and
hydro cycle
surface is (really) cold

Mars

6 mbar CO_2
former liquid water
surface is cold

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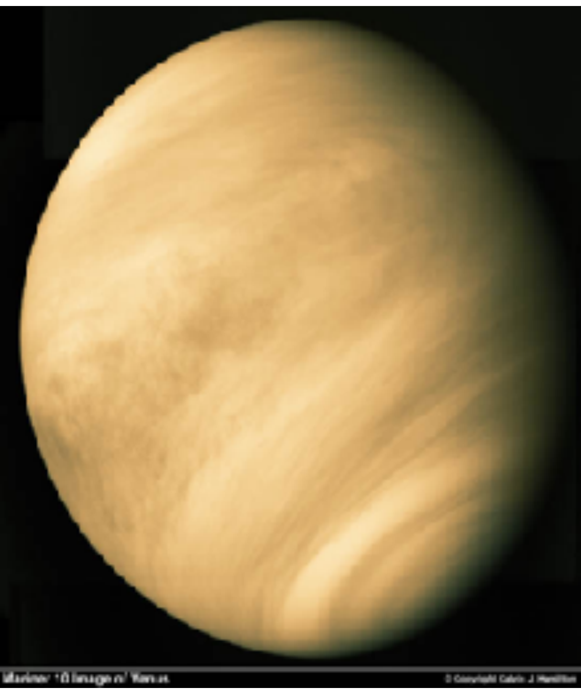
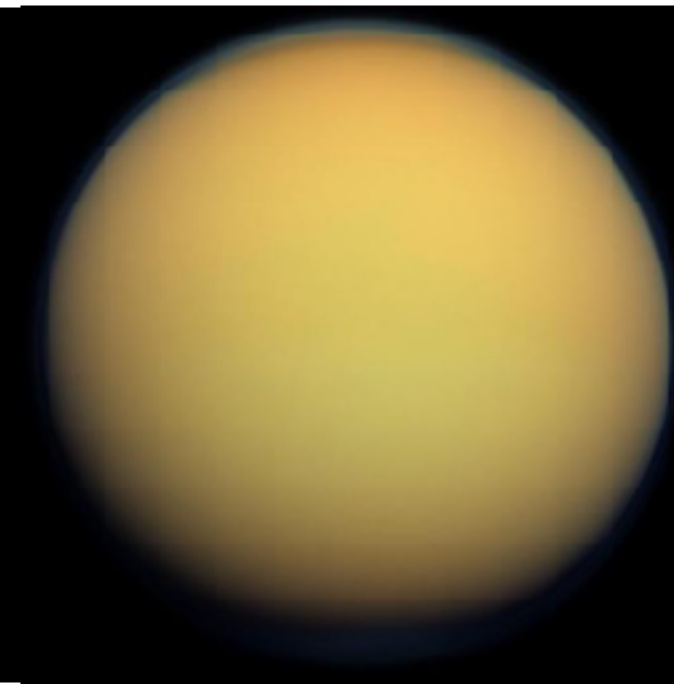
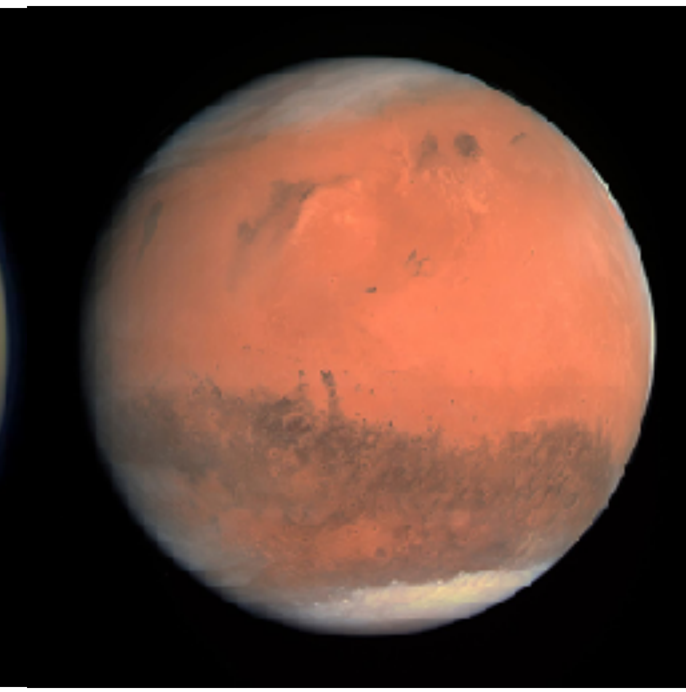
volatile delivery | interior composition | planet mass | atm loss (ocean loss) | UV flux (photochemistry)

How do terrestrial atmospheres form and evolve in planetary systems?

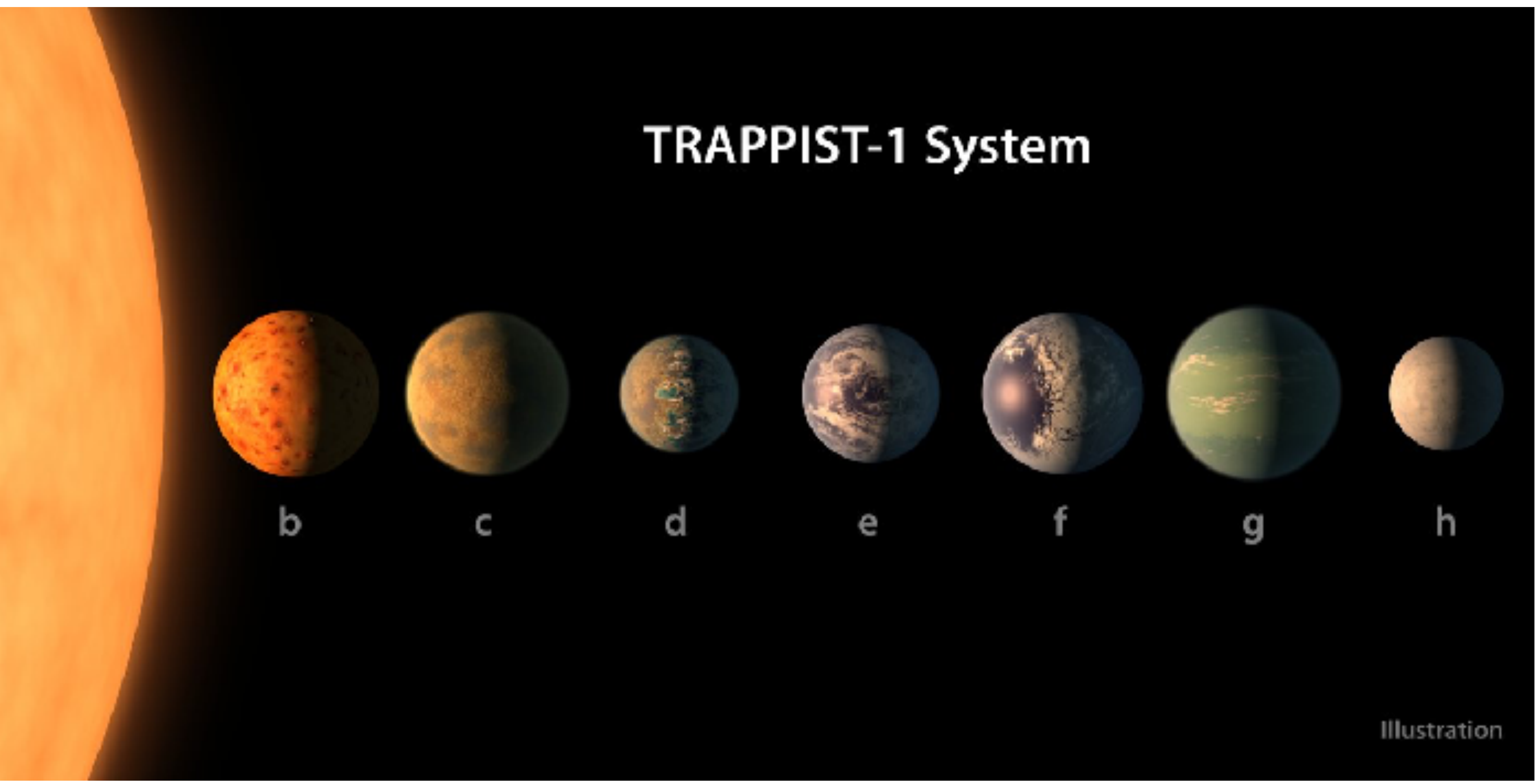


Two big problems:

1. very small sample size
2. all around the same star

For the first time ever, we have discovered temperate, terrestrial planets for which we have a fighting shot of **characterizing their atmospheres**



+

all small planets around some of the smallest nearby stars

Berta-Thompson et al. 2016

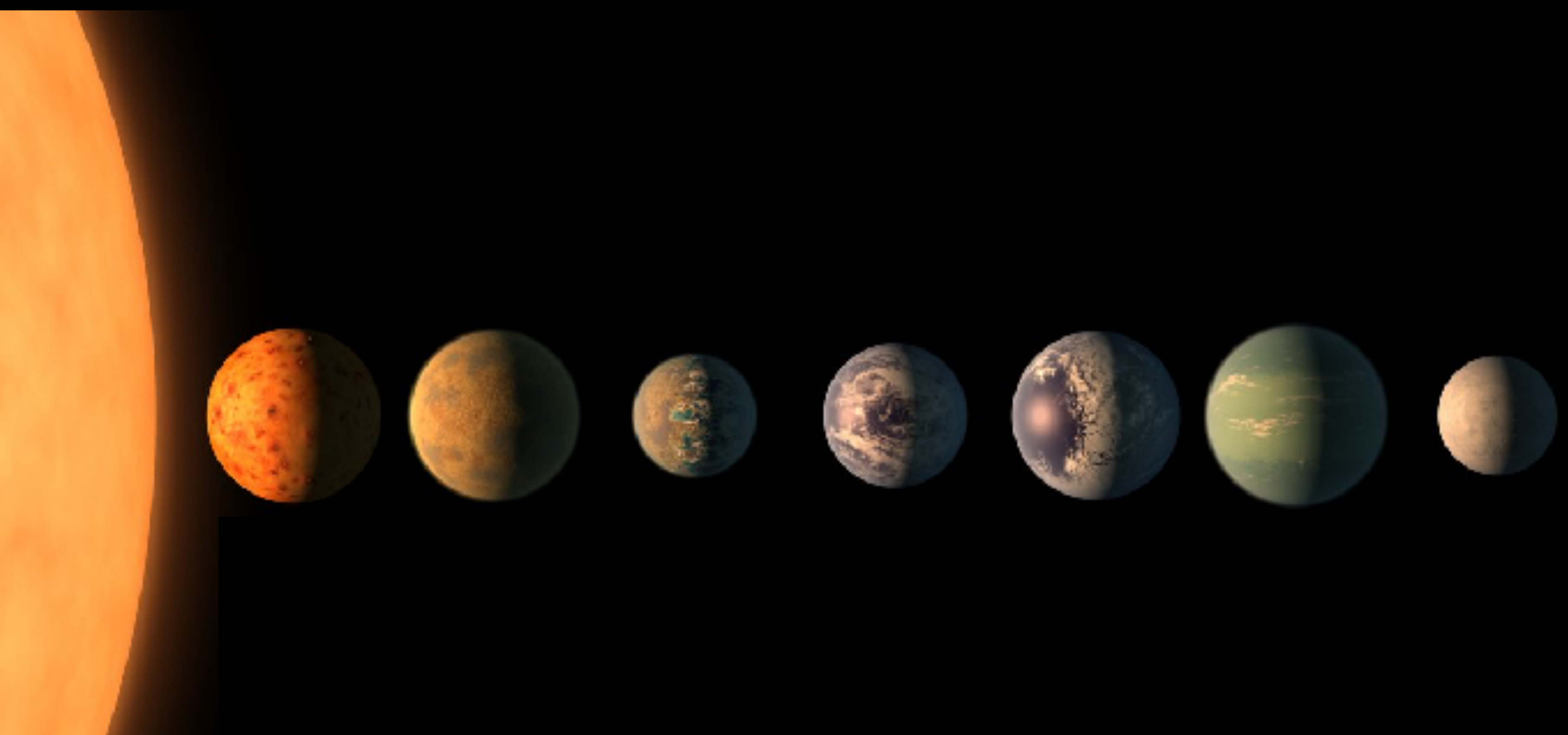
Gillon et al. 2017

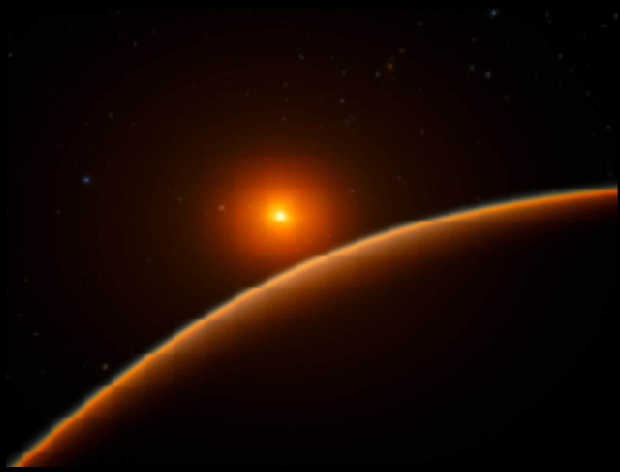
Dittmann et al. 2017

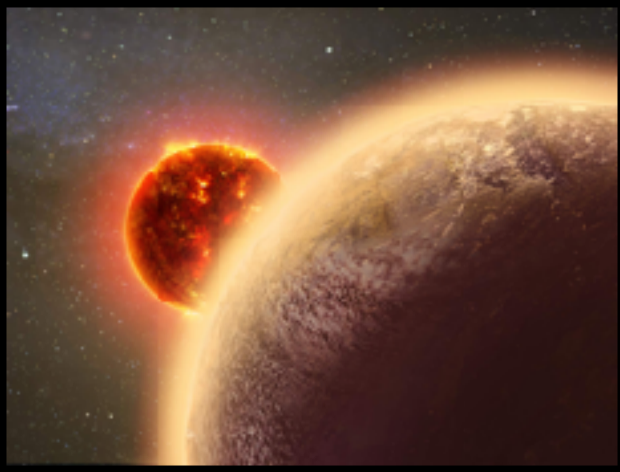
Outline

generating a diverse set of model planet spectra (transmission and emission)

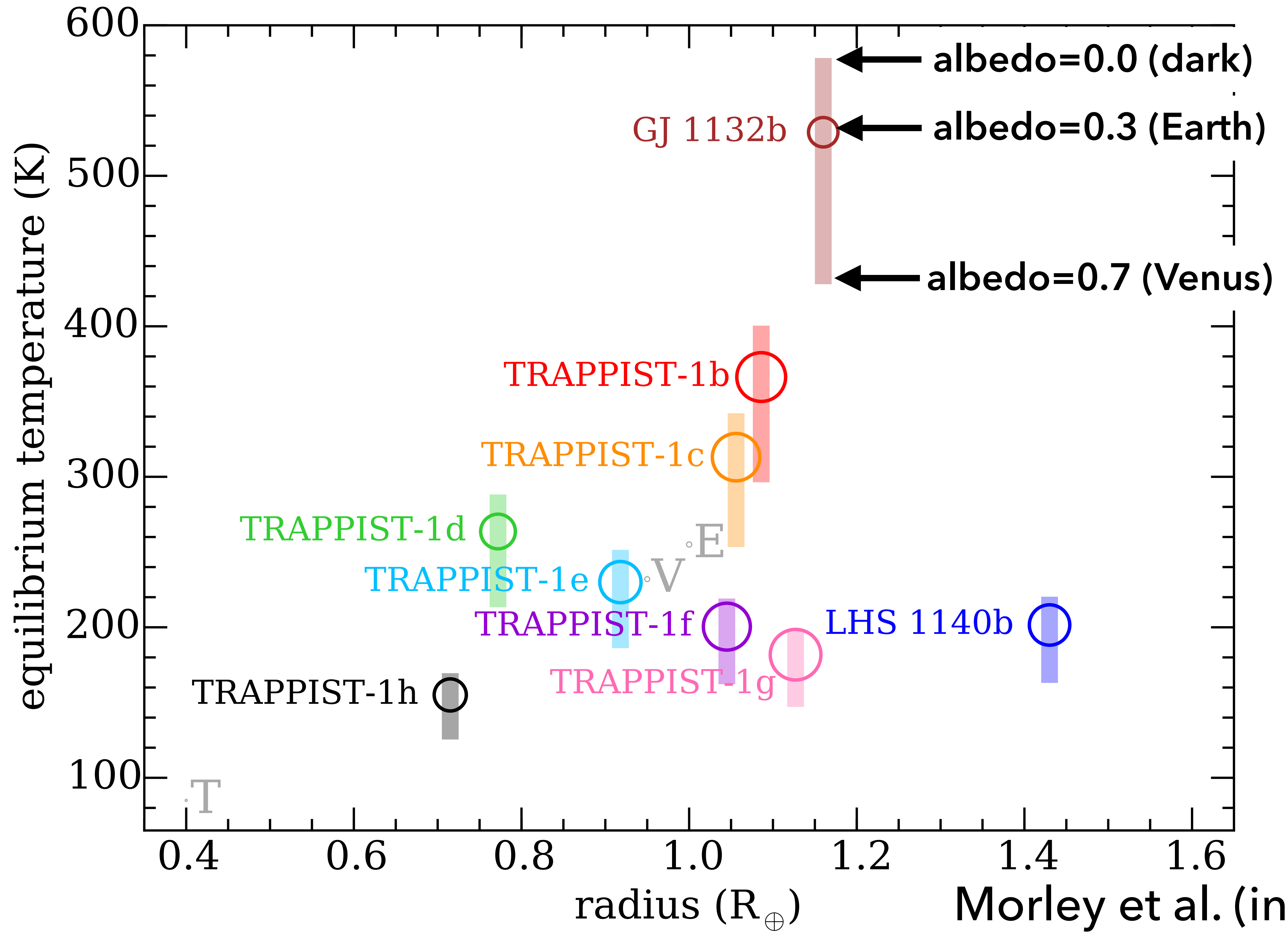
simulating observations with JWST





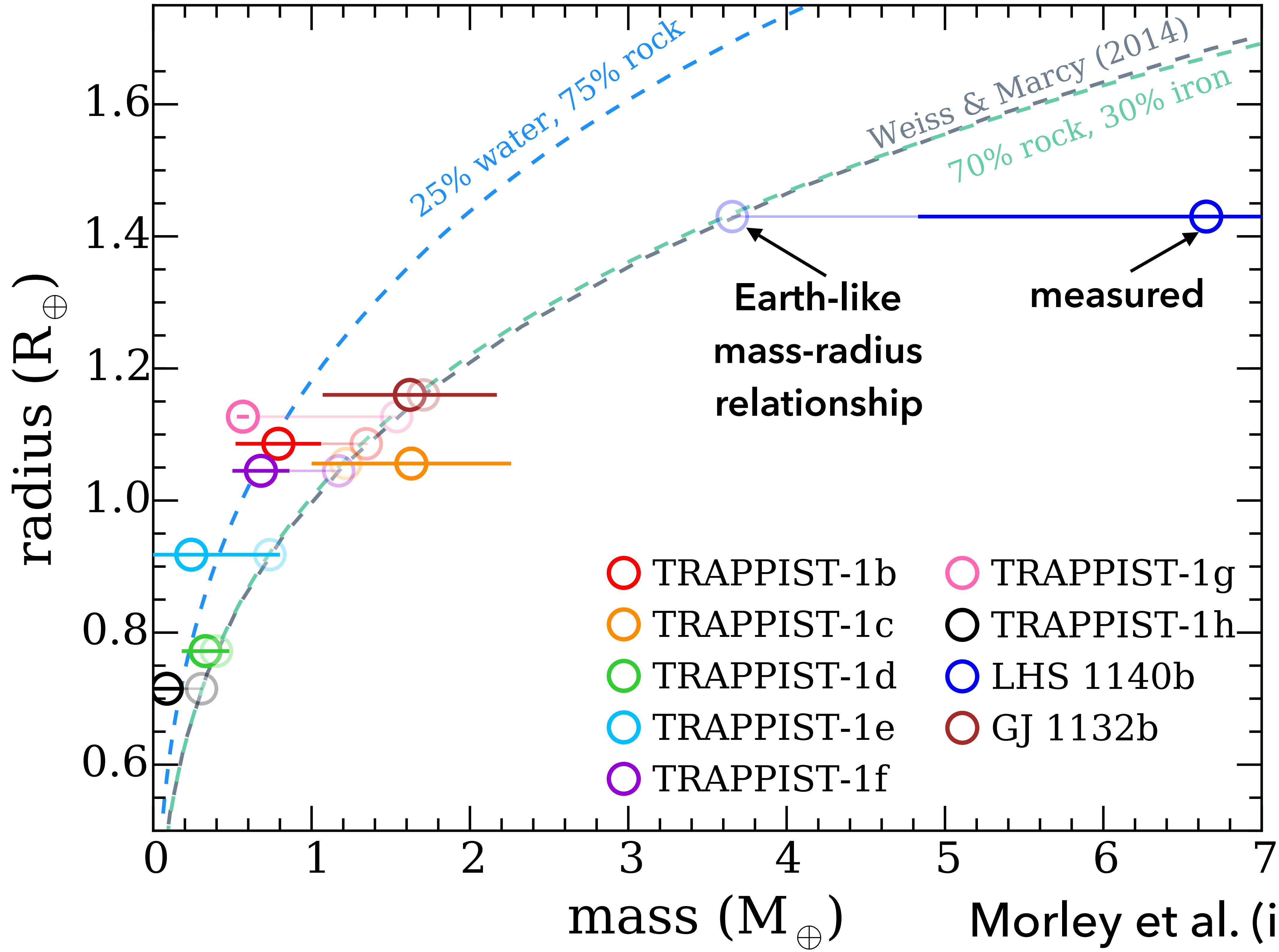


Good experimental setup: these planets span **sizes** from 0.7 to 1.4 R_{Earth} and $\mathbf{T_{eq}}$ from ~150 to 500+ K.



Morley et al. (in press)

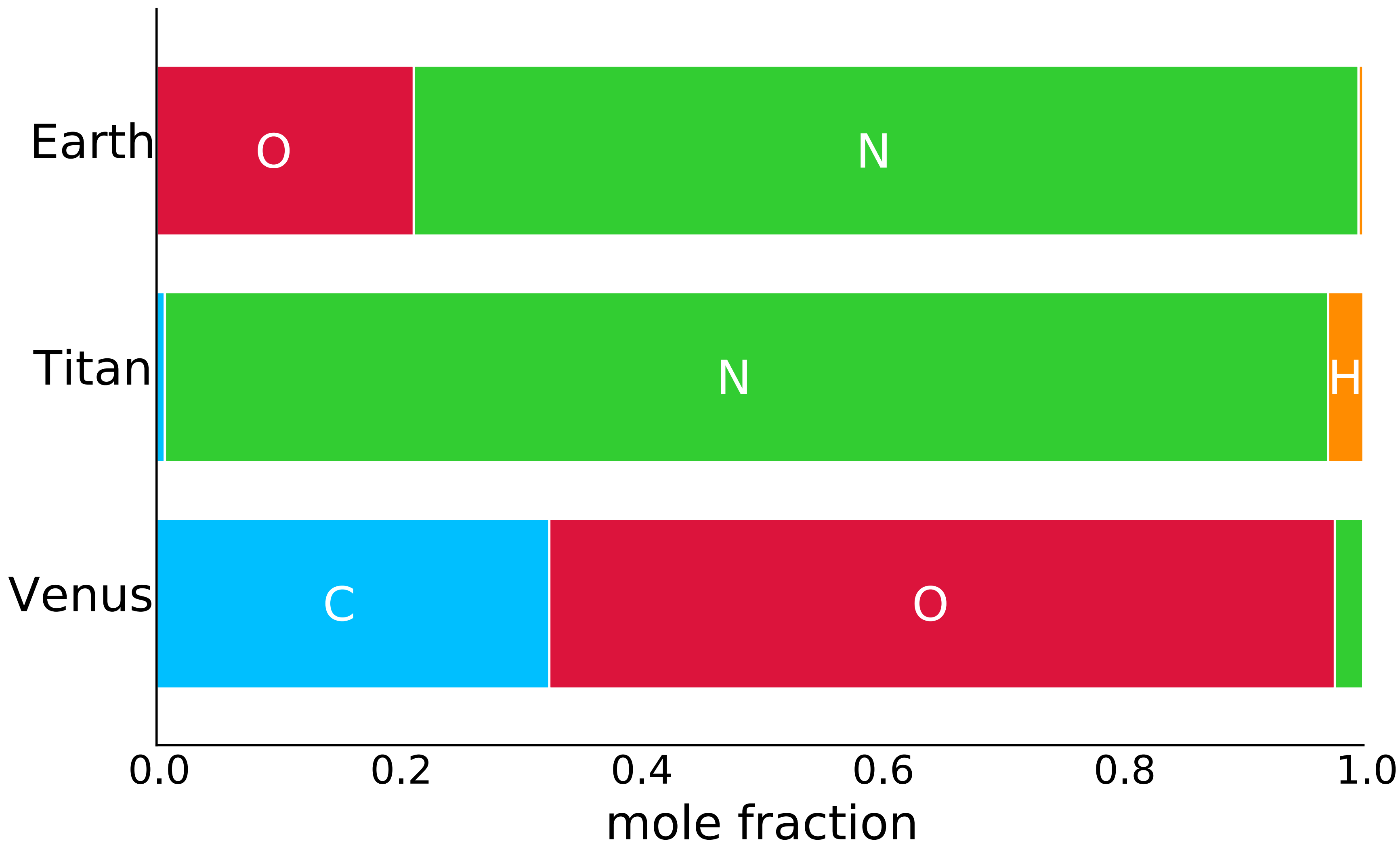
Some masses appear to be Earth-like (rock/iron); others may be low density?



Morley et al. (in press)

We construct a grid with a range of "plausible" compositions/surface pressures

Compositions



Surface pressures

100 ← **Venus**

10

1 ← **Earth & Titan**

0.1

0.01

← **Mars**

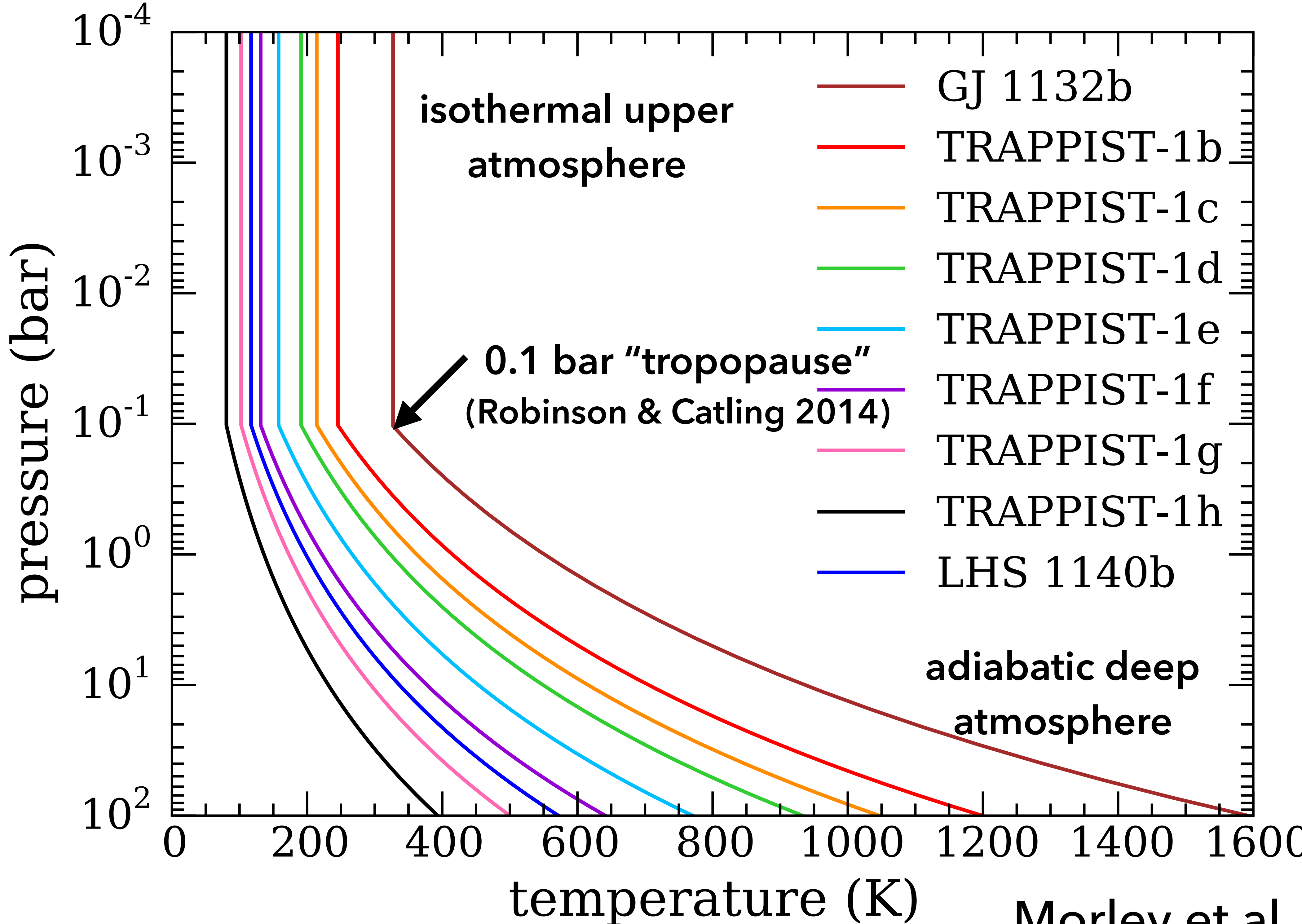
0.001

0.0001

← **Pluto (0.00001 bar)**

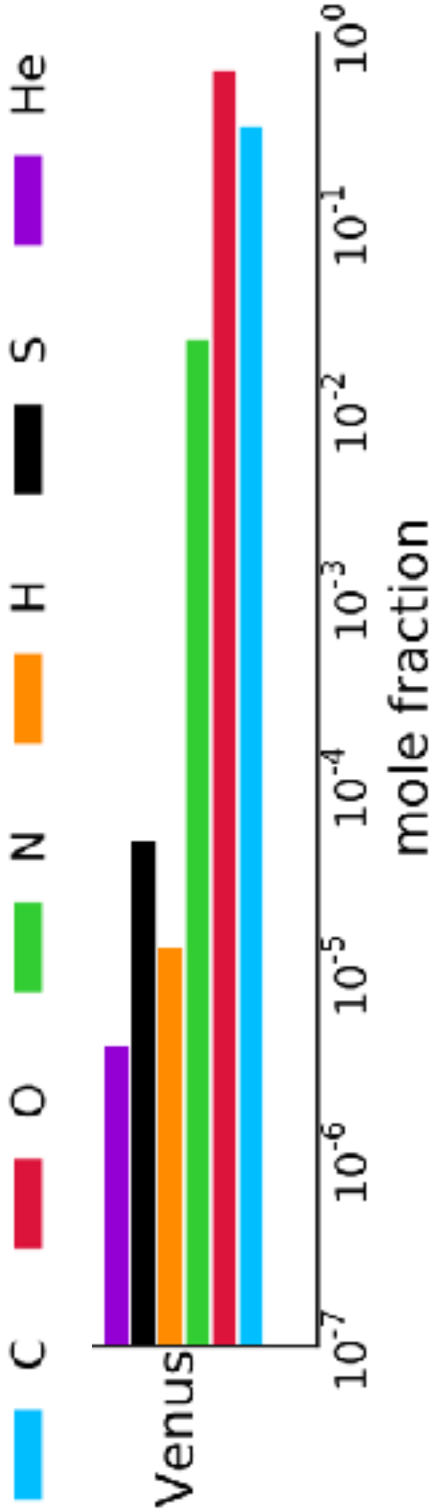
Morley et al. (in press)

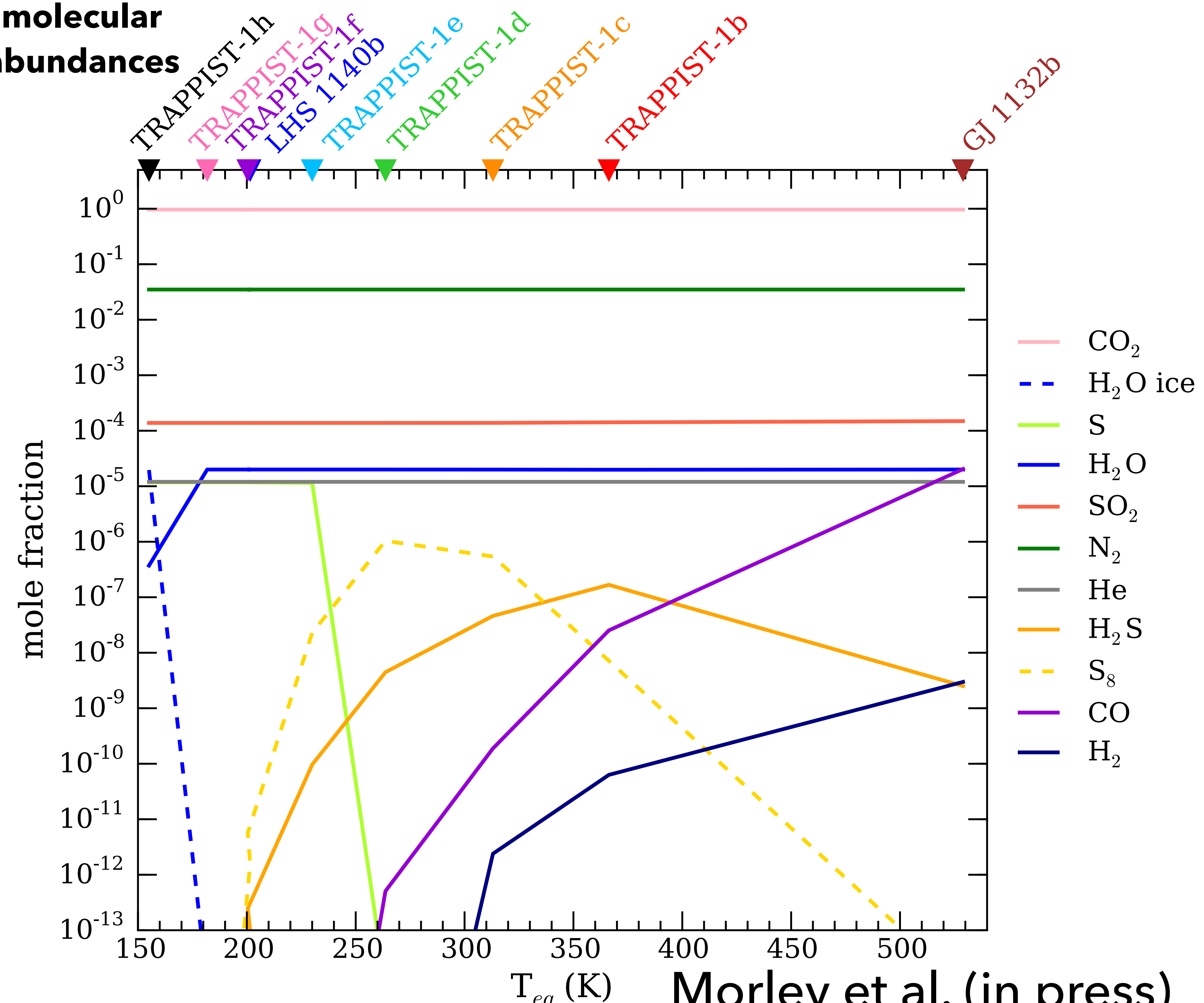
We construct atmospheres with simple temperature structures and chemistry



Morley et al. (in press)

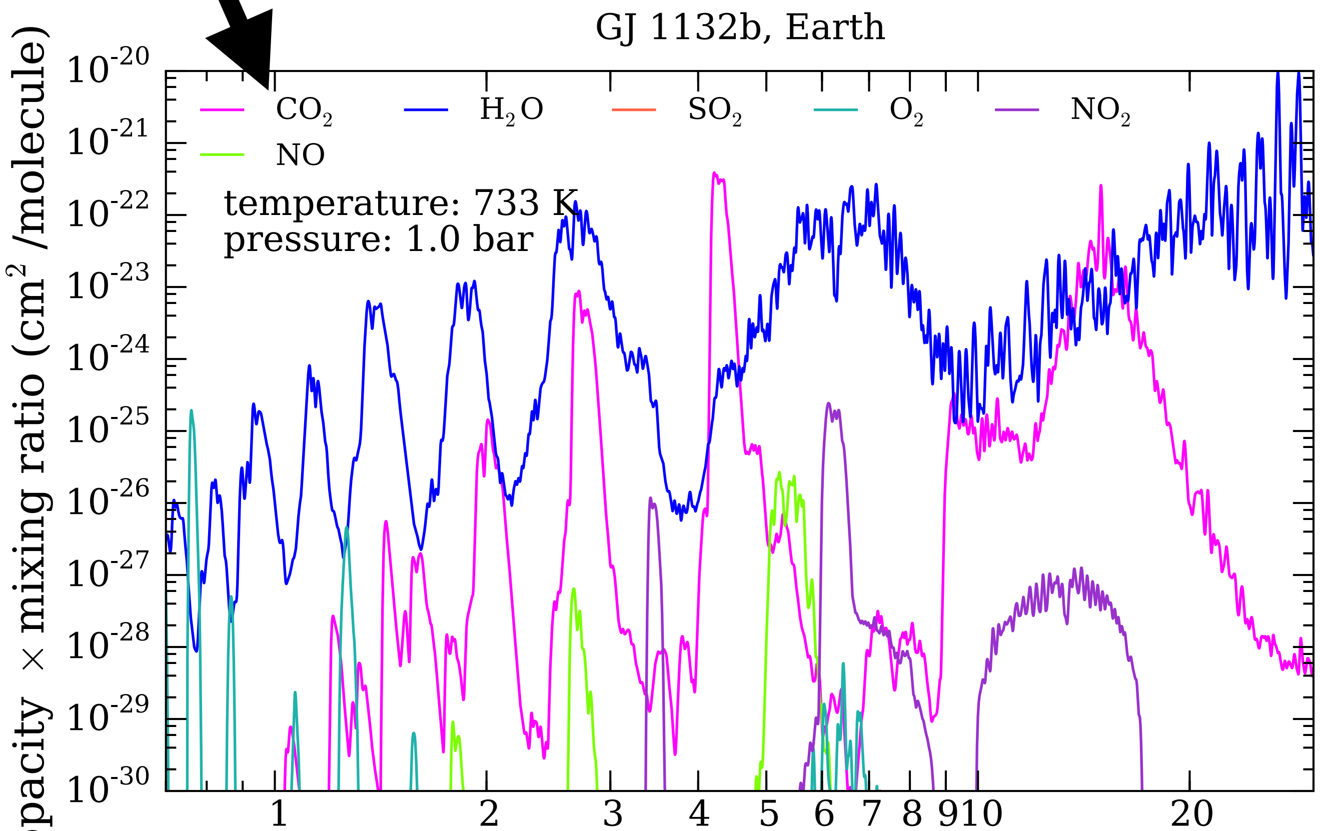
We model the molecular compositions assuming chemical equilibrium



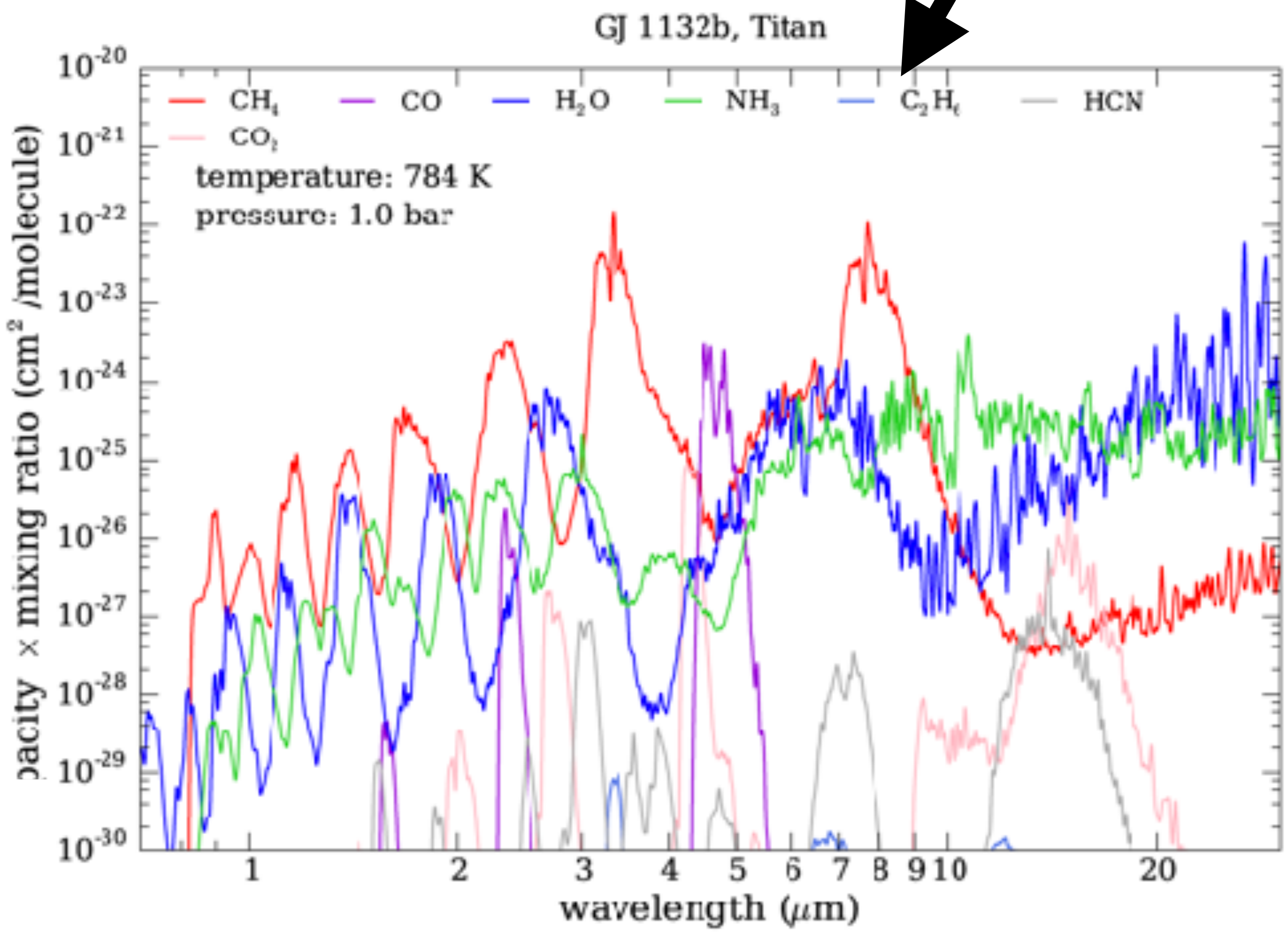


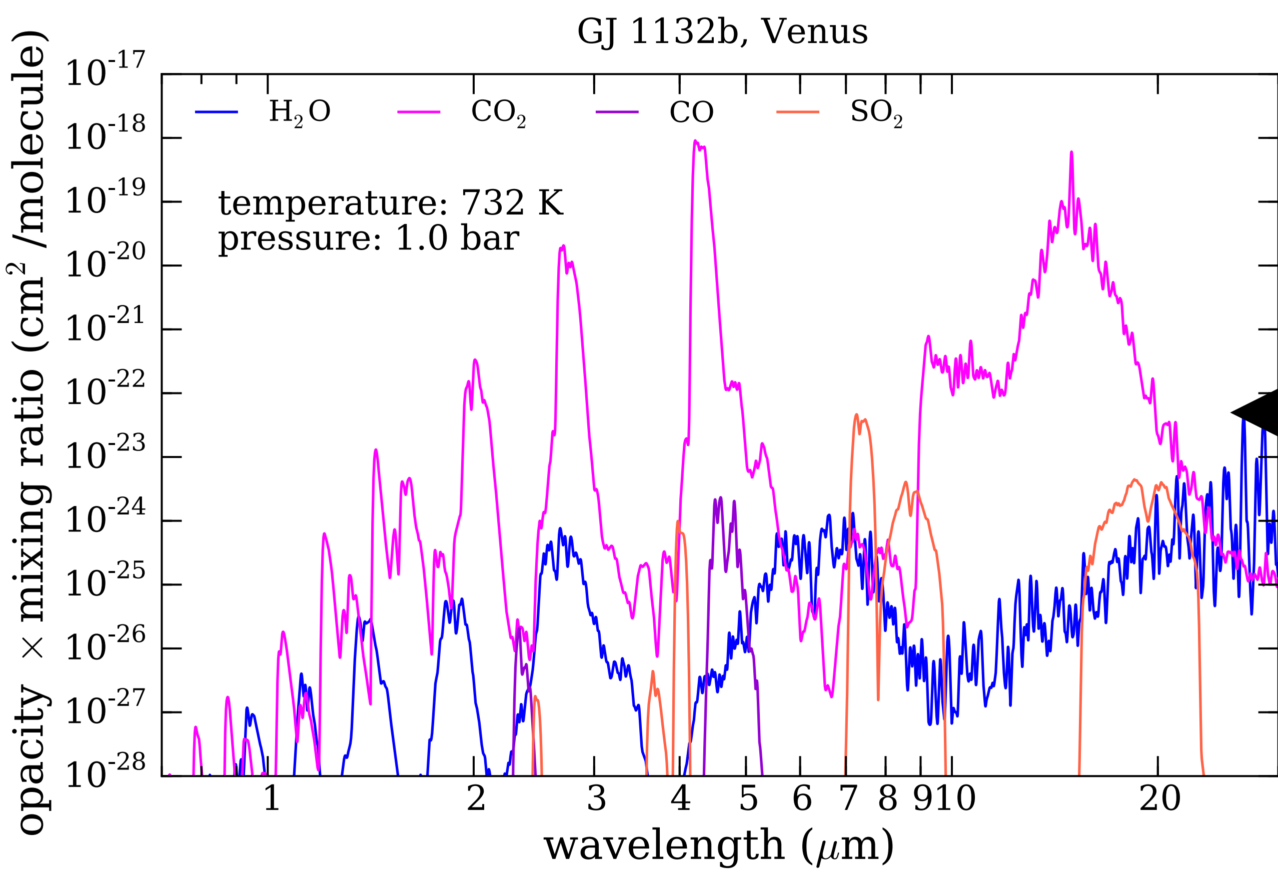
Morley et al. (in press)

"Earth-based" models are dominated by **H_2O,** plus CO_2, O_2.



"Titan-based" models are dominated by **CH_4**, plus NH_3, CO, H_2O.

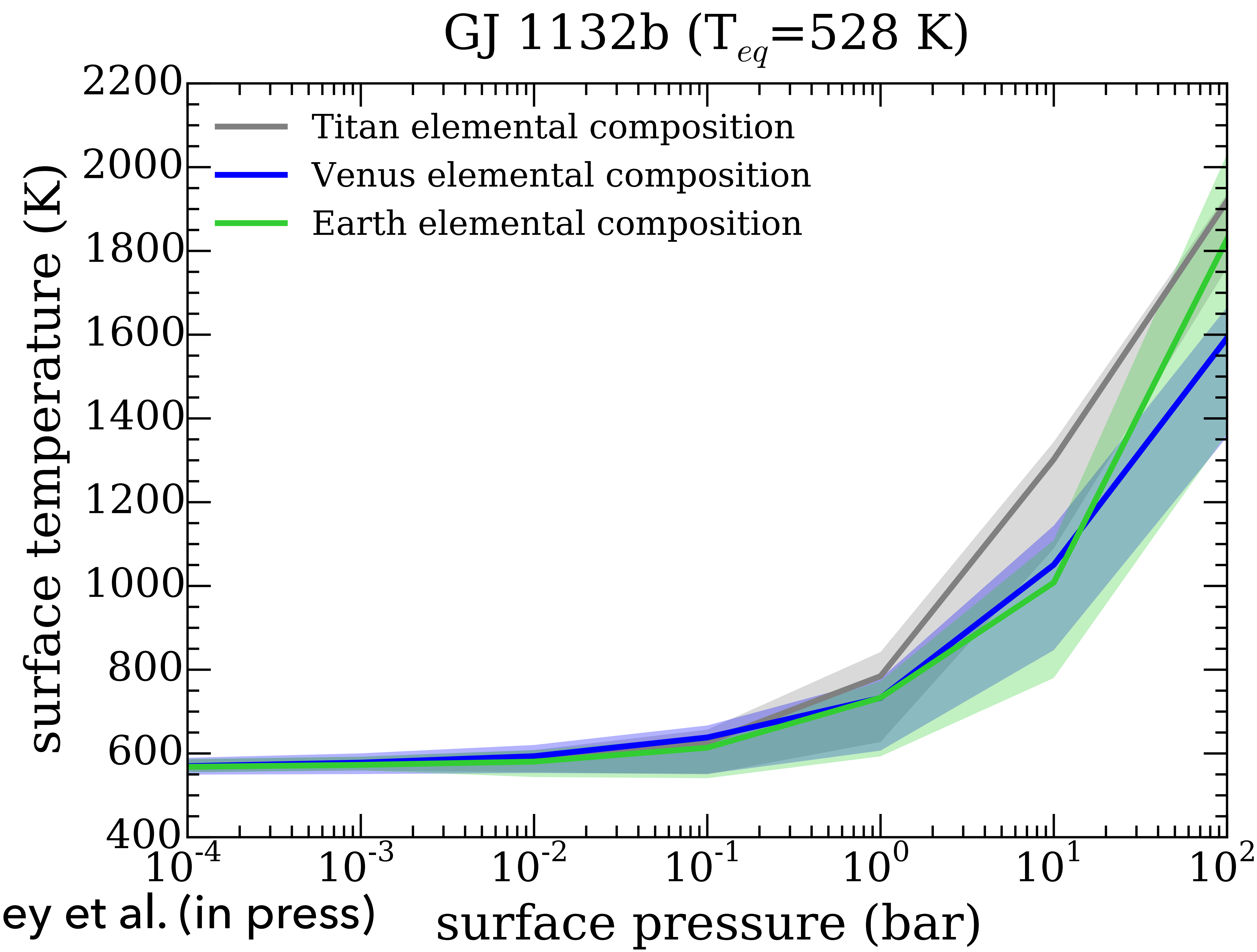




"Venus-based" models are dominated by **CO_2**, plus SO_2, H_2O.

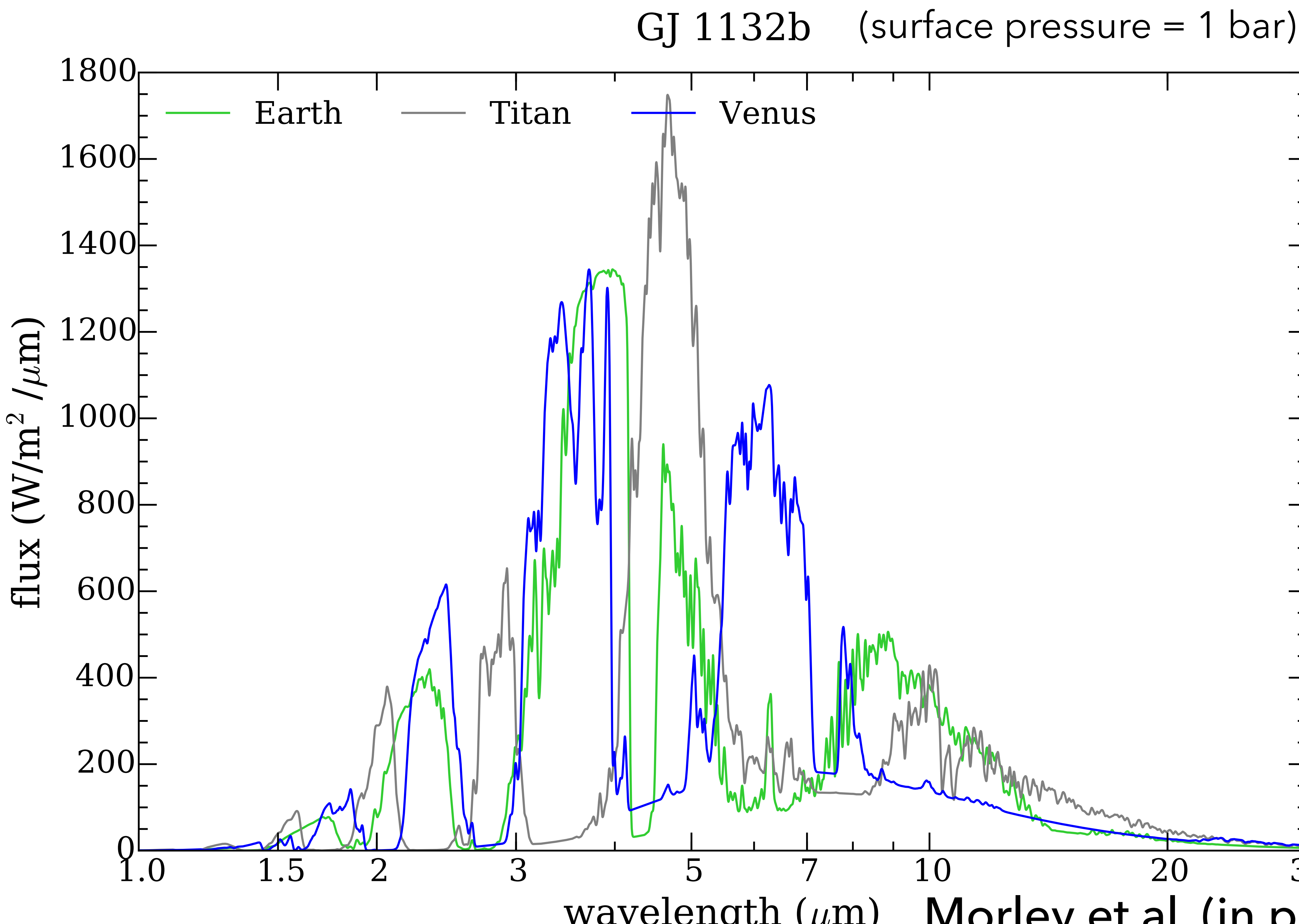
Morley et al. (in press)

Surface temperature increases with surface pressure; depends on composition and assumed albedo.



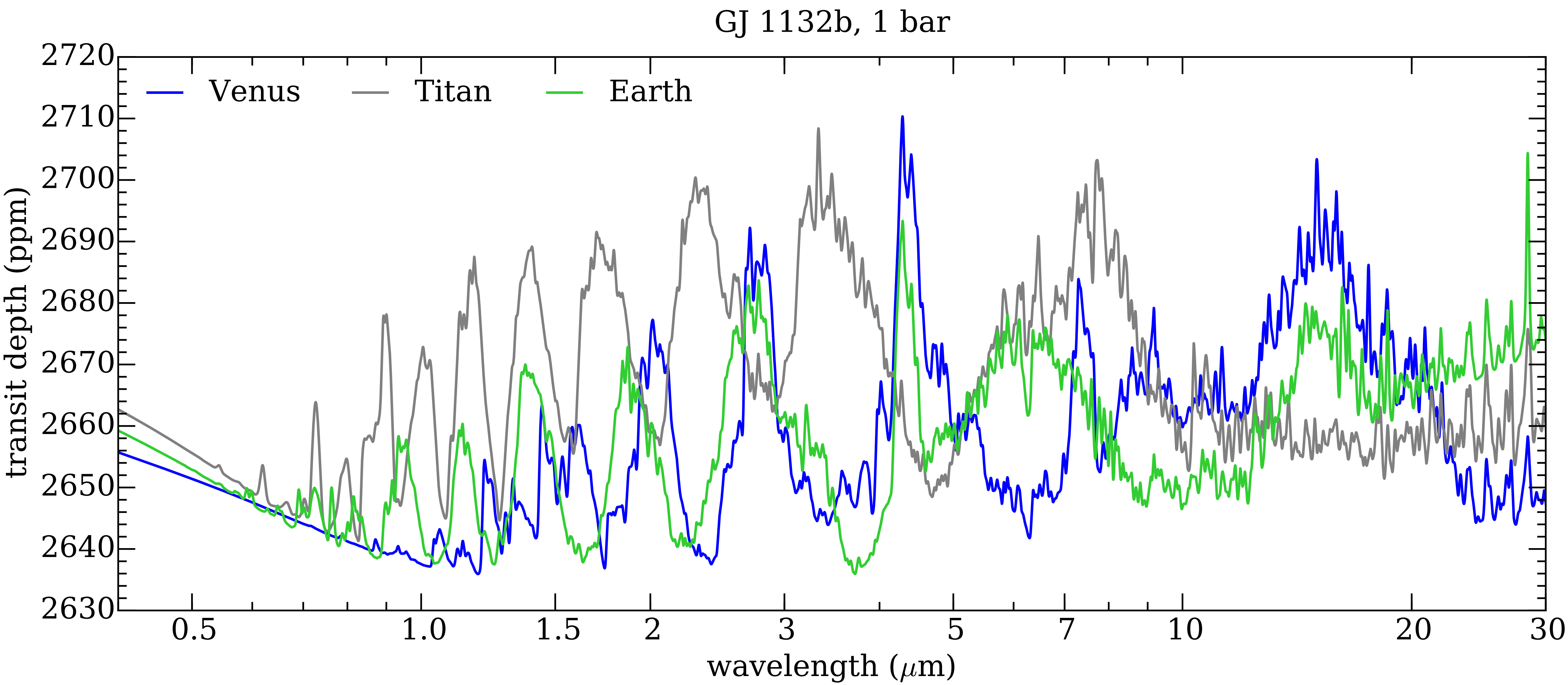
Morley et al. (in press)

Planet composition strongly effects the emergent spectrum, including where bright/faint windows are.



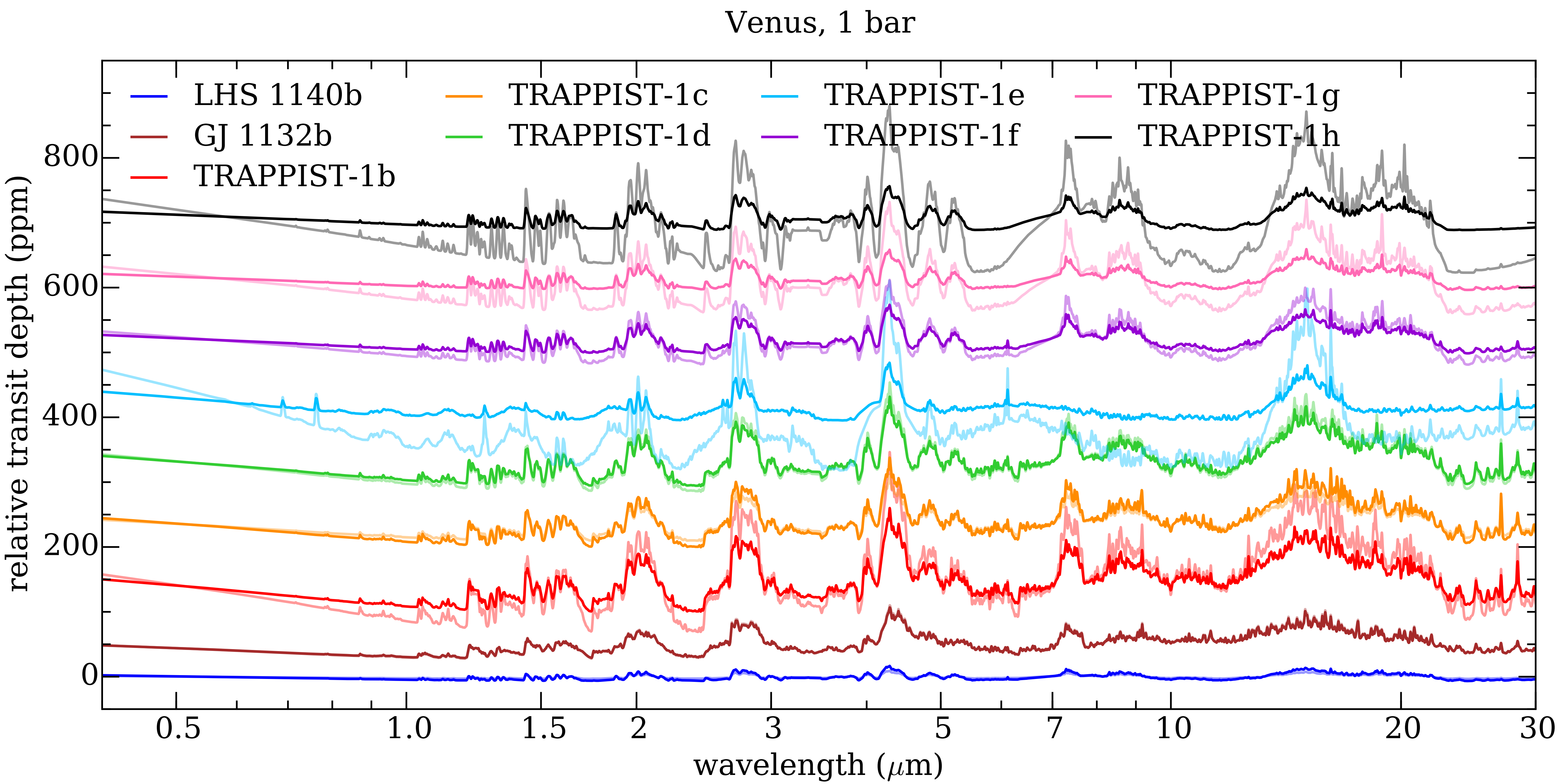
Morley et al. (in press)

Transmission spectra of the different compositions show a variety of spectral features (CO_2, H_2O, CH_4)



Morley et al. (in press)

Transmission spectra for all 9 planets; uncertainties in the planet's mass strongly affect the feature amplitude.

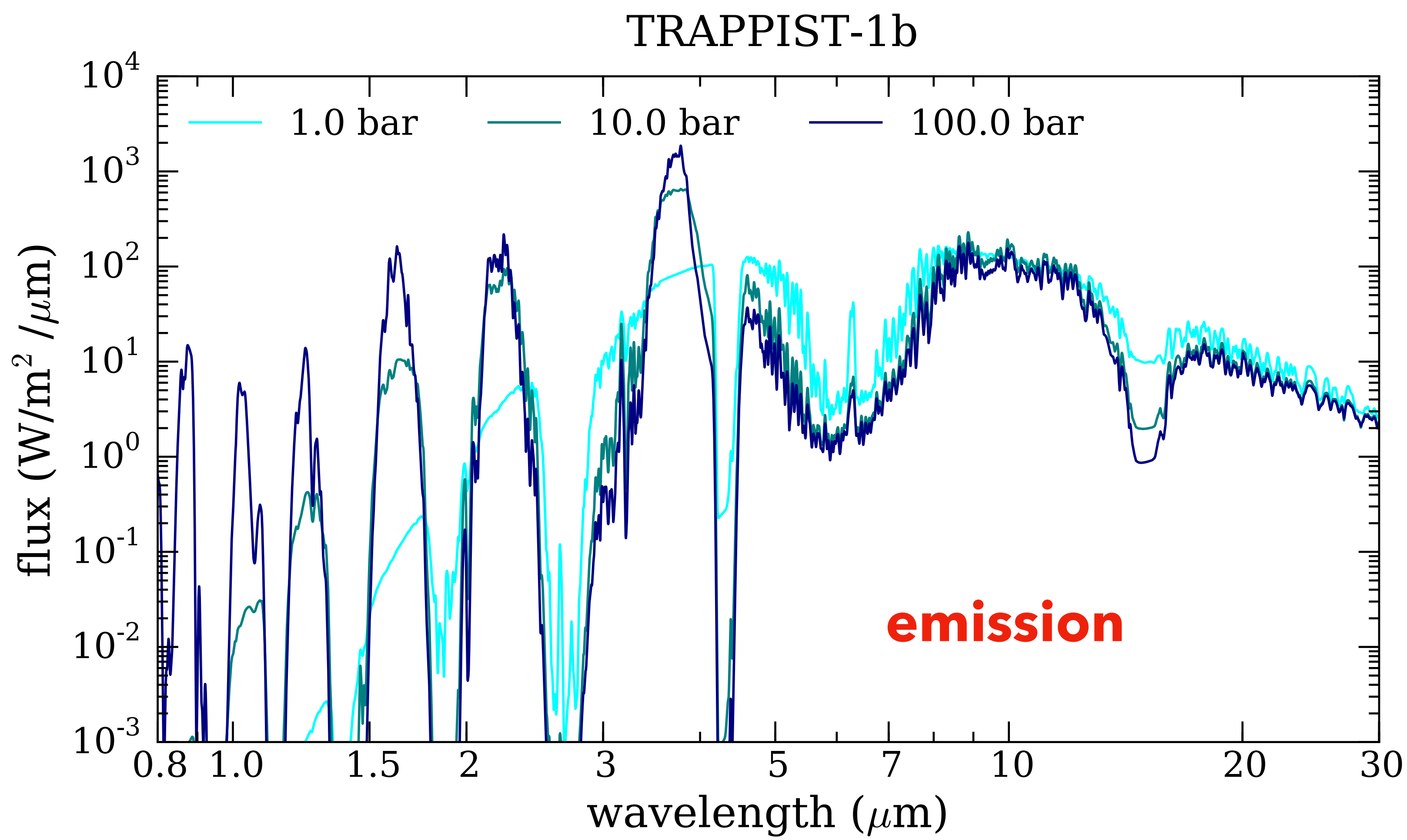


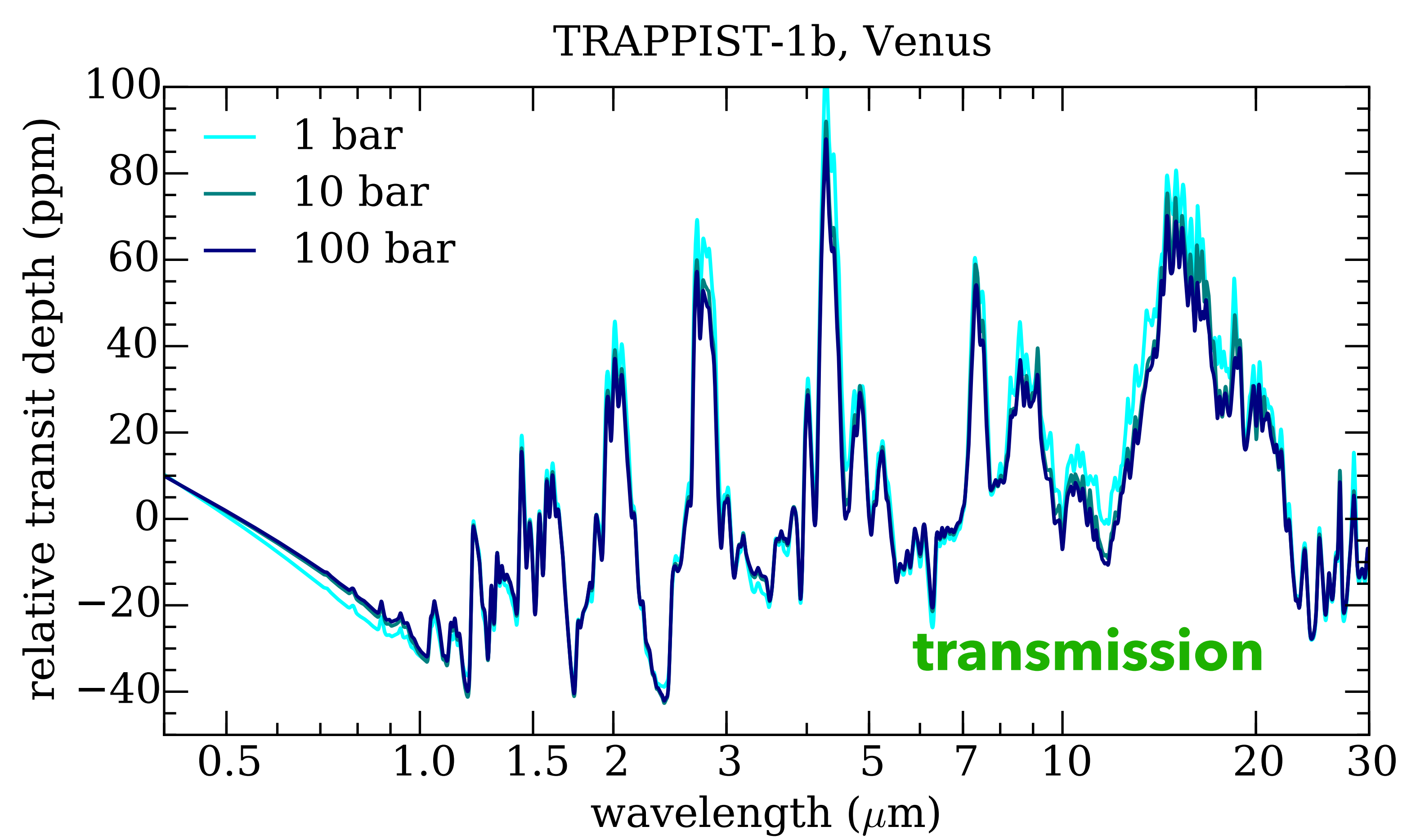
mass using rock/iron composition

measured mass

Morley et al. (in press)

For 1–100 bar atmospheres, **thermal emission** spectra are much more sensitive to **surface pressure** than transmission spectra



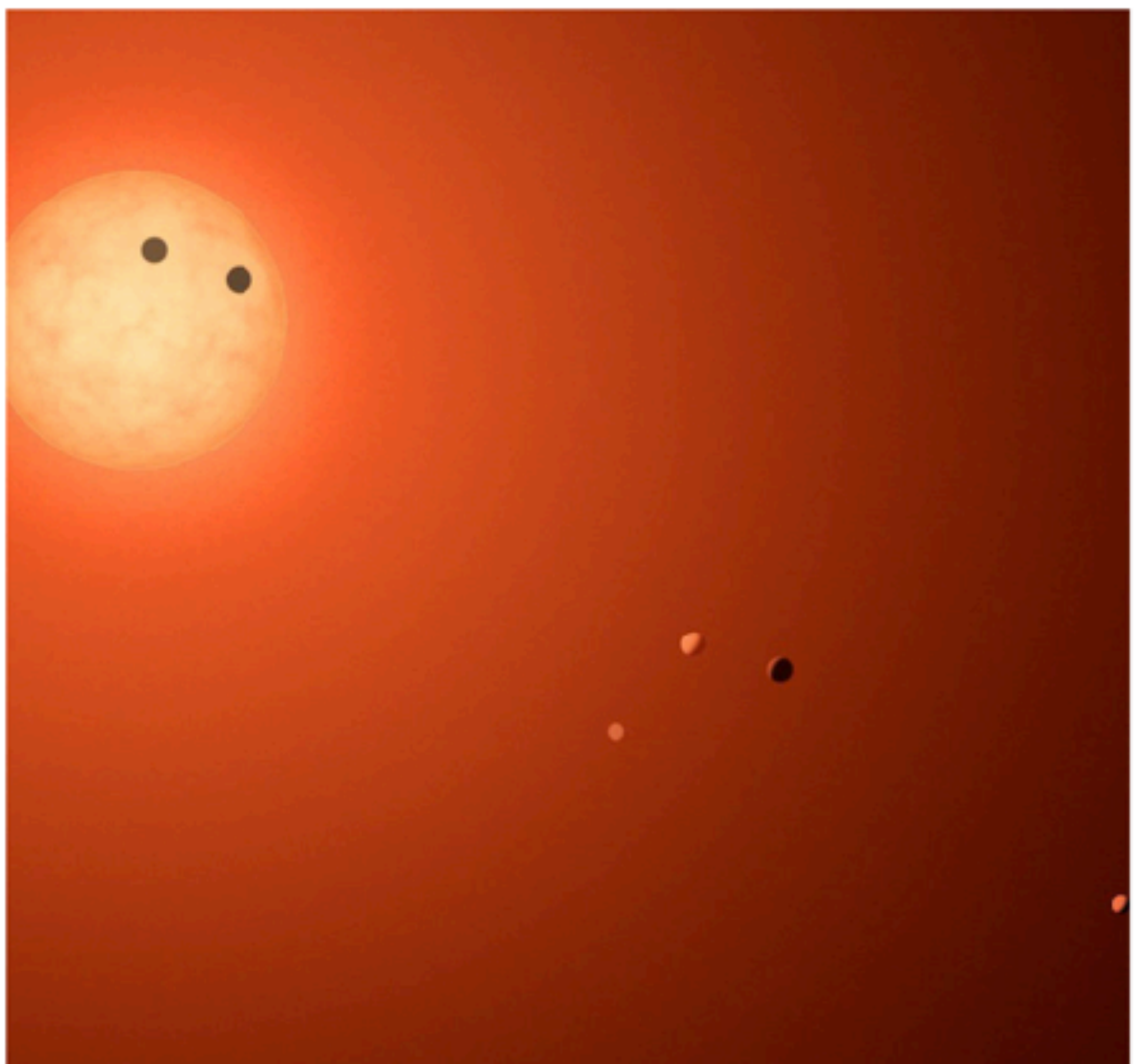


Morley et al. (in press)

All ~400 models (including emission spectra, transmission spectra, and MIRI eclipse depths) are publicly available online!

https://www.carolinemorley.com/models

`https://doi.org/10.5281/zenodo.1001033`



MORLEY ET AL. 2017: TRAPPIST/MEARTH PLANET MODELS

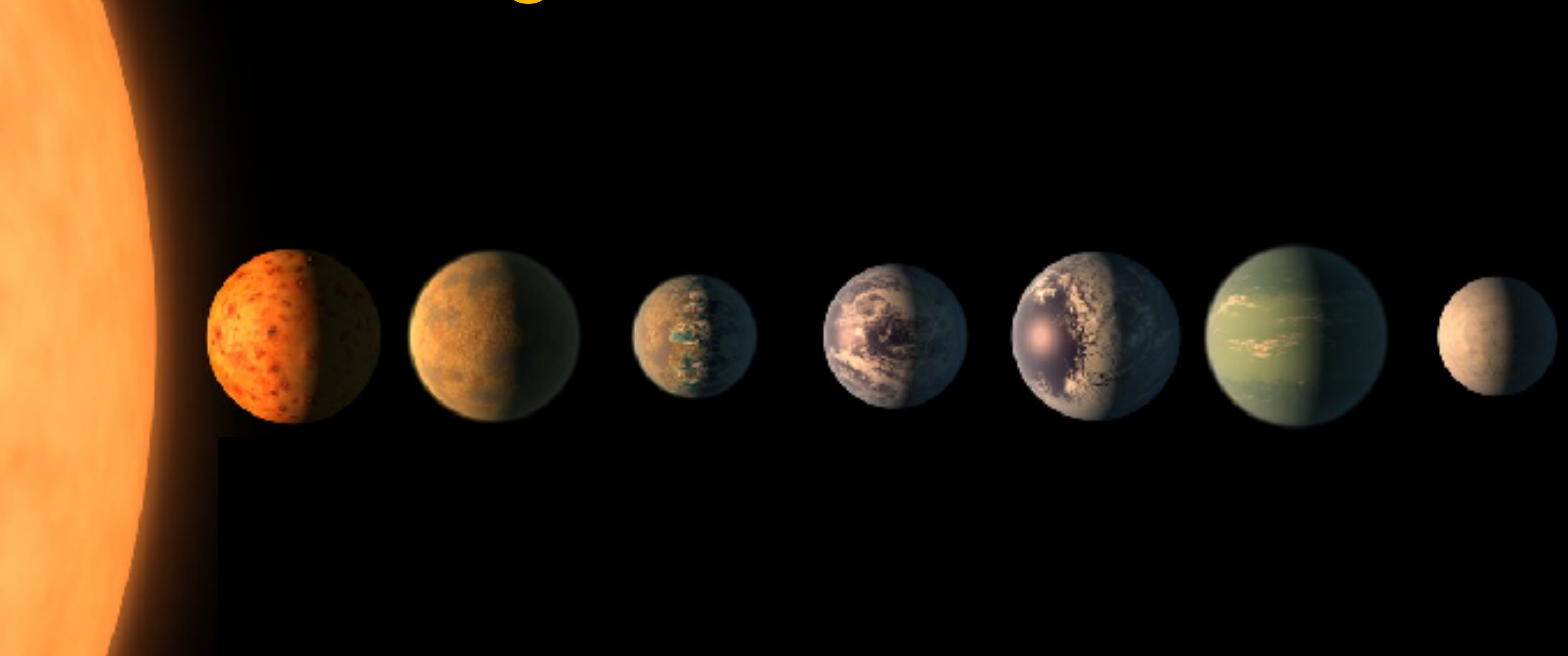
Model transmission and emission spectra, as well as JWST MIRI eclipse depths, for each of the 7 TRAPPIST-1 planets as well as two terrestrial planets found by MEarth, GJ 1132b and LHS 1140b.

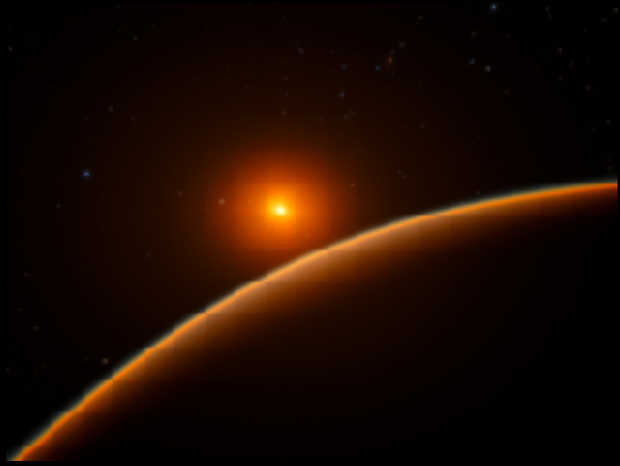
Download Models

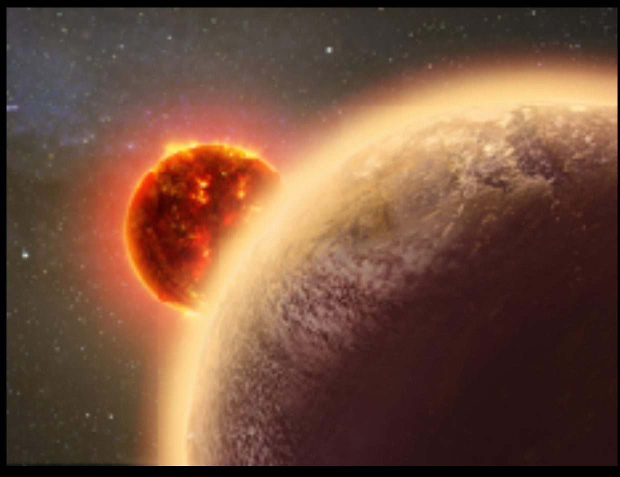
Outline

generating a diverse set of model planet spectra (transmission and emission)

simulating observations with JWST







We (Laura Kreidberg) simulate JWST observations with PandExo for near-IR (NIRSpec) and mid-IR (MIRI).

Table 1. Number of transits or eclipses required to detect a Venus-like atmosphere[a]

Planet	Emission P = 0.1 bar	Emission P = 1.0 bar	Emission P = 10.0 bar	Transmission P = 0.01 bar	Transmission P = 0.1 bar	Transmission P = 1.0 bar
TRAPPIST-1b	6 (11)	9 (18)	17 (30)	23 (89)	11 (40)	6 (21)
TRAPPIST-1c	19 (37)	29 (58)	48 (92)	–	73 (50)	36 (25)
TRAPPIST-1d	–	–	–	59 (–)	25 (46)	13 (24)
TRAPPIST-1e	–	–	–	15 (–)	6 (66)	4 (71)
TRAPPIST-1f	–	–	–	73 (–)	27 (92)	17 (54)
TRAPPIST-1g	–	–	–	36 (–)	15 (–)	10 (76)
TRAPPIST-1h	–	–	–	16 (–)	6 (90)	4 (56)
GJ 1132b	2 (2)	2 (3)	3 (6)	27 (38)	13 (20)	11 (13)
LHS 1140b	–	–	–	–	– (96)	– (64)

rock/iron composition (measured mass)

Morley et al. (in press)

We (Laura Kreidberg) simulate JWST observations with PandExo for near-IR (NIRSpec) and mid-IR (MIRI).

1. A number of these planets may be good transmission spectroscopy targets:
TRAPPIST-1b, d, e, f, g, h?
GJ 1132b

to detect a Venus-like atmosphere[a]

				Transmission P = 0.01 bar	Transmission P = 0.1 bar	Transmission P = 1.0 bar
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Morley et al. (in press)

We (Laura Kreidberg) simulate JWST observations with PandExo for near-IR (NIRSpec) and mid-IR (MIRI).

Table 1. Number of transits or eclipses requ

2. We have at least 2 great thermal emission spectroscopy targets
(TRAPPIST-1b and GJ 1132b)

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Morley et al. (in press)

We (Laura Kreidberg) simulate JWST observations with PandExo for near-IR (NIRSpec) and mid-IR (MIRI).

Table 1. Number of transits or eclipses required to detect a Venus-like atmosphere[a]

3. We need more precise constraints on planet's masses to plan JWST observations of "rocky" planets

TRAPPIST-1b	6 (11)	9 (18)	17 (30)	23 (89)	11 (40)	6 (21)
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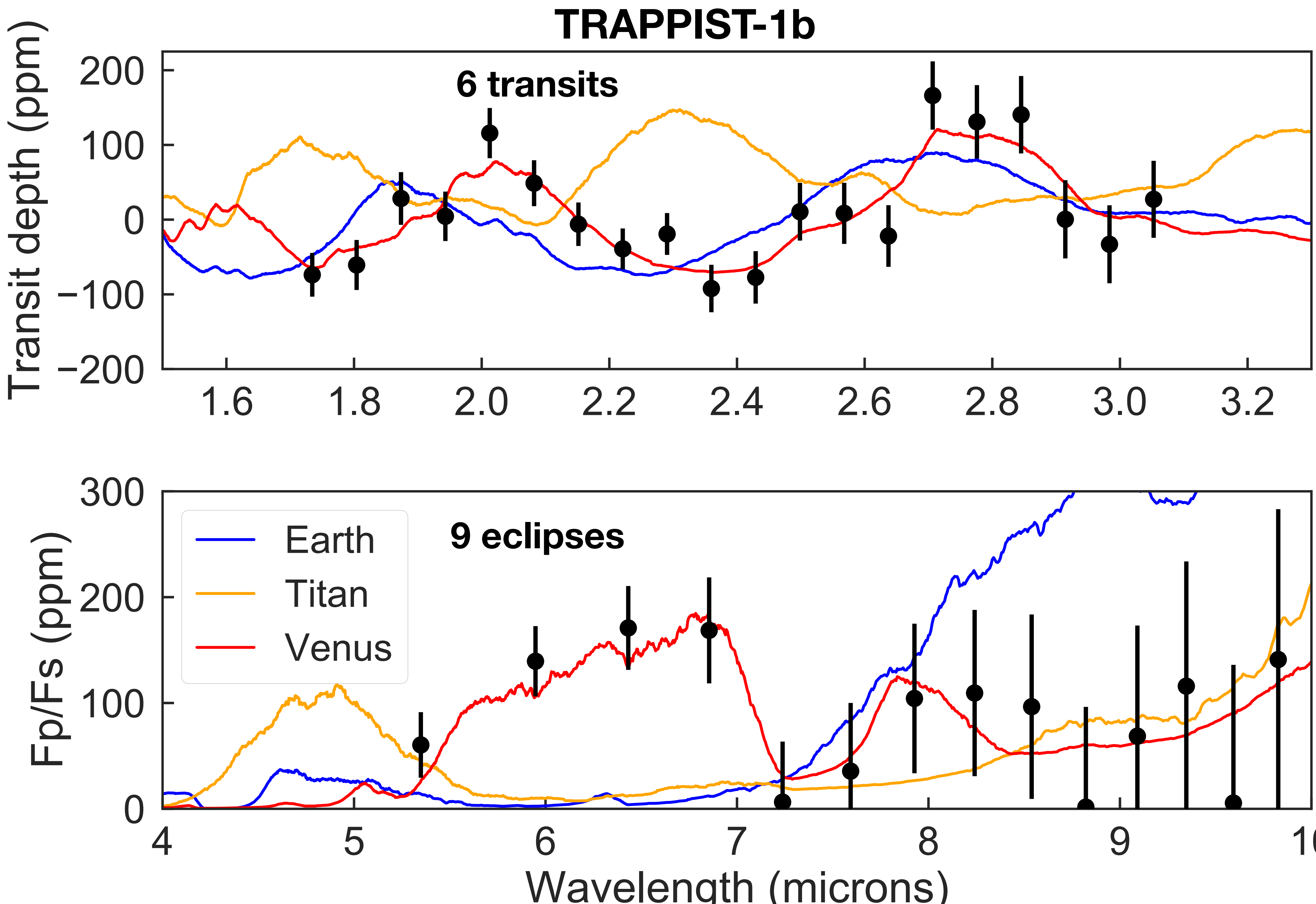
rock/iron composition (measured mass)

Morley et al. (in press)

For the best targets, we can detect spectral features and discern compositions



Morley et al. (in press)

Conclusions

With dedicated JWST observations of the best systems, we can detect the **atmospheres of terrestrial planets** for the first time

We generated a diverse set of model transmission & emission spectra based on solar system planet compositions that are published as a community resource

JWST simulations show that this will be a significant investment of resources, but we can (potentially) measure differences in compositions, temperatures, and surface pressures