

A large, blue, cloudy planet occupies the left side of the frame. In the upper center, a bright orange star with a visible surface texture and radiating light rays is positioned. The background is a deep black space.

Spectroscopy of Super-Earths

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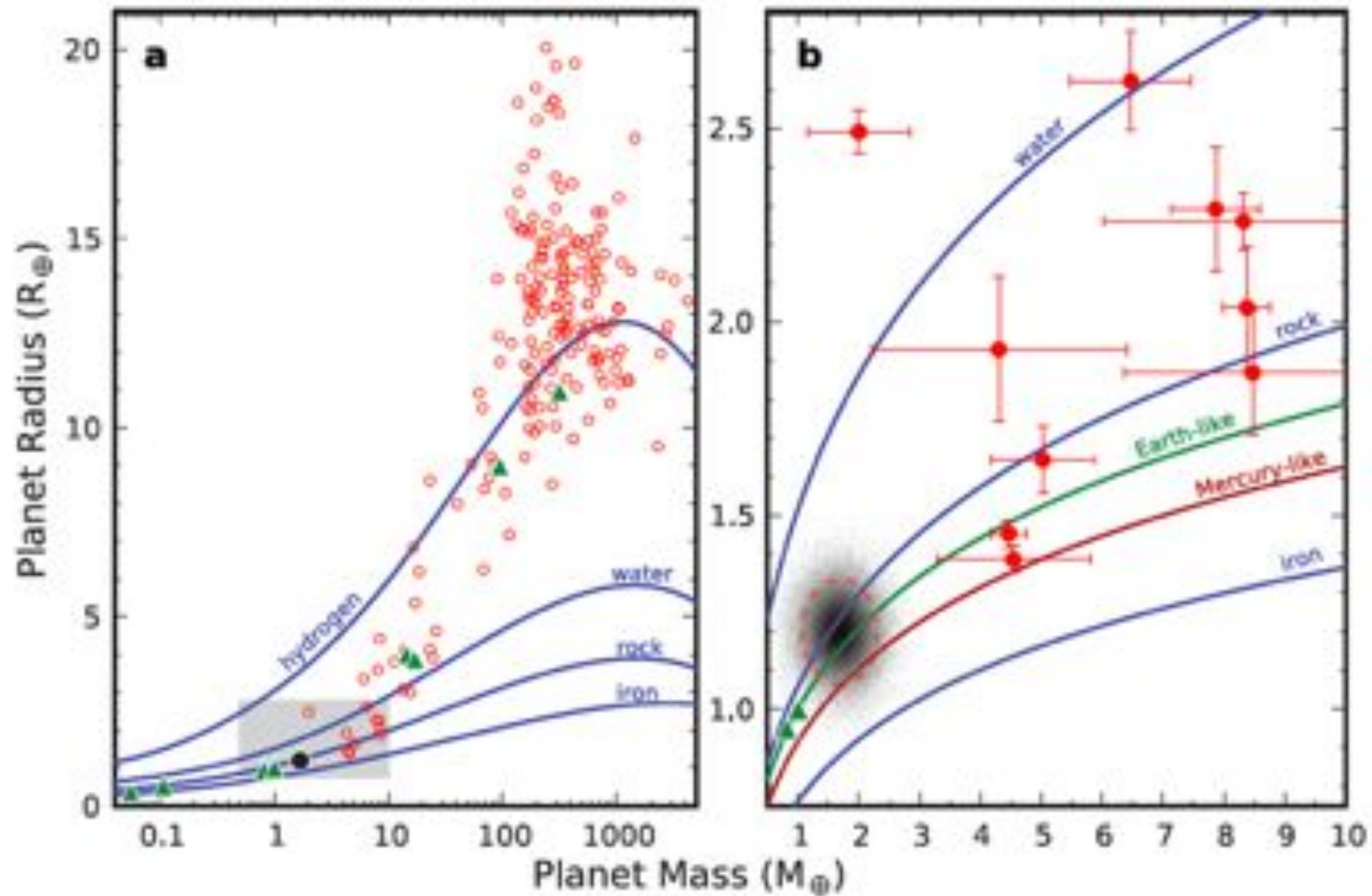
JWST Transit Planning Meeting
March 11, 2014

Why Super-Earths?

- Most common type of planet
- No solar system analogs
- Diverse bulk properties

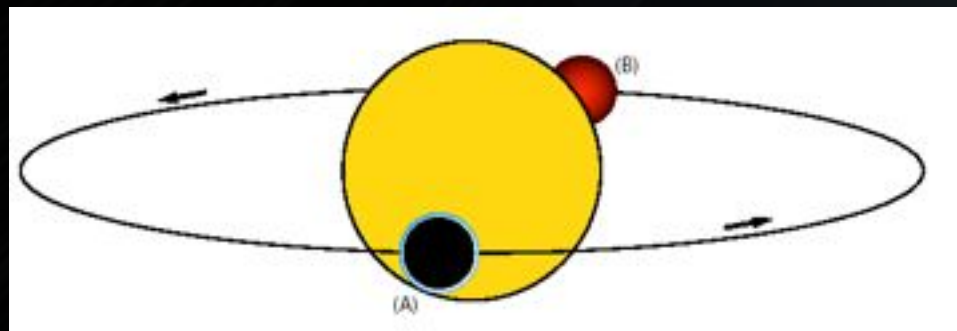


Super-Earths – a Diverse Population of Planets

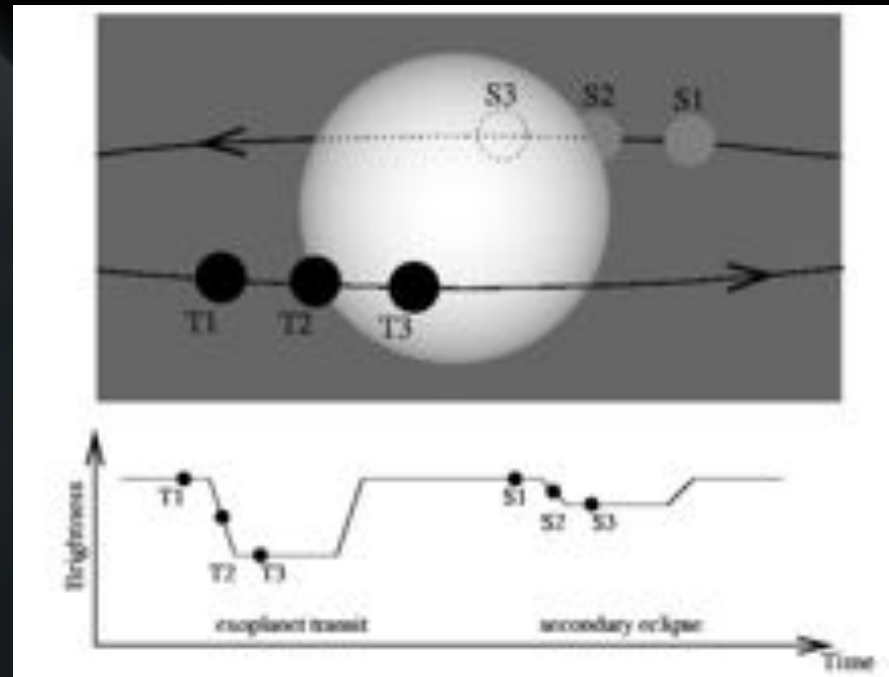


Transmission vs. Emission Spectroscopy

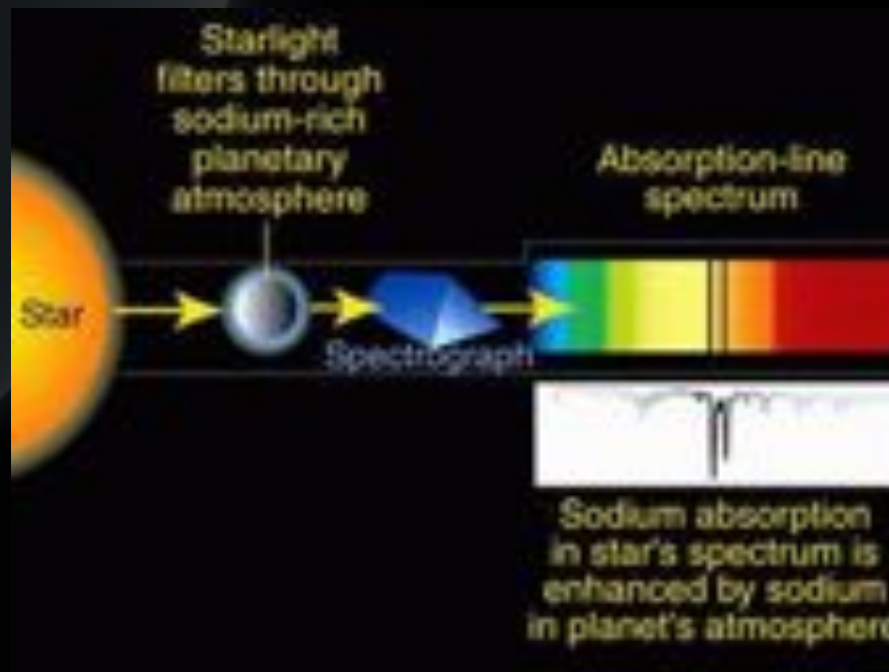
Emission



Transmission



- Composition
- Atmospheric structure (T-P profile)
- Global energy budget
- Clouds



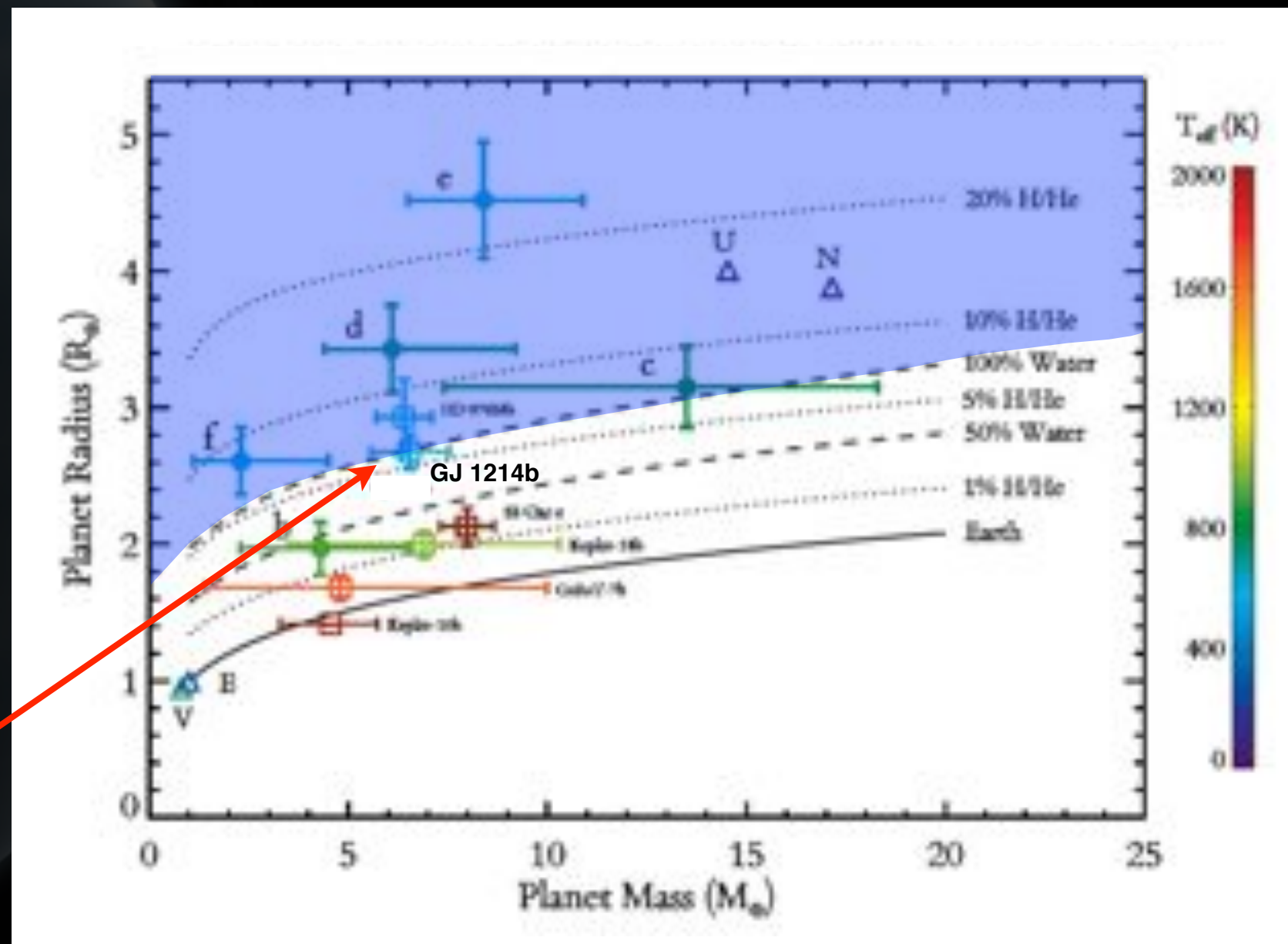
- Composition
- Scale height
- Clouds
- Planetary mass (?)

Lessons Learned to Date: GJ 1214b - A Transiting Super-Earth with a Thick Atmosphere

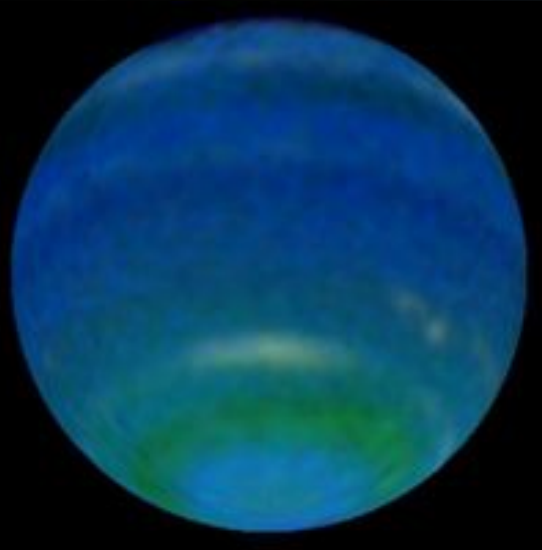
GJ 1214b:

- $M_{\text{pl}} = 6.6 M_{\oplus}$
- $R_{\text{pl}} = 2.7 R_{\oplus}$
- $\rho = 1.9 \text{ g/cm}^3$
- $P = 1.58 \text{ days}$
- $T_{\text{eq}} \approx 550 \text{ K}$

Planet is too big to be explained without the presence of a significant atmosphere!



2 Possible Compositions of GJ 1214b



1. “Mini-Neptune” Scenario:

Rock / ice interior + hydrogen-dominated atmosphere
(mostly H_2 + trace H_2O , CH_4 , etc.)



2. Water World Scenario:

Mostly H_2O - ice interior + steam atmosphere

(Rogers & Seager, *ApJ*, 2010 + Nettelmann et al. 2011)

GJ 1214b Transmission & Emission Spectra

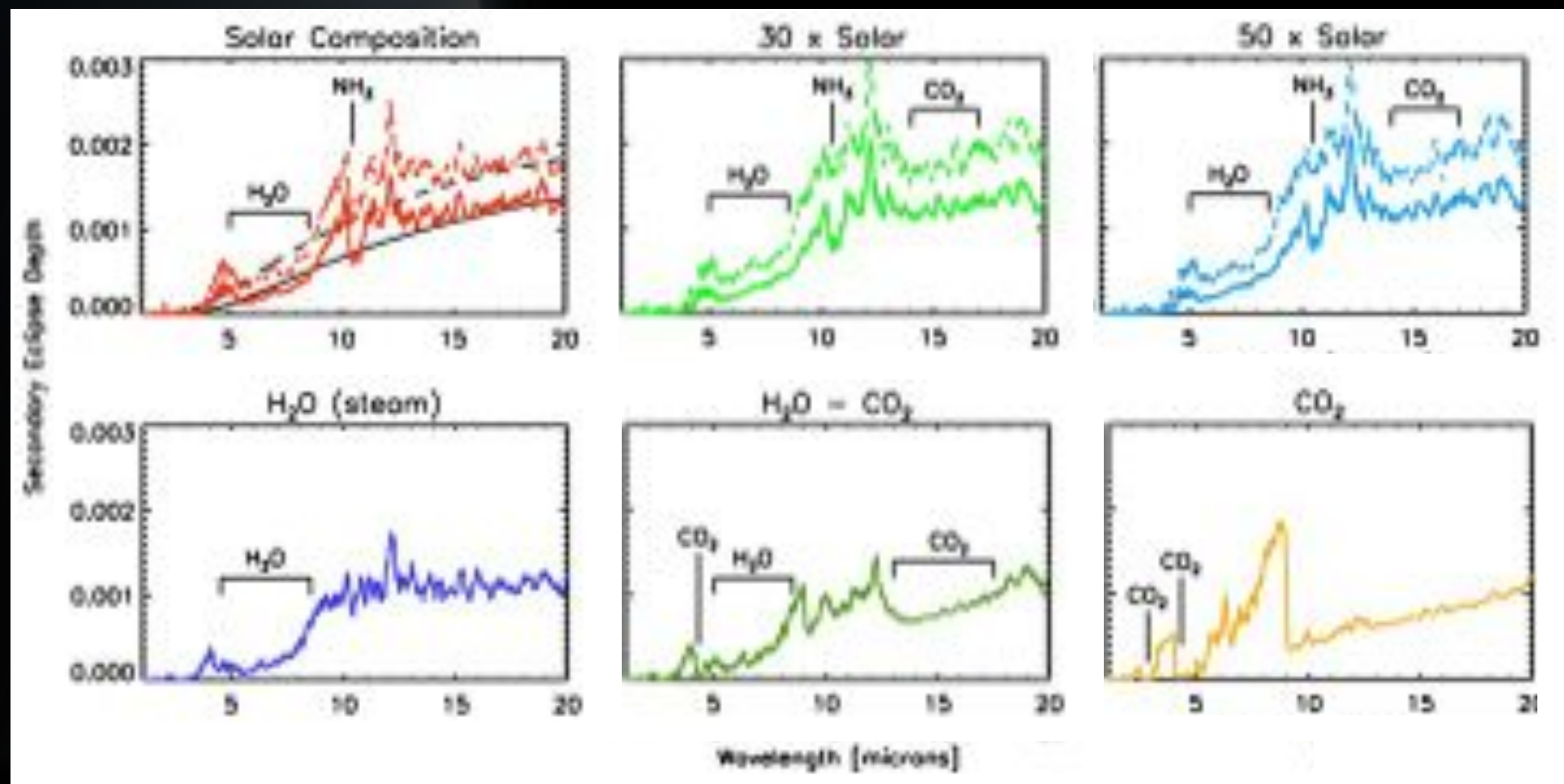
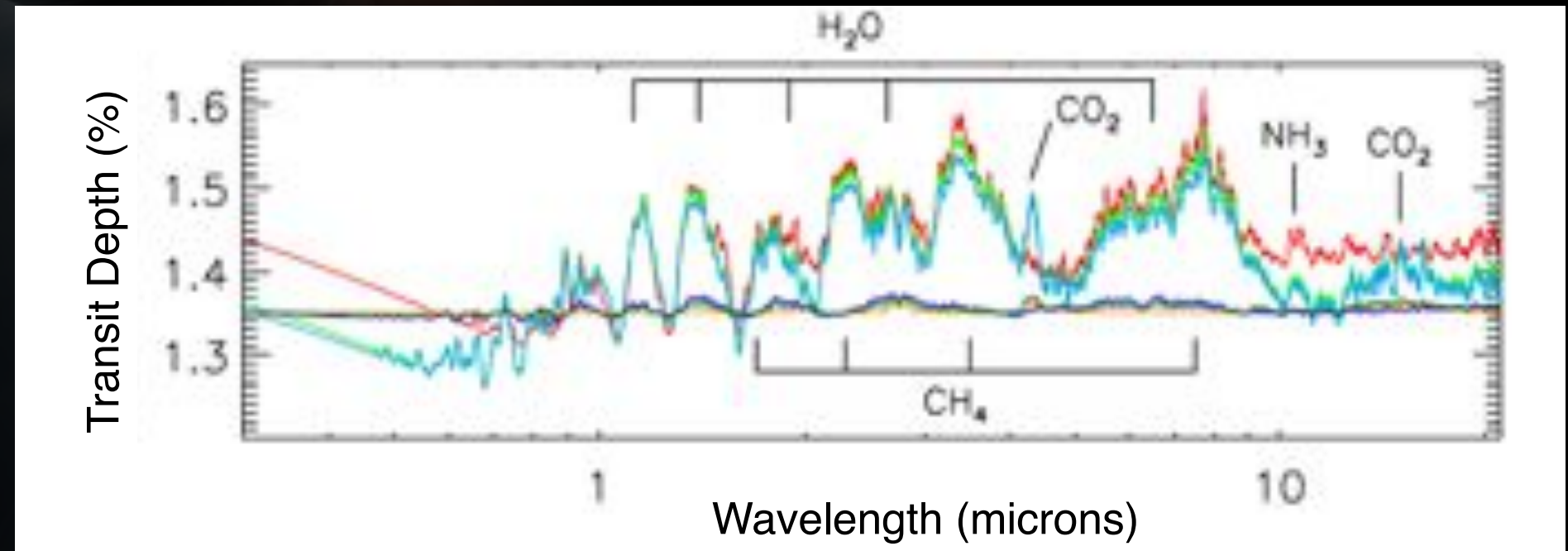
Transmission:

$$\Delta_{\text{depth}} \sim 20H R_{\text{pl}} / R_{*}^2$$

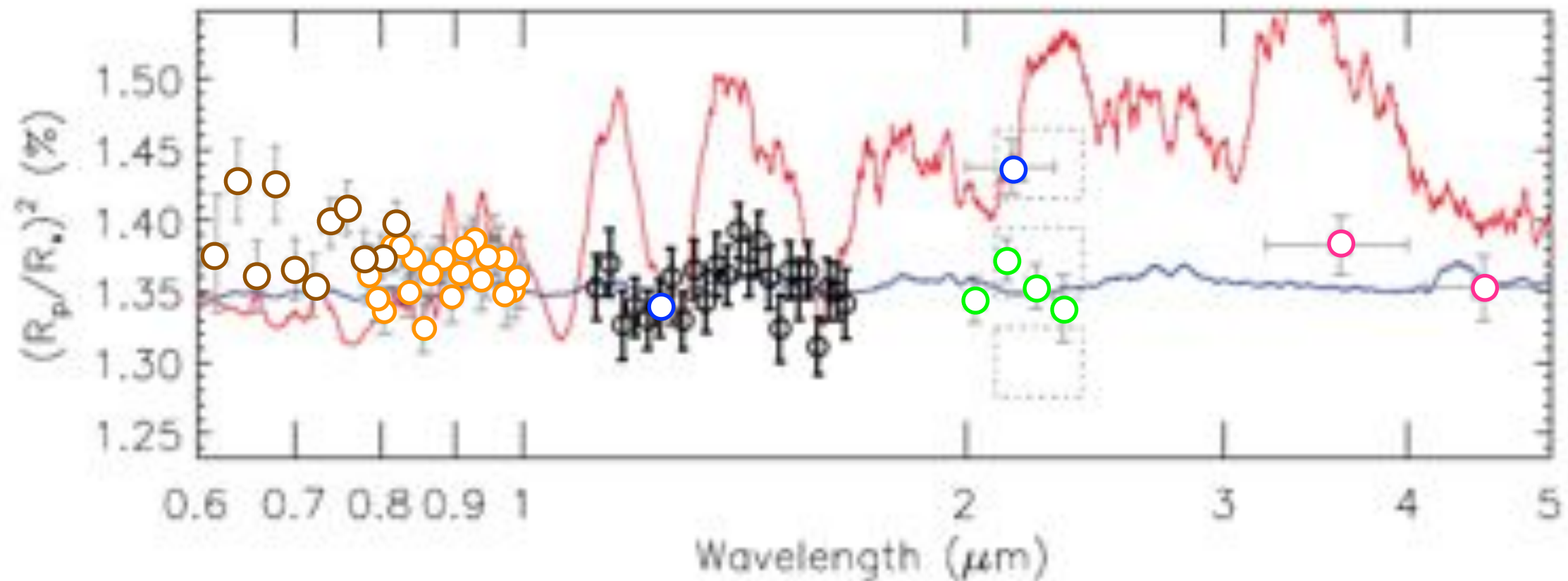
- Solar
- 30 x Solar
- 50 x Solar
- H₂O
- H₂O - CO₂
- CO₂

Secondary Eclipse:

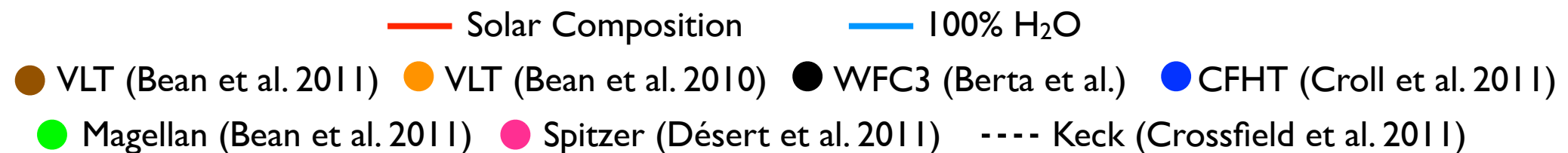
$$\text{Depth} = \text{Flux}_{\text{pl}} / \text{Flux}_{*}$$



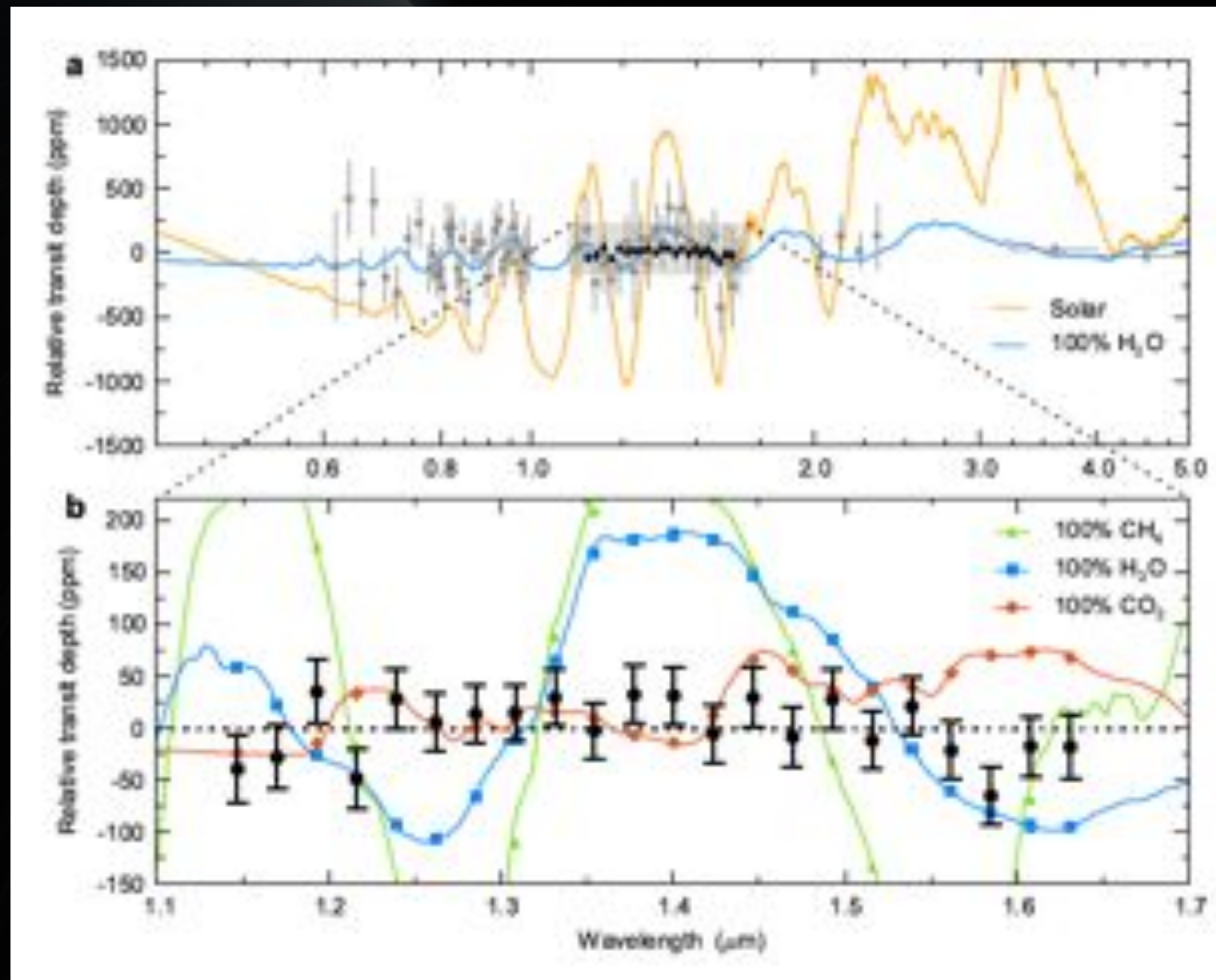
GJ 1214b – a benchmark Super-Earth



Berta, Charbonneau, Désert, Kempton et al., *ApJ* 2012

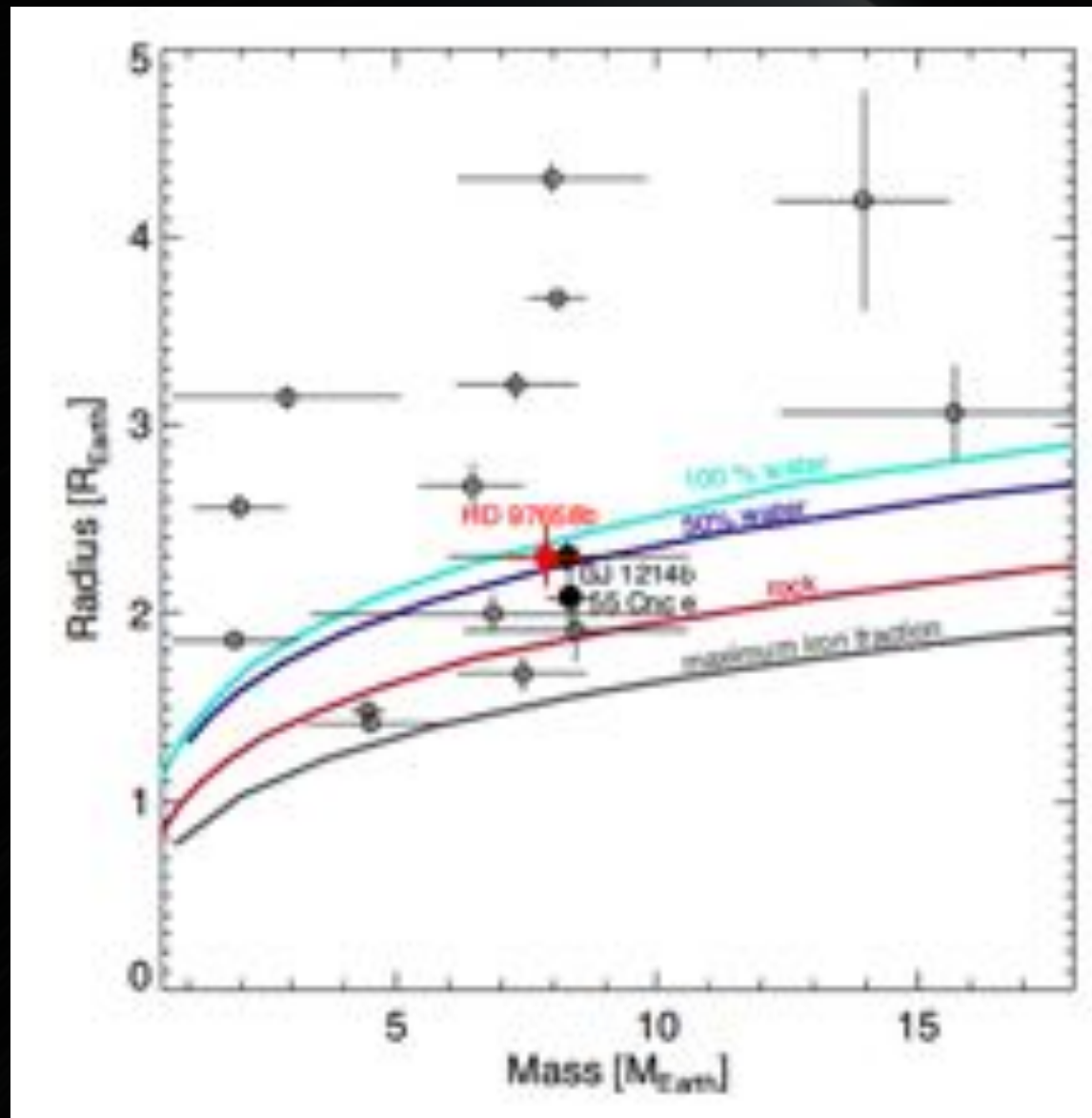


GJ 1214b – a benchmark Super-Earth

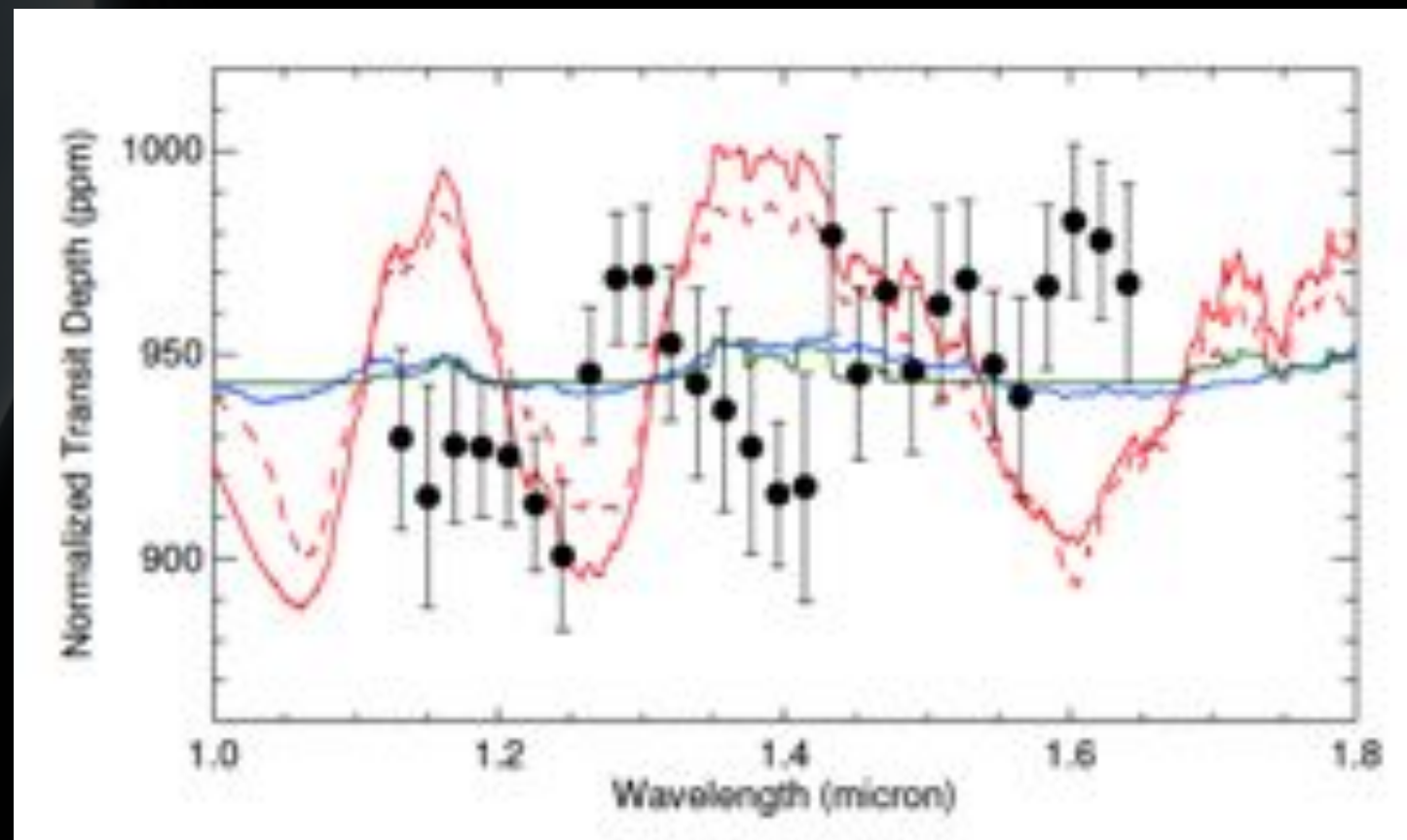


Kreidberg et al., *Nature* 2013

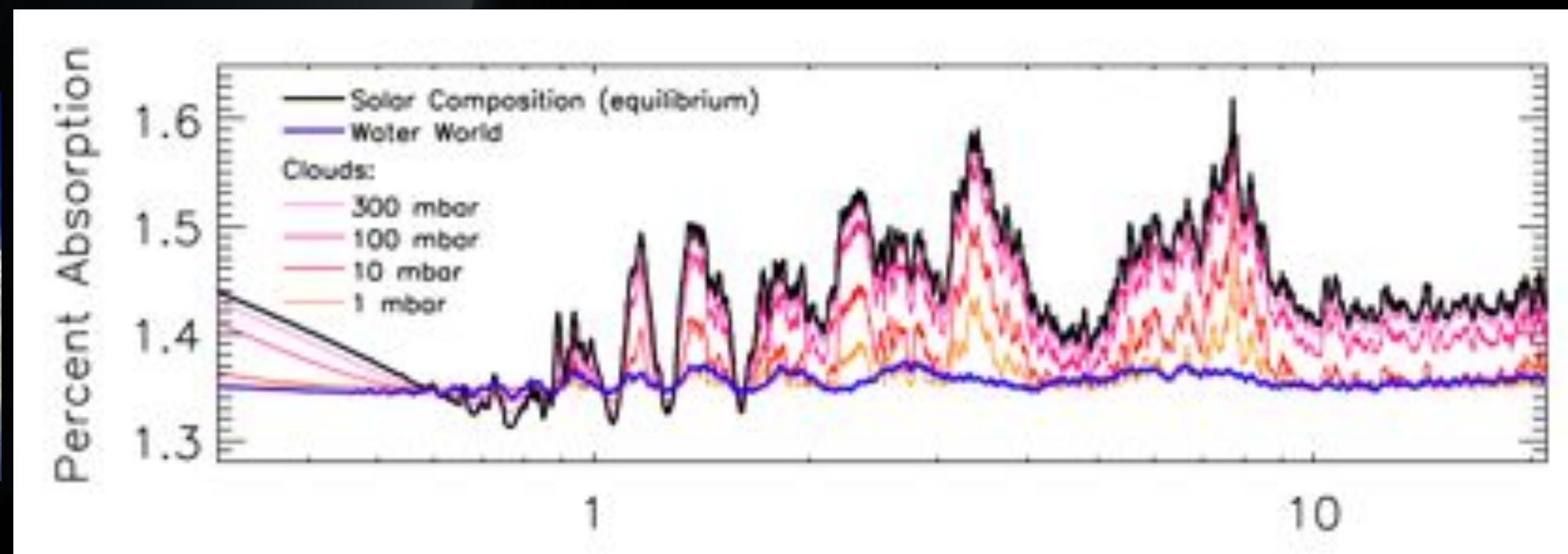
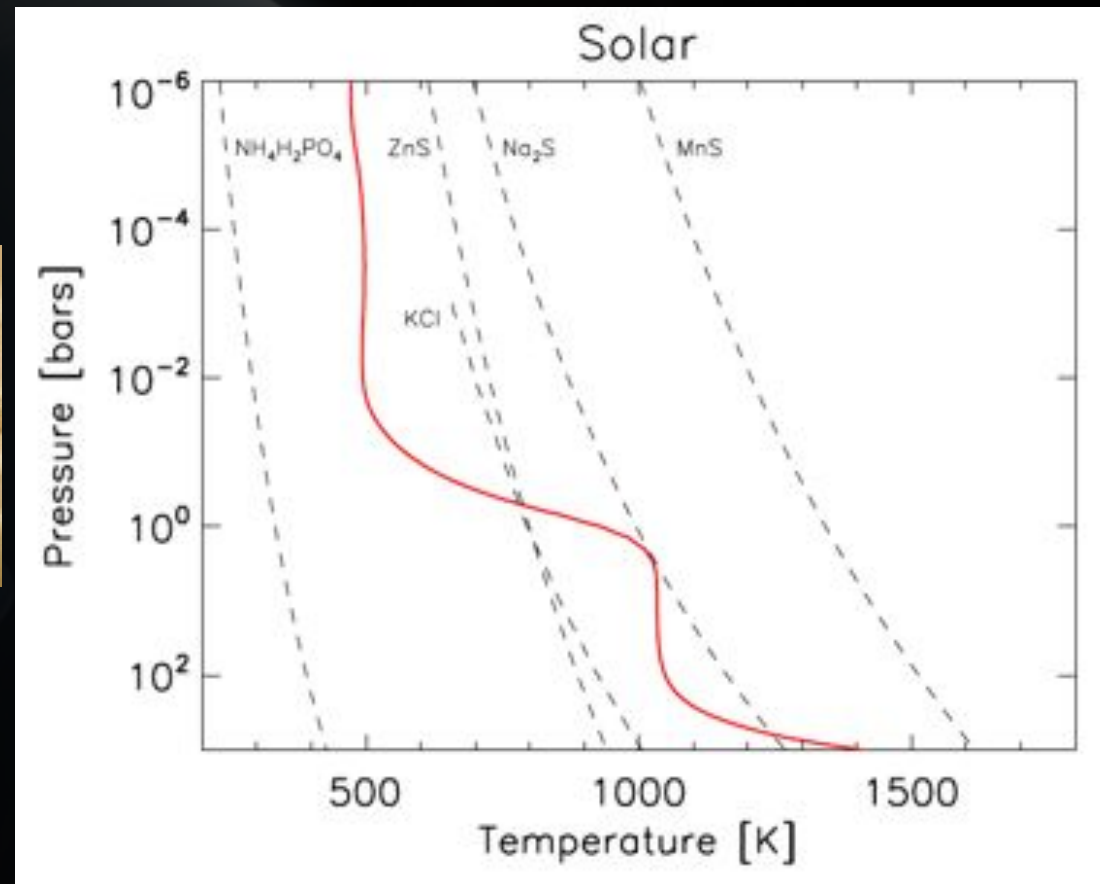
HD 97658b – A Second Benchmark Super-Earth



- $M_{\text{pl}} = 7.9 M_{\oplus}$
- $R_{\text{pl}} = 2.3 R_{\oplus}$
- $\rho = 3.4 \text{ g/cm}^3$
- $P = 9.49 \text{ days}$
- $T_{\text{eq}} \approx 700 \text{ K}$



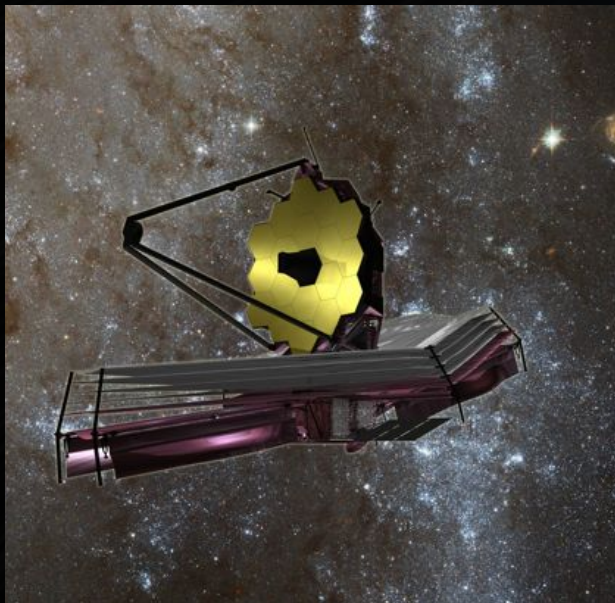
Clouds?



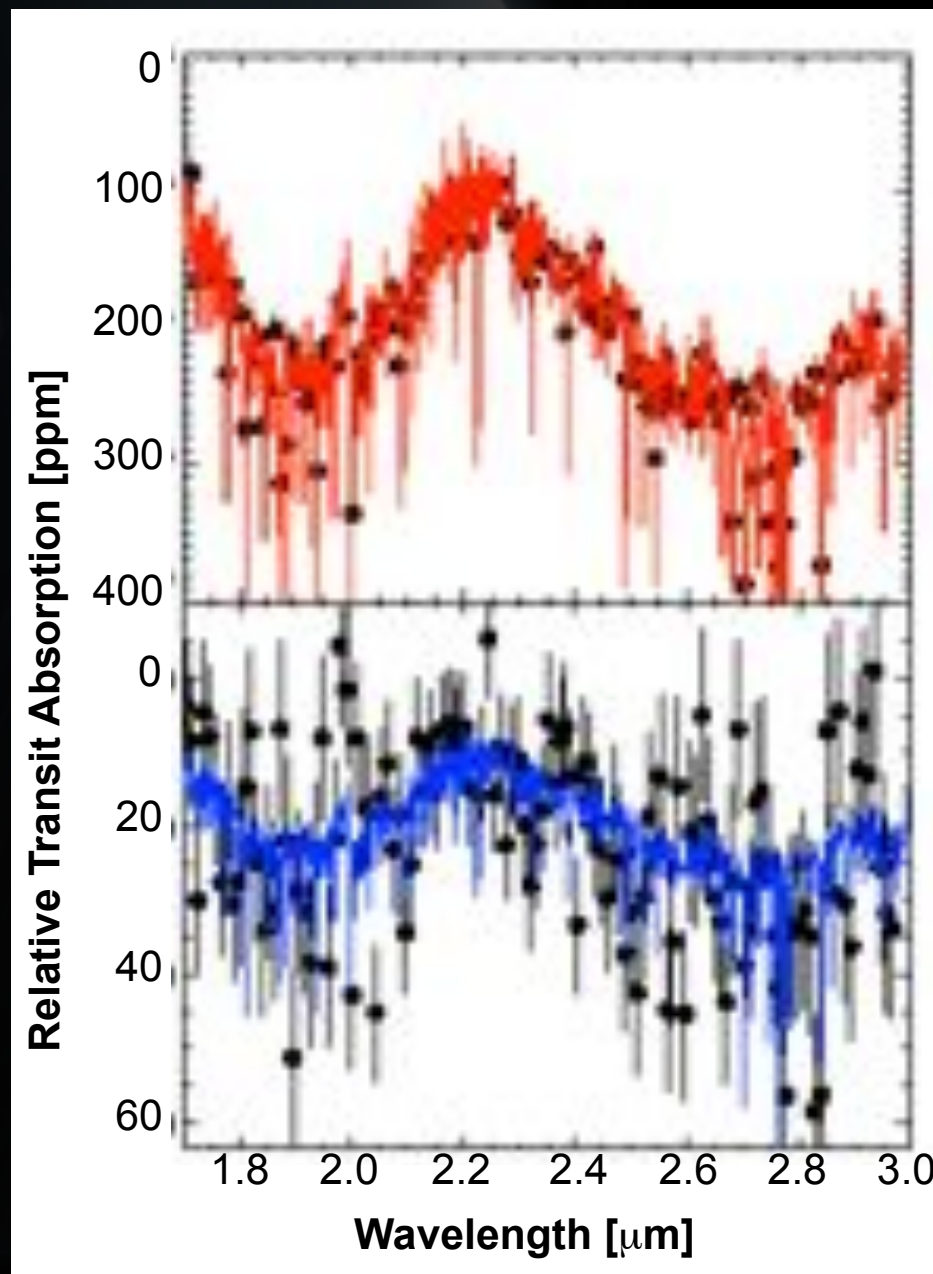
Observing Super Earth Atmospheres

- Signals of several to 100 ppm → JWST

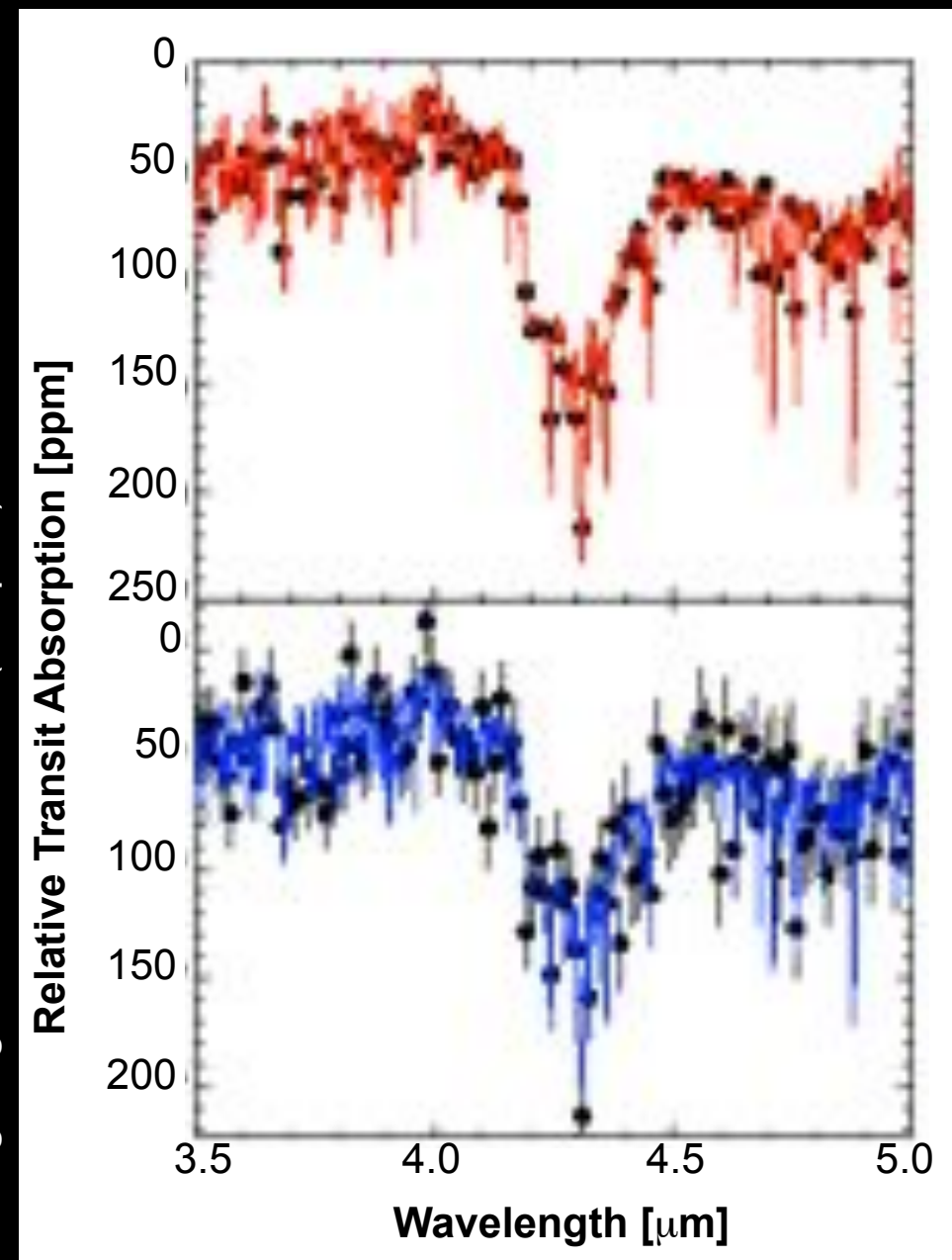
JWST



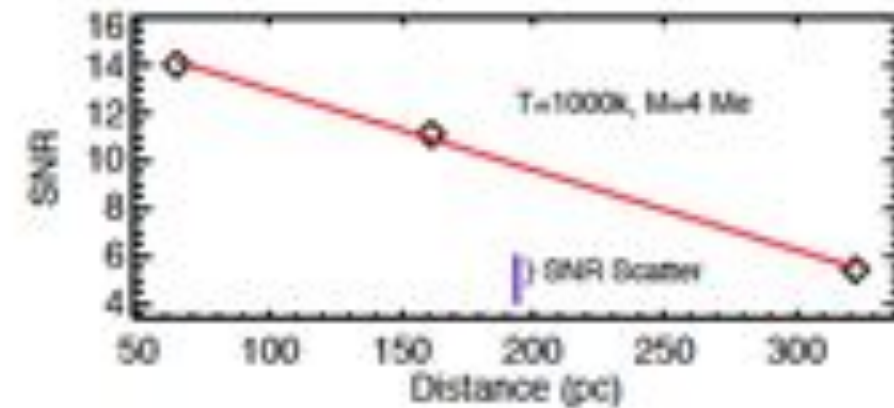
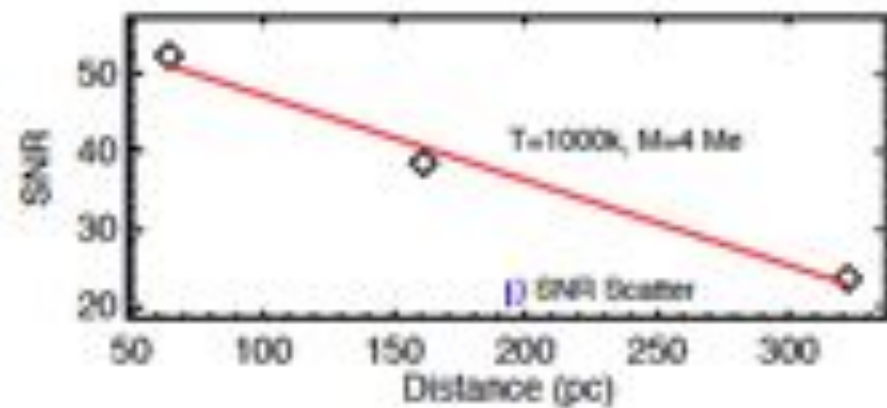
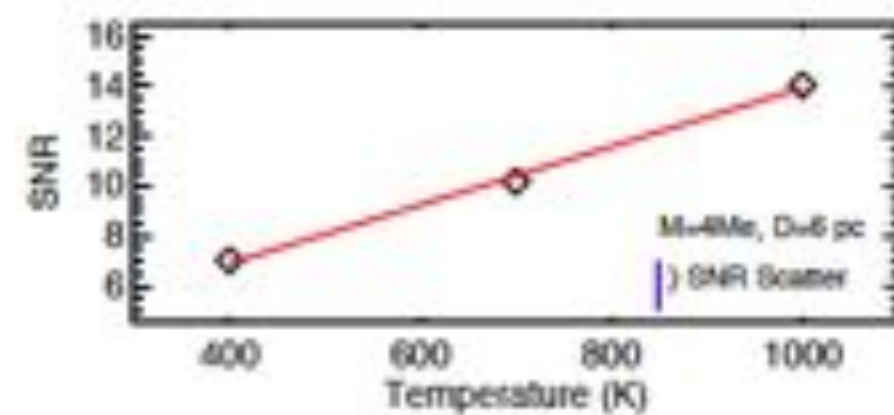
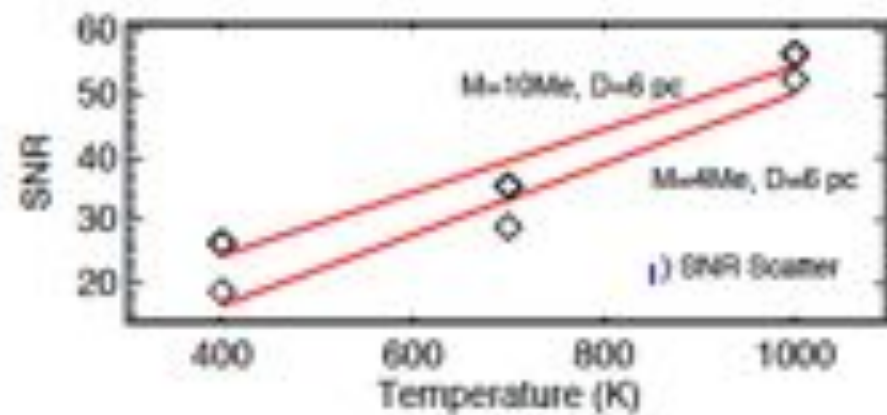
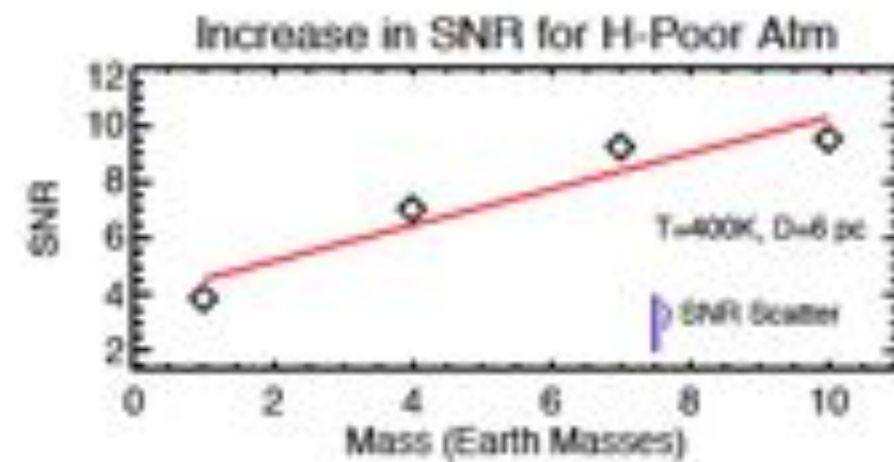
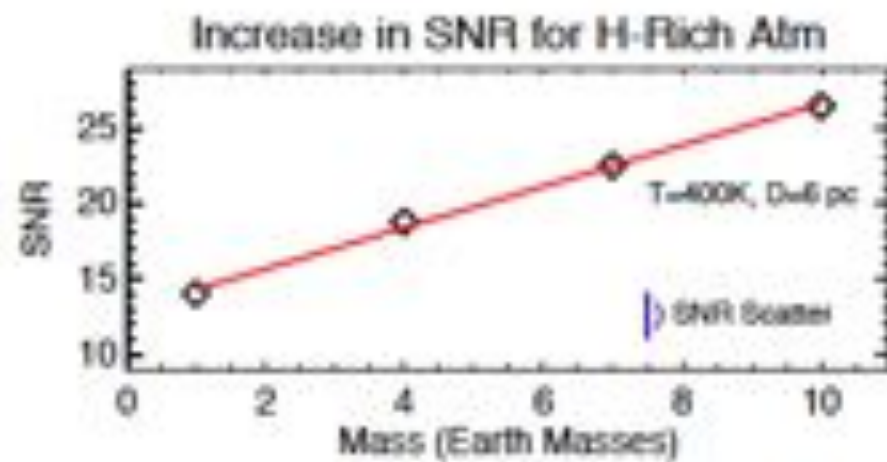
— Hot super-Earth
— Habitable super-Earth



Deming, Seager, Winn, Miller-Ricci (Kempton) et al., *PASP*, 2009



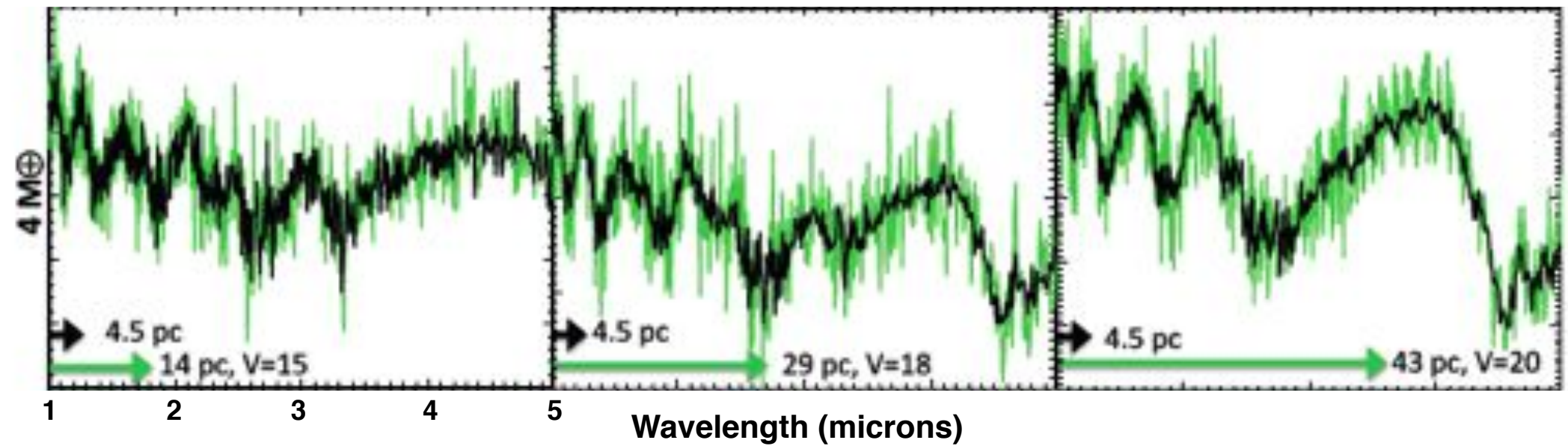
NIRSpec Simulations



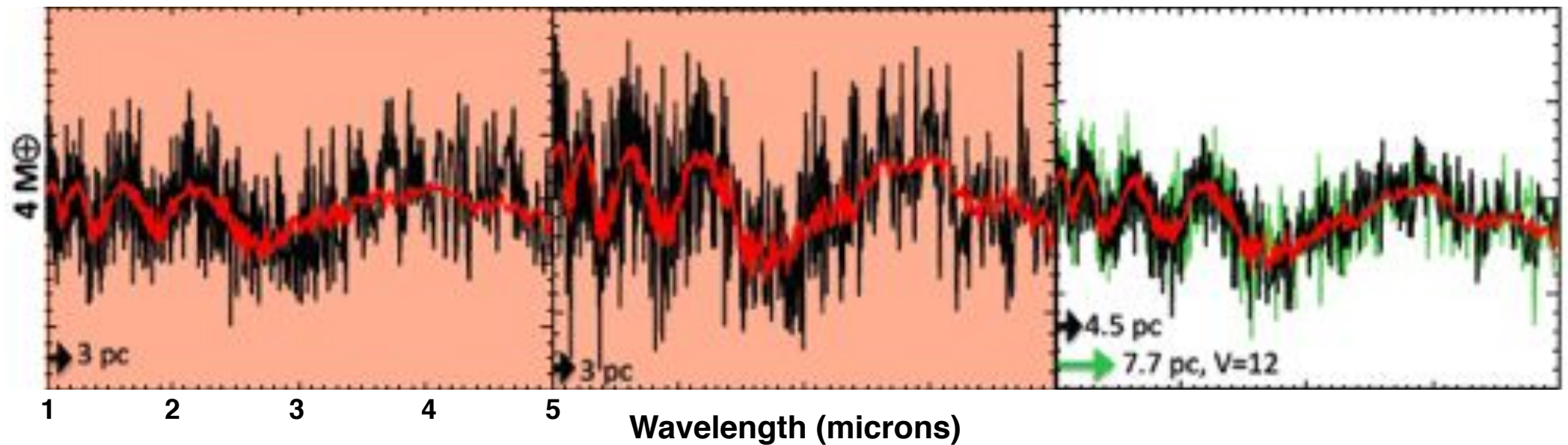
NIRSpec Simulations

Temperature: 400K 700 K 1000 K

H-Rich



H-Poor



Some goals for JWST

- Constrain compositions for a diverse set of super-Earths
- Differentiate between planets with clouds and those with high mean molecular weight atmospheres
- Constrain cloud properties
- Classify planets that fall within (and below) the “super-Earth” mass and radius range
- Choose between “low-cost” and “high reward” targets