Spectroscopy of Super-Earths

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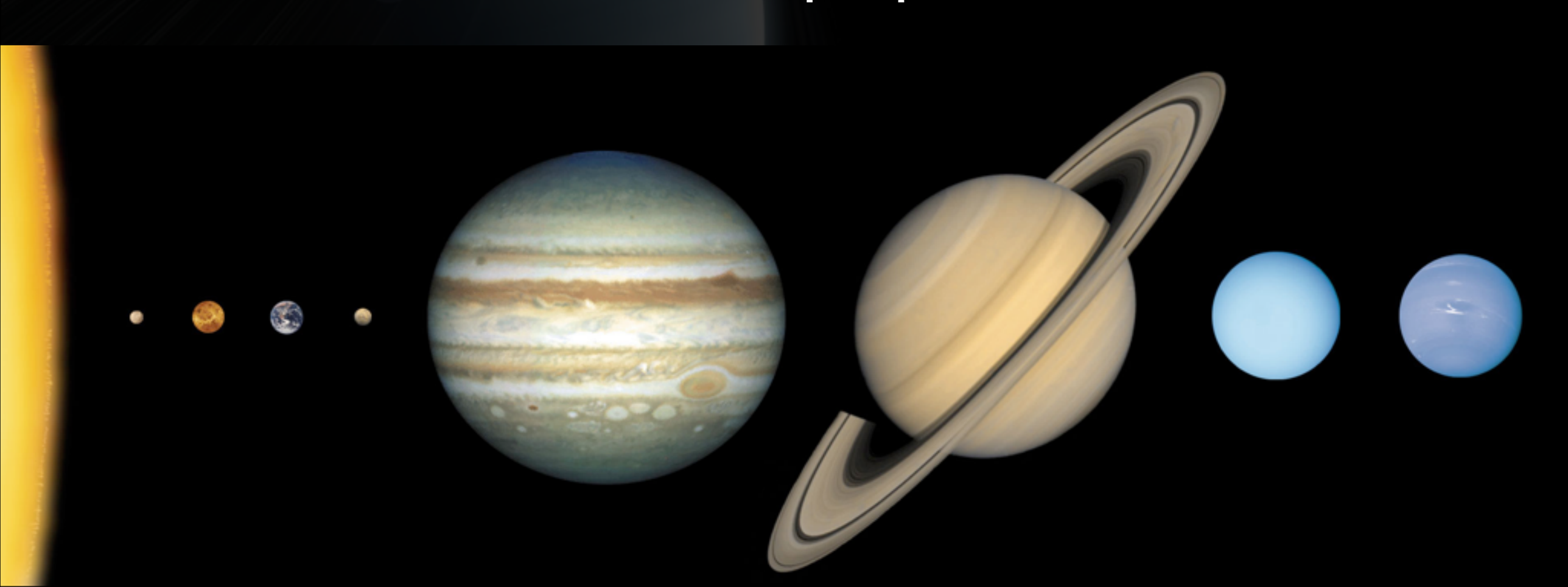
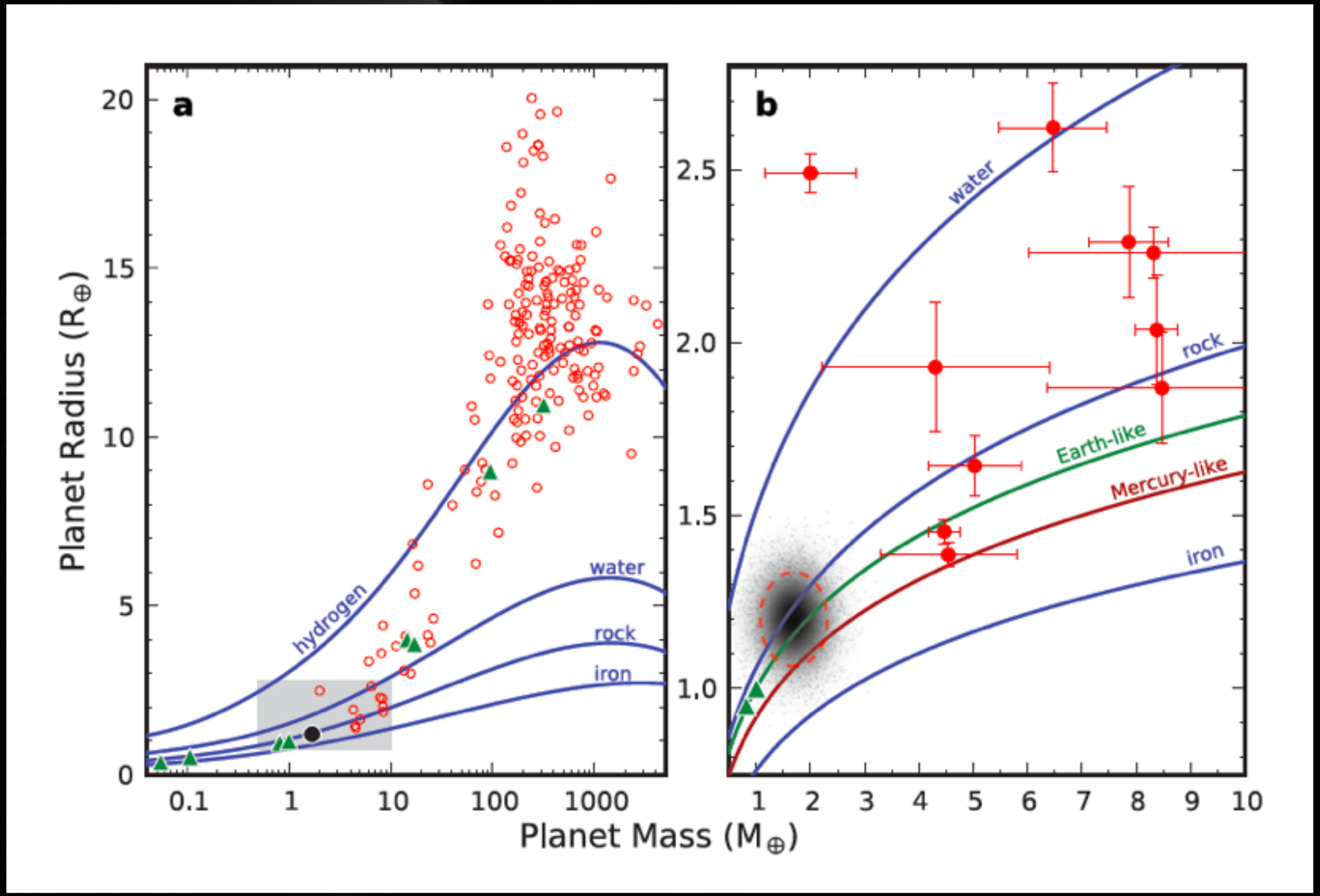
Image Credit: Paul A. Kempton

Why Super-Earths?

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



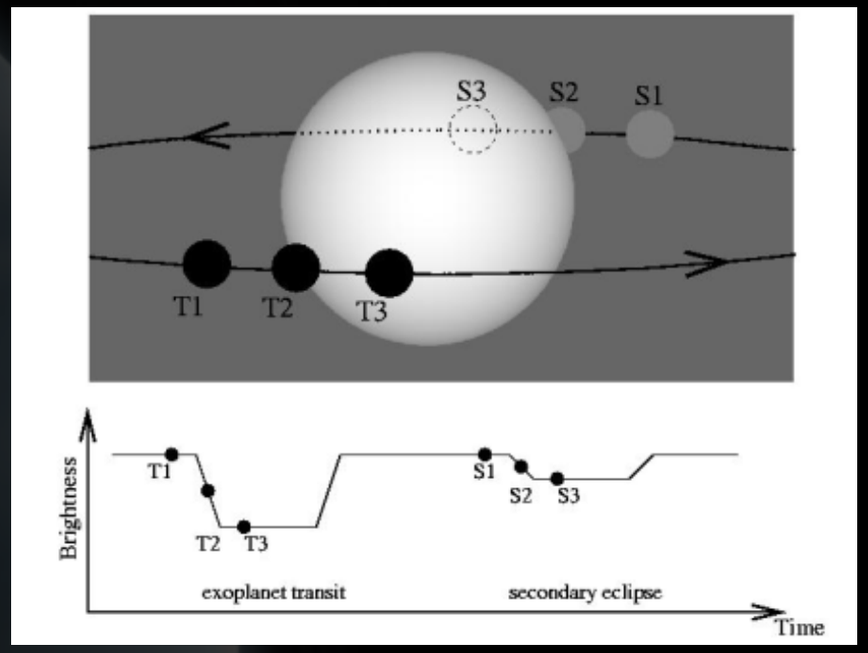
Super-Earths – a Diverse Population of Planets



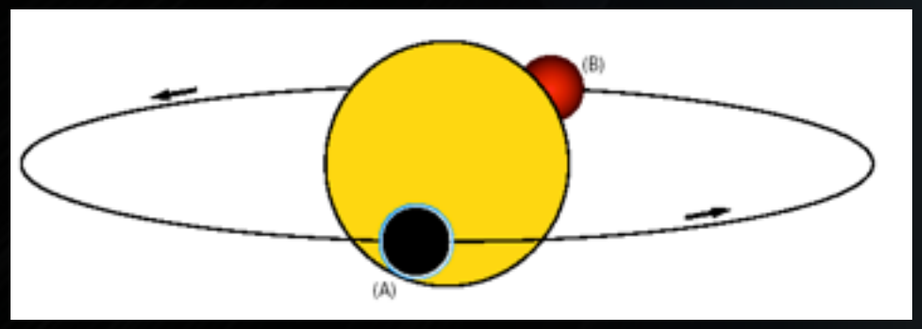
Howard et al., *Nature*, 2013

Transmission vs. Emission Spectroscopy

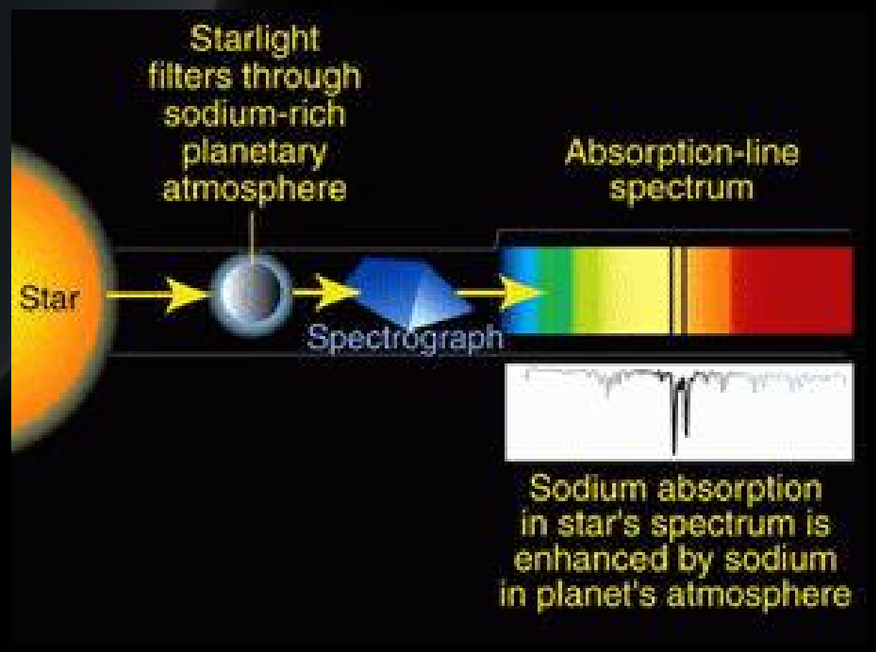
Emission



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



Transmission



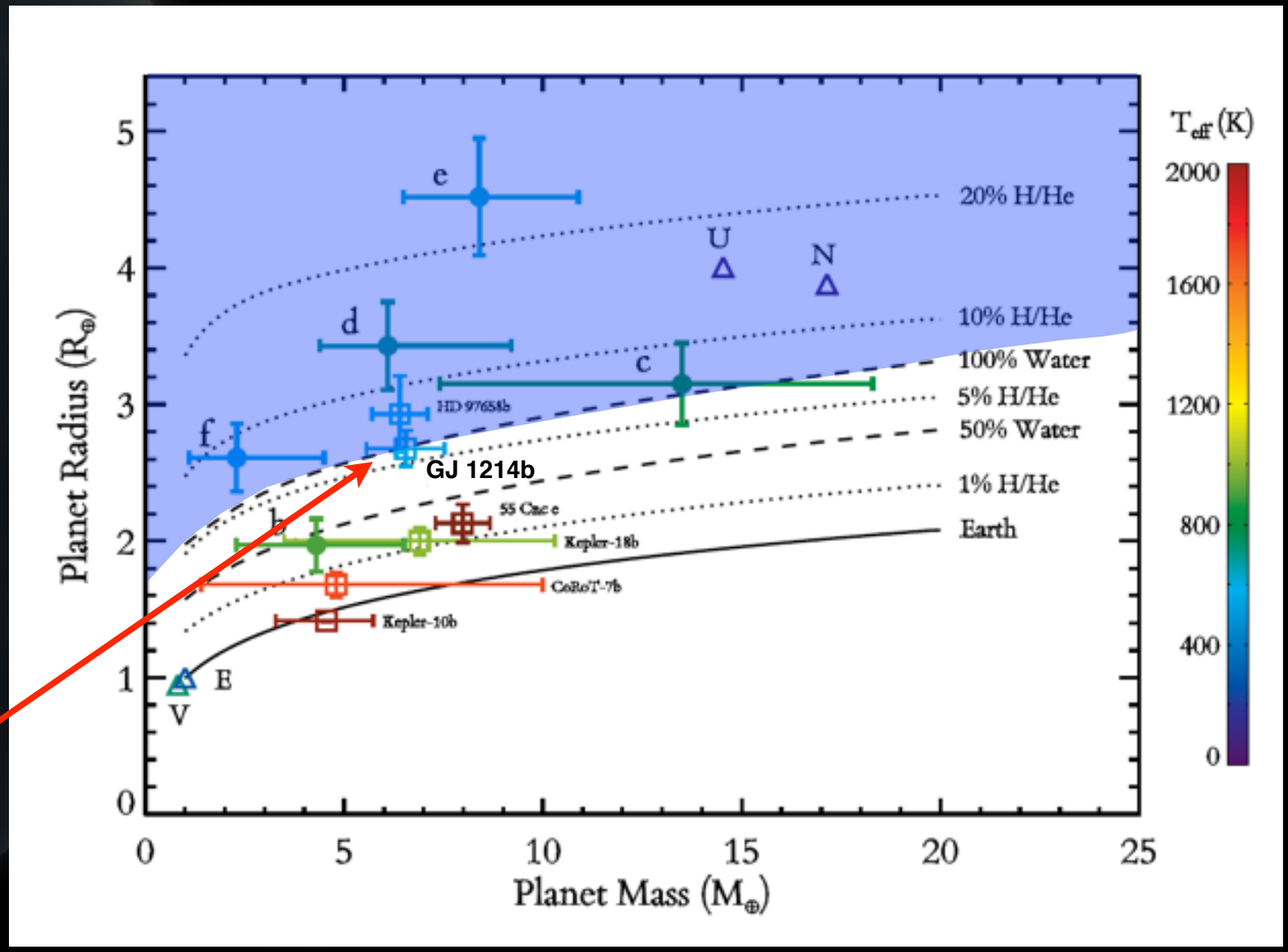
- Composition
- Scale height
- Clouds
- Planetary mass (?)

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

GJ 1214b:

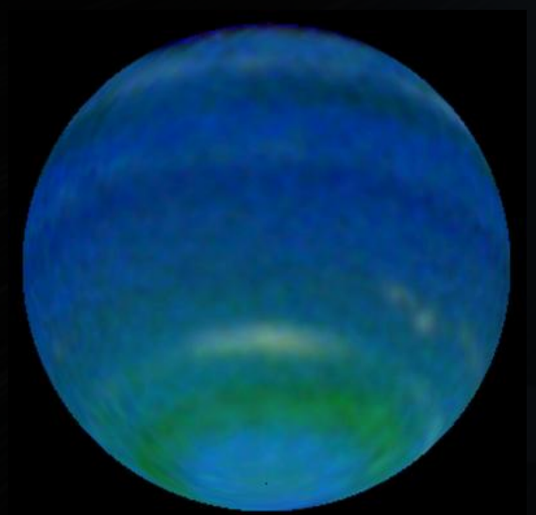
- $M_{pl} = 6.6\ M_{\oplus}$
- $R_{pl} = 2.7\ R_{\oplus}$
- $\rho = 1.9$ g/cm^3
- $P = 1.58$ days
- $T_{eq} \approx 550$ K

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



Lissauer et al., *Nature*, 2011 (modified c/o E. Lopez)

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:

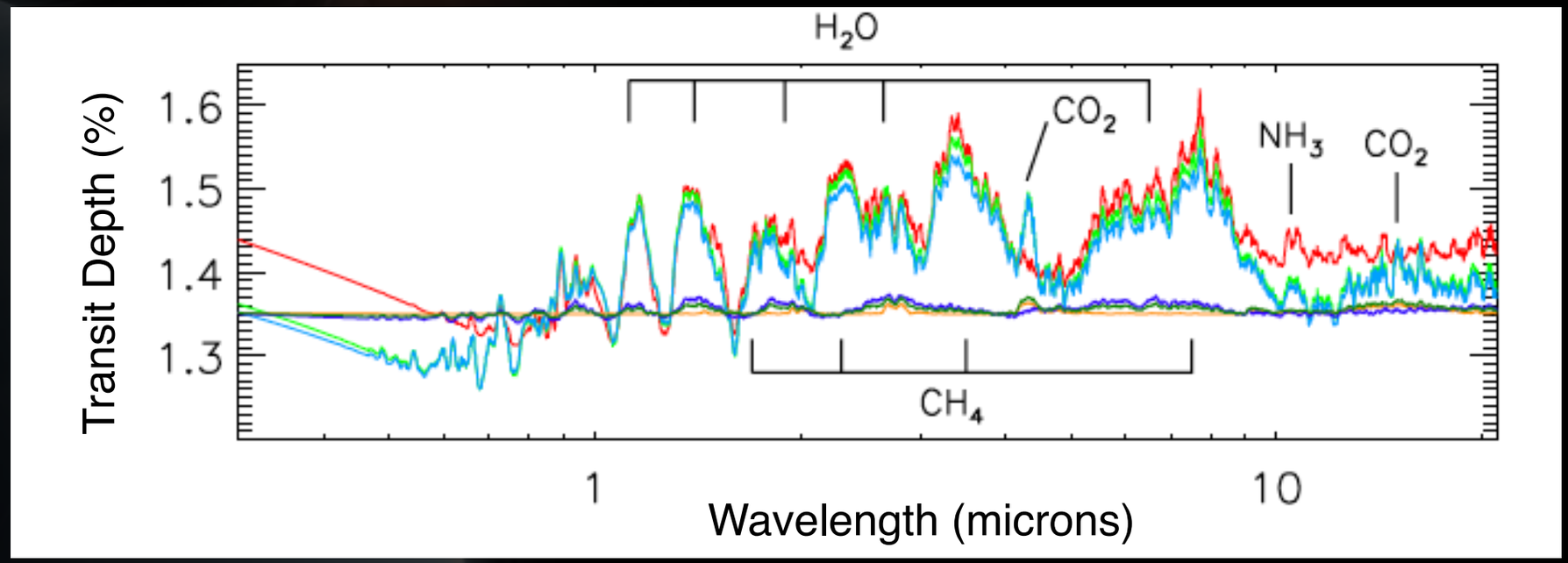
   Mostly H_2O - ice interior + steam atmosphere

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

GJ 1214b Transmission & Emission Spectra

Transmission:

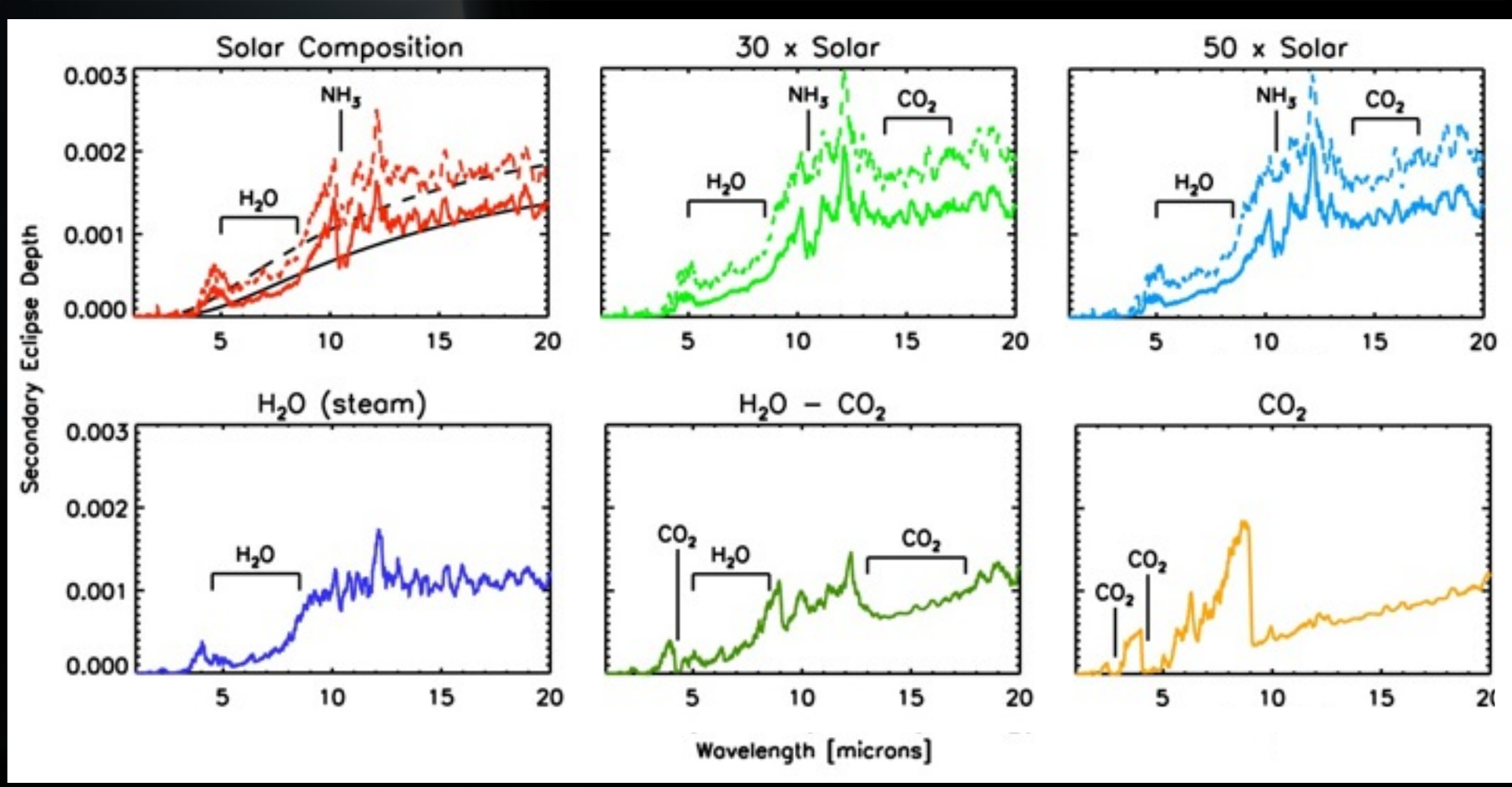
$\Delta_{depth} \sim 20H\ R_{pl} / R_*^2$



- Solar
- 30 x Solar
- 50 x Solar
- H_2O
- H_2O - CO_2
- CO_2

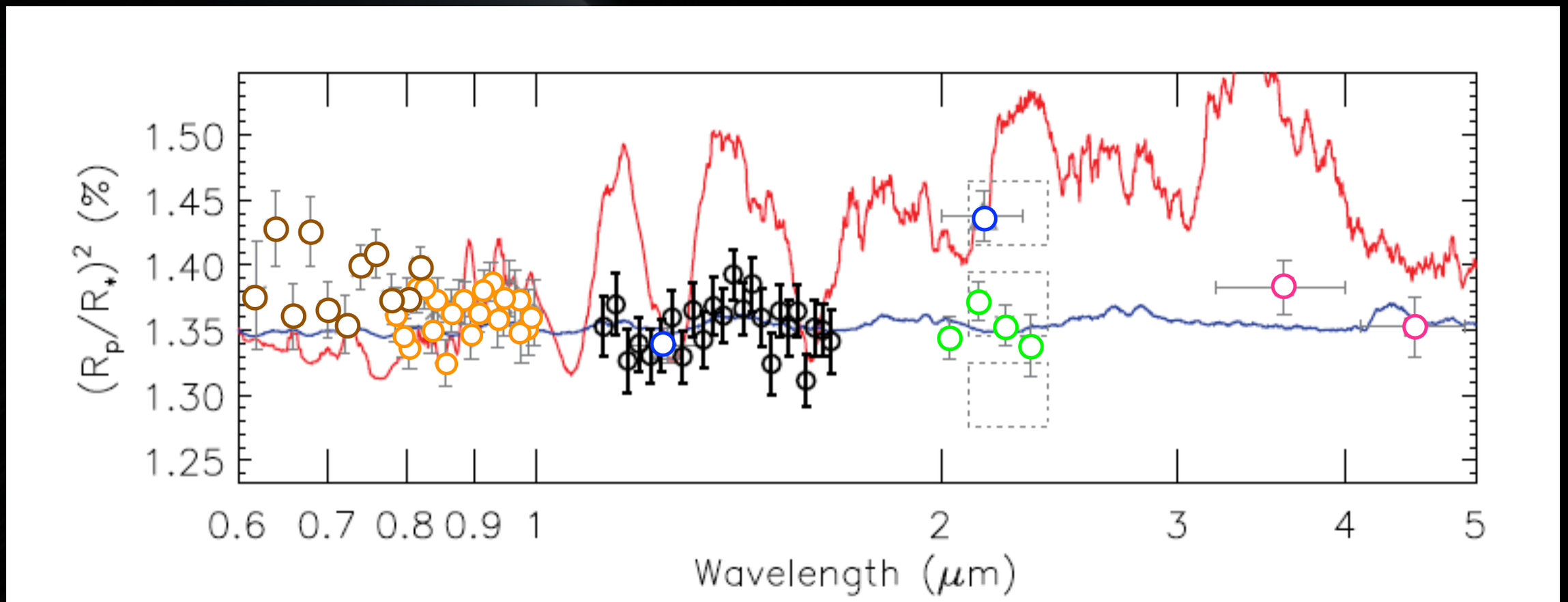
Secondary Eclipse:

Depth = $Flux_{pl} / Flux_*$



Miller-Ricci (Kempton) & Fortney, *ApJL* 2010

GJ 1214b – a benchmark Super-Earth



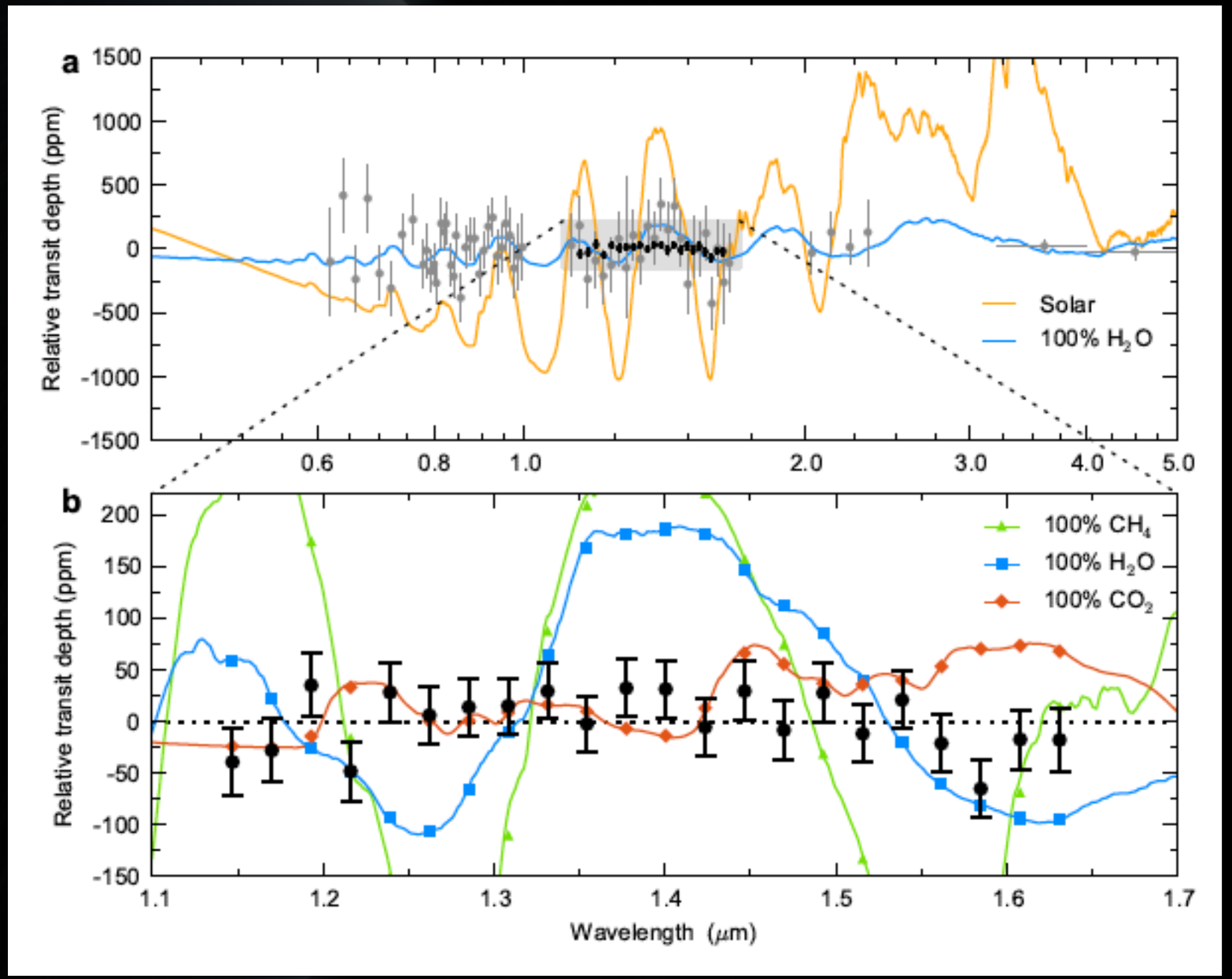
Berta, Charbonneau, Désert, Kempton et al., *ApJ* 2012

Solar Composition — 100% H_2O

VLT (Bean et al. 2011) · VLT (Bean et al. 2010) · WFC3 (Berta et al.) · CFHT (Croll et al. 2011)

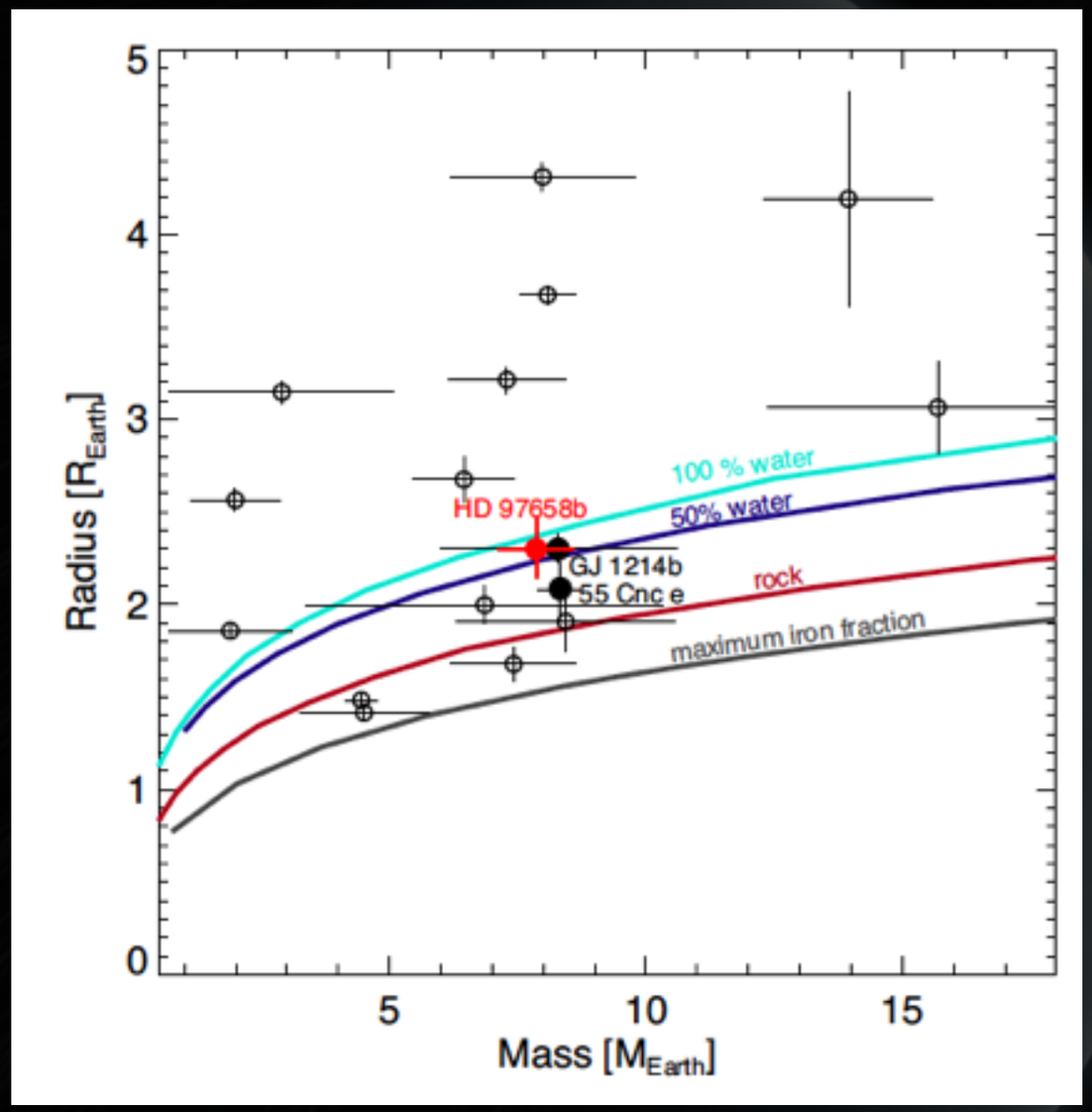
Magellan (Bean et al. 2011) · Spitzer (Désert et al. 2011) · ---- Keck (Crossfield et al. 2011)

GJ 1214b – a benchmark Super-Earth

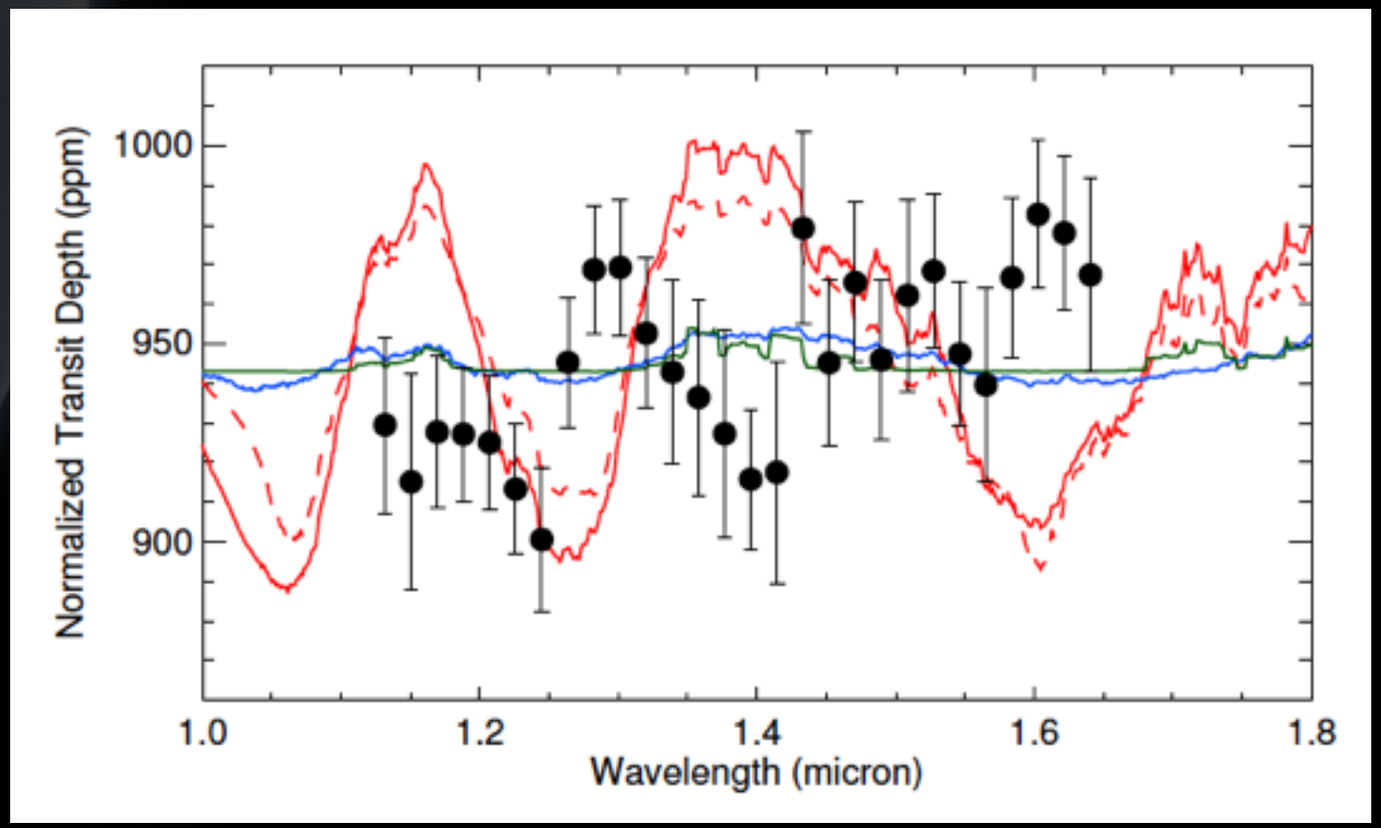


Kreidberg et al., *Nature* 2013

HD 97658b – A Second Benchmark Super-Earth

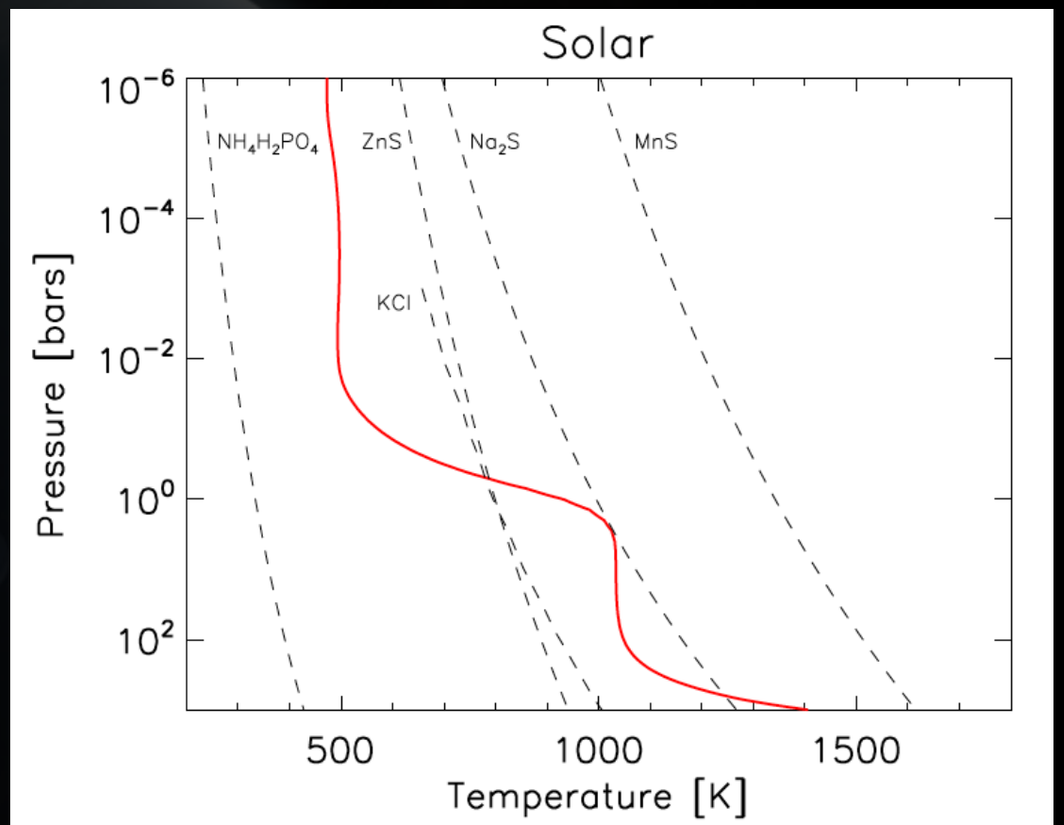


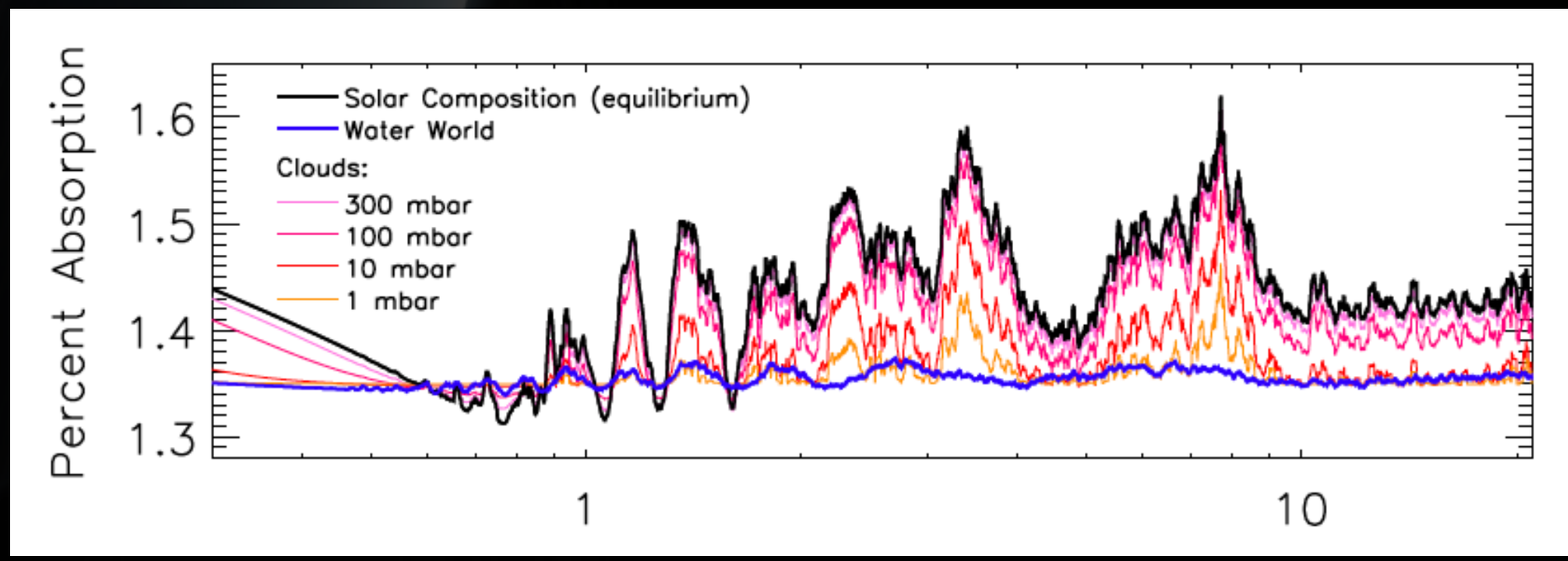
- M_{pl} = 7.9 $M_{\oplus}$
- R_{pl} = 2.3 $R_{\oplus}$
- ρ = 3.4 g/cm^3
- P = 9.49 days
- $T_{eq} \approx$ 700 K



Knutson et al. *in prep*

Clouds?

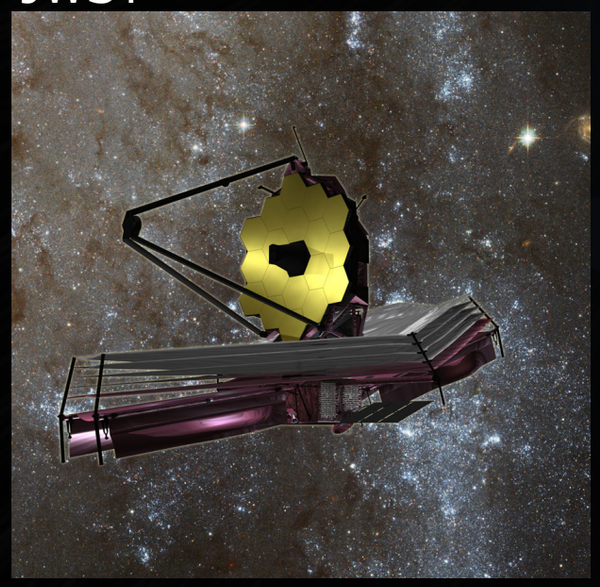

Solar
10^{-6}
10^{-4}
10^{-2}
10^{0}
10^{2}
Pressure [bars]
$NH_4H_2PO_4$
ZnS
Na_2S
MnS
KCl
500
1000
1500
Temperature [K]


Percent Absorption
1.6
1.5
1.4
1.3
Solar Composition (equilibrium)
Water World
Clouds:
300 mbar
100 mbar
10 mbar
1 mbar
1
10

Observing Super Earth Atmospheres

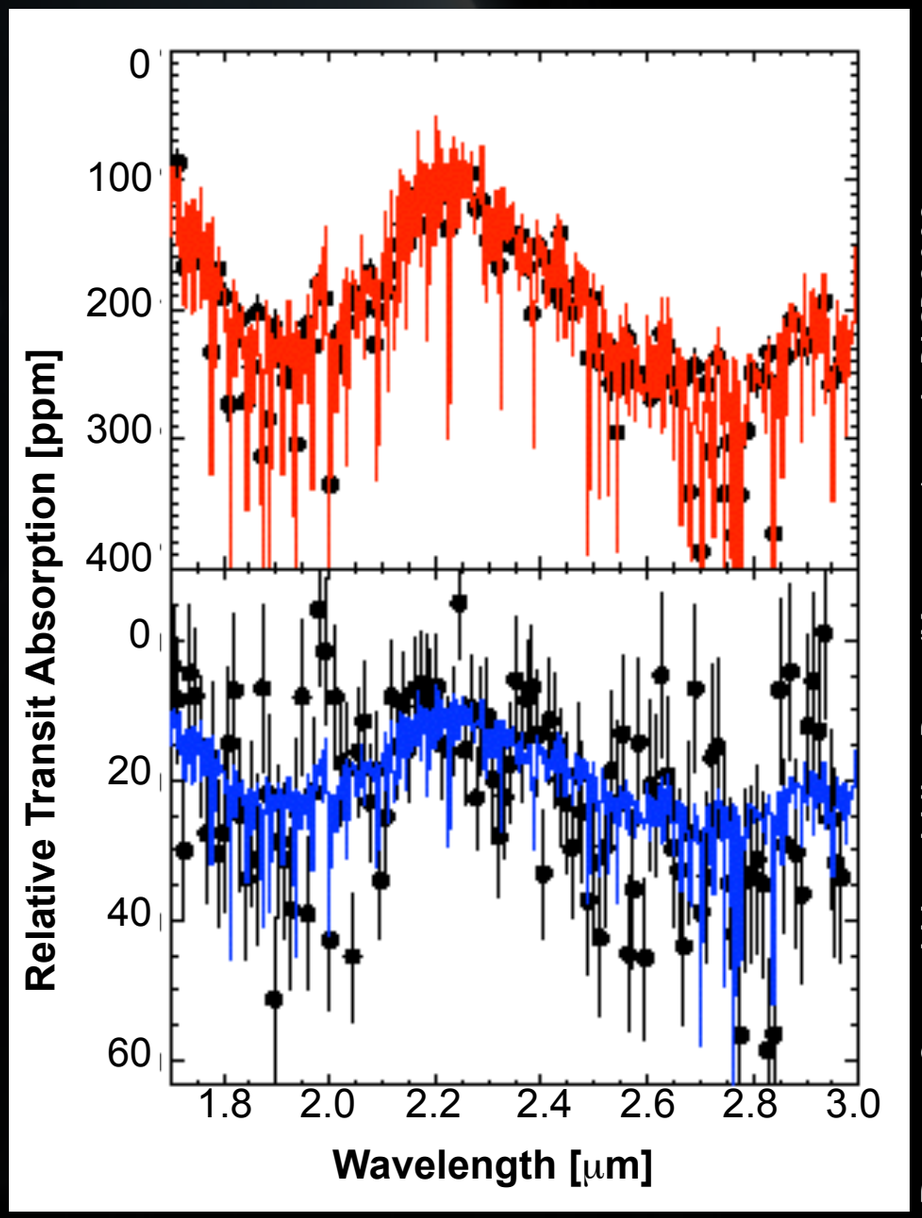
- Signals of several to 100 ppm → JWST

JWST

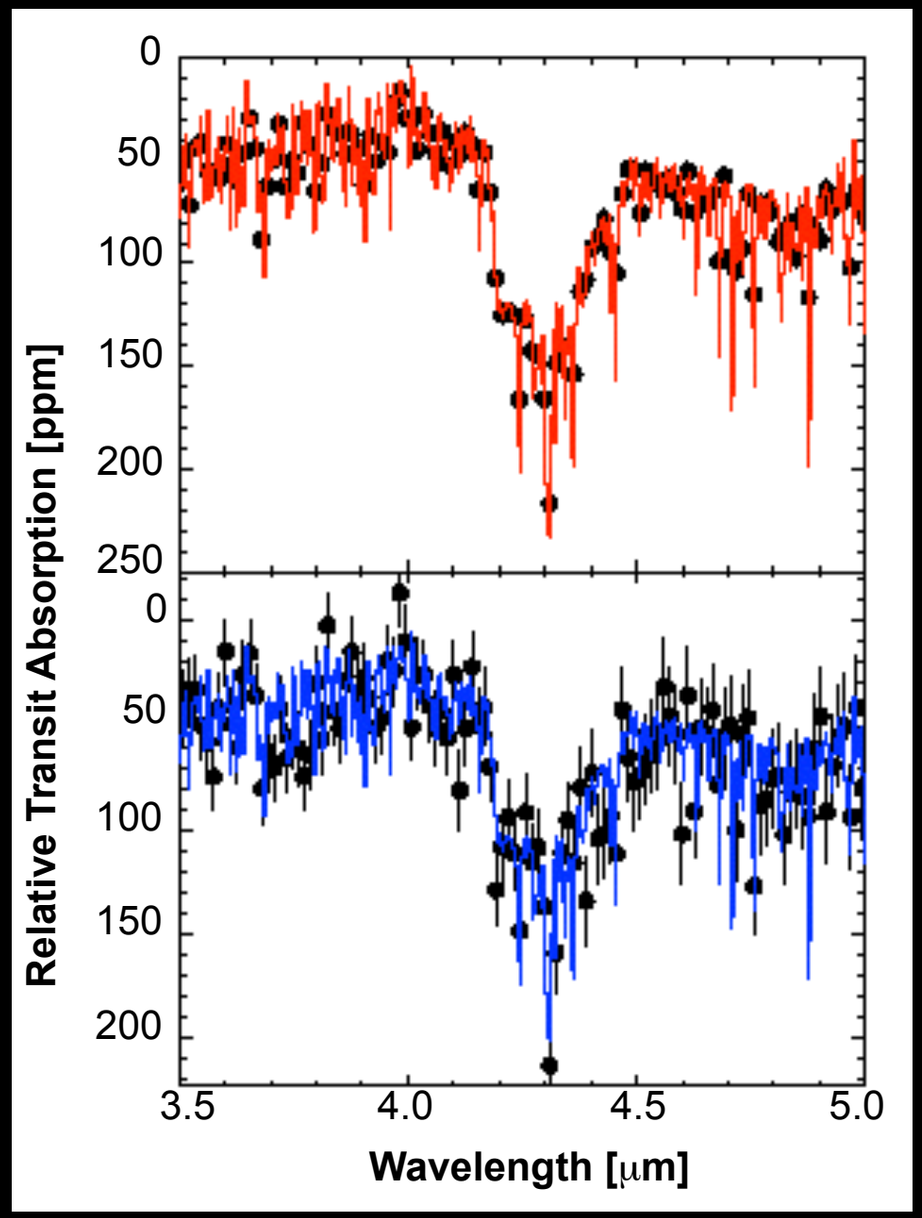


Hot super-Earth

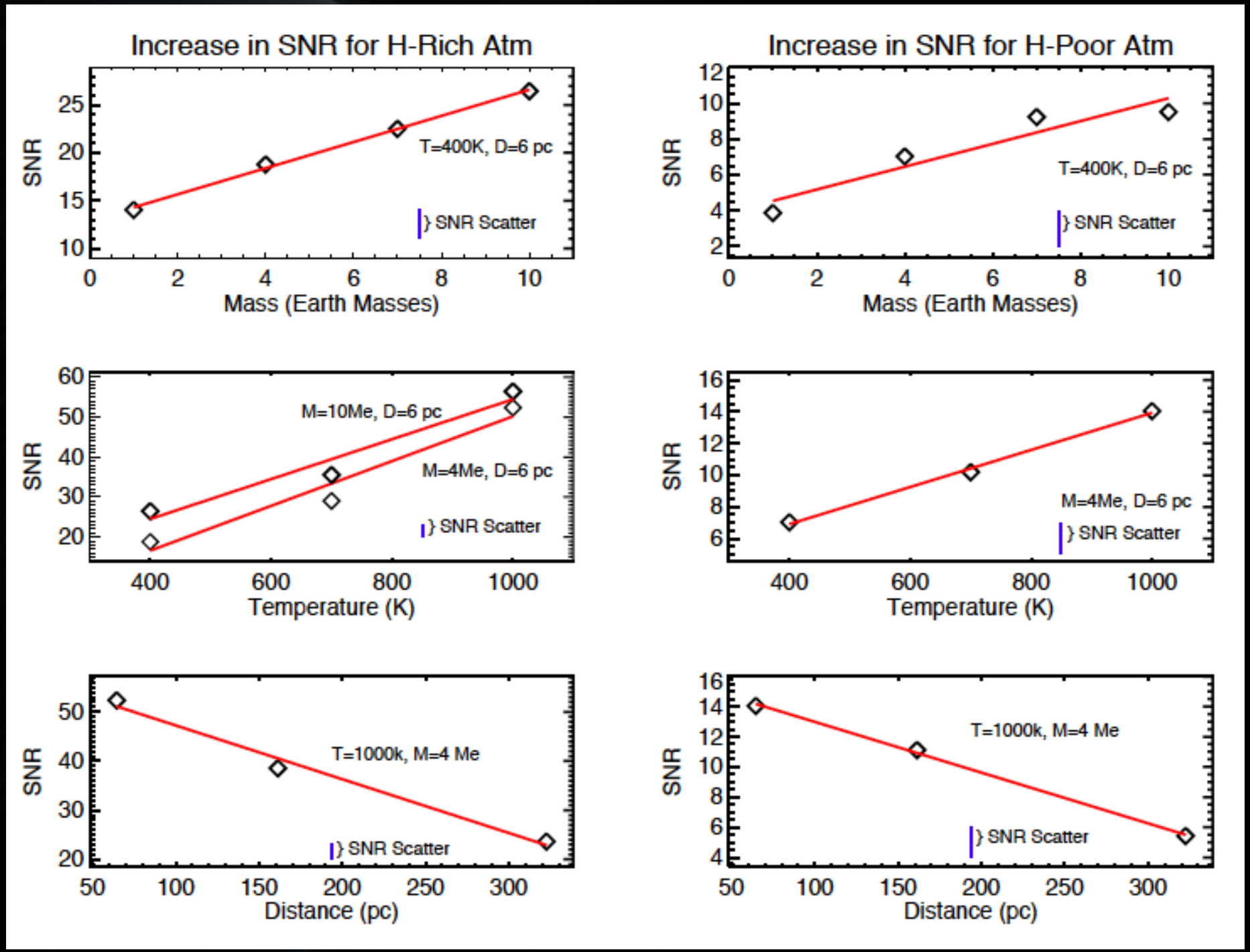
Habitable super-Earth



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



NIRSpec Simulations

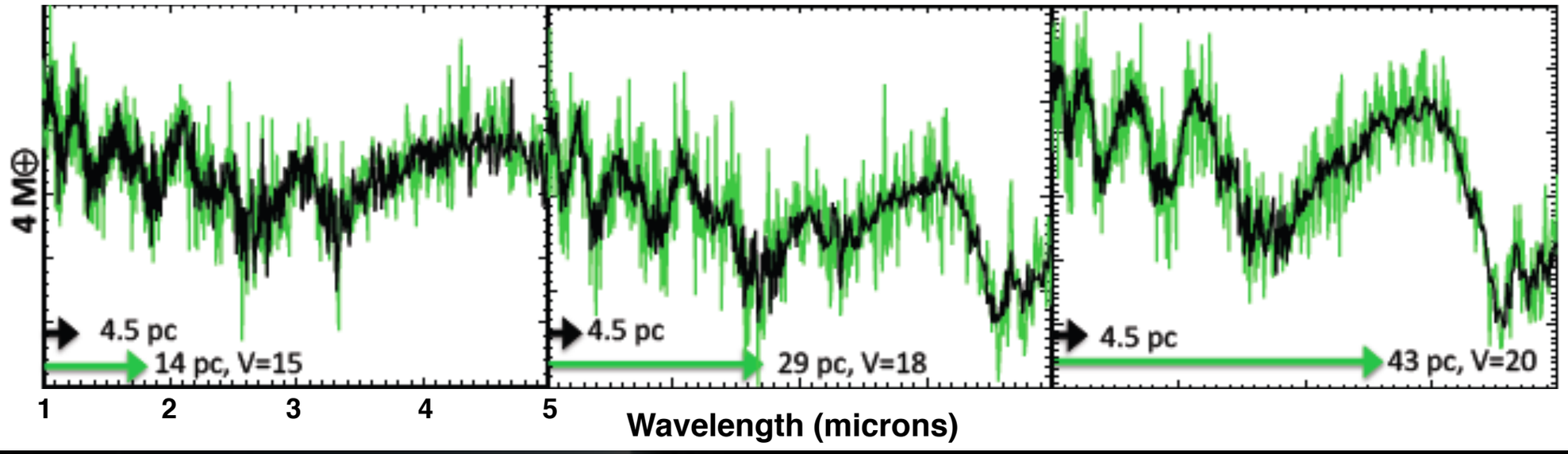


Batalha et al., 2013

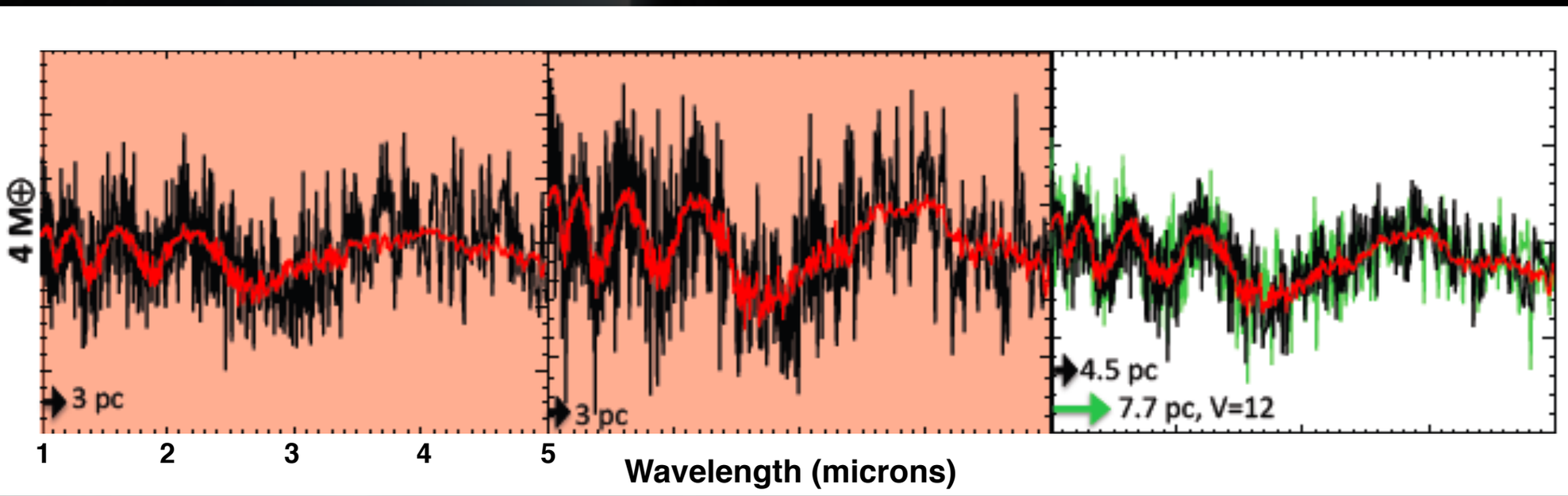
NIRSpec Simulations

Temperature:	400K	700 K	1000 K

H-Rich



H-Poor



Batalha et al., 2013

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