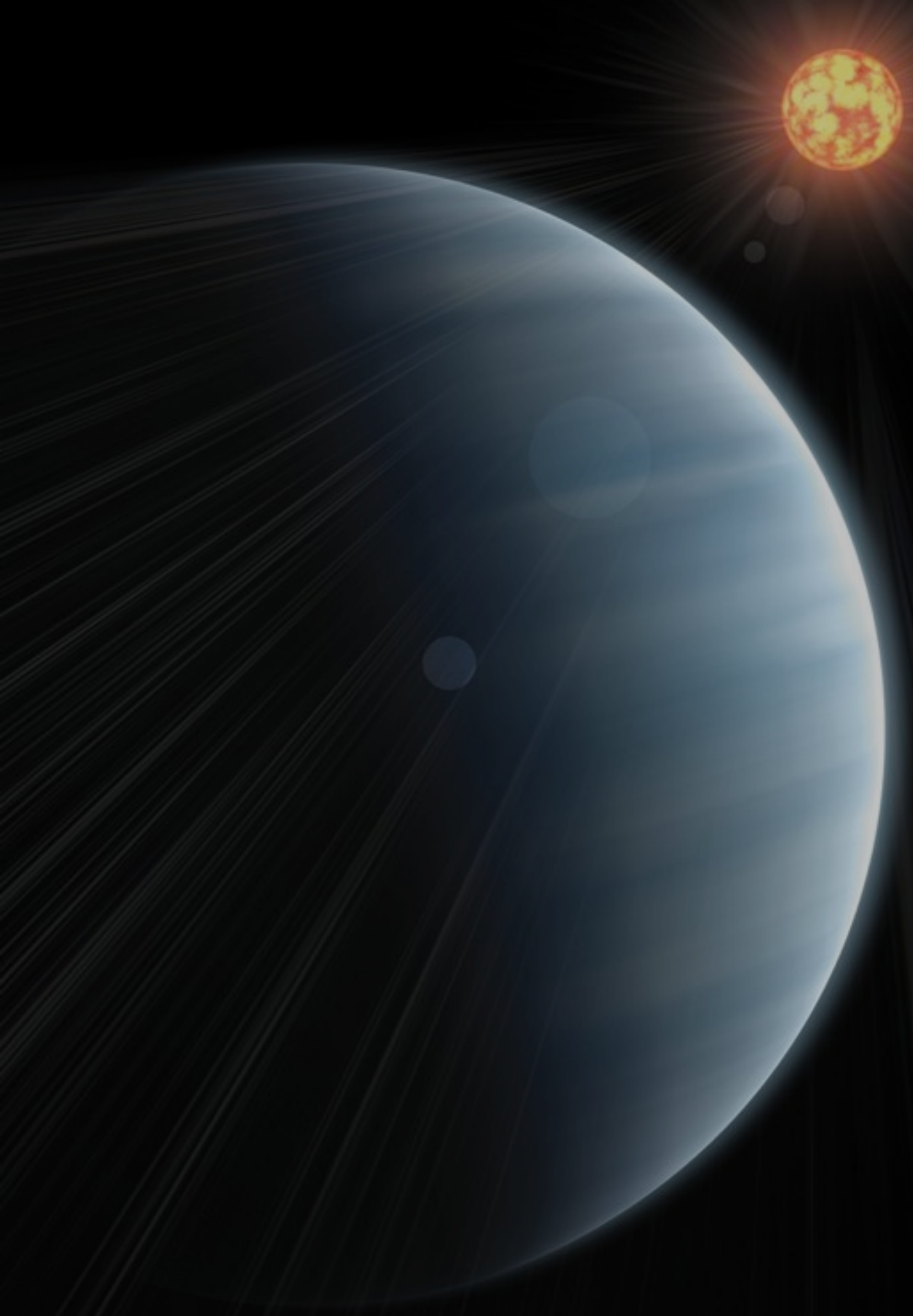


The Atmosphere of the Transiting Super-Earth GJ 1214b

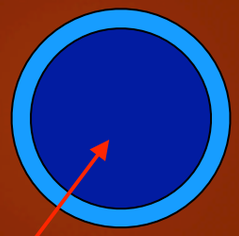
Eliza Kempton (*formerly: Miller-Ricci*)
Sagan Fellow
U.C. Santa Cruz

"The Future of Astronomy"
Northwestern University
August 31, 2011

The Transiting Super-Earth GJ 1214b

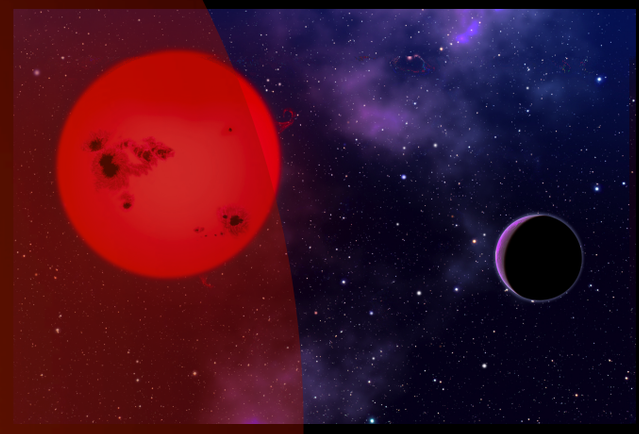
GJ 1214b:

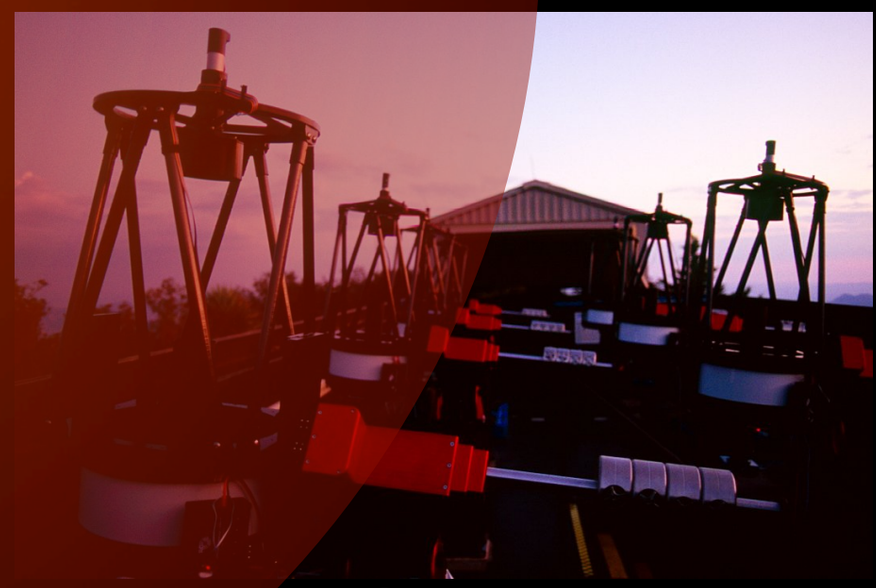
- $M_{pl} = 6.6\ M_{\oplus}$
- $R_{pl} = 2.7\ R_{\oplus}$
- $\rho = 1.9\ g/cm^3$
- $P = 1.58$ days
- $T_{eq} \approx 550$ K



GJ 1214b

1.4% transit depth

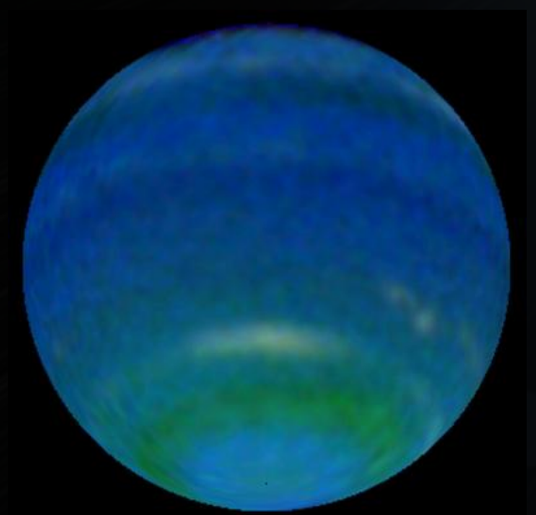




MEarth Observatory

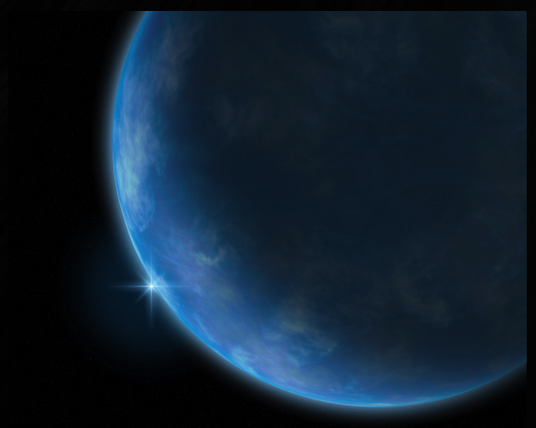
GJ 1214 system to scale:

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.)

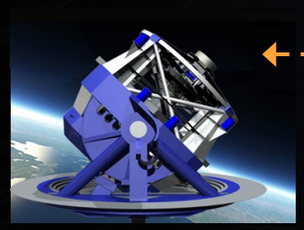


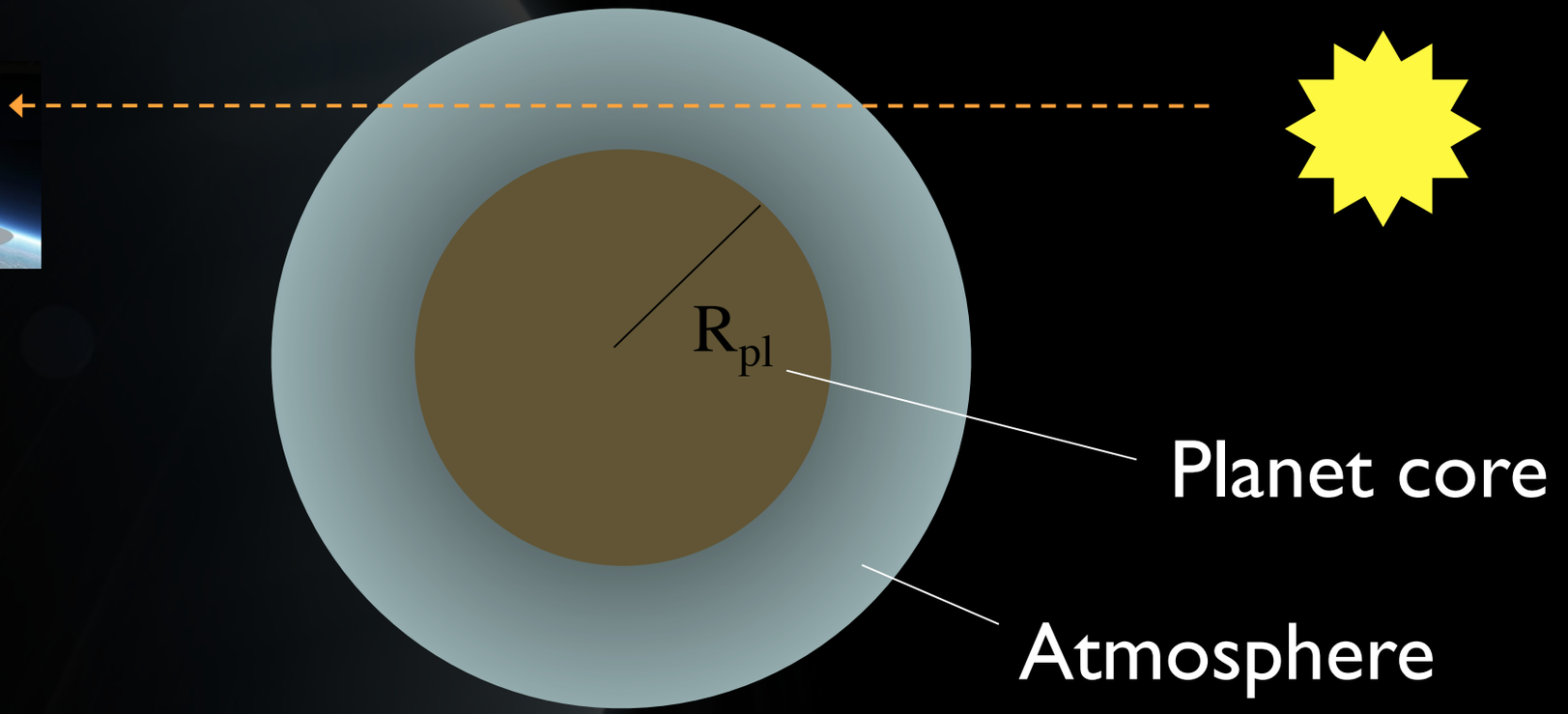
2. Water World Scenario:

   Mostly H_2O - ice interior + steam atmosphere

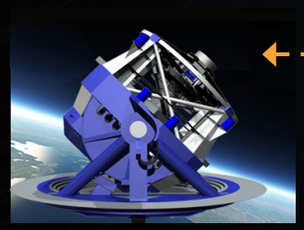
(Rogers & Seager, *ApJ*, 2010 + Nettelmann et al. 2011)

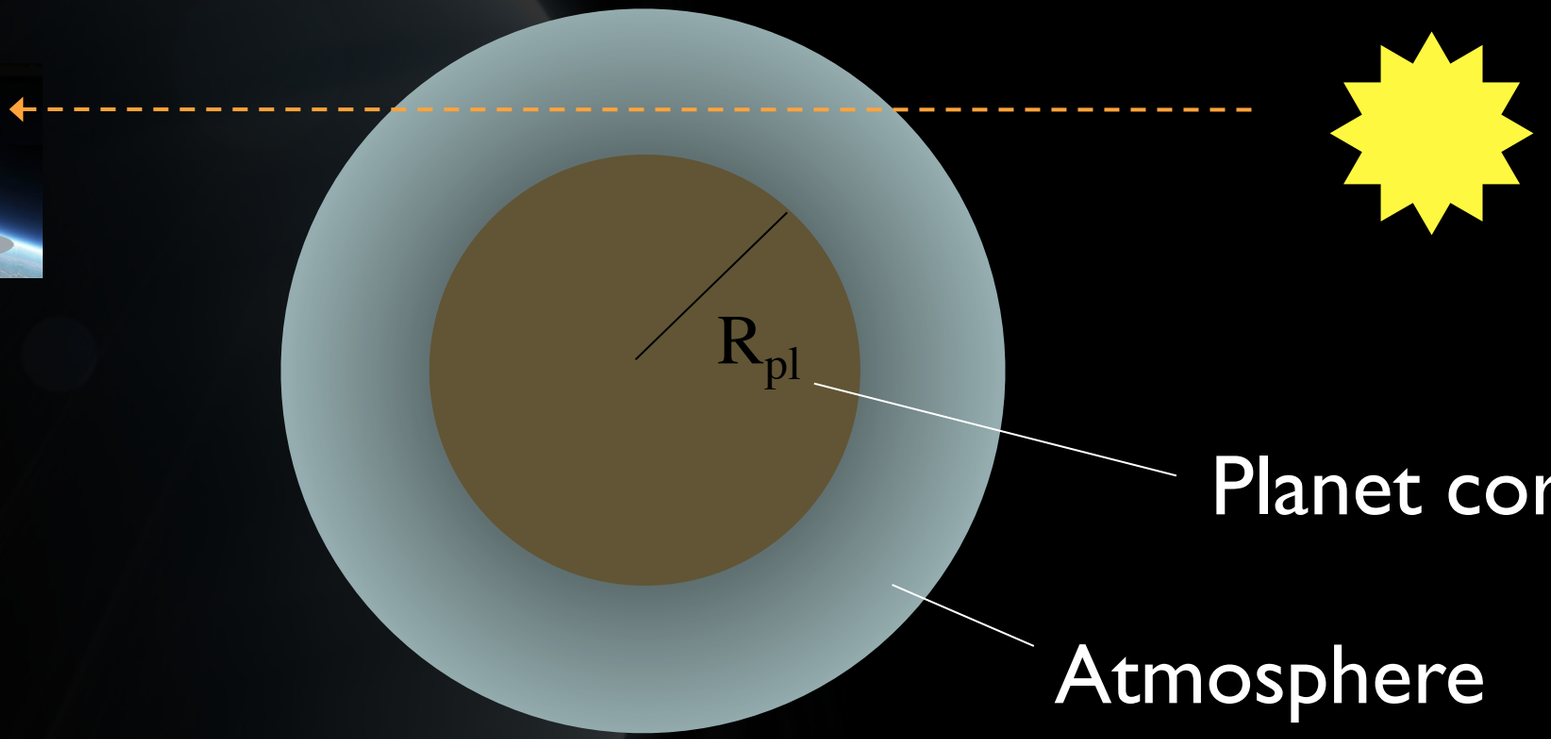
Transmission Spectroscopy

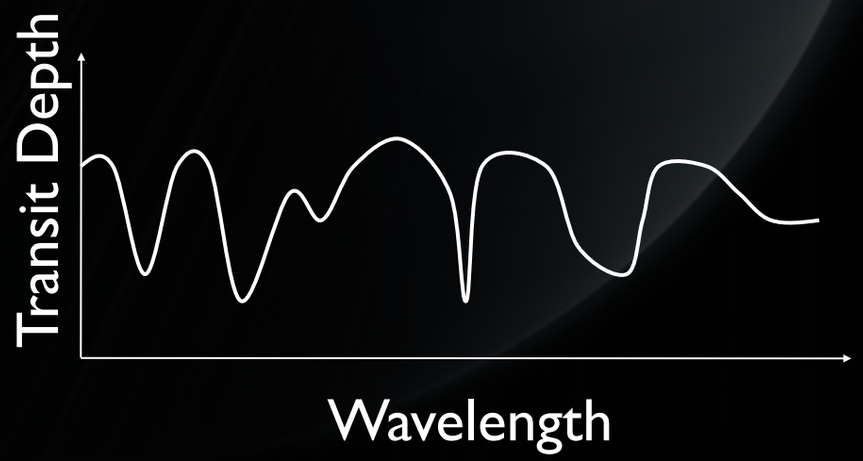




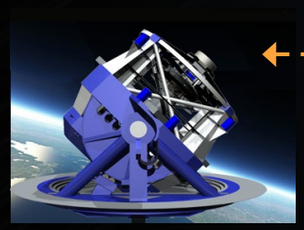
Transmission Spectroscopy

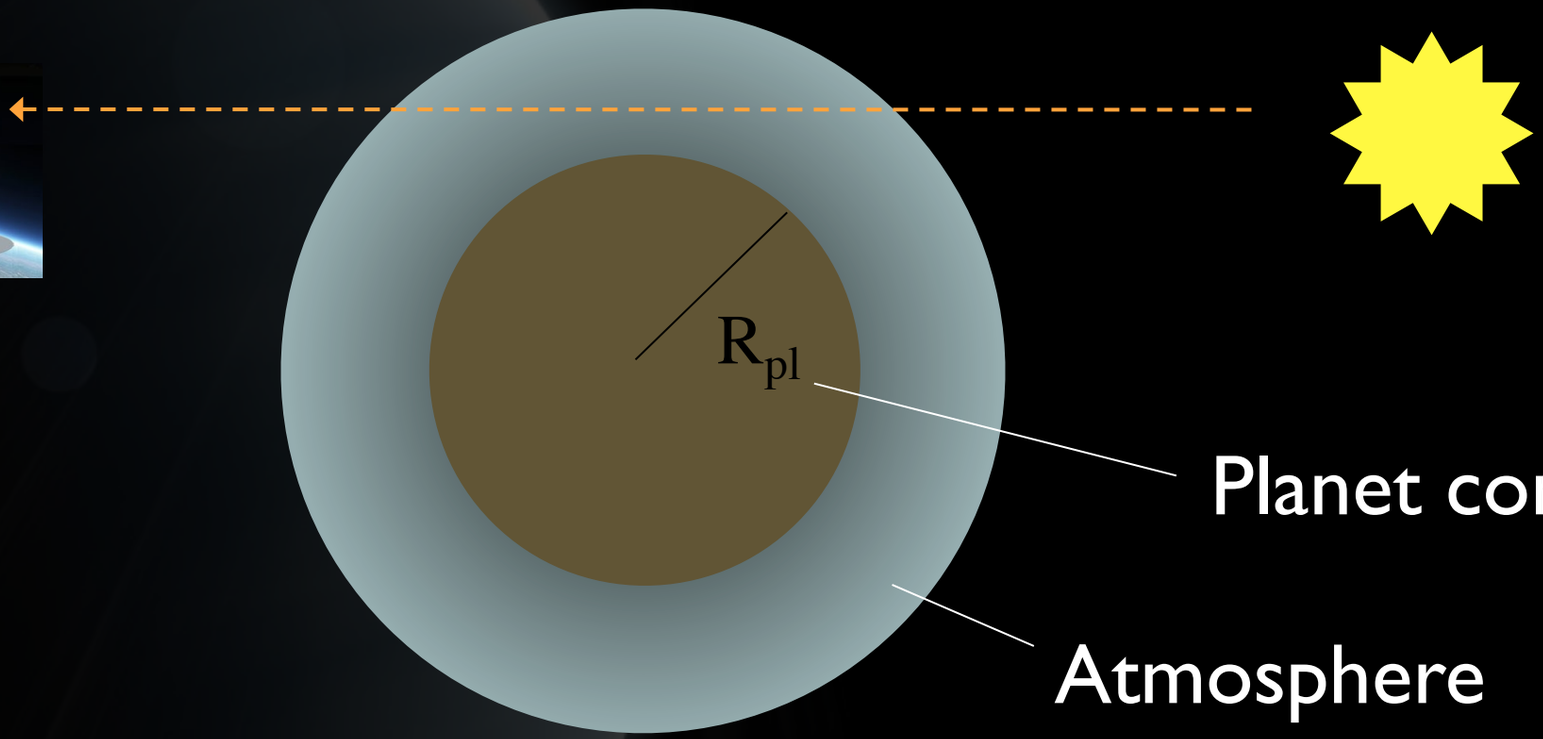


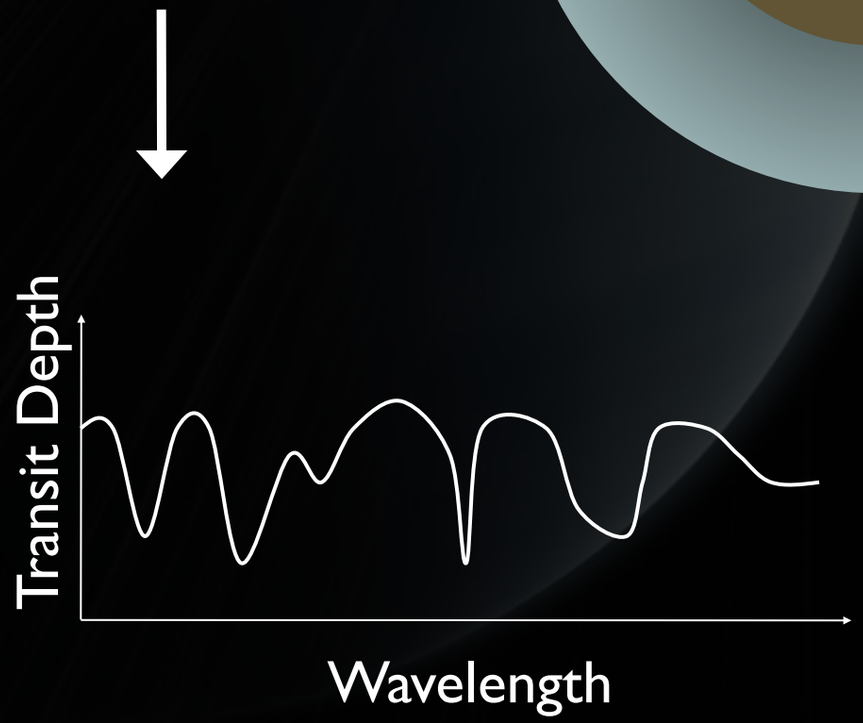




Transmission Spectroscopy

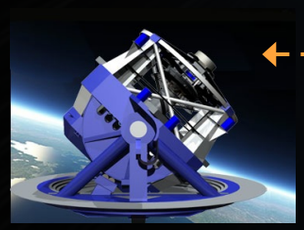


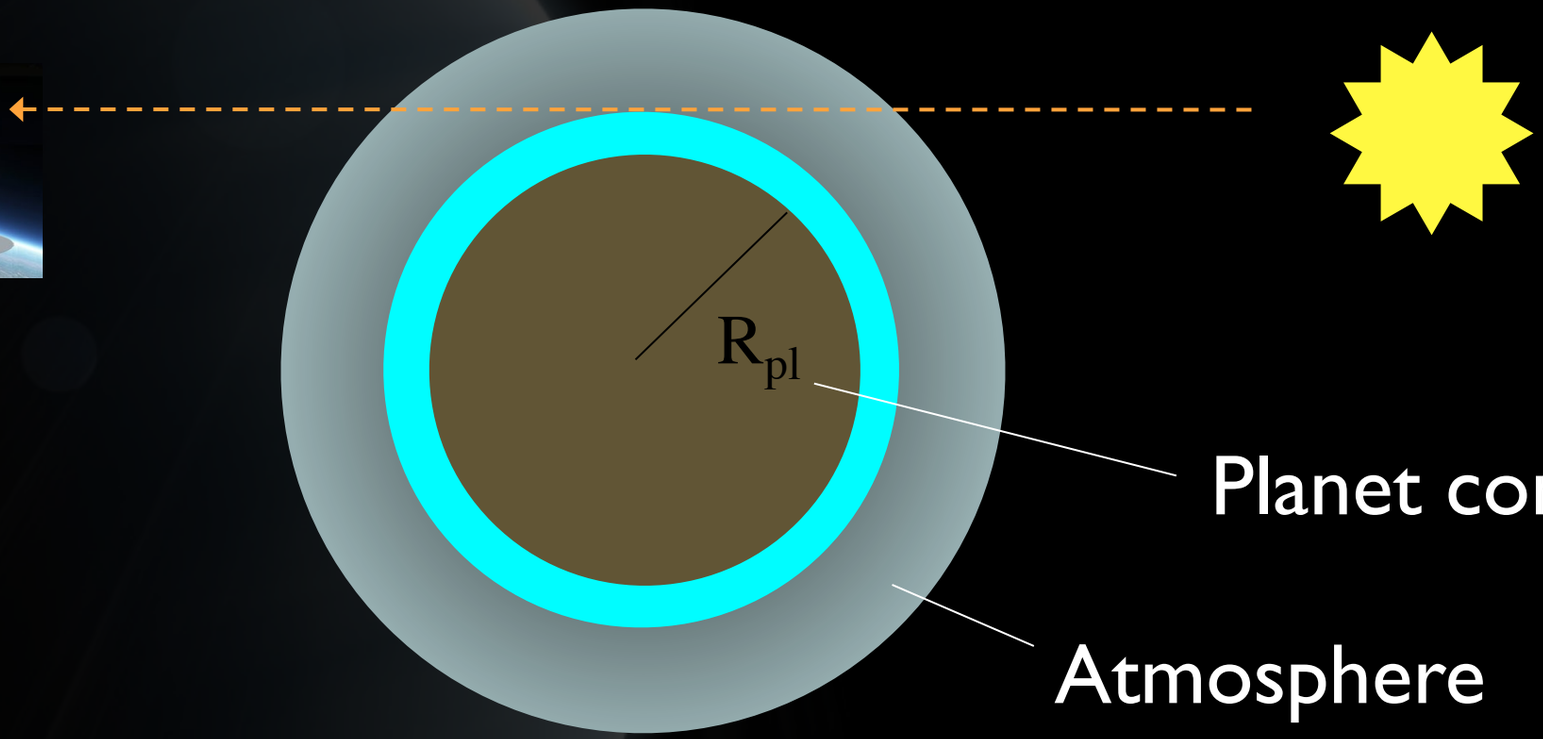


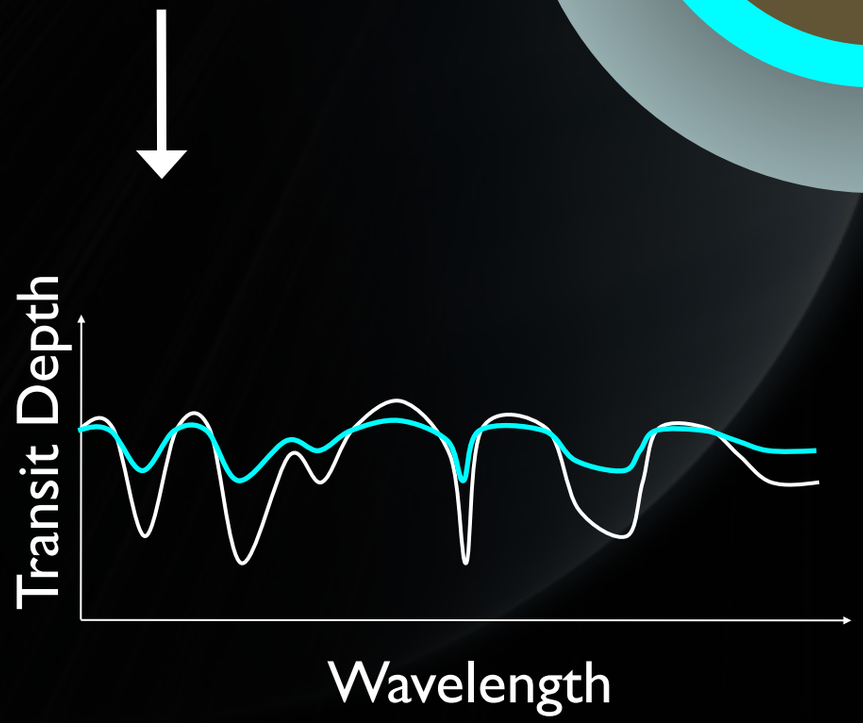


Scale Height: $H=kT/\mu g$

Transmission Spectroscopy







Scale Height: $H=kT/\mu g$

Transmission Spectroscopy - What We Expect

------ No atmosphere

Solar

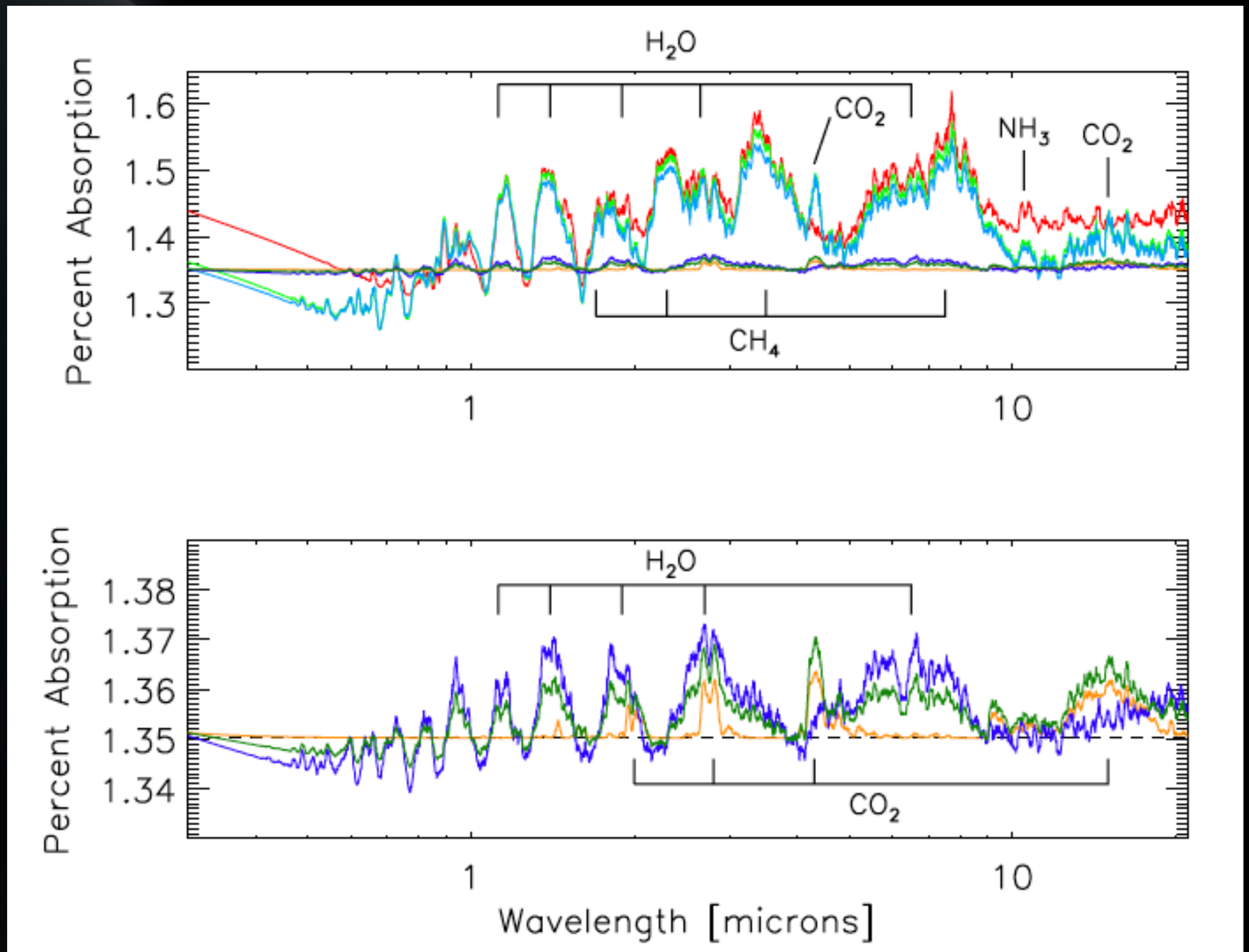
30 x Solar

50 x Solar

H_2O

H_2O - CO_2

CO_2



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

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

Transmission Spectroscopy - What We Expect

------ No atmosphere

Solar

30 x Solar

50 x Solar

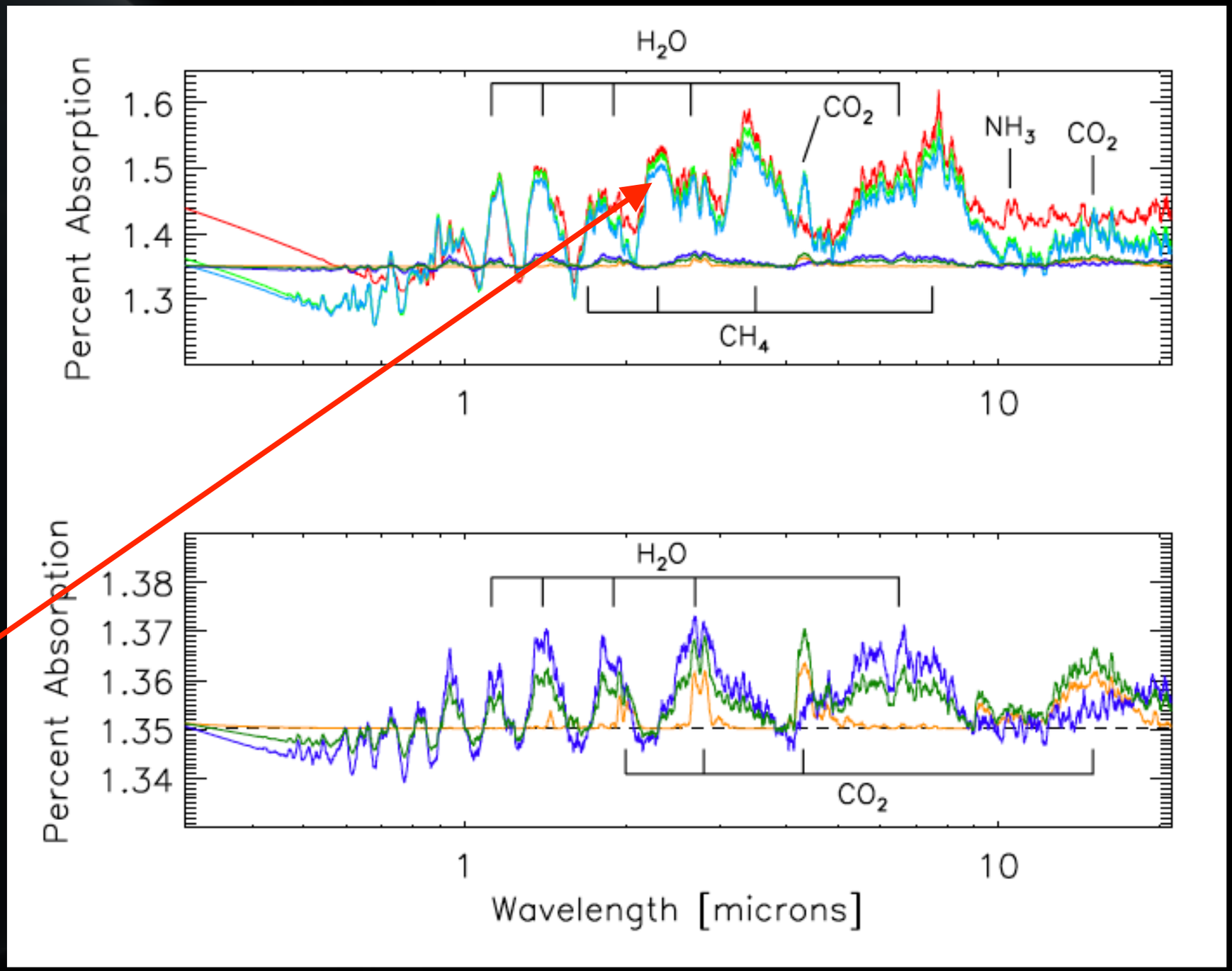
H_2O

H_2O - CO_2

CO_2

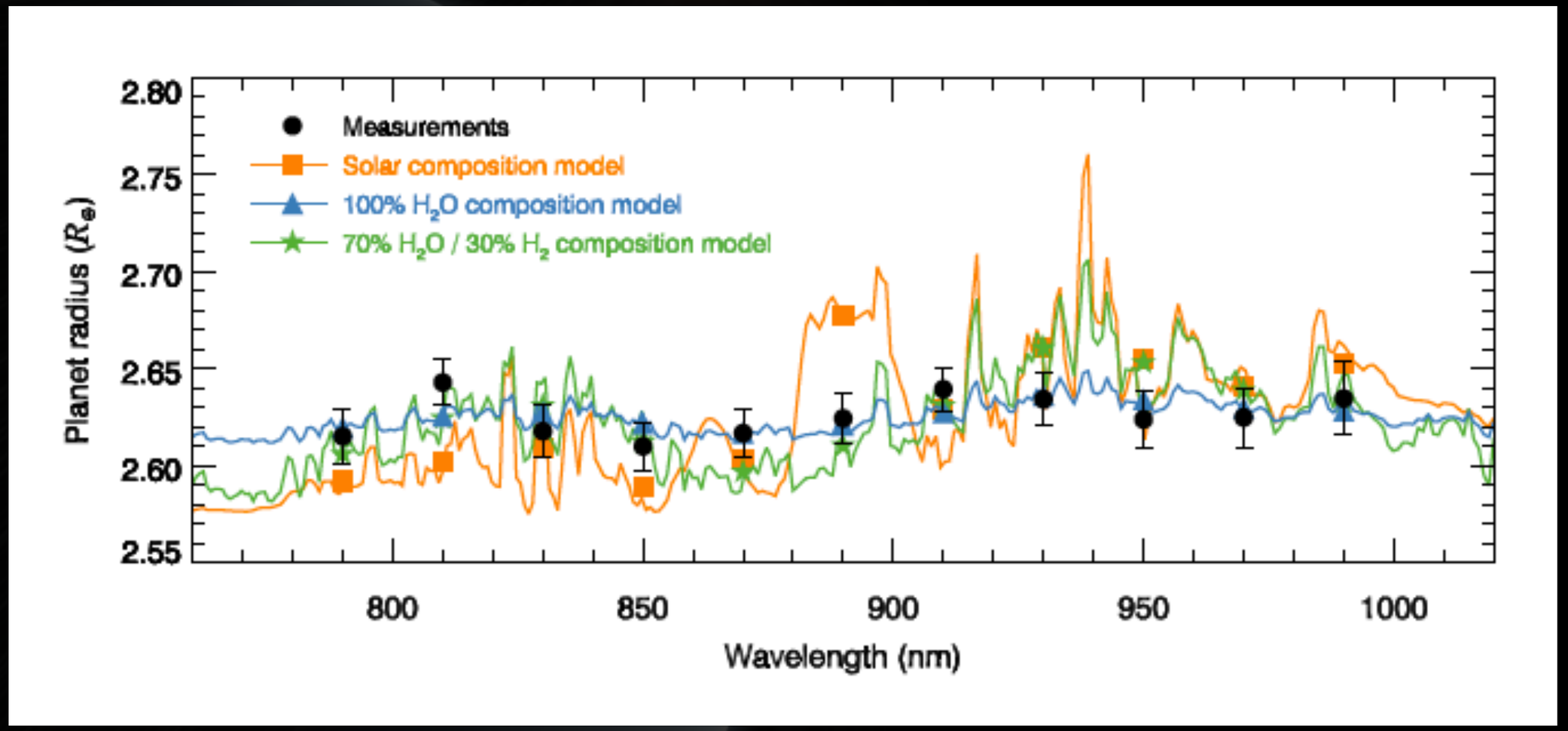
Signatures of 0.1 - 0.3% for H-rich atmospheres!

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



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

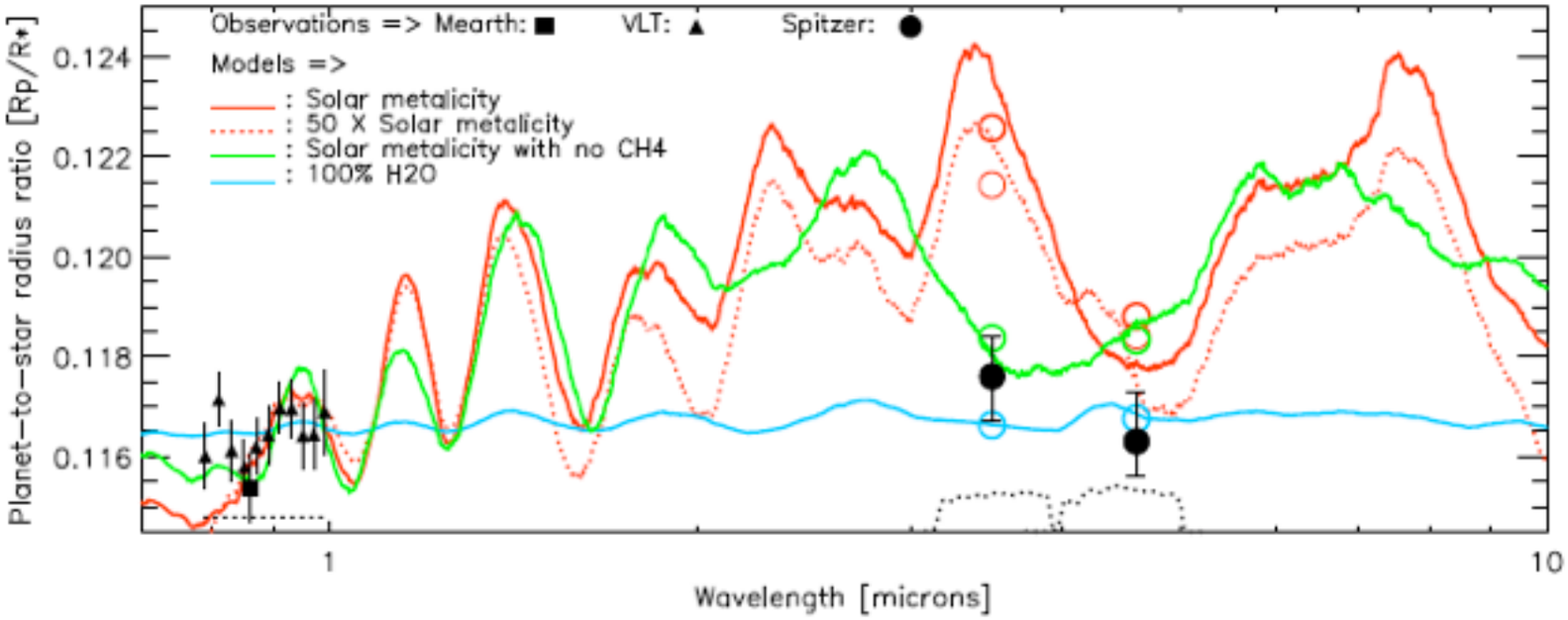
Transmission Spectroscopy - The Observations



Bean, Miller-Ricci Kempton, Homeier, *Nature*, 2010

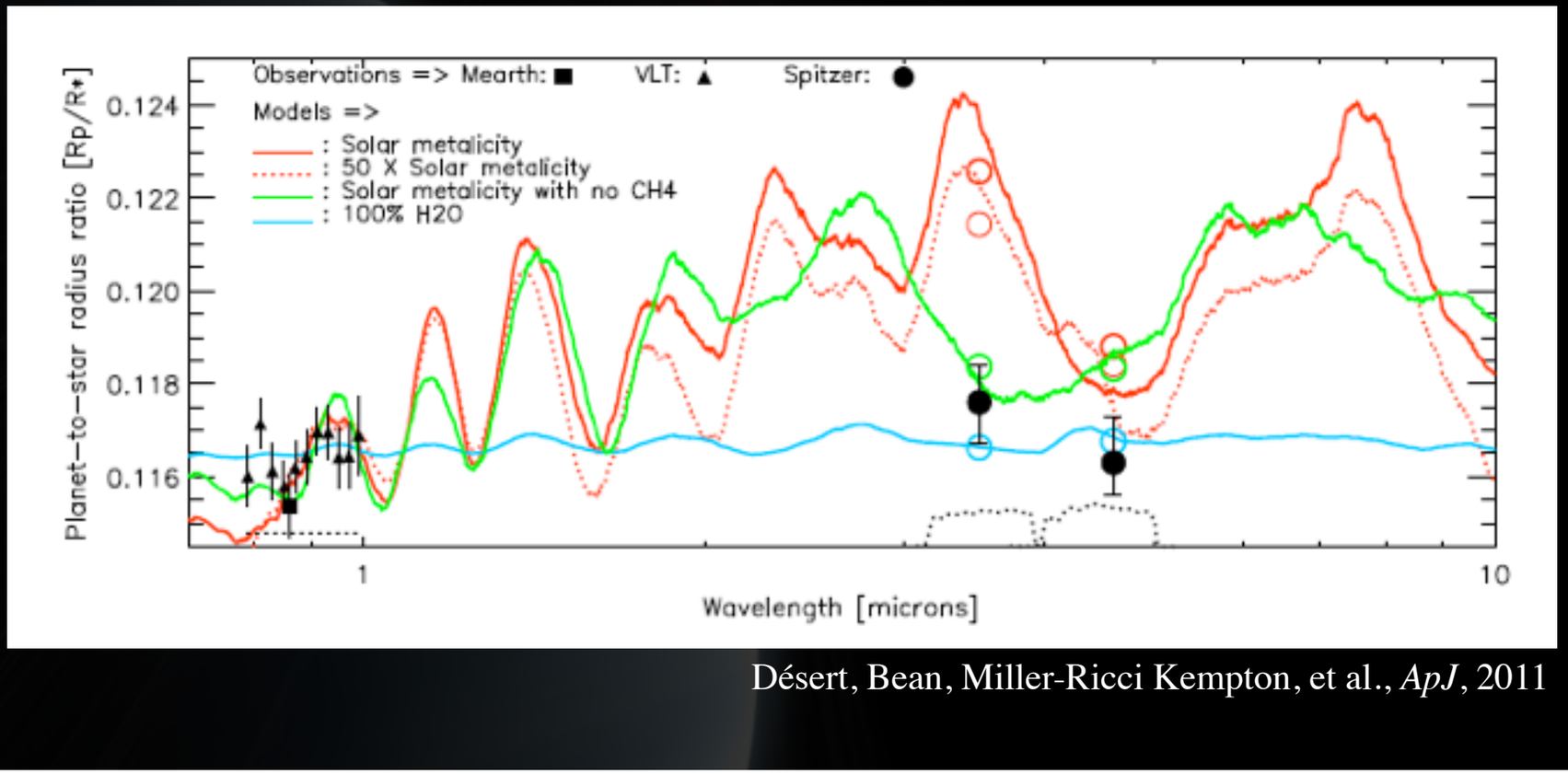
- H-rich composition ruled out at 4.9σ confidence
- 20% water by volume (70% by mass) required to be within 1σ
- Alternative is high-altitude clouds or hazes...

Other Data

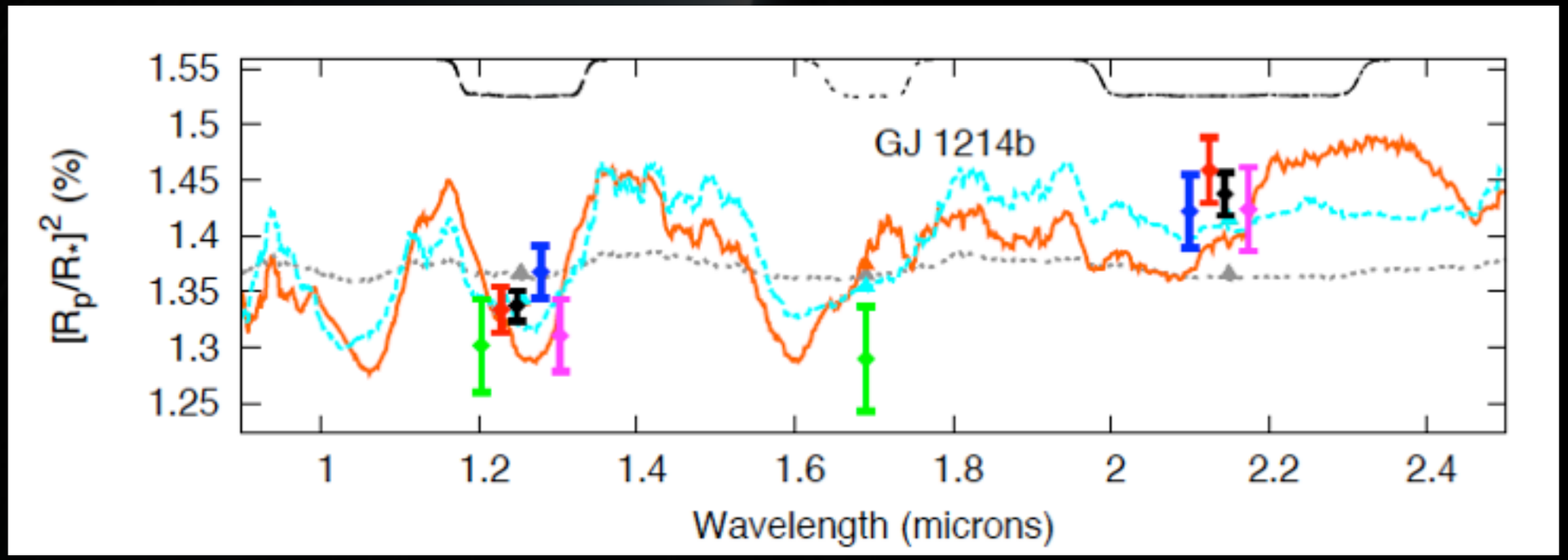


Désert, Bean, Miller-Ricci Kempton, et al., *ApJ*, 2011

Other Data

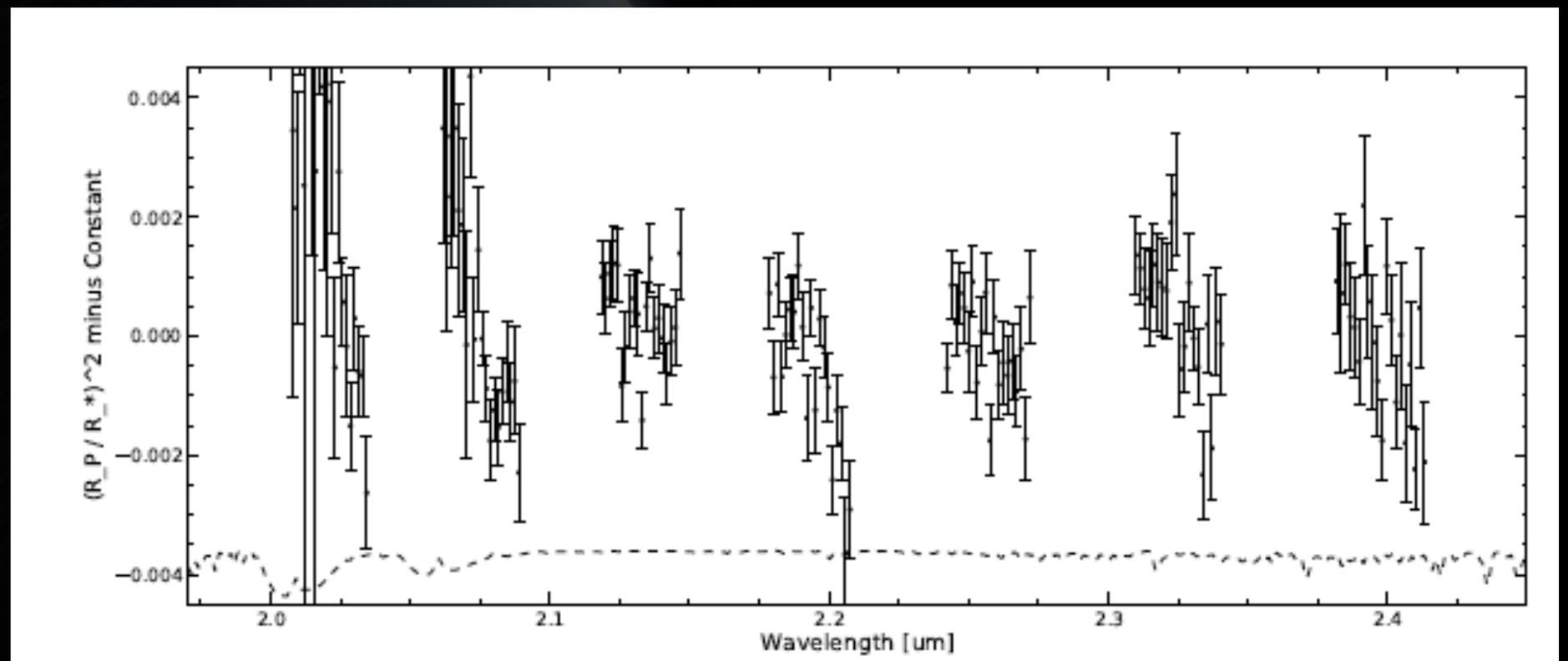


Désert, Bean, Miller-Ricci Kempton, et al., *ApJ*, 2011



Croll, Albert, Jayawardhana, Miller-Ricci Kempton, et al., *ApJ*, 2011

Other Data

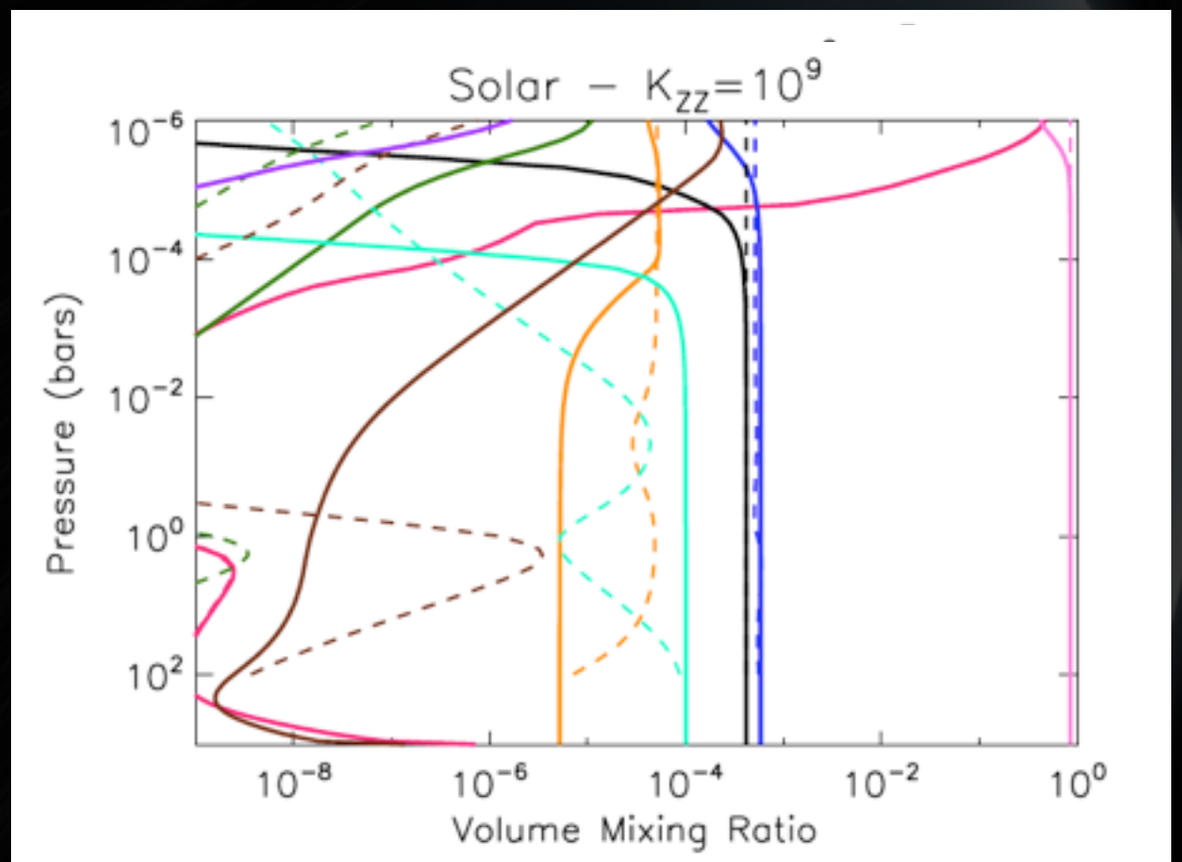


Crossfield, Barman, Hansen, *ApJ*, 2011

- Also Kundurthy et al., Berta et al., Sada et al., and more forthcoming!!

Non-equilibrium Chemistry

'Major' Species



Miller-Ricci Kempton, Zahnle, Fortney, arXiv:1104.5477

H_2 H_2O CH_4 NH_3 N_2

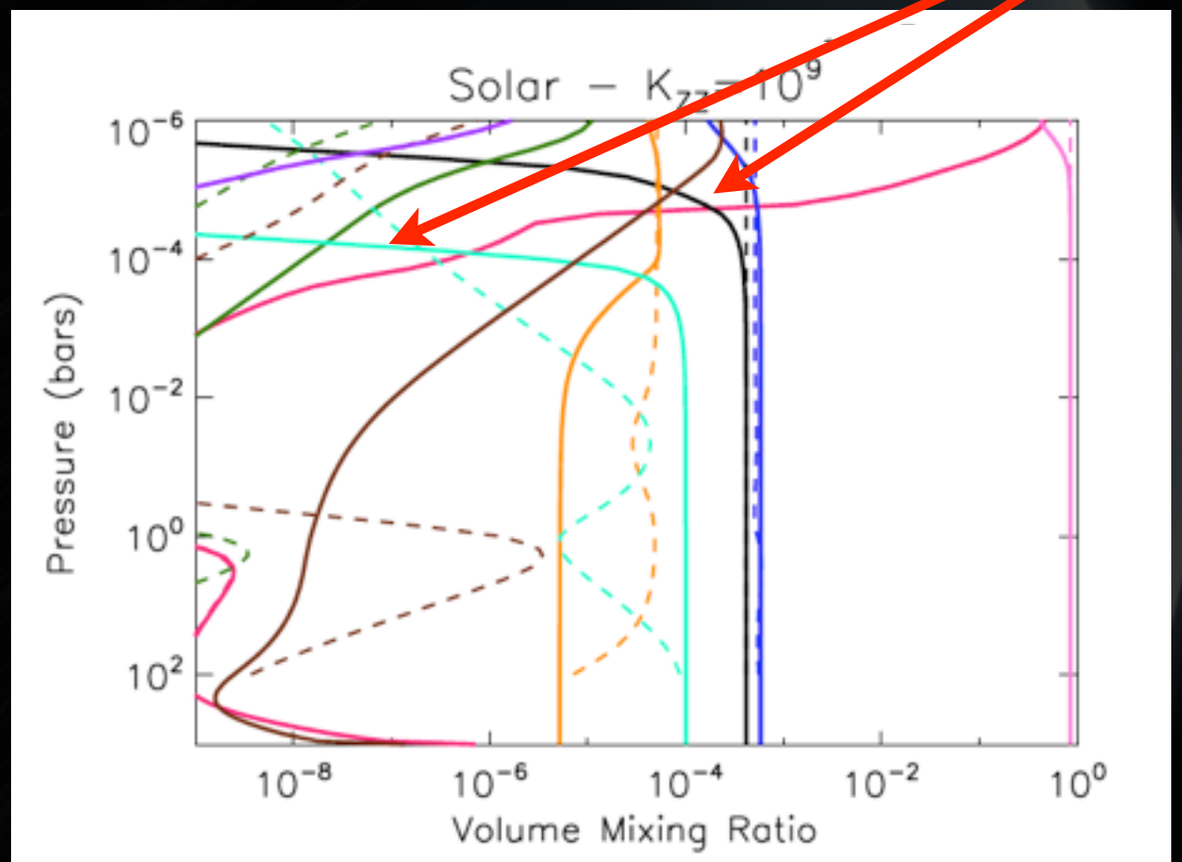
CO CO_2 H OH

- - - - Equilibrium Abundances —— Photochemical Abundances

Non-equilibrium Chemistry

'Major' Species

Depletion of methane + ammonia via photodissociation



Miller-Ricci Kempton, Zahnle, Fortney, arXiv:1104.5477

H_2 H_2O CH_4 NH_3 N_2

CO CO_2 H OH

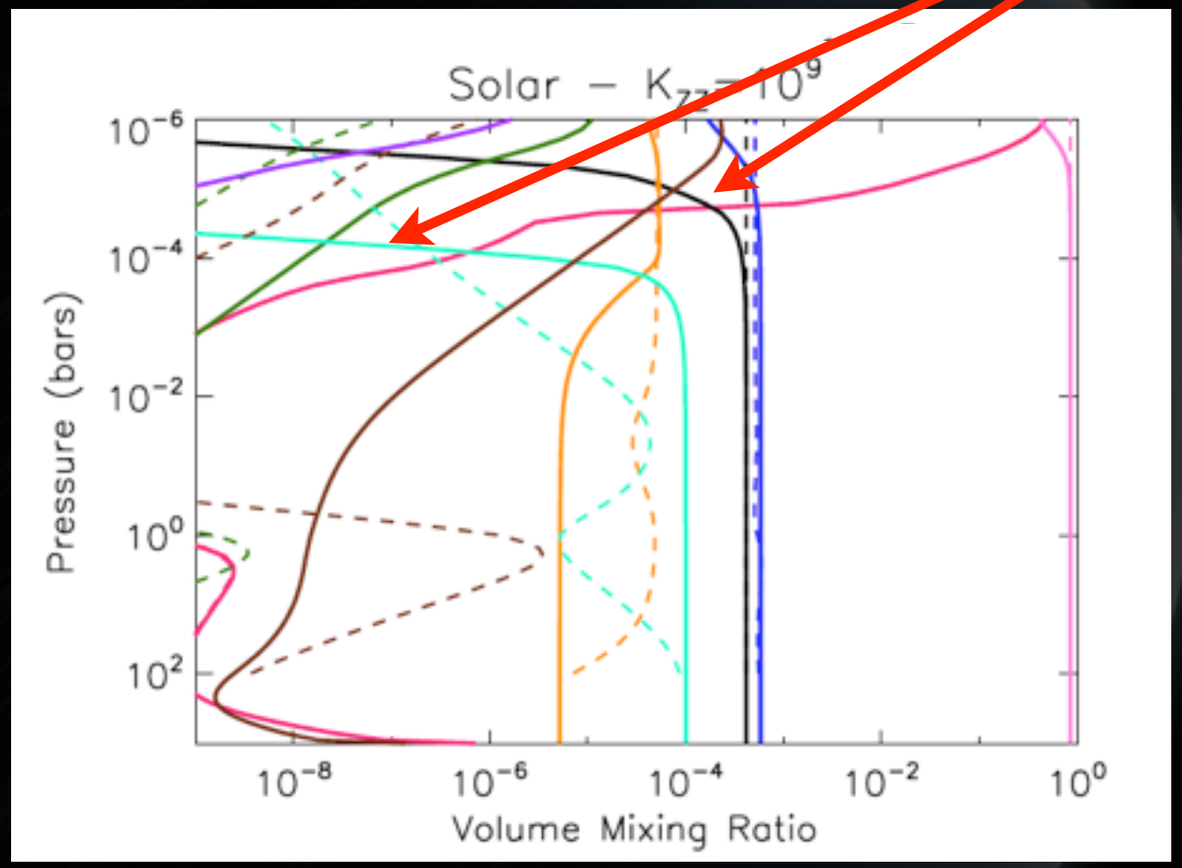
- - - - Equilibrium Abundances —— Photochemical Abundances

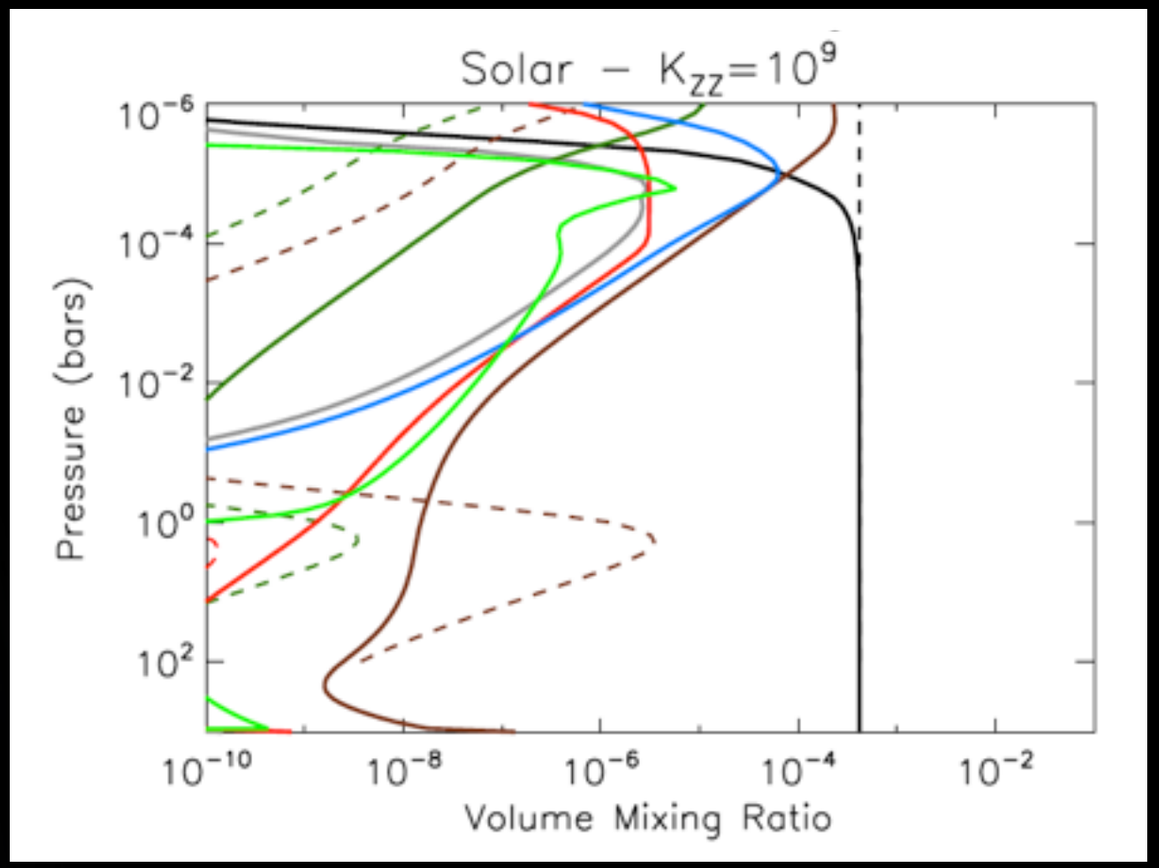
Non-equilibrium Chemistry

‘Major’ Species

Depletion of methane + ammonia via photodissociation

Carbon-Bearing Species





Miller-Ricci Kempton, Zahnle, Fortney, arXiv:1104.5477

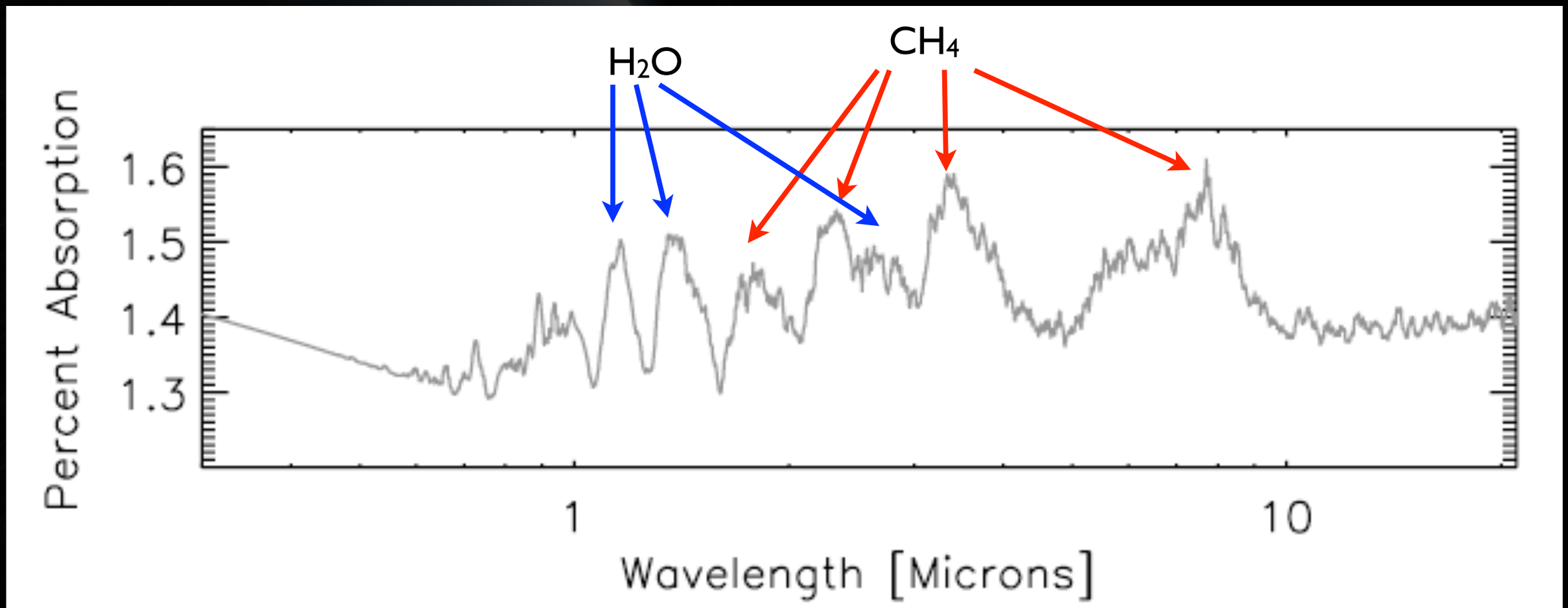
H_2 H_2O CH_4 NH_3 N_2 CO CO_2 H OH

CH_4 C_2H_2 C_2H_4 C_2H_6 HCN CO CO_2

- - - - Equilibrium Abundances —— Photochemical Abundances

Transmission Spectra

5 x Solar



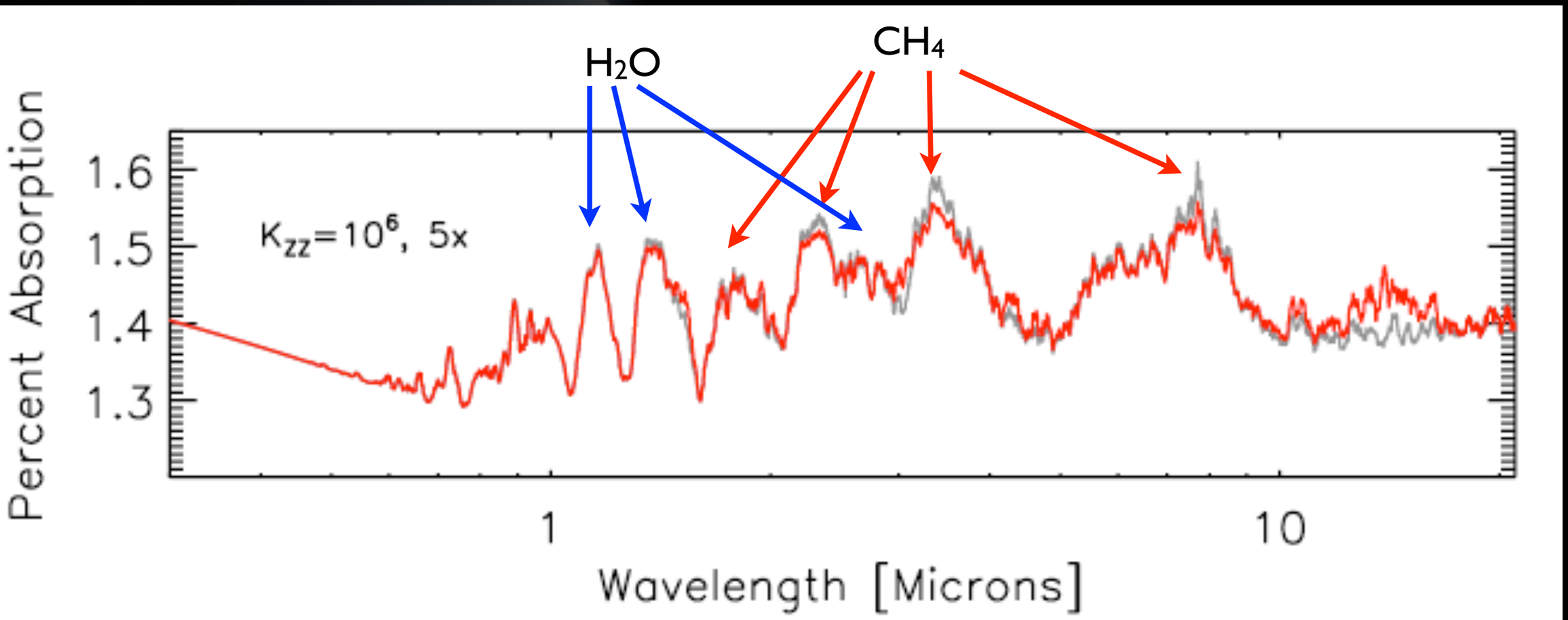
Miller-Ricci Kempton, Zahnle, Fortney, arXiv:1104.5477

Equilibrium Abundances

Photochemical Abundances

Transmission Spectra

5 x Solar



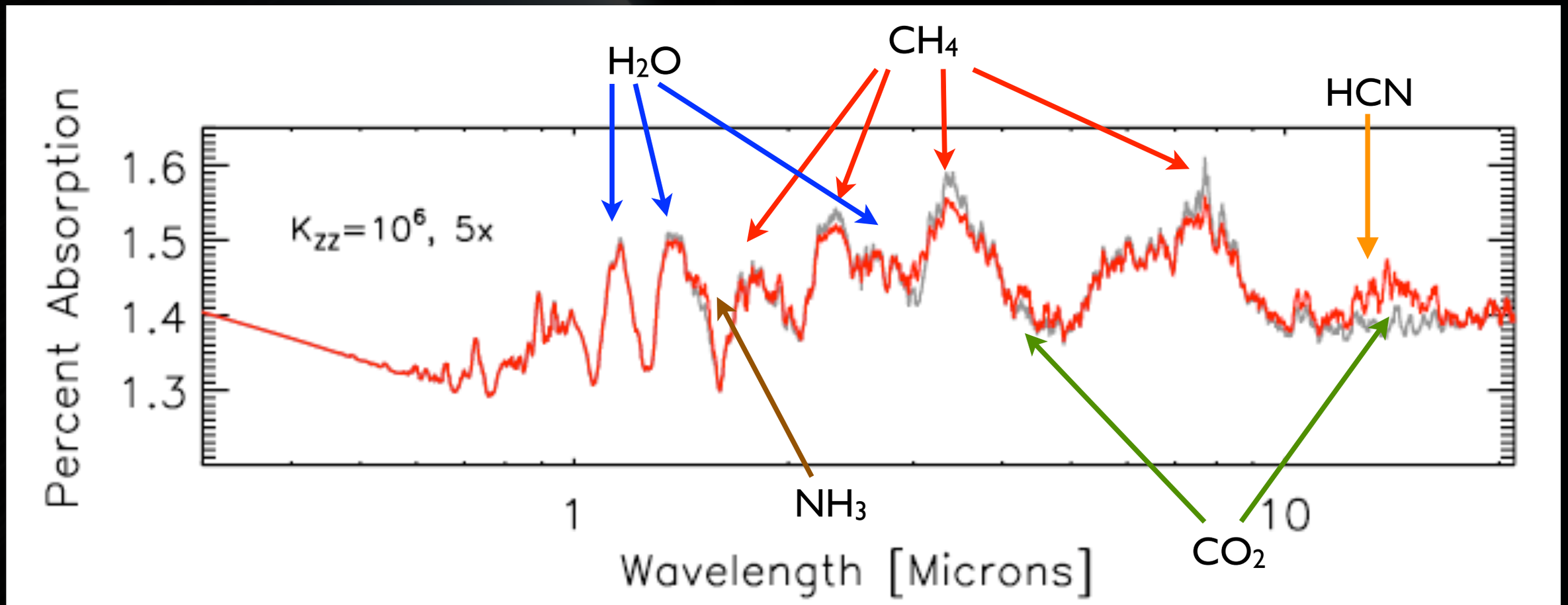
Miller-Ricci Kempton, Zahnle, Fortney, arXiv:1104.5477

Equilibrium Abundances

Photochemical Abundances

Transmission Spectra

5 x Solar

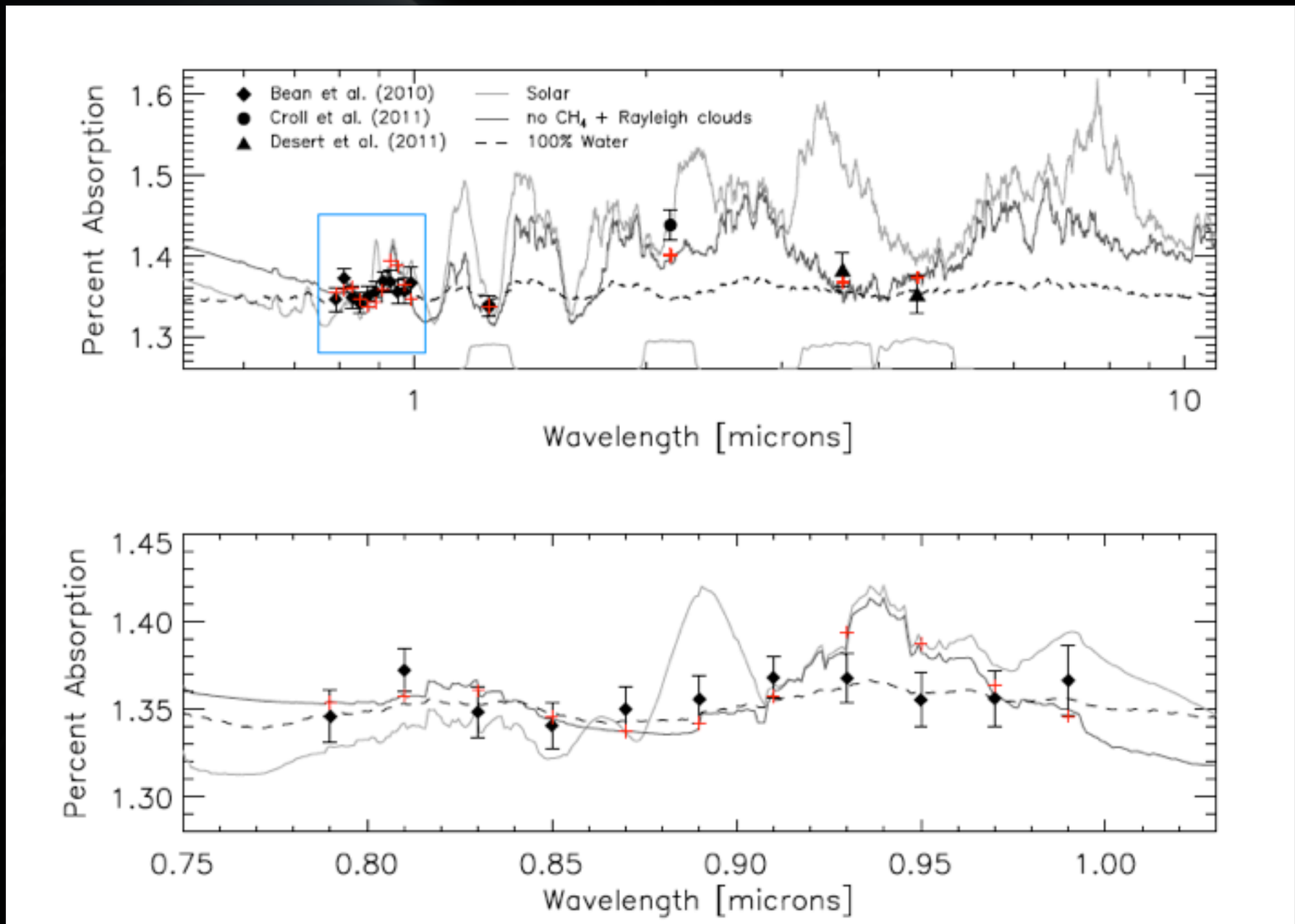


Equilibrium Abundances

Photochemical Abundances

Miller-Ricci Kempton, Zahnle, Fortney, arXiv:1104.5477

Comparison of Models and Data



Miller-Ricci Kempton, Zahnle, Fortney, arXiv:1104.5477

Conclusions

- GJ 1214b is the first super-Earth to have its atmosphere characterized

- GJ 1214b's atmosphere is not well-described by a hydrogen-dominated atmosphere in chemical equilibrium

- Other possibilities include:
  - No methane / High clouds
  - High mean molecular weight atmosphere (> 20% H_2O)

- Additional observations will be necessary to break the degeneracy between the different possibilities (forthcoming!)