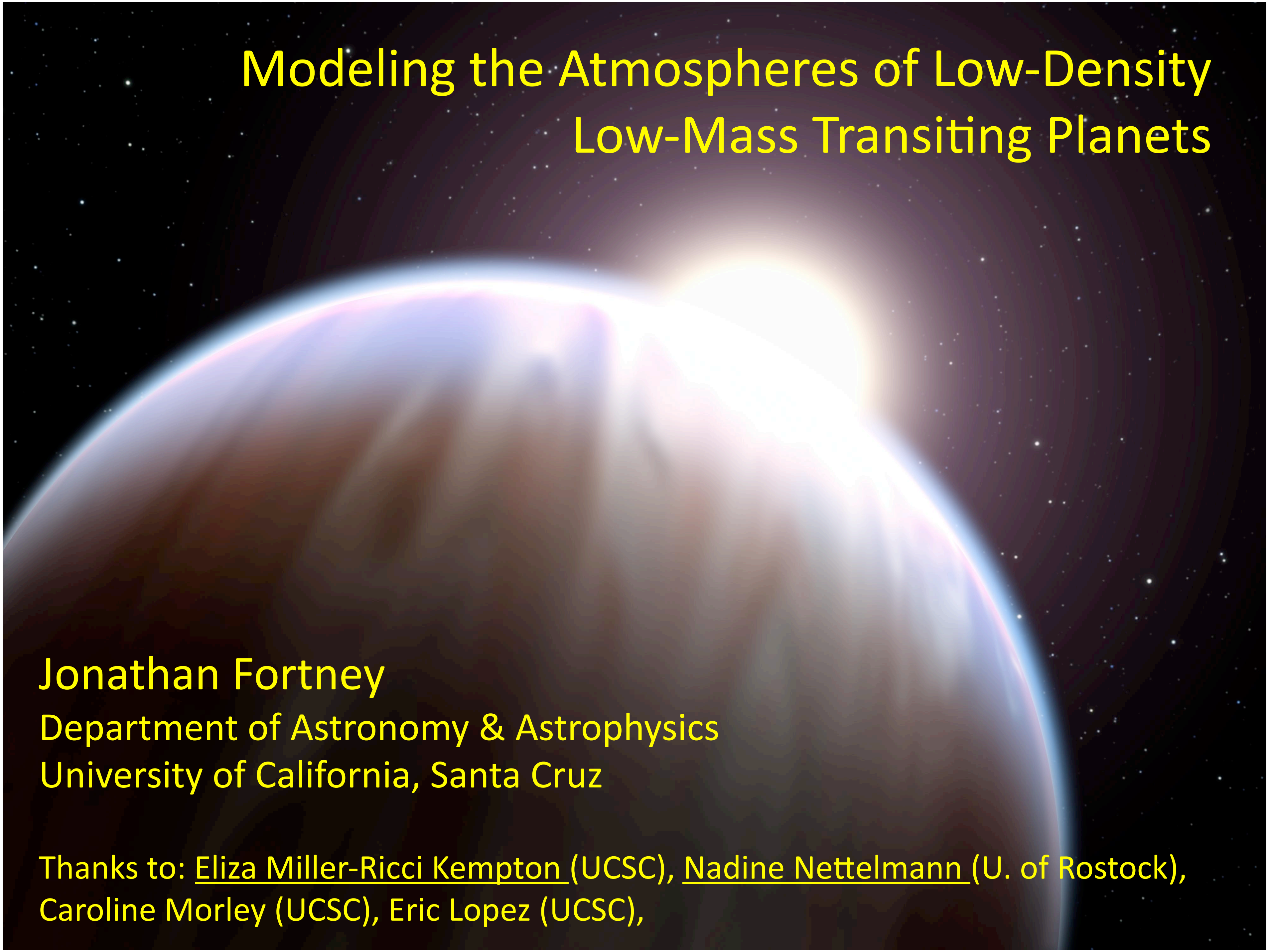

Modeling the Atmospheres of Low-Density Low-Mass Transiting Planets

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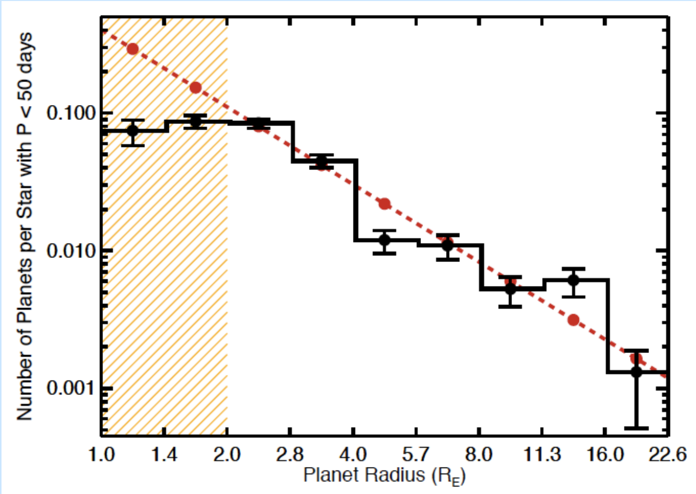
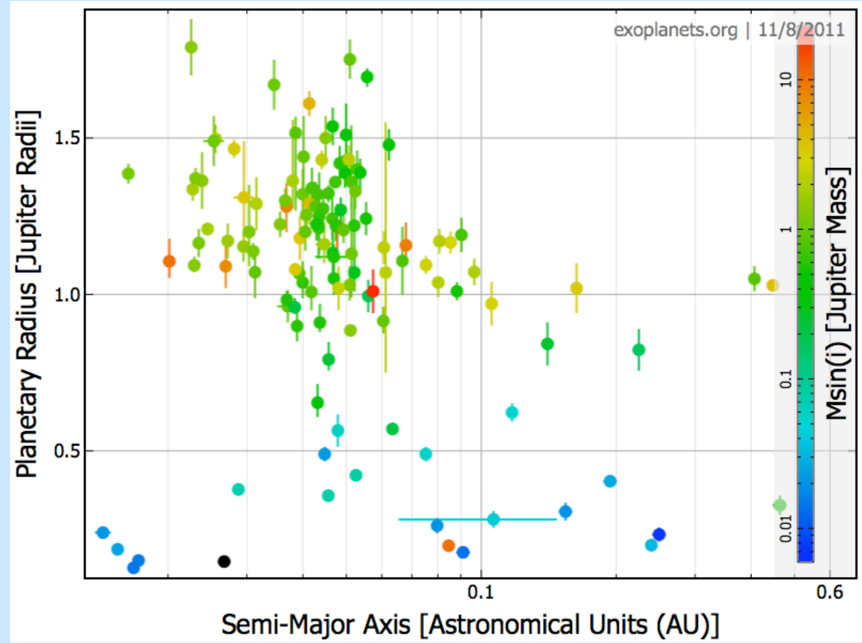
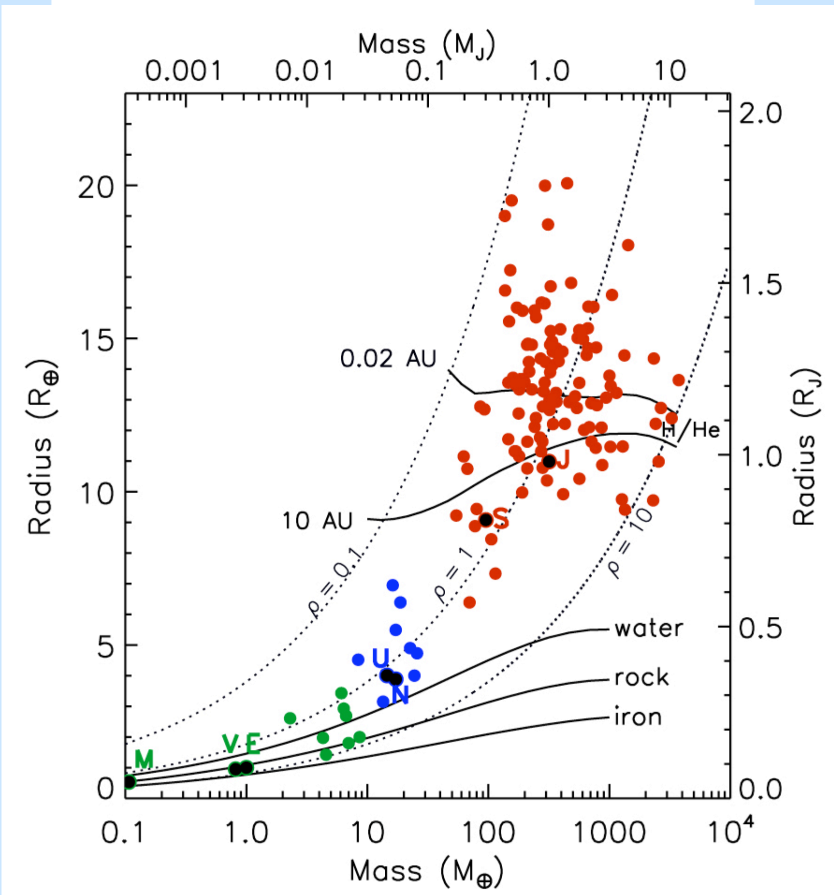
Thanks to: Eliza Miller-Ricci Kempton (UCSC), Nadine Nettelmann (U. of Rostock), Caroline Morley (UCSC), Eric Lopez (UCSC),







Low-Mass, Low-Density Planets are Common and Important

GJ 1214b as a Prototype for a Class of Planets

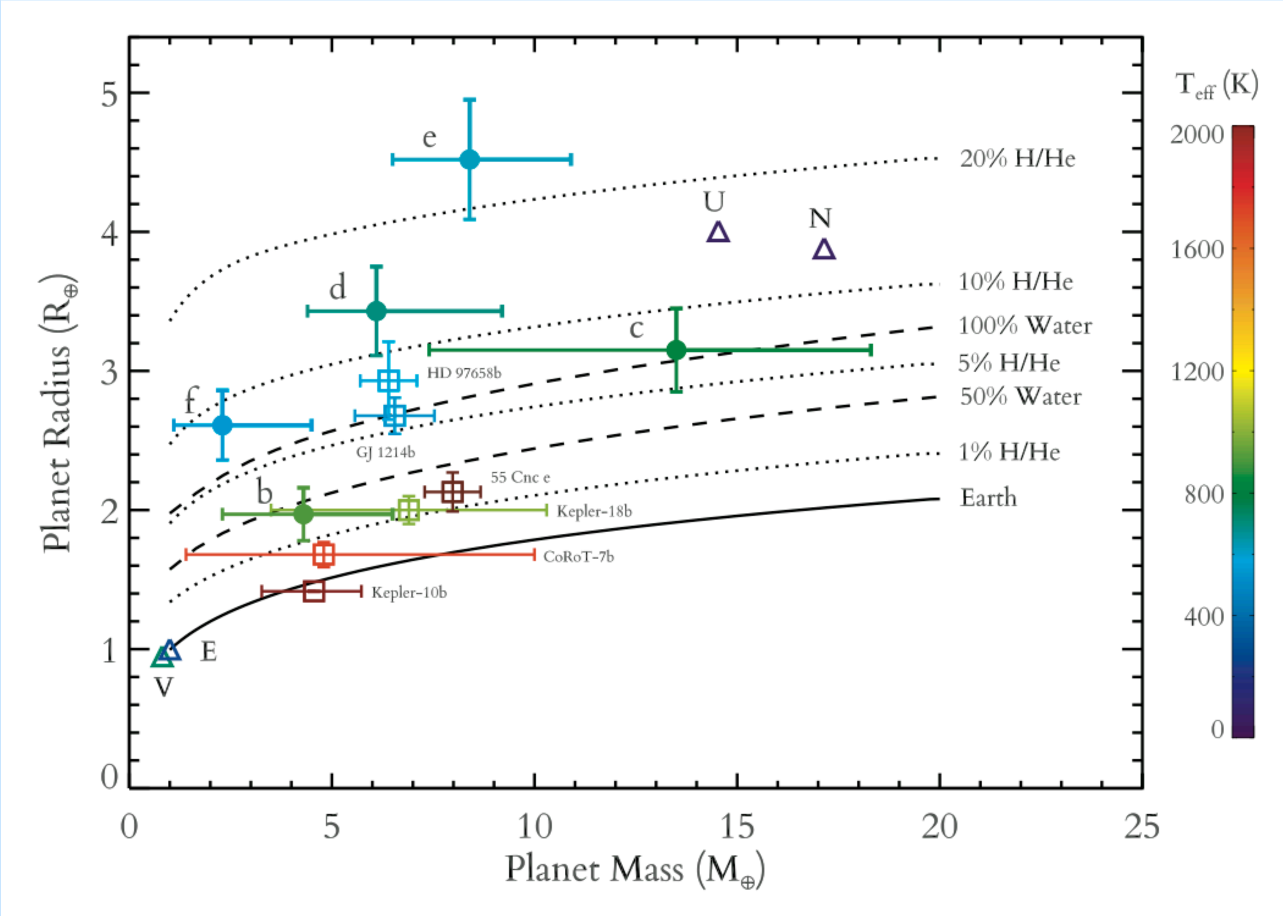
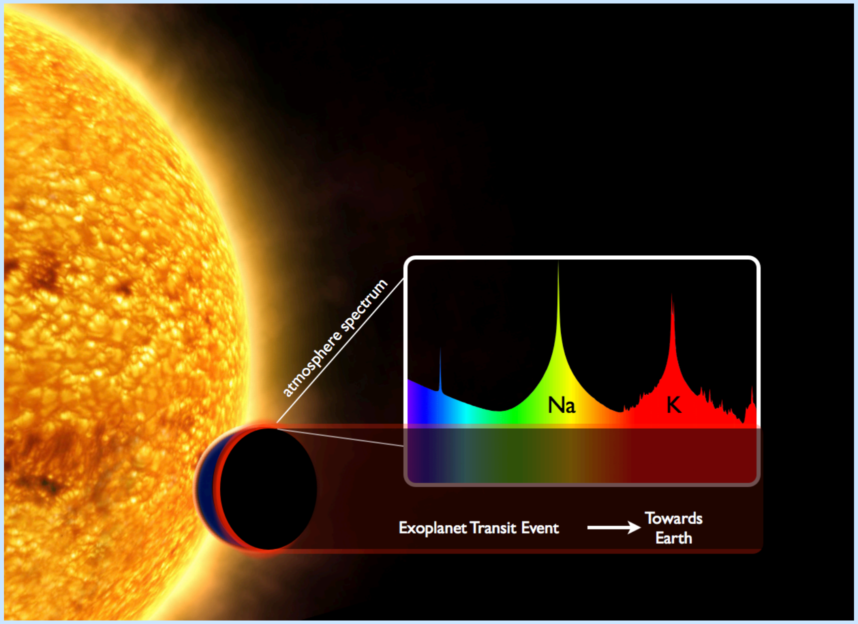
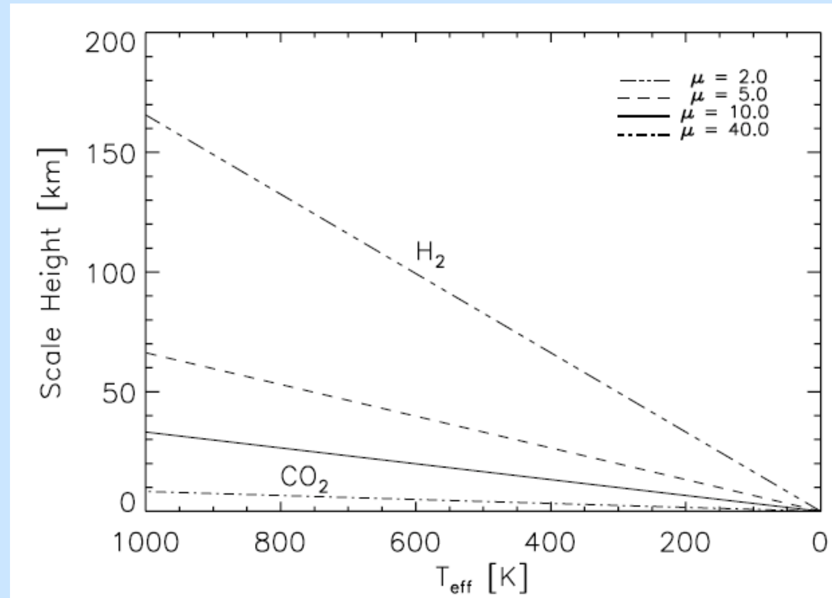


Figure by Eric Lopez

Probing the Atmosphere to Better Understand the Composition of Low-Mass Planets





Miller-Ricci et al. (2009)

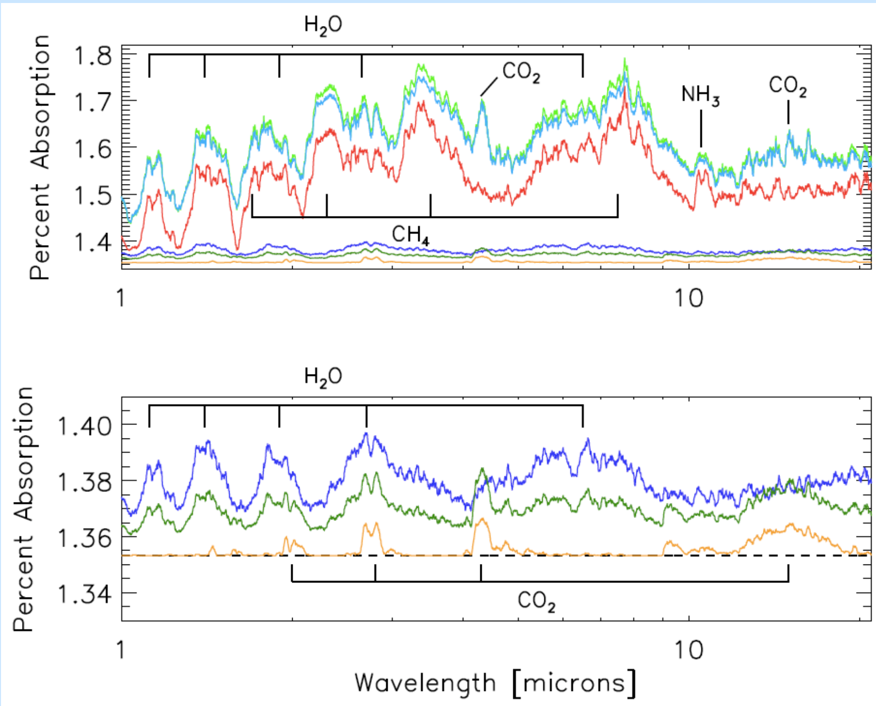
•One can probe the "transmission spectrum" of transiting planets to look for absorption features in a planet's atmosphere

•Annular area of atmosphere probed is are much larger for atmospheres made of hydrogen

- This leads to larger variations in planet radius / transit depth

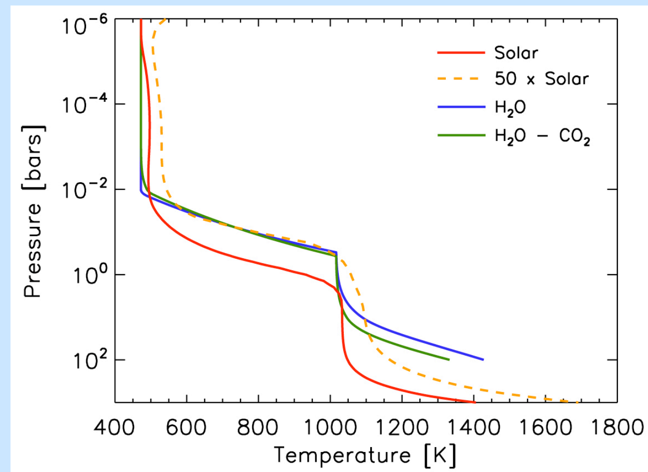
$$\Delta D \sim \frac{20 H R_{pl}}{R_*^2}$$

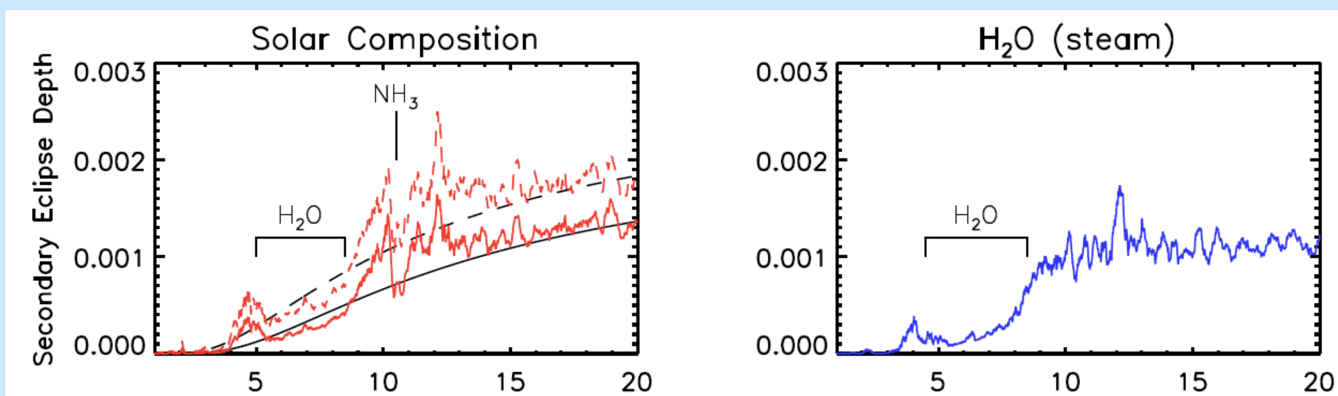
GJ 1214: Initial Calculations



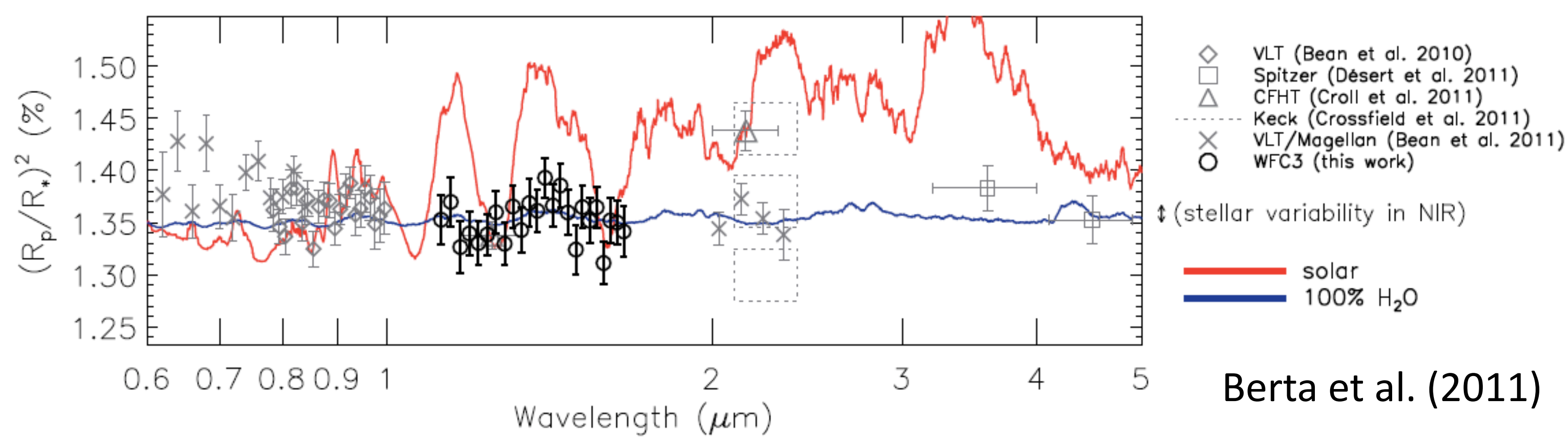
Miller-Ricci & Fortney (2010)

Determining atmospheric composition from transmission spectrum observations easier than observations at secondary eclipse





GJ 1214 Data Yield an Essentially Flat Transmission Spectrum



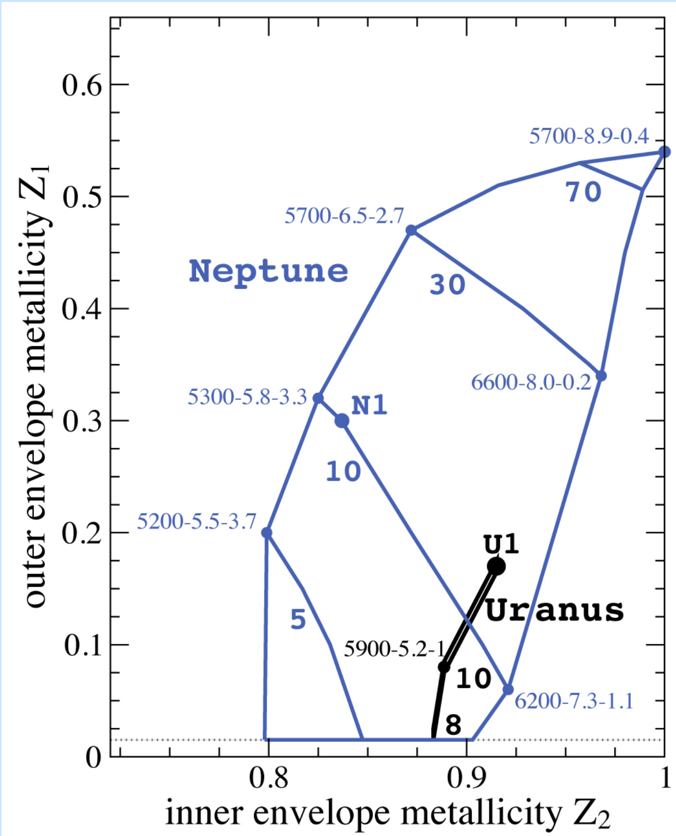
Berta et al. (2011)

Implies the atmosphere has one or more of:

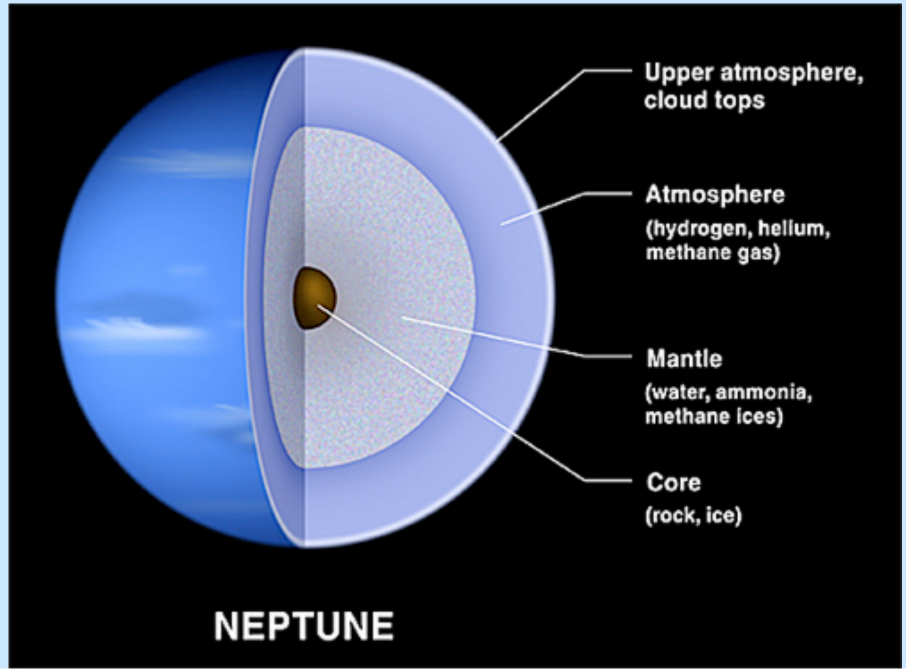
1) A high mean molecular weight, leading to small scale height
2) Equilibrium condensate clouds obscuring the atmosphere (Caroline Morley talk, Thurs)
3) Photochemically derived cloud/haze (from methane?), as in Titan or Jupiter

But, upon reflection: A "fluffy" solar-composition atmosphere is exceptionally unlikely, just from looking in our solar system

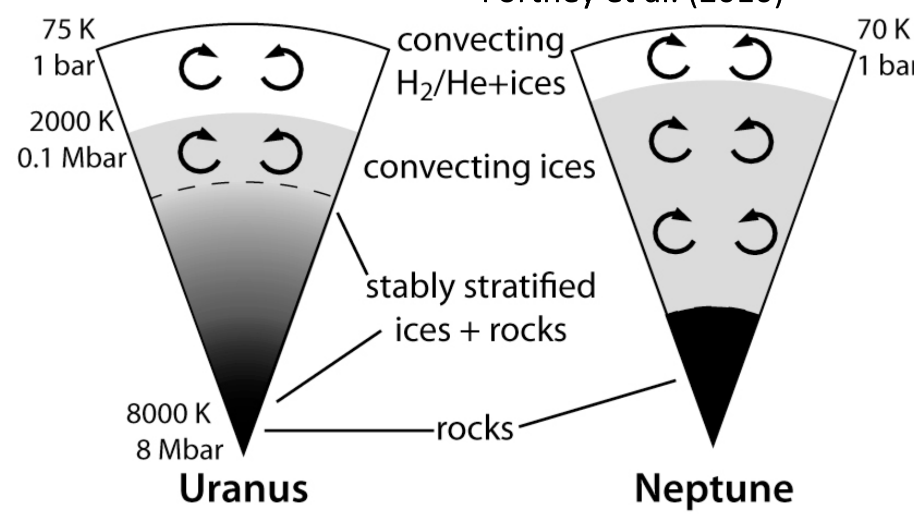
Comparative Planetology Starts With What you Know



Nettelmann et al. (2012)



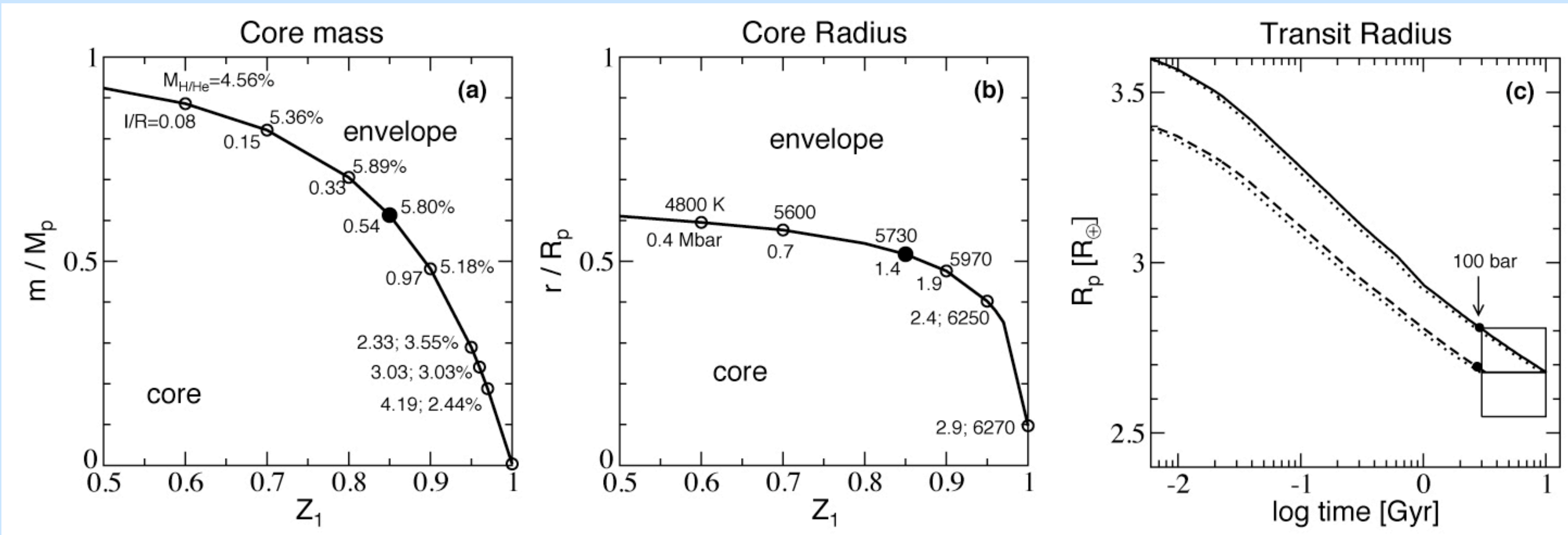
Fortney et al. (2010)



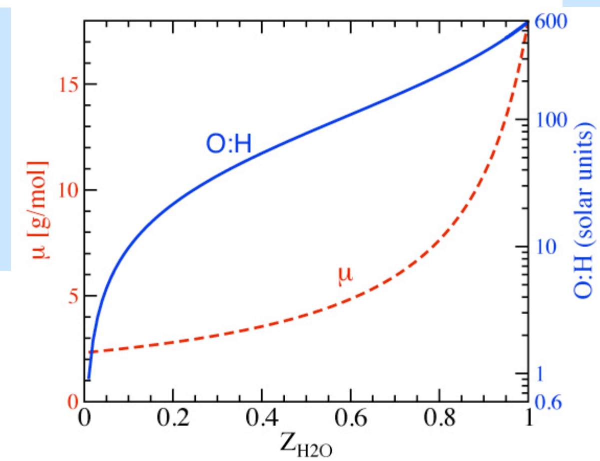
- •Outer layer of U & N is potentially very ice-rich
- •Inner layer of U & N is absolutely ice-rich

GJ 1214b as Quite Reasonable Neptune-like Planet

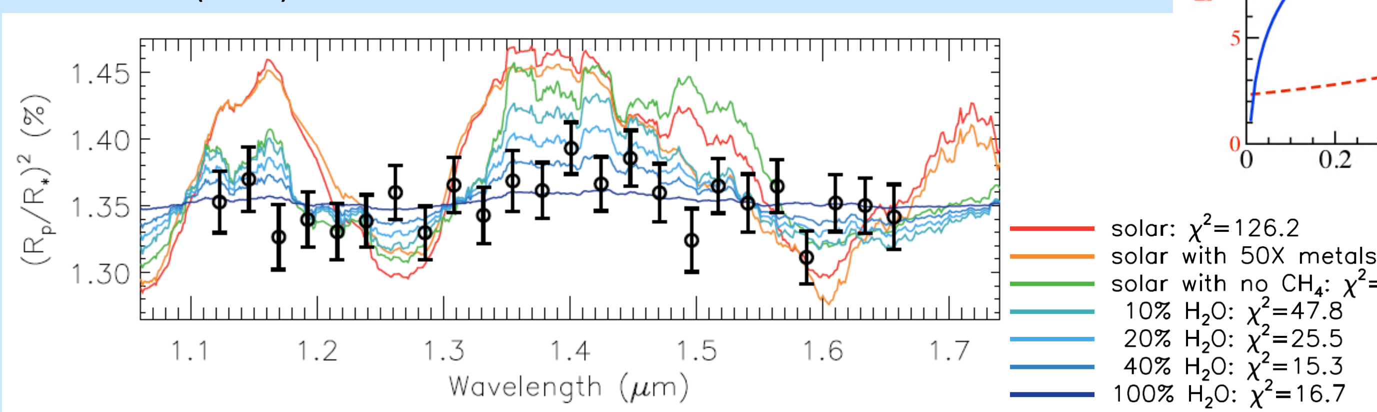
Nettelmann et al. (2011)



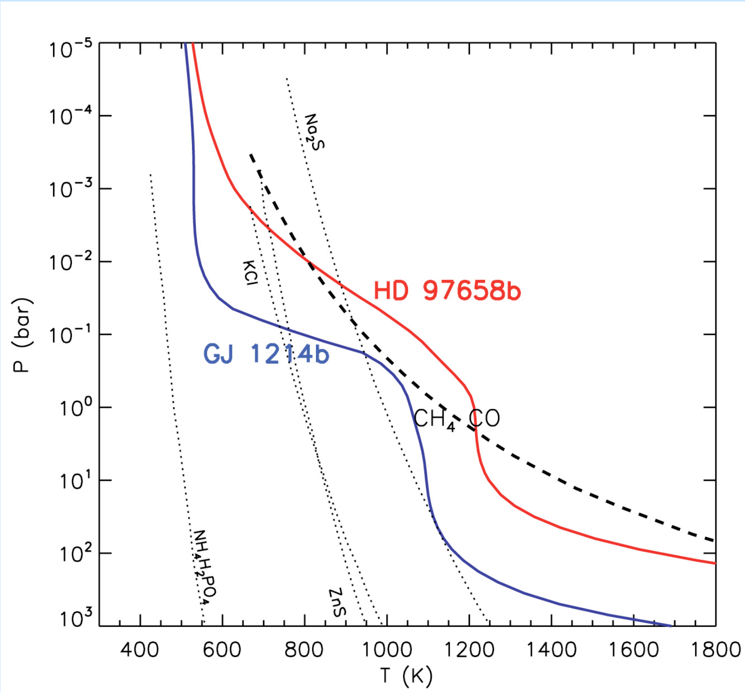
Thermal Evolution of GJ 1214b with H_2O/H_2 atop a rocky core

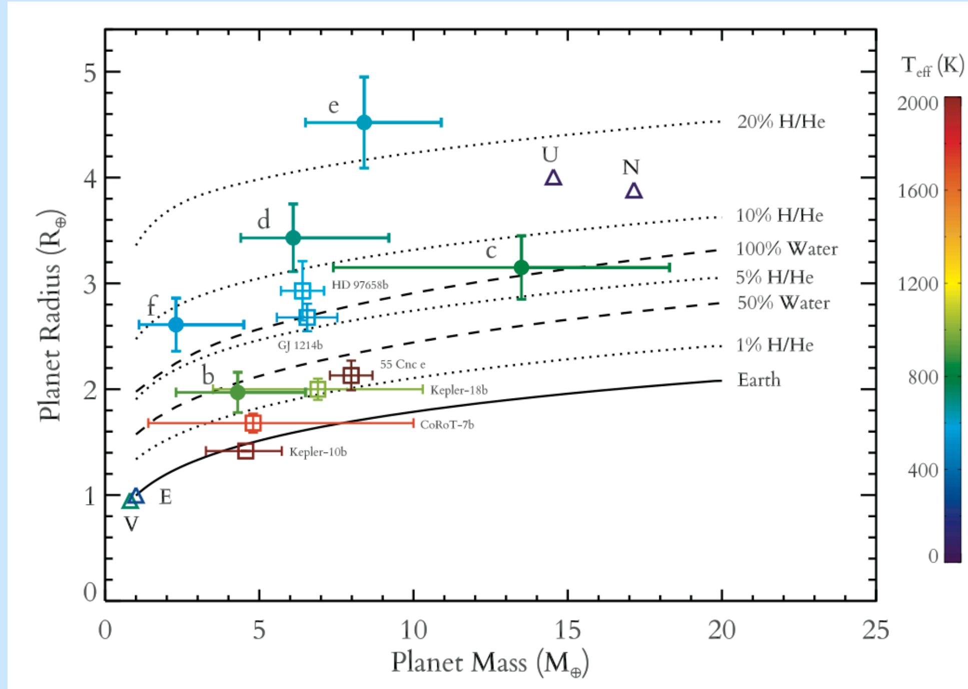


Berta et al. (2012)



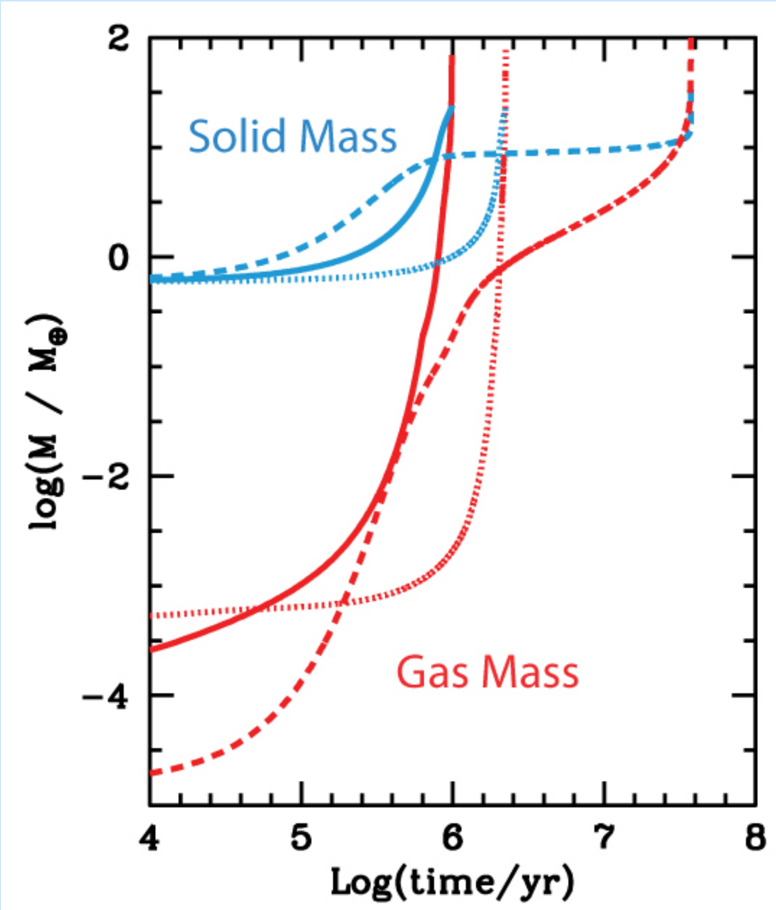
HD 97658: More Comparative Planetology



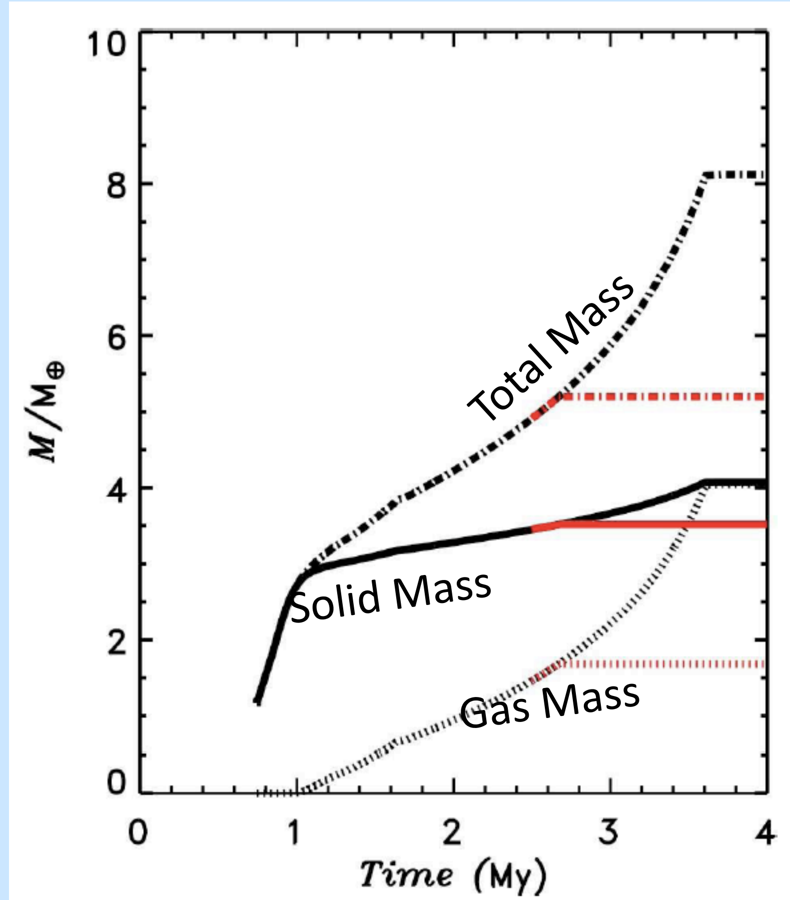


- HD 97658b, as GJ 1214b's slight warmer twin
- Same place on the Mass-Radius diagram
  - If they both have water-rich envelopes, the two planets should appear similar
  - If envelopes *are predominantly hydrogen, then:*
    - Equilibrium condensate clouds will form at different pressures
    - Different stellar spectra and incident fluxes --> different photochemistry?
    - Less CH_4 and more CO and CO_2 in the warmer HD 98658b

"Core Accretion" formation of sub-Neptunes



Alibert et al. (2005)



Rogers et al. (2011)

- Given that "sub-Neptunes" *vastly outnumber* gas giants, core-accretion planet formation models must be explored in more more detail on the low-mass end

Conclusions

• A batch of new discoveries show that "sub-Neptunes" are a very common type of planet

• GJ 1214b is the original, and best-studied to date
  • Flat transmission spectrum at basically all wavelengths

• The processes that affect mixed H_2O/H_2-dominated atmosphere gain/escape should be investigated in much more detail
  • The Kepler-11 system is a natural laboratory to study atmospheric mass loss
  • Look for a forthcoming paper by Eric Lopez

• Comparative planetology with GJ 1214b, HD 97658b, and others, will be extremely enlightening. Perhaps they are quite Neptune-like?