The Atmosphere of the Transiting Super-Earth GJ 1214b

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Collaborators:
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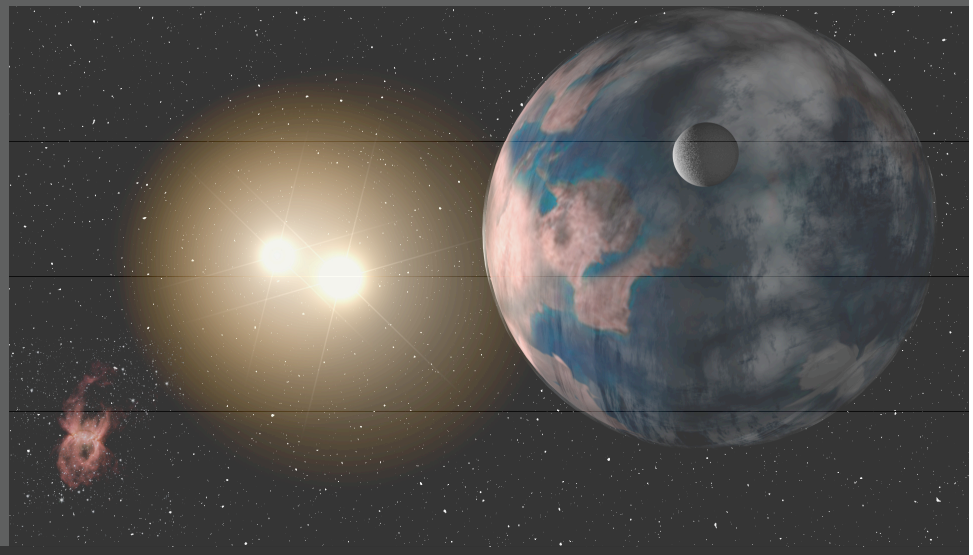
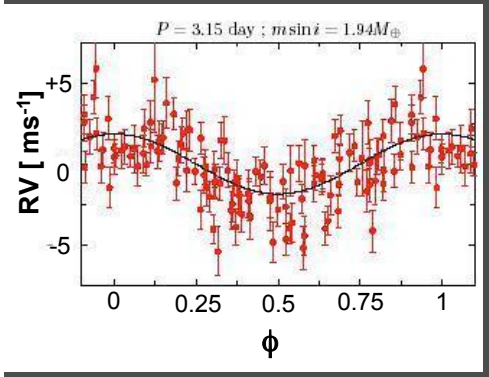
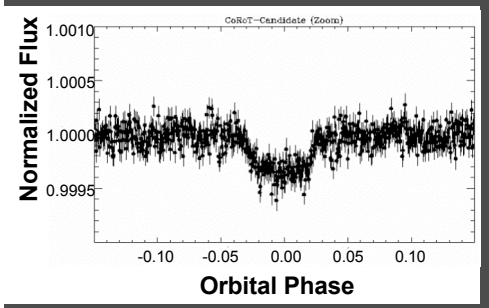
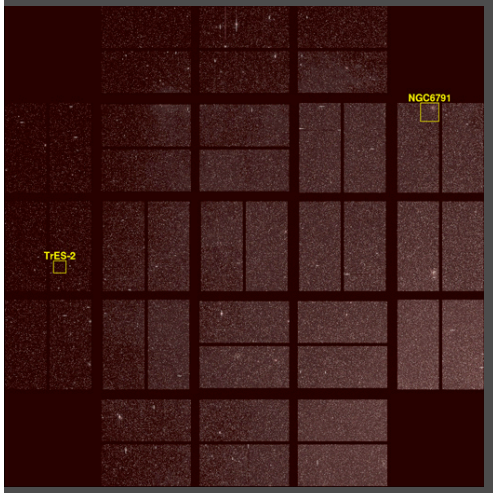








The Age of the Super-Earth

- ~20 super-Earths with mass < $10_\oplus$ (HARPS, HiRes)
- CoRoT: launched 12/27/2006

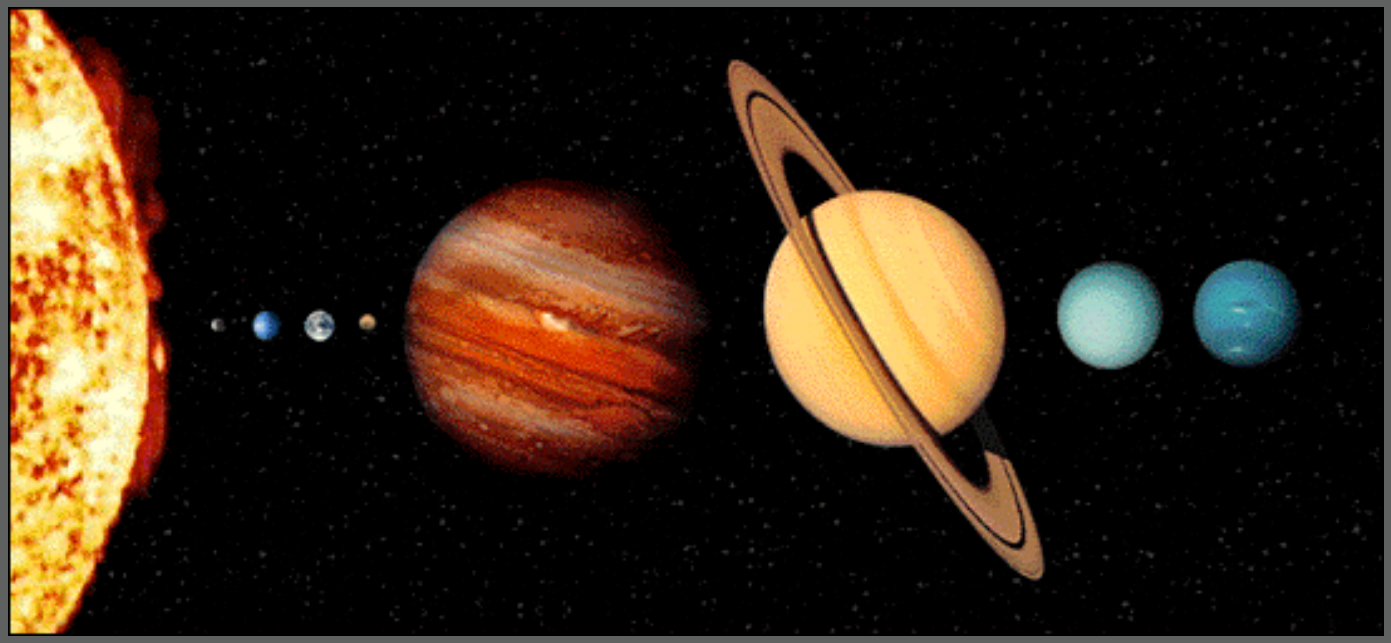
  1 super-Earth detected (CoRoT-7b)
- MEarth: capable of detecting super-Earths transiting M-dwarfs from the ground

  1 super-Earth detected (GJ 1214b)
- Kepler: launched successfully - March 6, 2009

Super-Earths - Bridging the Gap

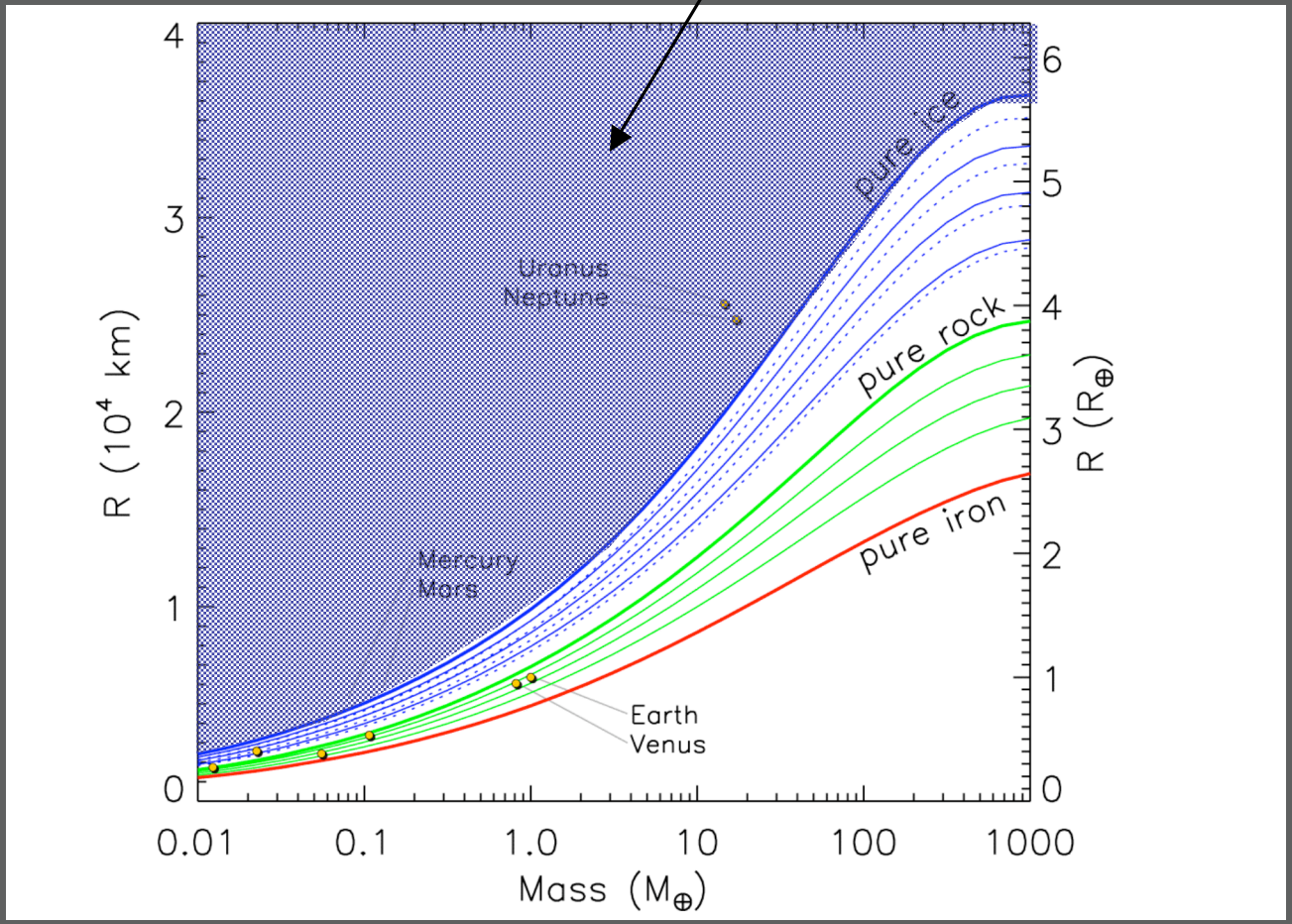
- No planets between 1 and 17 $M_{\oplus}$ in our solar system
- Super-Earths are predicted to have higher surface gravities than Earth / Venus

  -> H_2 atmospheres?
- Where is the dividing line between mini-Neptunes and large terrestrial planets?



M-R Relationship

- Super Earths have diverse interior structures
- They are composed of up to 4 possible materials (EOS - equations of state)
- Hence, the mass-radius plane has serious degeneracies



Fortney et al., 2007

A Tale of Two Planets

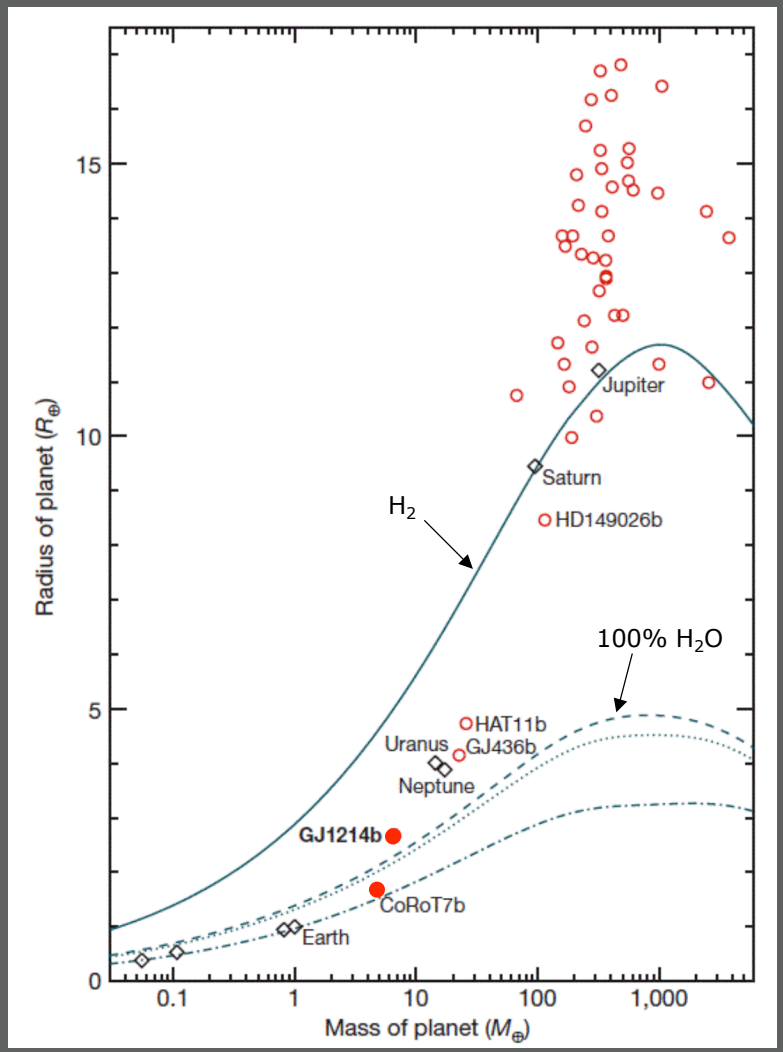
CoRoT-7b

- M_{pl} = 4.8 $M_{\oplus}$ (?)
- R_{pl} = 1.7 $R_{\oplus}$
- ρ = 5.6 g/cm^3
- R_* = 0.87 $R_{\odot}$ (K0V)
- P = 0.85 days
- T_{eq} ≈ 1800-2600 K

GJ 1214b

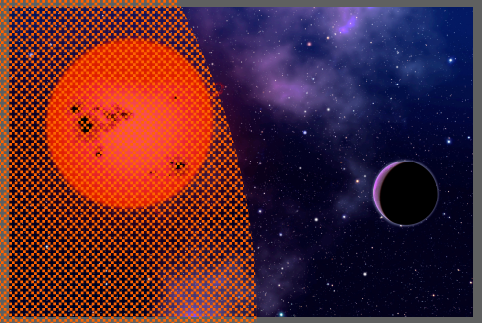
- M_{pl} = 6.6 $M_{\oplus}$
- R_{pl} = 2.7 $R_{\oplus}$
- ρ = 1.9 g/cm^3
- R_* = 0.21 $R_{\odot}$ (M4.5)
- P = 1.58 days
- T_{eq} ≈ 550 K

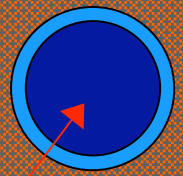
Planet is too big to be explained without the presence of a significant atmosphere!



Charbonneau et al., 2009

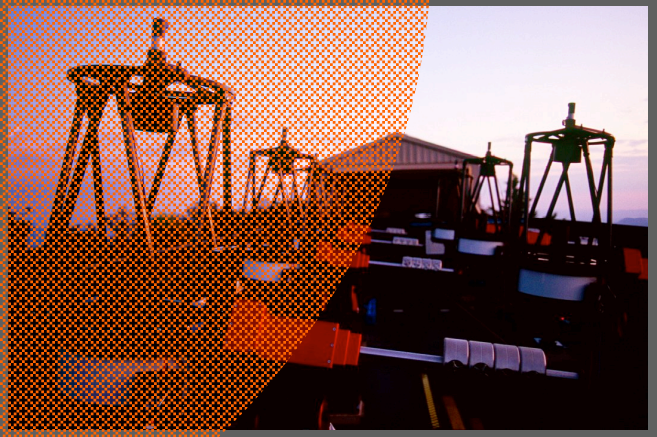
The M-Dwarf Opportunity





GJ 1214b

1.4% transit depth



GJ 1214 system
to scale.

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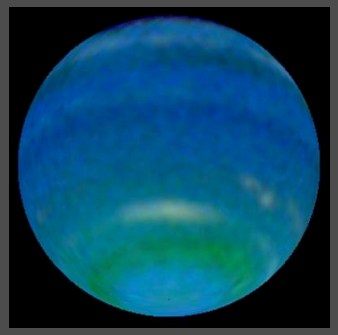
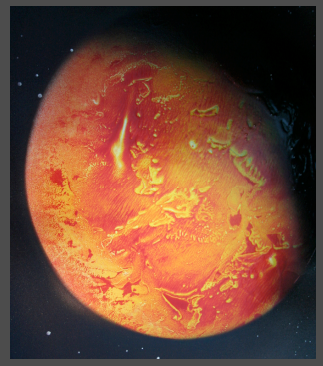
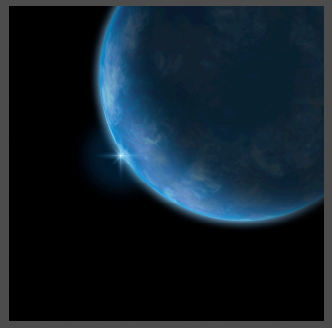
3 Possible Compositions of GJ 1214b







1) Accretion Scenario:
   Rock / Ice + Accreted gas (mostly H_2)

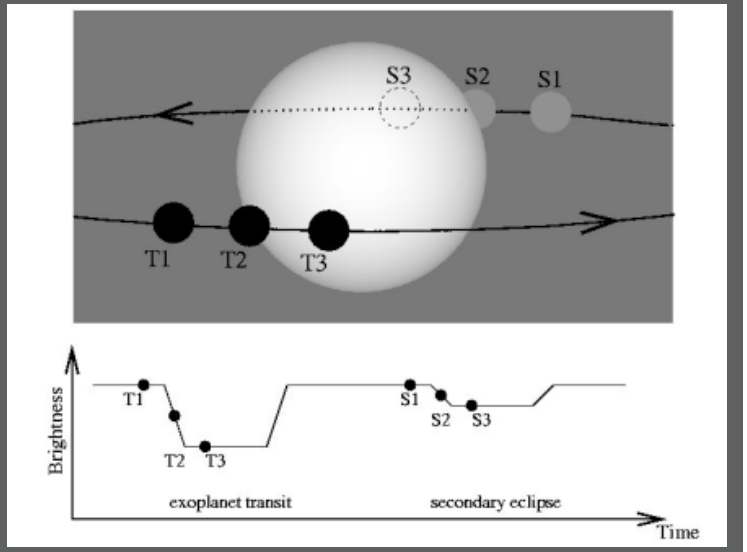
2) Outgassing Scenario:
   Rock / Ice + Outgassed material (mostly H_2 but with no He)

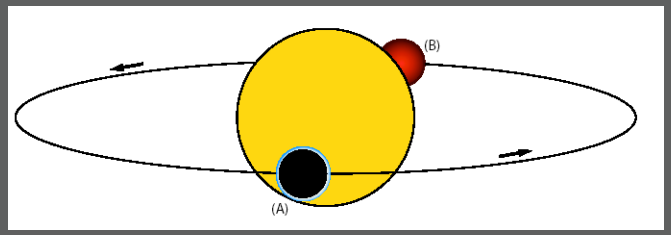
3) Water World Scenario:
   Mostly H_2O

(Rogers & Seager 2010)

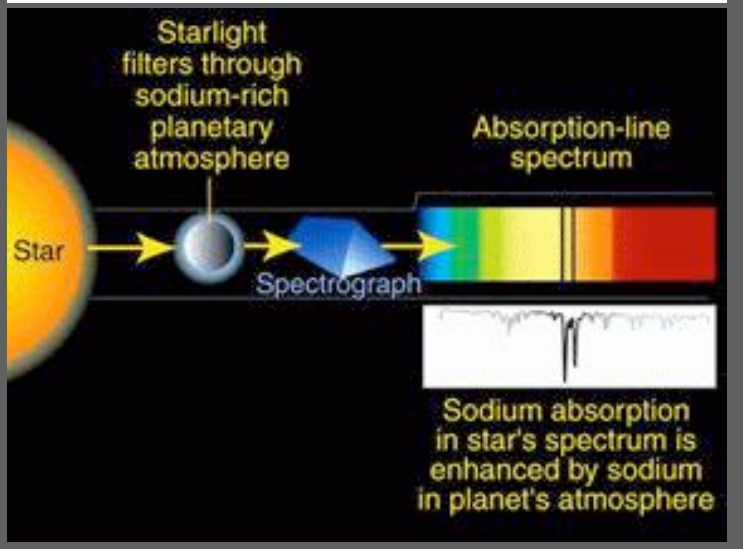
Observing Exoplanet Atmospheres

Emission

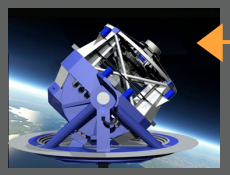


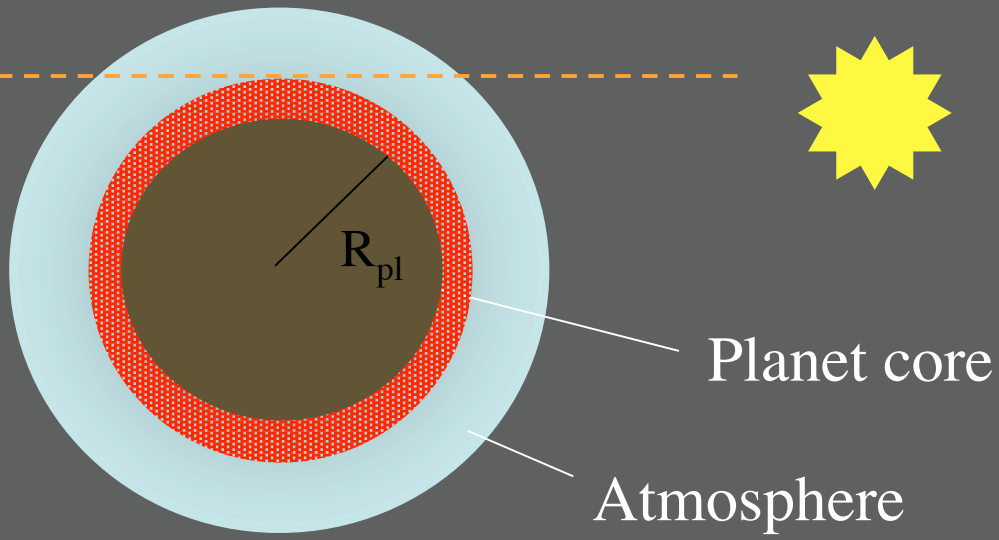


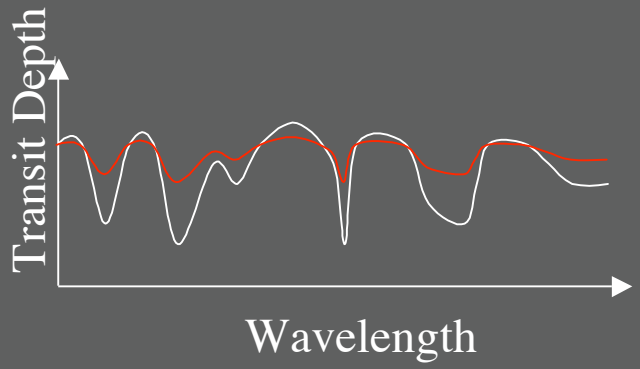
Transmission



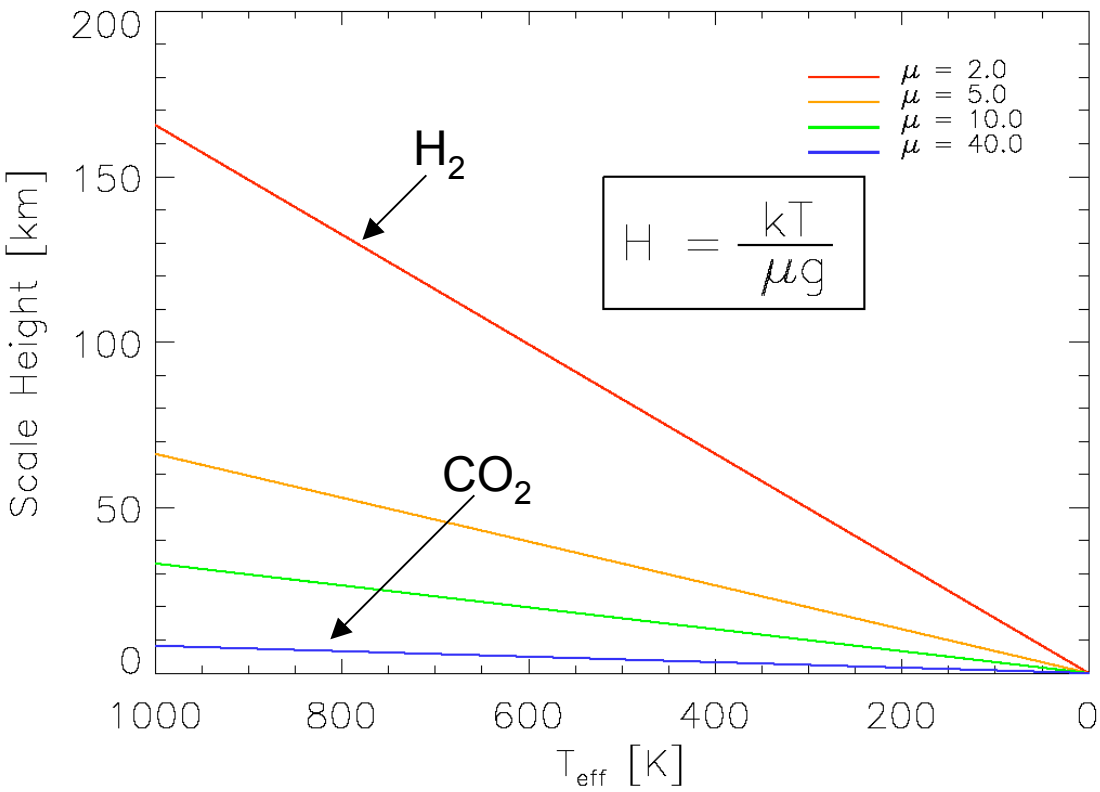
Transmission Spectroscopy







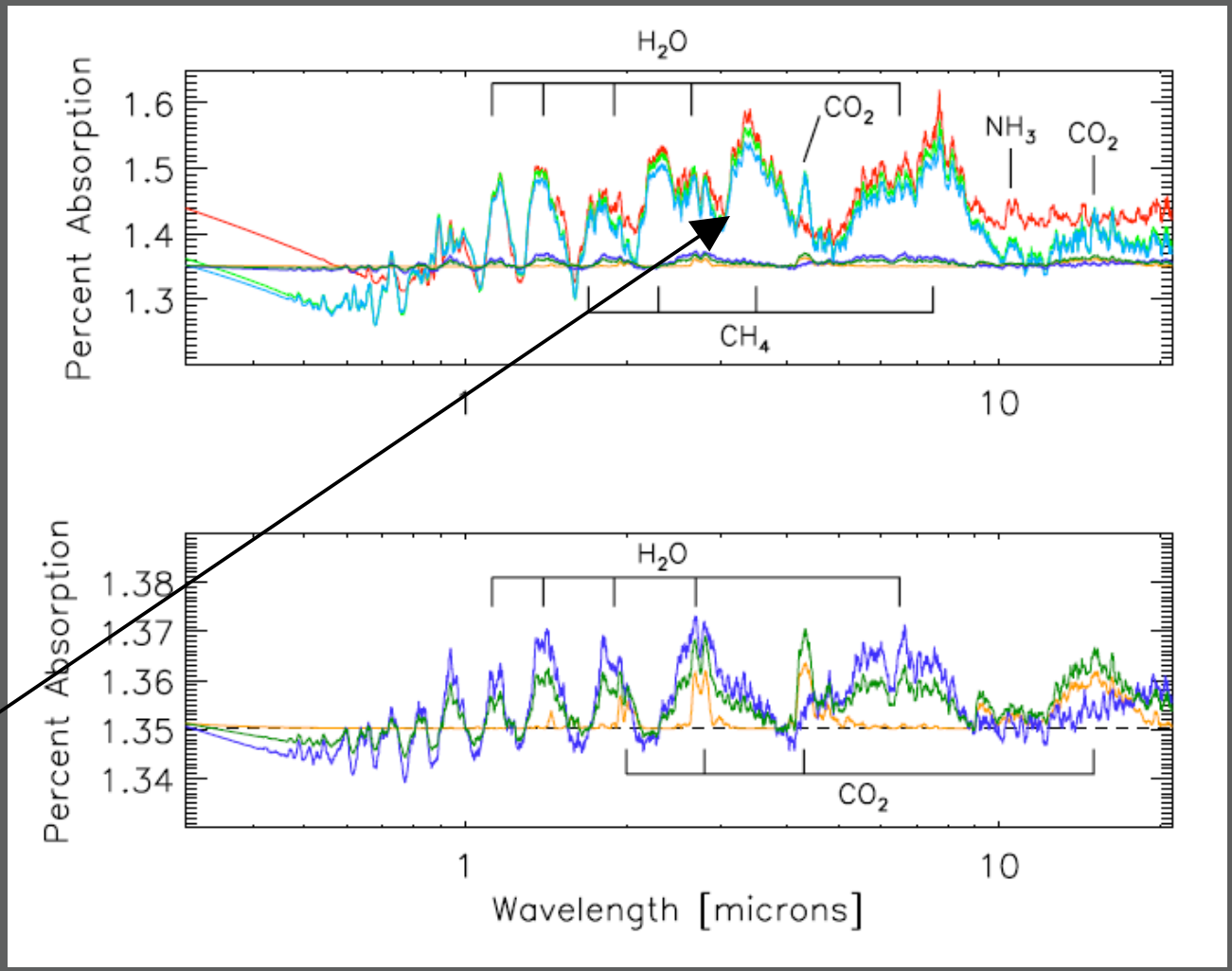
Atmosphere Scale Height



Miller-Ricci et al., 2009

GJ 1214b Transmission Spectra

------ No atmosphere
Solar
30 x Solar
50 x Solar
H_2O
H_2O - CO_2
CO_2



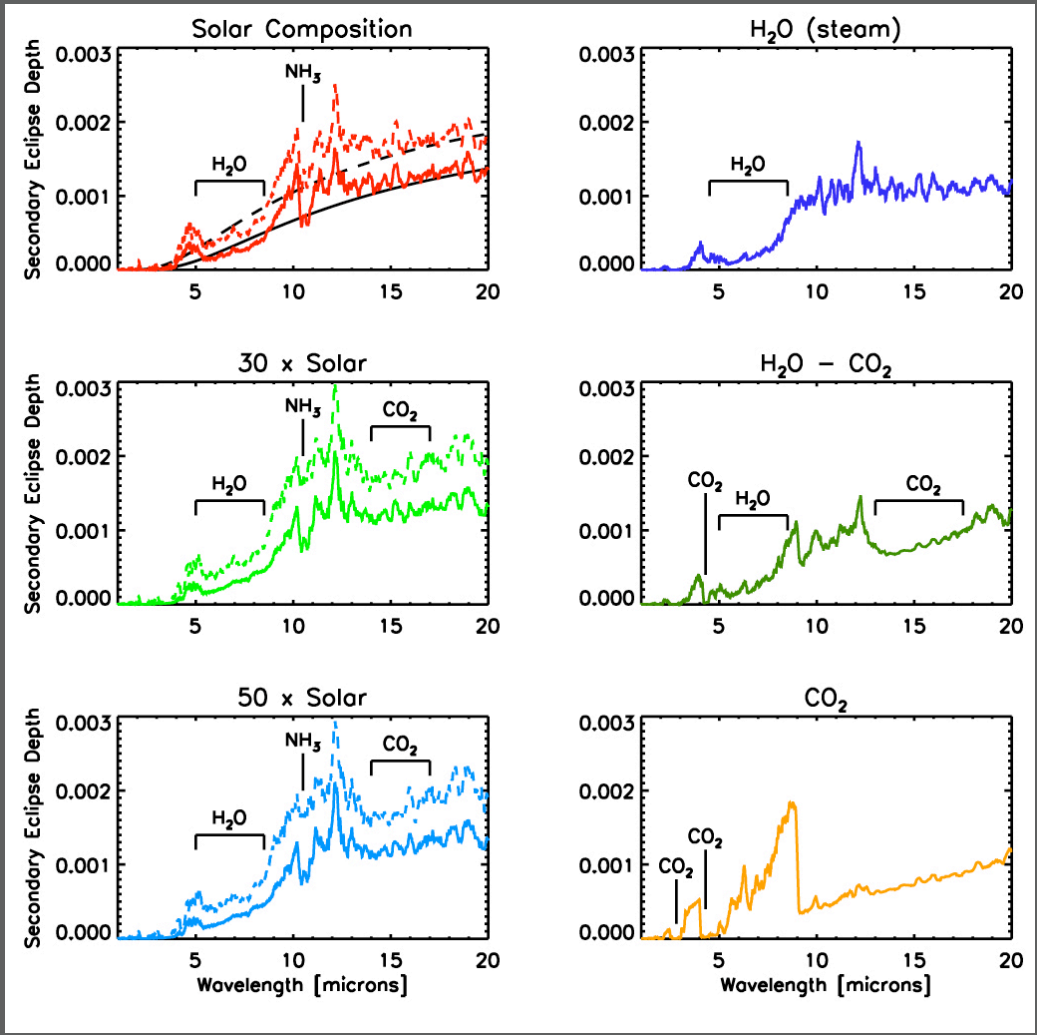
Signatures of 0.1 - 0.3% for H-rich atmospheres!

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

Miller-Ricci & Fortney, 2010

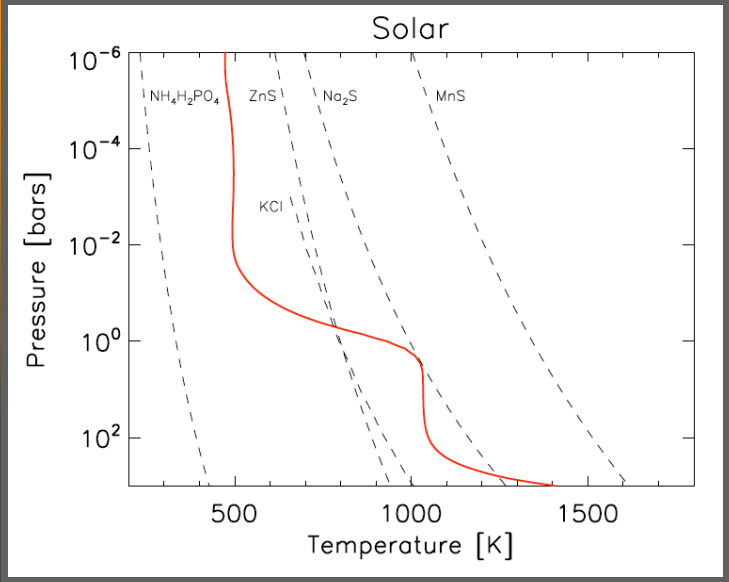
GJ 1214b Emission Spectra

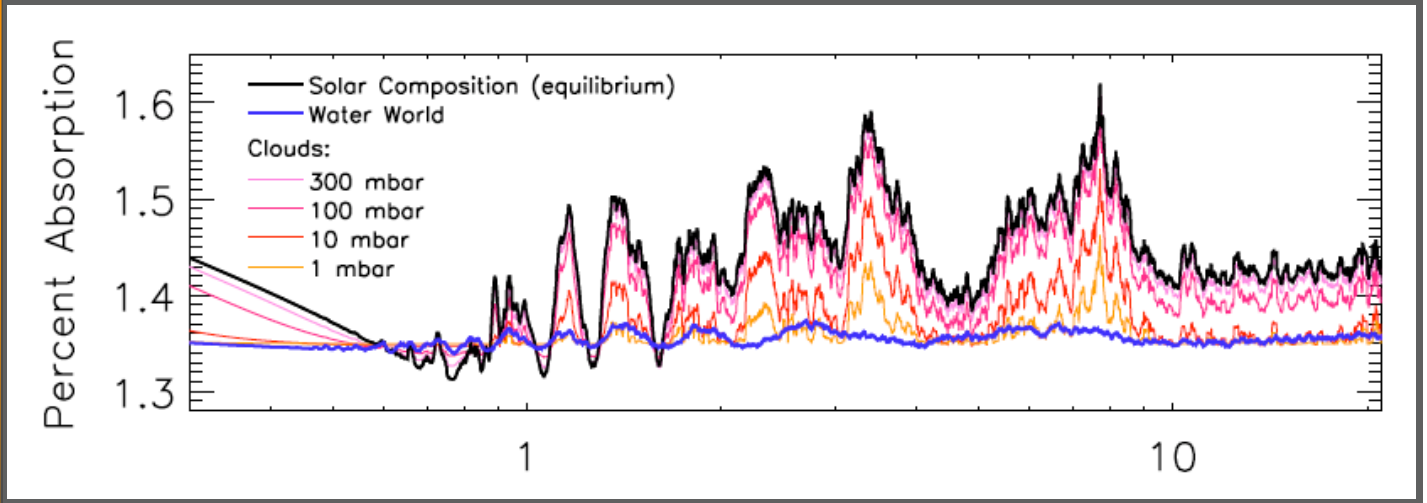
Secondary Eclipse Depth = $Flux_{pl}$ / $Flux_{*}$



Miller-Ricci & Fortney, 2010

GJ 1214b - Clouds





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Conclusions

- GJ 1214b is the first super-Earth to have a potentially observable atmosphere with current instrumentation
- Transmission spectroscopy of the planet's atmosphere can break the degeneracy between interior composition models
- Clouds can add additional complexity to the interpretation of GJ 1214b's spectral signature

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Super Earth Atmosphere Model

- 1-D plane-parallel structure
- Pressure profile: hydrostatic equilibrium
- Temperature profile: Irradiated grey atmosphere (Hansen et al.) + adiabatic convection
- Chemical equilibrium + photochemical considerations
- Molecular opacities (H_2O, CO, CO_2, CH_4, NH_3, O_2, O_3)
- Produces emission and transmission spectra