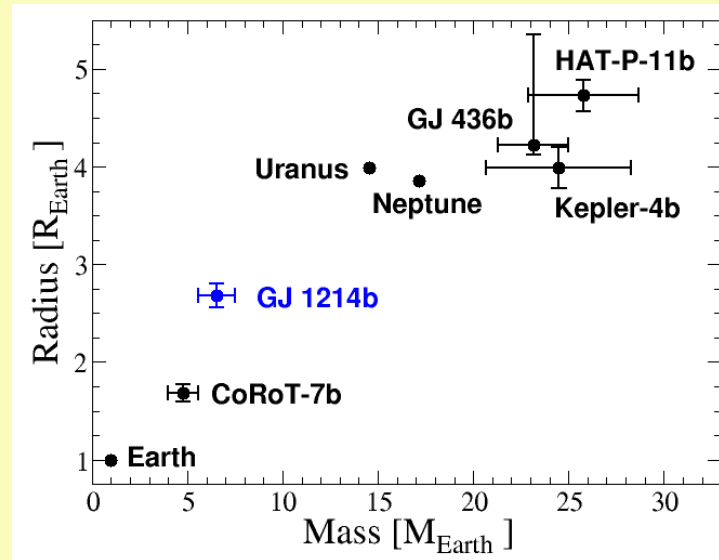




# GJ 1214b: a warm super-Earth (WASP-10b: a hot Jupiter)

N. Nettelmann<sup>1,2</sup>, J.J. Fortney<sup>1</sup>, U. Kramm<sup>2</sup>, R. Redmer<sup>2</sup>

1: UC Santa Cruz, 2: U Rostock



*Acknowledgements: E. Kempton, T. Guillot, D. Valencia, R. Neuhäuser*



# Interior model construction



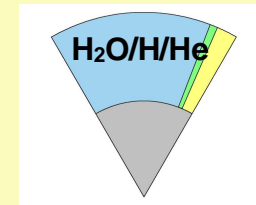
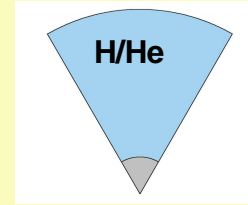
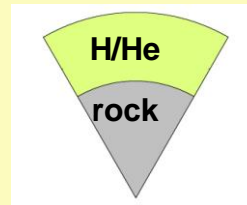
## General assumptions of our structure and evolutions calculations

### Observational constraints

$$M_p = 6.55 M_E , \quad R_p = 2.678 R_E$$

$$T_{eq} = 555 \text{ K} , \quad \tau = 3-10 \text{ Gyr}$$

### Structure: two layers



### Evolution

$$T_{\text{eff}} = T_{\text{eq}} + T_{\text{int}}(g, s)$$

$$4\pi R_p^2 \sigma T_{\text{int}} = -\int_0^{M_p} dm \frac{T(m) ds(m)}{dt} + L_{\text{radioactive}}$$

➤ Charbonneau et al. (2009), Nature

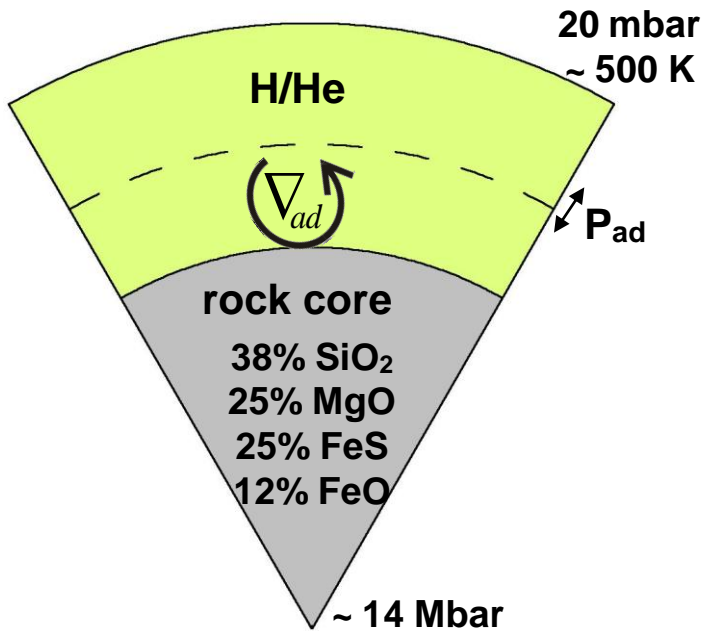
➤ Miller-Ricci & Fortney (2010), ApJ



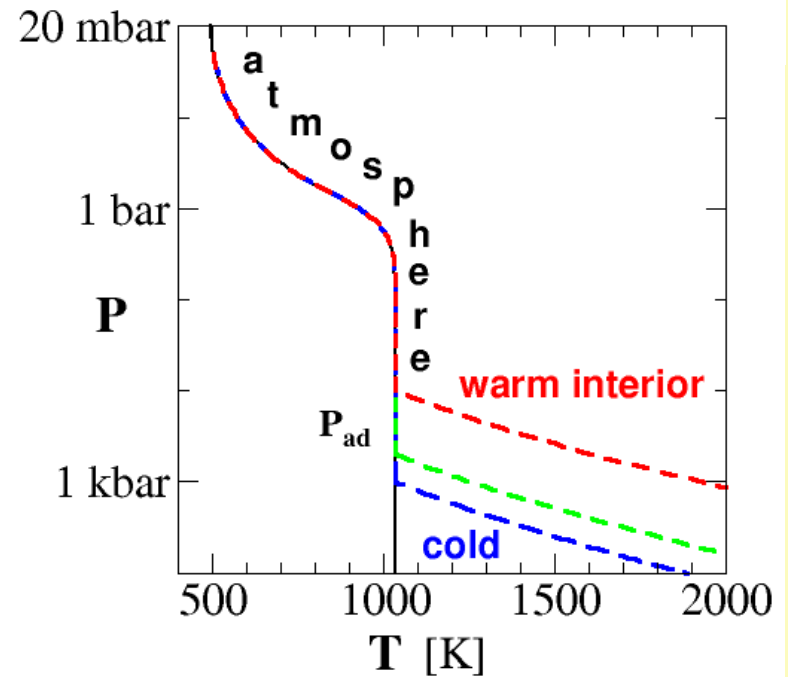
# GJ 1214b models with H/He envelope



Pie chart illustration.



Pressure-Temperature profile in the envelope.

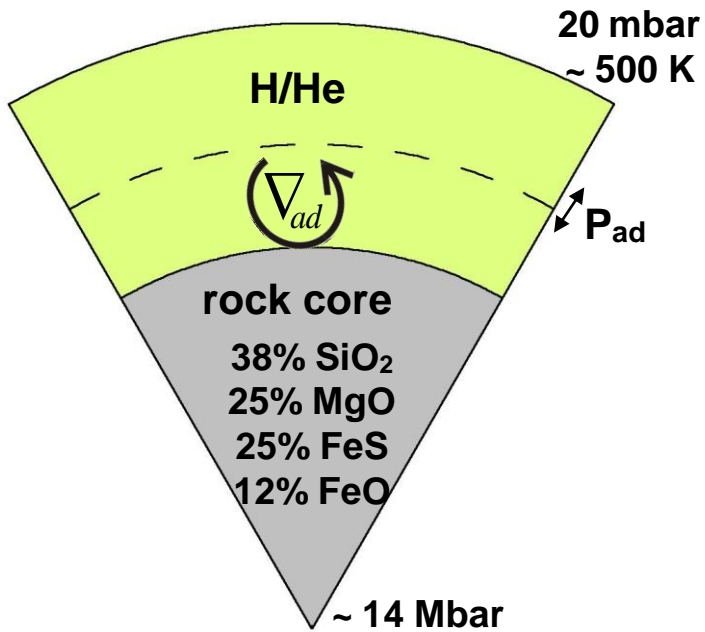




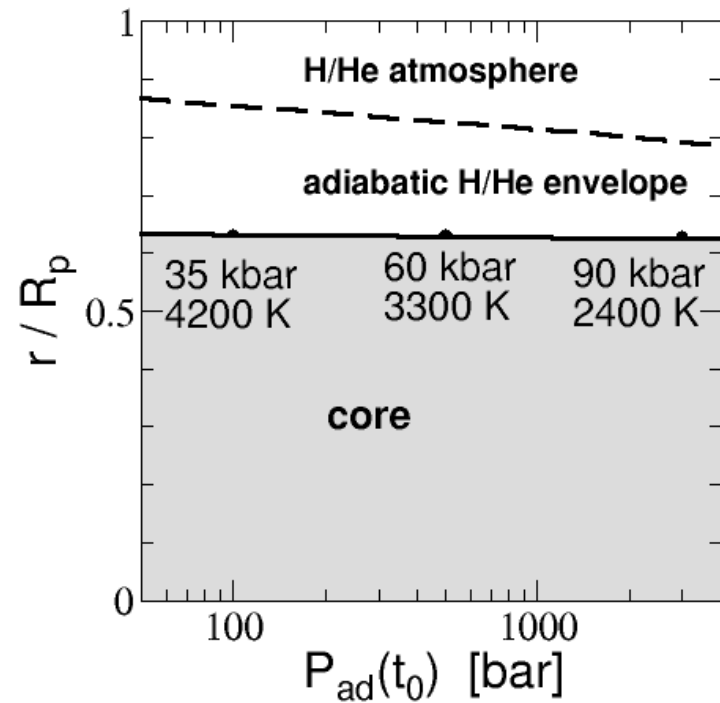
# GJ 1214b models with H/He envelope



Pie chart illustration.



The H/He envelope extends over ~0.4  $R_p$  independent on internal temperatures.

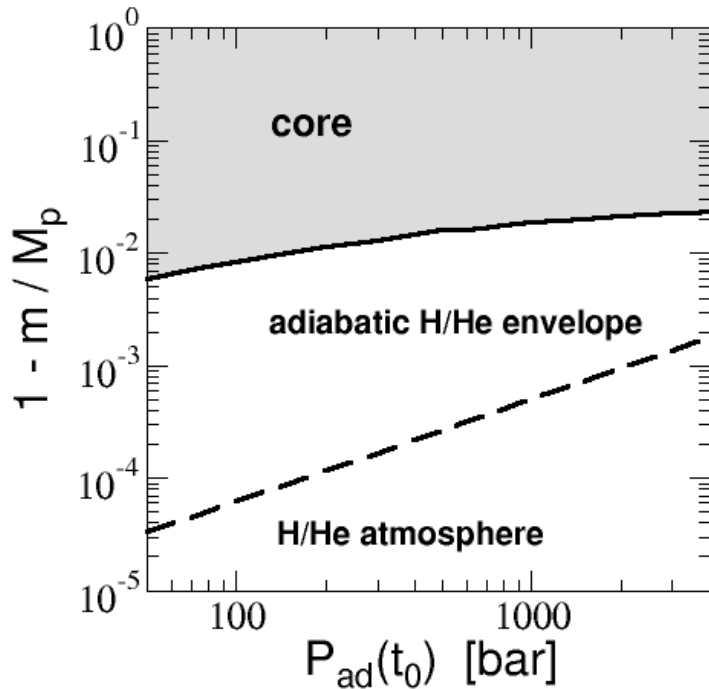




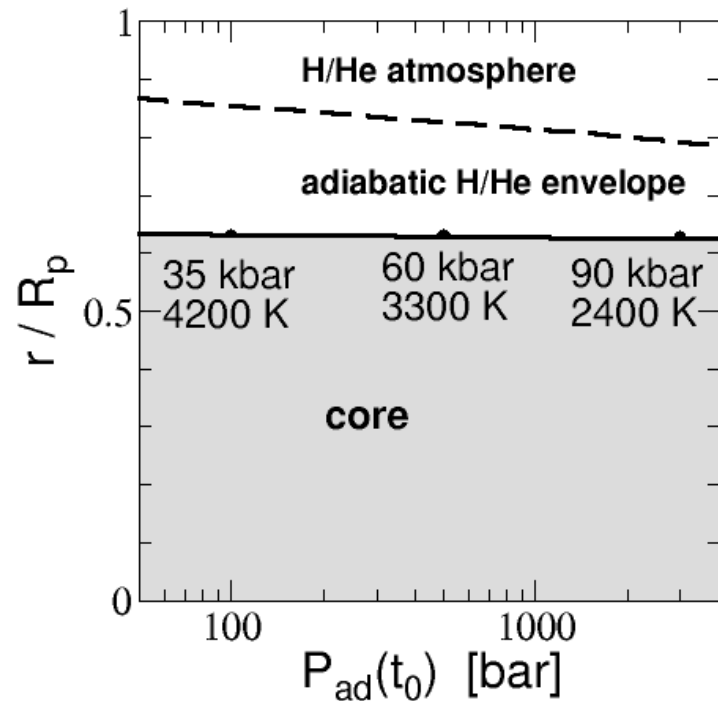
# GJ 1214b models with H/He envelope



The H/He envelope contributes at most 2% to total mass (today).



The H/He envelope extends over  $\sim 0.4 R_p$  independent on internal temperatures.



**GJ 1214b is not a mini-Jupiter.**

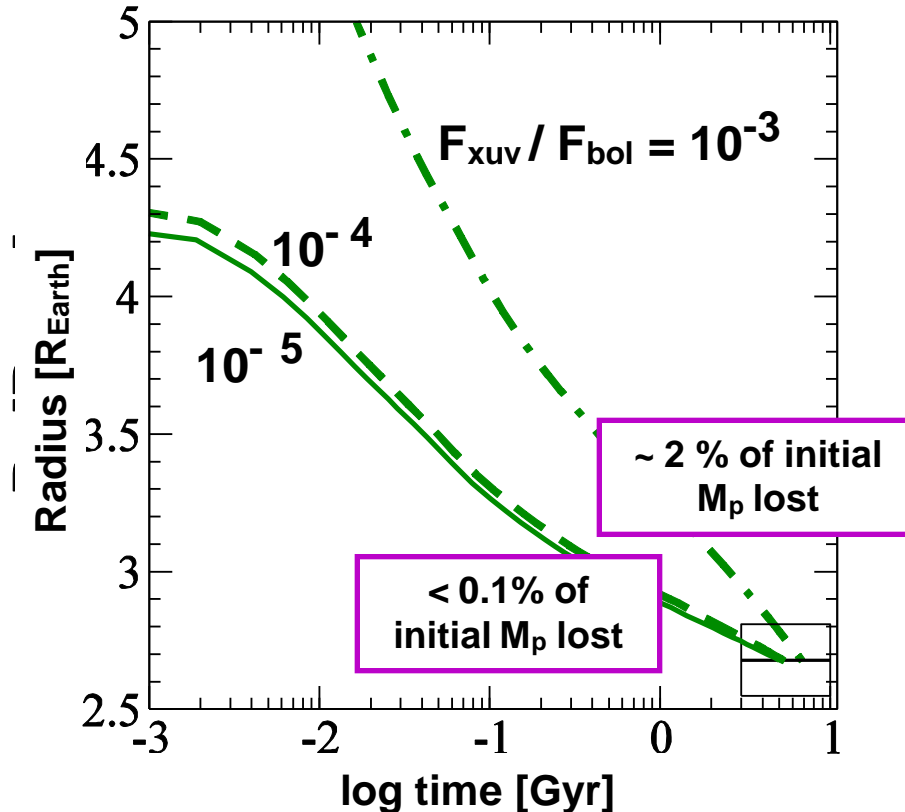
**Can GJ 1214b be an evaporated gas planet?**



# Evolution of GJ 1214b with H/He atmosphere



Cooling time in dependence on XUV irradiation,  
driving energy-limited mass loss



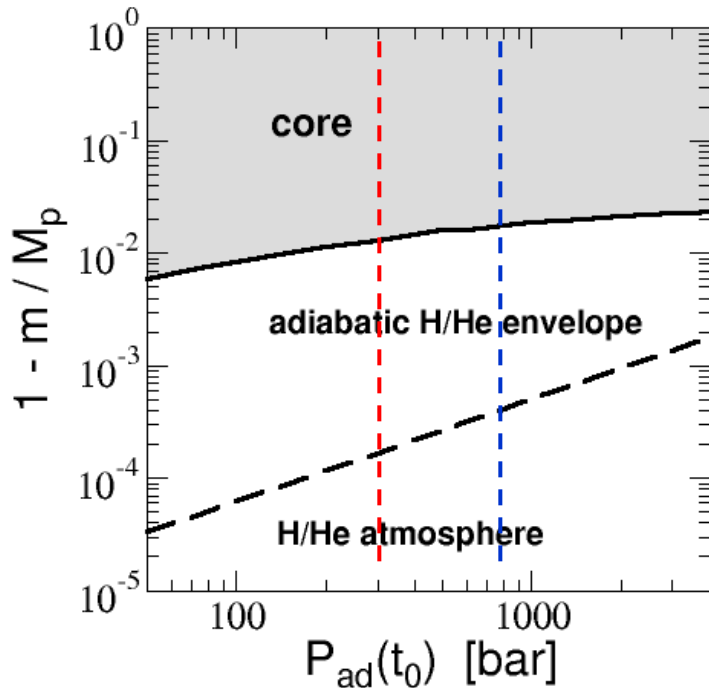
For moderate XUV irradiation, GJ1214b appears to be a genuine super-Earth.



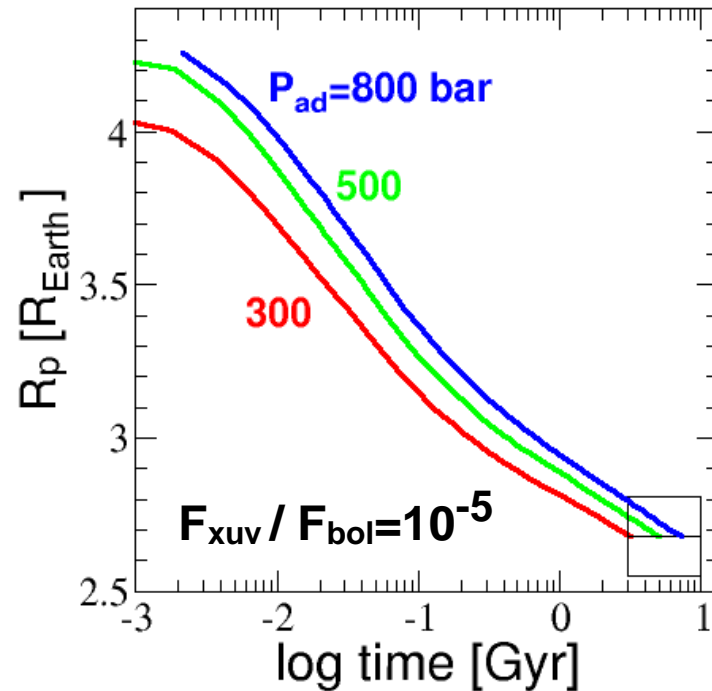
# GJ 1214b models with H/He envelope



The H/He envelope contributes at most 2% to total mass (today).



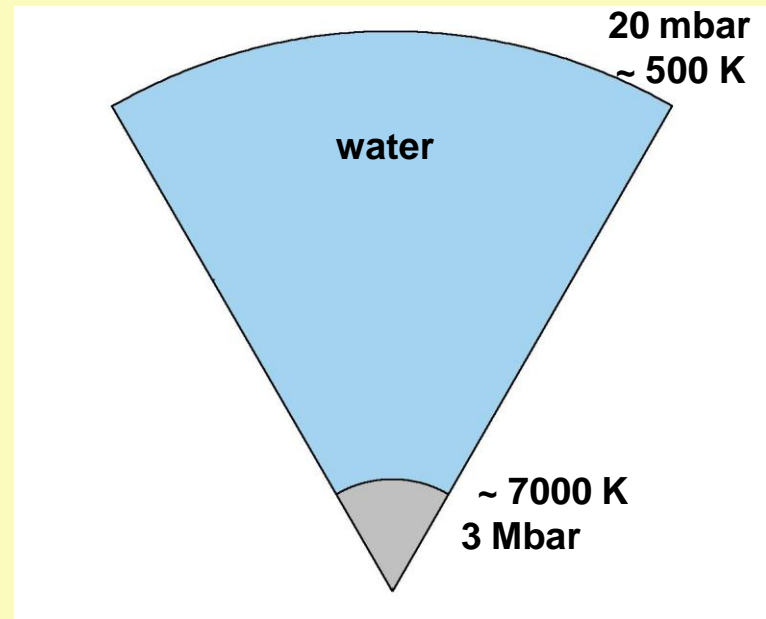
Reproducing an age of 3-10 Gyrs requires  $P_{adiabatic} \sim 300-800$  bar.



Our thermal evolution calculations limit the mass the of the H/He envelope further to 1.3 - 2% of  $M_p$ .



# GJ 1214b models with water envelope



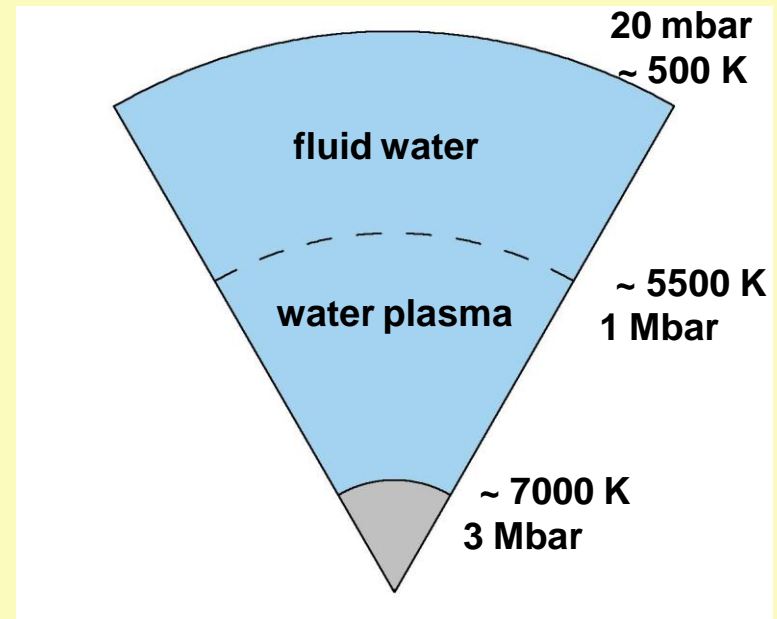
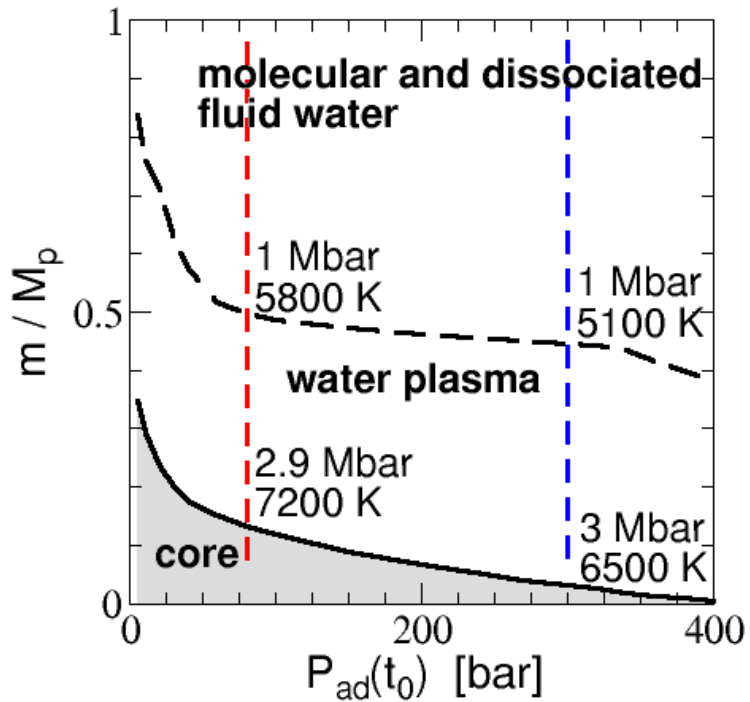




# GJ 1214b models with water envelope



Water envelopes are warm, dense, and massive.

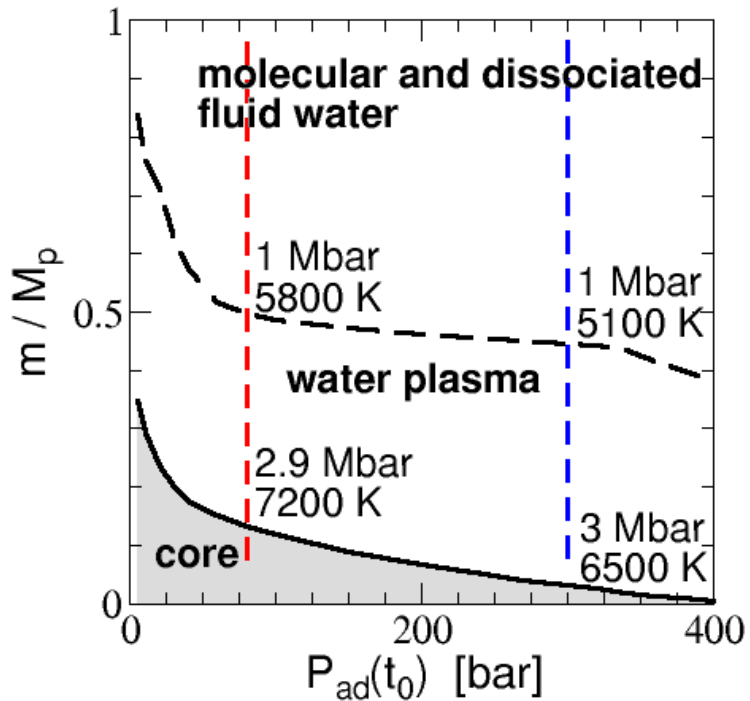




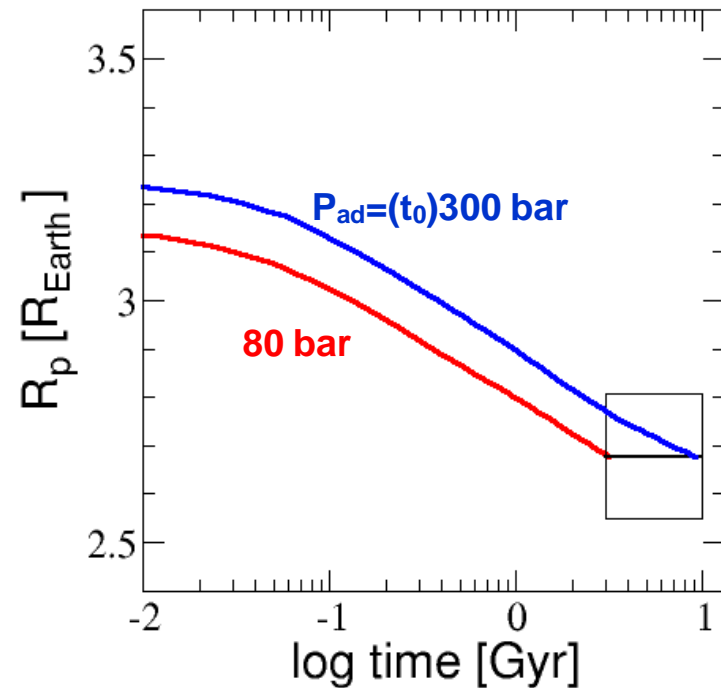
# GJ 1214b models with water envelope



Water envelopes are warm, dense, and massive.



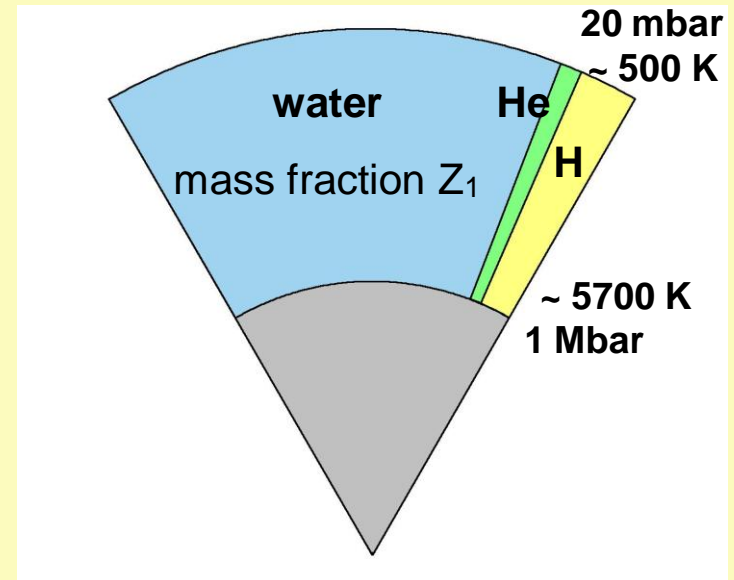
Pure water models or large cores are excluded by the cooling time.



Pure water models are too cold to give a cooling time  $< 10$  Gyr.  
Acceptable models have ice:rock  $> 6$



# GJ 1214b models with H/He/H<sub>2</sub>O envelope

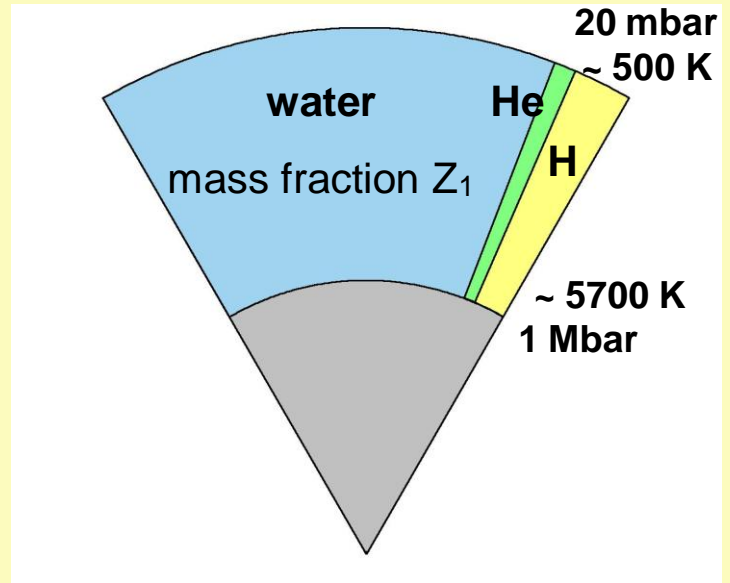
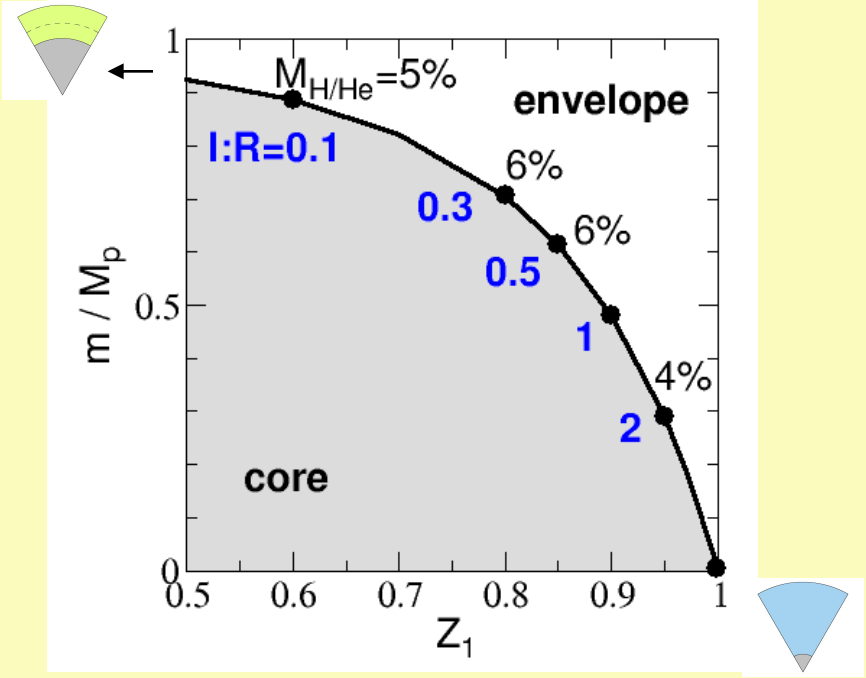




# GJ 1214b models with H/He/H<sub>2</sub>O envelope



Core mass in dependence on the envelope water mass fraction



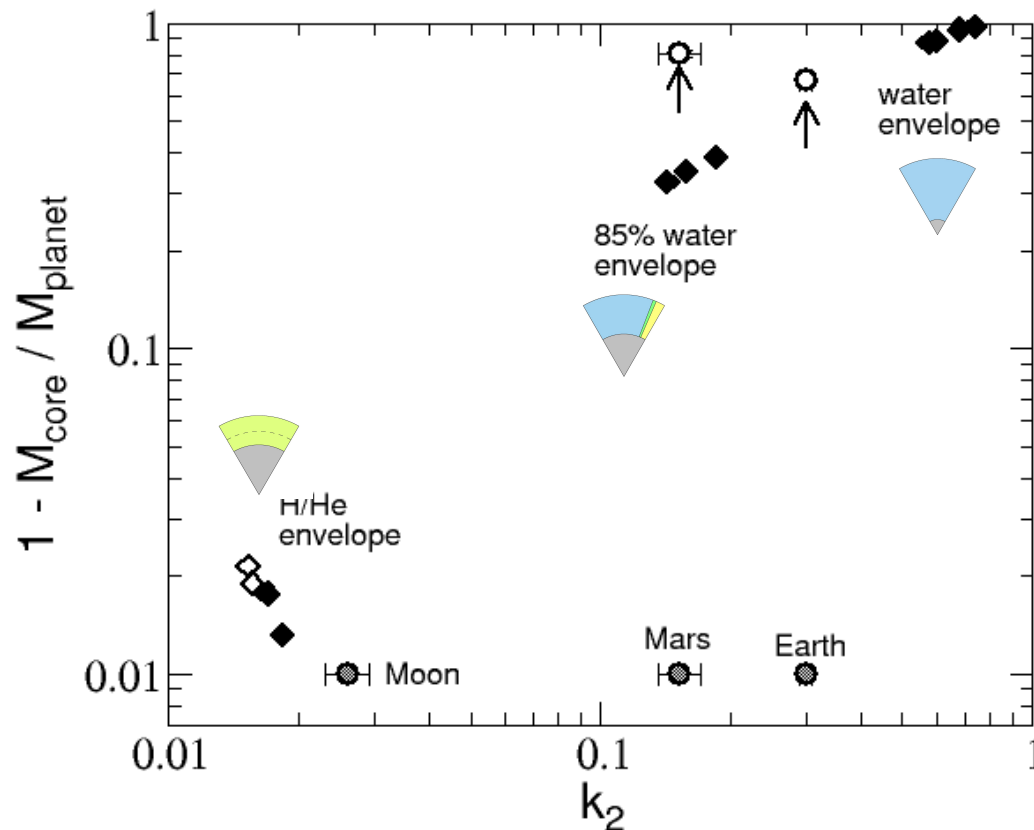
1x solar ice:rock ratio is obtained for  $Z_1=0.95$ .  
 $Z_1 < 0.5$  implies a rock body with an envelope of  $< 0.5 M_{\text{Earth}}$ .



# The Love number of GJ 1214b models



Models with different envelope composition differ significantly in their **Love number  $k_2$**  and core mass.





# Conclusions about GJ1214b



## H/He envelope models

- GJ1214b is not a gas-planet, nor was that in the past.
- mass of H/He envelope 1.3 - 2% of total mass,  $k_2 \sim 0.015$

## water envelope models

- water does not crystallize in GJ 1214b
- core-less models are excluded,  $I:R = 6 - 30$ ,  $k_2 \sim 0.7$

## H/He/H<sub>2</sub>O envelope models

- 1x solar ice:rock ratio is obtained for  $Z_1=0.95$ .
- $Z_1 < 0.5$  implies a rock body with  $< 0.5 M_E$  envelope



# Hot Jupiter WASP-10b

?

- **young** → **planet formation**
- **TTV indicate another planet**

➤ Maciejewski et al. 2010, MNRAS



# Outlook: Hot Jupiter WASP-10b



## Given parameters

### PLANET:

$$M_p = 3.0 \pm 0.2 M_{\text{Jup}}$$

$$R_p = 1.3 \pm 0.1 R_{\text{Jup}}$$

$$a = 0.037 \text{ AU}$$

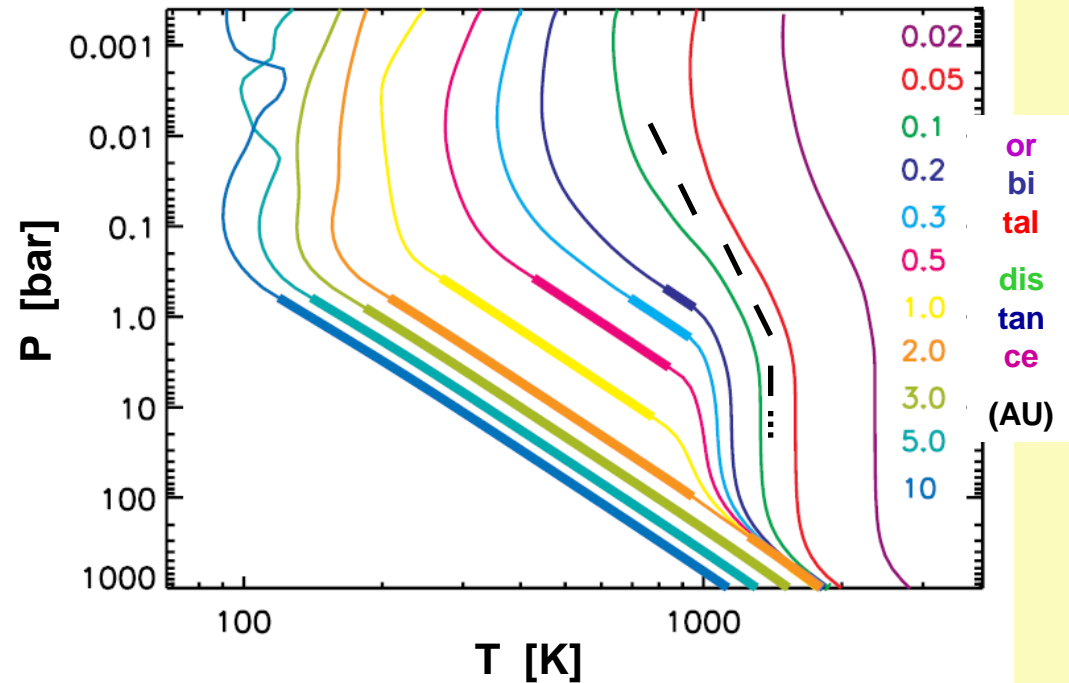
$$e = 0.06$$

### STAR:

$$\text{K5, } T_{\text{eff}} = 4700 \text{ K}$$

190 - 350 Myr young

Atmosphere profiles of  $1 M_{\text{Jup}}$  model planets around 4.5 Gyr old sunlike stars



➤ Fortney, Marley, Barnes 2007, ApJ, figure 3





# Outlook: Hot Jupiter WASP-10b



## Given parameters

### PLANET:

$$M_p = 3.0 \pm 0.2 M_{\text{Jup}}$$

$$R_p = 1.3 \pm 0.1 R_{\text{Jup}}$$

$$a = 0.037 \text{ AU}$$

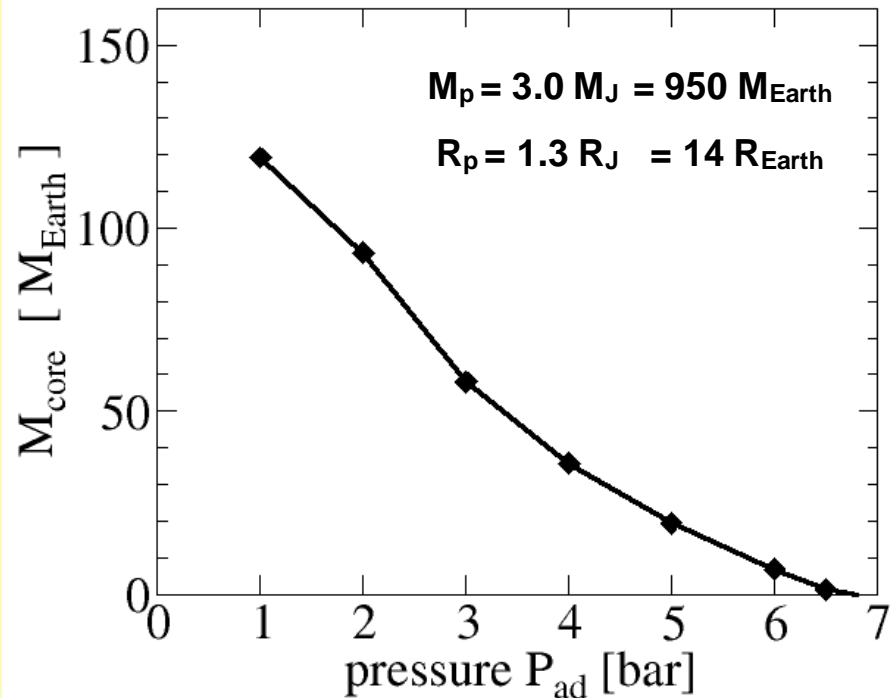
$$e = 0.06$$

### STAR:

$$\text{K5, } T_{\text{eff}} = 4700 \text{ K}$$

190 - 350 Myr young

## Structure models poorly constrain the core mass of WASP-10b



Thermal evolution calculations (ROSTOCK) and a model atmosphere grid (HAMBURG?) are needed to narrow down the core mass.



# Appendix



# Appendix



## Mean molecular weight and O:H ratio of H/He/water envelope models

