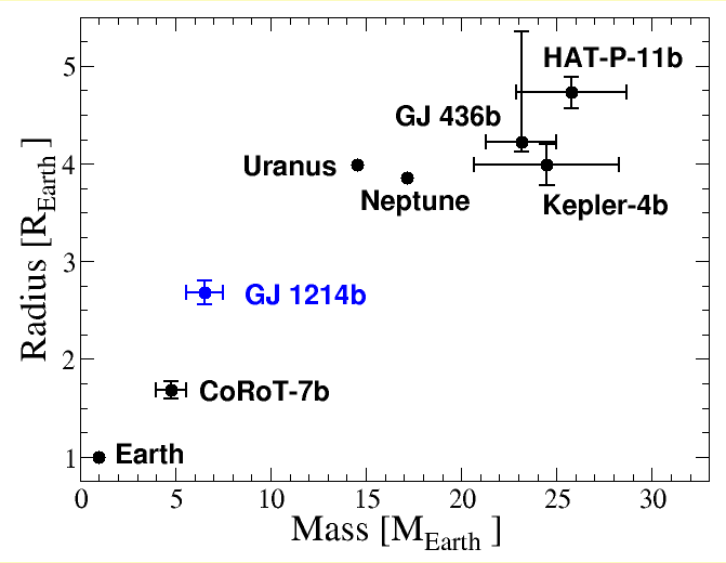
GJ 1214b: a warm super-Earth

(WASP-10b: a hot Jupiter)

N. Nettelmann[1,2], J.J. Fortney[1], U. Kramm[2], R. Redmer[2]

[1:] UC Santa Cruz, [2:] U Rostock



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

Interior model construction

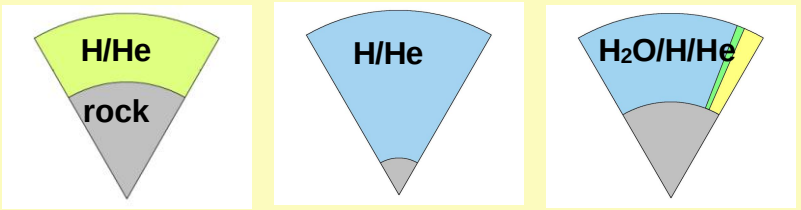
General assumptions of our structure and evolutions calculations

Observational constraints

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

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

Structure: two layers



Evolution

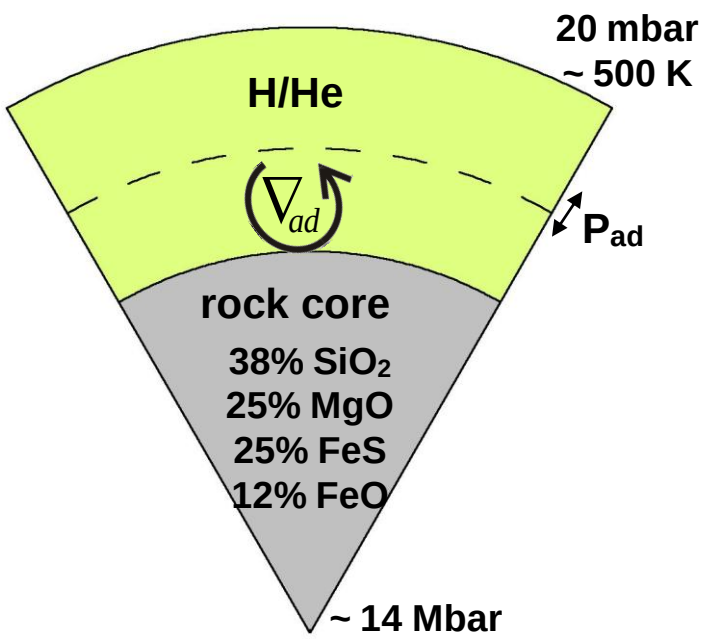
$$T_{\text{eff}} = T_{\text{eq}} + T_{\text{int}}(g,s)$$

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

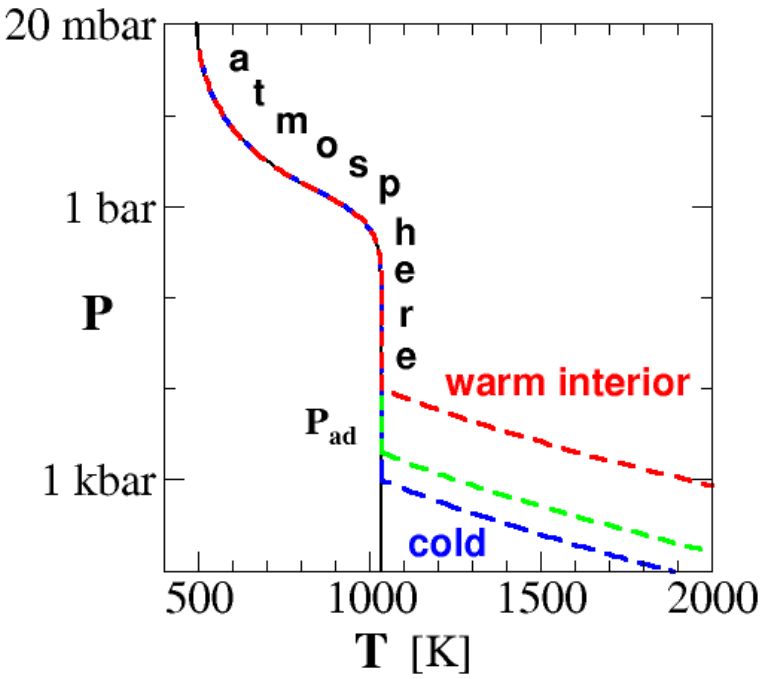
- Charbonneau et al. (2009), Nature
- Miller-Ricci & Fortney (2010), ApJ

GJ 1214b models with H/He envelope

Pie chart illustration.

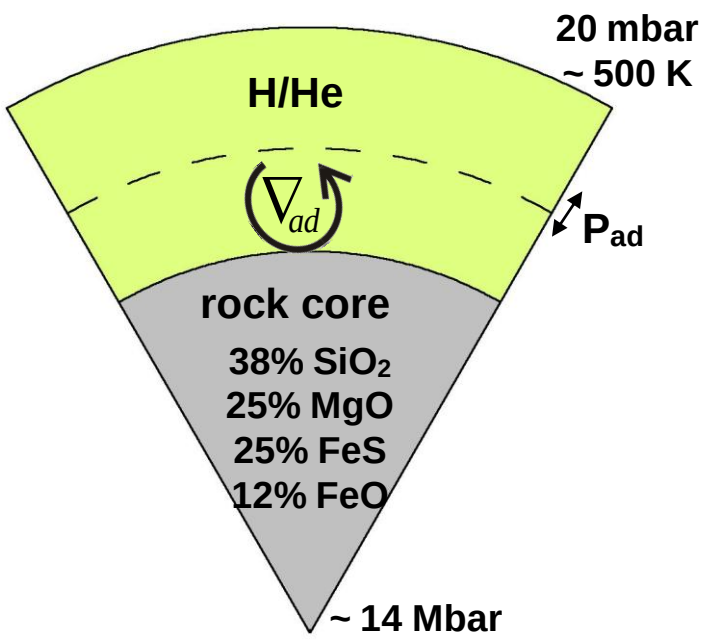


Pressure-Temperature profile in the envelope.

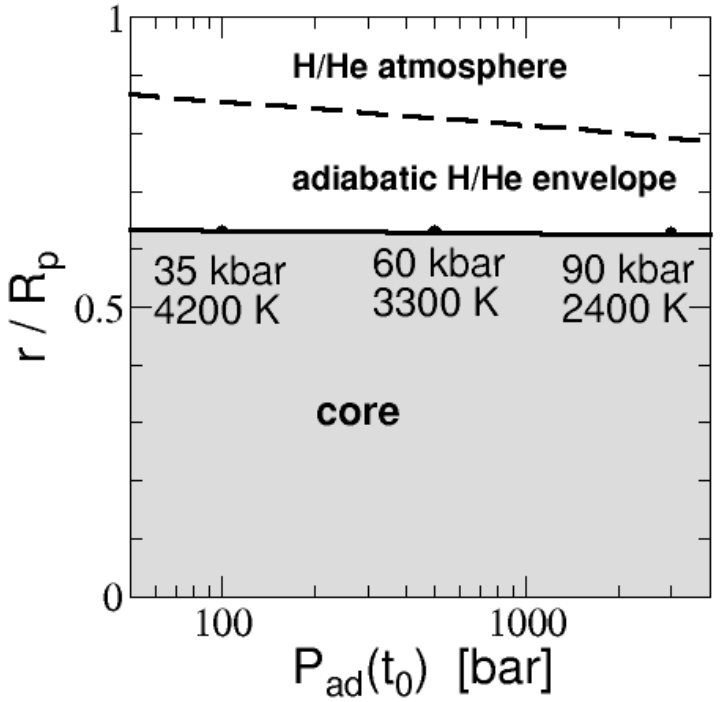


GJ 1214b models with H/He envelope

Pie chart illustration.

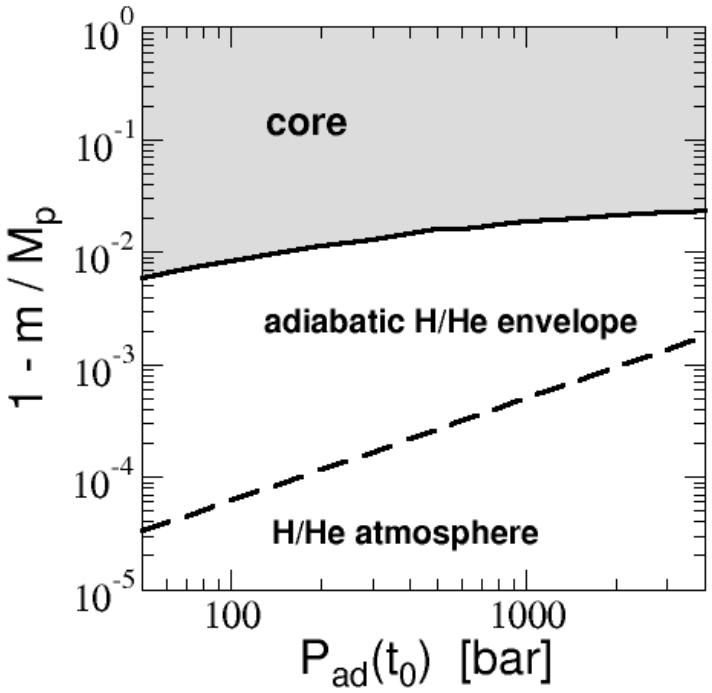


The H/He envelope extends over ~0.4 R_p independent on internal temperatures.

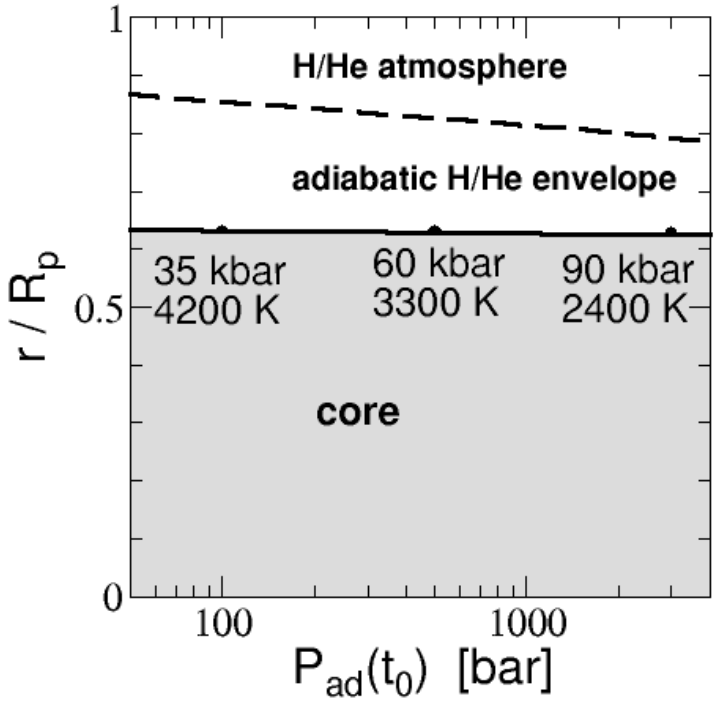


GJ 1214b models with H/He envelope

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



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

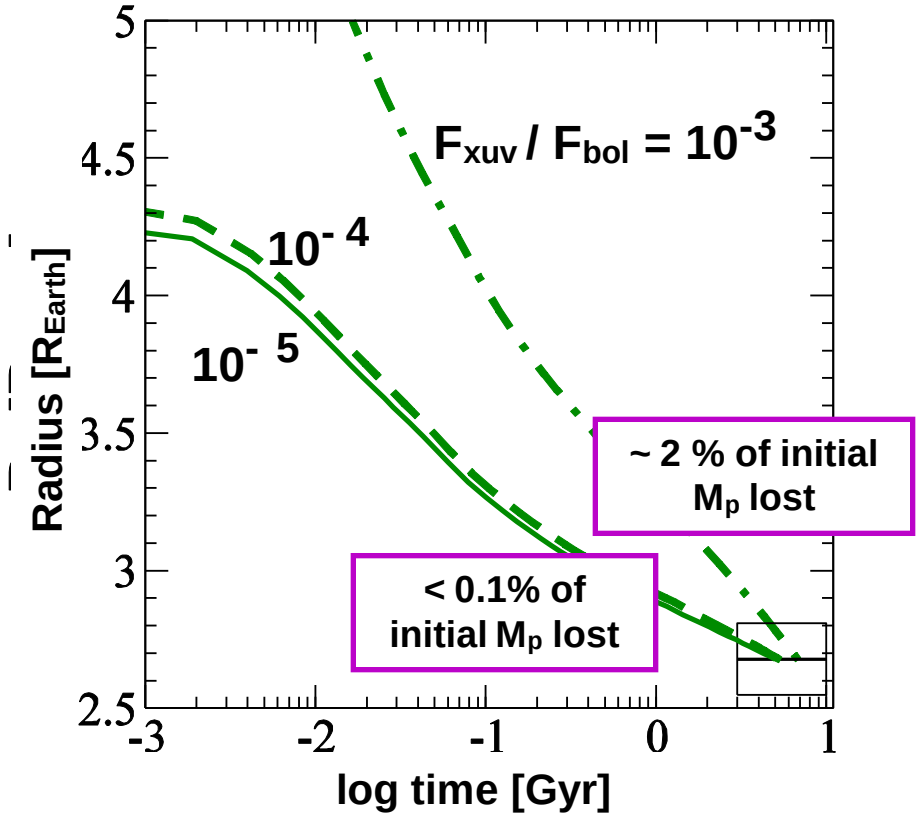


GJ 1214b is not a mini-Jupiter.

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

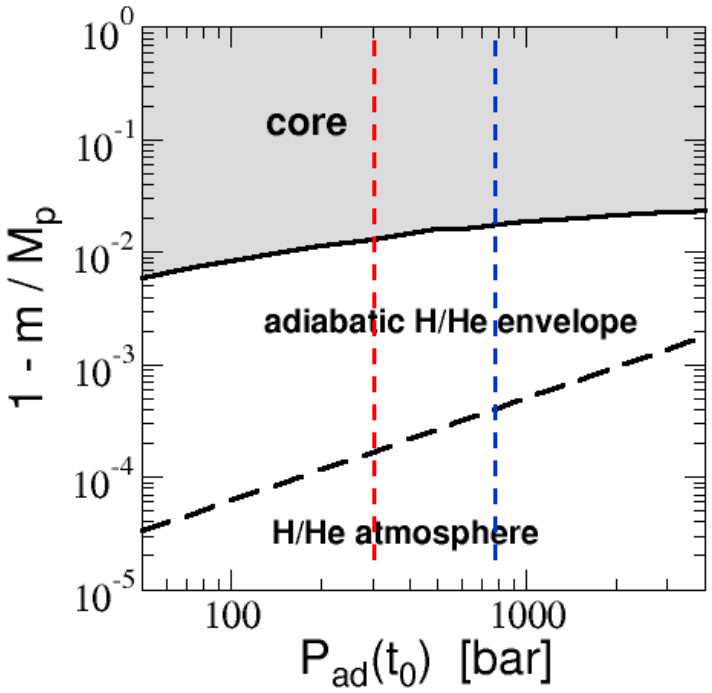


For moderate XUV irradiation, GJ1214b appears to be a genuine super-Earth.

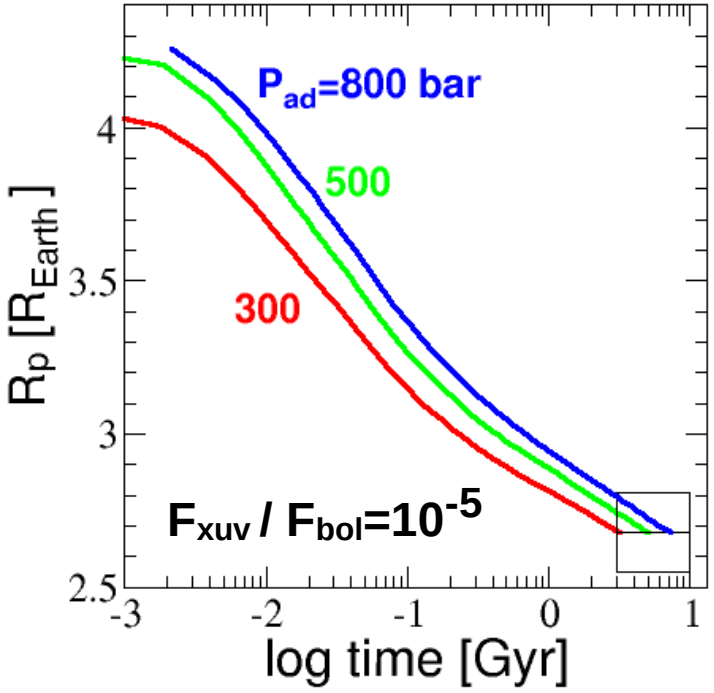
- Scalo, ..., Rauer et al. (2007), Astrobiology
- Nettelmann et al. 2010, astro-ph

GJ 1214b models with H/He envelope

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

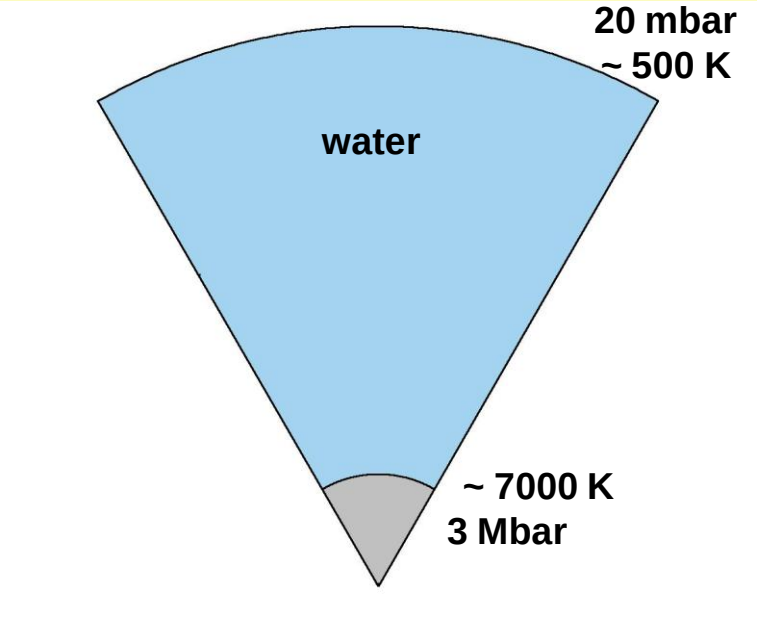


Reproducing an age of 3-10 Gyrs requires $P_{adiabatic}$ ~ 300-800 bar.



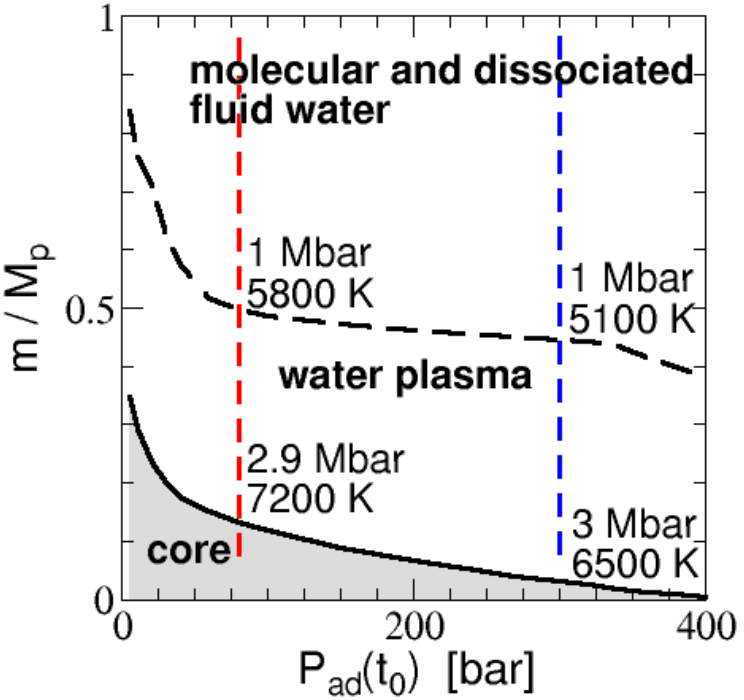
Our thermal evolution calculations limit the mass the of the H/He envelope further to 1.3 - 2% of M_p.

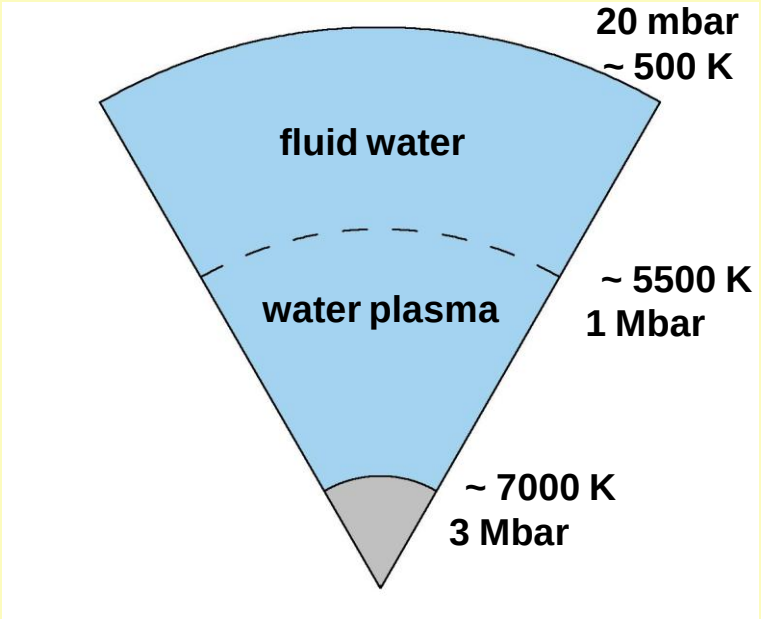
GJ 1214b models with water envelope



GJ 1214b models with water envelope

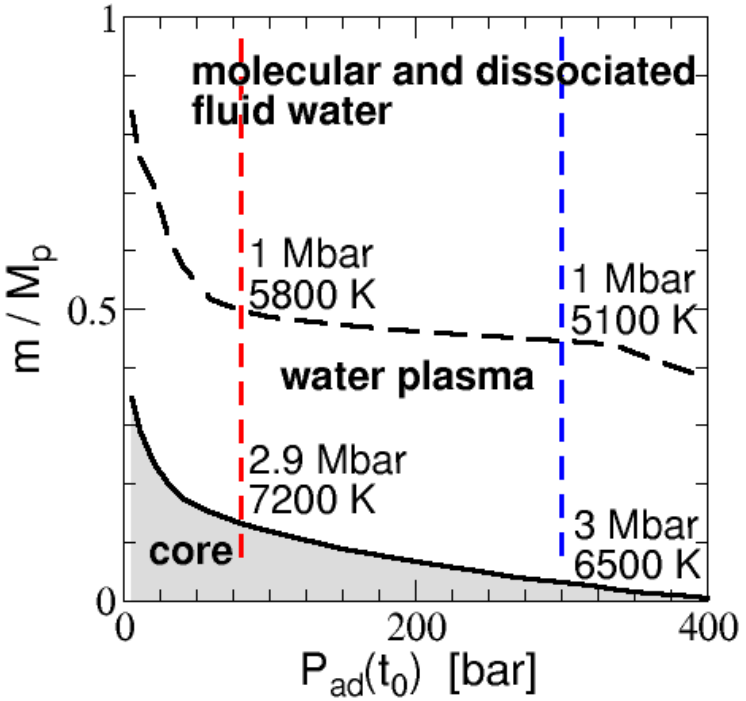
Water envelopes are warm, dense, and massive.



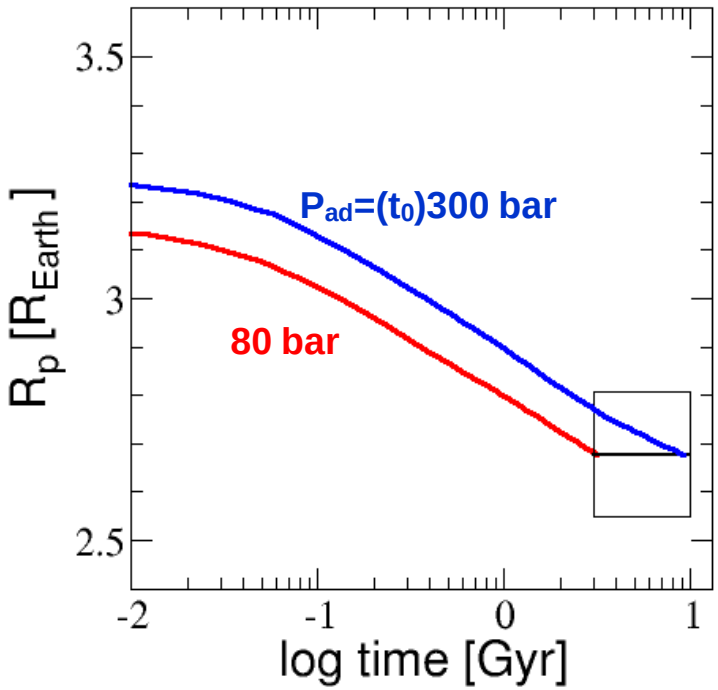


GJ 1214b models with water envelope

Water envelopes are warm, dense, and massive.

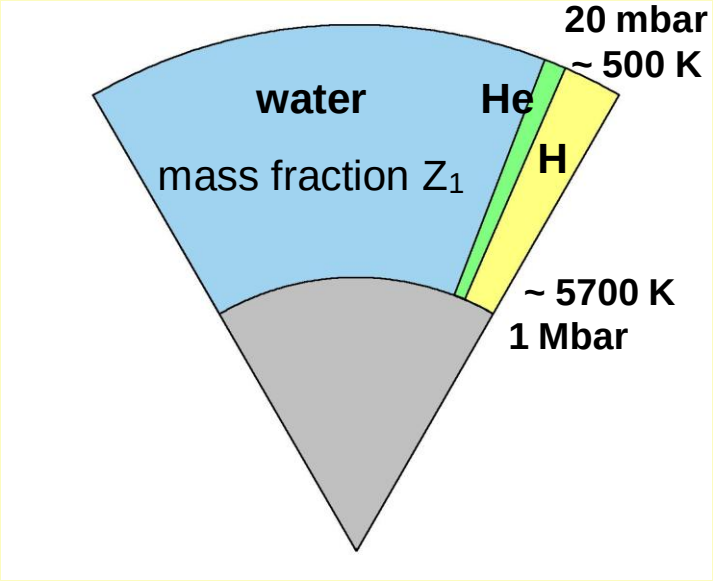


Pure water models or large cores are excluded be the cooling time.



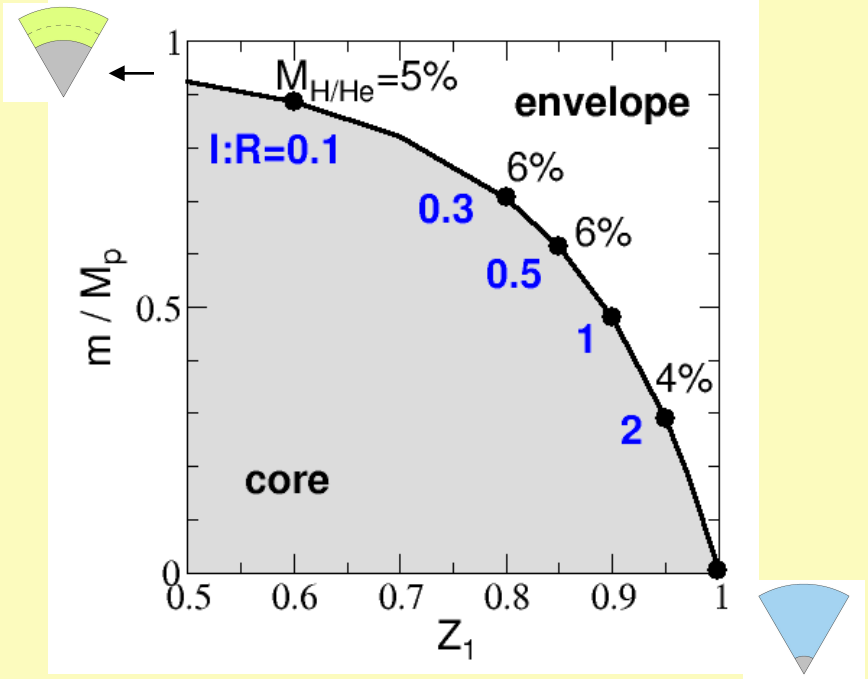
Pure water models are too cold to give a cooling time < 10 Gyr.
Acceptable models have ice:rock > 6

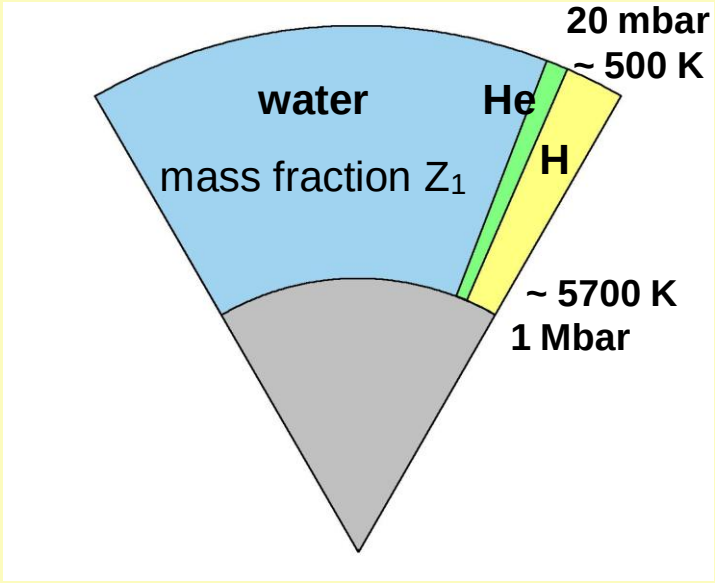
GJ 1214b models with H/He/H_2O envelope



GJ 1214b models with H/He/H_2O envelope

Core mass in dependence on the envelope water mass fraction

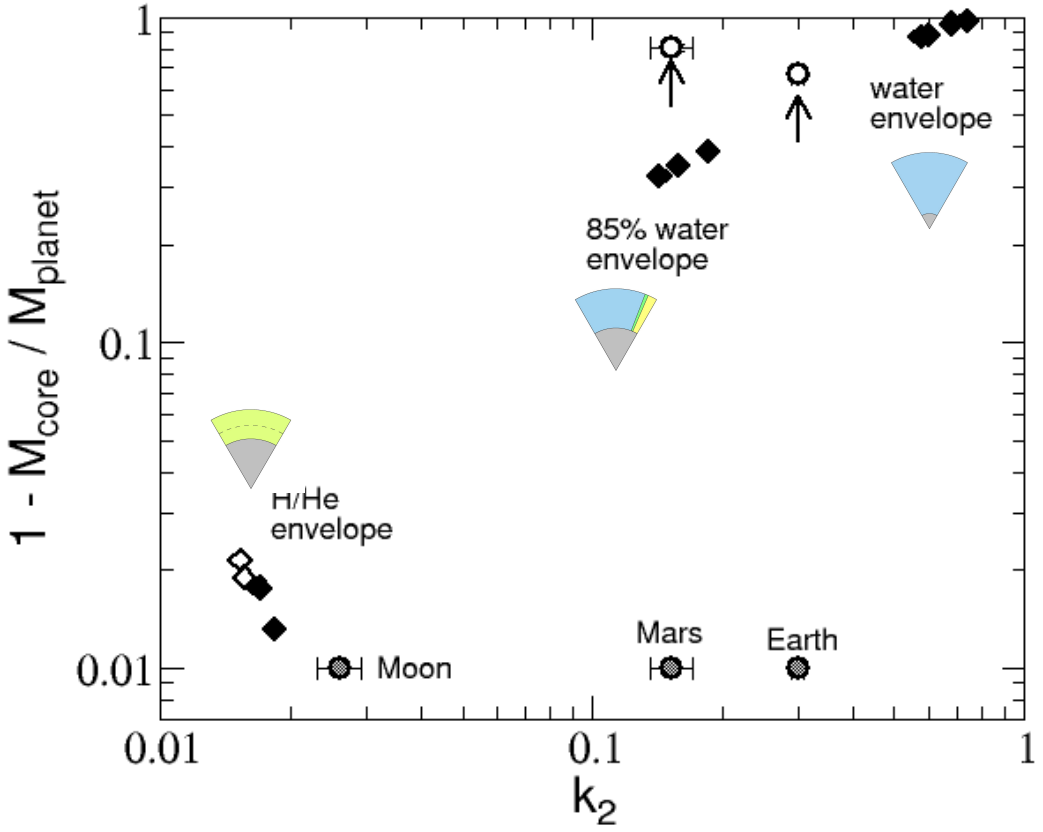




1x solar ice:rock ratio is obtained for Z_1=0.95.
Z_1 < 0.5 implys a rock body with an envelope of < 0.5 M_{Earth} .

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 ~ 0.015
water envelope models	• water does not crystallize in GJ 1214b • core-less models are excluded, I:R = 6 – 30, k_2 ~ 0.7
H/He/H_2O envelope models	• 1x solar ice:rock ratio is obtained for Z_1=0.95. • Z_1 < 0.5 implys 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:

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

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

$a = 0.037$ AU

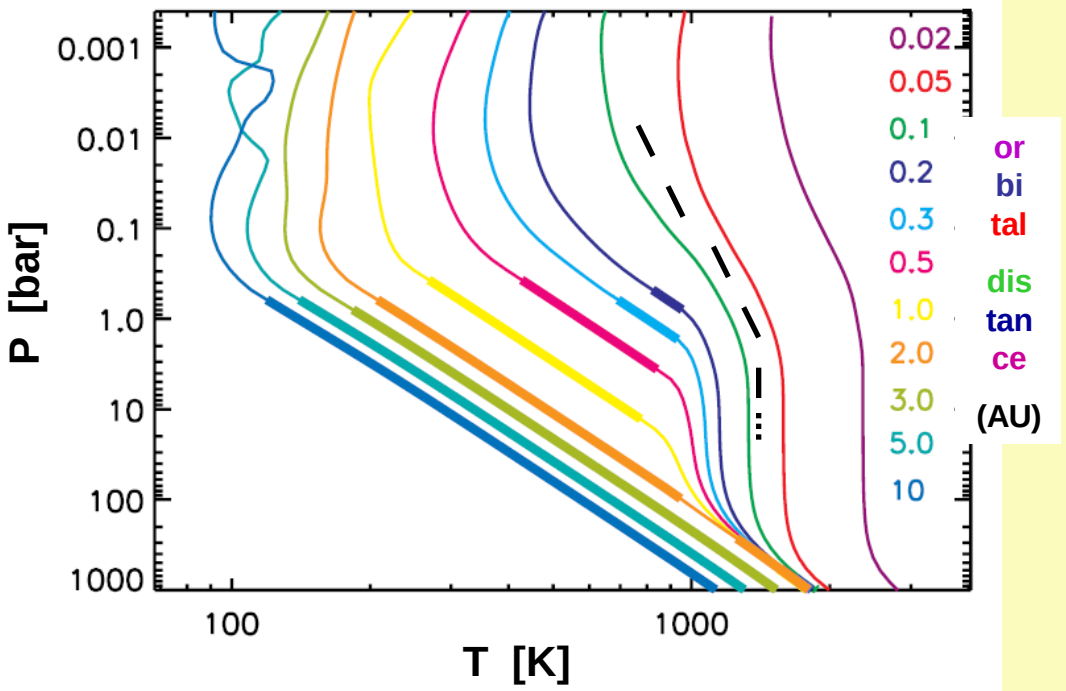
$e = 0.06$

STAR:

K5, $T_{eff} = 4700$ K

190 - 350 Myr young

Atmosphere profiles of 1 M_{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:

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

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

$a = 0.037$ AU

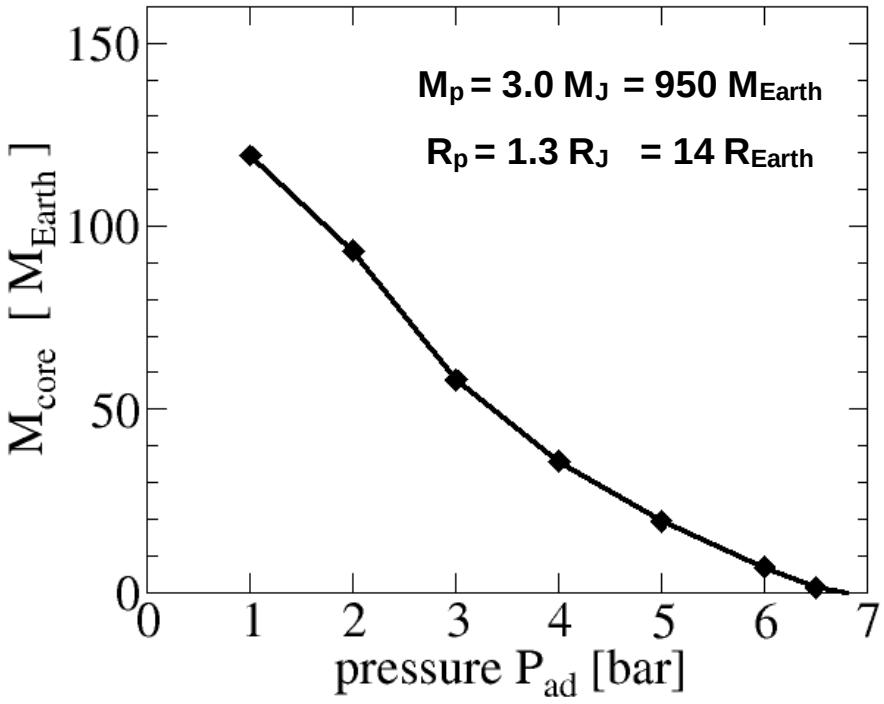
$e = 0.06$

STAR:

K5, $T_{eff} = 4700$ 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