Investigating the Influence of Mean-Opacity (κ) Values on Interior-Atmosphere Modelling

Jasmine MacKenzie (1), Philipp Baumeister (1)
Mareike Godolt (1,2), John Lee Grenfell (2), Nicola Tosi (2)

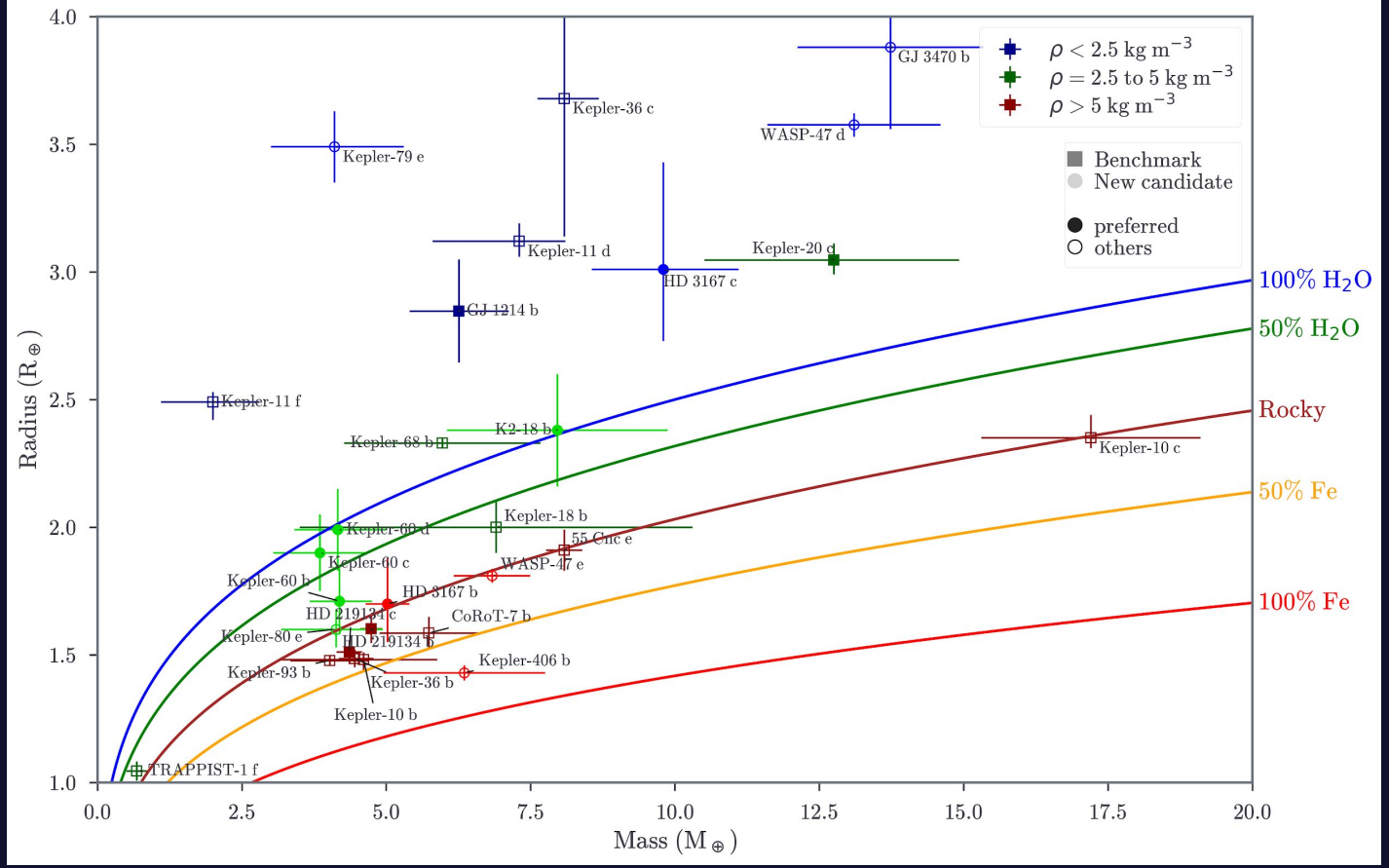
(1) Zentrum für Astronomie und Astrophysik, Technische Universität Berlin, Berlin, Germany
(2) Institut für Planetenforschung, Deutsches Zentrum für Luft- und- Raumfahrt, Berlin, Germany

Technische Universität Berlin

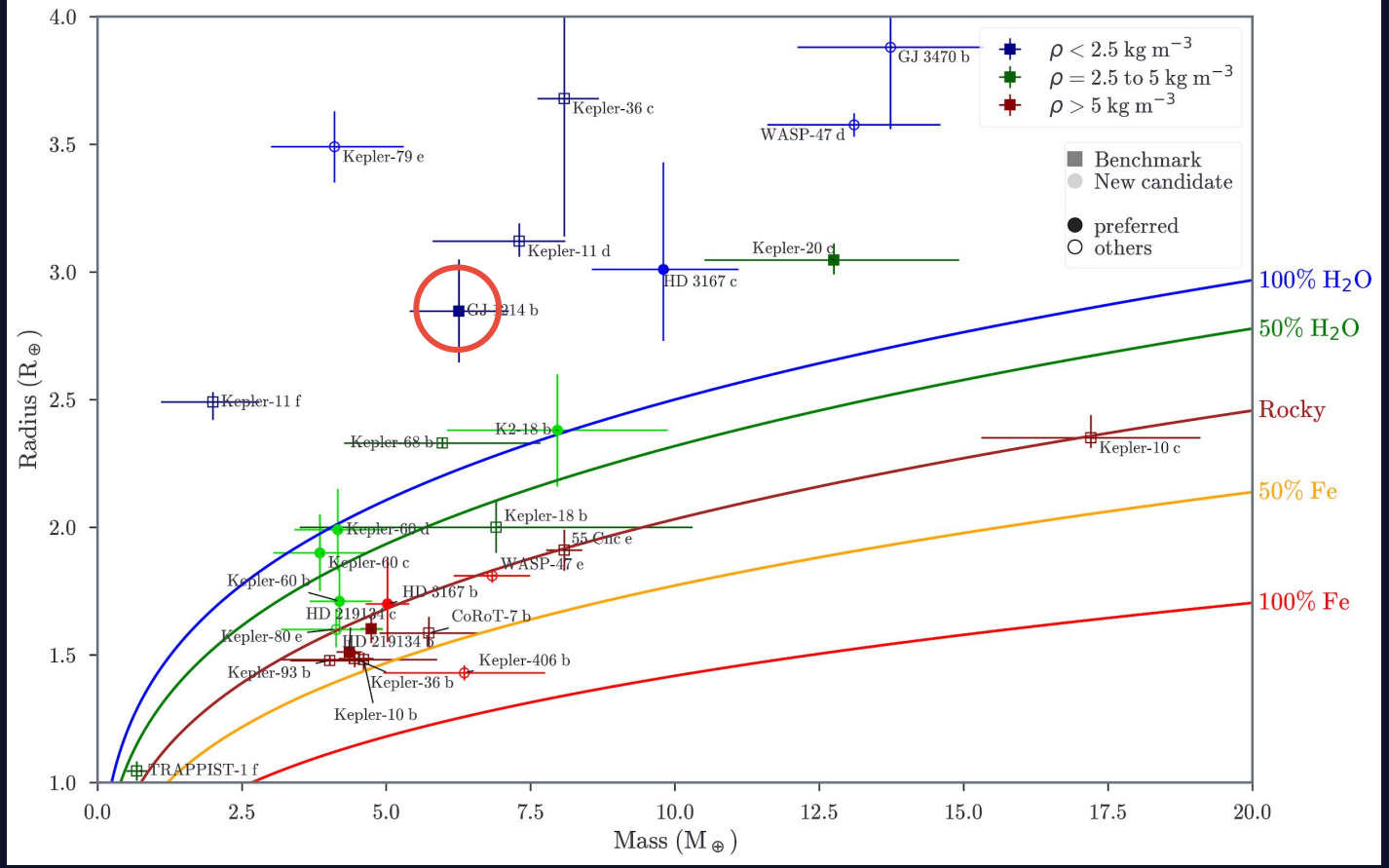
DLR

exoplanet diversity
SPP 1992

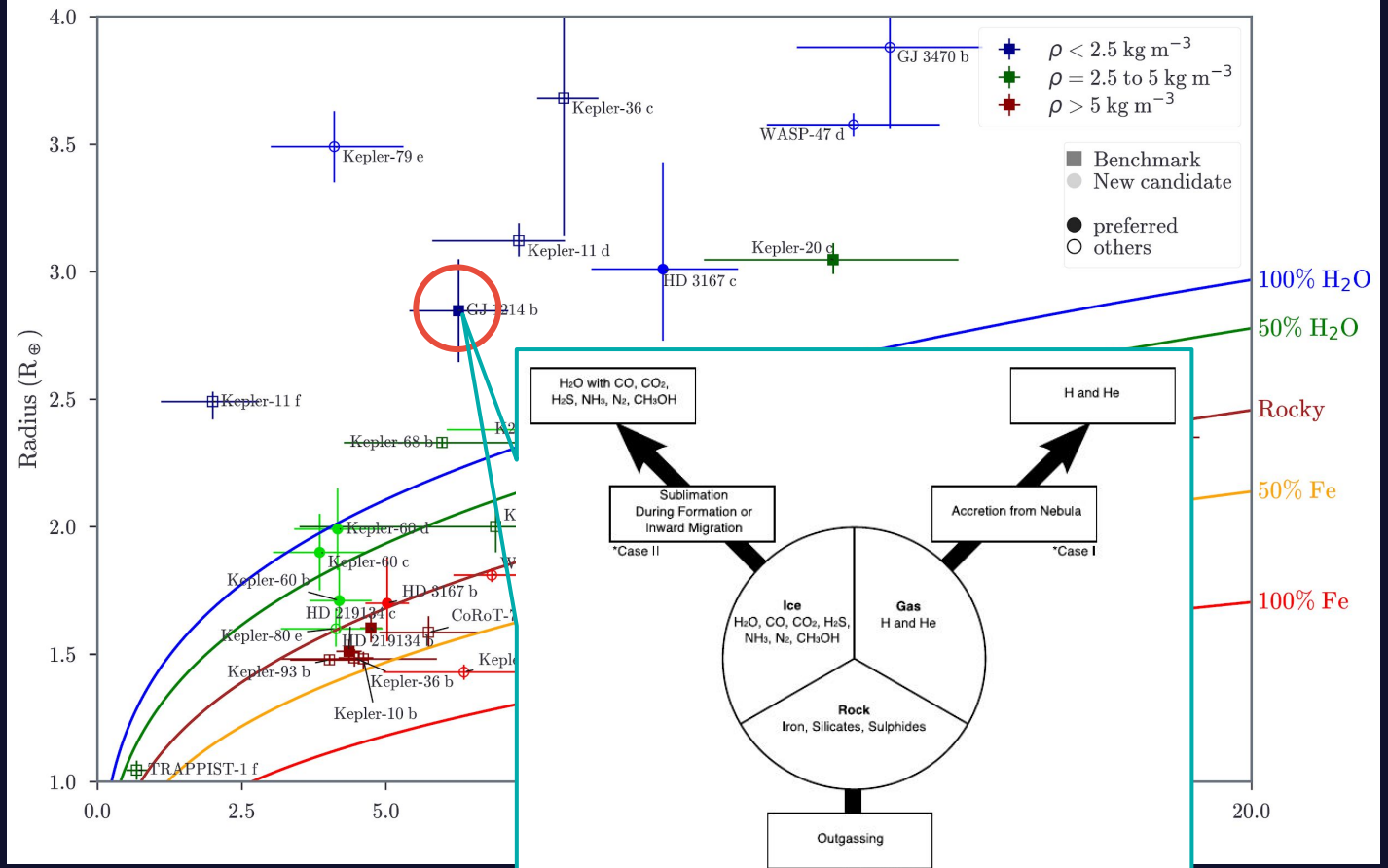
EGU 2020 04.05.2020



Planets of interest

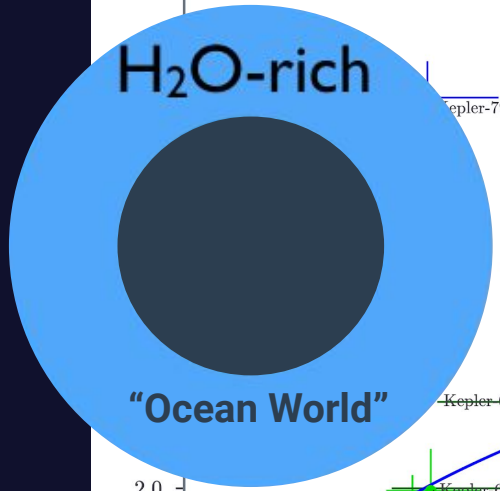


Planets of interest



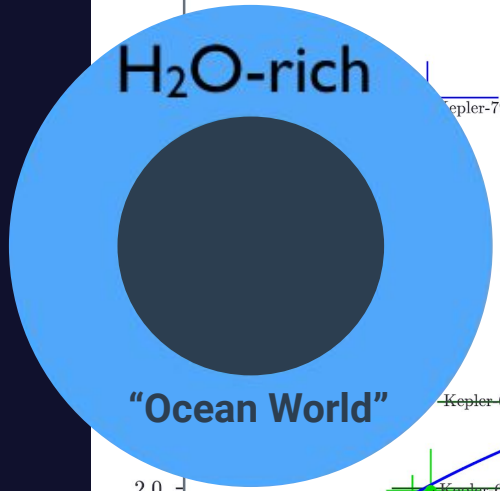
Planets of interest

Rogers & Seager (2010)



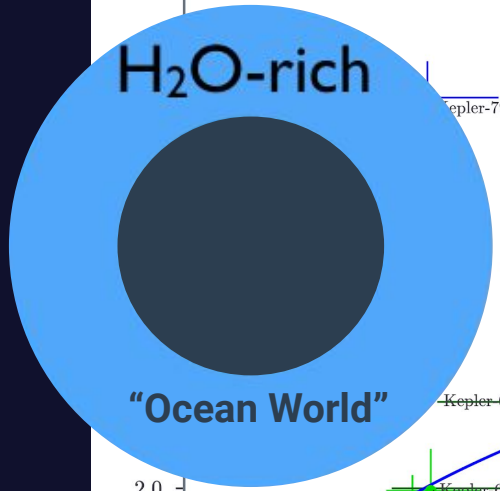
Planets of interest

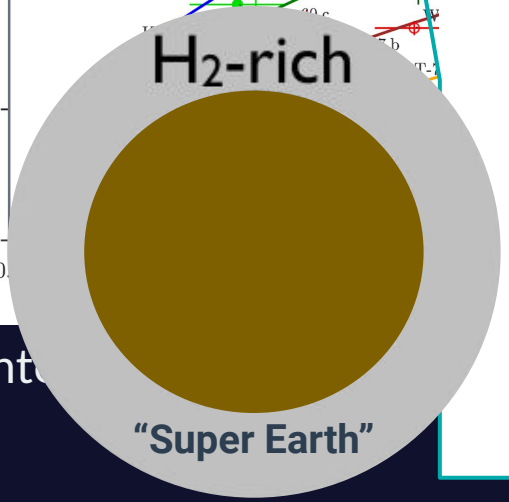
Rogers & Seager (2010)



Planets of interest

Rogers & Seager (2010)





Planets of int

Rogers & Seager (2010)

TATOOINE Tool for **AT**mospheres, **O**utgassing, and **O**ptimal **IN**teriors of **E**xoplanets

Planet mass

Layer composition

Layer mass fractions

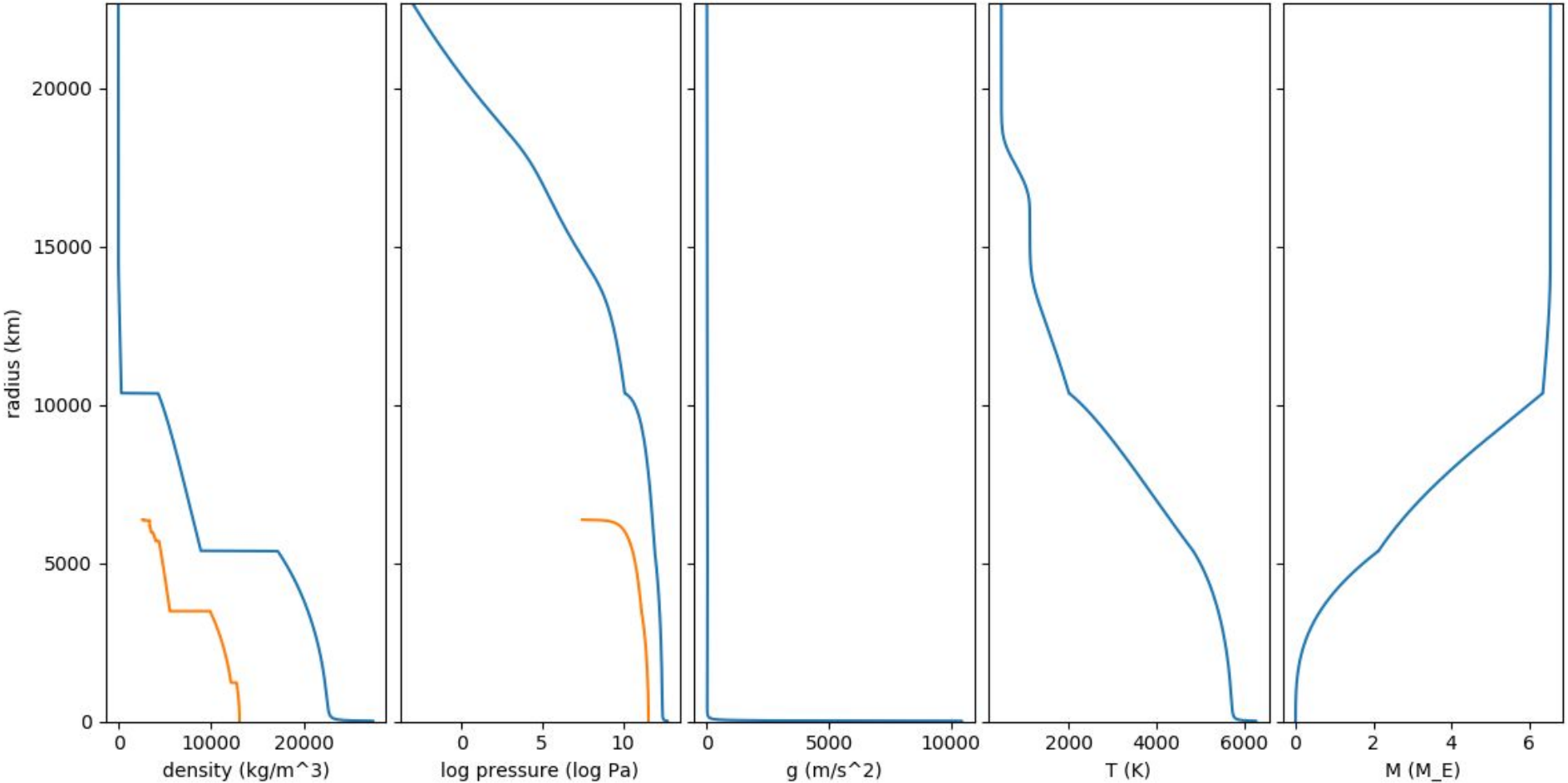
System Parameters: Stellar luminosity, orbital distance, etc

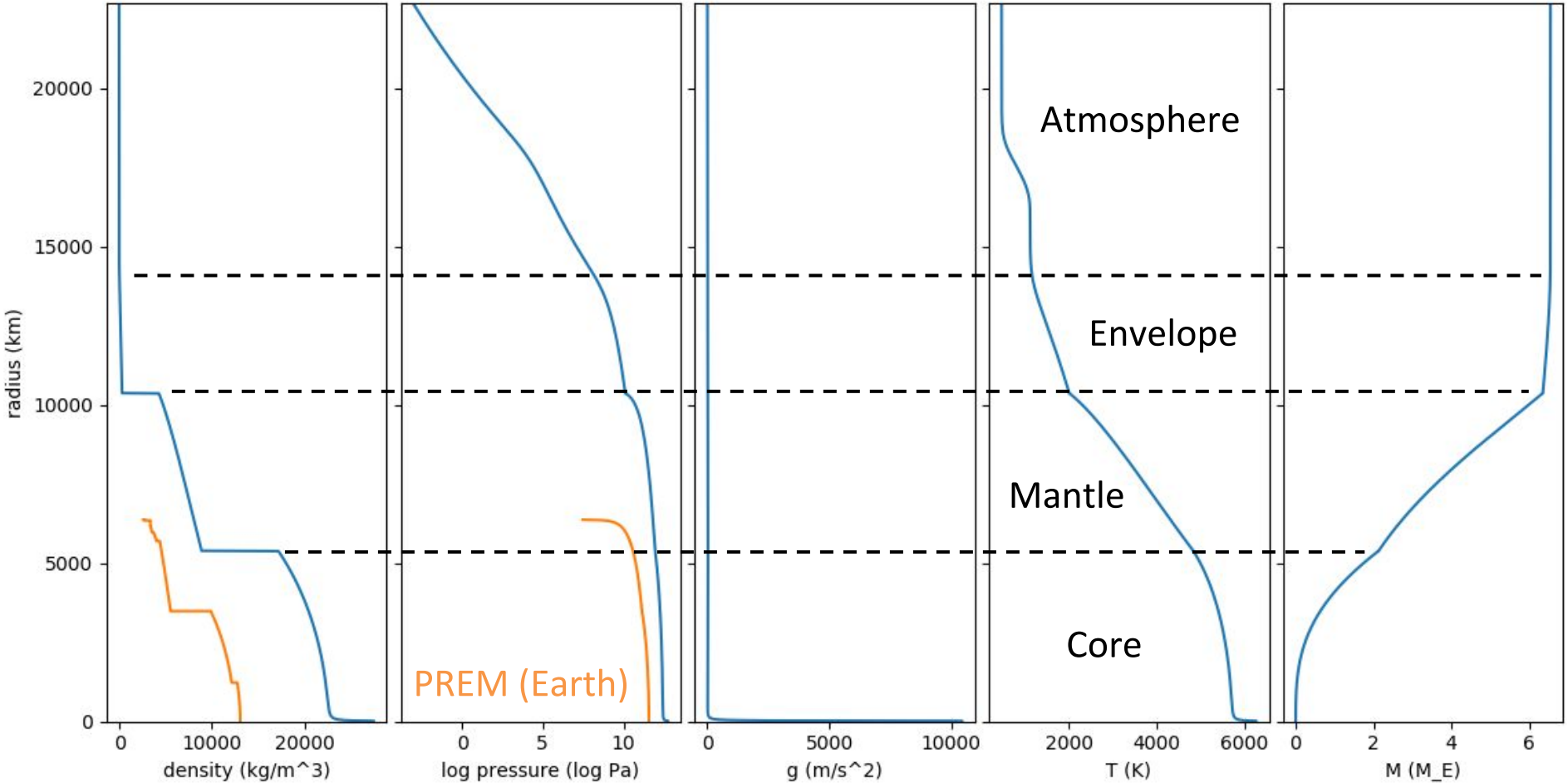
Planet radius

Interior structure

Pressure, temperature, gravity...

Other outputs: Love numbers, Fe/Si ratio, ...


radius (km)
0
5000
10000
15000
20000
0
10000
20000
density (kg/m^3)
0
5
10
log pressure (log Pa)
0
5000
10000
g (m/s^2)
2000
4000
6000
T (K)
0
2
4
6
M (M_E)

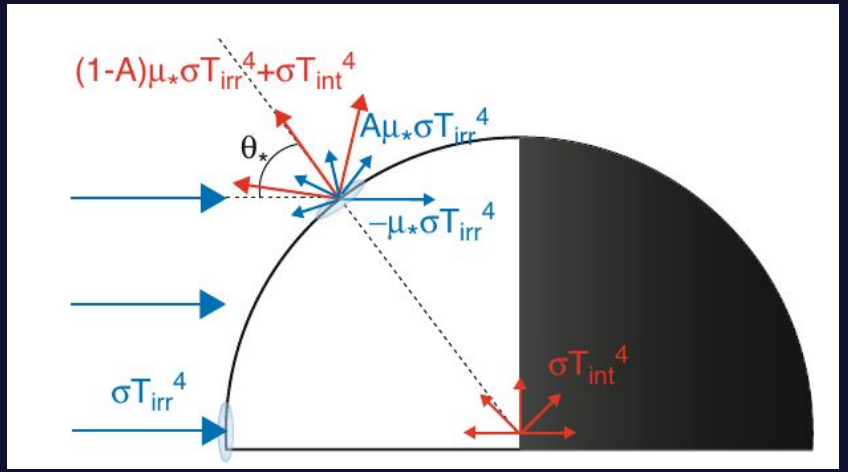

radius (km)
20000
15000
10000
5000
0
0
10000
20000
density (kg/m^3)
PREM (Earth)
0
5
10
log pressure (log Pa)
0
5000
10000
g (m/s^2)
Atmosphere
Envelope
Mantle
Core
2000
4000
6000
T (K)
0
2
4
6
M (M_E)

Interior Modelling

- Core (Fe) Mass Fraction: 30%
  - Valencia et al. (2006) - Vinet
- Pv ($MgSiO_3$) Mantle
  - Wagner et al. 2011 - Vinet
- Water/Ice Mass Fraction: 0%
- Gas (H/He) Mass Fraction: 3%
  - Atmosphere: Semi-Grey Approximation Guillot (2010)
  - High Pressure Envelope: Chabrier, Mazevet, & Soubiran (2019)

Semi-Grey Approximation (Guillot 2010)

- Analytical approximation of a full radiative transfer line-by-line model
- Absorption of radiation approximated by mean opacities:
  - Planetary thermal radiation (κ_{th})
  - Incident visible flux from star (κ_v)
- Temperature is a function of optical depth (τ) and mean opacity ratio ($\gamma = \kappa_v / \kappa_{th}$)
- Optical depth is a function of the thermal mean opacity
  - $\tau = \kappa_{th}$ m̃
- Pressure is linearly dependant on optical depth
  - $P = \tau g/\kappa_{th}$
- Transit radius calculated where $\tau_{chord} = 2/3$

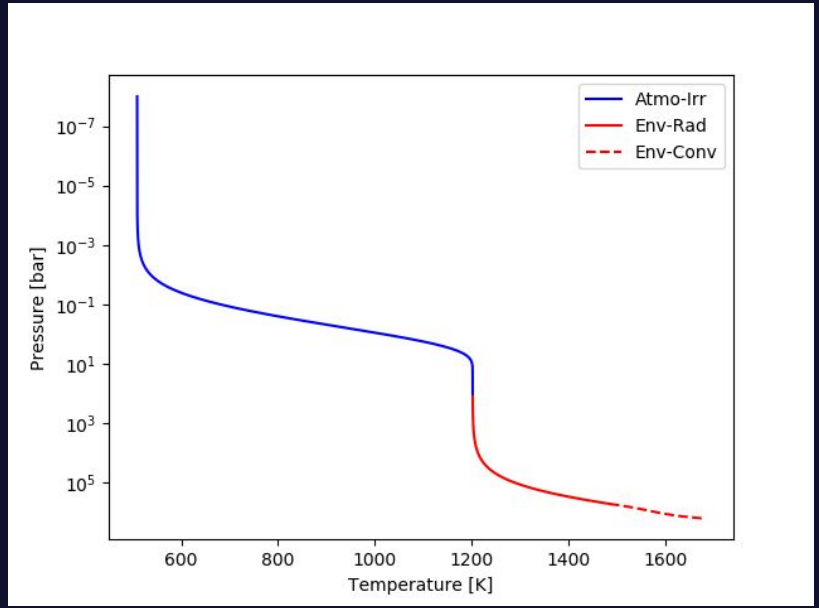


Mean Opacity (κ) Study

How significant of an impact does one's choice of mean opacity have on atmospheric profiles and exoplanet interior characterization.

Mean Opacity Usage in TATOOINE

- Semi-Grey Pressure-Temperature profile
  - Guillot 2010
- Transit Pressure and Radius
  - Following Guillot 2010
- Switch from Irradiated Atmosphere to High Pressure Envelope
  - Following Jin et al. 2014
- Switch within envelope between Radiative and Convective regimes
  - Schwarzschild Criterion



Choosing κ_v & κ_{th} (Freedman et al. 2014)

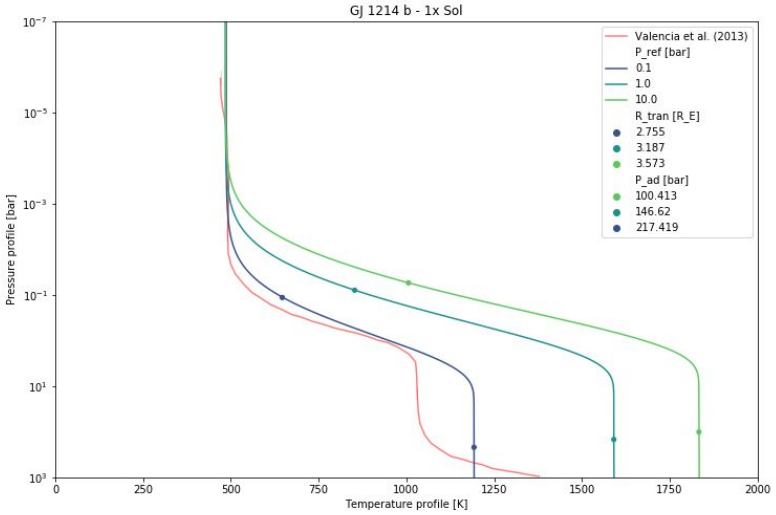
1. Metallicity = Composition
   a. 1x to 50x solar metallicity
2. Local Reference Pressure
   a. [0.1, 1.0, 10.0] bar
3. Local Reference Temperature
   a. Equilibrium Temperature (T_{eq})
4. Stellar Effective Temperature for κ_v
   a. T_{eff} = 3000 K

$$B_\lambda(\lambda, T) = \frac{2hc^2}{\lambda^5}\left(e^{hc/\lambda k_B T} - 1\right)^{-1}$$

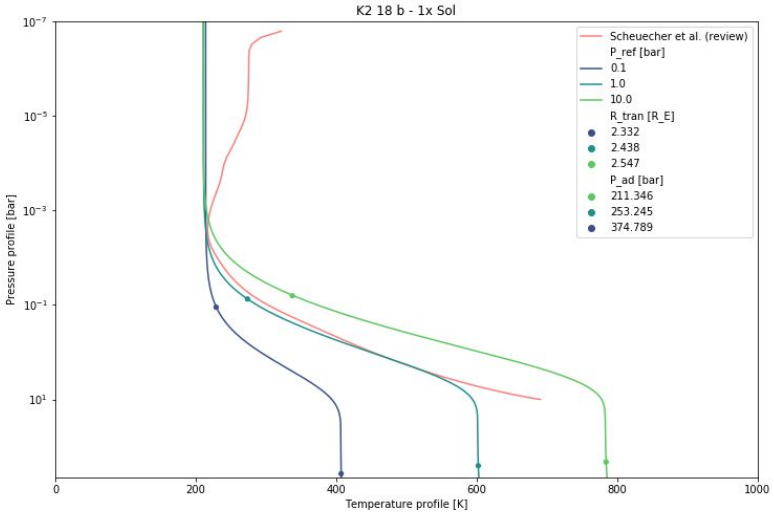
$$\kappa_R \equiv \left(\frac{\int \frac{1}{\kappa} \frac{\partial B}{\partial T} d\tilde{\nu}}{\int \frac{\partial B}{\partial T} d\tilde{\nu}} \right)^{-1}$$

Comparison of Atmosphere Profiles to other Models

GJ 1214 b 1x Solar & Valencia (2013)

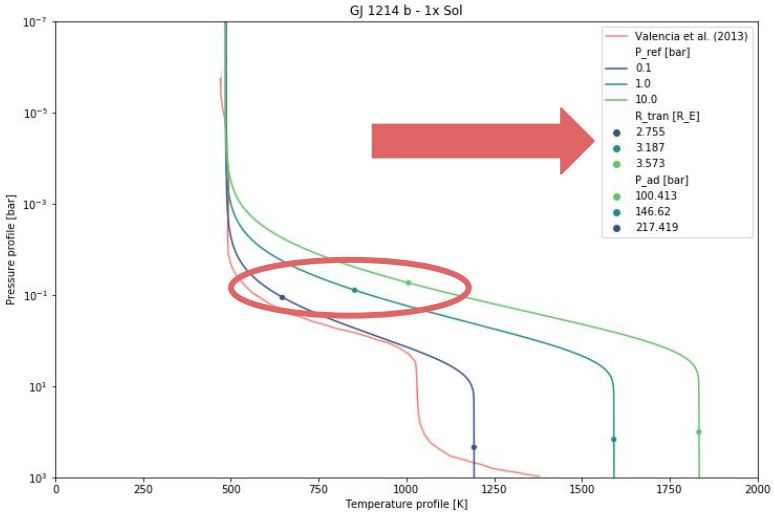


K2-18 b 1x Solar & Scheuecher et al. (review)

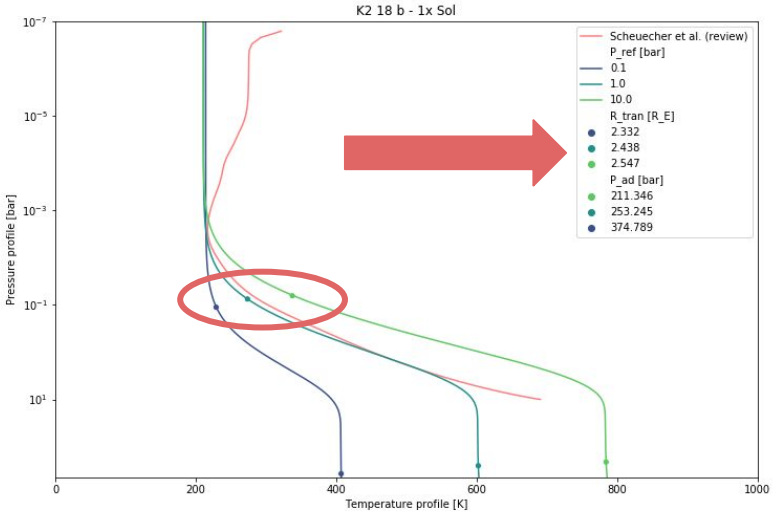


Comparison of Atmosphere Profiles to other Models

GJ 1214 b 1x Solar & Valencia (2013)

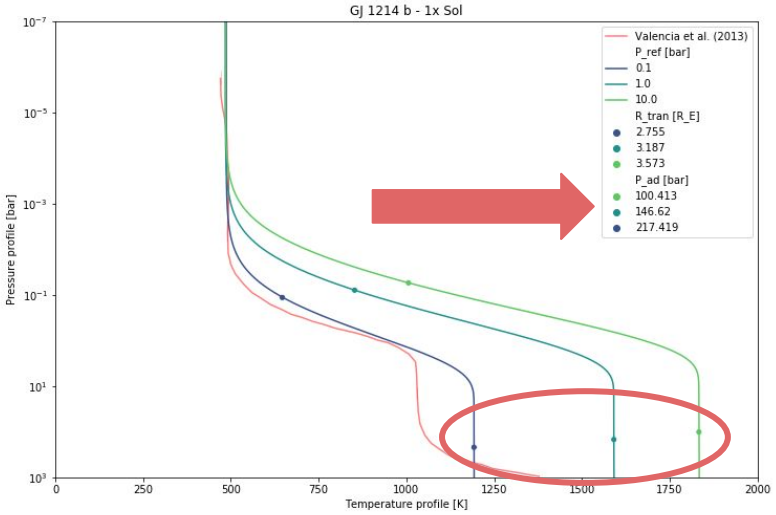


K2-18 b 1x Solar & Scheuecher et al. (review)

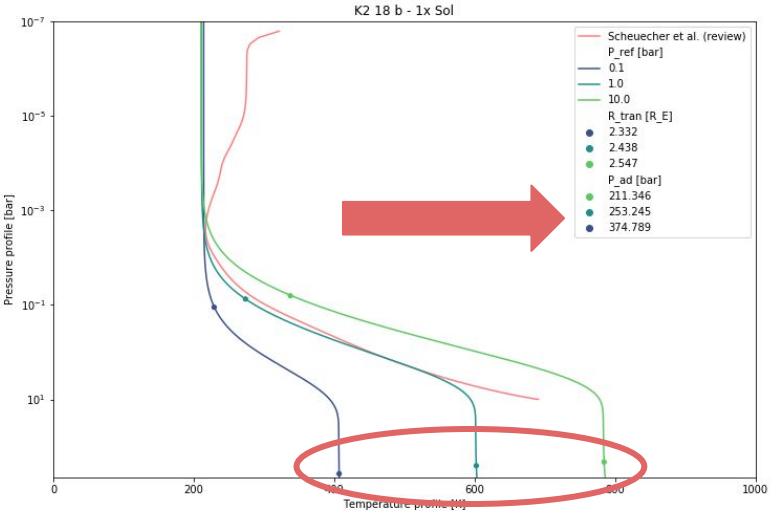


Comparison of Atmosphere Profiles to other Models

GJ 1214 b 1x Solar & Valencia (2013)

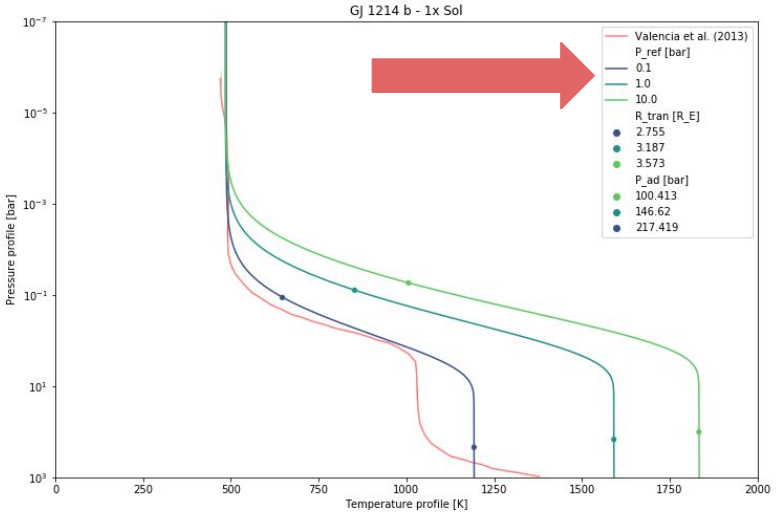


K2-18 b 1x Solar & Scheuecher et al. (review)

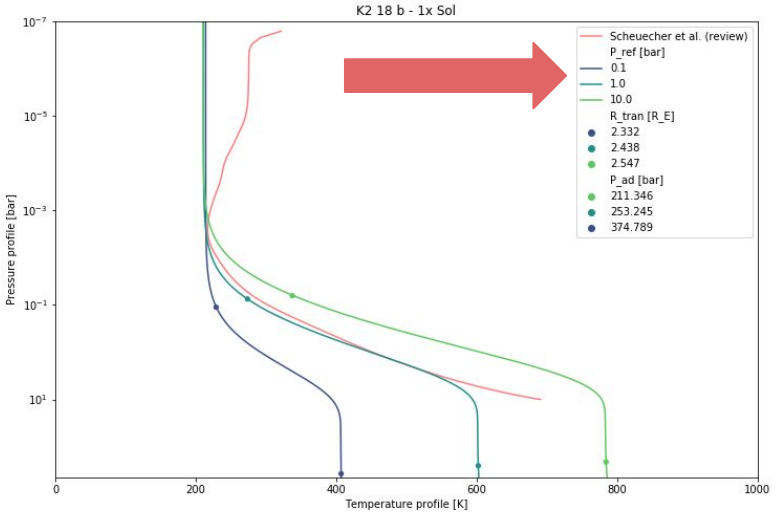


Comparison of Atmosphere Profiles to other Models

GJ 1214 b 1x Solar & Valencia (2013)

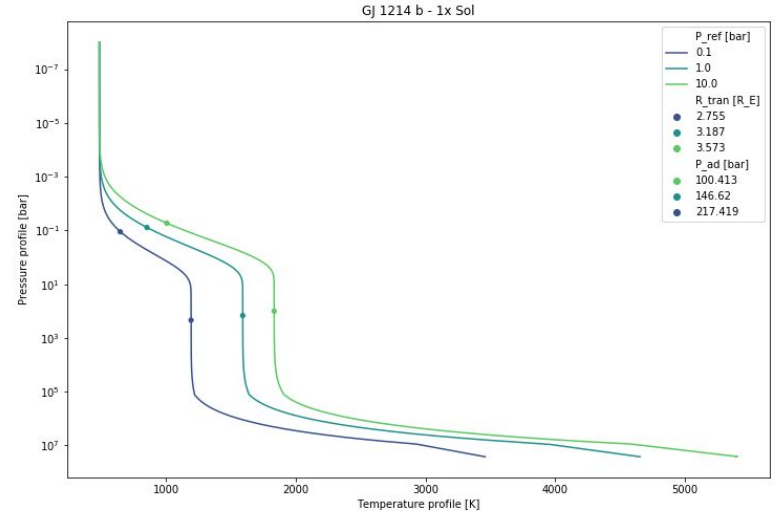


K2-18 b 1x Solar & Scheuecher et al. (review)

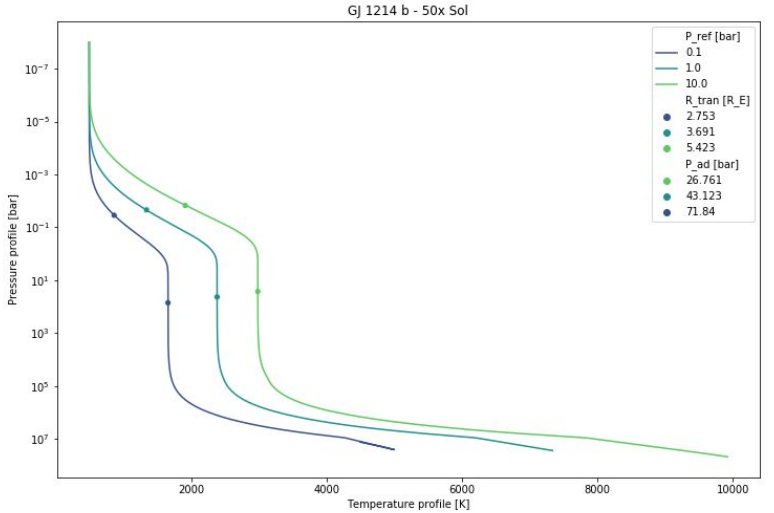


Effect of Atmospheric Metallicity on Interior

GJ 1214 b - 1x Solar Metallicity

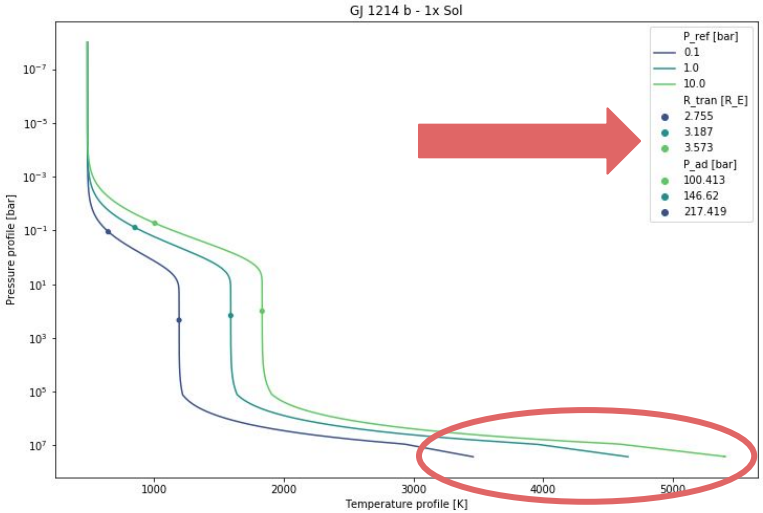


GJ 1214 b - 50x Solar Metallicity

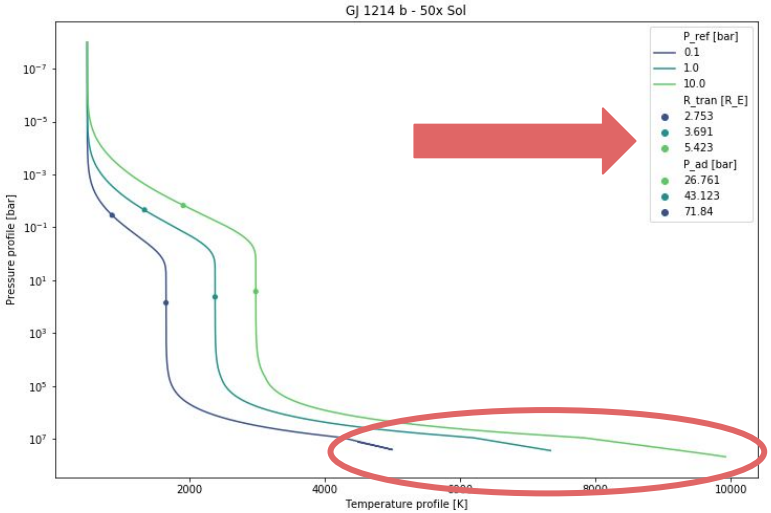


Effect of Atmospheric Metallicity on Interior

GJ 1214 b - 1x Solar Metallicity

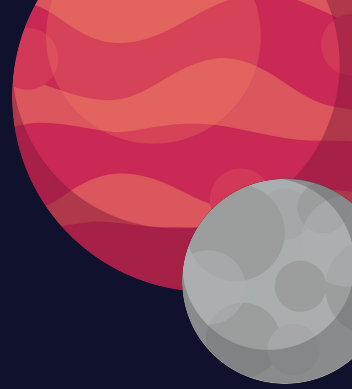


GJ 1214 b - 50x Solar Metallicity



Conclusion & Closing Remarks

- How one chooses a value for mean opacities is non-trivial.
- The influence extends beyond the atmosphere and into the interior.
- The impact on the interior has implications for things such as formation of a crust or magma ocean, the solubility of the interior, etc.



Thanks for Listening!