On the radius of habitable planets

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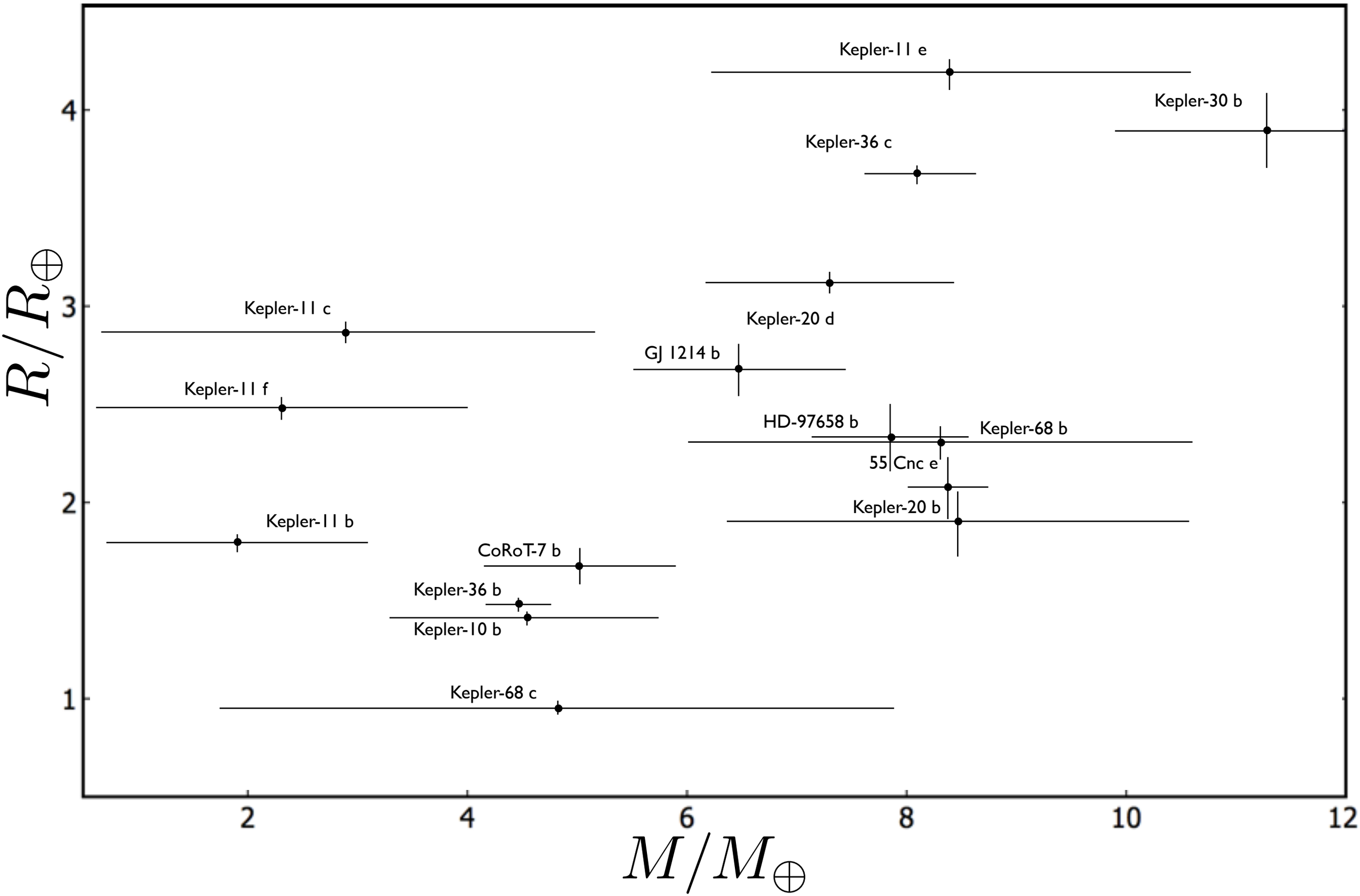
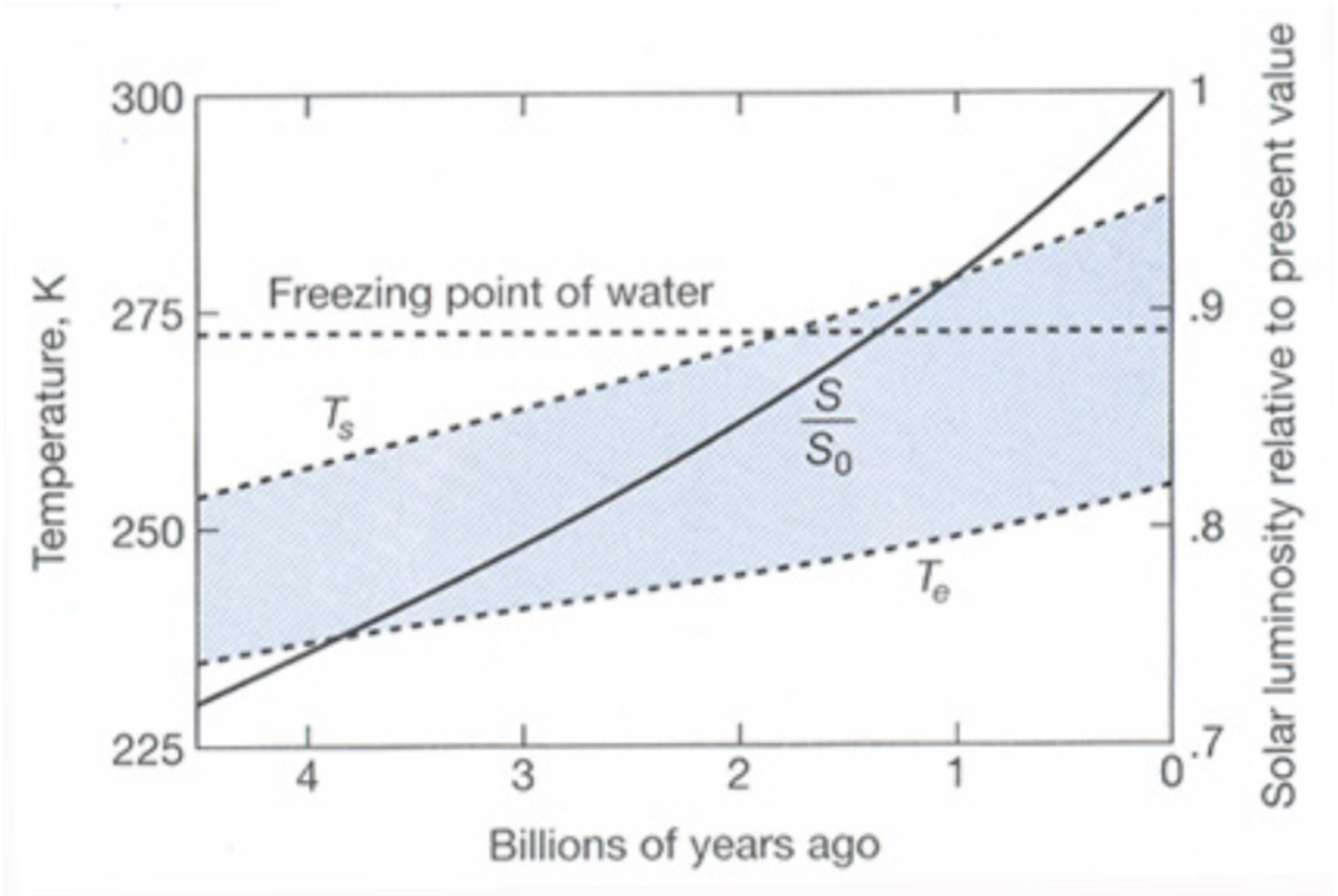
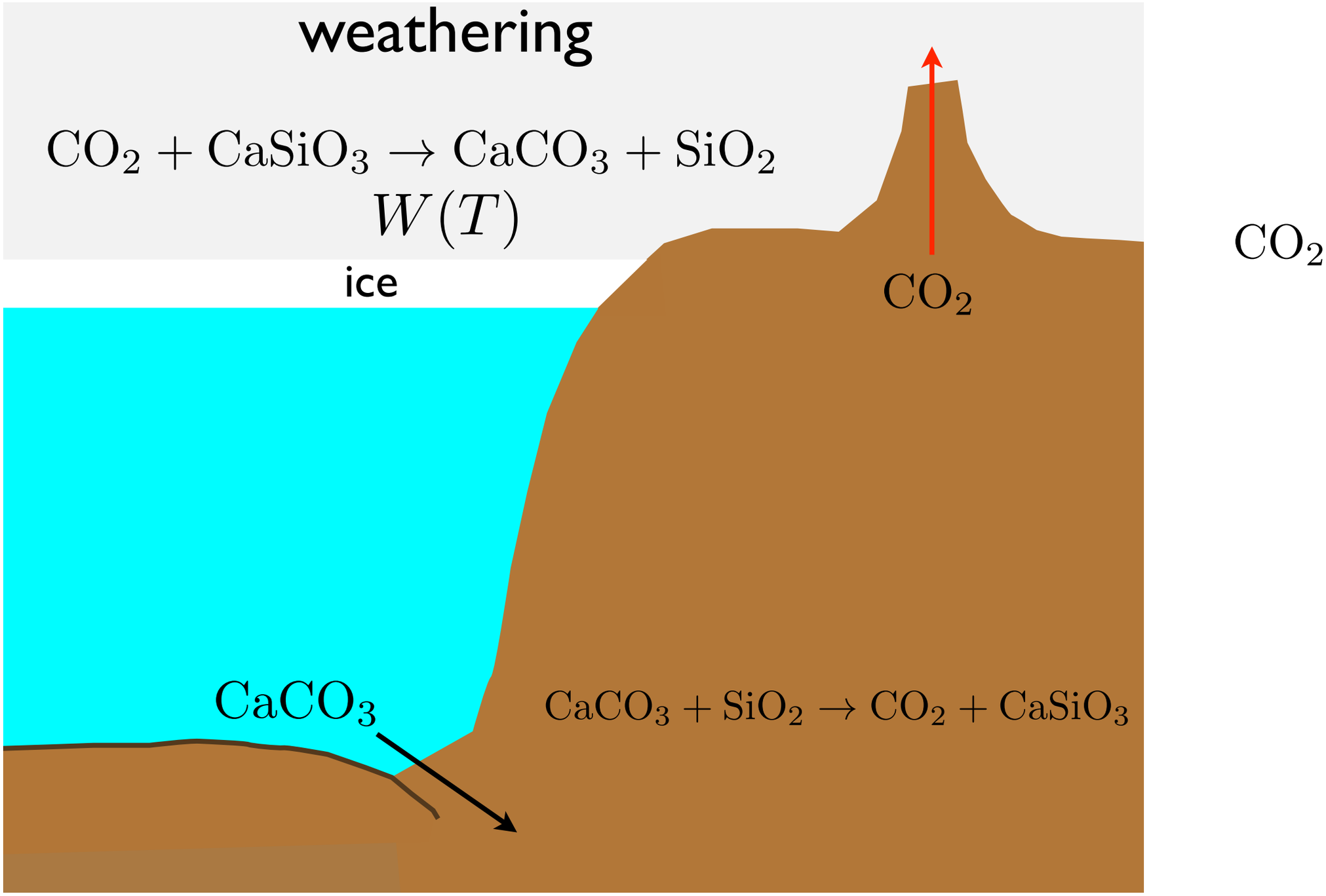
Low mass transiting planets



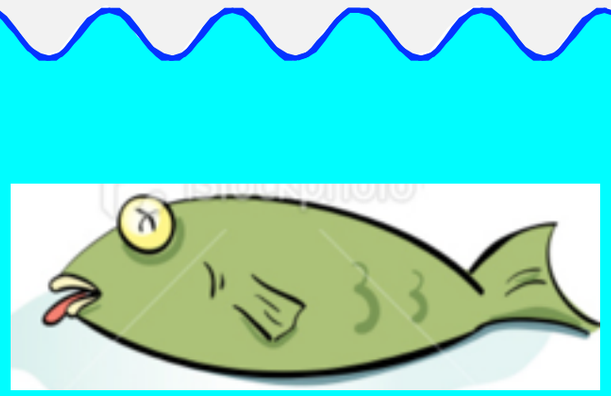
The Sun's luminosity



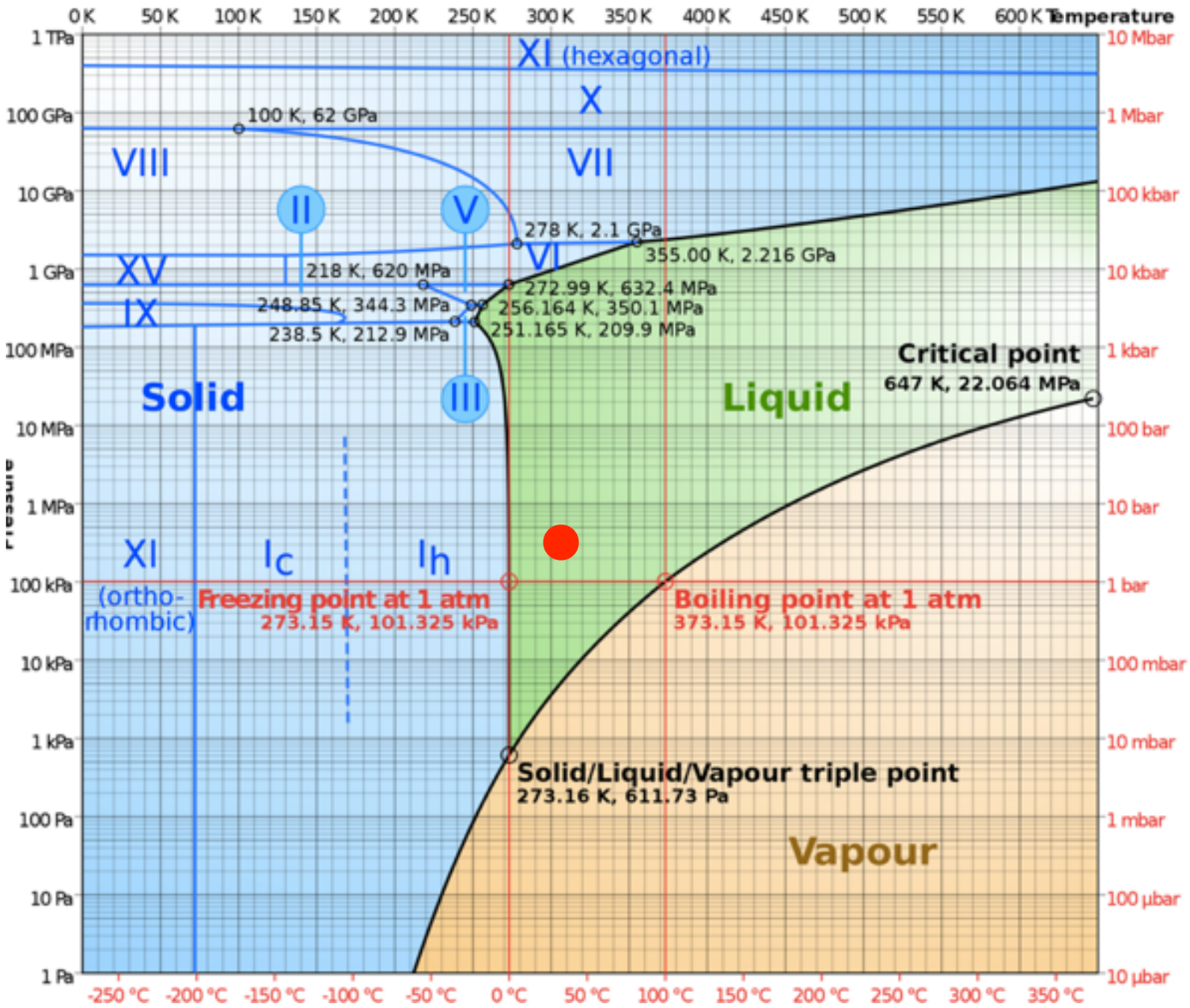
The geological C cycle stabilizes the surface temperature



Effect of Ocean mass

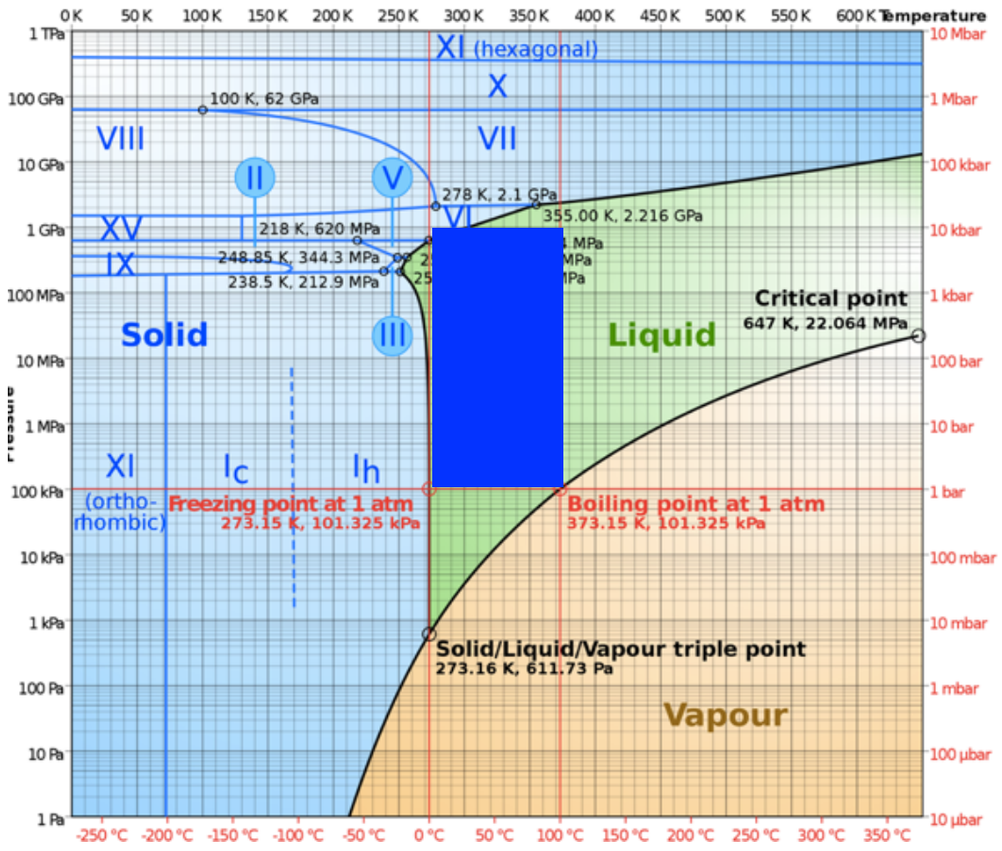


High pressure ice



Necessary condition for habitable planet

1- the surface temperature and pressure are ‘nice’



2- there is a CO2 cycle

the pressure at the bottom of the (global) ocean cannot be too high

A maximum radius for habitable planets

Large radius implies

large water fraction

no CO2 cycle

large gas fraction

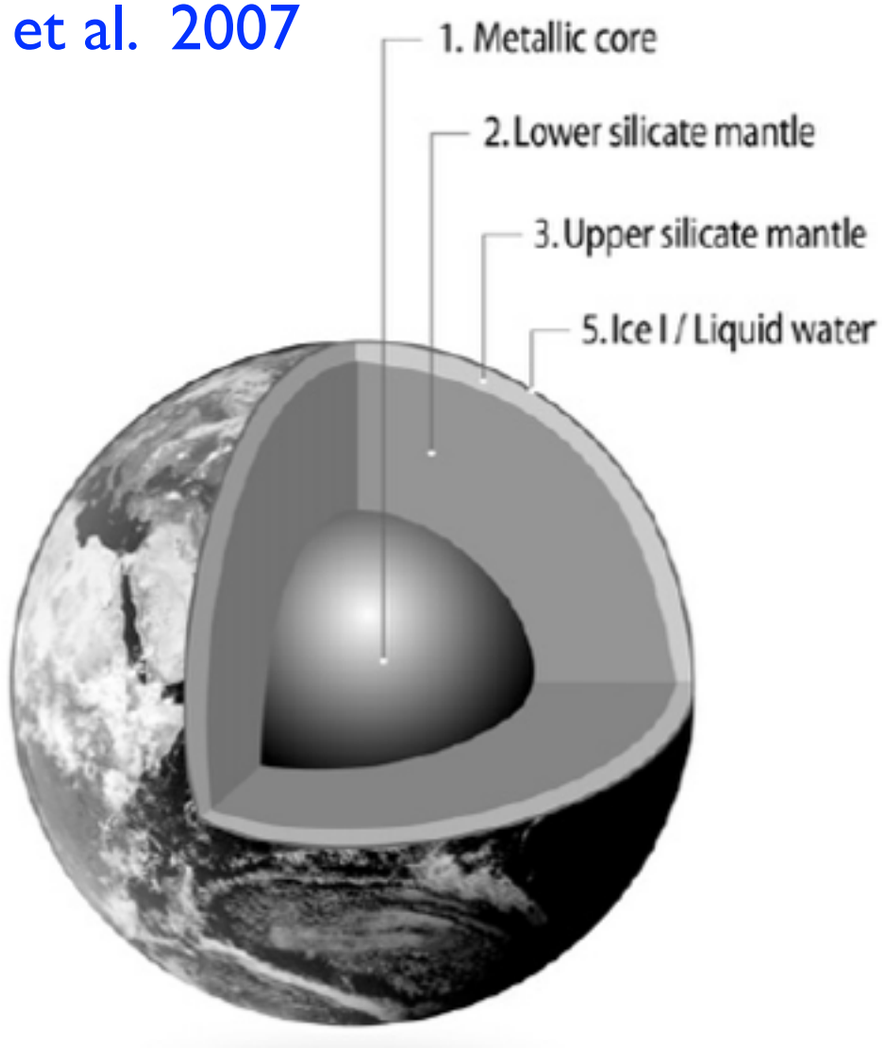
surface T,P outside of the 'nice' zone

large-R planets are NOT habitable

small-R planets: we don't know

Simplified planetary structure

Sotin et al. 2007



5 layers

- a core
- an inner mantle
- an outer mantle
- a water layer
- a gas envelope

Adiabatic T profile

$$\frac{dr}{dP} = \frac{1}{\rho g}$$

hydrostatic equilibrium

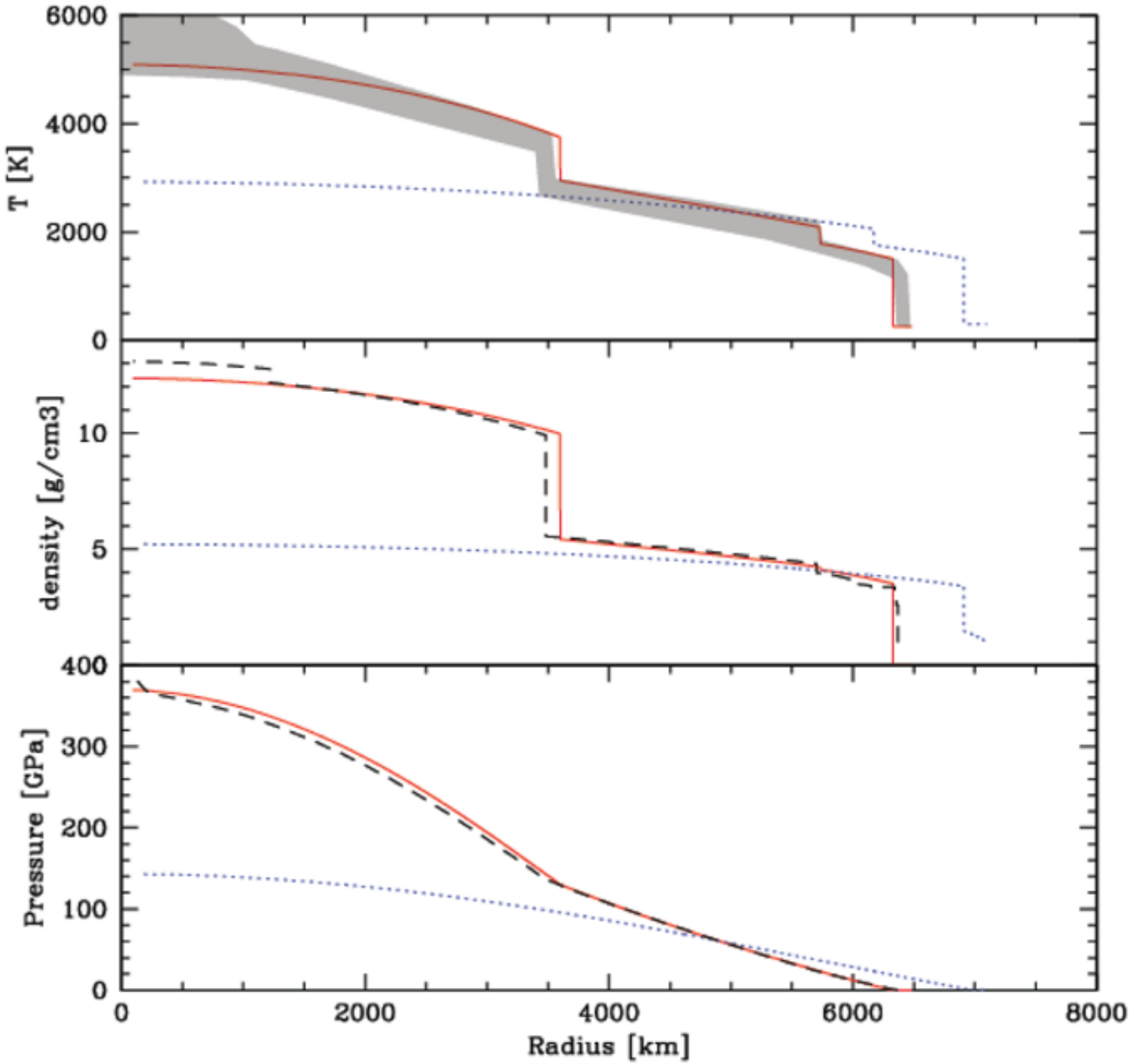
$$\frac{dm}{dP} = \frac{4\pi r^2}{g}$$

mass conservation

$$\frac{dT}{dP} = \nabla_{ad}$$

energy transport

Test of the model: the Earth

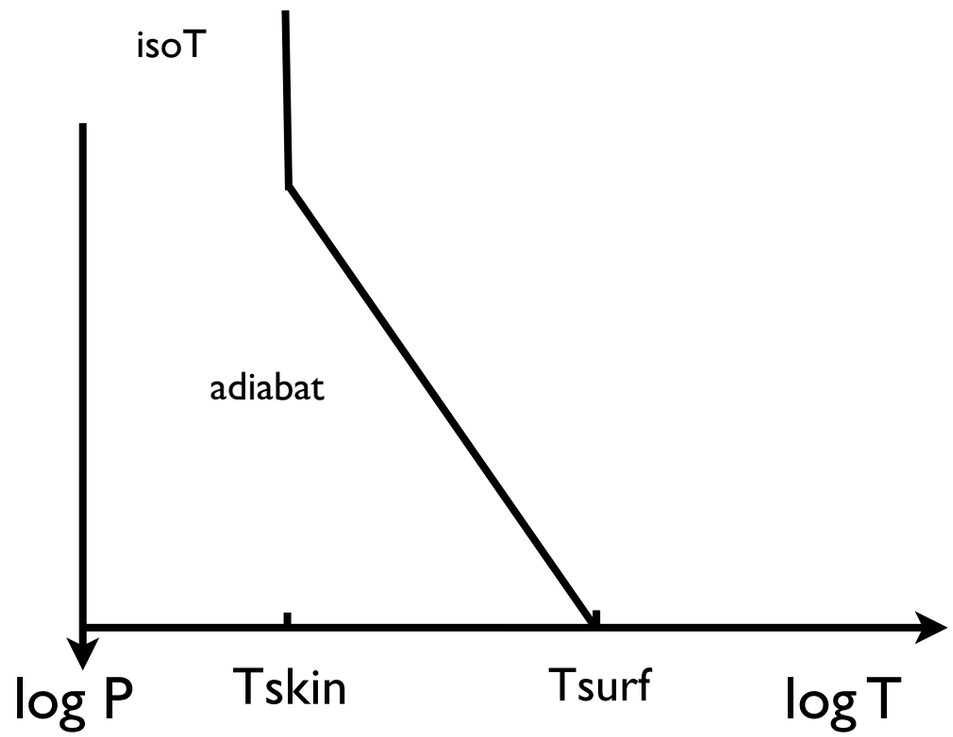


The gaseous part

convective-isothermal model

$$T_{\rm skin} = T_{\rm surf}/2^{1/4}$$

perfect gas with different composition

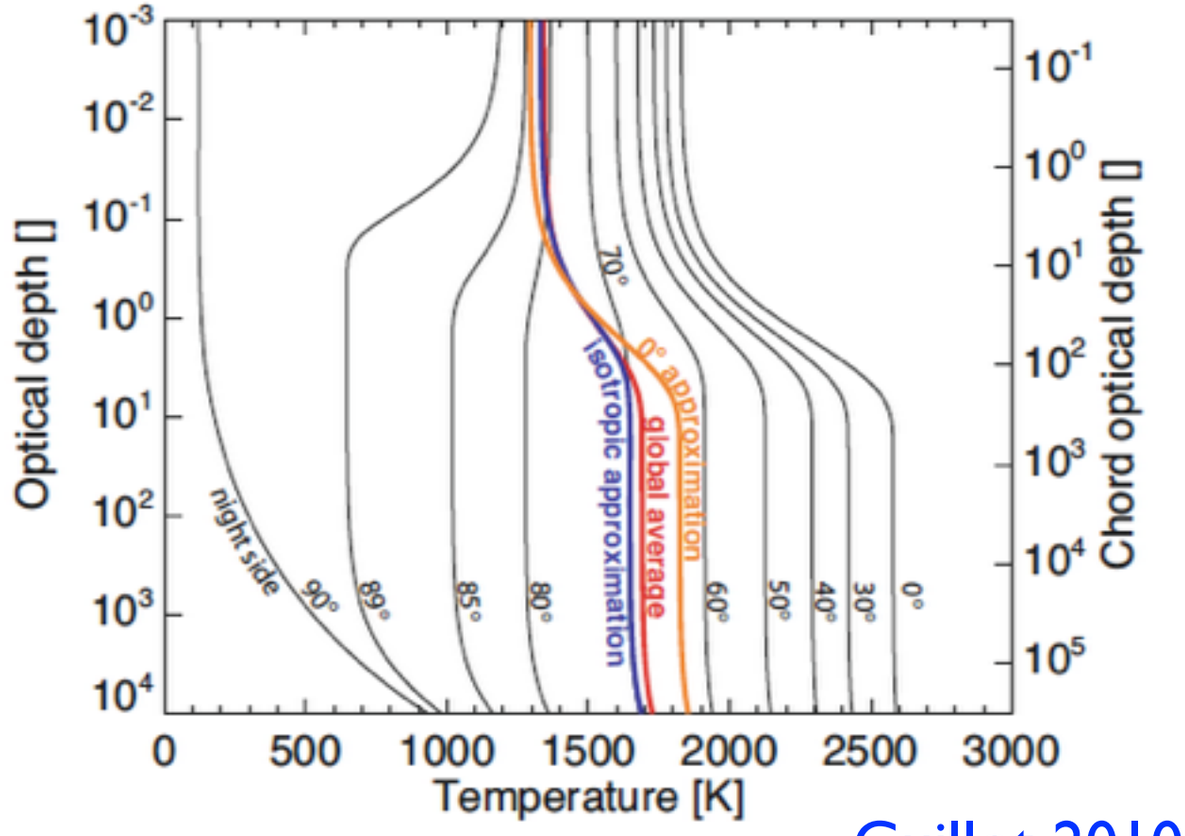


convective-radiative model

$$T^4 = \frac{3T_{\rm int}^4}{4}\left[\frac{2}{3}+\tau\right] + \frac{3T_{\rm irr}^4}{4} f \left[\frac{2}{3} + \frac{1}{\gamma\sqrt{3}} + \left(\frac{\gamma}{\sqrt{3}} - \frac{1}{\gamma\sqrt{3}}\right) e^{-\gamma\tau\sqrt{3}}\right]$$

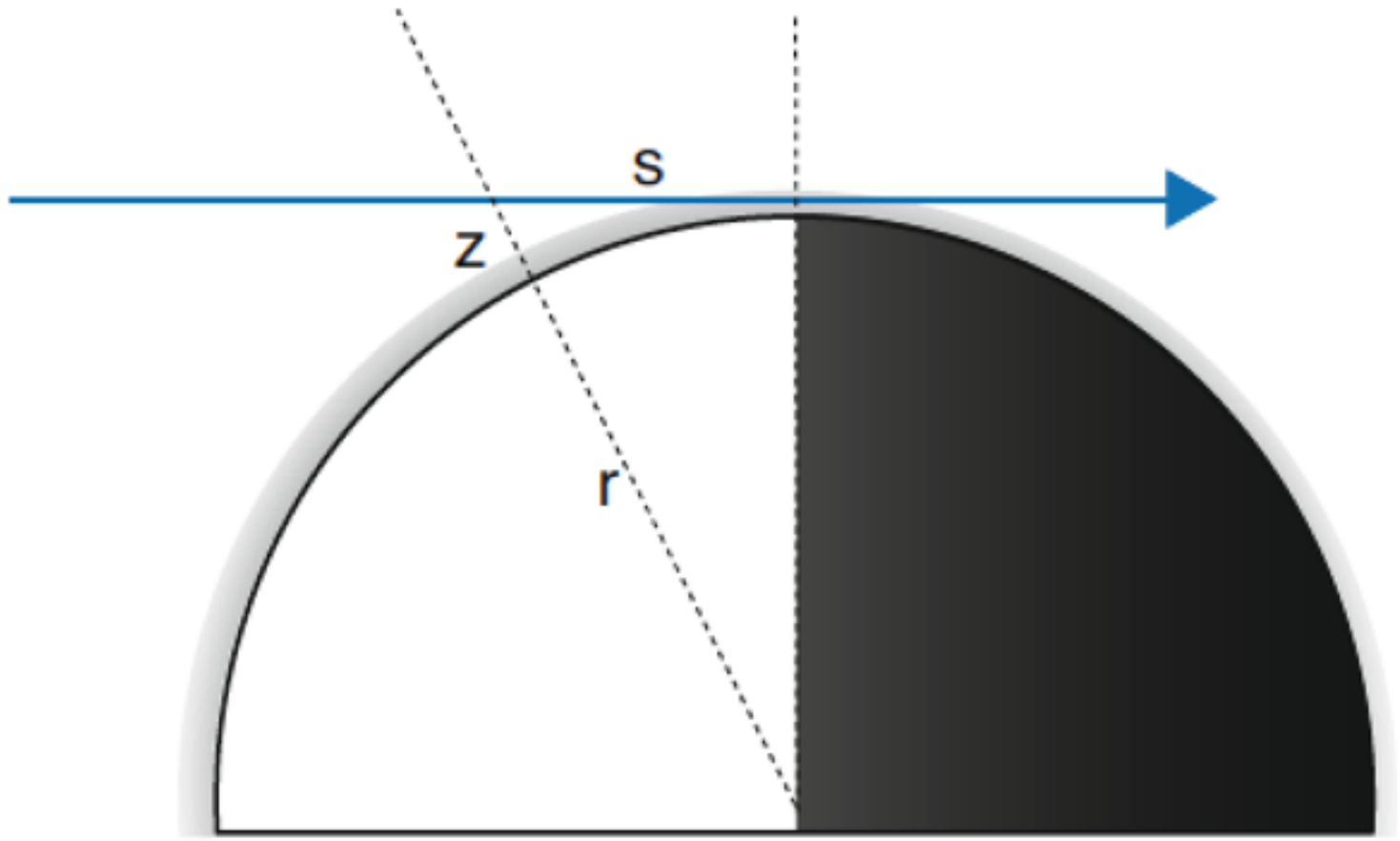
$$\gamma = \kappa_{\rm V}/\kappa_{\rm th}$$

includes greenhouse effect



Guillot 2010

Transit radius



$$\tau_{\rm ch}(\nu, r) = 2\int_0^{\infty} \rho\kappa_\nu \frac{z+r}{(z^2+2rz)^{1/2}} {\rm d}z.$$

opacity in the visible

transit radius for

$$\tau_{\rm ch} = 2/3$$

Guillot 2010

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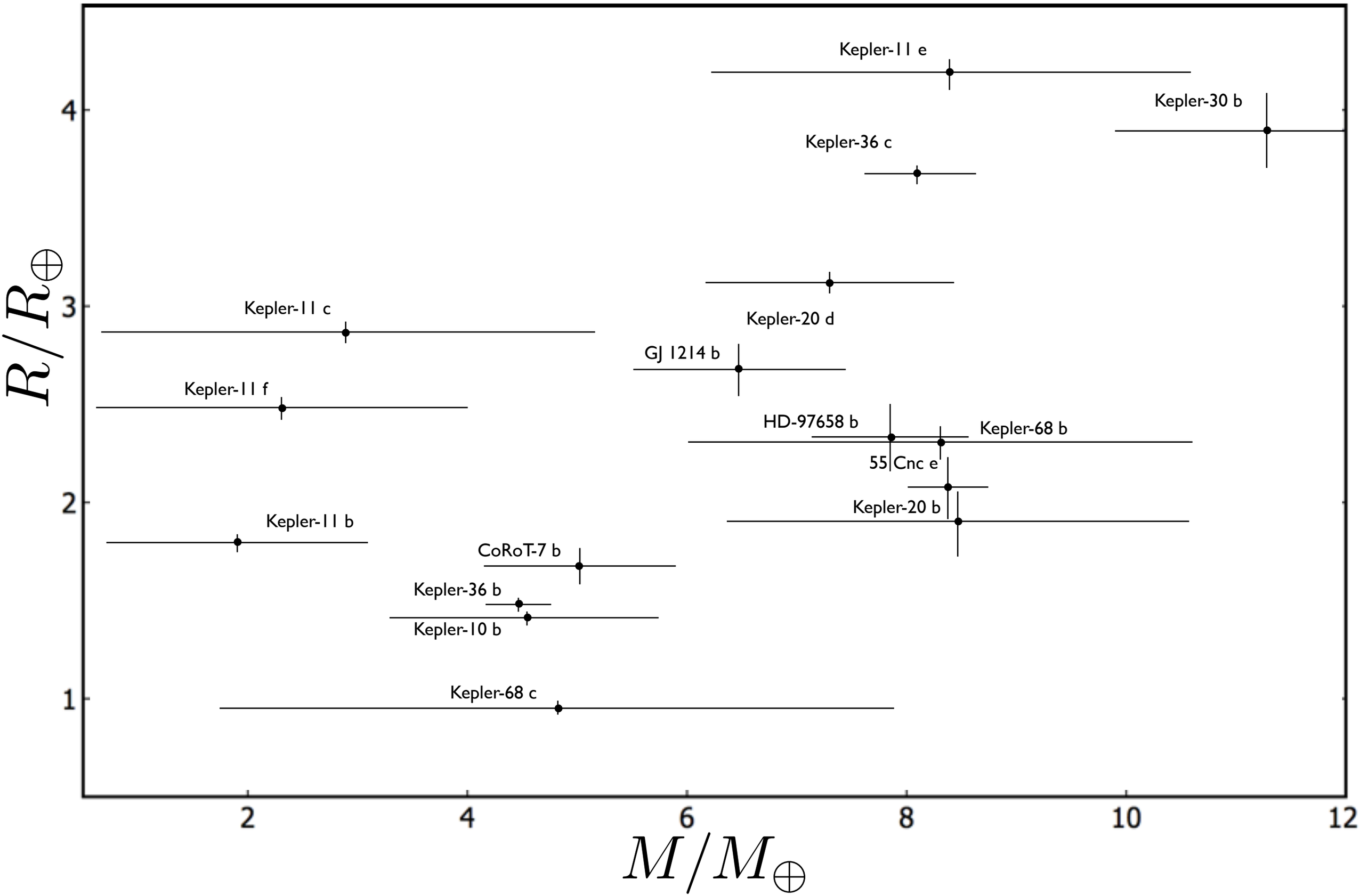


water ice sphere
silicate sphere
overall maximum
maximum for solar composition
maximum for Fe/Si = 2 times solar
maximum for Fe/Si = 5 times solar

Kepler-11 e
Kepler-30 b
Kepler-36 c
Kepler-20 d
Kepler-11 c
GJ 1214 b
Kepler-11 f
HD-97658 b
Kepler-68 b
55 Cnc e
Kepler-20 b
Kepler-11 b
CoRoT-7 b
Kepler-36 b
Kepler-10 b
Kepler-68 c

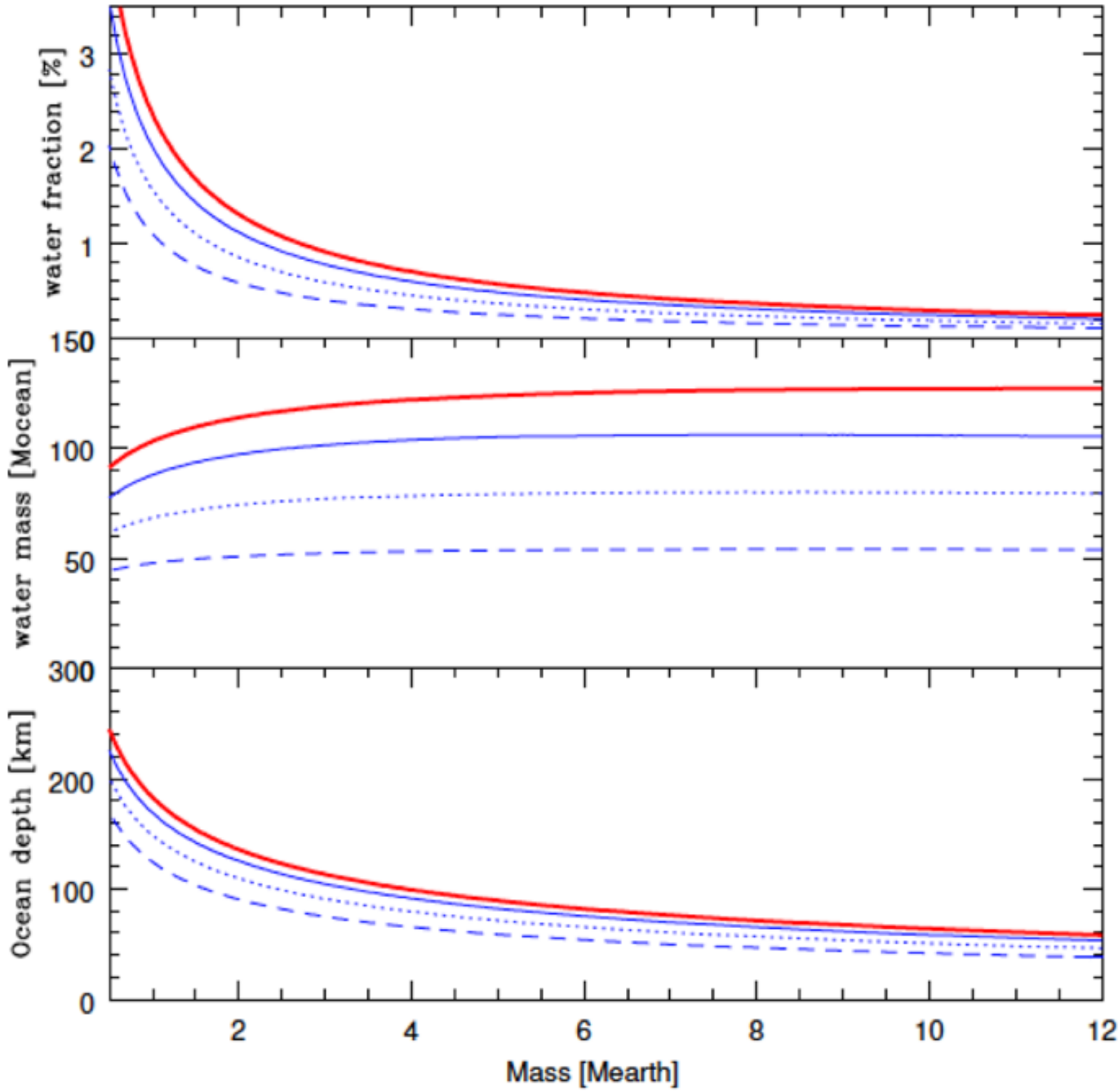
5
4
3
2
1

2
4
6
8
10
12

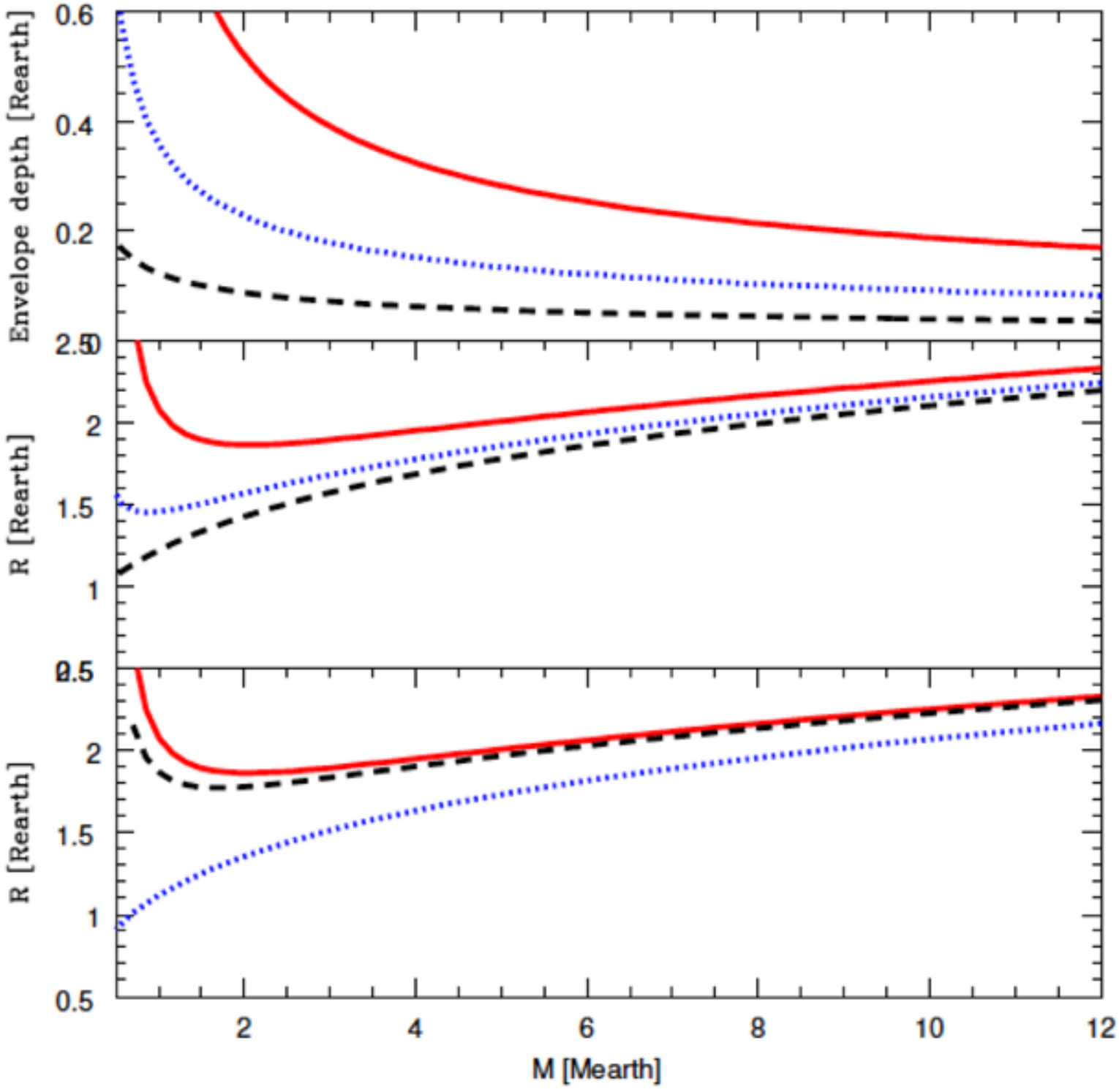
$R/R_\oplus$

$M/M_\oplus$

Ocean mass and water fraction



Using different gas models



convective-isothermal

radiative-convective

with irradiation

convective-isothermal

radiative-convective

with irradiation

convective-isothermal

H2

H/He

CO2

Thank you!