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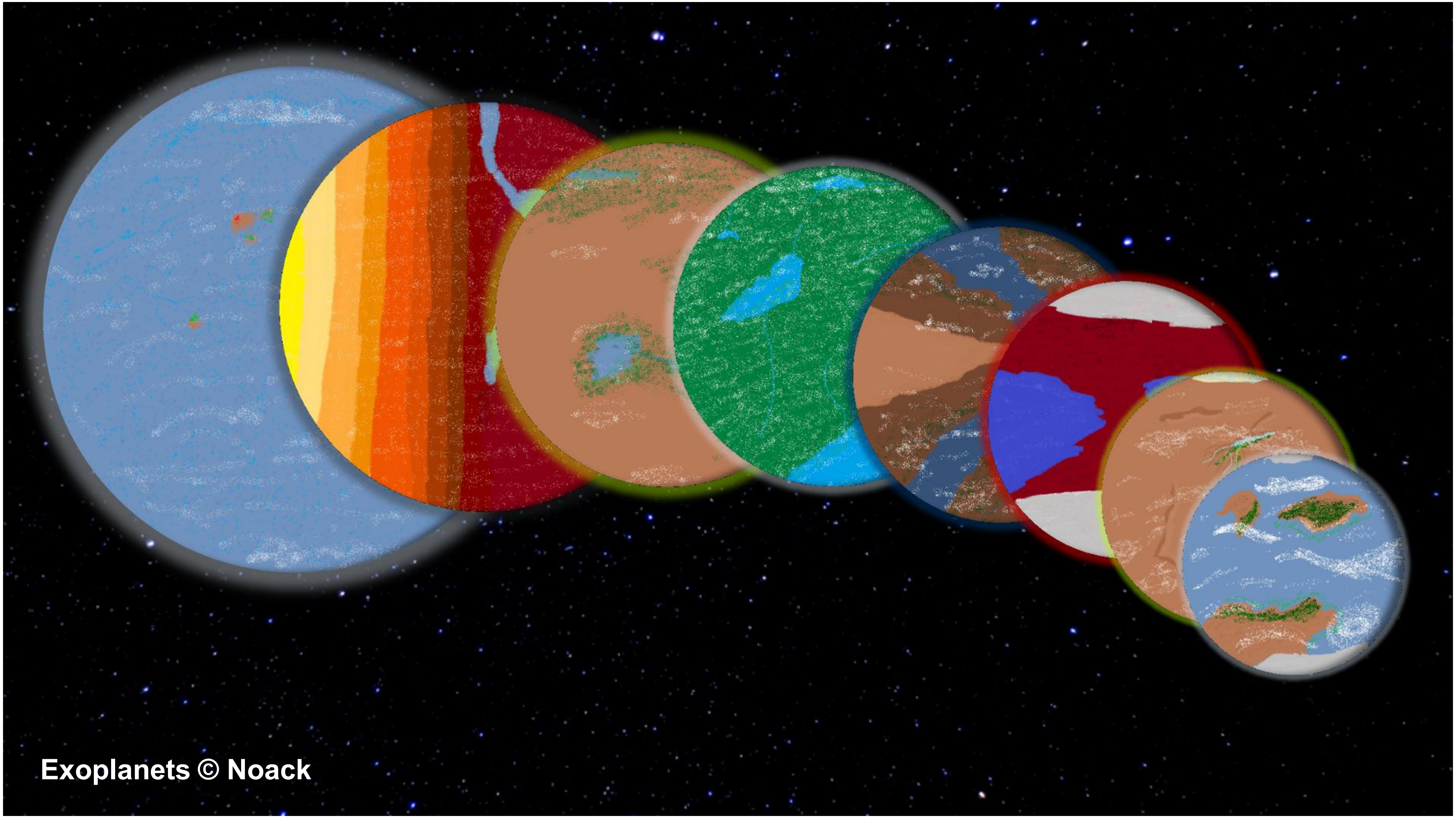
Volcanic activity on rocky planets - implications for the habitability of exoplanets

HIFOL Seminar, MPIA Heidelberg, 28 February 2018

Lena Noack
Free University Berlin, Department of Earth Sciences


Exoplanets © Noack

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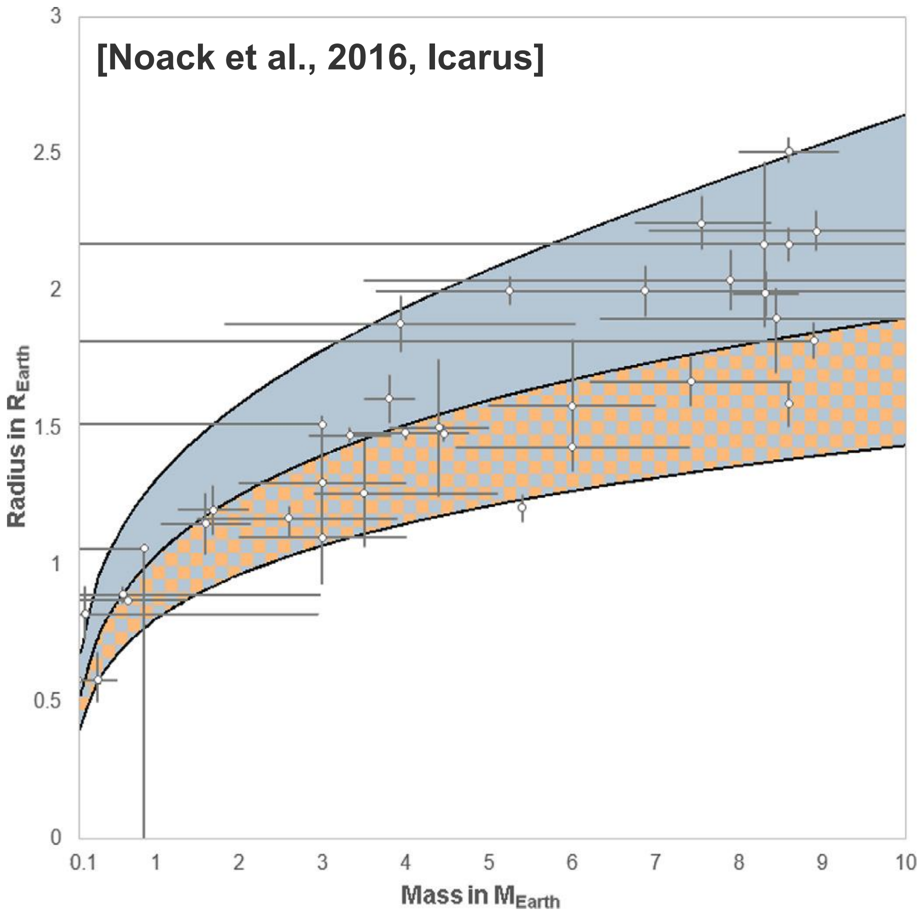
The reality



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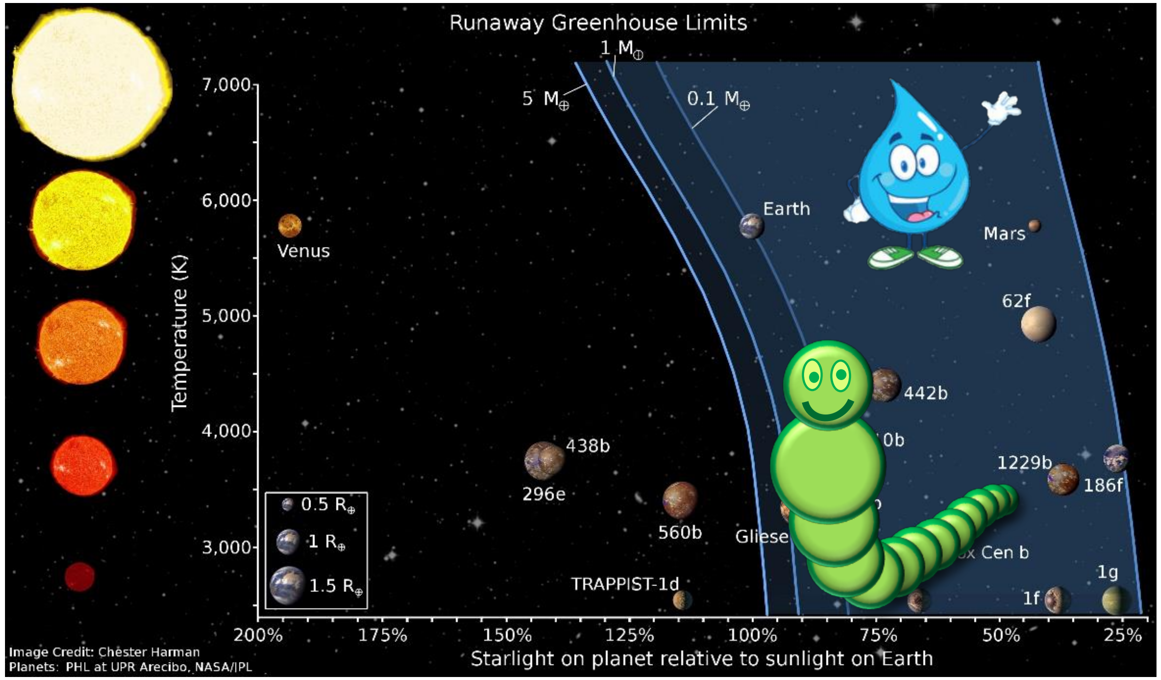

- Where there is water, there may be life
- Thousand of exoplanets detected
- Follow-up mission are expensive and need „golden targets“!

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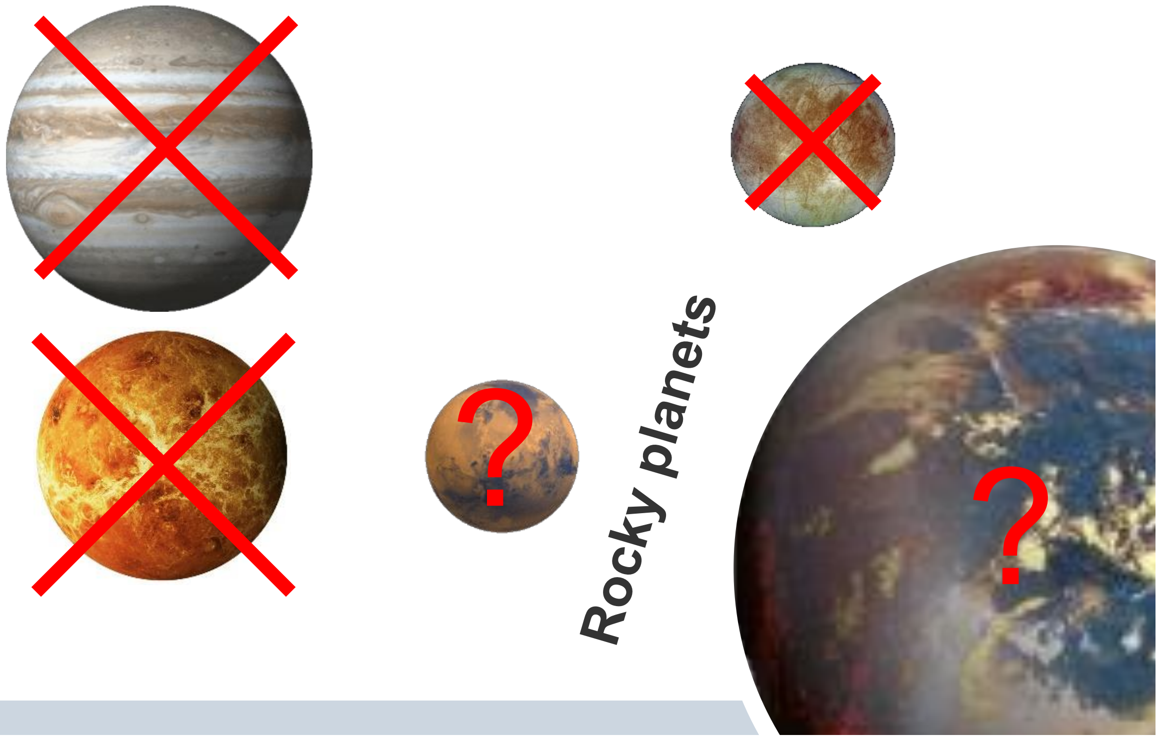
What can we learn about exoplanets?

Mass
Size (→Density)
Effective surf. temp.
Albedo
Upper atmosphere
Age of system
Composition of star
Stellar activity, wind
Stellar magnetic field

What exoplanets are the best candidates for detecting life?



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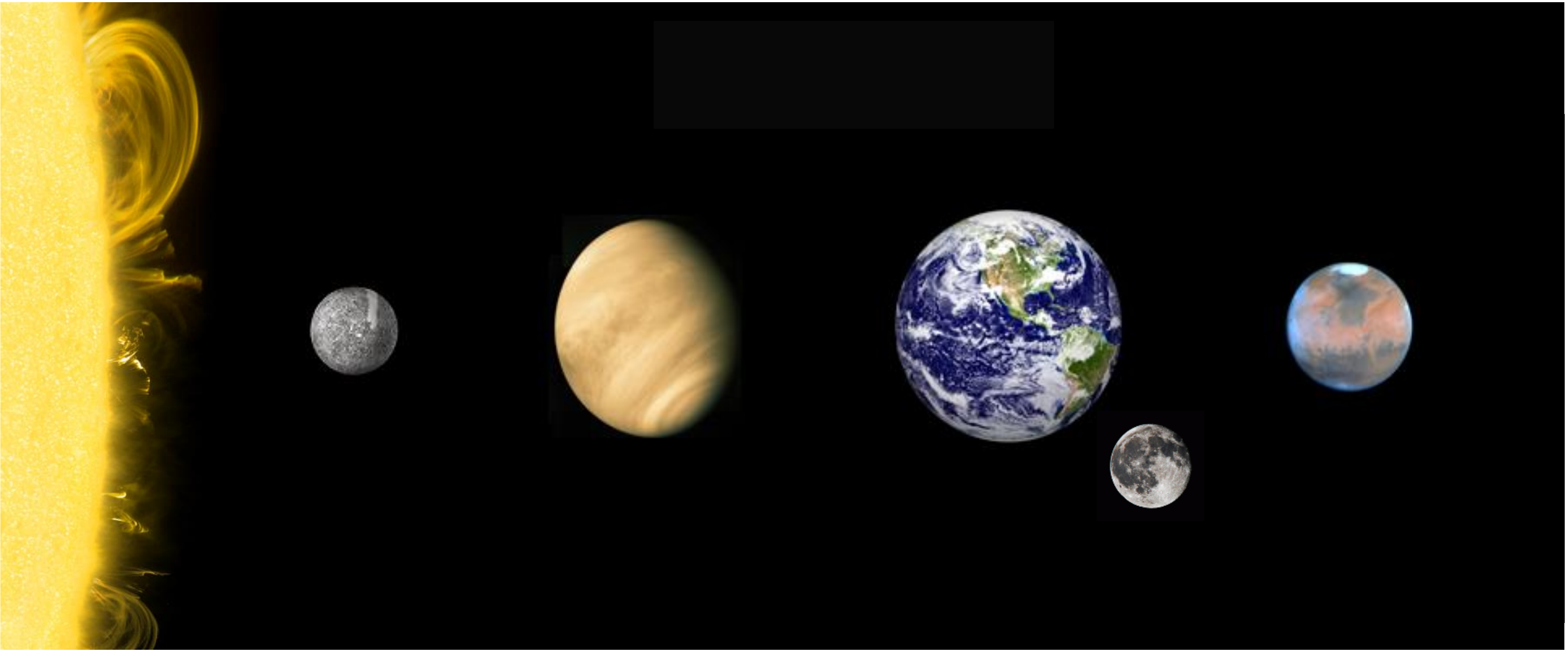
Rocky planets in the solar system



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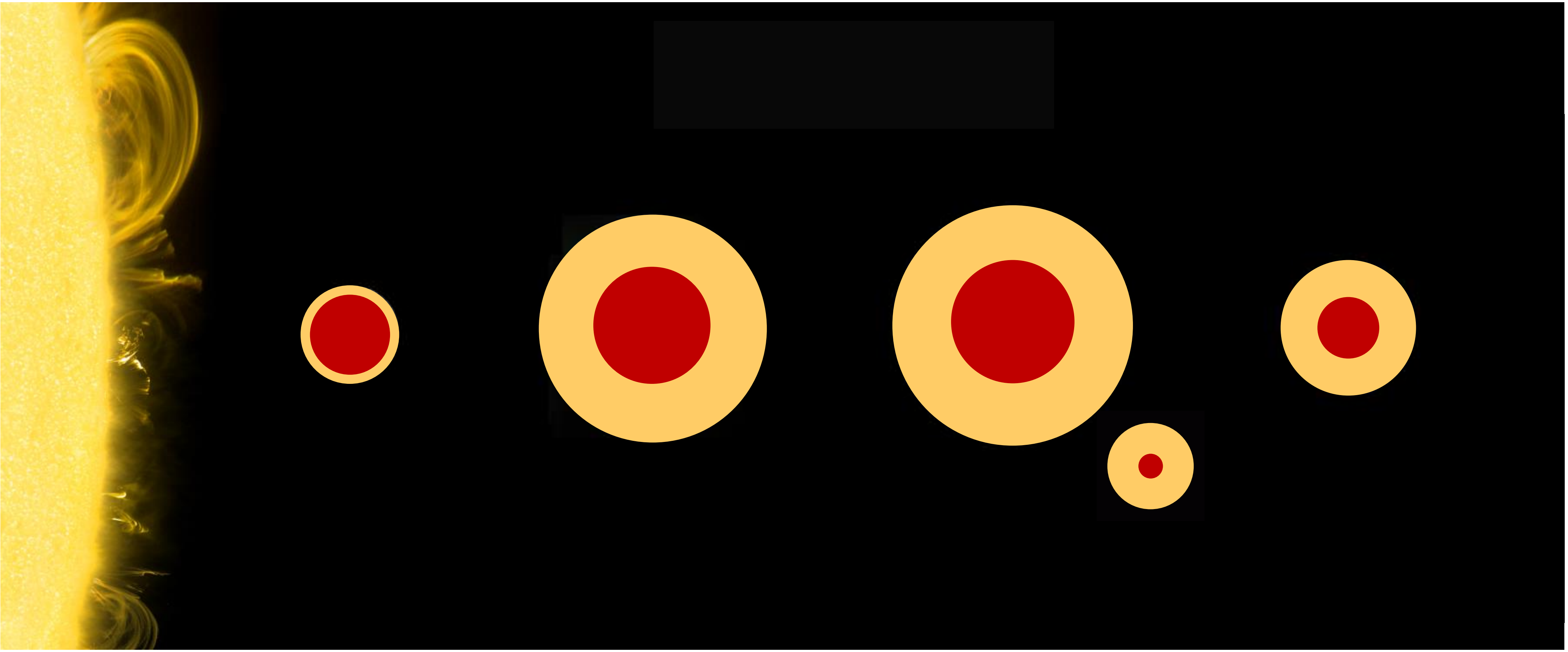
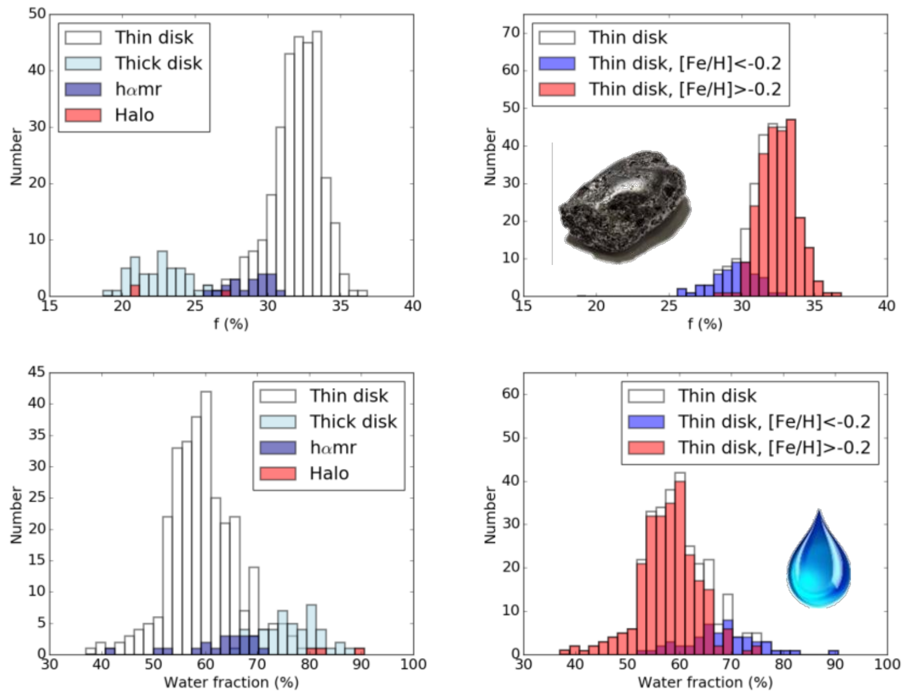


Composition and interior structure (/)

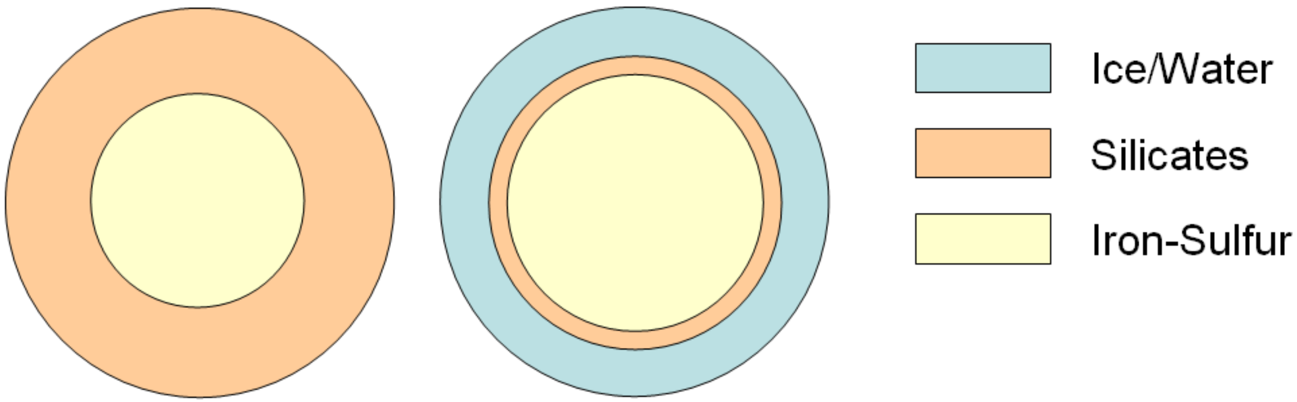
- can be inferred from stellar spectrum ⇒ planet composition

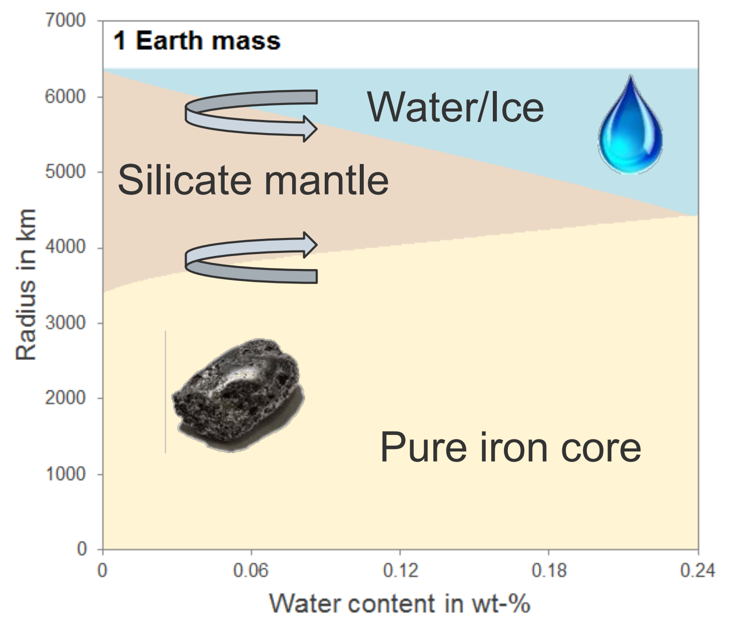


[Santos et al., 2017]

Composition and interior structure (/)

- can be inferred from stellar spectrum ⇒ planet composition
- influence interior structure of planets

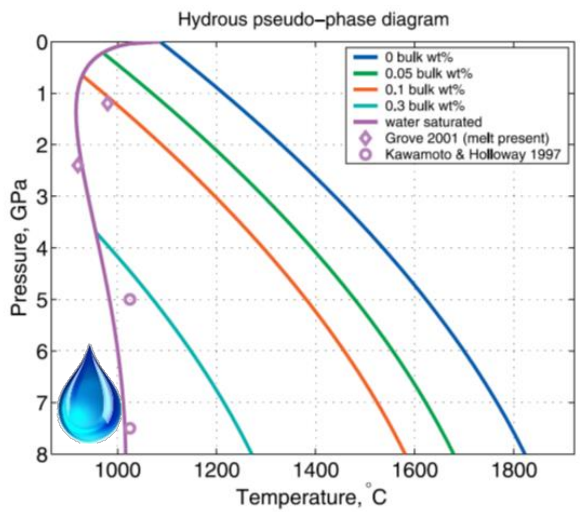




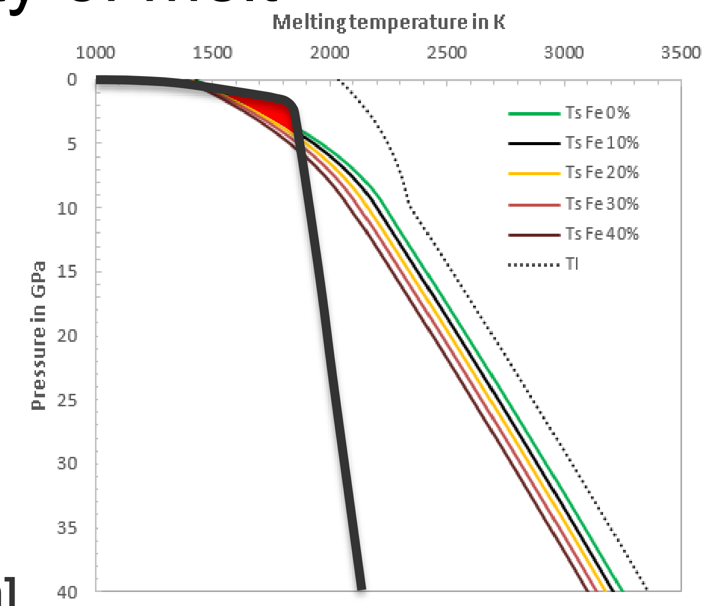
[Noack et al., 2017, SpaceSciRev]

Composition and interior structure ( / )

- can be inferred from stellar spectrum ⇒ planet composition
- influence interior structure of planets
- influence melting temperature and density of melt



[Katz et al., 2003]



[Dorn et al., in revision]

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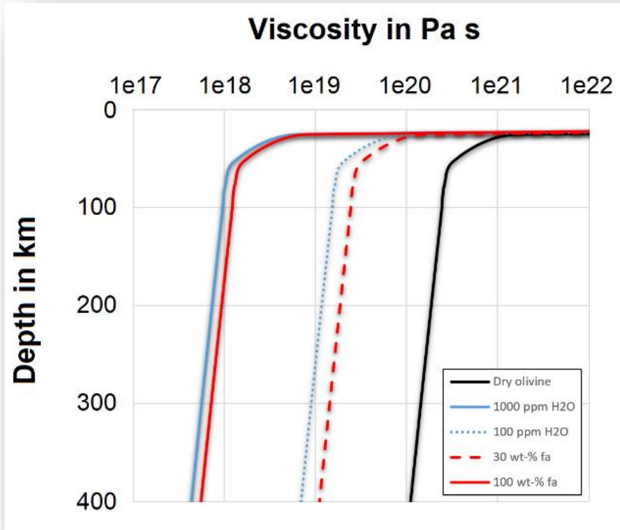
Composition and interior structure ( / )

- can be inferred from stellar spectrum ⇒ planet composition
- influence interior structure of planets
- influence melting temperature and density of melt
- influence convection speed



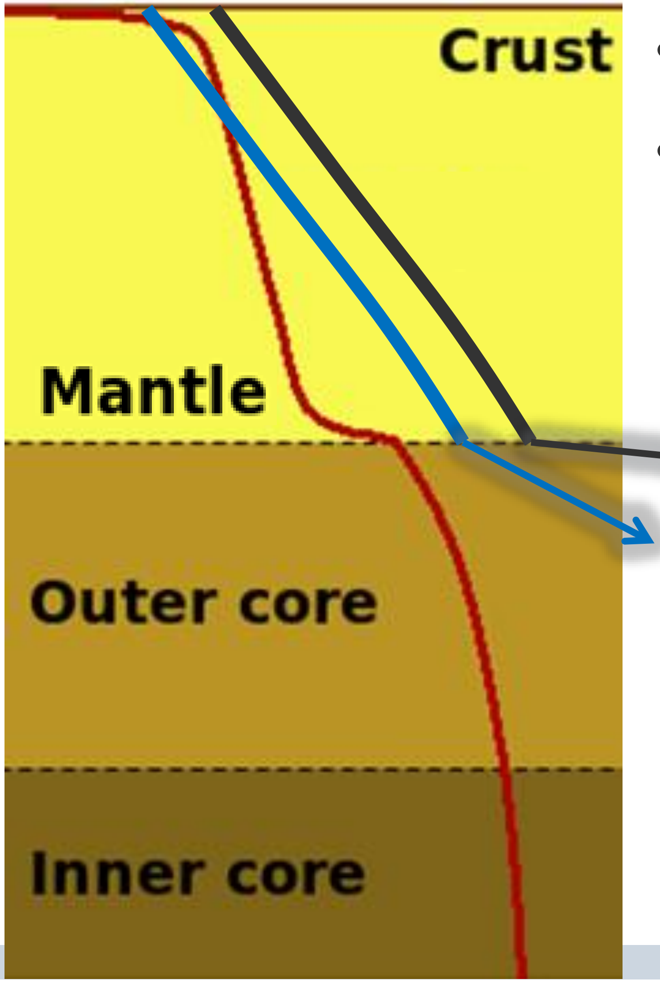
[after Zhao et al., 2009, EPSL, and Hirth and Kohlstedt, 2003]

Composition and interior structure ( / )

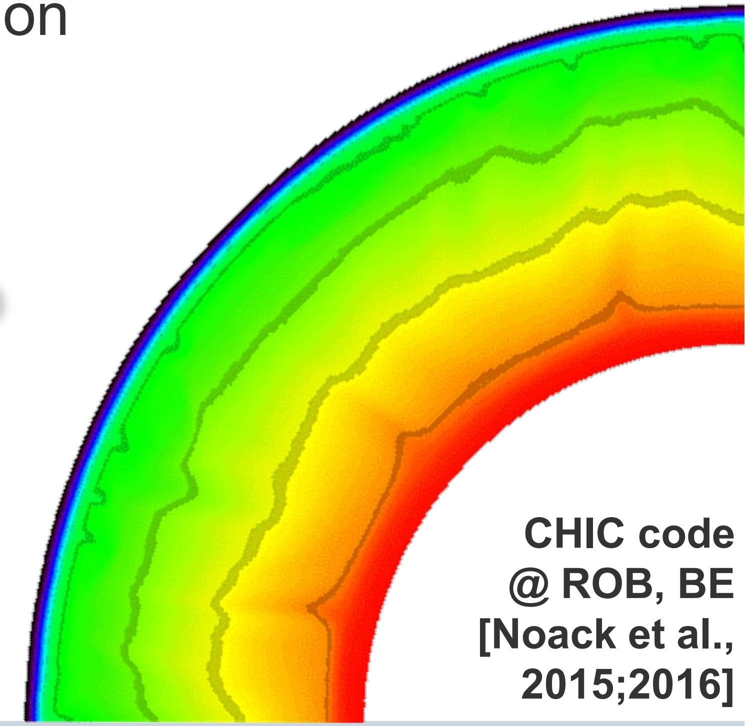
- can be inferred from stellar spectrum ⇒ planet composition
- influence interior structure of planets
- influence melting temperature and density of melt
- influence convection speed
- redox state of mantle influences outgassing products

⇒ What we observe at the surface is influenced by the interior!

Thermal evolution and partial melting



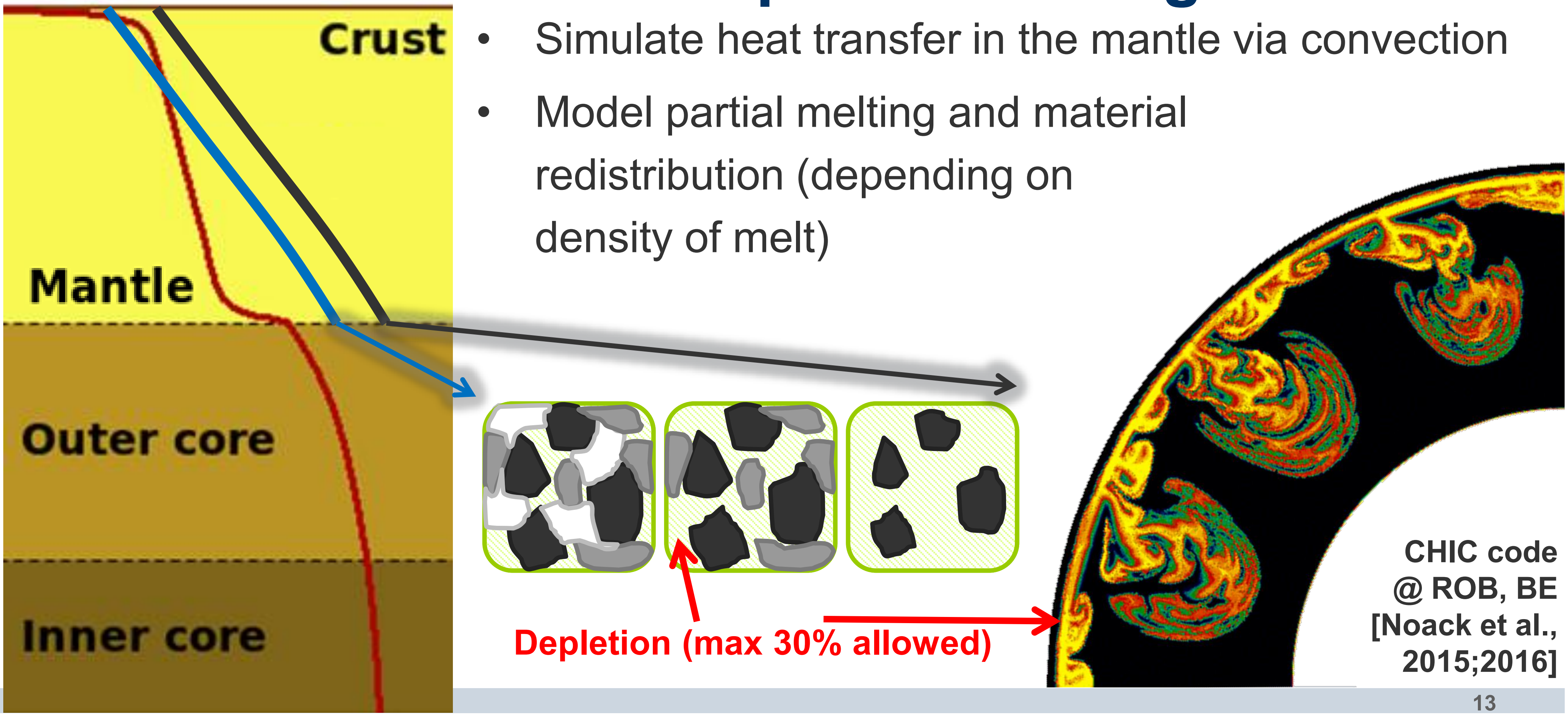
- Simulate heat transfer in the mantle via convection
- Model partial melting and material redistribution (depending on density of melt)



CHIC code @ ROB, BE [Noack et al., 2015;2016]

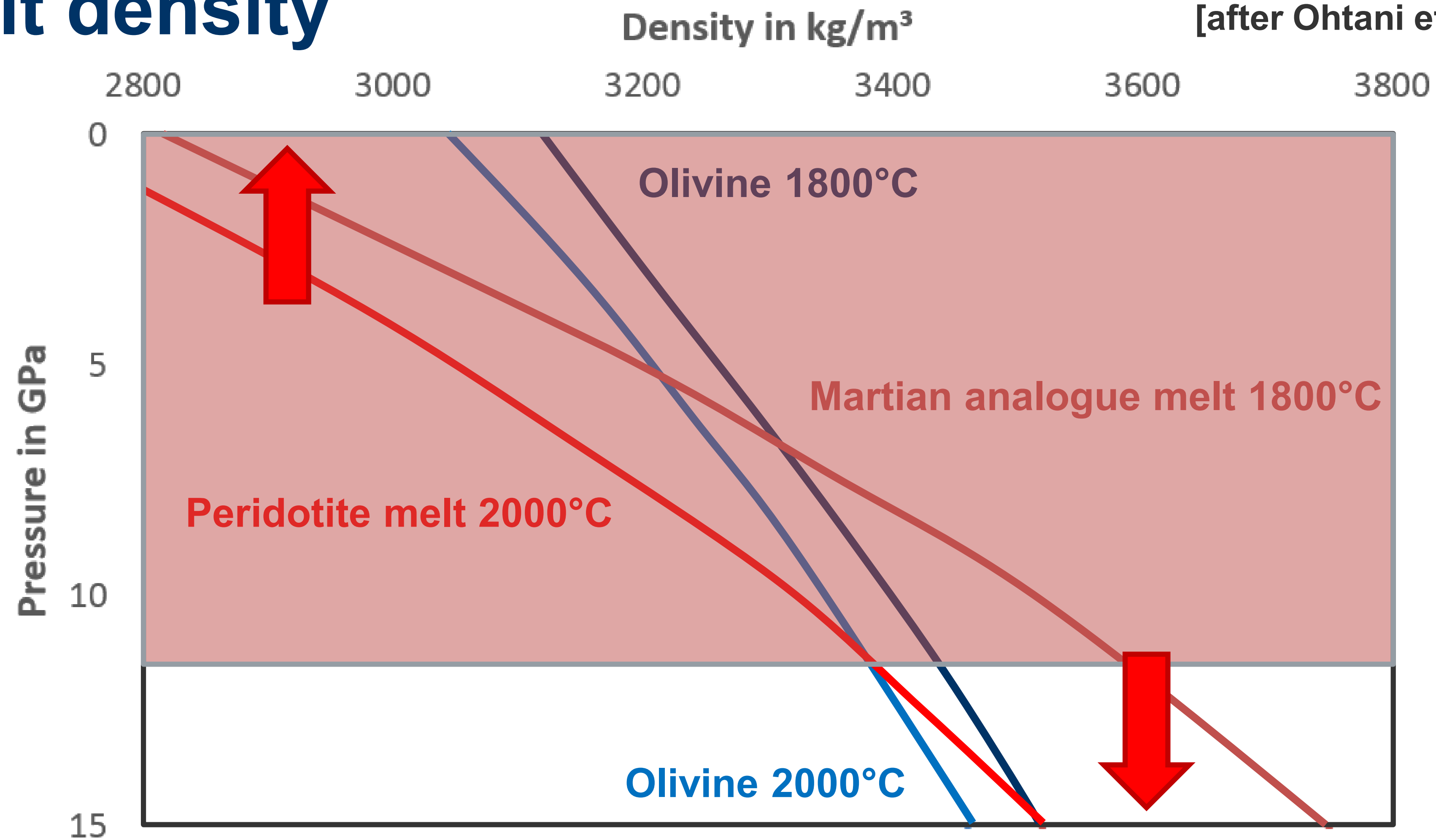
Thermal evolution and partial melting

- Simulate heat transfer in the mantle via convection
- Model partial melting and material redistribution (depending on density of melt)

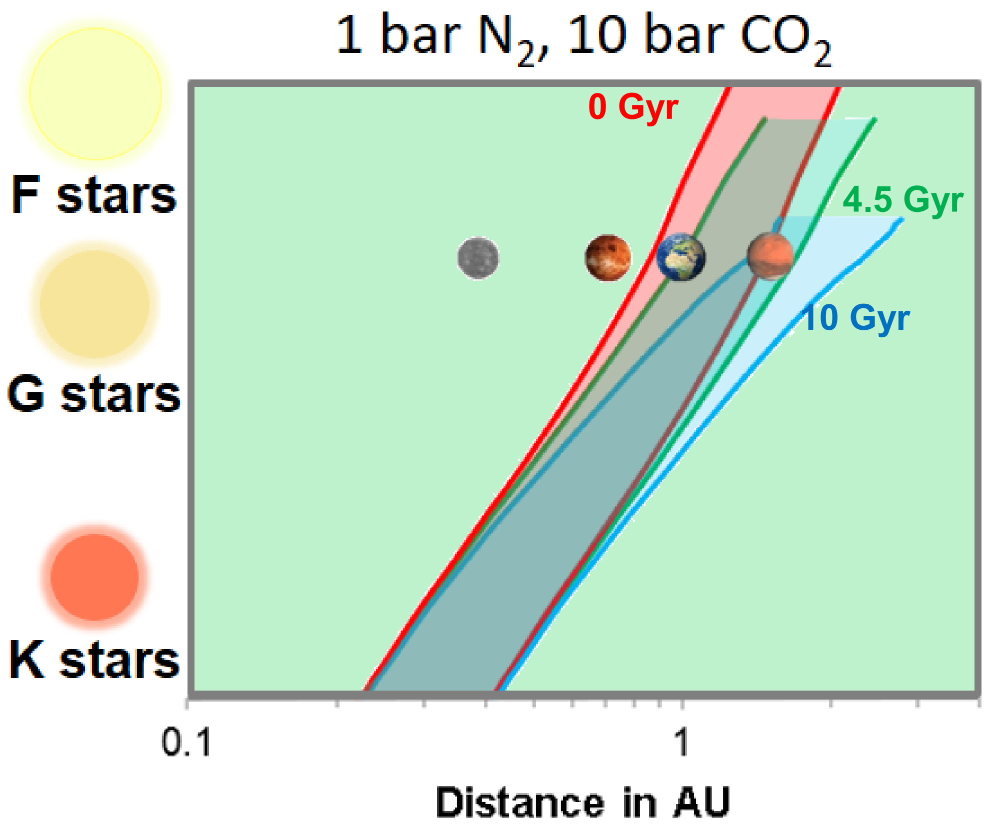


Melt density

[after Ohtani et al., 1995]



Outgassing and habitable zone



Noack et al., 2017, PEPI; based on HZ limits from Kopparapu et al., 2013 and stellar evolution from Mowlavi et al., 2012

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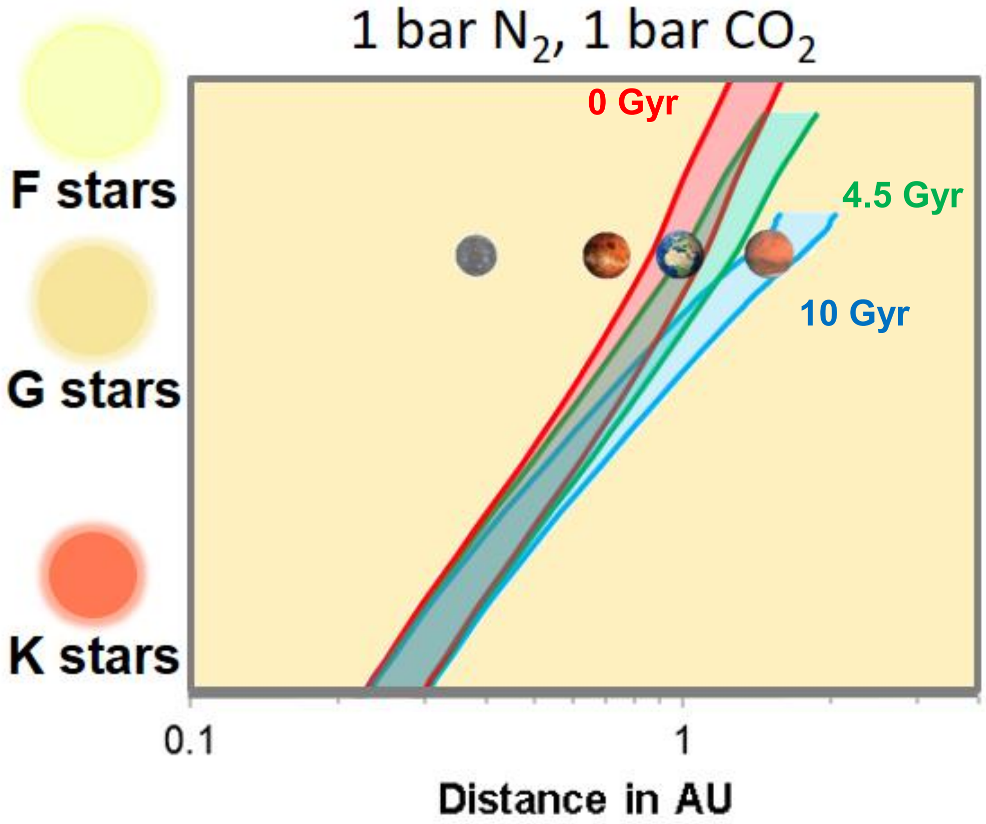
Outgassing and habitable zone



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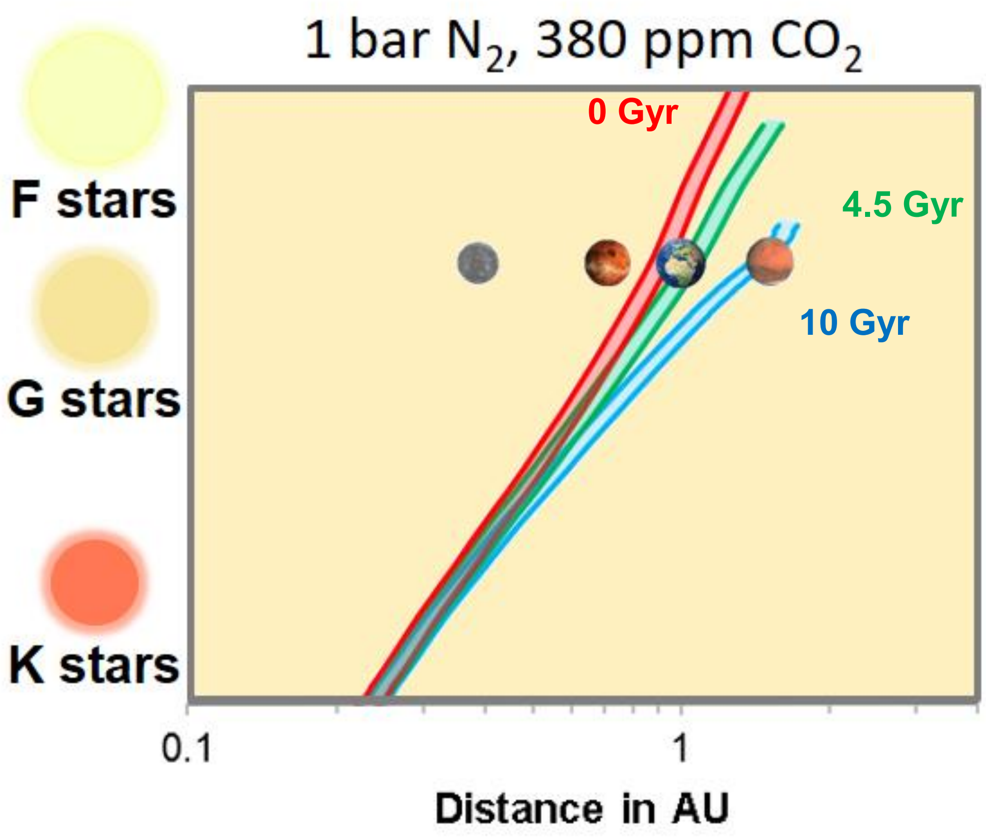

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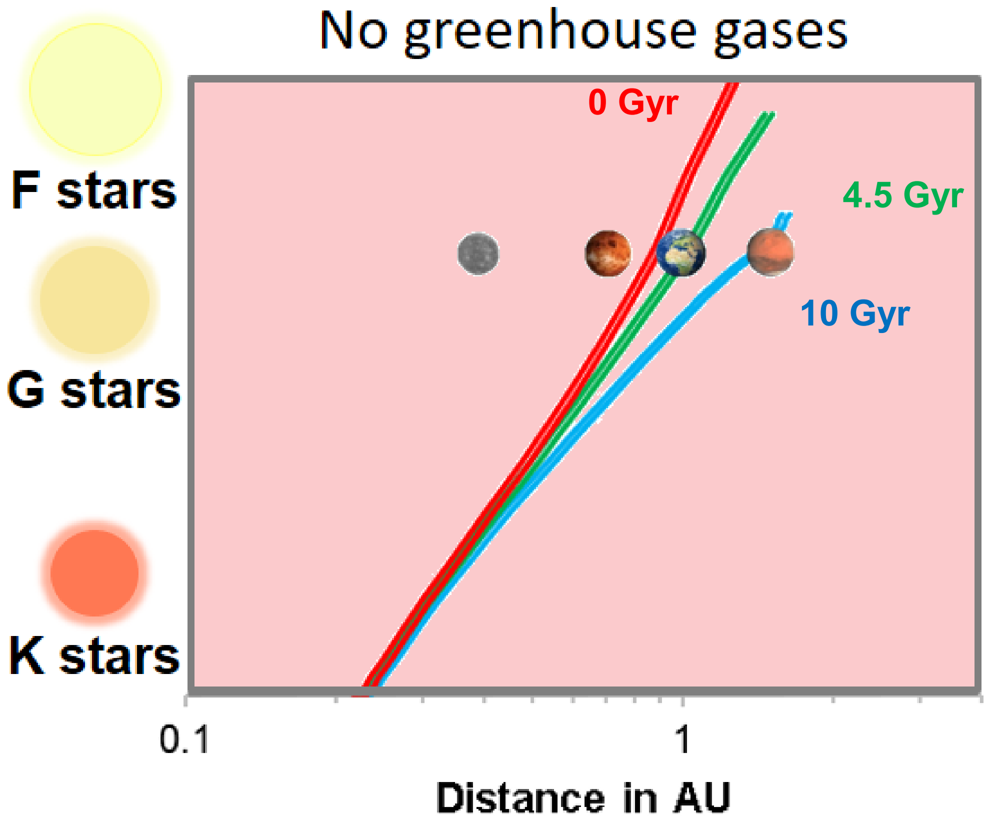
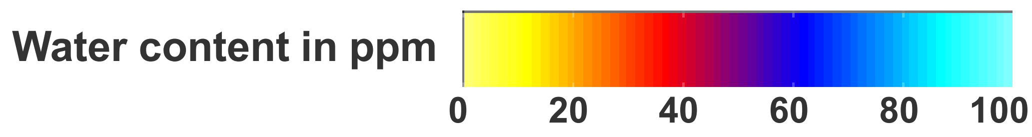
Outgassing and habitable zone

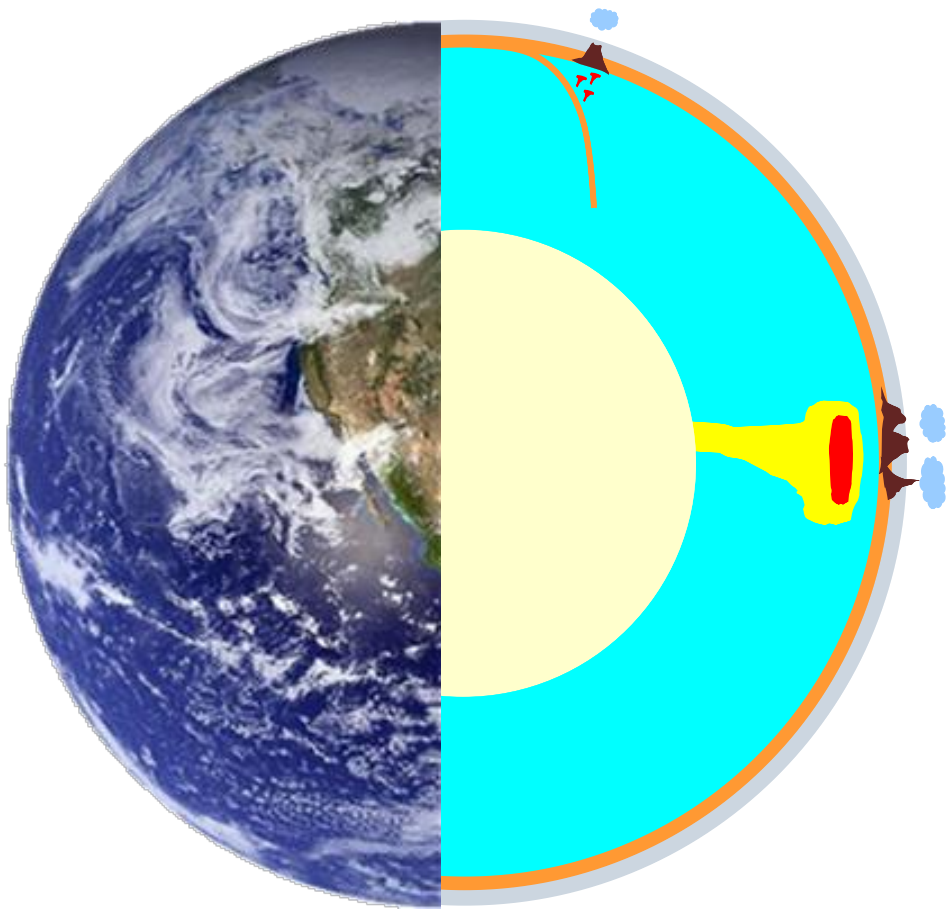


Outer boundary of habitable zone limited here by available CO_2 -> less than ~10 bar lead to thinner HZ

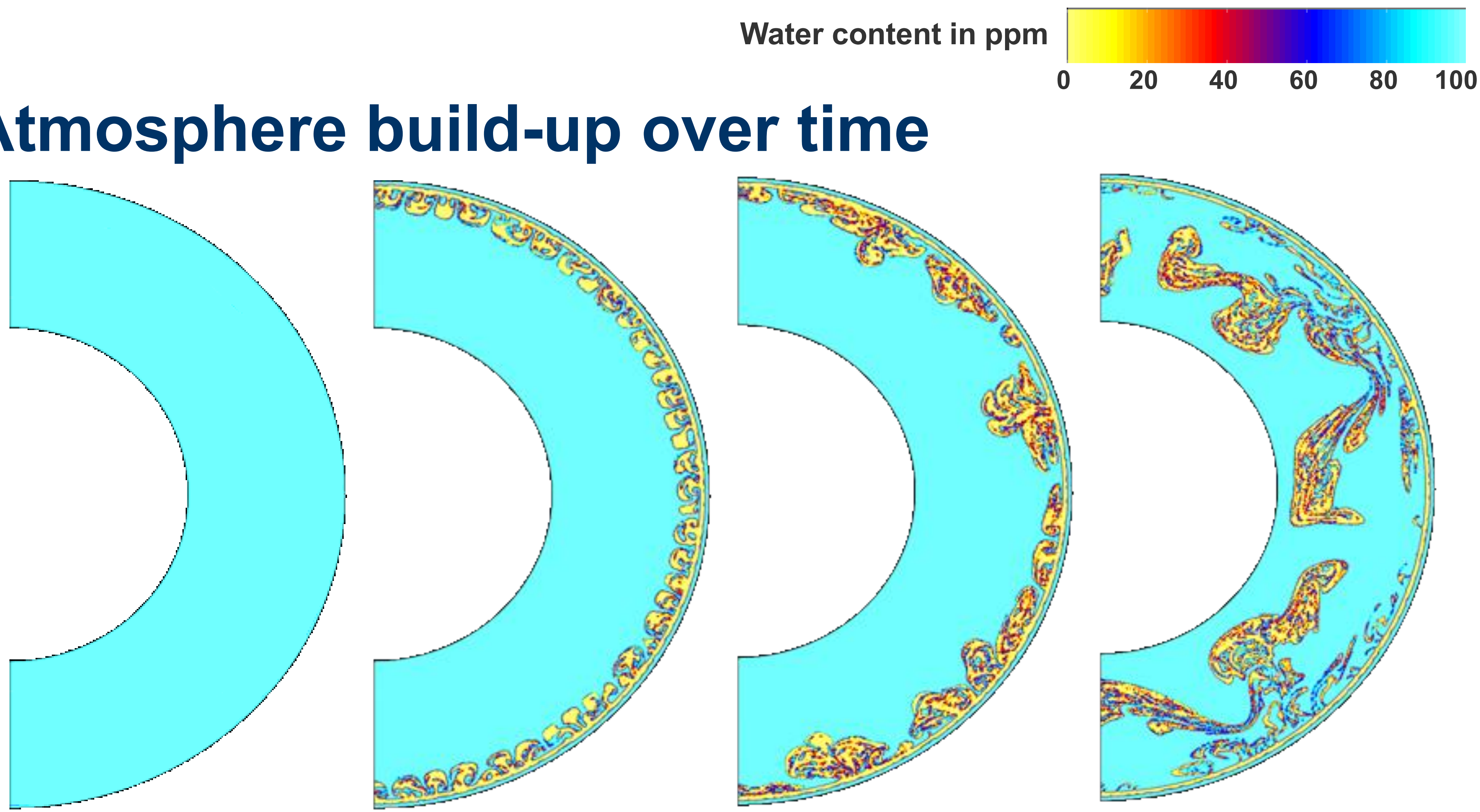
Noack et al., 2017, PEPI; based on HZ limits from Kopparapu et al., 2013 and stellar evolution from Mowlavi et al., 2012



Atmosphere build-up over time



Atmosphere build-up over time



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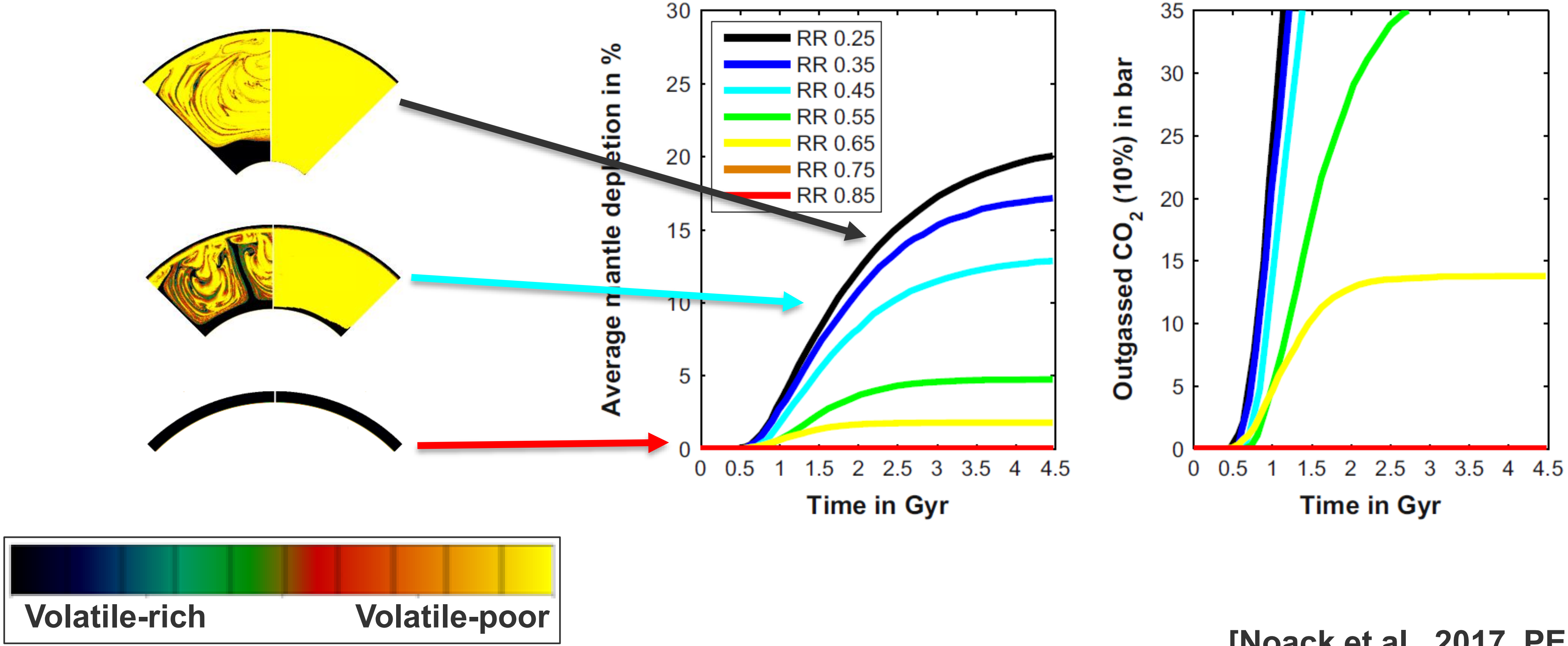
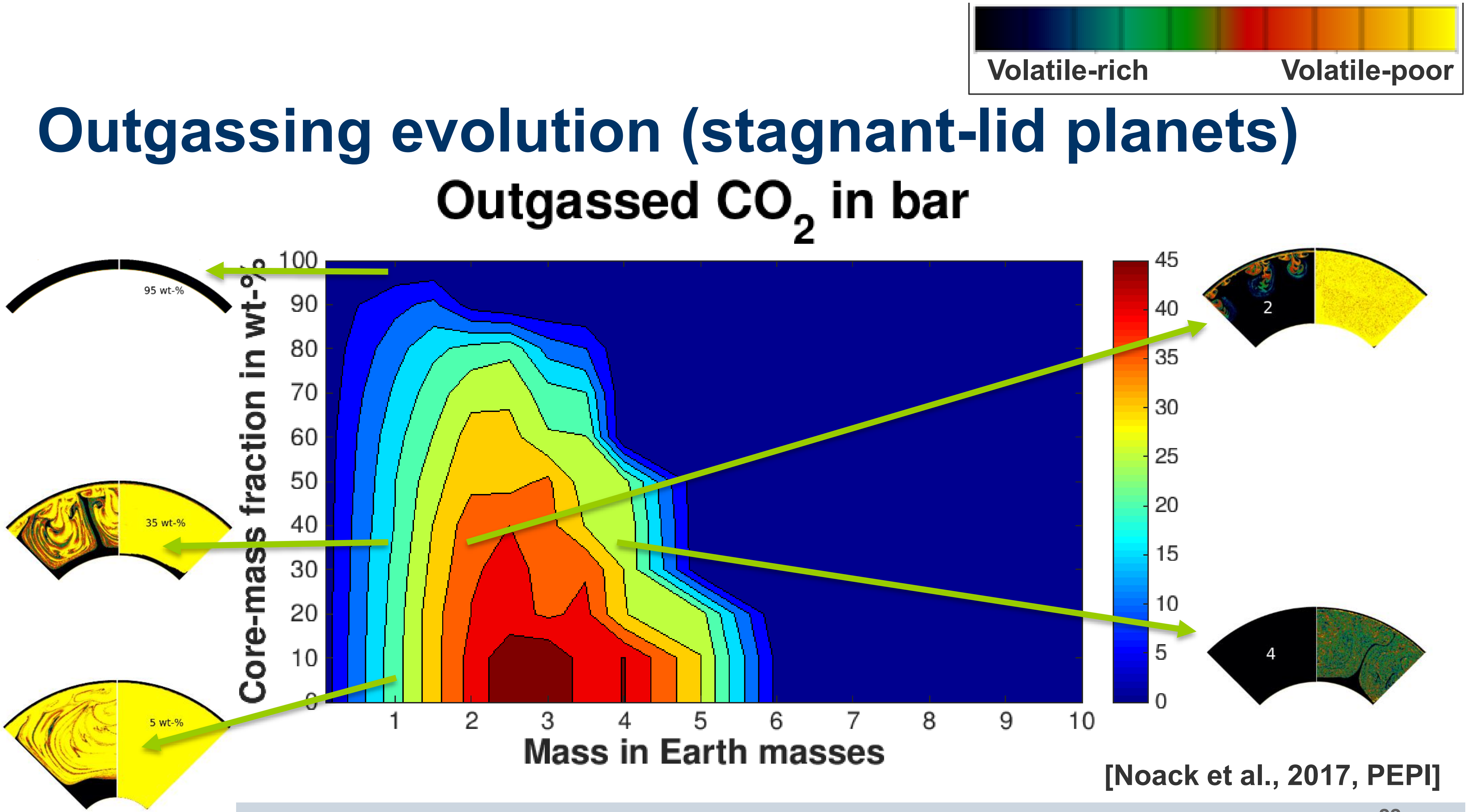
Atmosphere build-up over time



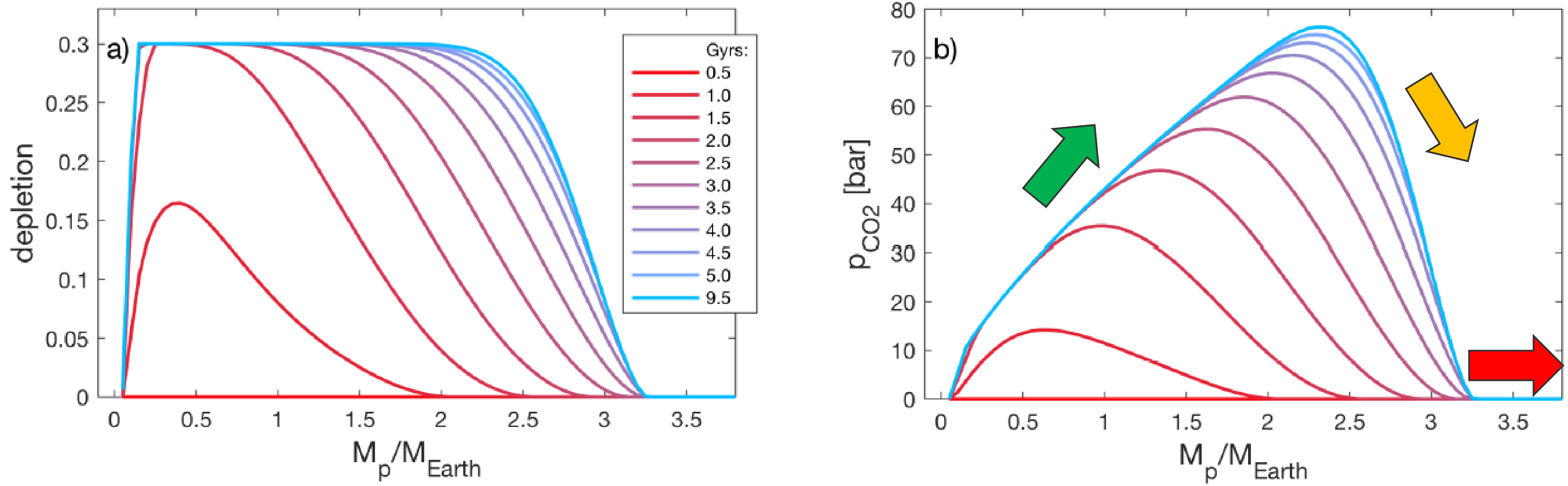
[Noack et al., 2017, PEPI]

Outgassing evolution (stagnant-lid planets)



[Noack et al., 2017, PEPI]

Influence of mass on outgassing over time



Earth-like stagnant-lid planets:

1-2 M_{Earth}: more volatiles in mantle ⇒ more outgassing for increasing mass

>2 M_{Earth}: increased mass leads to higher pressure in lithosphere ⇒ decreasing outgassing

> $M_{crit.}$: no outgassing

[Dorn et al., accepted]

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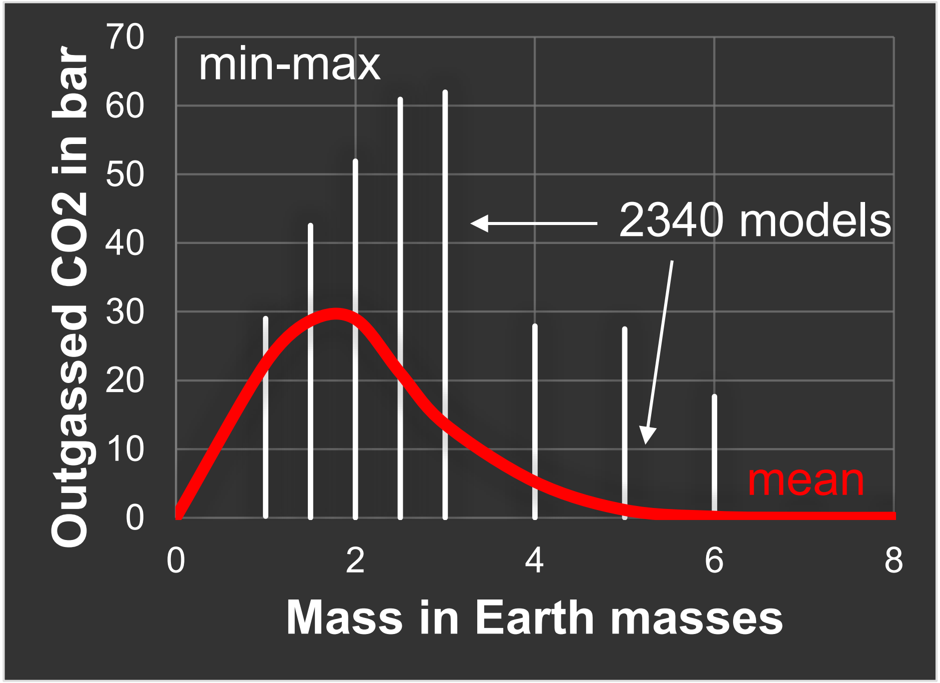
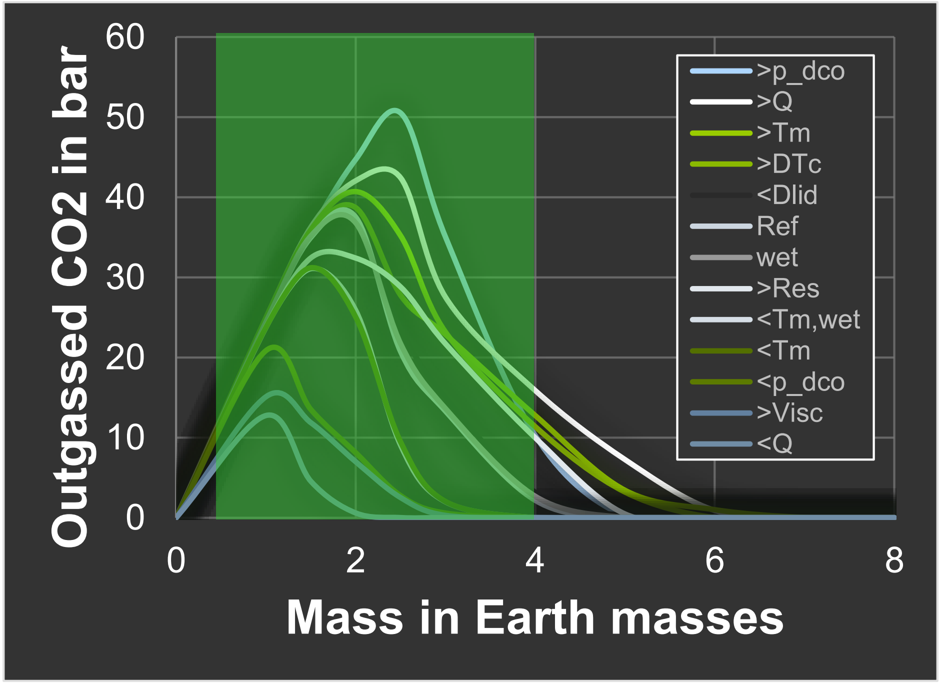
Influence of mantle composition

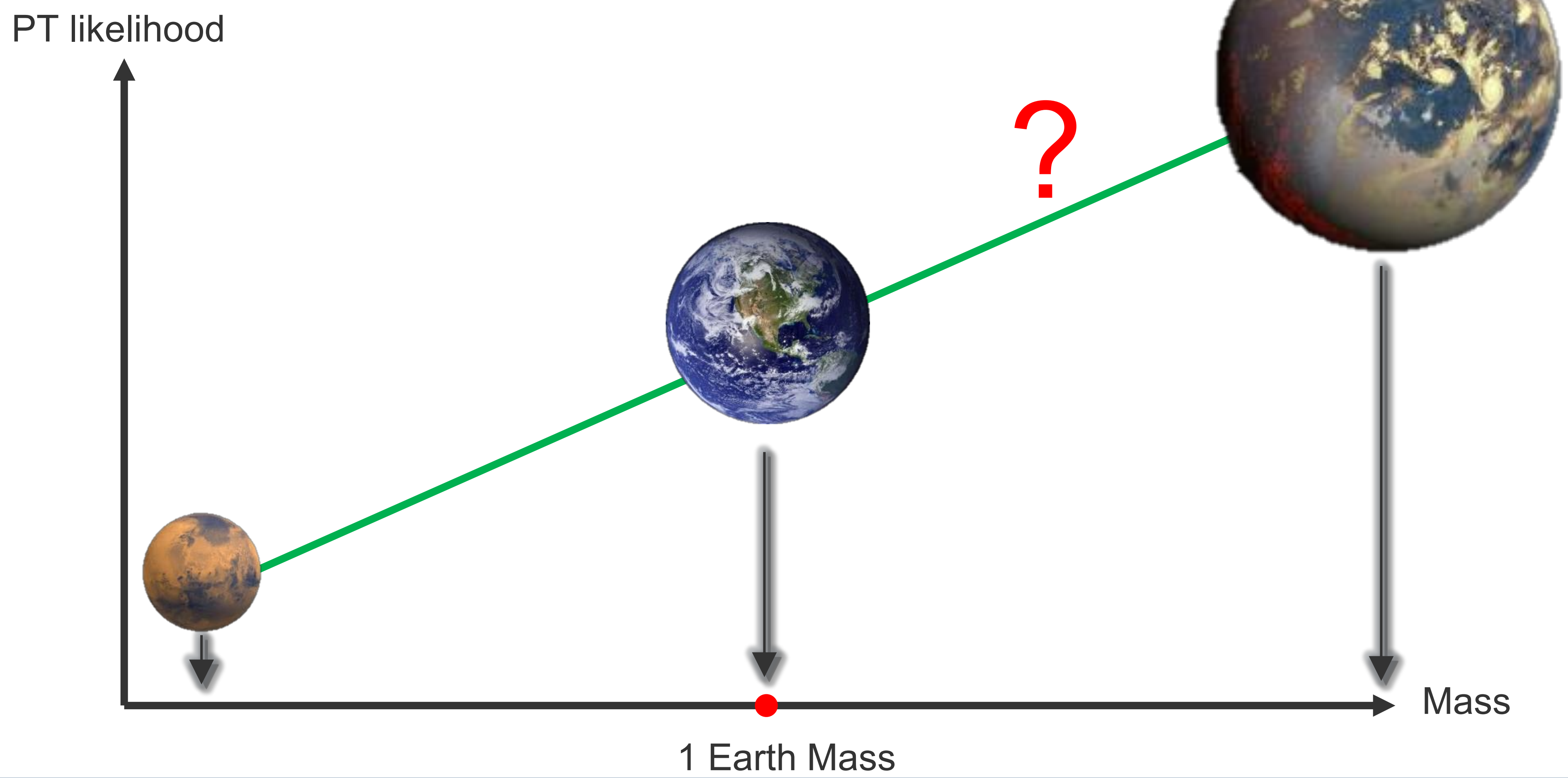
[Dorn et al., accepted]





Low-mass planets (~0.5-4 Earth masses) are more likely habitable at their surface, since enough volcanic activity should take place to ensure a dense enough atmosphere on stagnant-lid planets

Plate tectonics on super-Earths



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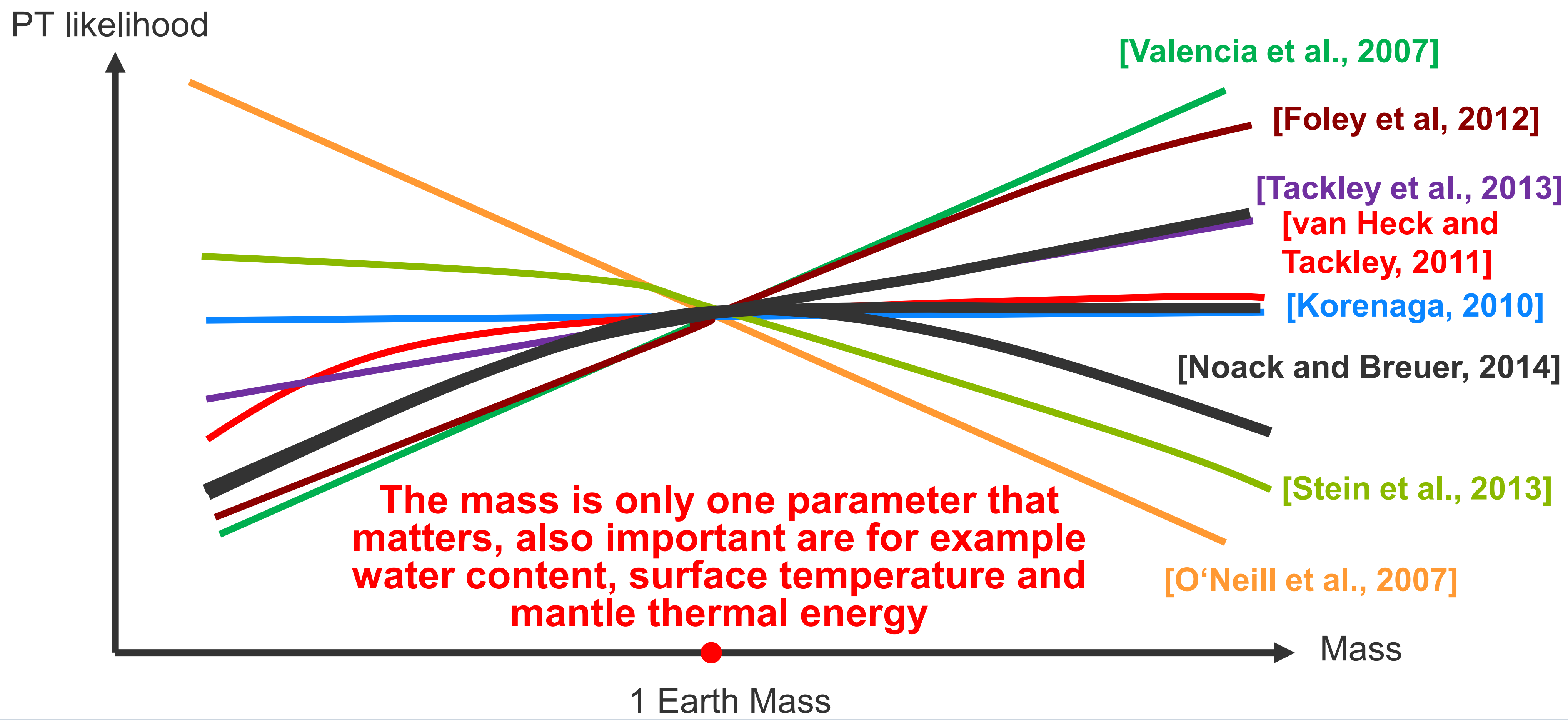
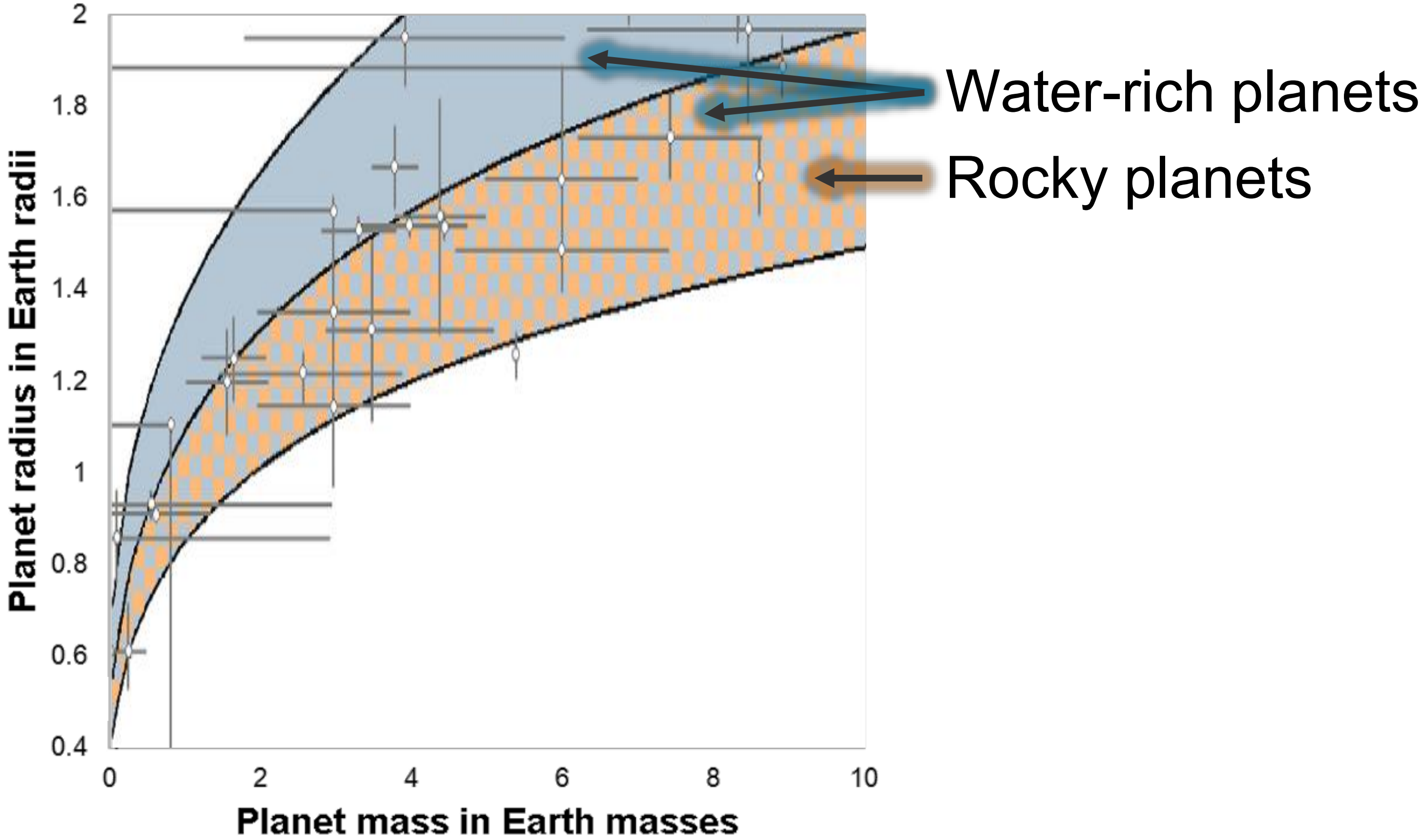
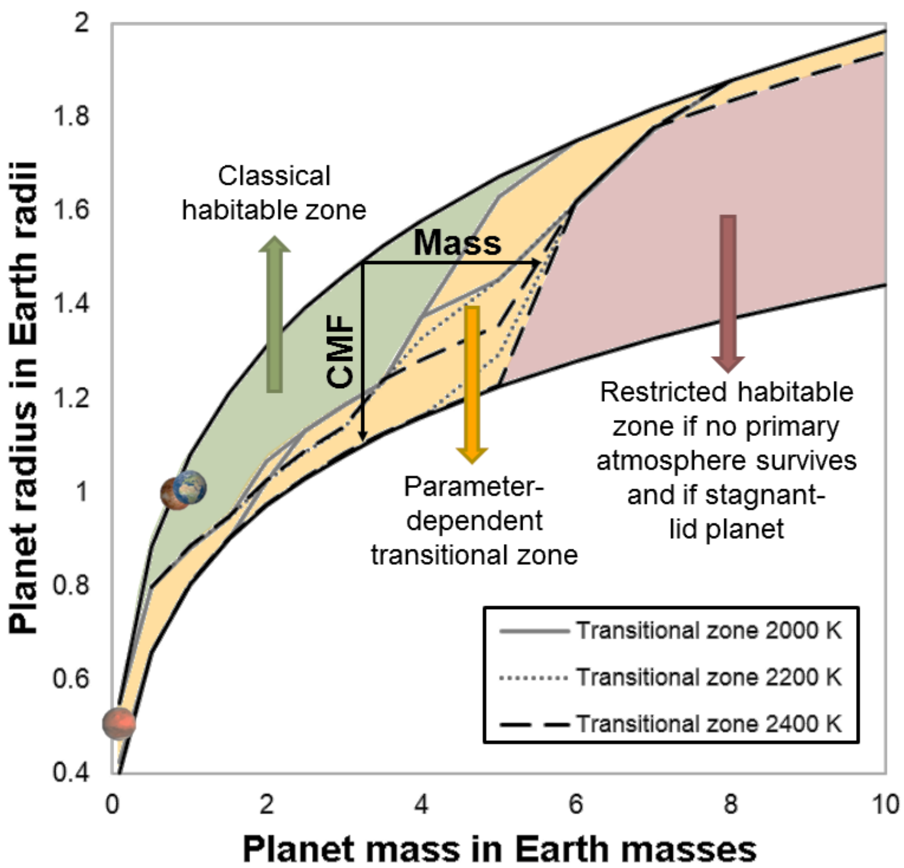


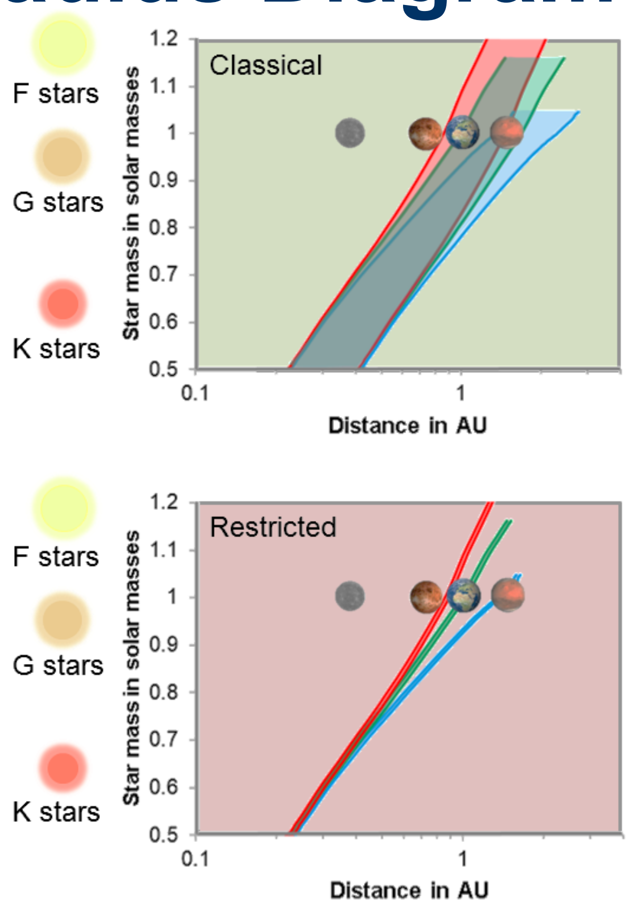
Golden targets: New Mass-Radius Diagram



[Noack et al., 2016, Icarus]

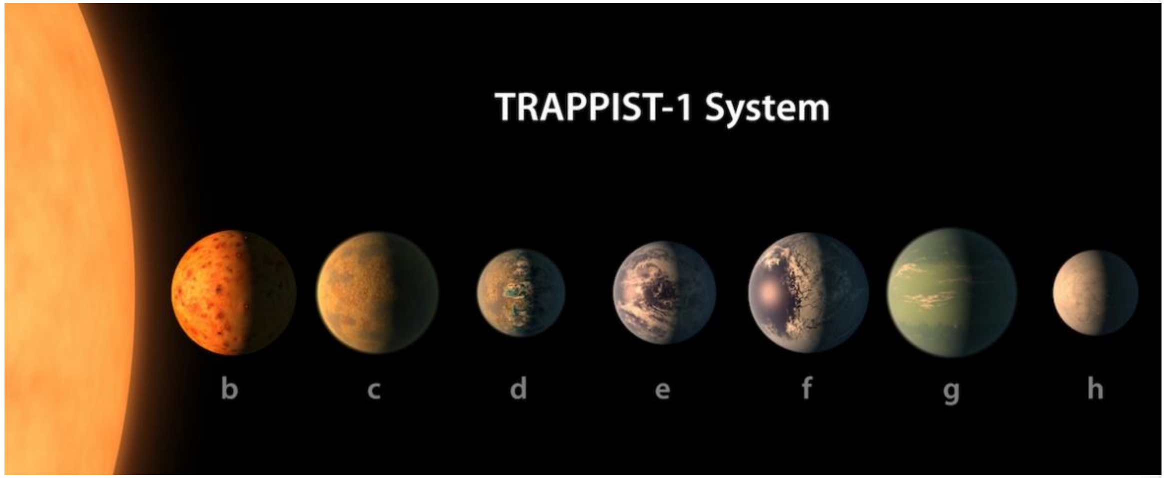
Golden targets: New Mass-Radius Diagram





[Noack et al., 2017, PEPI]

TRAPPIST-1 system

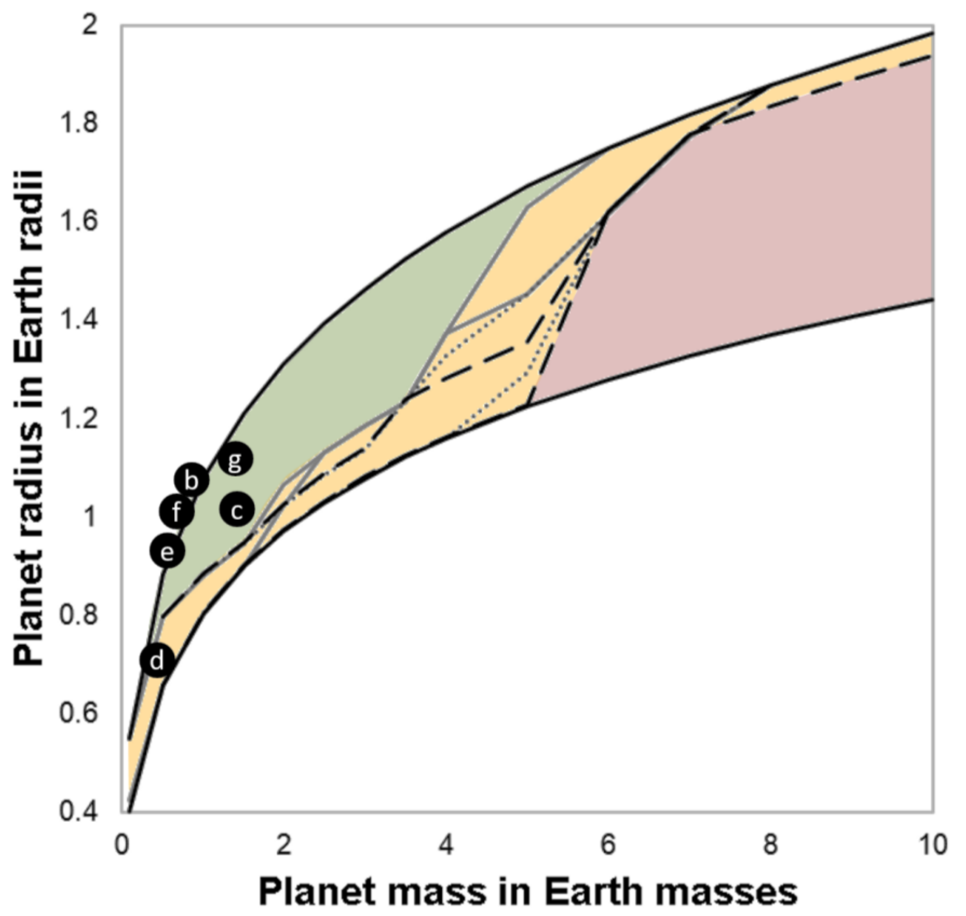


LETTER

doi:10.1038/nature21360

Seven temperate terrestrial planets around the nearby ultracool dwarf star TRAPPIST-1

Michaël Gillon[1], Amaury H. M. J. Triaud[2], Brice-Olivier Demory[3,4], Emmanuël Jehin[1], Eric Agol[5,6], Katherine M. Deck[7], Susan M. Lederer[8], Julien de Wit[9], Artem Burdanov[1], James G. Ingalls[10], Emeline Bolmont[11,12], Jeremy Leconte[13], Sean N. Raymond[13], Franck Selsis[13], Martin Turbet[14], Khalid Barkaoui[15], Adam Burgasser[16], Matthew R. Burleigh[17], Sean J. Carey[10], Aleksander Chaushev[17], Chris M. Copperwheat[18], Laetitia Delrez[1,4], Catarina S. Fernandes[1], Daniel L. Holdsworth[19], Enrico J. Kotze[20], Valérie Van Grootel[1], Yaseen Almleaky[21,22], Zouhair Benkhaldoun[15], Pierre Magain[1] & Didier Queloz[4,23]



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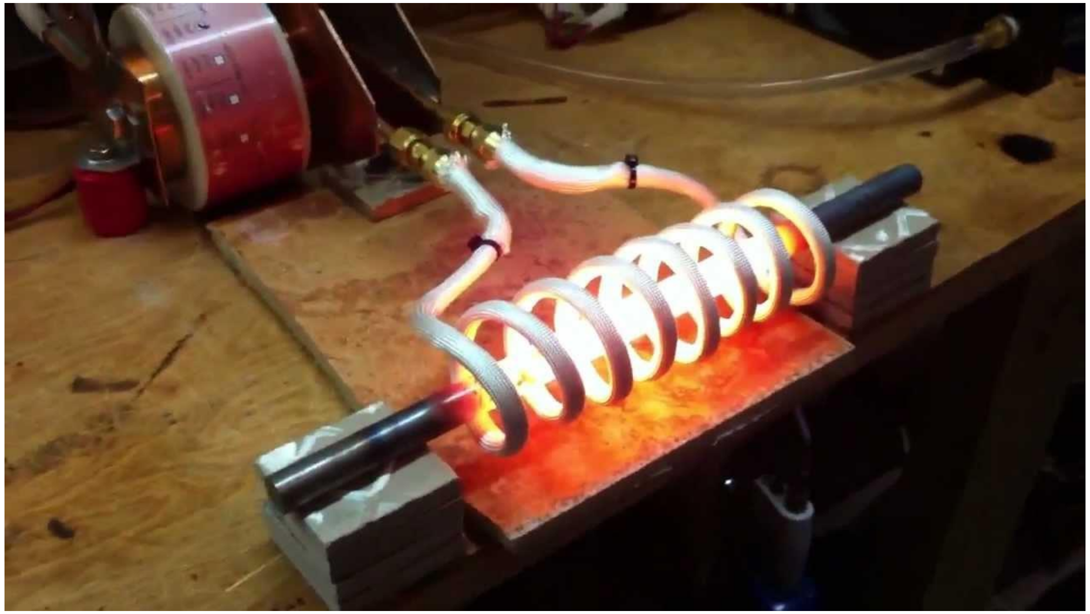
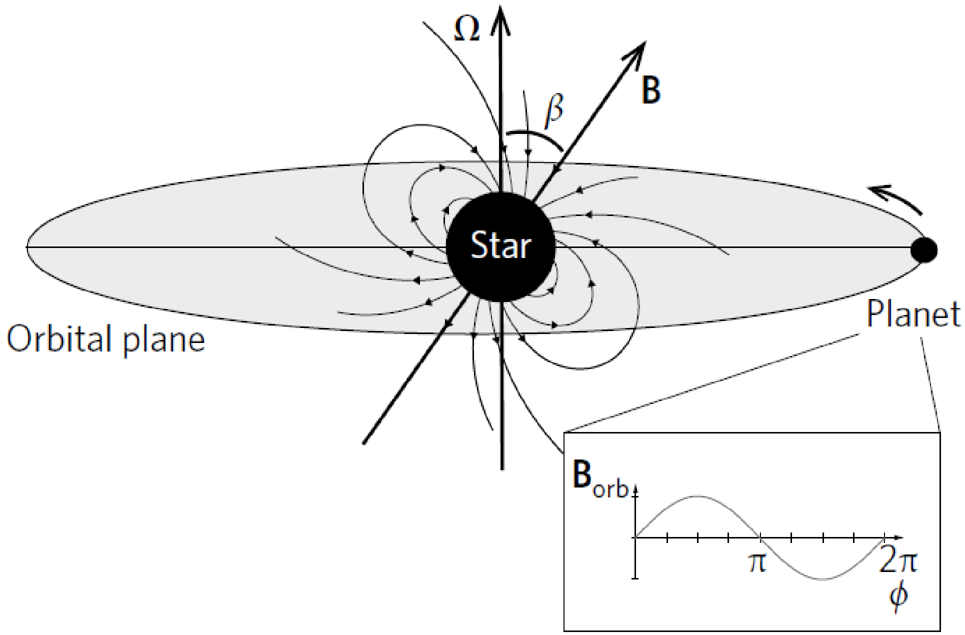
TRAPPIST-1 system: Induction heating

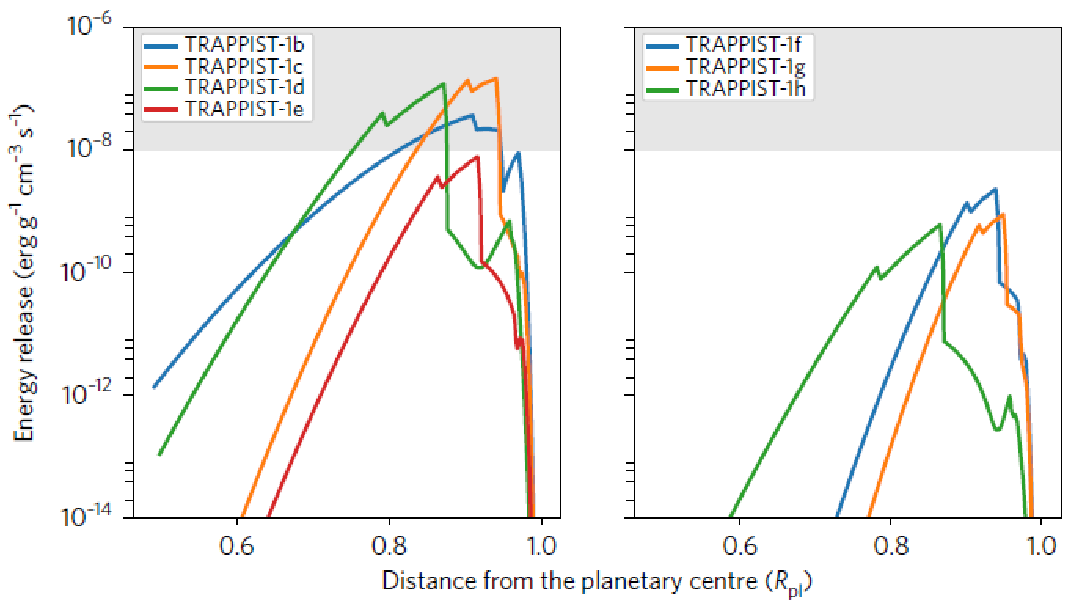




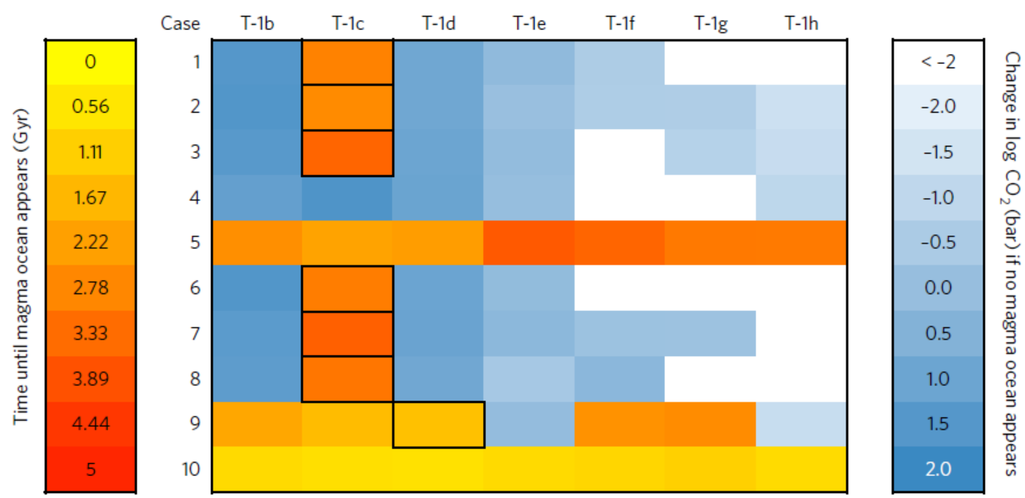
[Kislyakova, Noack et al., Nature Astronomy, 2017]

TRAPPIST-1 system: Induction heating

Strong magnetic field leads to energy dissipation in planet interiors caused by induction heating



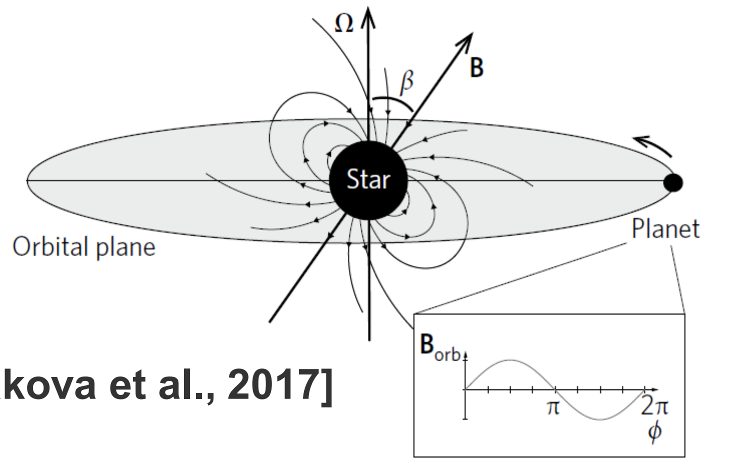
Present-day radioactive heating in Earth's mantle



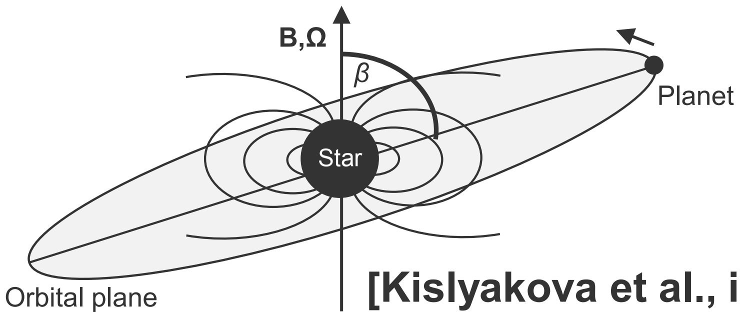
[Kislyakova et al., 2017, Nature Astronomy]

Induction heating for other stars

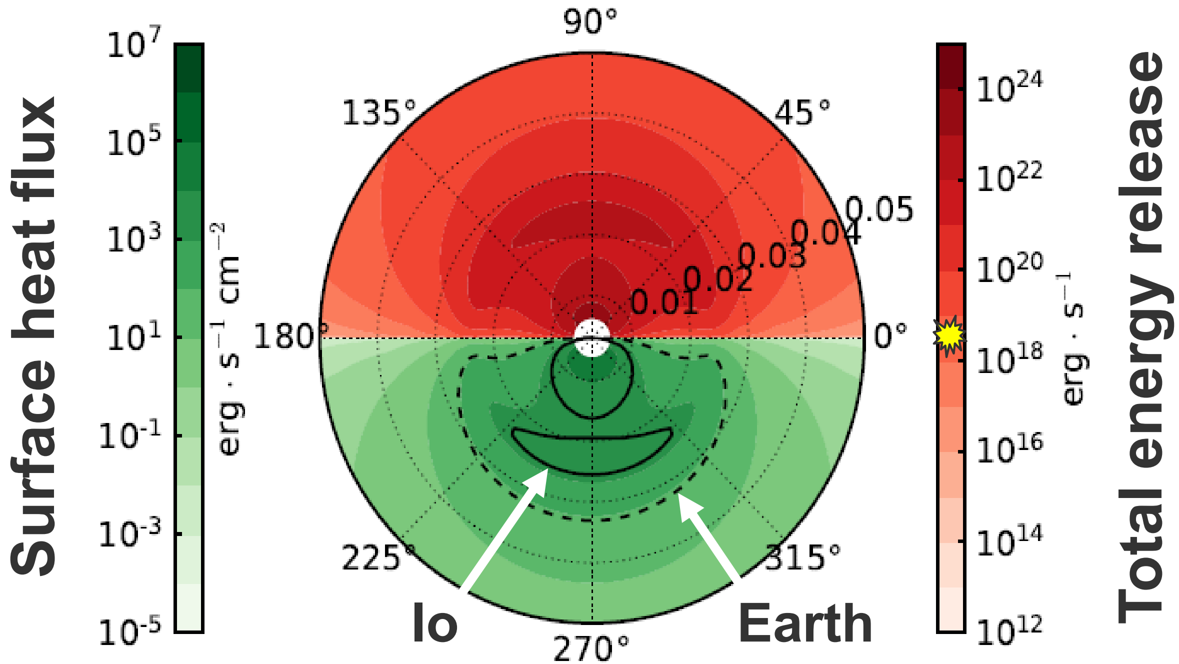
WX UMa: dipole magnetic field, upper limit 7300 G



[Kislyakova et al., 2017]

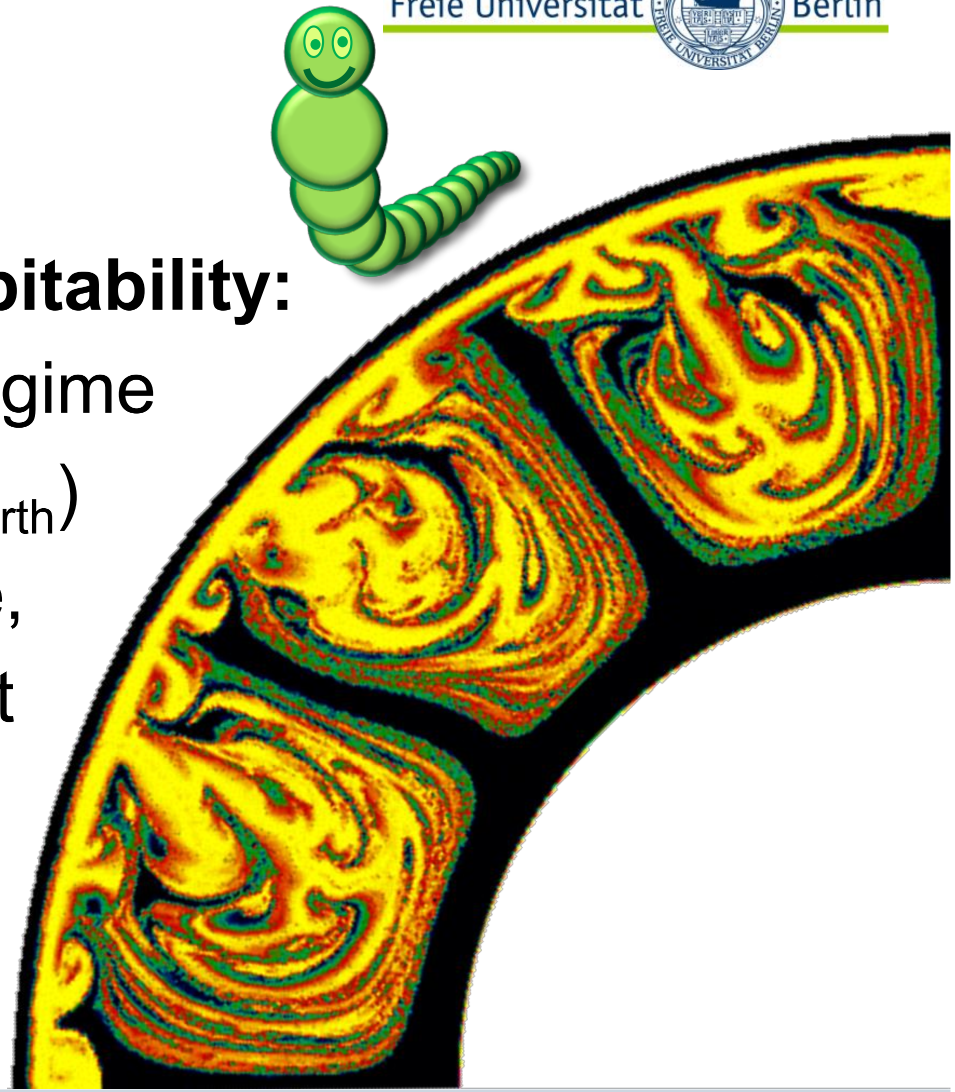


[Kislyakova et al., in review]



Present-day radioactive heating in Earth's mantle

Conclusions



Best candidates for long-term habitability:

- Planets in the **plate tectonics** regime
- **Small massive** planets (few M_{Earth})
- Planets with a **water-rich** mantle, small to intermediate iron content
- Planets where a **primordial atmosphere** remains
- Planets around less-active stars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