Effects of different equations of state on interior structure models of exoplanets

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Exploring the Diversity of Extrasolar Planets

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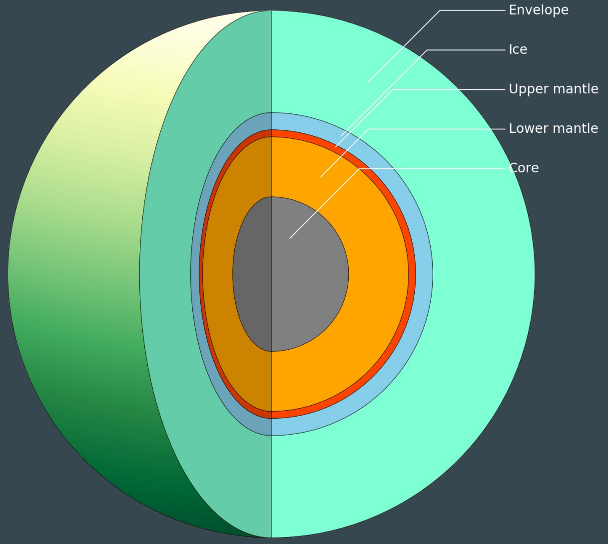
A cookbook for sub-Neptunian exoplanet modelling

- Which parameters lead to the biggest model uncertainties?
- What is the simplest model still yielding accurate results?
- Comparison with previous studies

What are possible sources of model uncertainties?

- Equations of State (EoS) of each planetary layer
- Interior temperature
- Layer composition
- Atmospheric contribution



Best (expected) radius accuracy:
2% (PLATO 2.0)
3% (Kepler)
5% (CHEOPS)

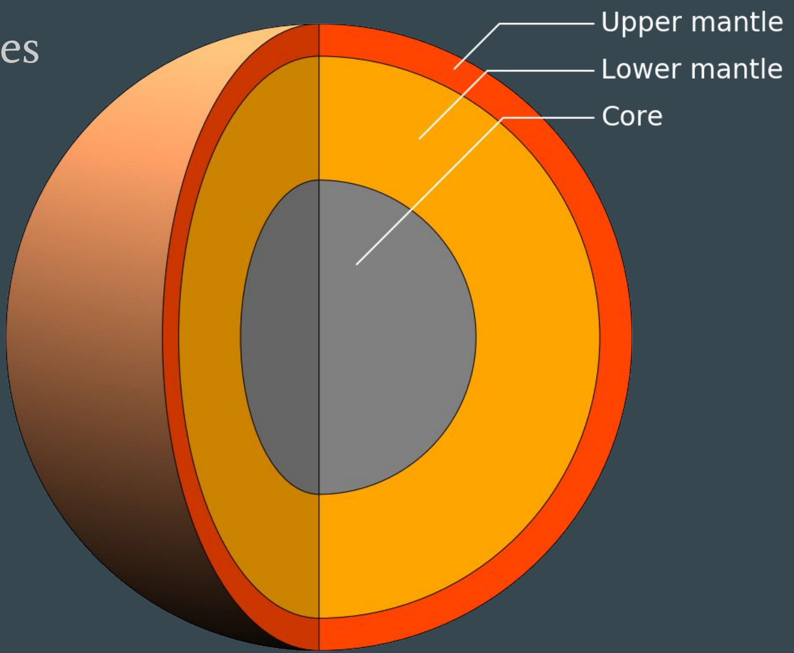
Main planetary layers:

- Iron core
- Silicate mantle
- Ice shell
- Gaseous envelope

Model setup

- Currently: terrestrial planets without volatiles
- Core: pure Fe (hcp)
- Lower mantle: Perovskite ($MgSiO_3$)
- Upper mantle: Olivine (Mg_2SiO_4)

- Pressure dependent phase transition Olivine→Perovskite
- Mass range: 0.5 - 20 $M_\oplus$



Equations of state

Fe core:

Reference	*EoS used*
Dewaele et al. 2006	Birch-Murnaghan 3rd order (BM3)
Sotin et al. 2007	BM3
Sotin et al. 2010	BM3
Wagner 2014 (PhD thesis)	BM3
Dewaele et al. 2006	Vinet
Valencia et al. 2006	Vinet
Seager et al. 2007	Vinet
Wagner et al. 2011	mod. Rydberg
Wagner 2014 (PhD thesis)	Keane

$MgSiO_3$ (pv) mantle:

Reference	*EoS used*
Sotin et al. 2007	BM3
Sotin et al. 2010	BM3
Wagner 2014 (PhD thesis)	BM3
Seager et al. 2007	BM4
Wagner 2014 (PhD thesis)	Vinet
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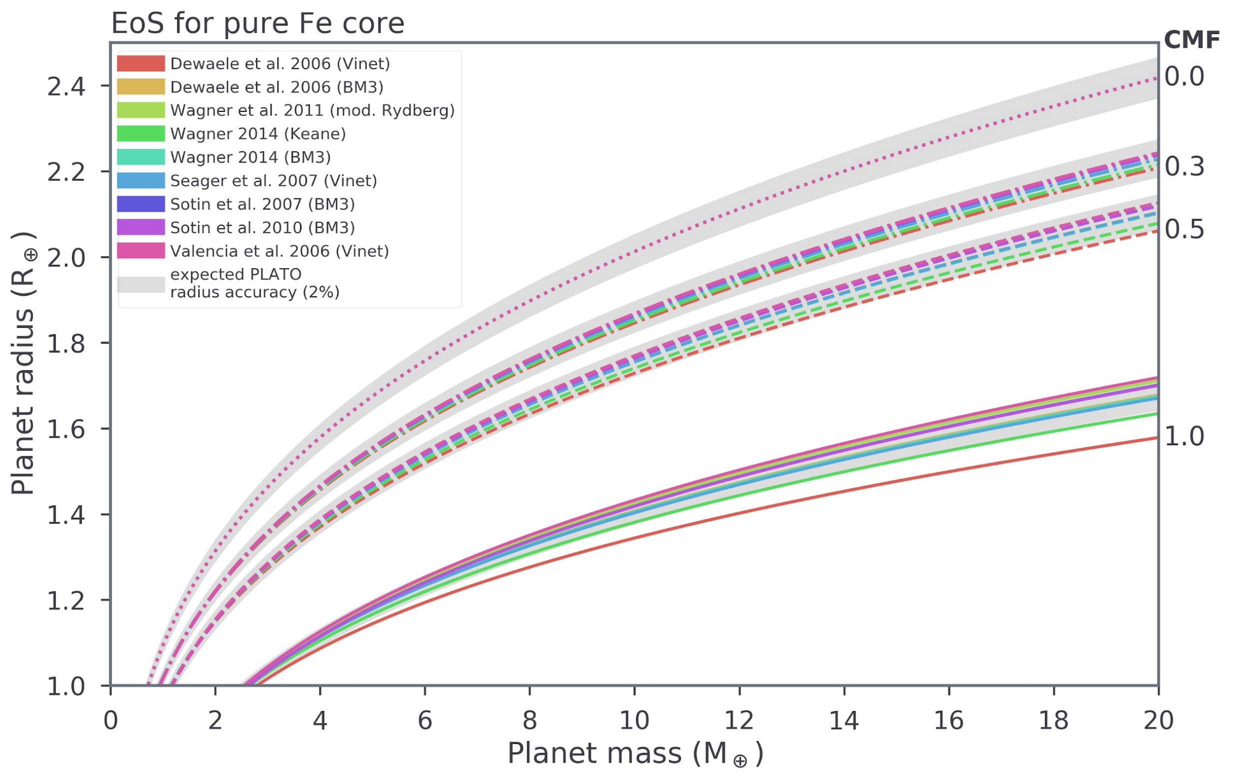
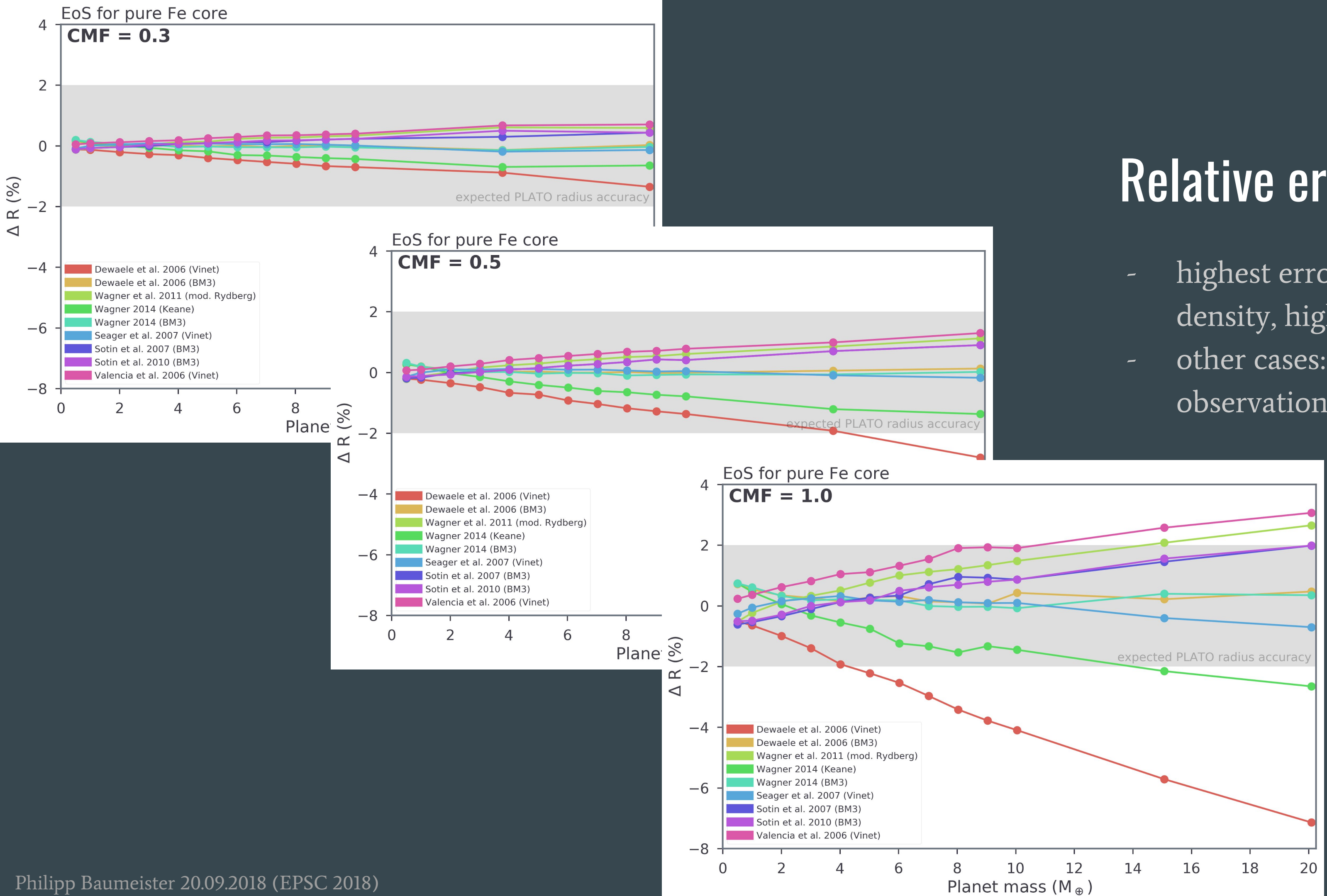
Varying EoS for the core

- errors for pure iron planets are above observational limits
- effects of EoS diminish rapidly with smaller core sizes



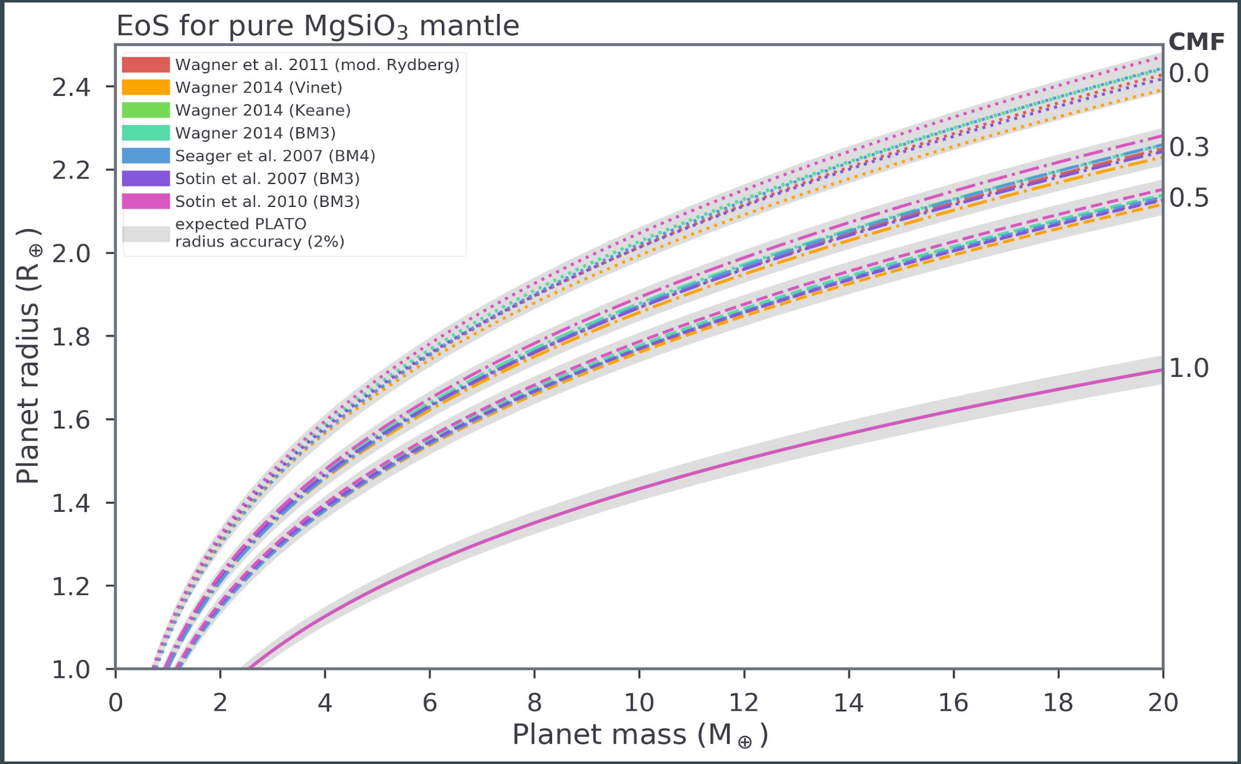


Relative errors

- highest errors for high density, high mass planets
- other cases: errors within observational constraints

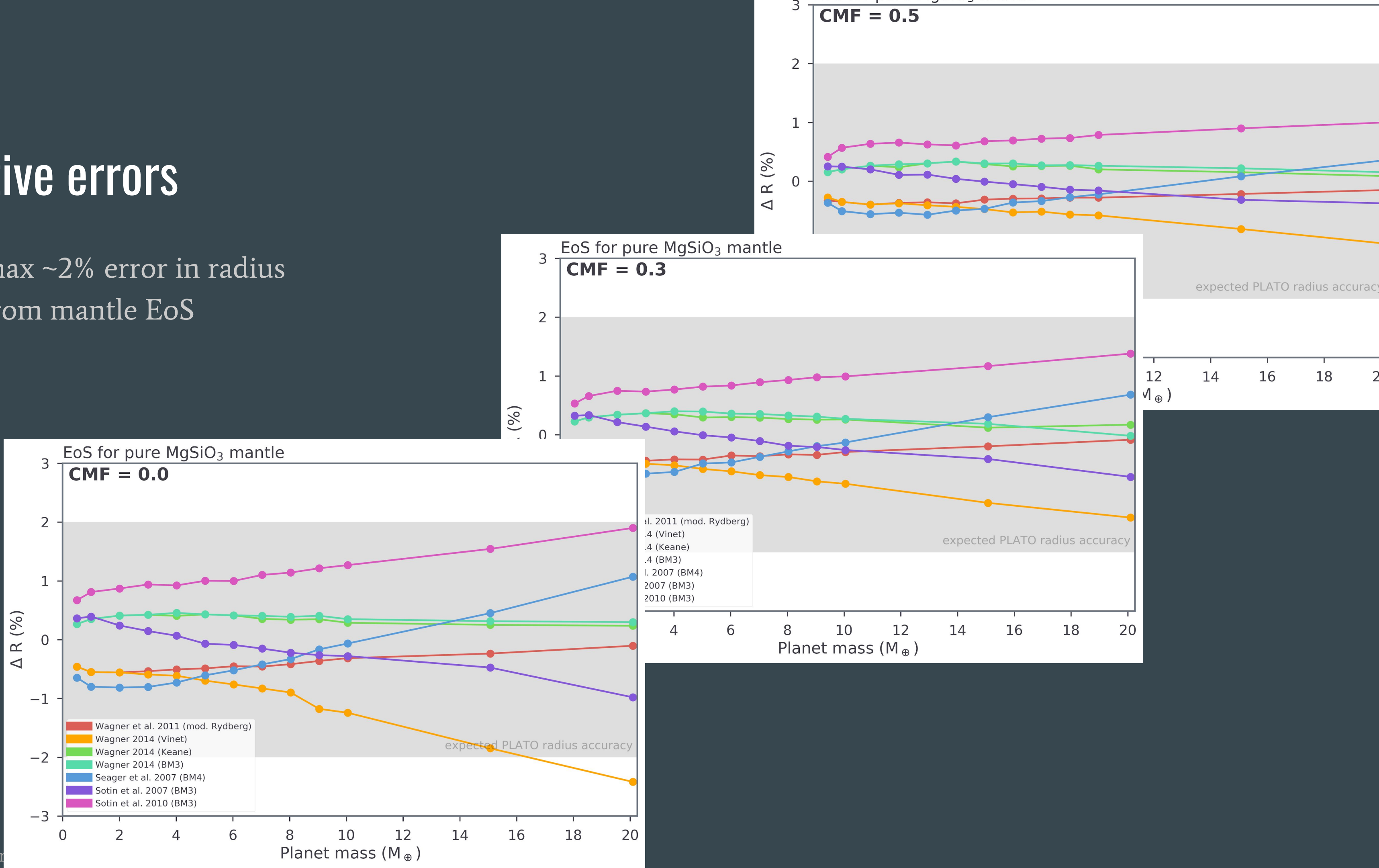
Varying EoS for the mantle

- all errors within observational limits
- effect of mantle EoS smaller than effect of core EoS

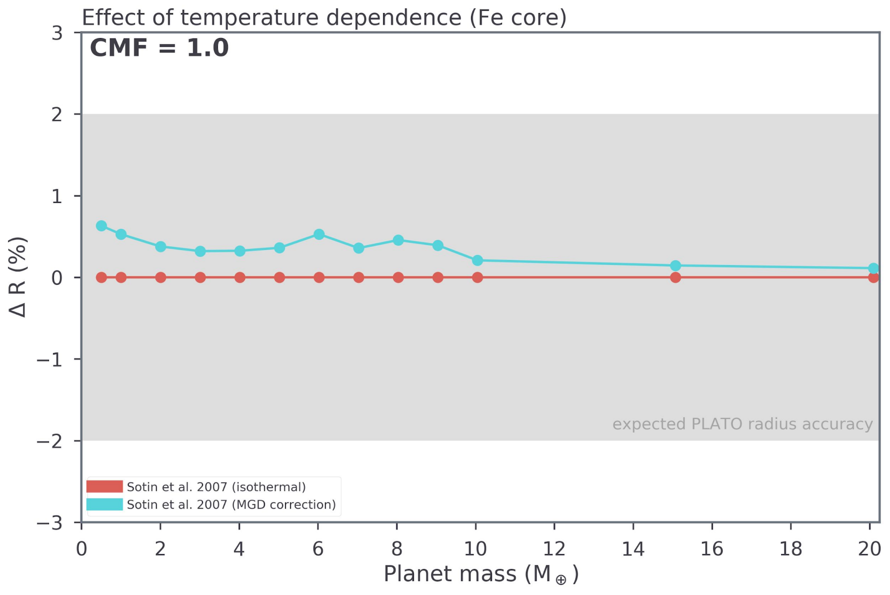


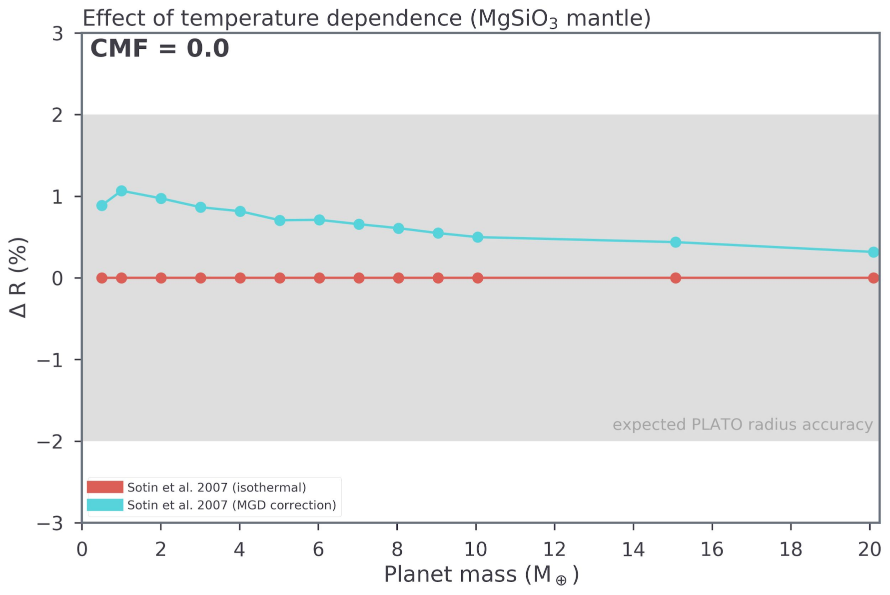
Relative errors

- max ~2% error in radius from mantle EoS



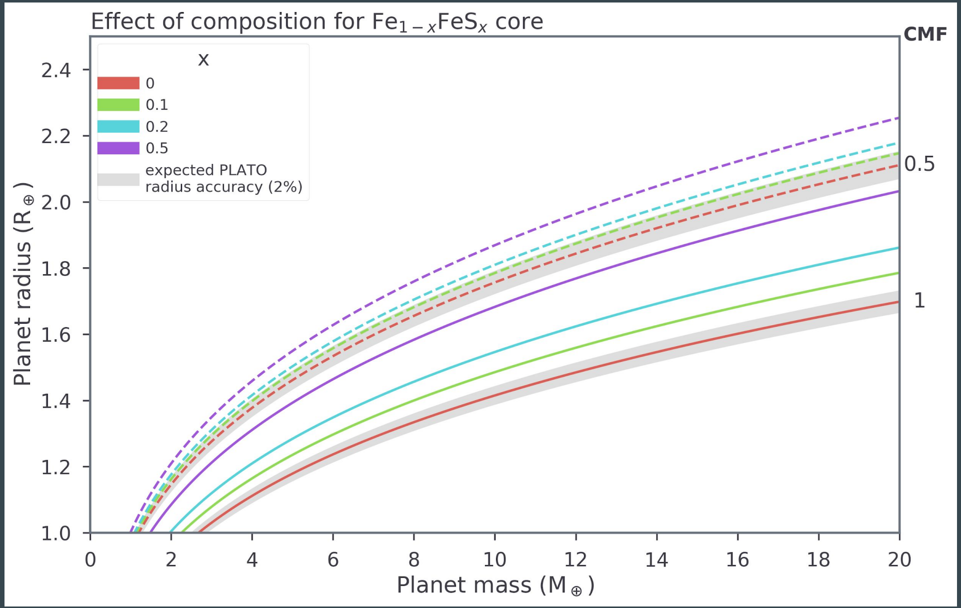
Effect of temperature dependence

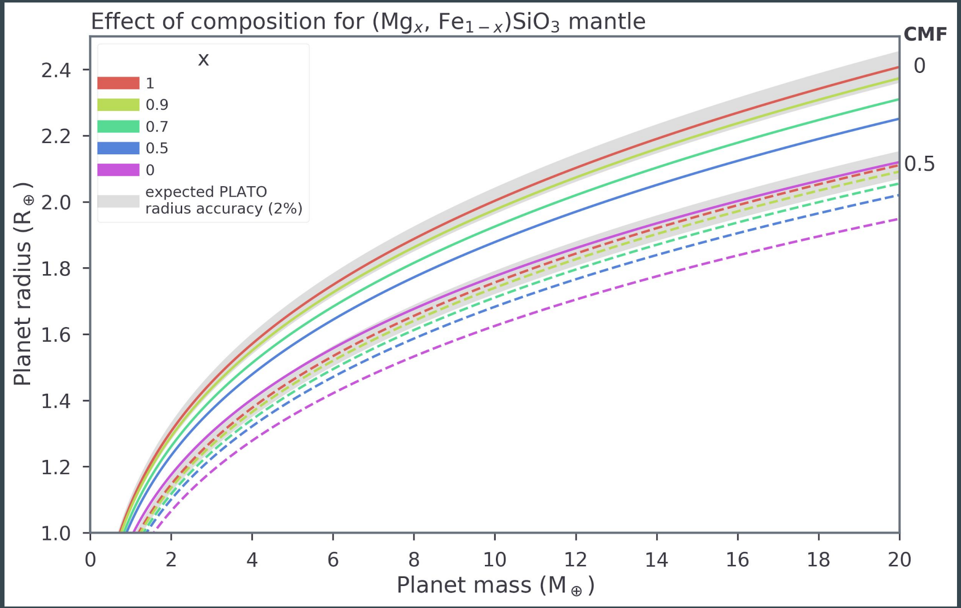




Effect of temperature correction negligible to radius contribution

Effect of composition





Impact of mineral composition is extremely significant!

Conclusions

Temperature dependence:	negligible
Silicate EoS:	probably negligible
Iron EoS:	probably important for high mass, high density planets
Composition:	very important! Small composition changes can result in huge radius changes.
Ices / Atmosphere	*?, but probably quite important*

Conclusions

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Simple isothermal EoS for the solid interior are probably sufficiently accurate for mass-radius diagrams, because mineral composition is hard to constrain