Modeling the structure of irradiated ocean planets - implications for mass-radius relationships

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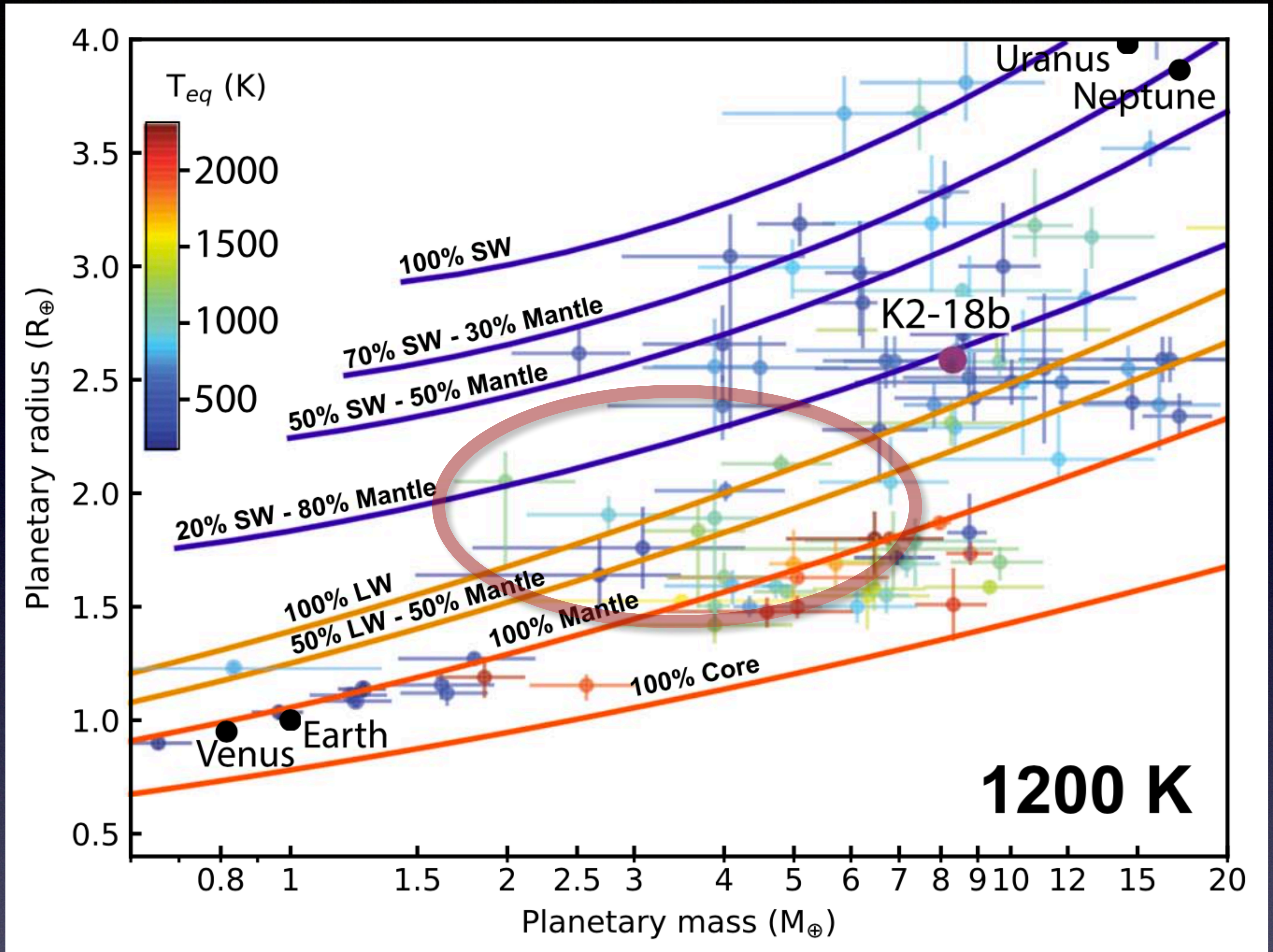


Figure 1 : Mass-radius diagrams of detected exoplanets, and mass-radius relationships involving core, mantle, liquid water and supercritical water (Mousis et al. 2020).

The case of hot sub-Neptunes

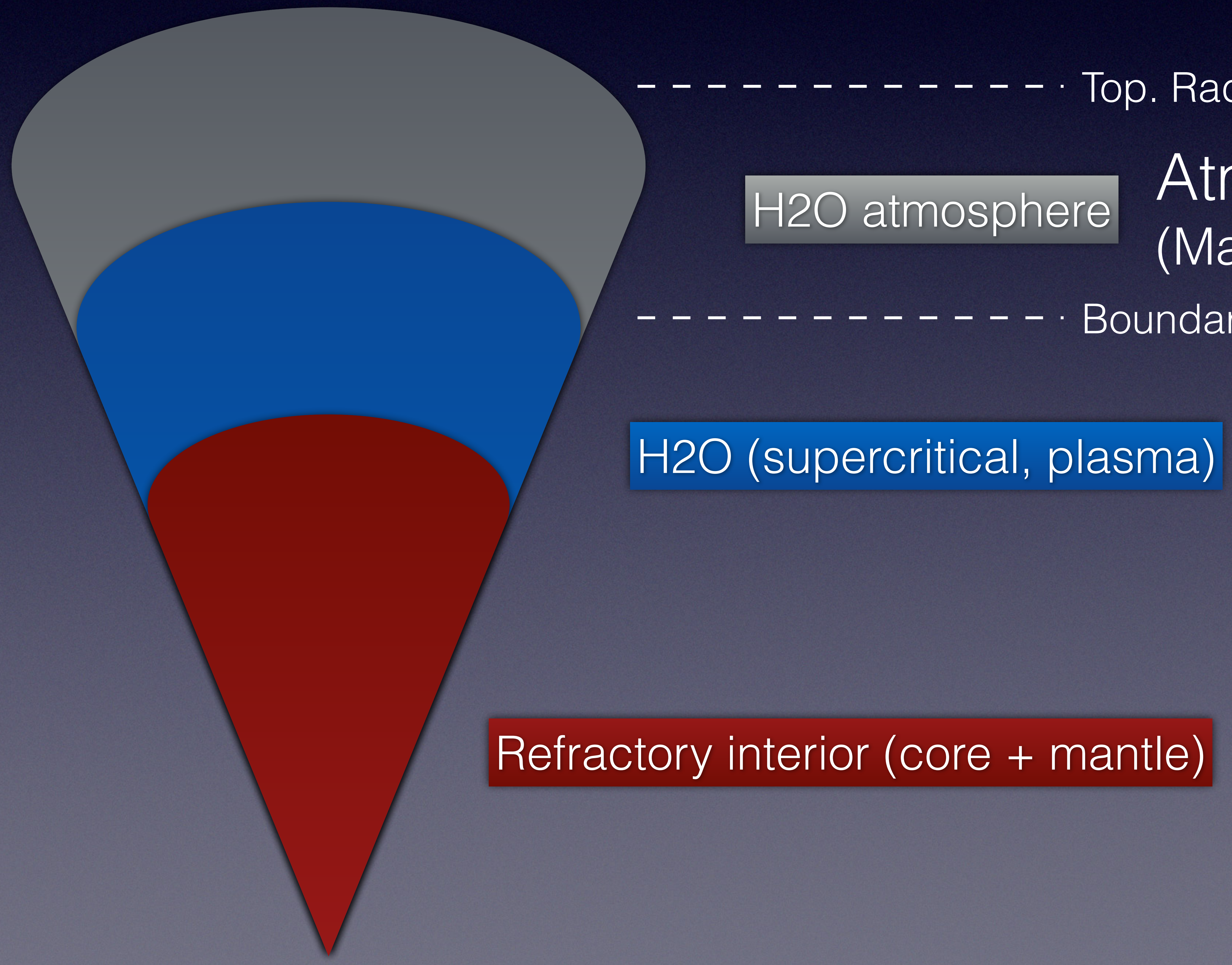
When modeling highly irradiated ocean planets (IOP), the atmosphere plays an important role :
- Blanketing effect that heats the top of the refractory layers
- An expanded atmosphere has little mass, but great thickness

Modeling of planetary interiors

- Require the use of updated EoS at extreme conditions.
- For planets in condensed phase, surface properties mimic the presence of a thin atmosphere, the properties of which might be discarded.

IOP model (Aguichine et. al 2021)

Combining interior model with atmosphere model :



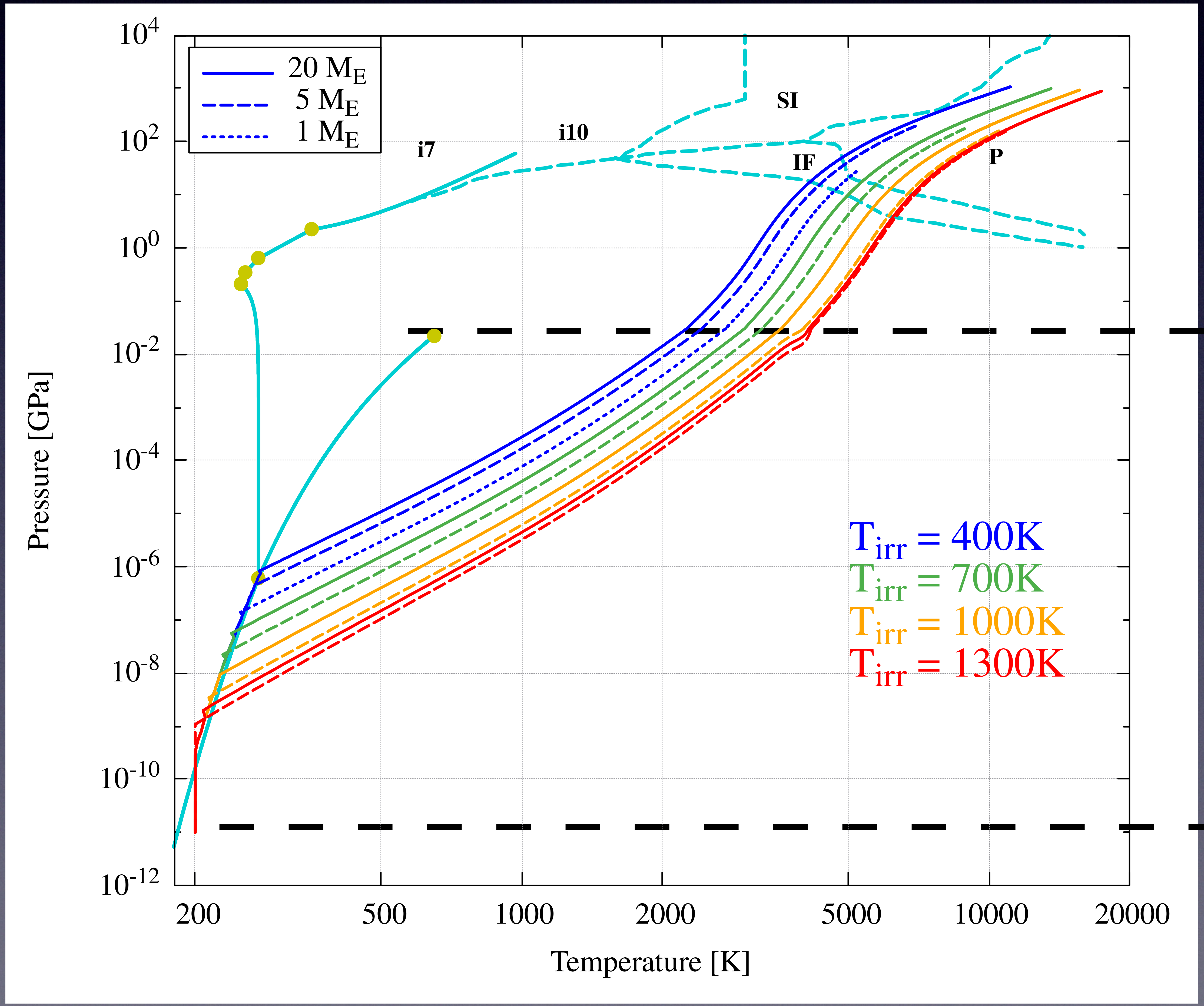
Top. Radiative equilibrium $OLR=(1-A)\sigma_{sb}T_{irr}^4$

Atmosphere adiabatic/radiative transfer
(Marcq et al. 2019)

Boundary : R_b, M_b, T_b, P_b=300 bar

Adiabatic interior
(Brugger et al. 2017,
Mousis et al. 2020)

IOP model (Aguichine et. al 2021)



H2O (supercritical, plasma)

Boundary : R_b, M_b, T_b, P_b=300 bar

H2O atmosphere

Top. Radiative equilibrium OLR=(1-A)$\sigma_{sb}T_{irr}^4$

- Updated EoS (Mazevet et al. 2019)
- Stability of the code

Figure 2 : (P,T) profiles of planetary structures (Aguichine et al. 2021).

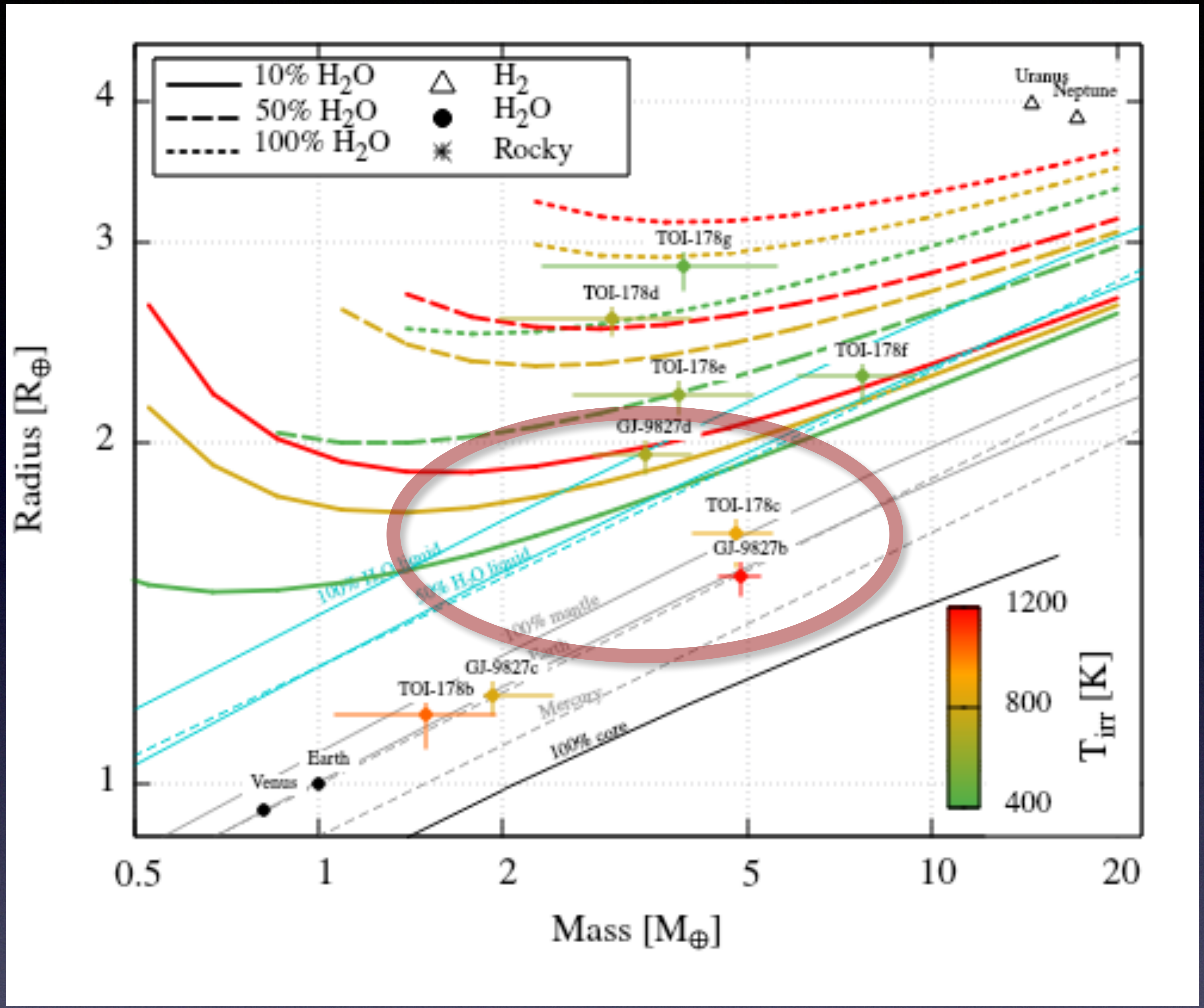


Figure 3 : Comparison between mass-radius relationships with condensed phases, and IOP model.

The case of hot sub-Neptunes

- 50% liquid H_2O matches 10-20% supercritical H_2O
- Explains hot sub-Neptunes distribution with 0-20% of steam/supercritical H_2O

Determination of planetary composition

- Visual guess from MR-relationships
- Ternary diagrams
- MCMC

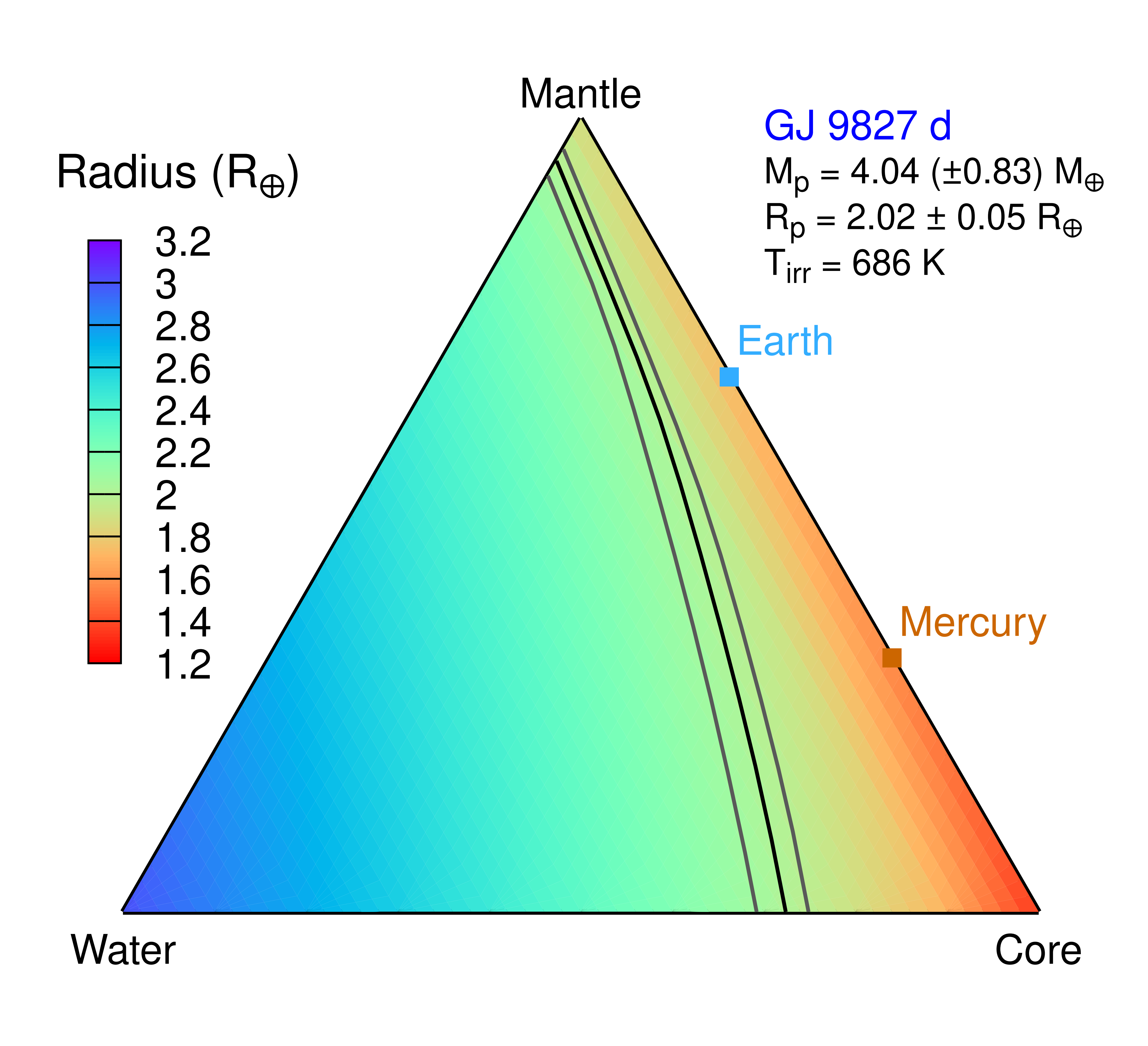


Figure 4 : Ternary diagram applied to planet GJ-9827b (Aguichine et al. 2021).

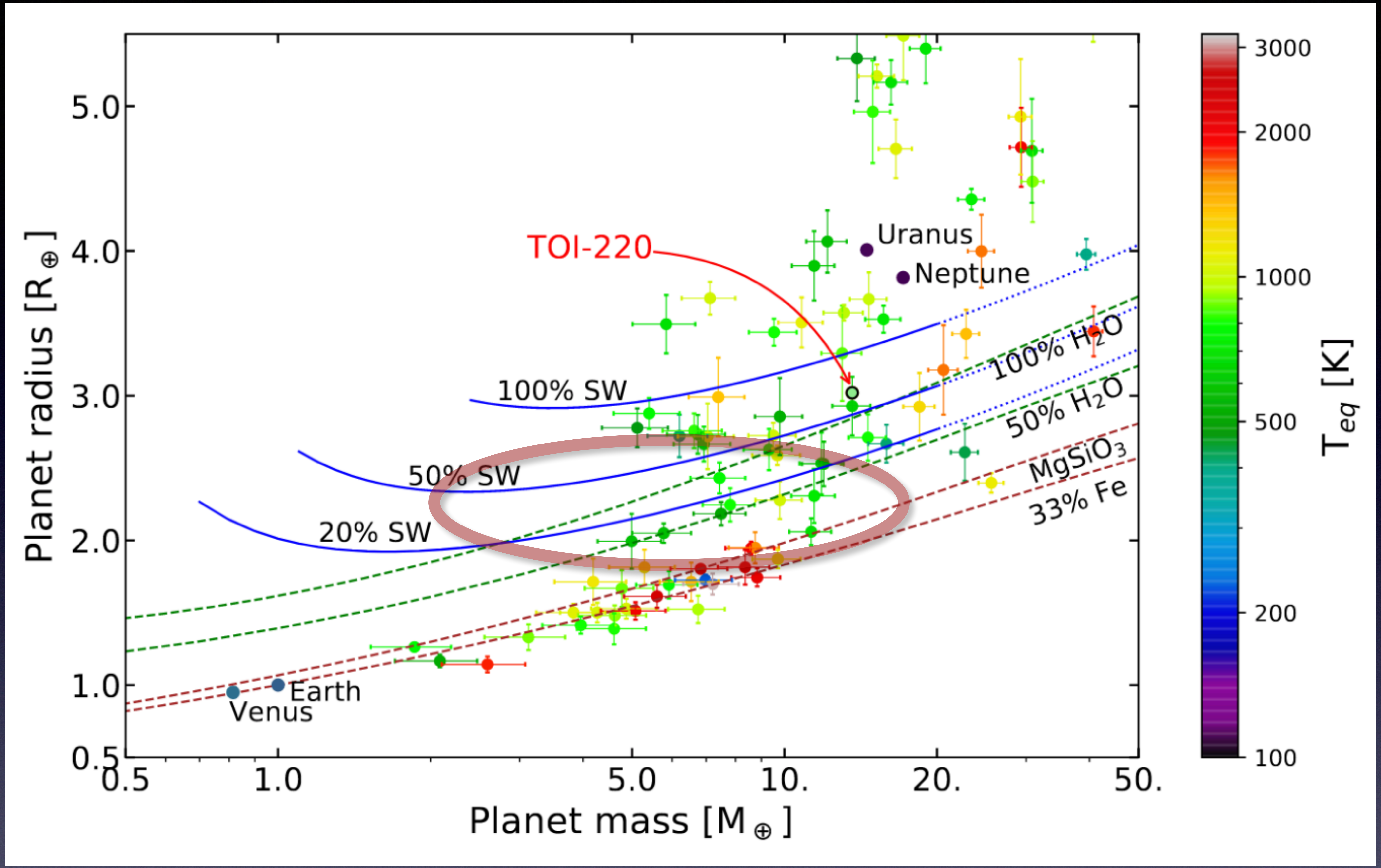


Figure 5 : Curves using analytical fits (solid blue, dotted blue) in Hoyer et al. 2020.

Results of the model

- Raw data available in Aguichine et al. 2021, with intermediate points can be interpolated : https://archive.lam.fr/GSP/MSEI/IOPmodel/mr_all.dat
- Analytical fit, coefficients at : https://archive.lam.fr/GSP/MSEI/IOPmodel/fit_coefficients.dat

Dynamical stability : atmospheric escape

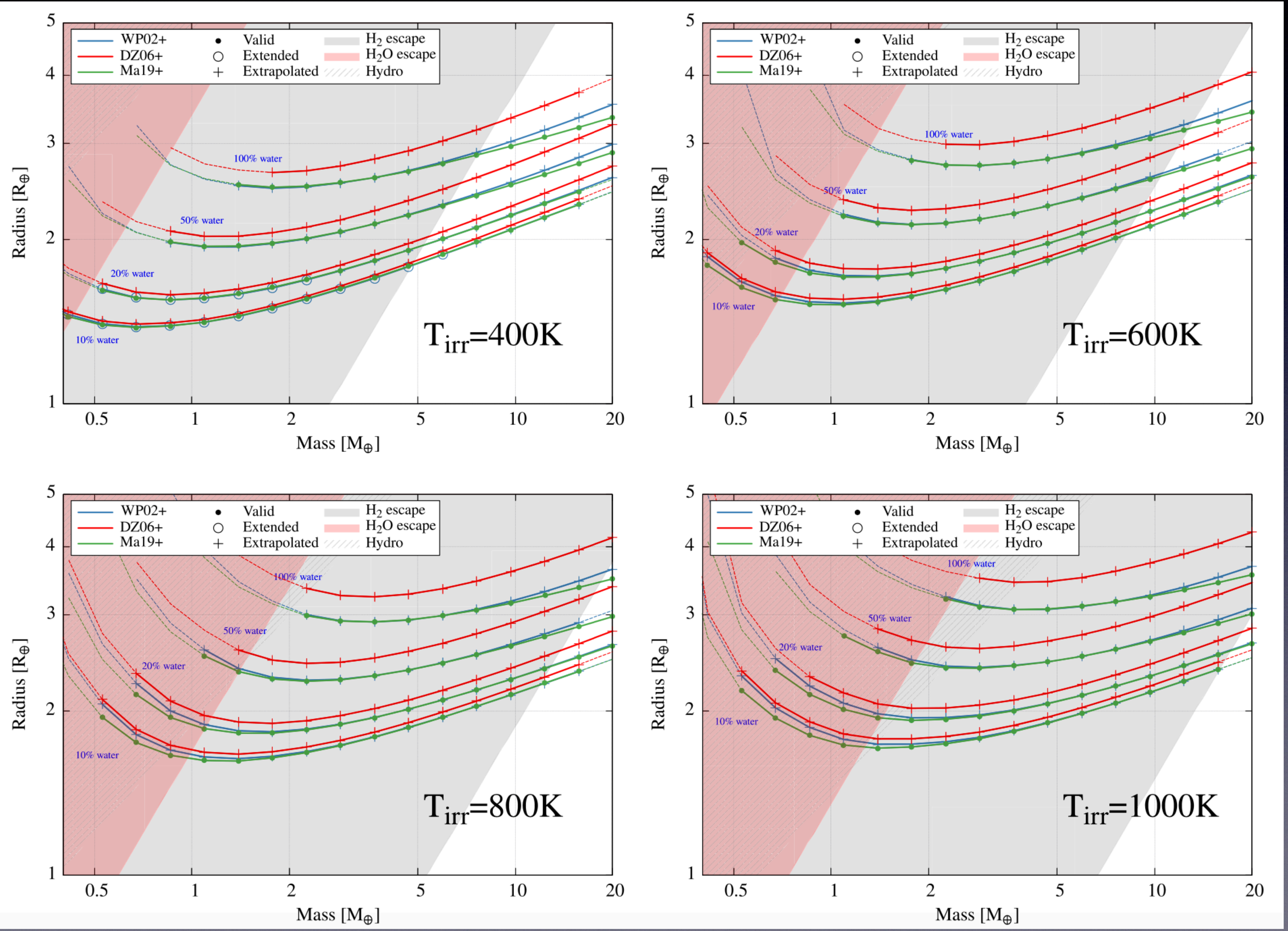


Figure 6 : Mass-radius relationships over domains of strong escape of H_2-He and H_2O (Aguichine et al. 2021).

Discussion and conclusion

- Fully self-consistent model
- Model results and analytical fits available for a wide range of parameters (M_p = 0.2 — 20 $M_\oplus$, WMF = 0.1 — 1, CMF = 0 — 0.9, T_{irr} = 400 — 1300 K)
- Dynamical stability of atmospheres help discriminate between H_2-He and H_2O envelopes.
- Strong hypotheses : fully differentiated, adiabatic interior, pure H_2O.

References

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