UNIVERSITY OF CALIFORNIA
SANTA CRUZ

ASTROBIOLOGY at NASA
LIFE IN THE UNIVERSE

1

Structure and evolution of the envelopes of hot water worlds

Dr. Artem (Artyom) Aguichine

Postdoc at University of California, Santa Cruz

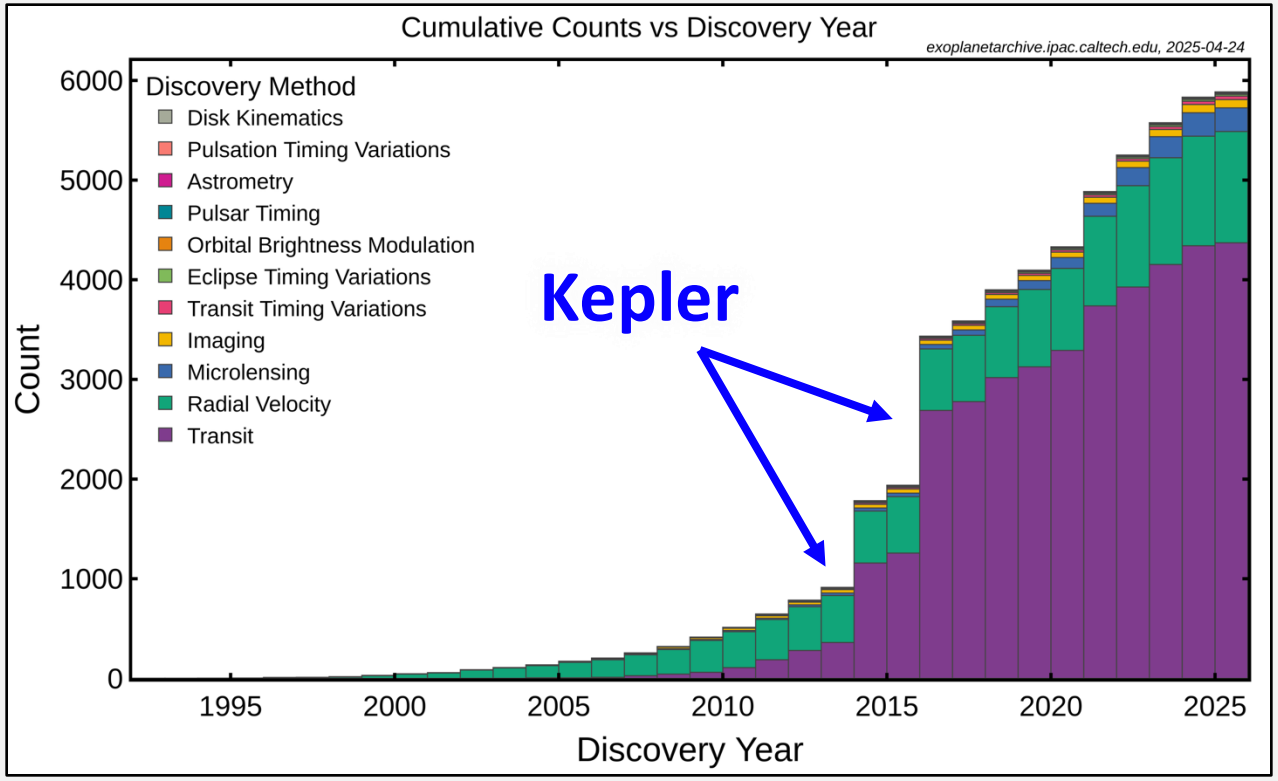
Collaborators: Olivier Mousis, Natalie Batalha, Jonathan J. Fortney, James E. Owen, Nadine Nettelmann, Eliza M.-R. Kempton, Natasha Batalha, Johanna Teske, Francis Nimmo, Lily Larkins*, Emerson Tao*

PLATO meeting, Marseille, June 24th, 2025

*students

The era of exoplanet demographics

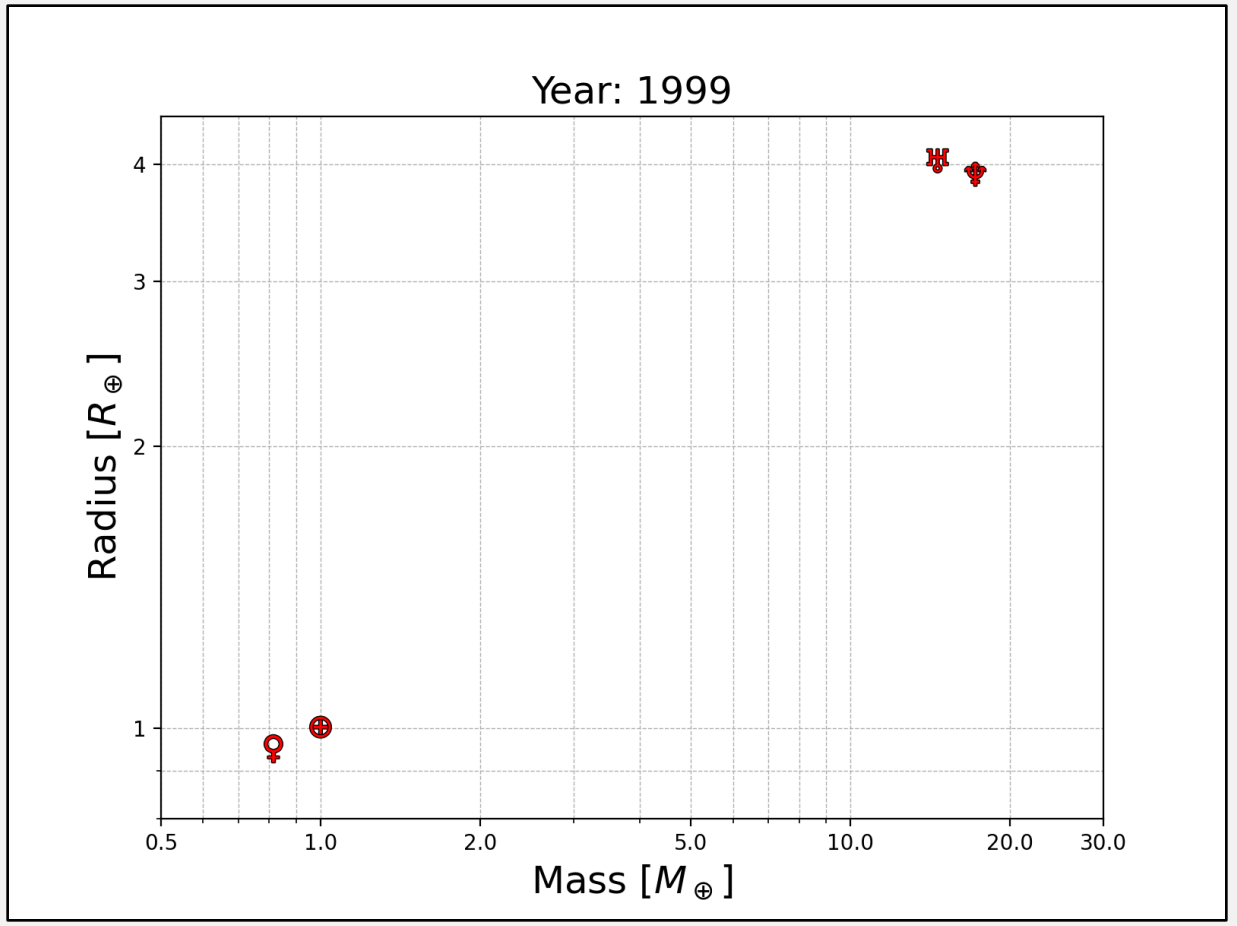
Credit: NASA Exoplanet Archive



Transit: planet radius

Radial Velocity: planet mass

Credit: Artem Aguichine



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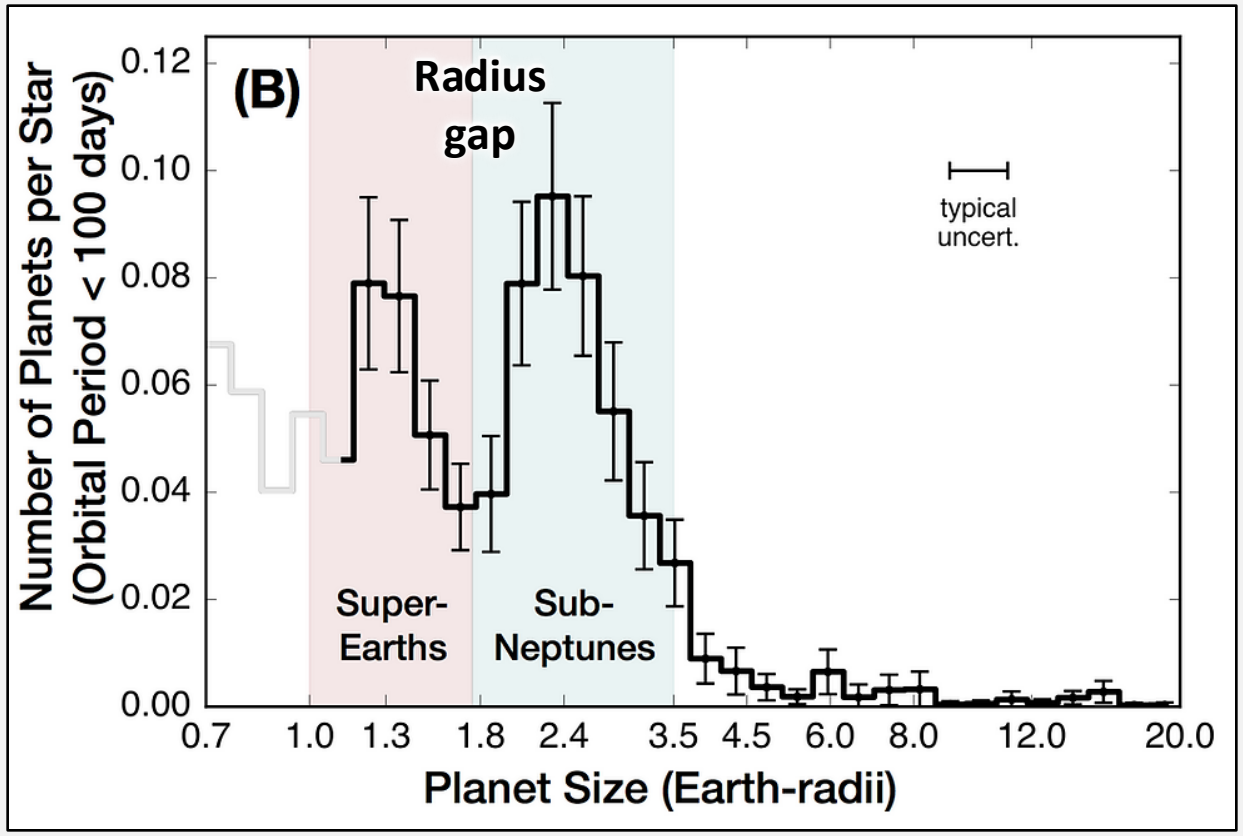
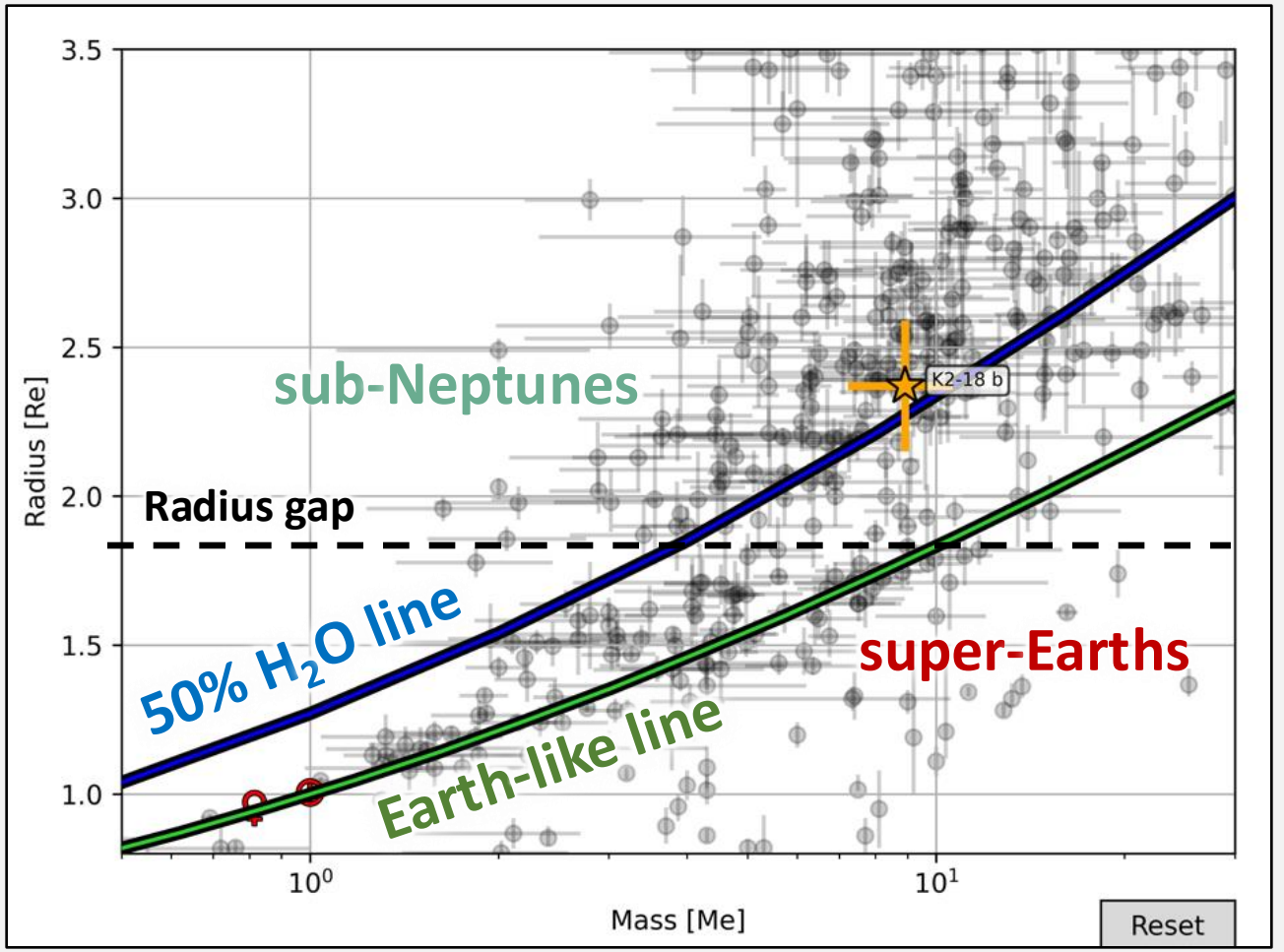
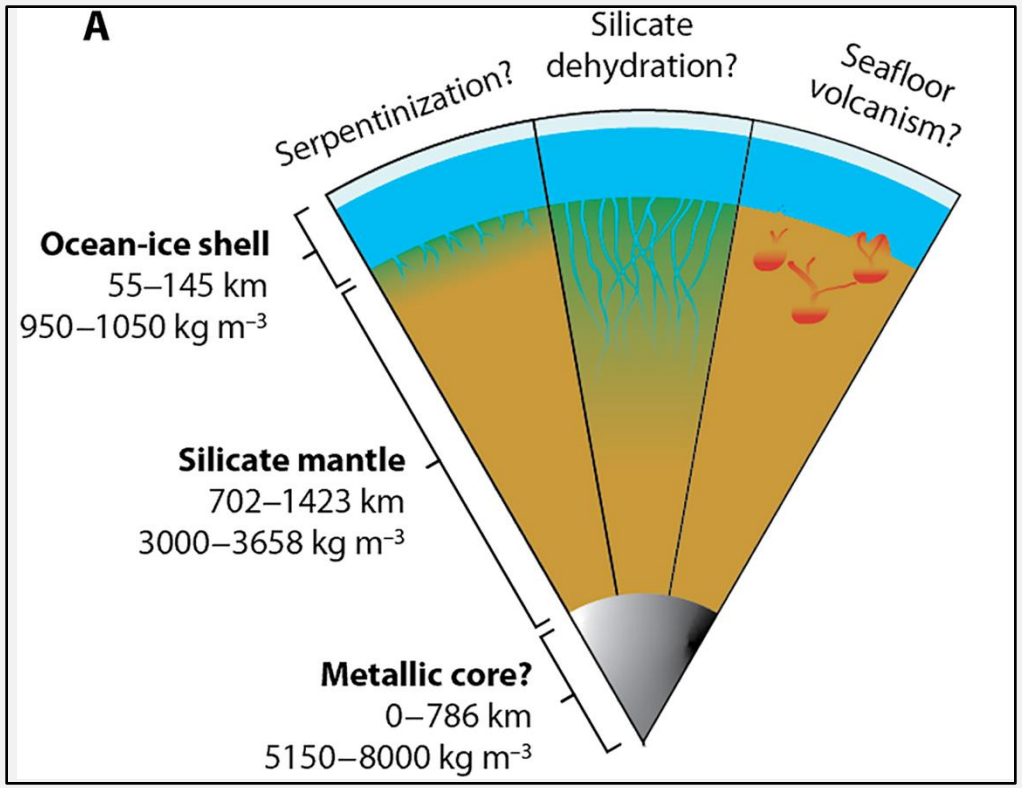


Fulton+2017



The runaway greenhouse effect

3% of sub-Neptunes:
Water is liquid or solid
Water Worlds



Trinh+2023

97% of sub-Neptunes:
Water is steam and supercritical
Steam Worlds

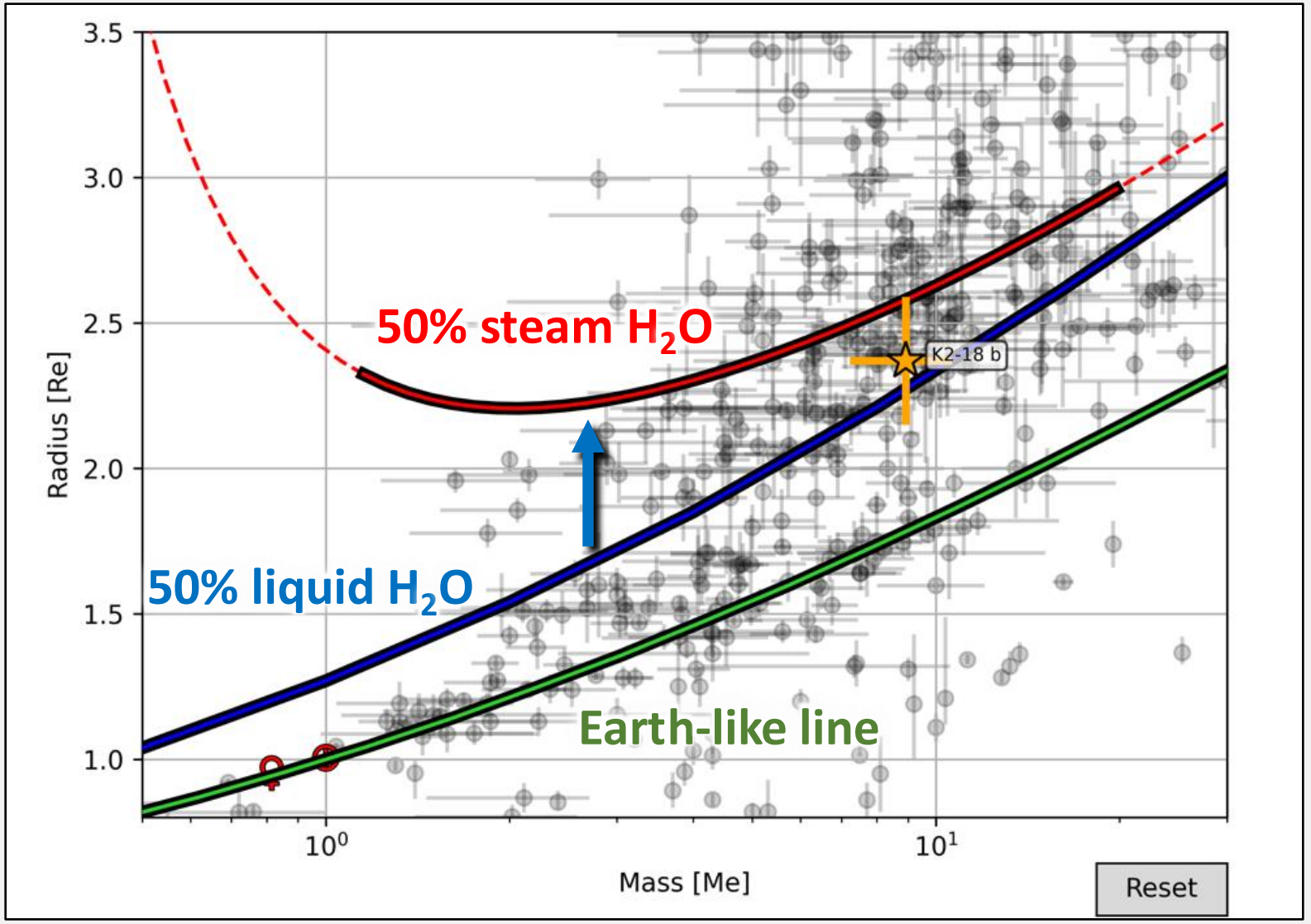
Irradiated Ocean Planet (IOP) model (**Mousis,Deleuil, Aguichine+2020**, **Aguichine+2021**)

Used in Acuña+2021,2024,2025

Reinterpretation of sub-Neptune's interiors

Steam H_2O:
Aguichine+2021

Liquid H_2O:
Zeng+2016



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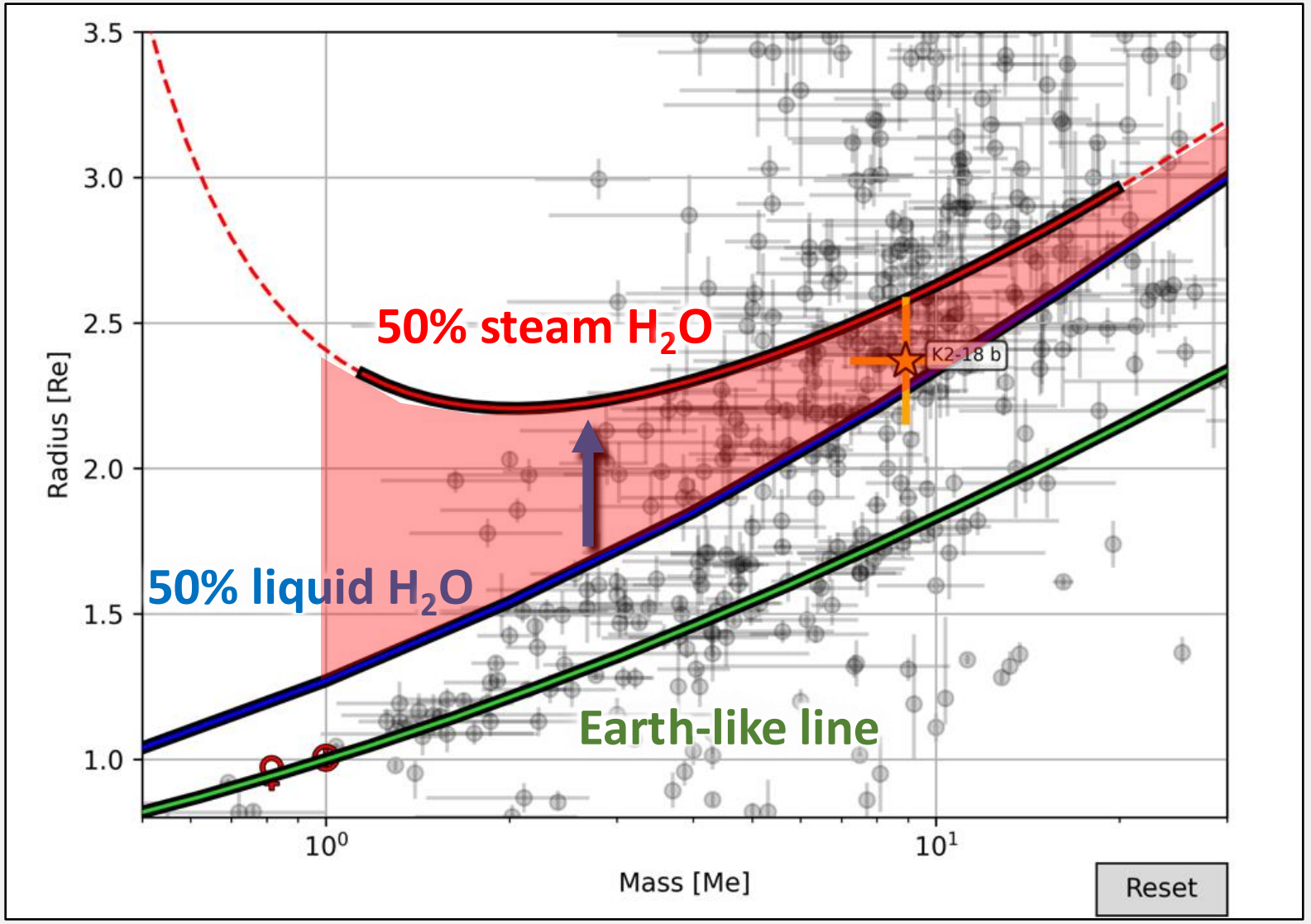

Sub-Neptunes could be **steam worlds**.

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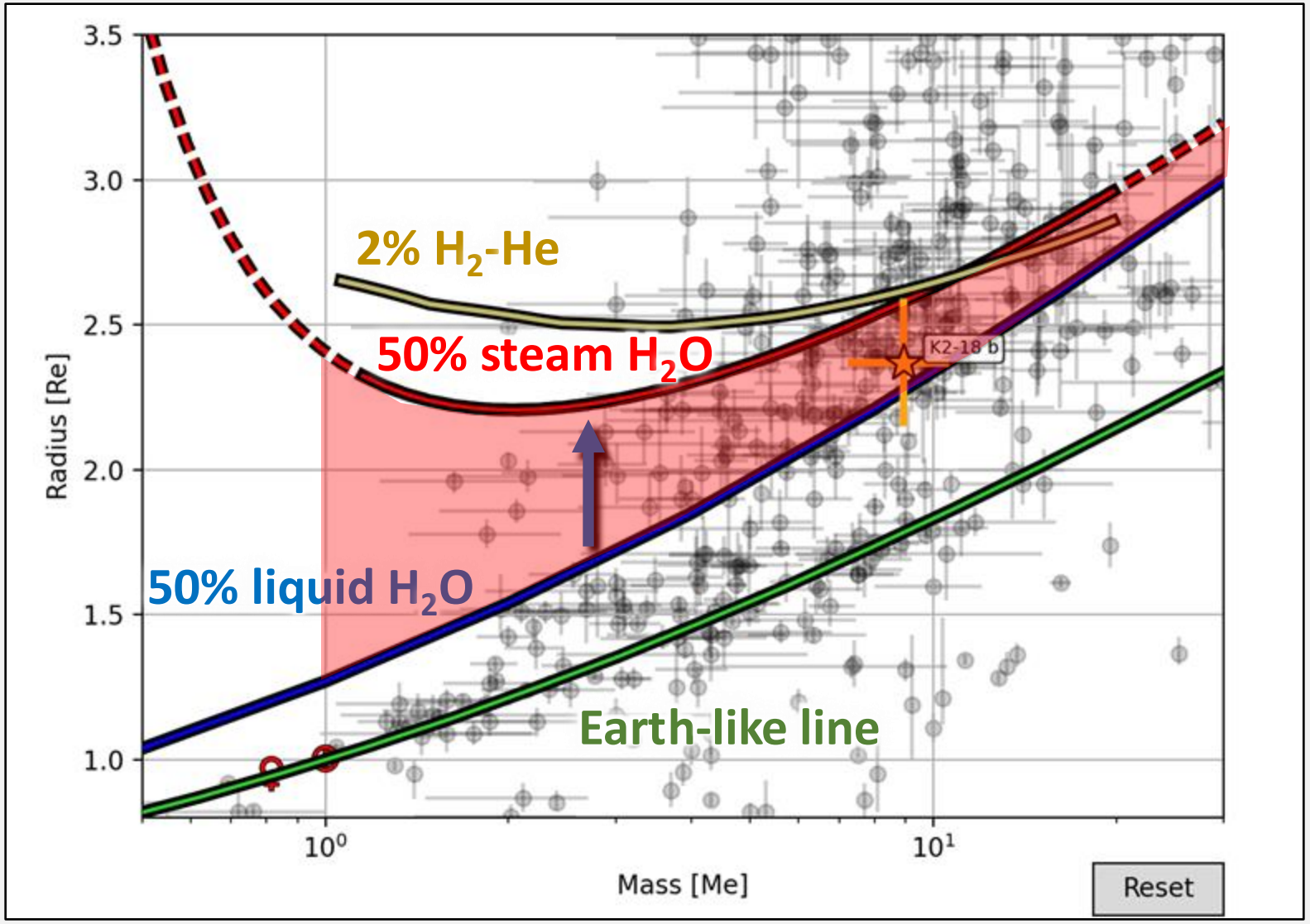
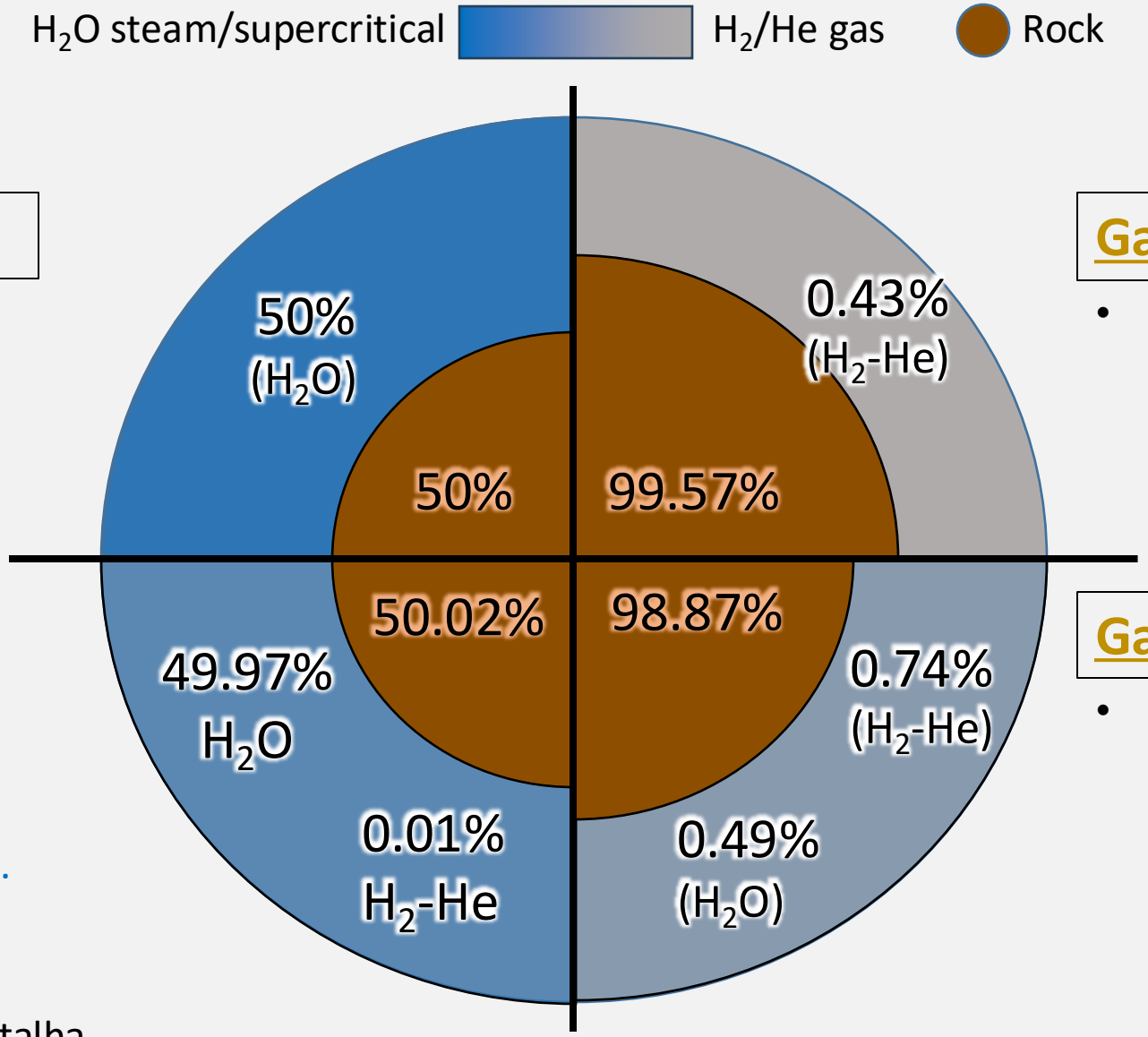


Sub-Neptunes could be **steam worlds**

or **gas dwarf**??

Same mass, same radius, different composition



Steam World

- Pure H_2O envelope: Aguichine+2025

Gas Dwarf

- H_2-He (1x solar): Tang+2024

Steam dominated

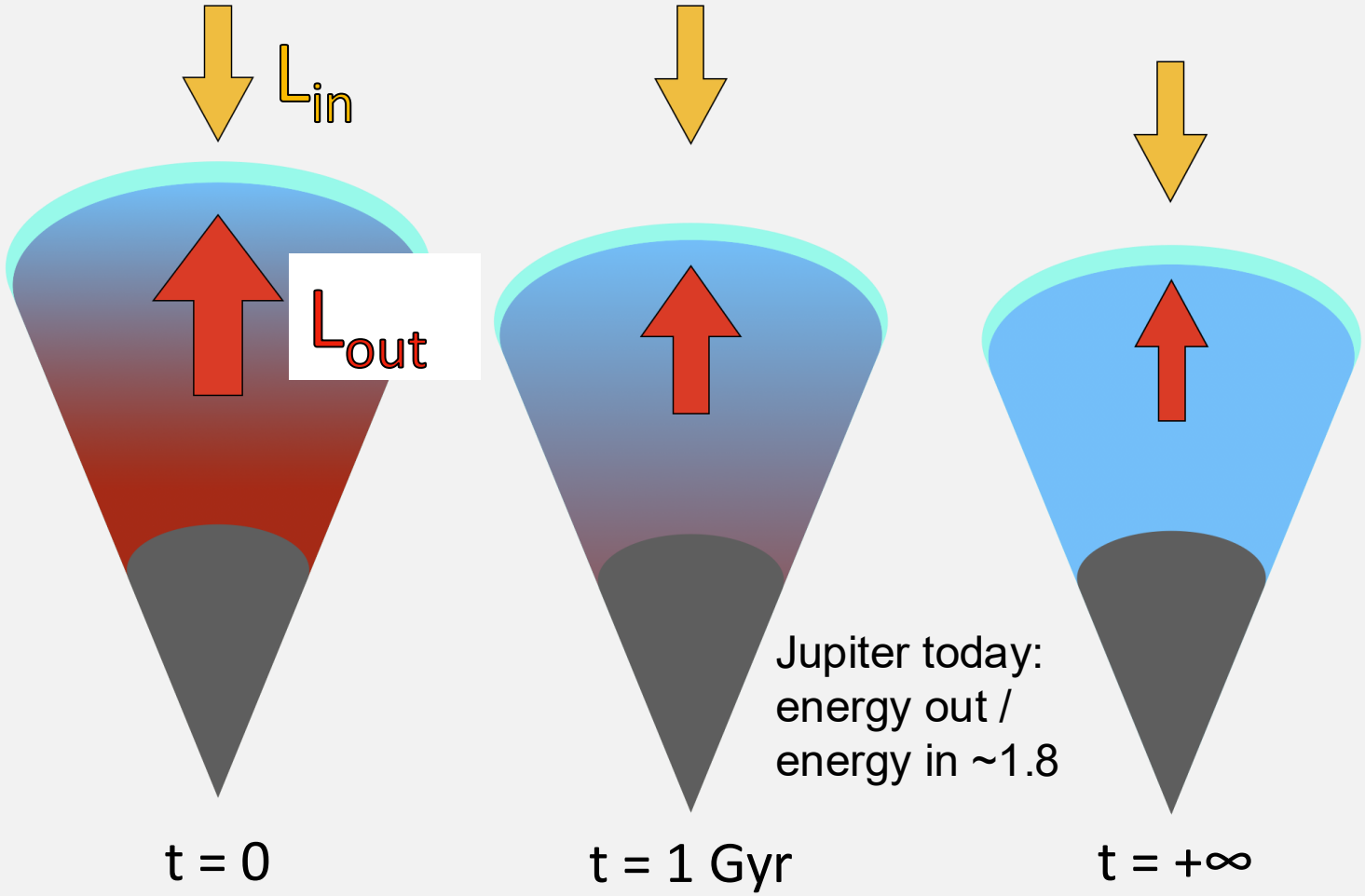
- Hycean? (Madhusudhan+2020)
- Aguichine+2026, in prep.

Gas dominated

- H_2-He (50x solar): Tang+2024

Image Credit: Aguichine & Batalha

Steam World Evolution (SWE) Aguichine+2025



Atmosphere

Controls heat evacuation rate
Pure steam atmosphere
H_2O opacity computed up to 1000 bar
Kempton+2023

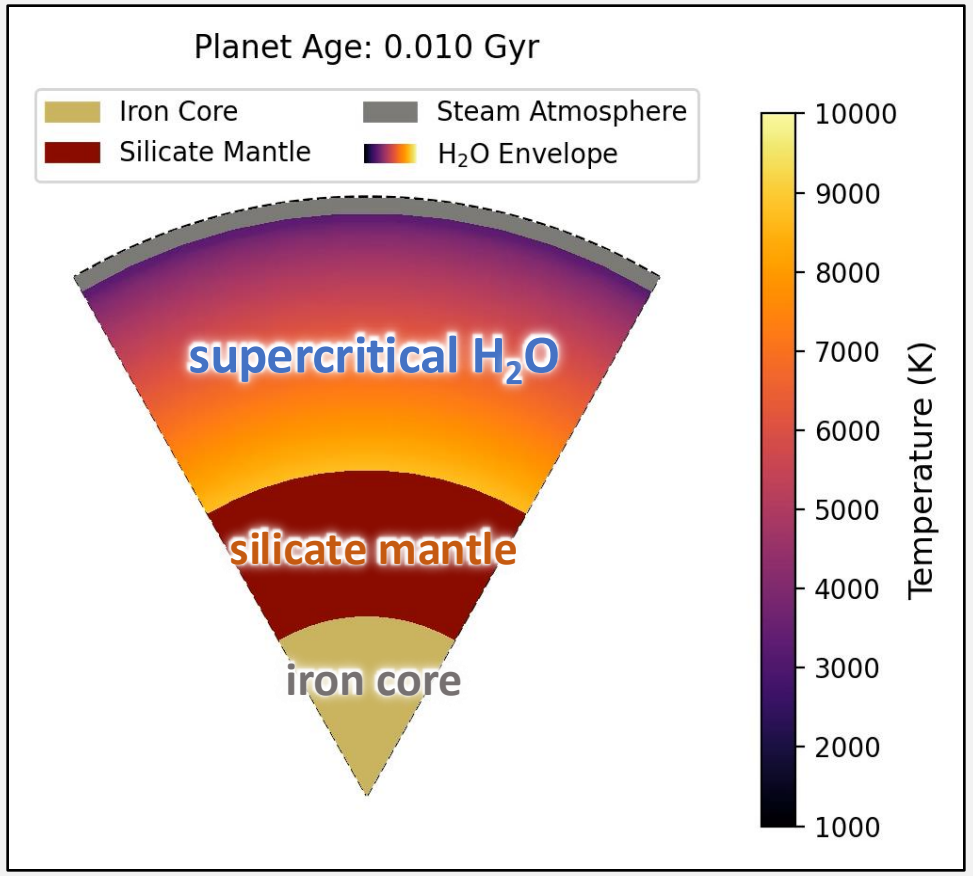
Envelope

Supercritical H_2O envelop
Thermal and gravitational energy
Aguichine+2021

Core (IOP model)

Earth-like core, but hotter
Thermal, gravitational, and radiogenic energy
Brugger+2016,Aguichine+2021

Steam World Evolution (SWE) Aguichine+2025



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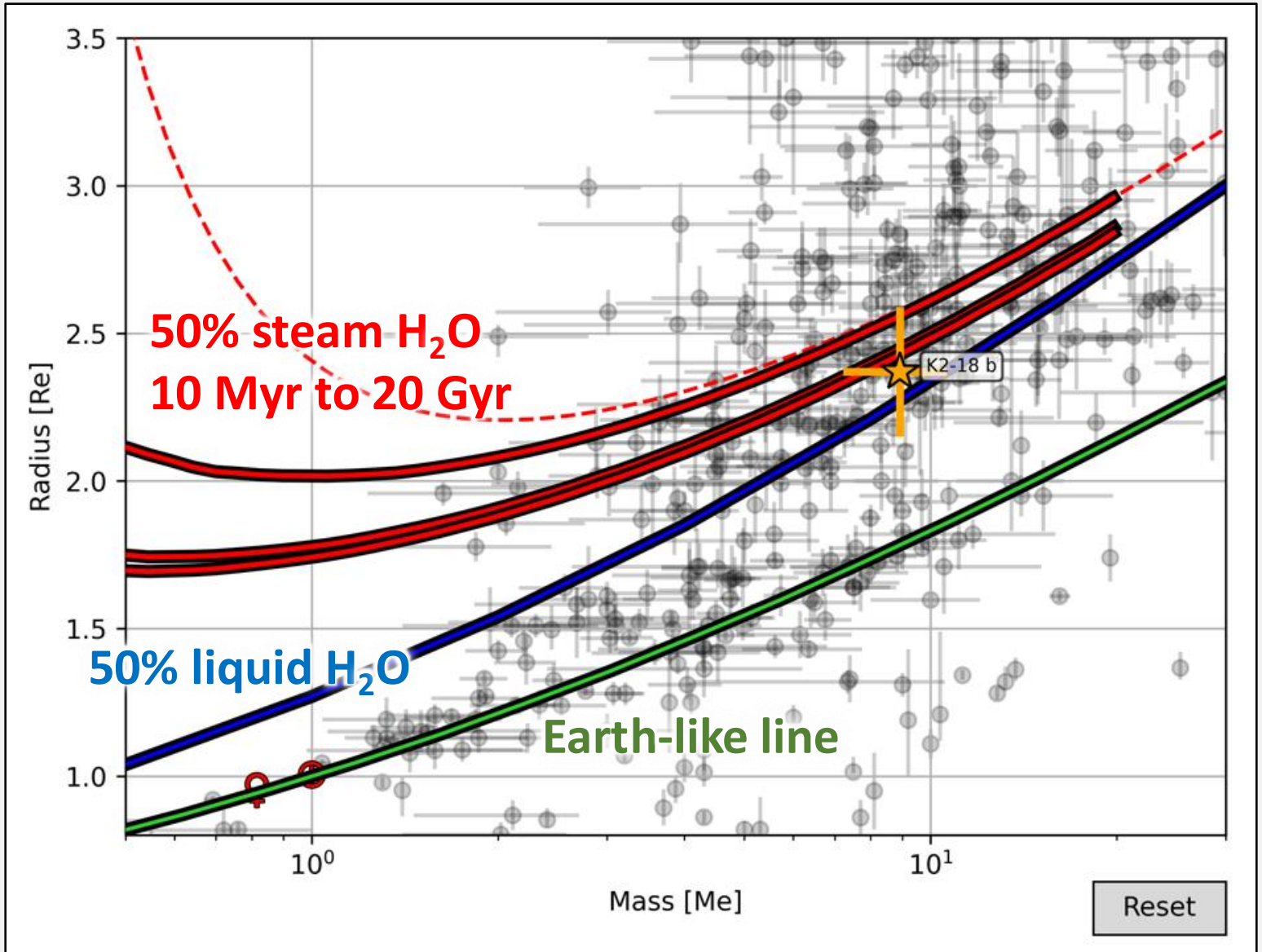
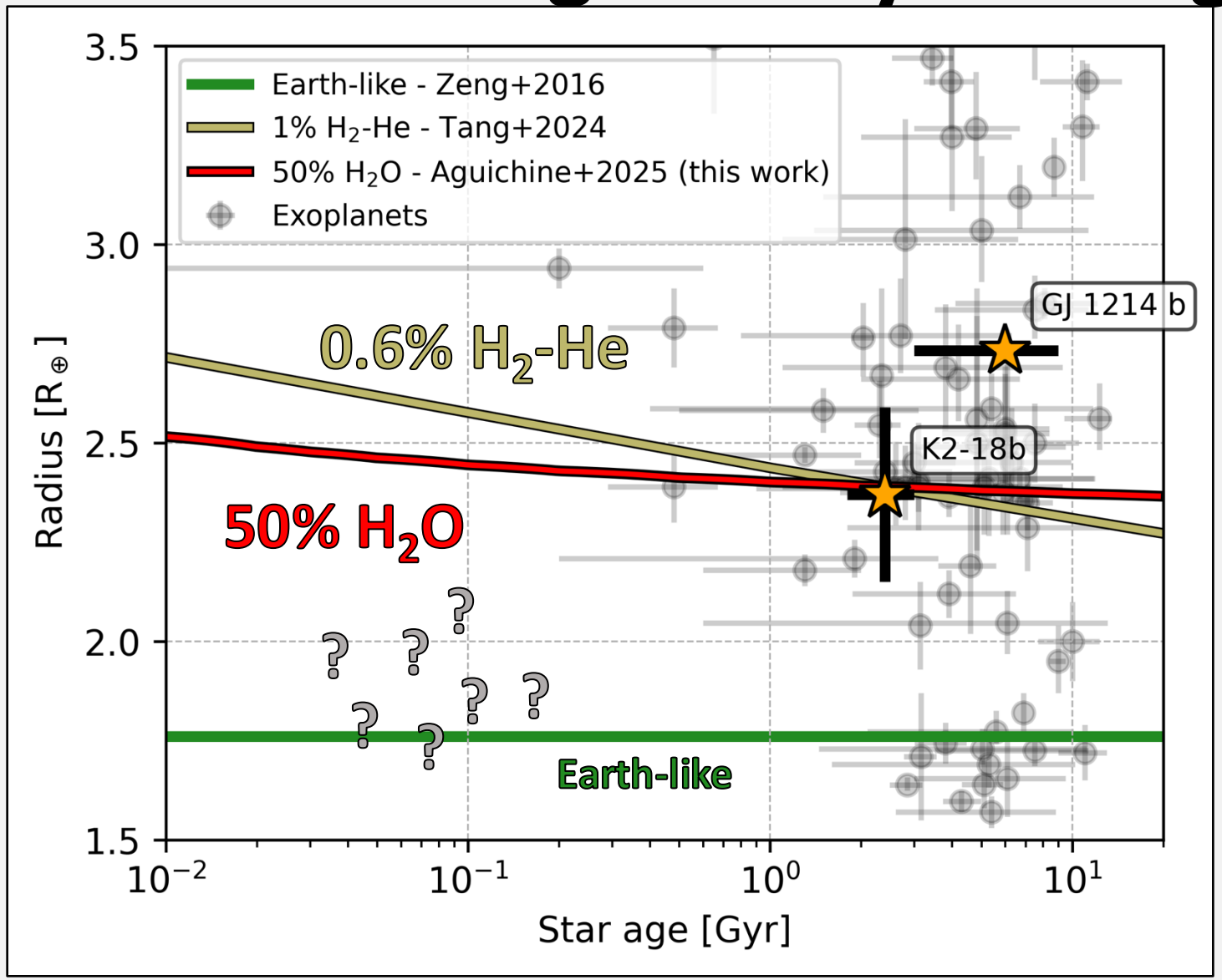


Break the degeneracy with age

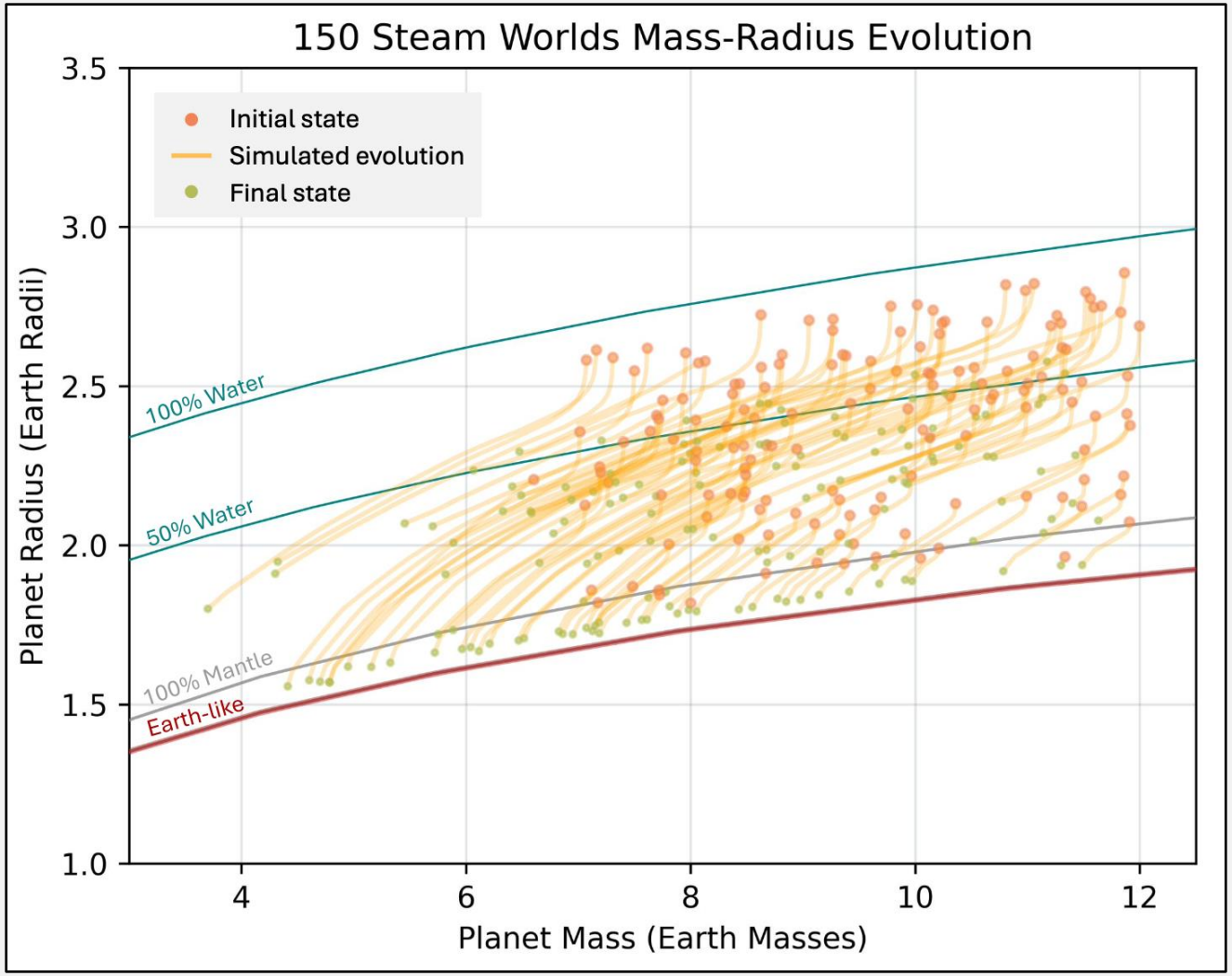


Better radius and age measurements with **PLATO**:

are sub-Neptunes H_2-He or H_2O?

Aguichine & Owen 2025 (in prep)
See also Rogers 2025

Atmospheric escape of Steam

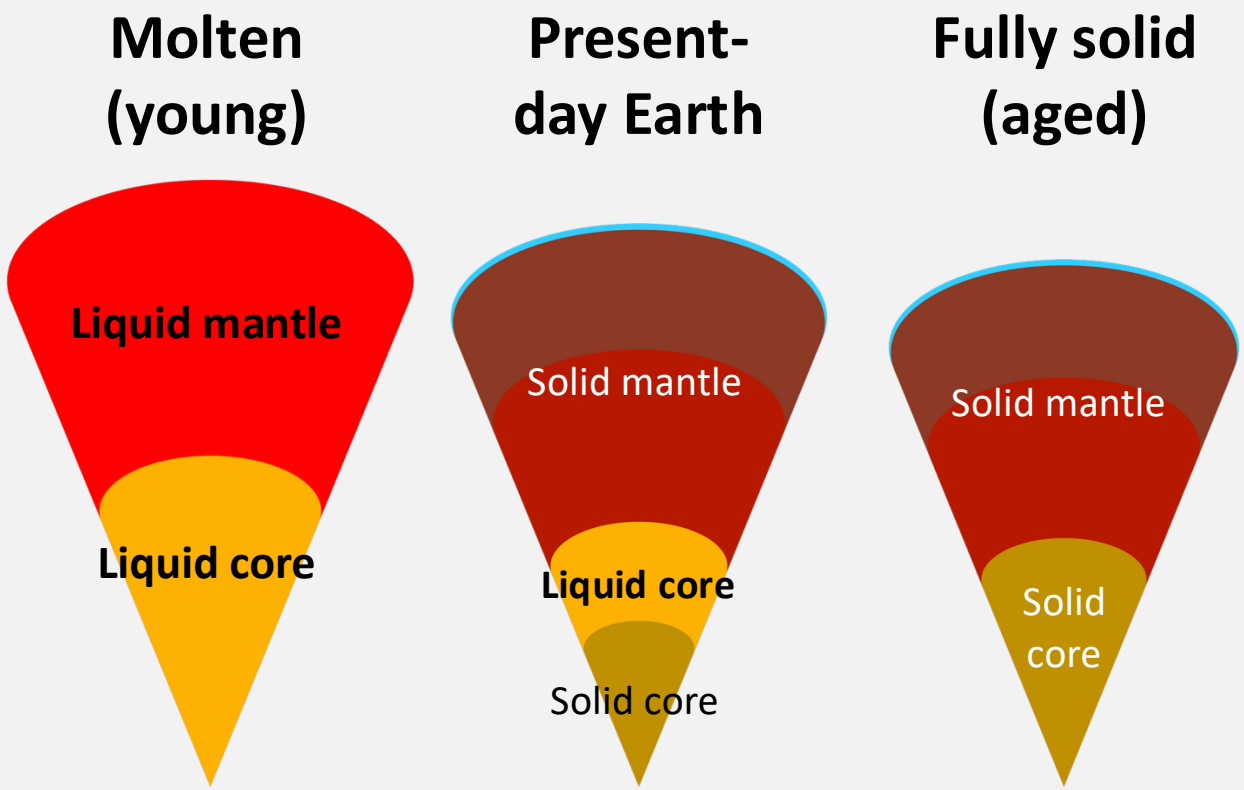


- Envelopes can be stripped by atmospheric escape
- Interior composition changes over time

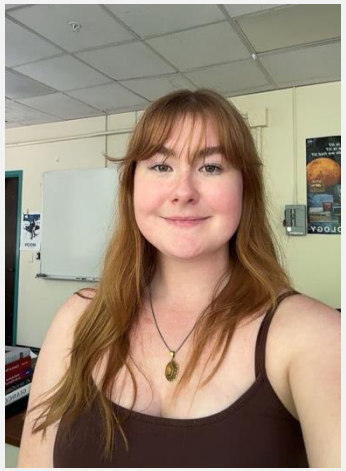
Emerson Tao
(undergraduate)

Tao, Aguichine+2025
"Planets on the Edge" conference
Santa Barbara, CA, USA
May 6-9, 2025

Rocky planets' age matters too



- Rocky planets could be molten inside: change in radius
- Updated equations of state (EOS) for iron (Hakim+2018) and mantle (Caracas+2024)



Lily Larkins (undergraduate)

Aguichine+2025 (in prep), Larkins+2026 (in prep)

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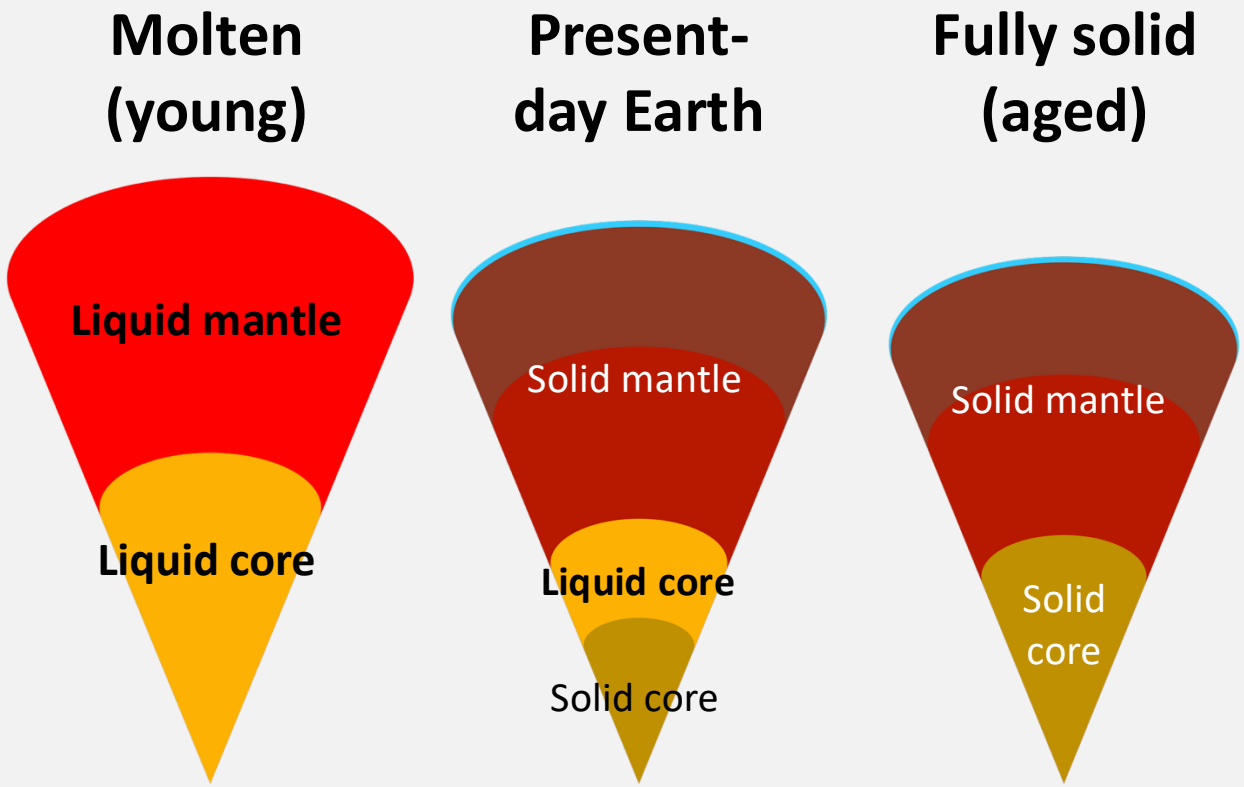

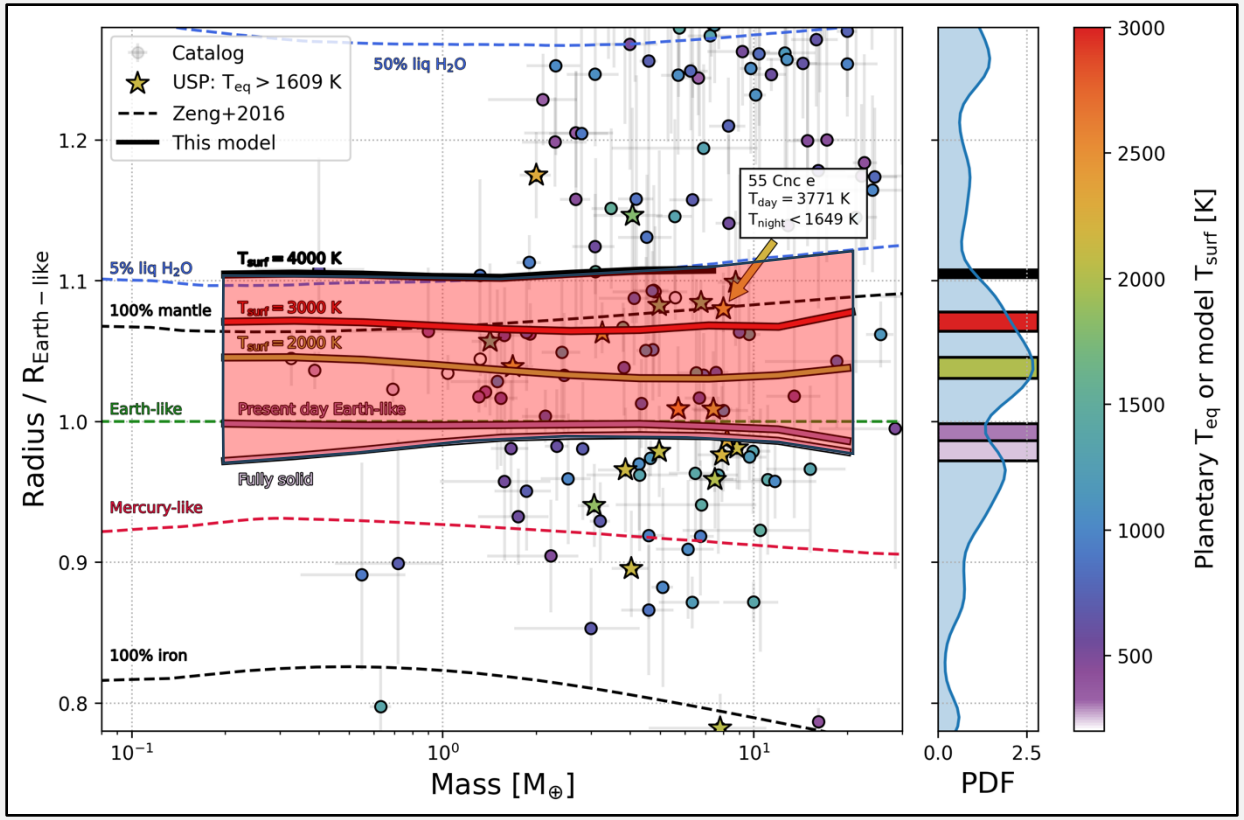

- See our poster ☺

Aguichine+2025 (in prep), Larkins+2026 (in prep)

Summary

- **Evolution (stellar age) can distinguish between steam worlds and gas dwarfs**
  - ➢ Time is key!
- **Modeling is exciting (but hard):**
  - ➢ Need more experiments (opacity, EOS)
  - ➢ Other phenomenons (mixing, chemistry, etc.) (Kite+2020, Dorn+2021,Vazan+2022)
  - ➢ Next step: H_2O + H_2-He
- **MARDIGRAS (visualisation tool):**
  - ➢ For observers: interpret exoplanet composition, use grids with MCMC
  - ➢ For experts: compare models
  - ➢ For educators: teaching tool

MARDIGRAS, Aguichine+2024