Water oceans on dense exoplanets from outgassing and interior-atmosphere feedback processes

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exoplanet diversity
SPP 1992

The search for habitable planets

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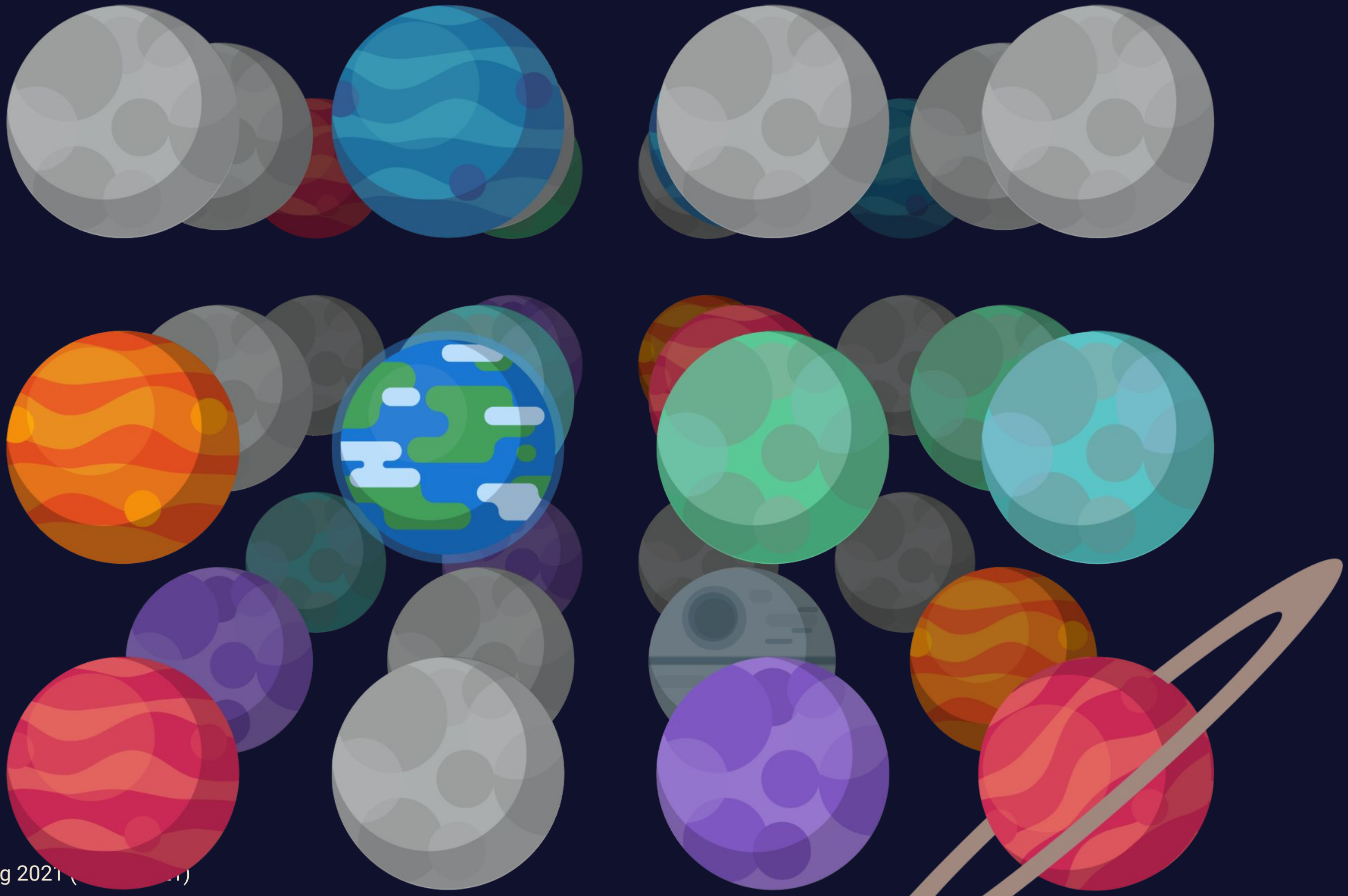
Direct detection of an ocean is extremely challenging

Atmosphere measurements can only give indirect evidence

Which planets *can* have oceans?



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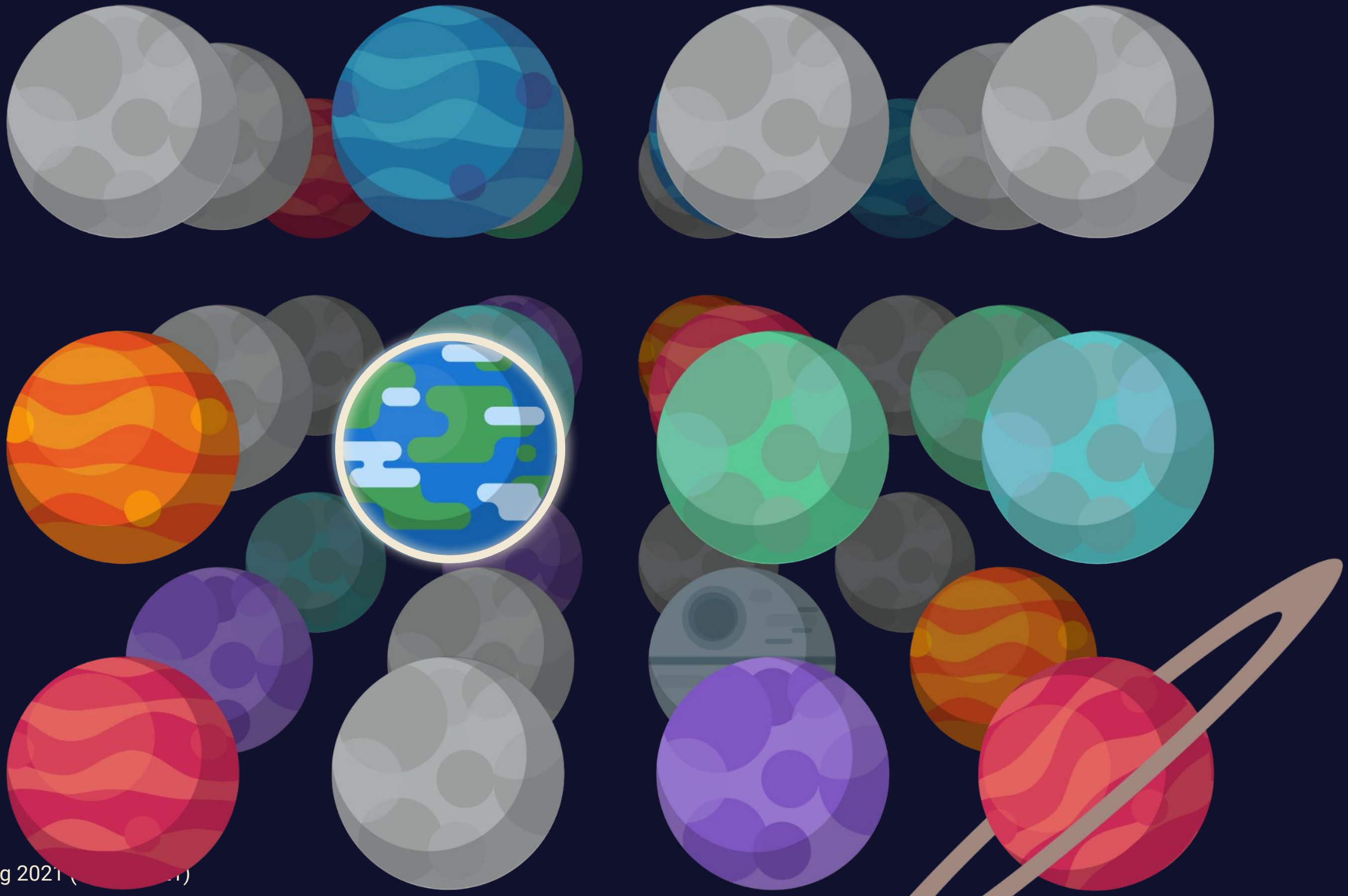
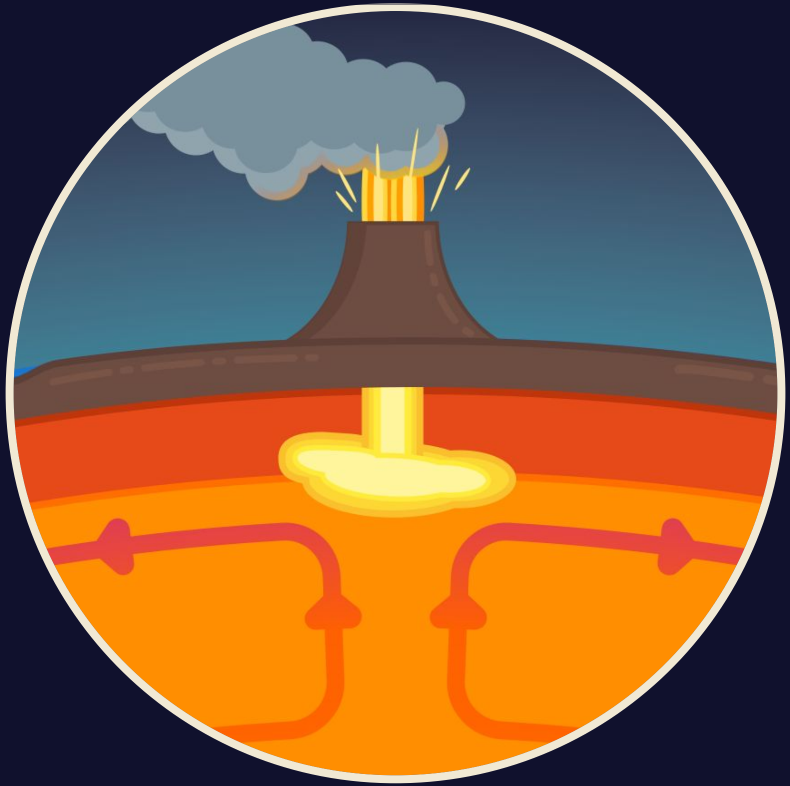


The planet interior is a major source of water



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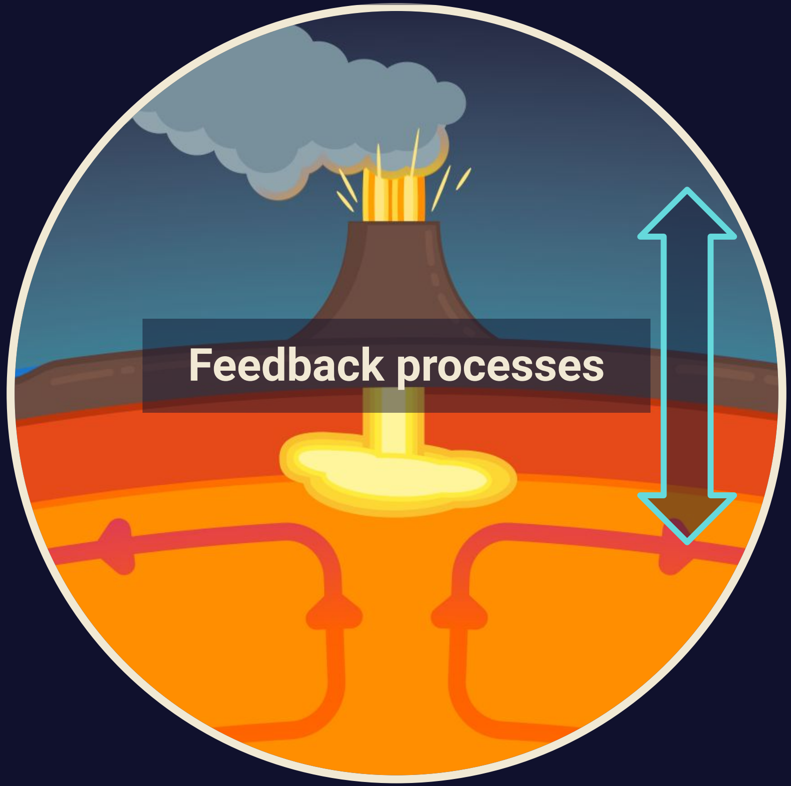
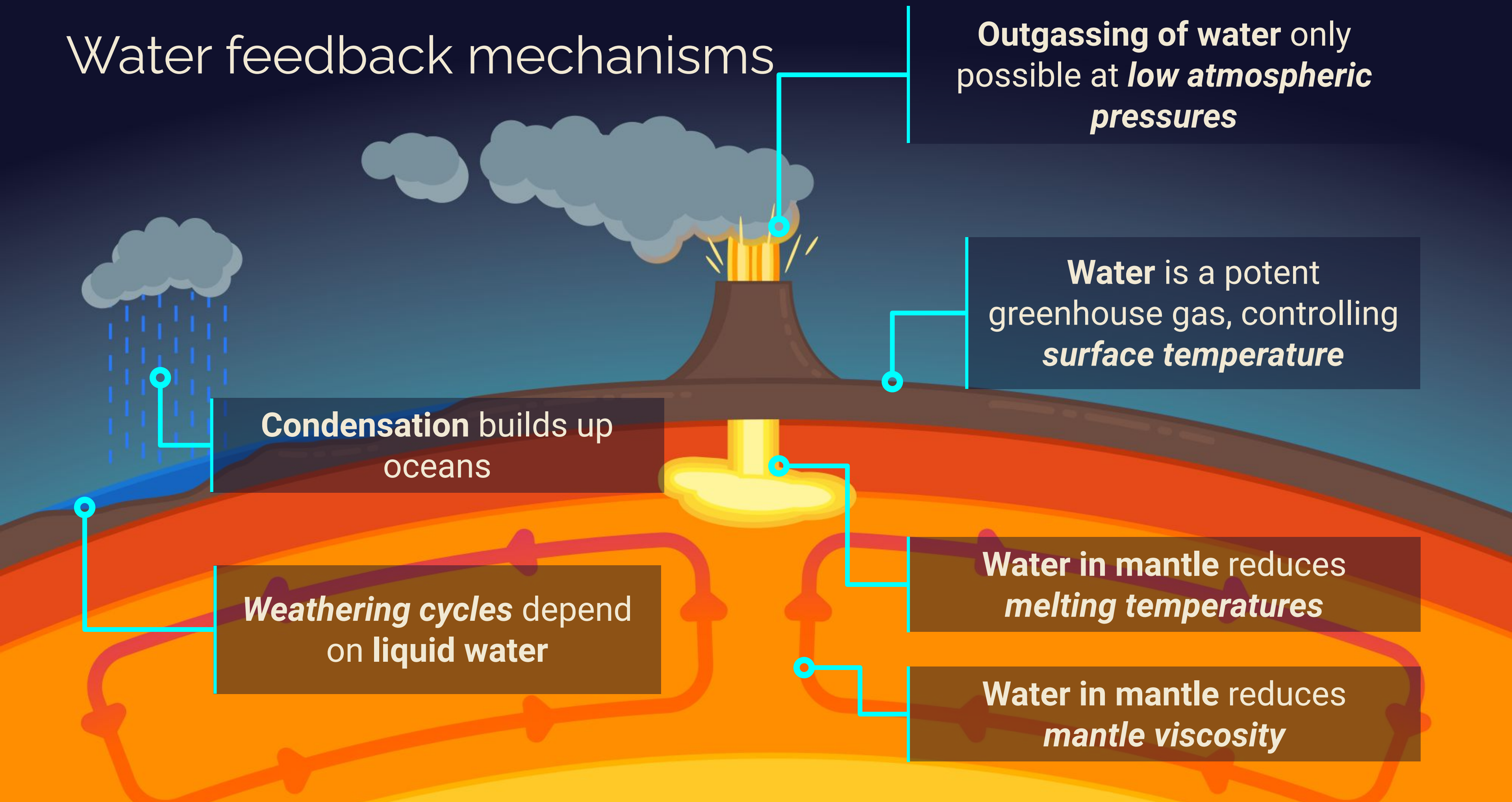
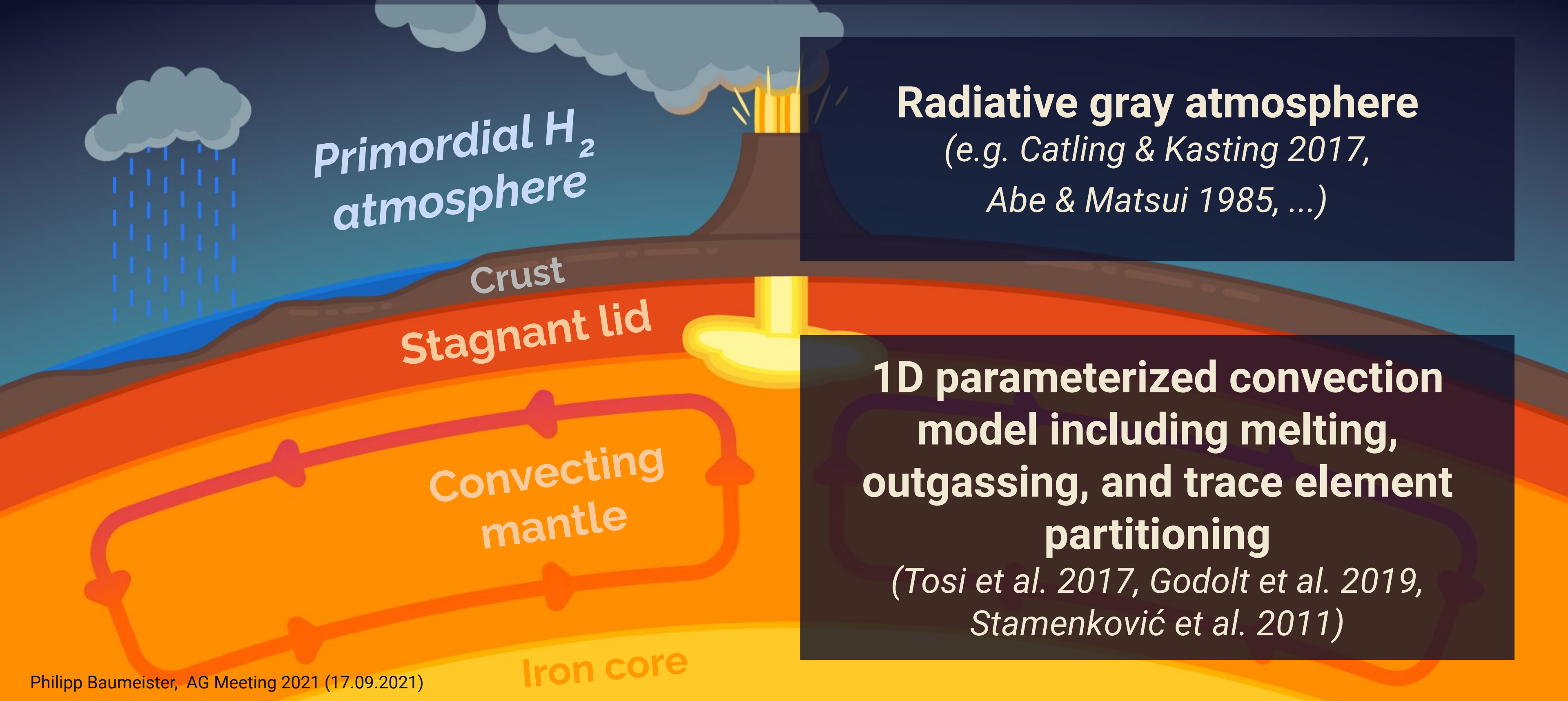


Water feedback mechanisms



Our modeling approach:

Run > 30.000 planet evolutions for varying initial conditions



Radiative gray atmosphere

(e.g. Catling & Kasting 2017, Abe & Matsui 1985, ...)

1D parameterized convection model including melting, outgassing, and trace element partitioning

(Tosi et al. 2017, Godolt et al. 2019, Stamenković et al. 2011)

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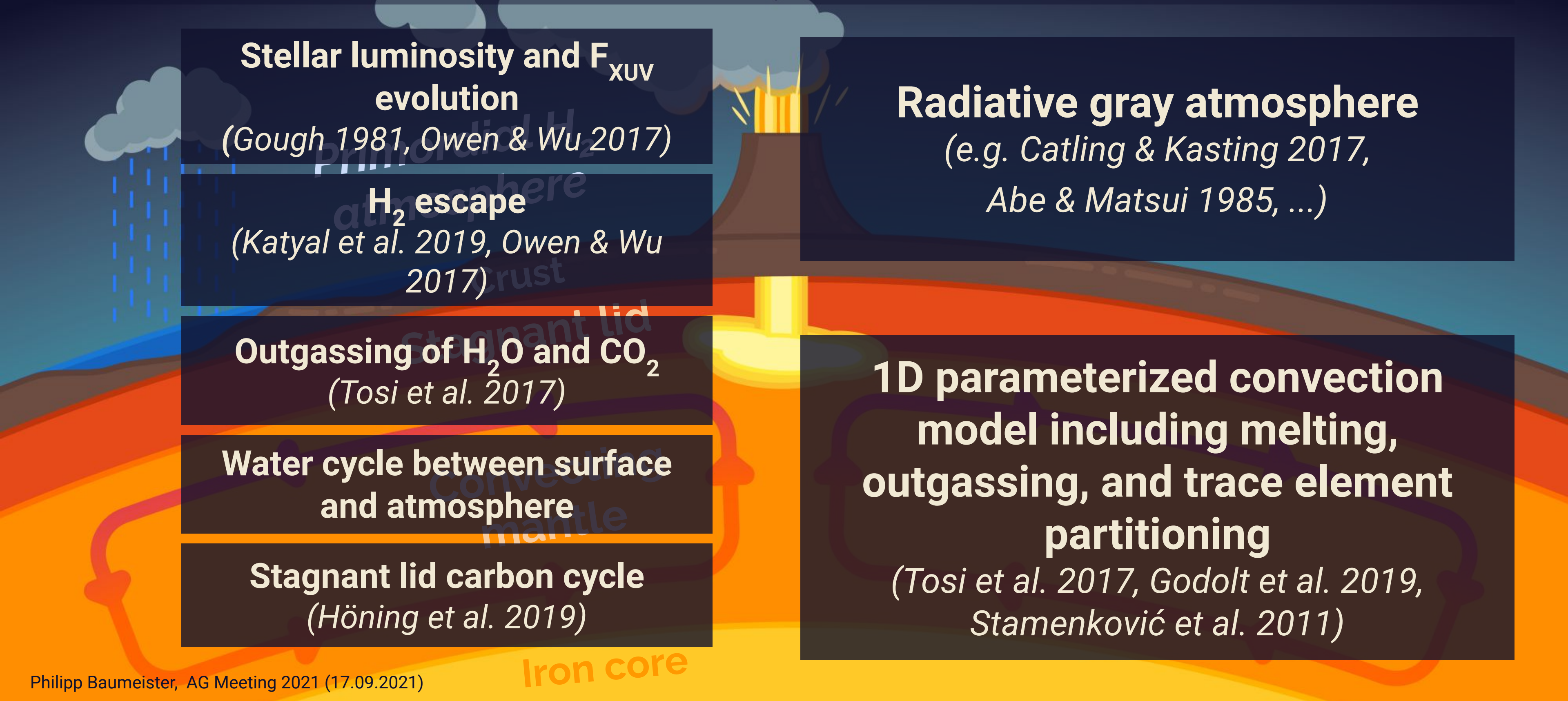

Stellar luminosity and F_{XUV} evolution
(Gough 1981, Owen & Wu 2017)

H_2 escape
(Katyal et al. 2019, Owen & Wu 2017)

Outgassing of H_2O and CO_2
(Tosi et al. 2017)

Water cycle between surface and atmosphere

Stagnant lid carbon cycle
(Höning et al. 2019)

Radiative gray atmosphere
(e.g. Catling & Kasting 2017, Abe & Matsui 1985, ...)

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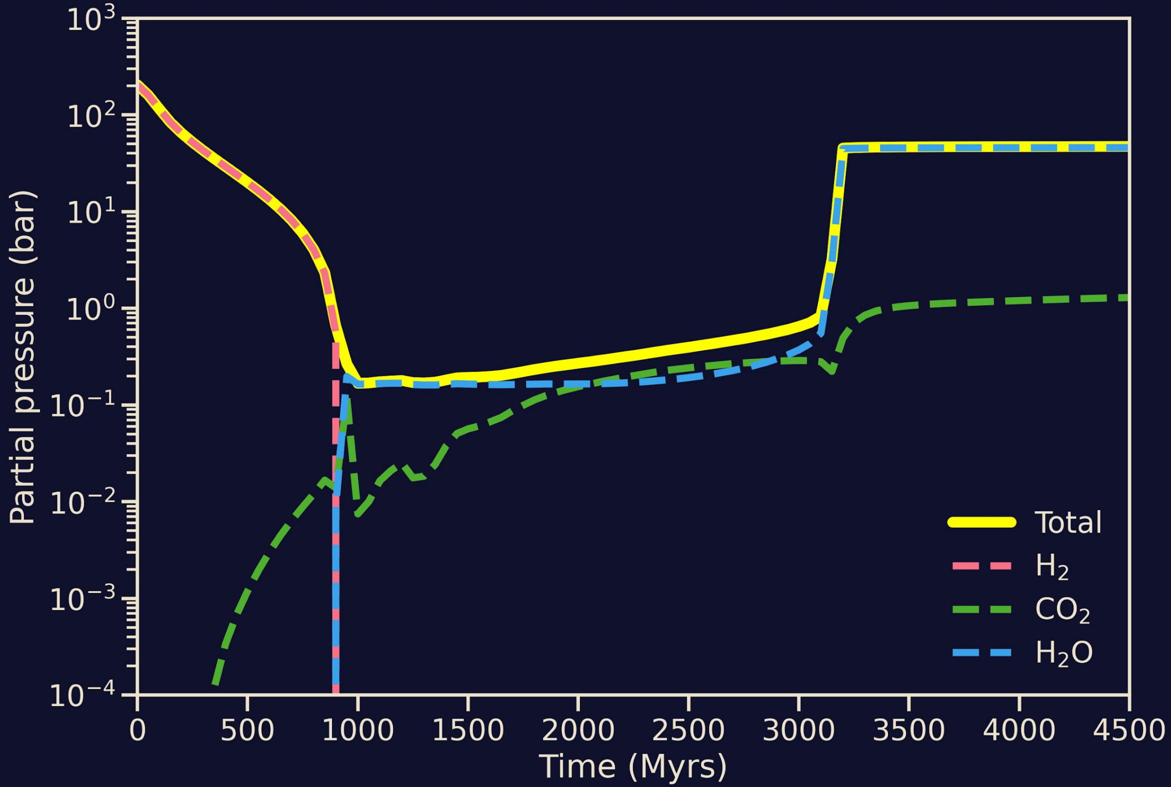
Characteristic outgassing evolution



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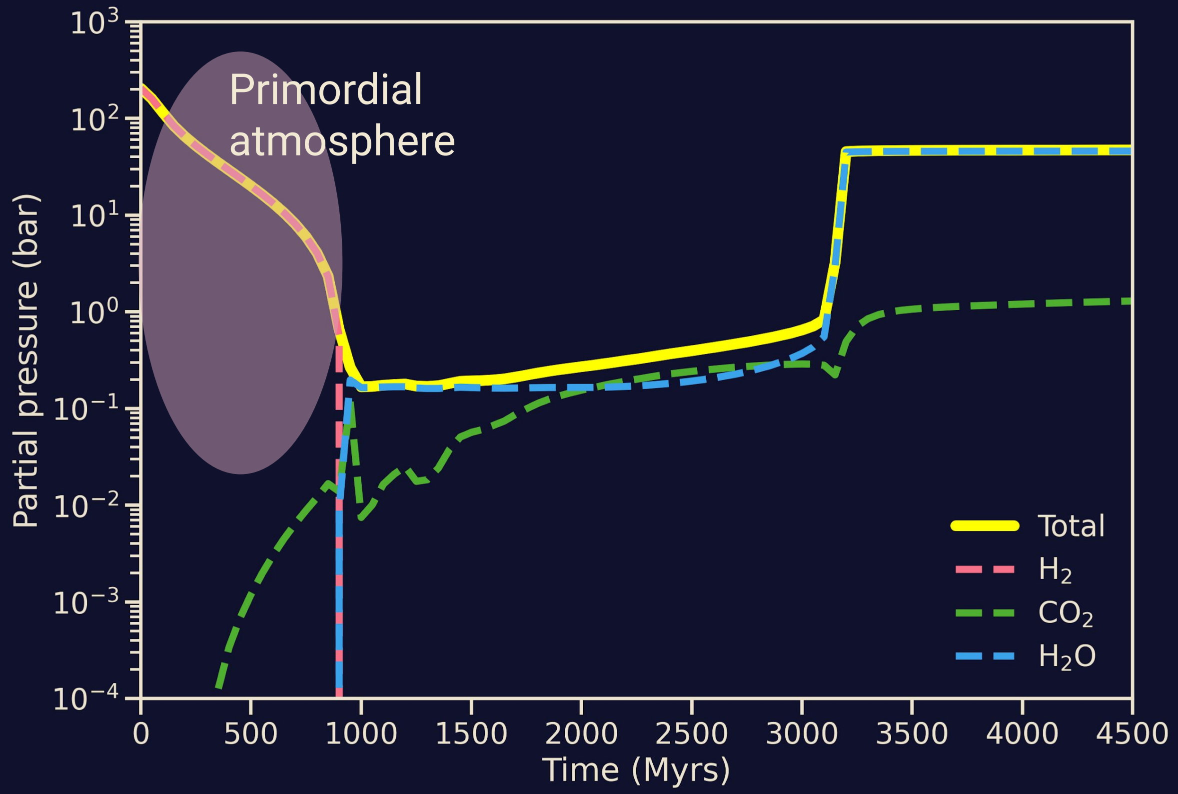

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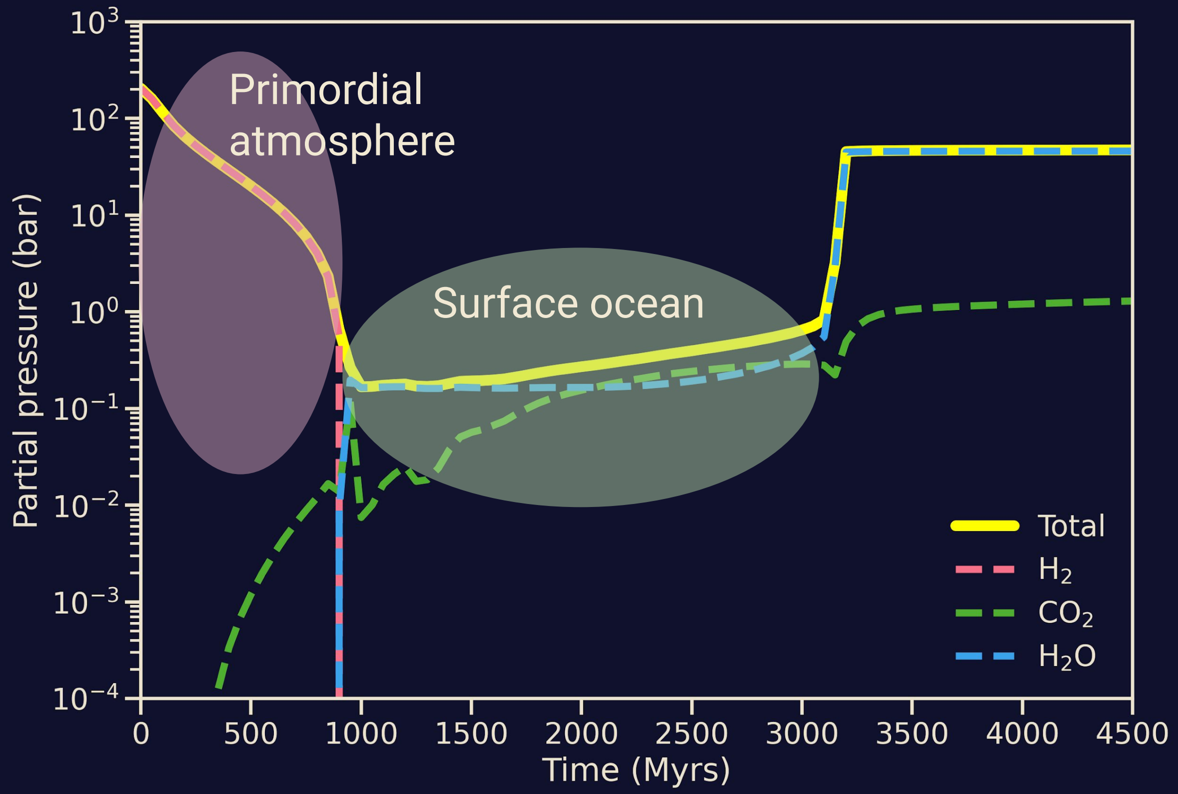

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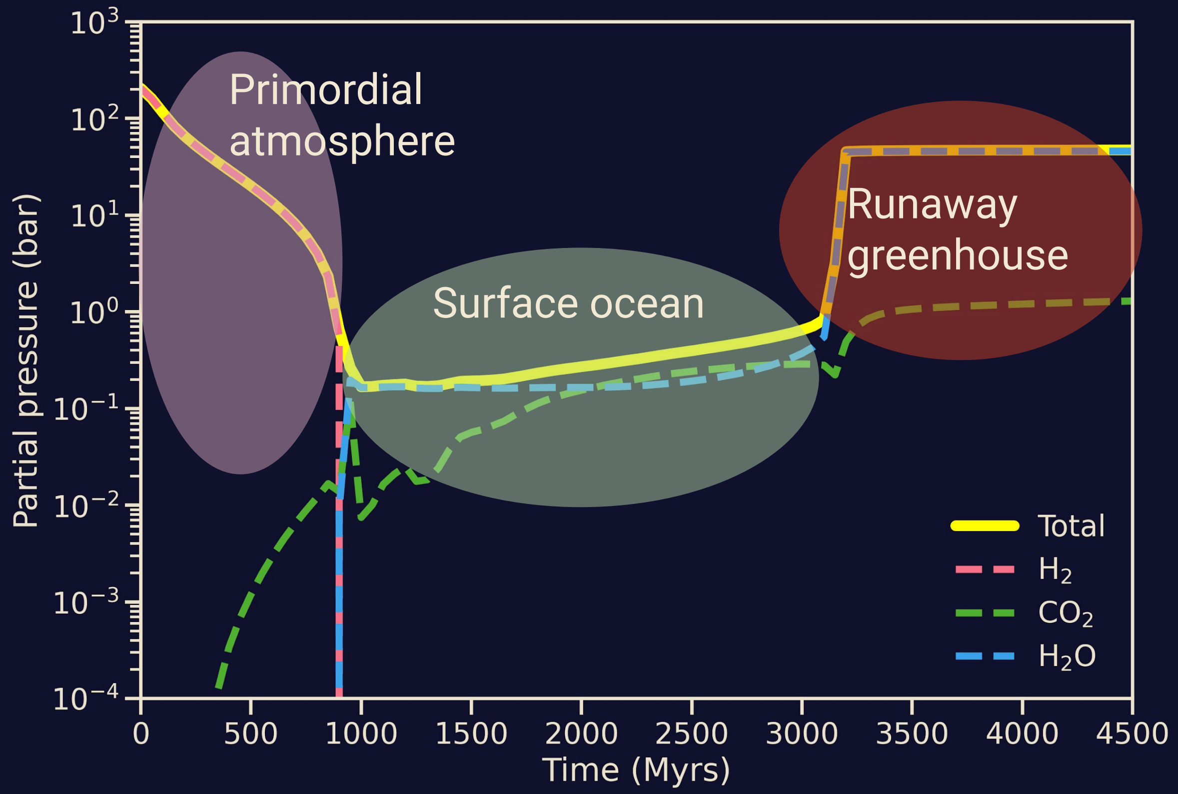
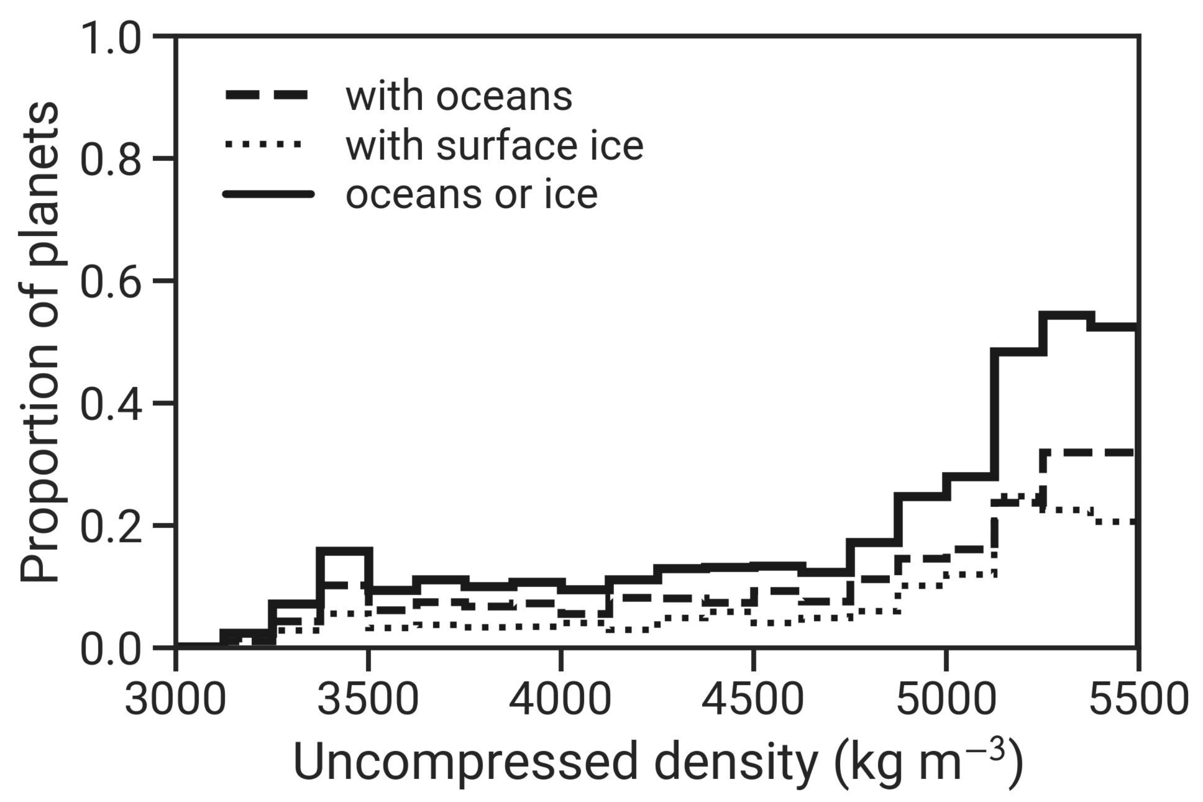


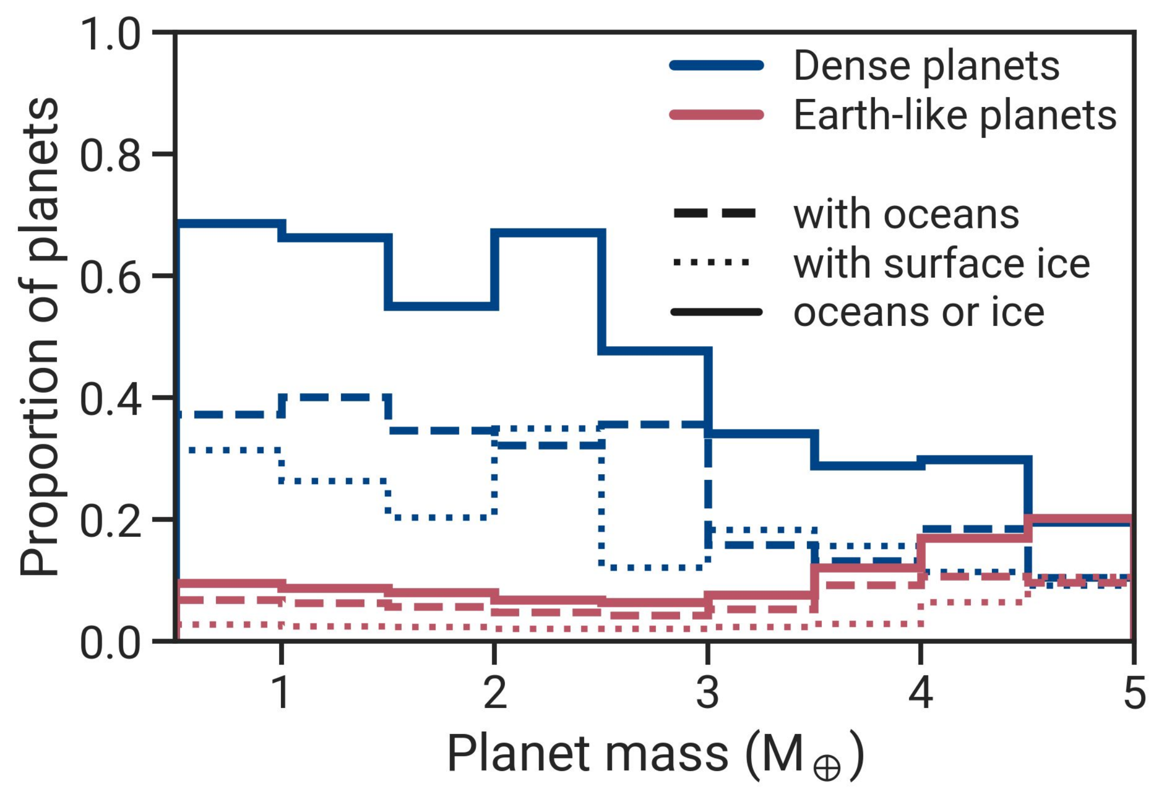
Most dense planets have oceans ...

Baumeister et al. 2021, under review.



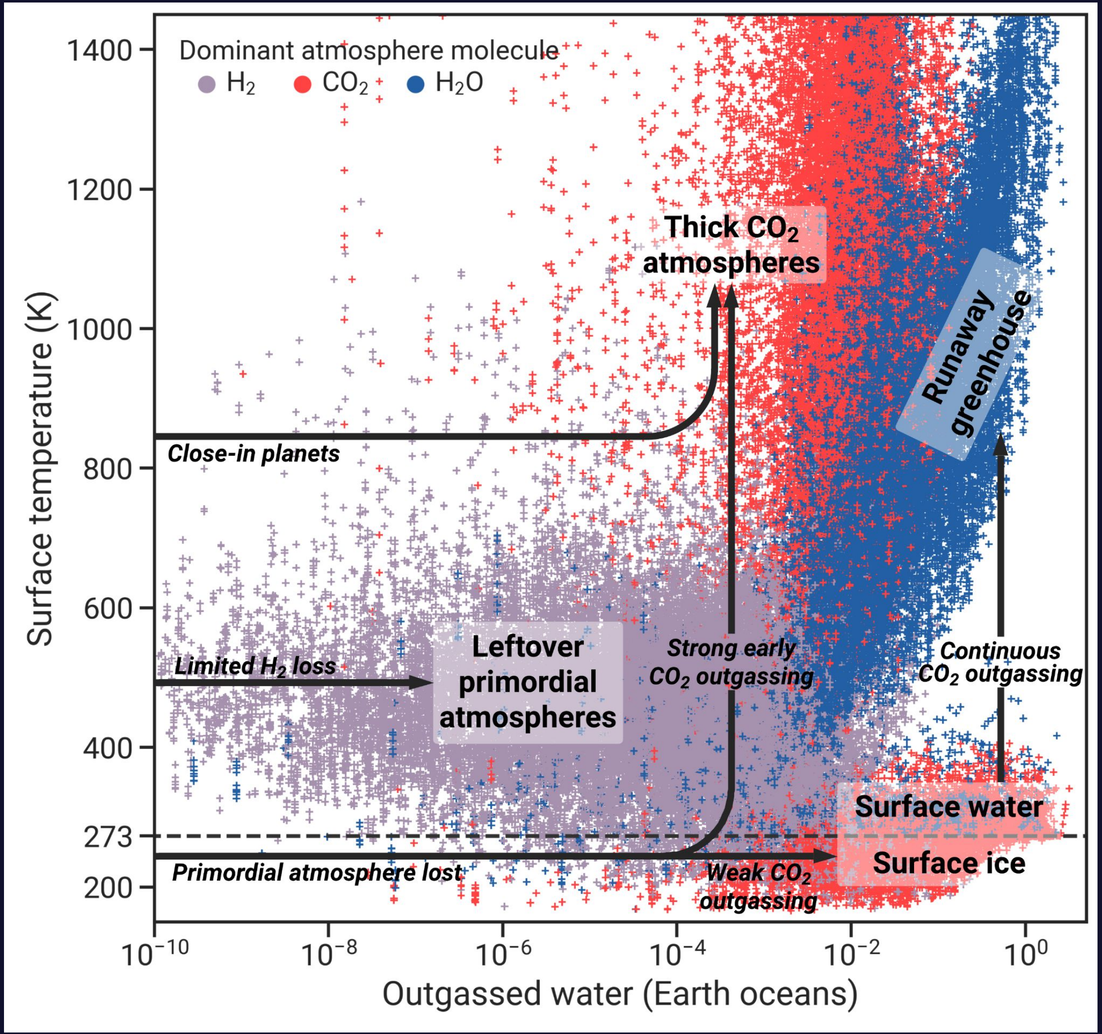
…especially at low masses

Baumeister et al. 2021, under review.



CO_2 outgassing rate determines ocean evolution

- Stagnant-lid planets lack efficient process for long-term CO_2 removal
- For water outgassing, surface pressure needs to be low
- For surface water, CO_2 outgassing needs to be low
- Otherwise: Runaway greenhouse



Baumeister et al. 2021,
under review.

- **Less volcanic activity due to large pressure gradients** *(see also e.g. Noack et al. 2017)*
- **Faster mantle cooling**
- **Water outgassing is favoured**

- **Long-lived, stronger volcanic activity**
- **CO_2 outgassing is favoured**

High-density planets planets may offer a better chance at detecting an ocean than Earth-like planets

Conclusions

- A majority of high-density planets have water oceans/surface water
- Rate of CO_2 outgassing drives the coupled interior-atmosphere evolution
- Water outgassing is favored on planets with large cores
- Planets with small cores tend to transition into a runaway greenhouse regime

Thank you for your attention!

High-density planets planets may offer a better chance at detecting an ocean than Earth-like planets