ATMOSPHERIC CARBON DEPLETION

as a

TRACER for HABITABILITY











https://doi.org/10.1038/s41550-023-02157-9

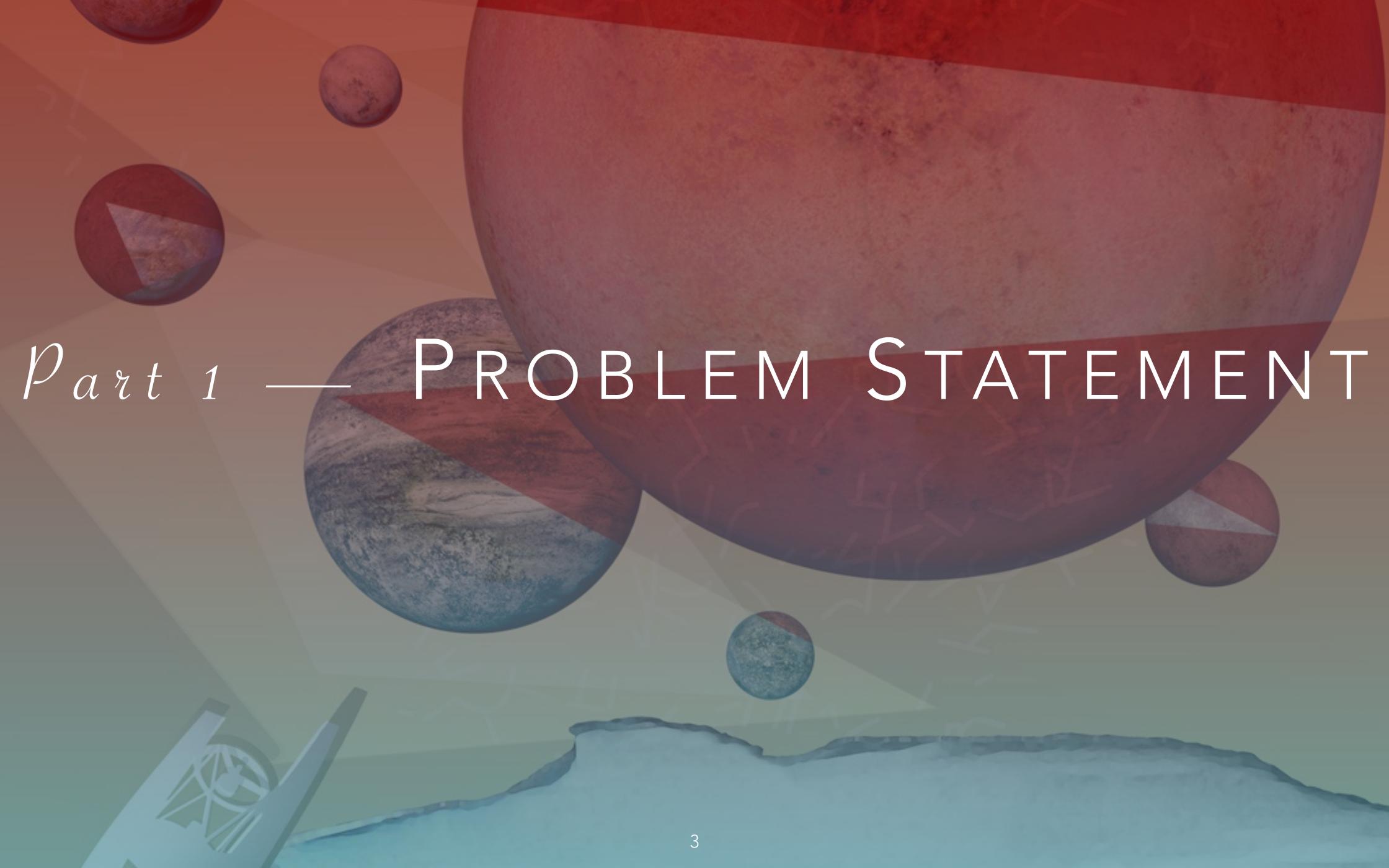
Atmospheric carbon depletion as a tracer of water oceans and biomass on temperate terrestrial exoplanets

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Accepted: 23 October 2023

Published online: 28 December 2023

Amaury H. M. J. Triaud (1) Julien de Wit (2) Frieder Klein, Frieder Klein, Martin Turbet, Benjamin V. Rackham, Prajwal Niraula, Ana Glidden, Oliver E. Jagoutz, Matej Peč (2), Janusz J. Petkowski (2), Sara Seager (2), Sara Seager (3), Franck Selsis (3)



There is a health body of academic research on bio-signatures definition, type, detectability, suitability to life, false positives...

this is both theoretical & empirical

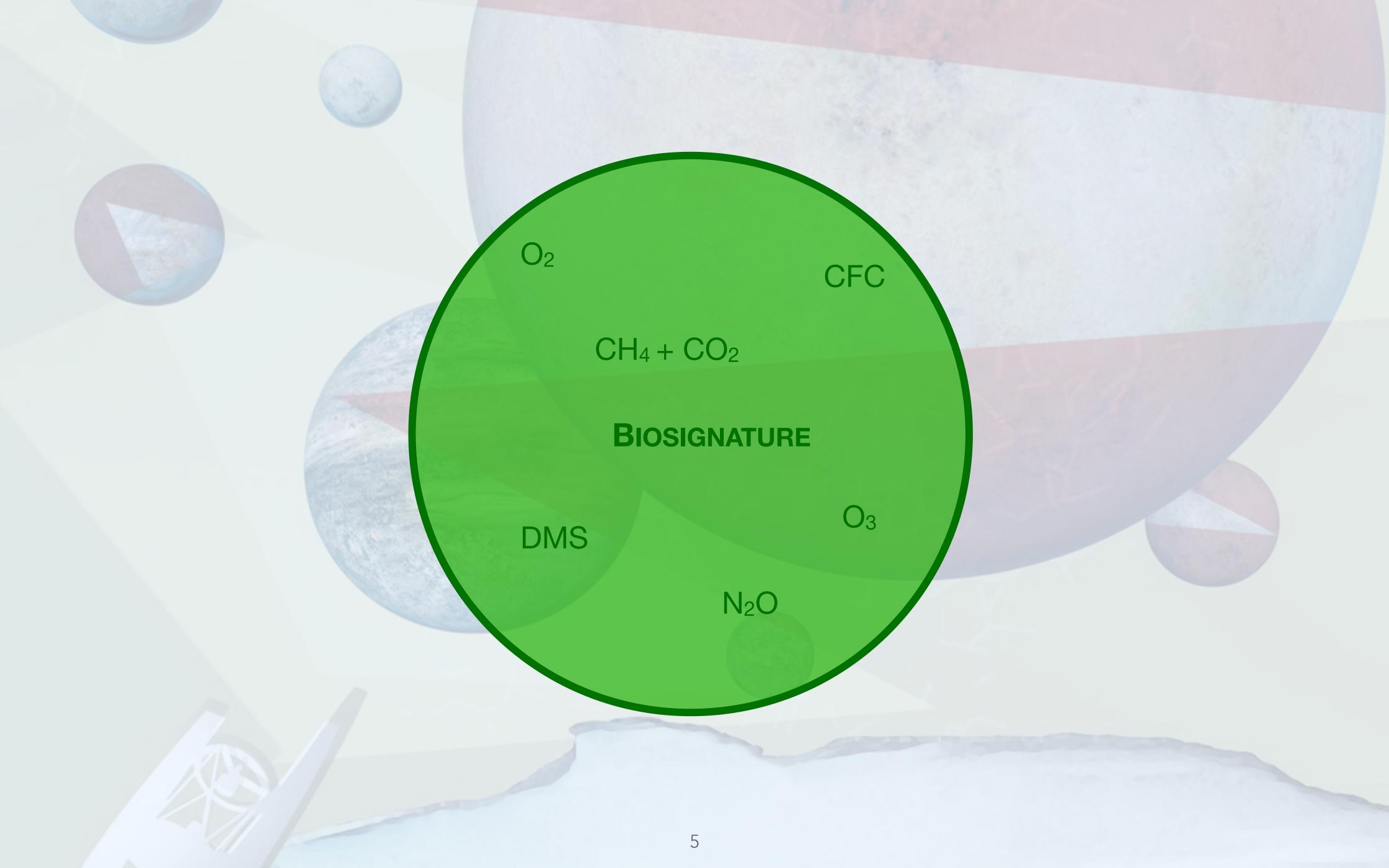
Habitability is a planet's property to host liquid water on its surface

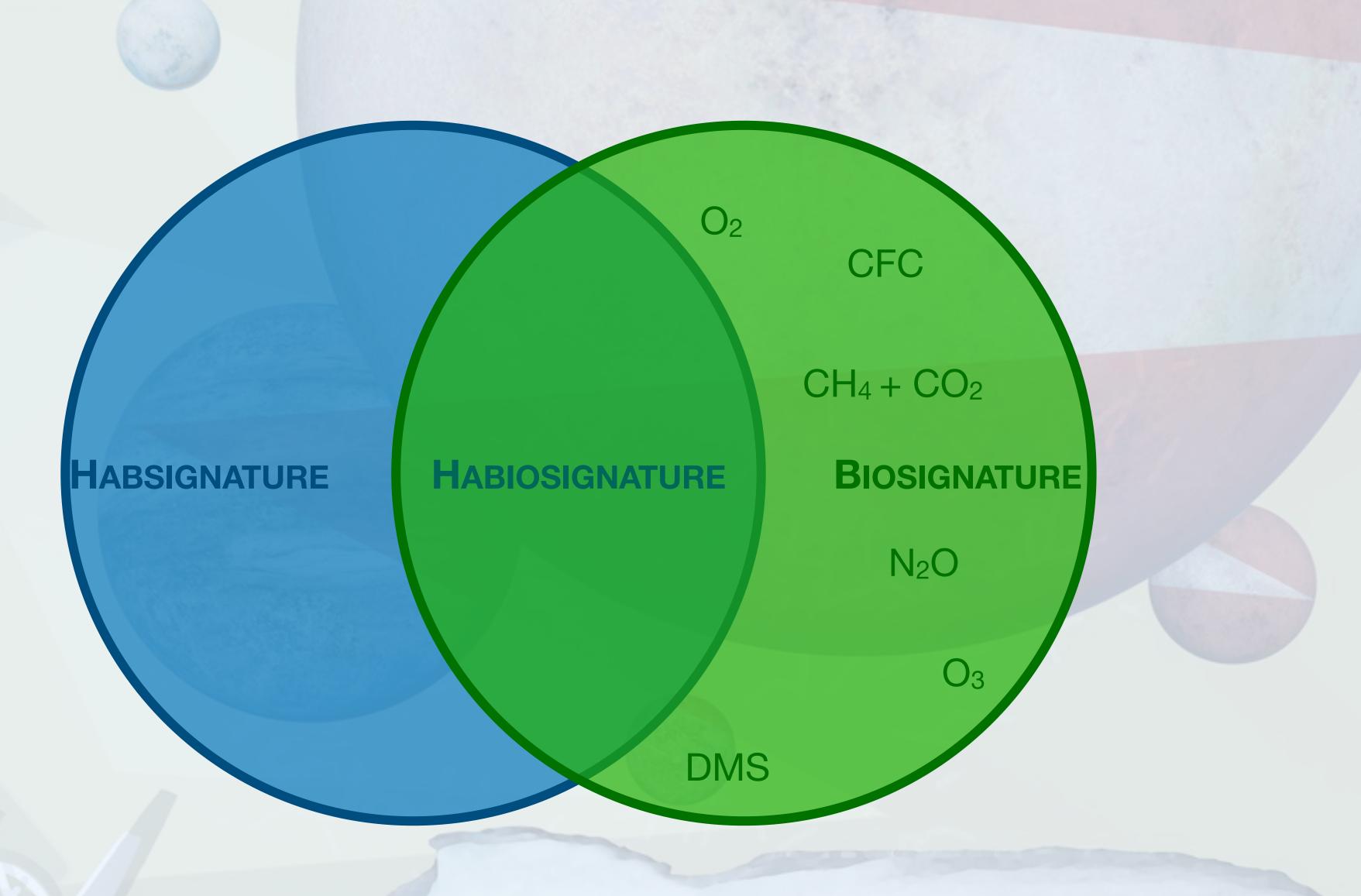
There is a healthy body of theoretical research on habitability definition, irradiation, bulk composition, tectonics, magnetic fields...

but

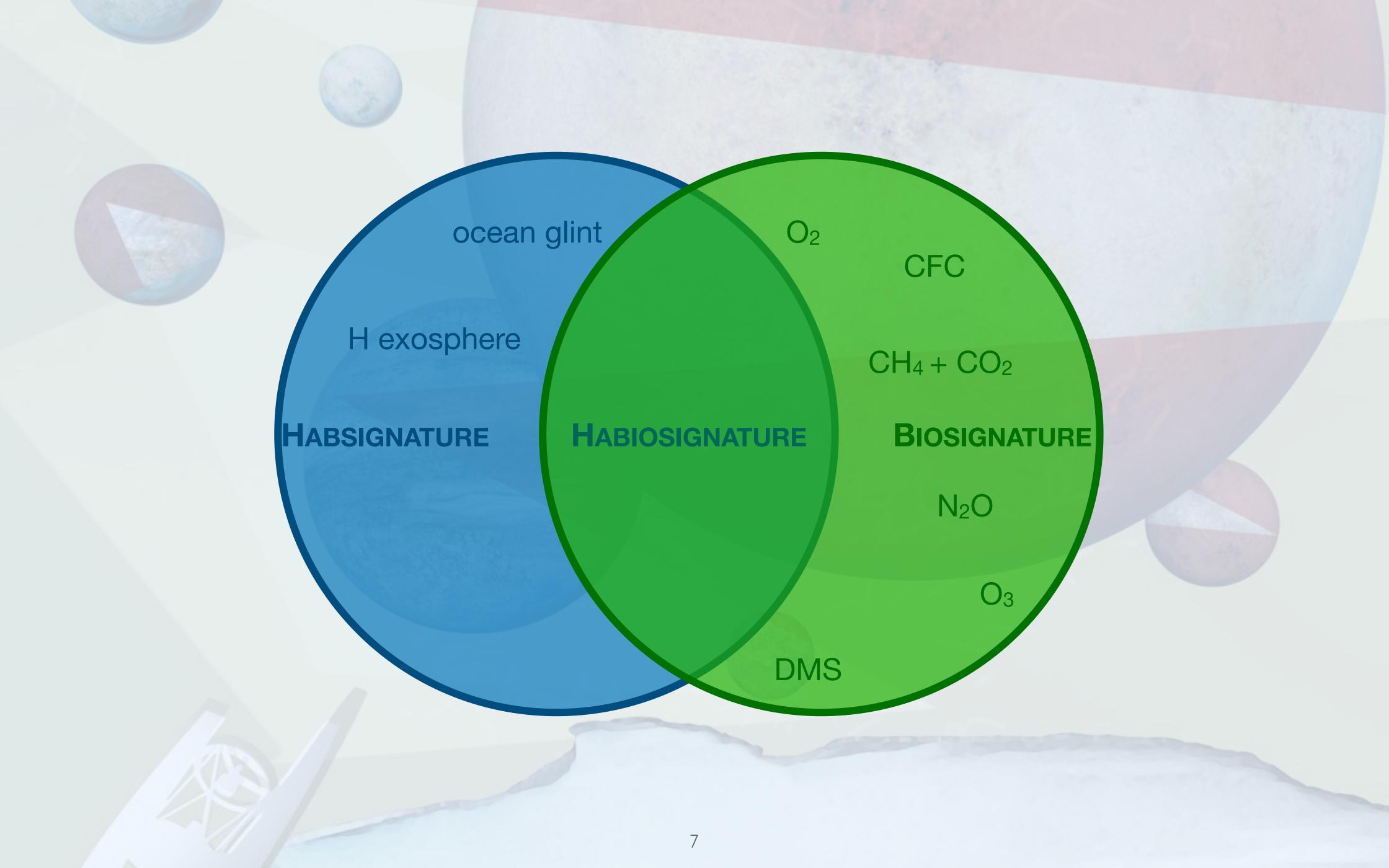
not many about empirical tracers

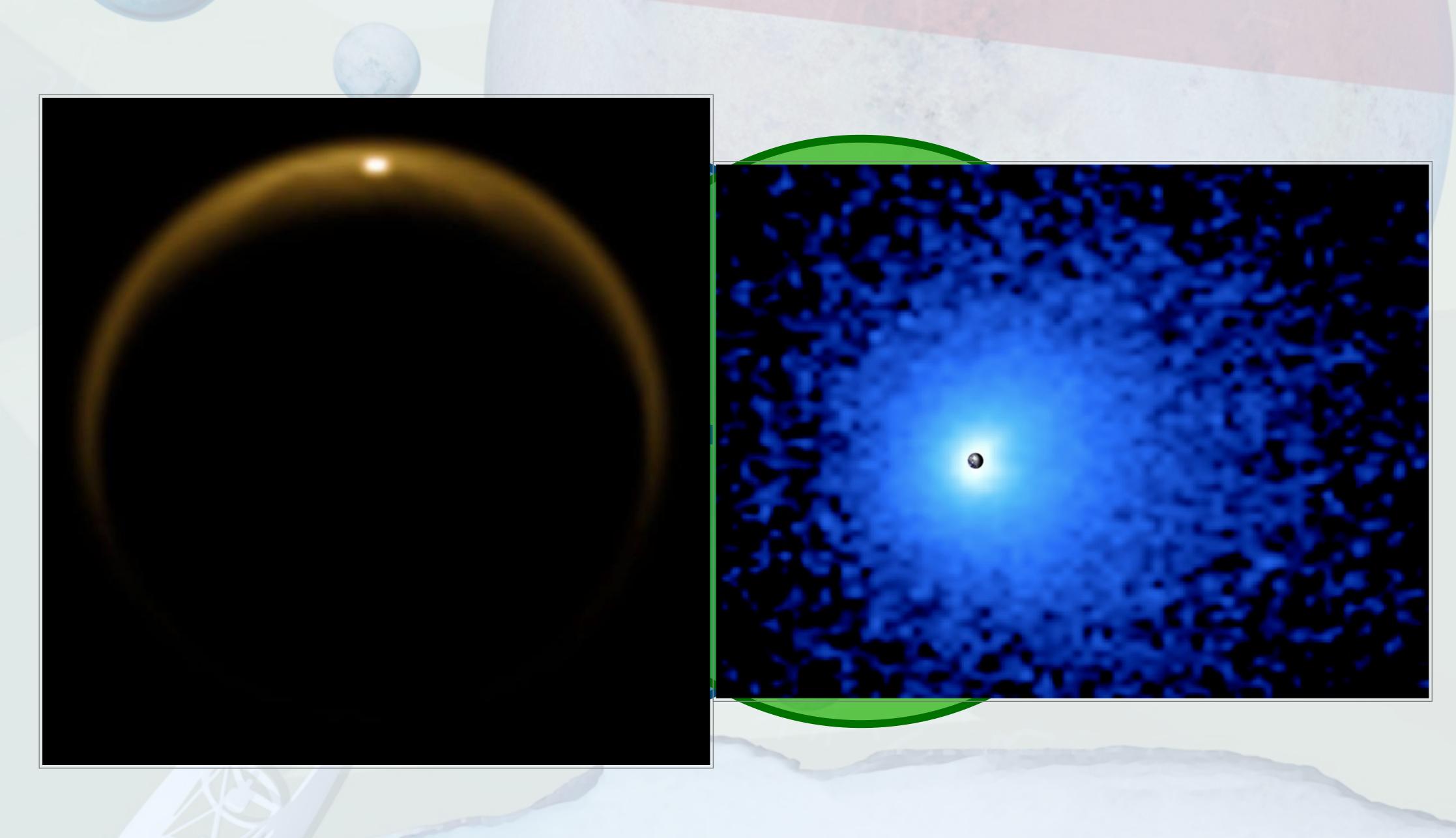


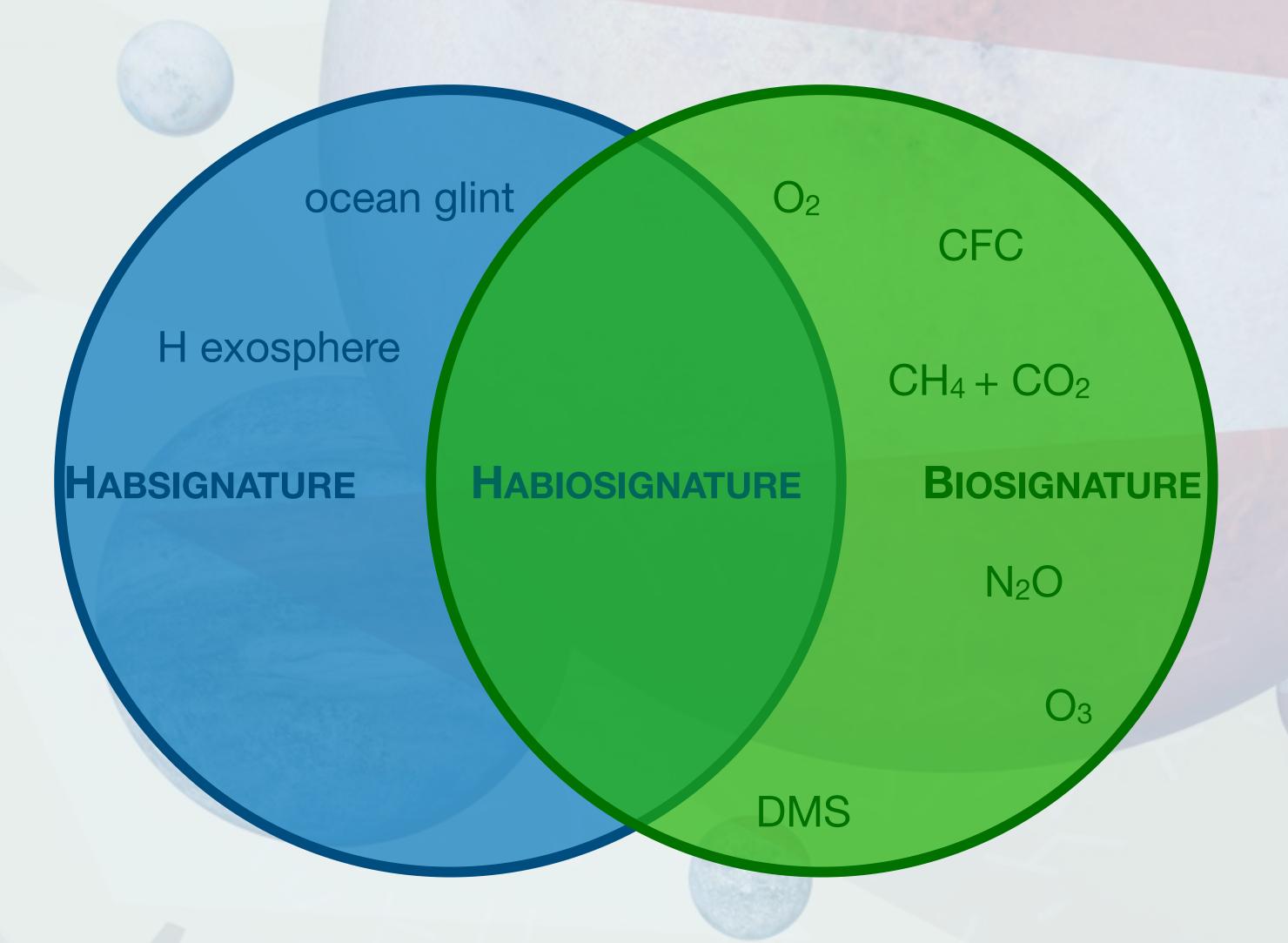




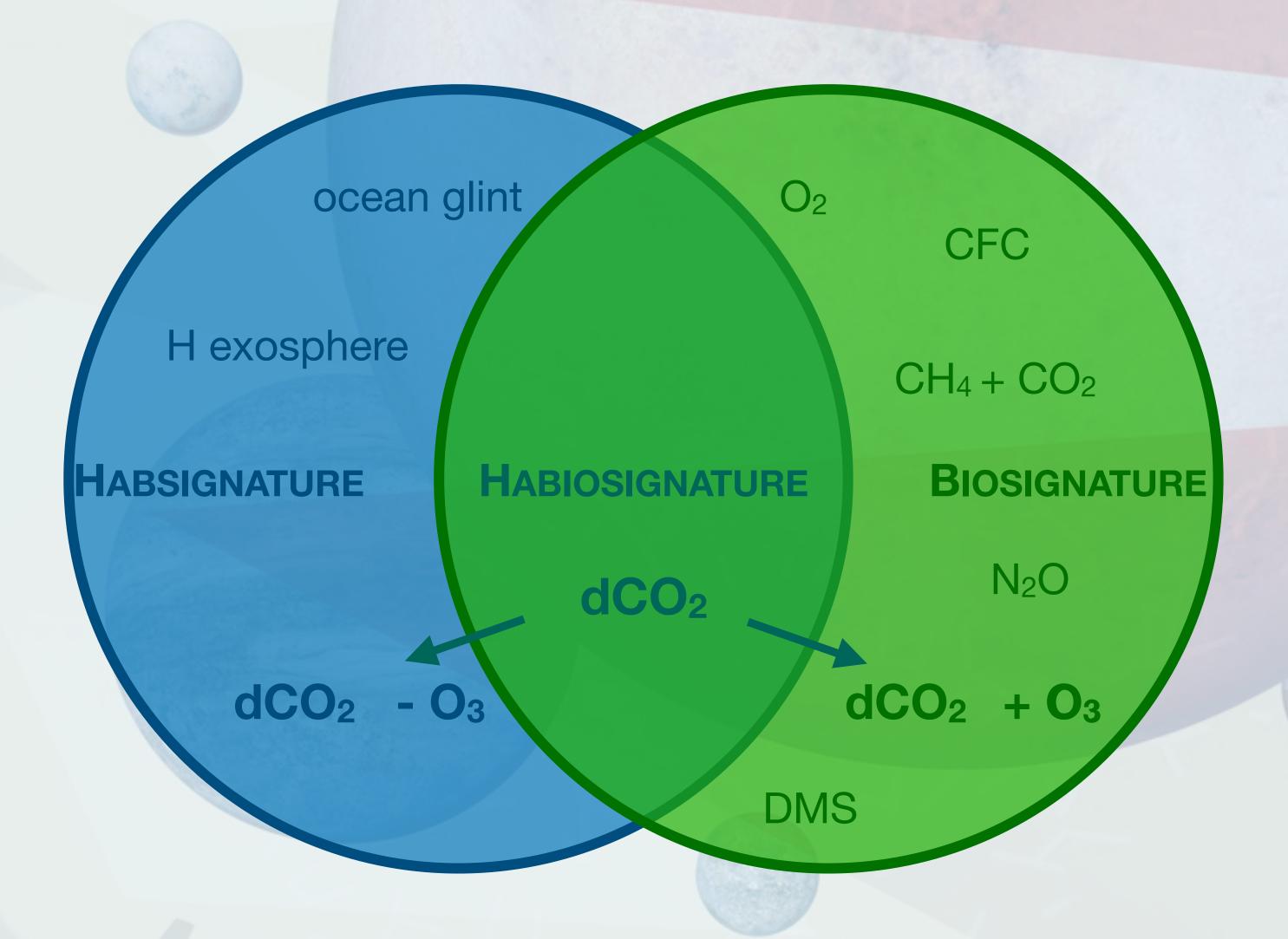
habsignature: an empirical tracer of surface liquid water





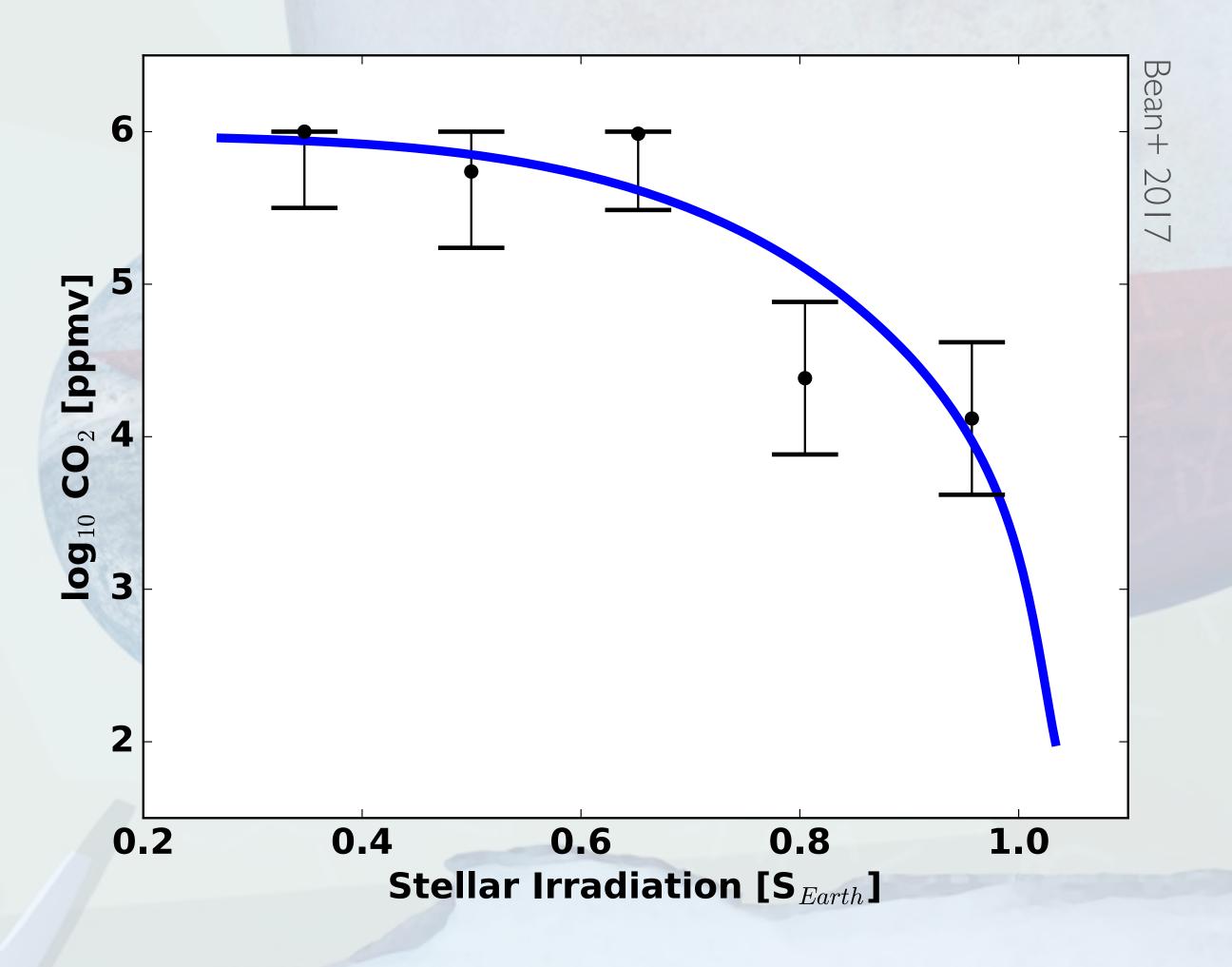


Anti-habsignature: SO₂ (Jordan, Rimmer+ 2021)
Other name? Aquasignature?

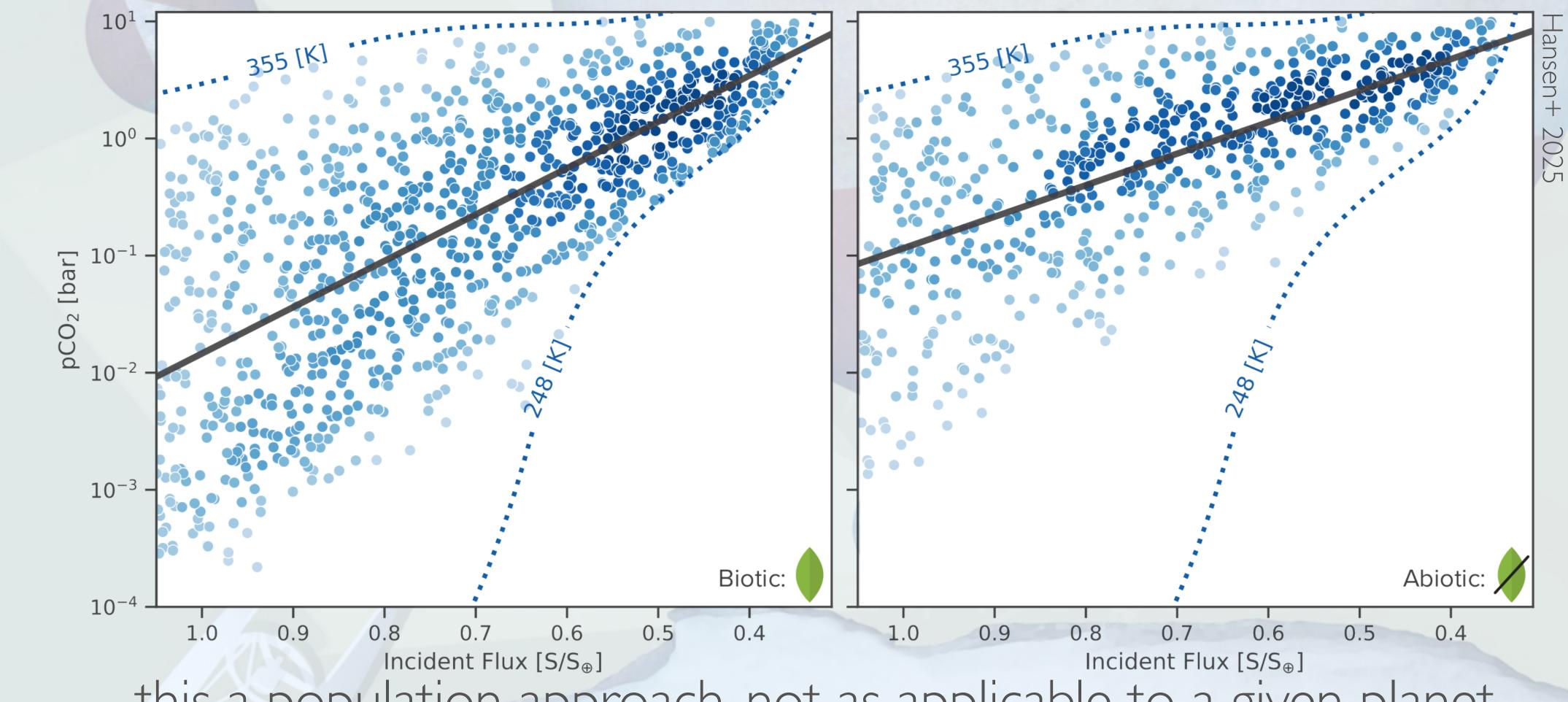


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Using the carbon-silicate cycle to study habitability is not new

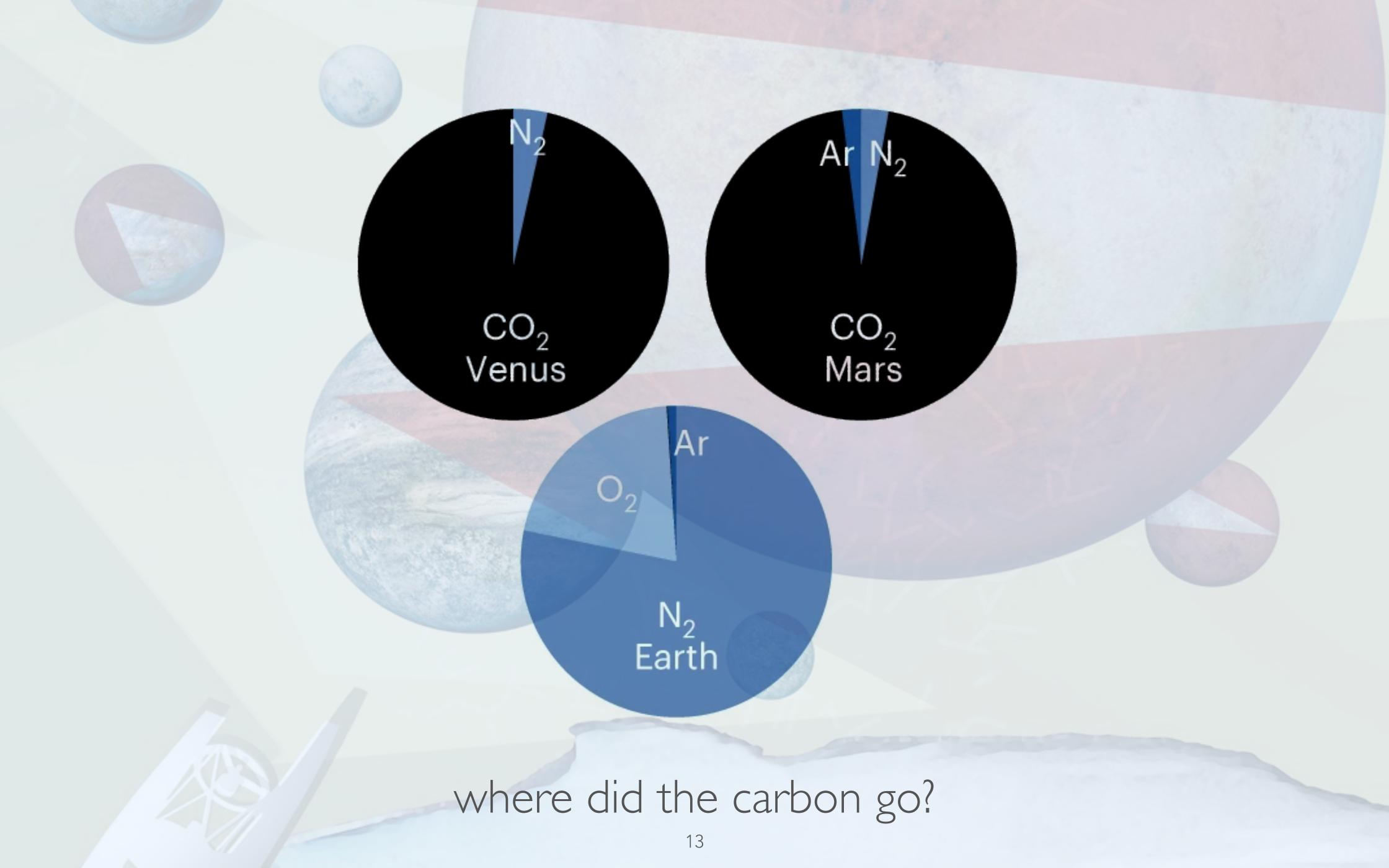


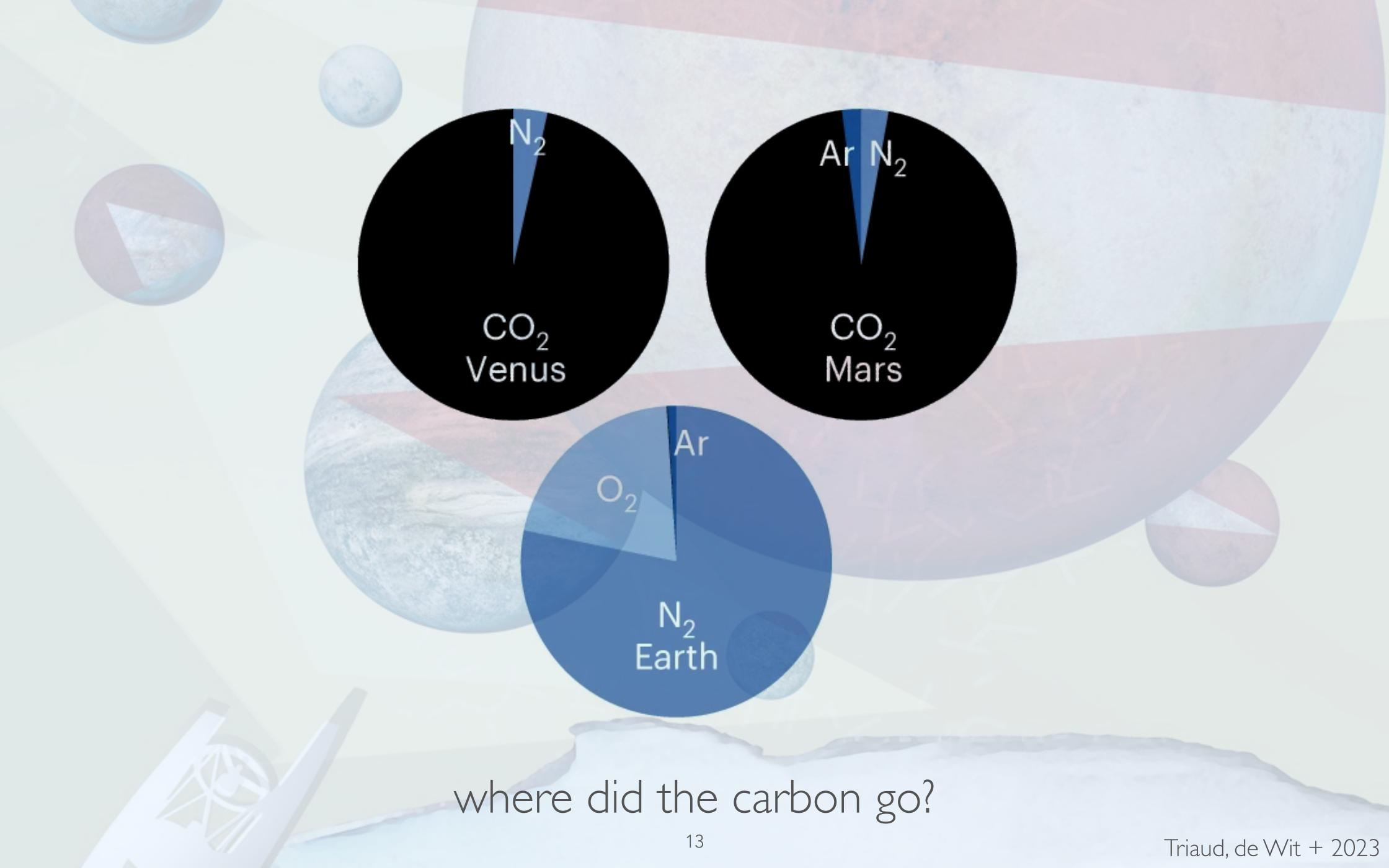
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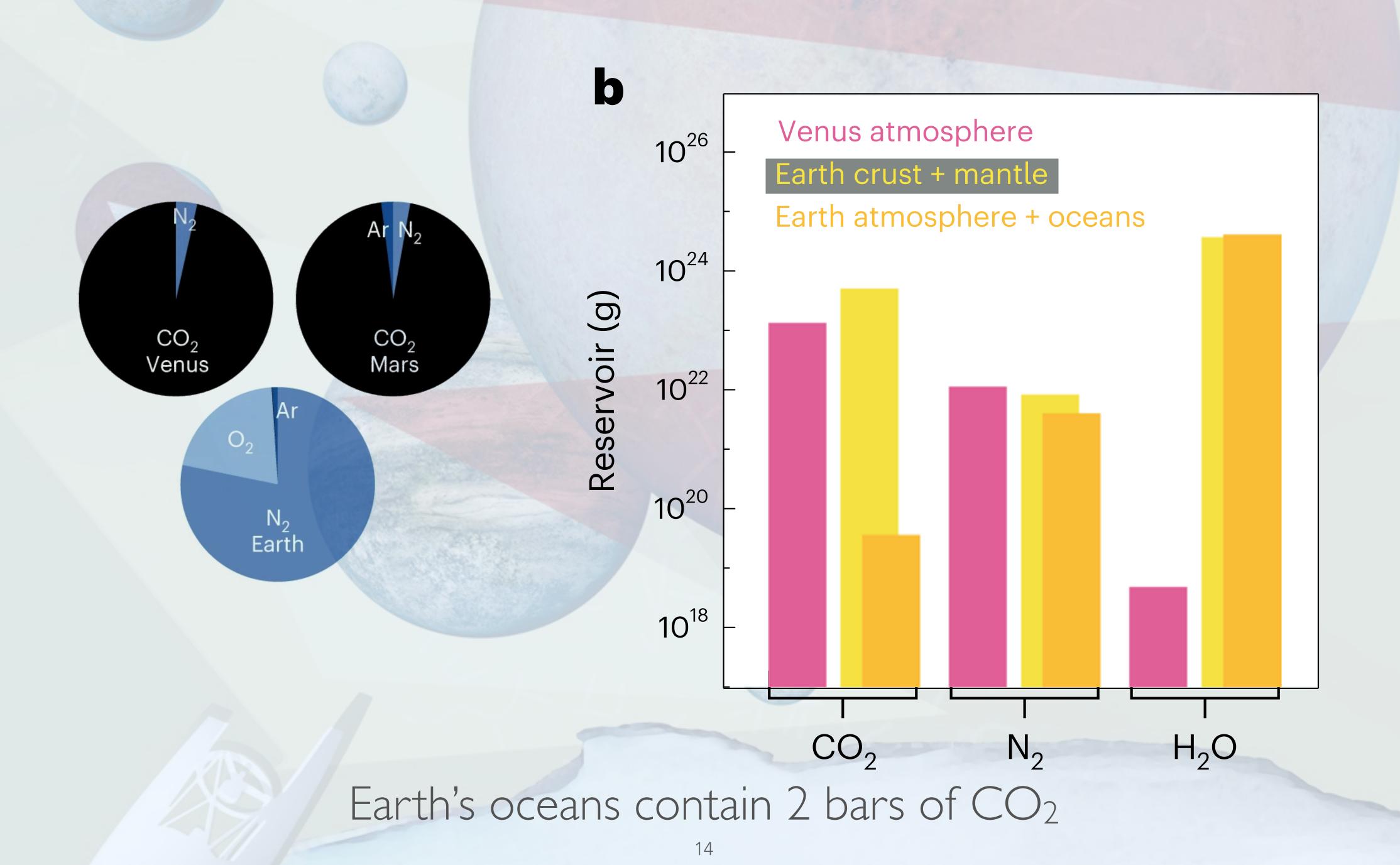


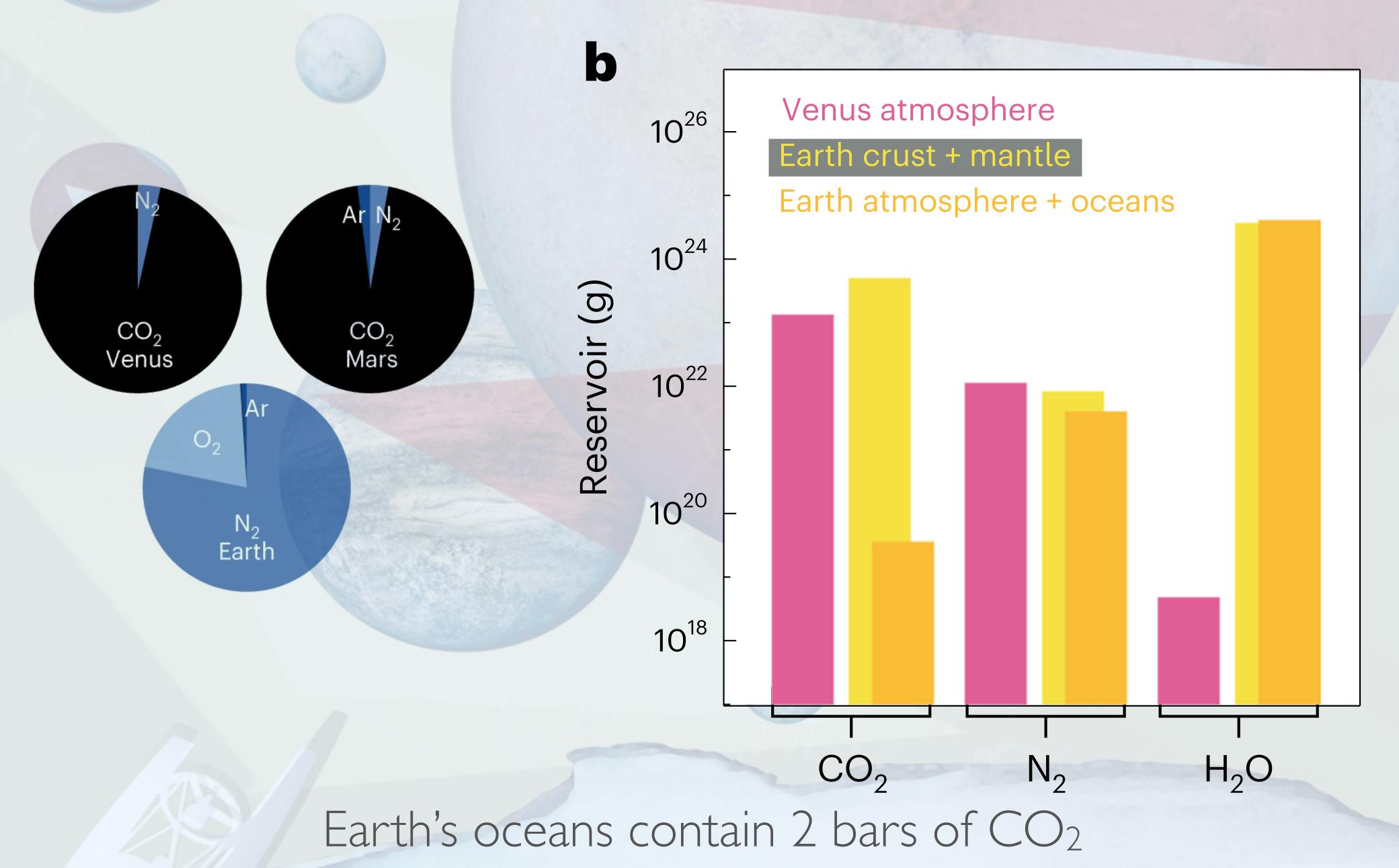
this a population approach, not as applicable to a given planet

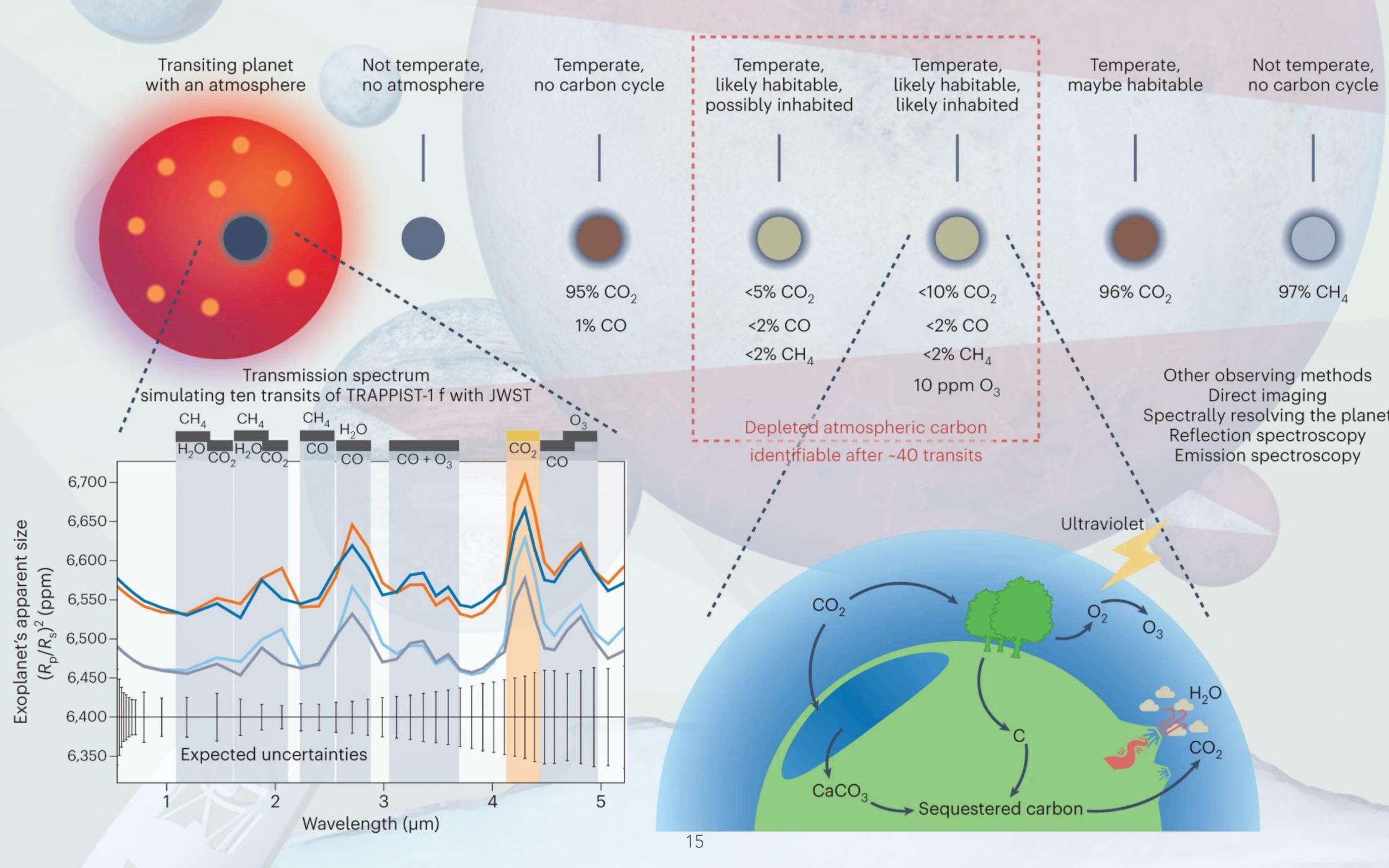


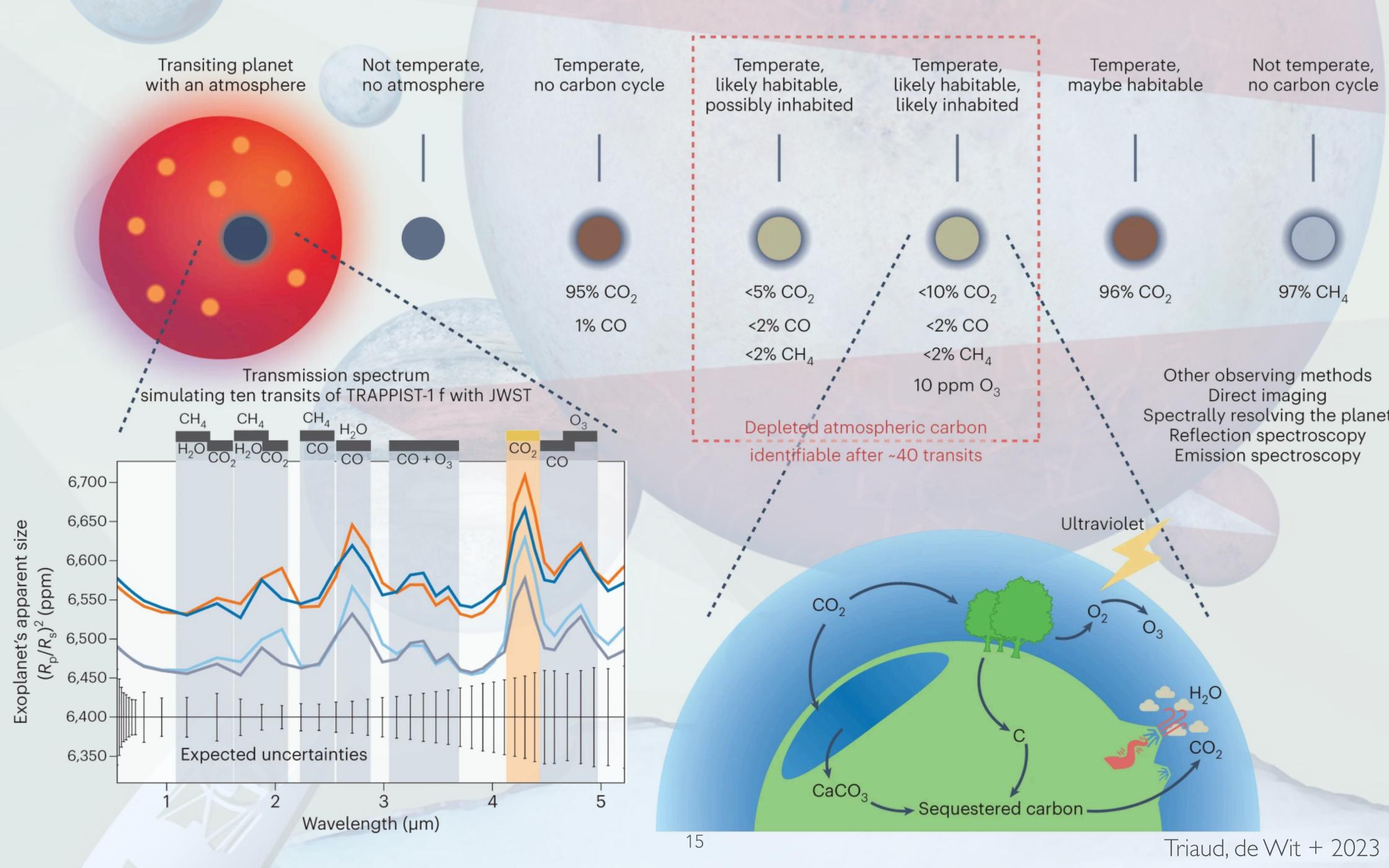


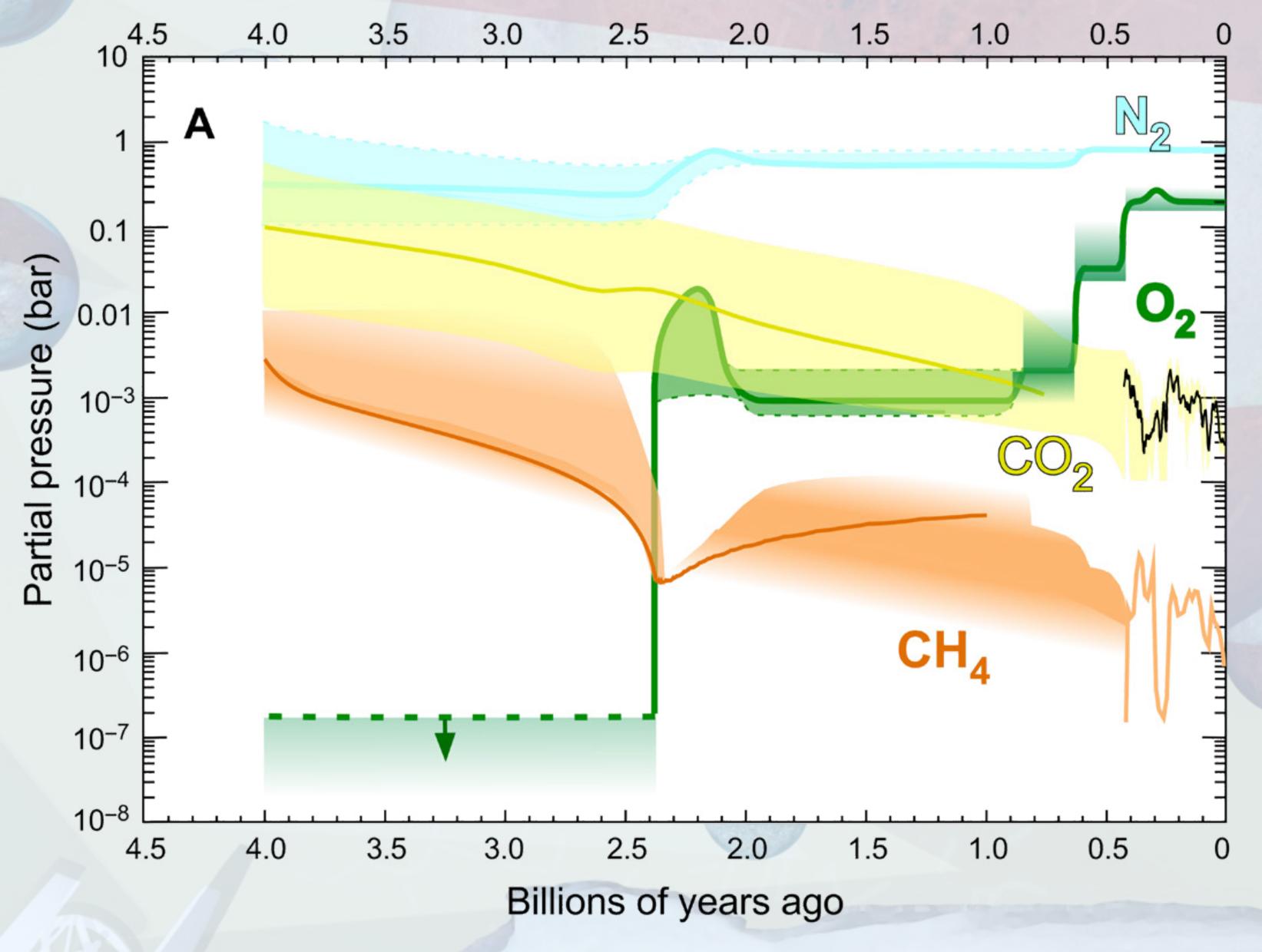




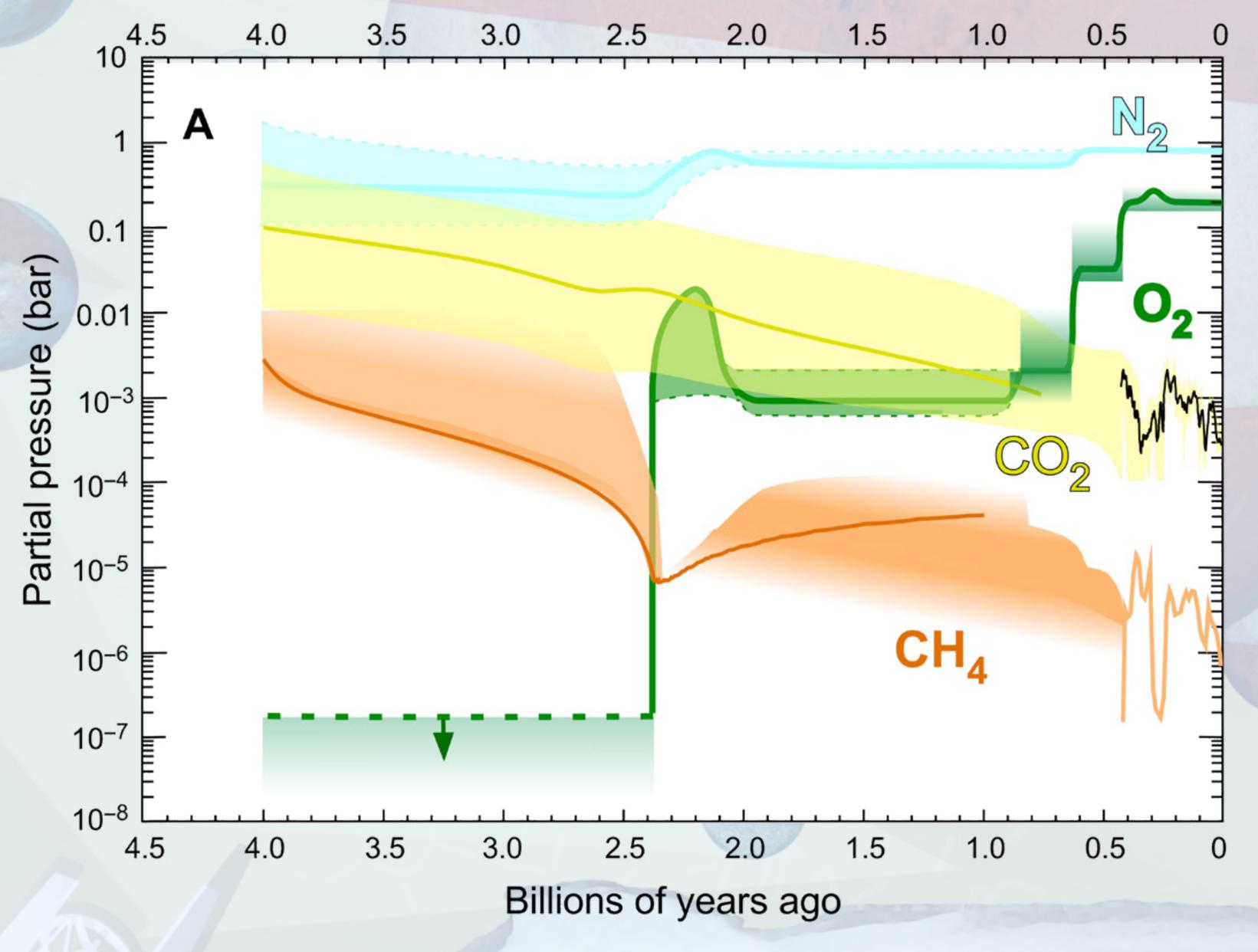








Most of Earth's CO₂ already absorbed by ~ 0.5 Gyr after formation



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To detect a deficit, we need to calibrate.

Calibration is achieved by using > I planet.

This concept now extended to biosignatures (Constantinou, Shorttle+ 2025)

False positives

CO2 depleted but not by water



Dry sequestration unlikely in dry conditions

Night-side cold-trap possible for tidally locked, if $P_{atmos} < 0.7$ bar

CO₂ dissociation (photo/chemo) at most 10% of CO₂ affected at 1 bar

Reduced interior

unlikely, but detectable from atmospheric composition

comparison to other planets

Other solvent

none known (would be great to find one)

False negatives

CO2 not depleted, but surface water



Sub-surface hydro/biosphere we need an atmosphere for detection

Saturated oceans

would it mean no tectonics?
need more work on sequestration

Transient CO₂ concentration

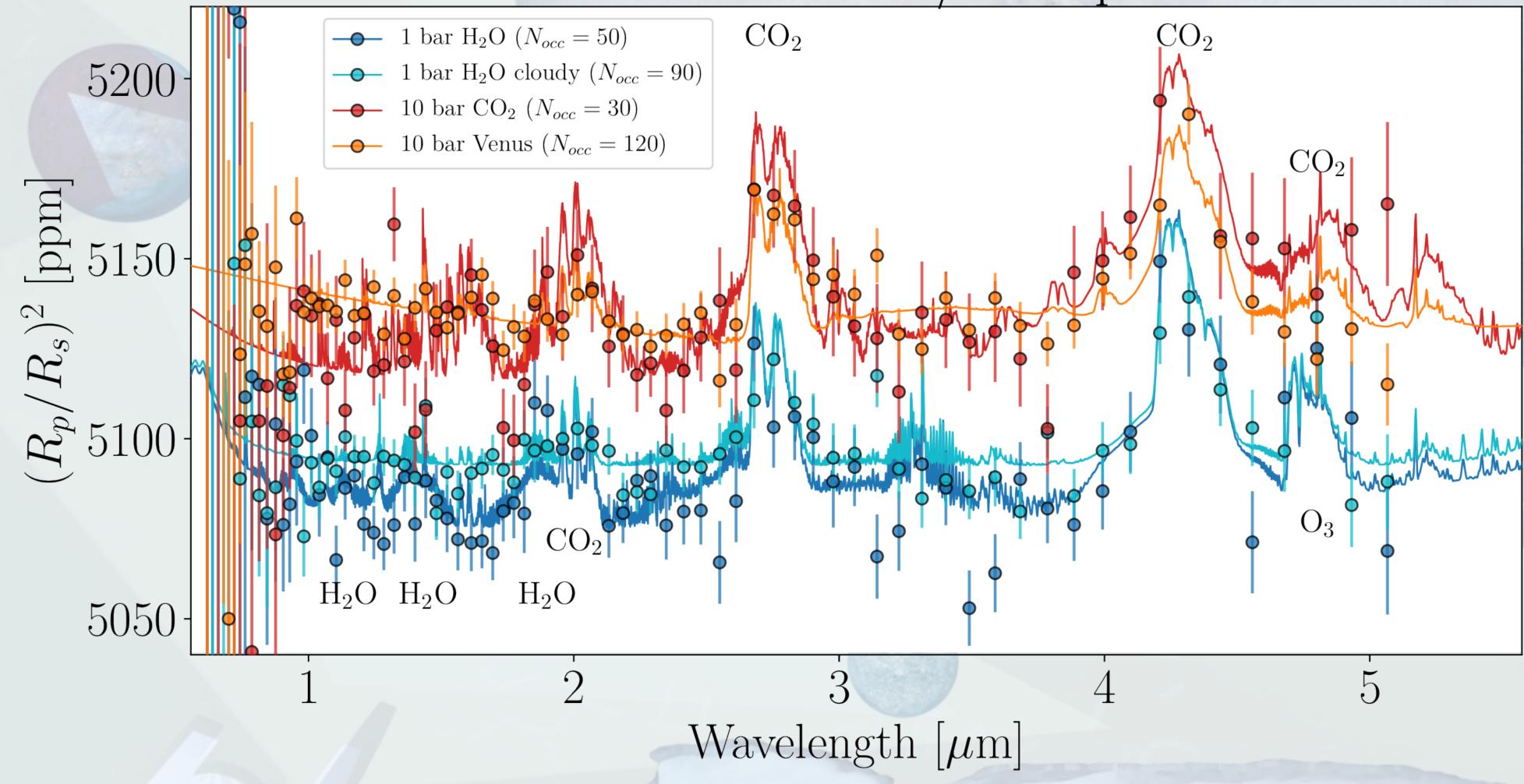
CO₂ absorbed rapidly probability < 1/50 surface no longer habitable?

Planet near outer edge of HZ

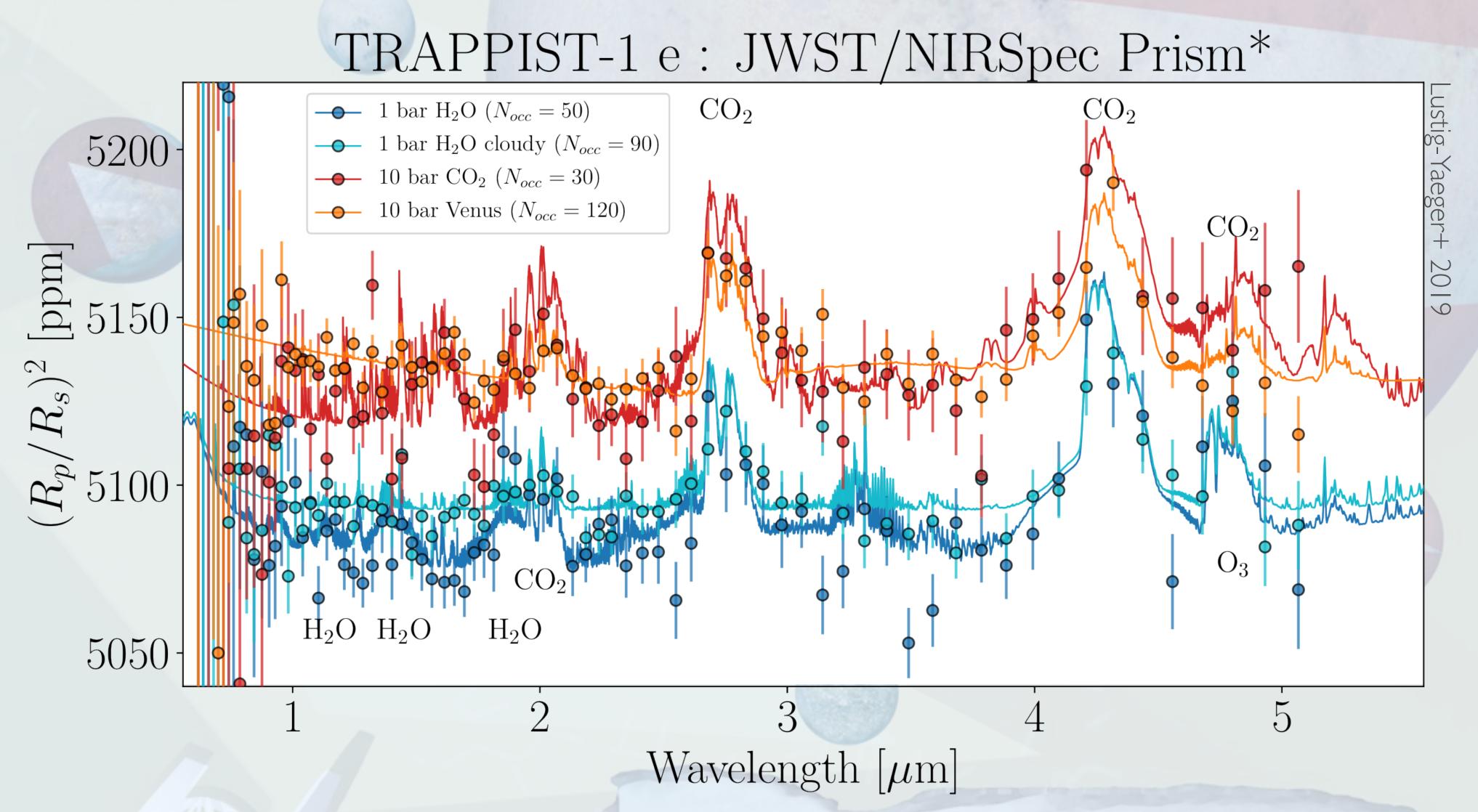
Earth @ Mars's orbit needs 2 bars of CO₂ > 50% CO₂, scenario difficult to distinguish



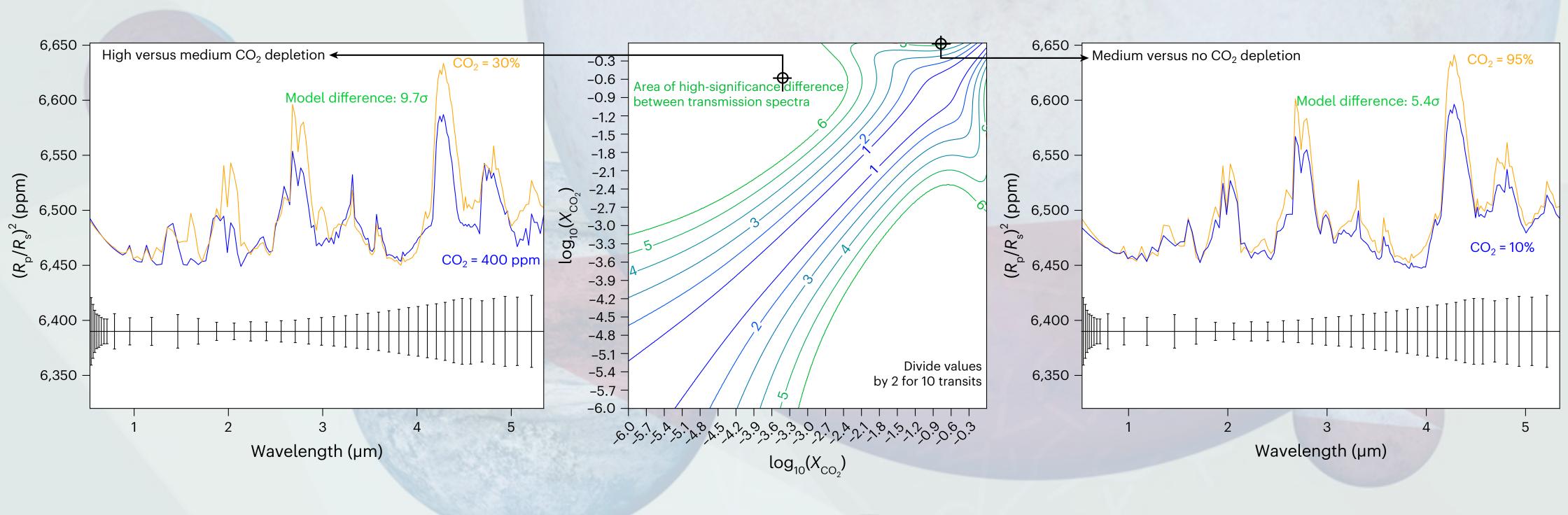
TRAPPIST-1 e : JWST/NIRSpec Prism*



Searching for O₂ not really reachable with JWST However CO₂ is a lot easier

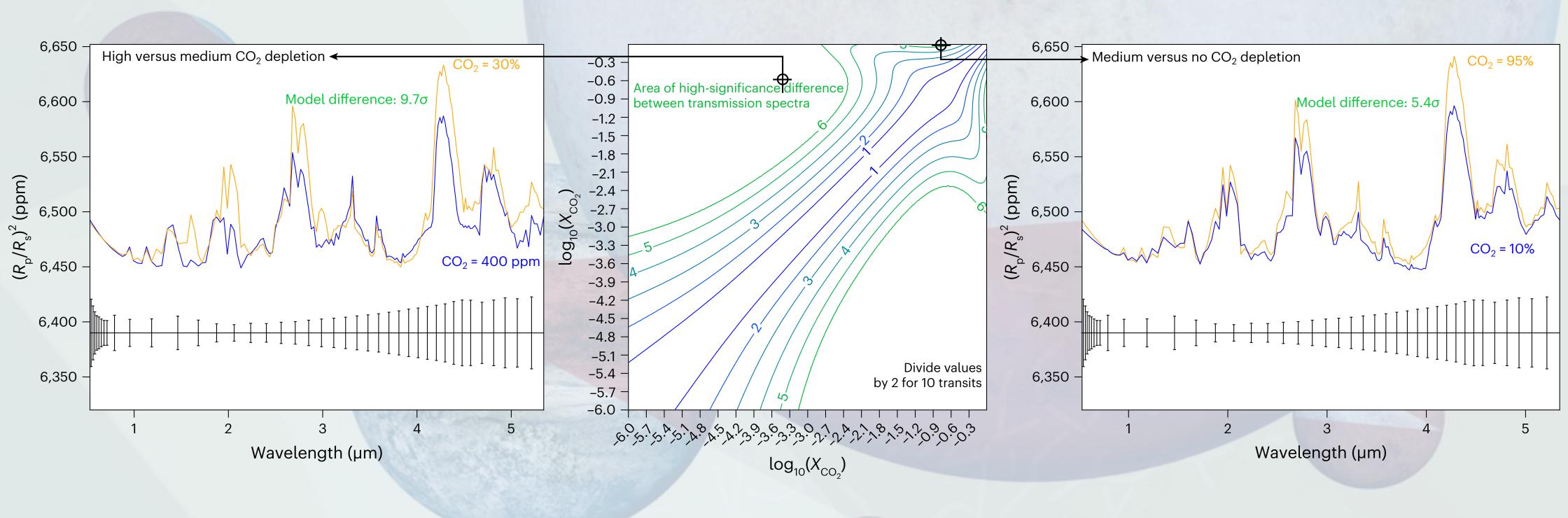


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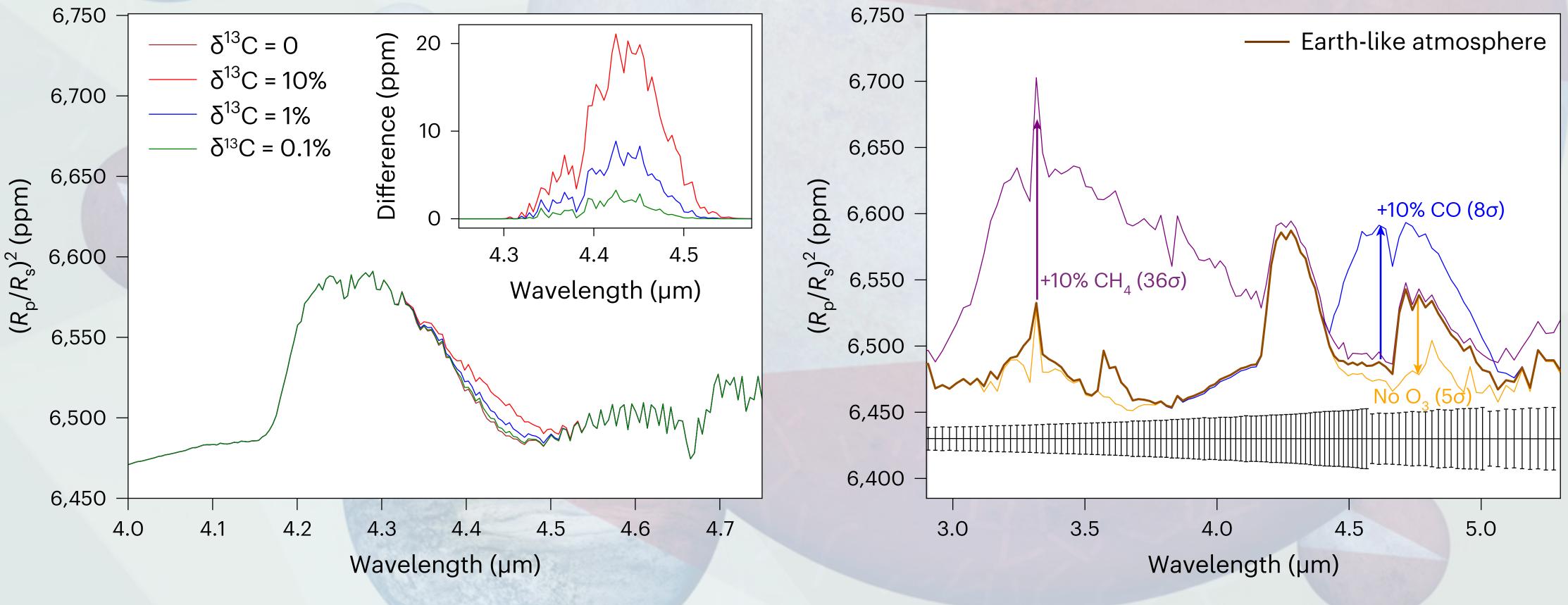
About 10 transits on TRAPPIST-If are sufficient to detect CO2

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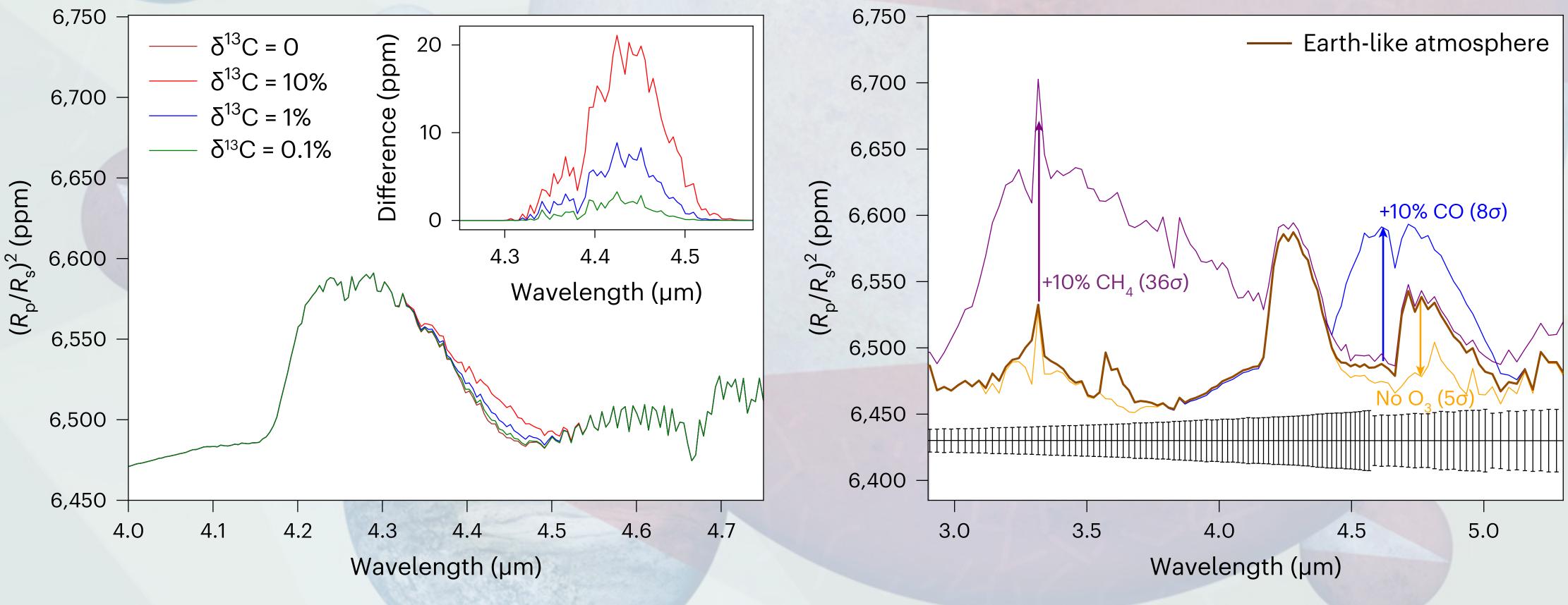
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About 100 transits on TRAPPIST- If would give you precise CO₂ abundance (habsignature)

Non/detection of O₃ (biosignature)

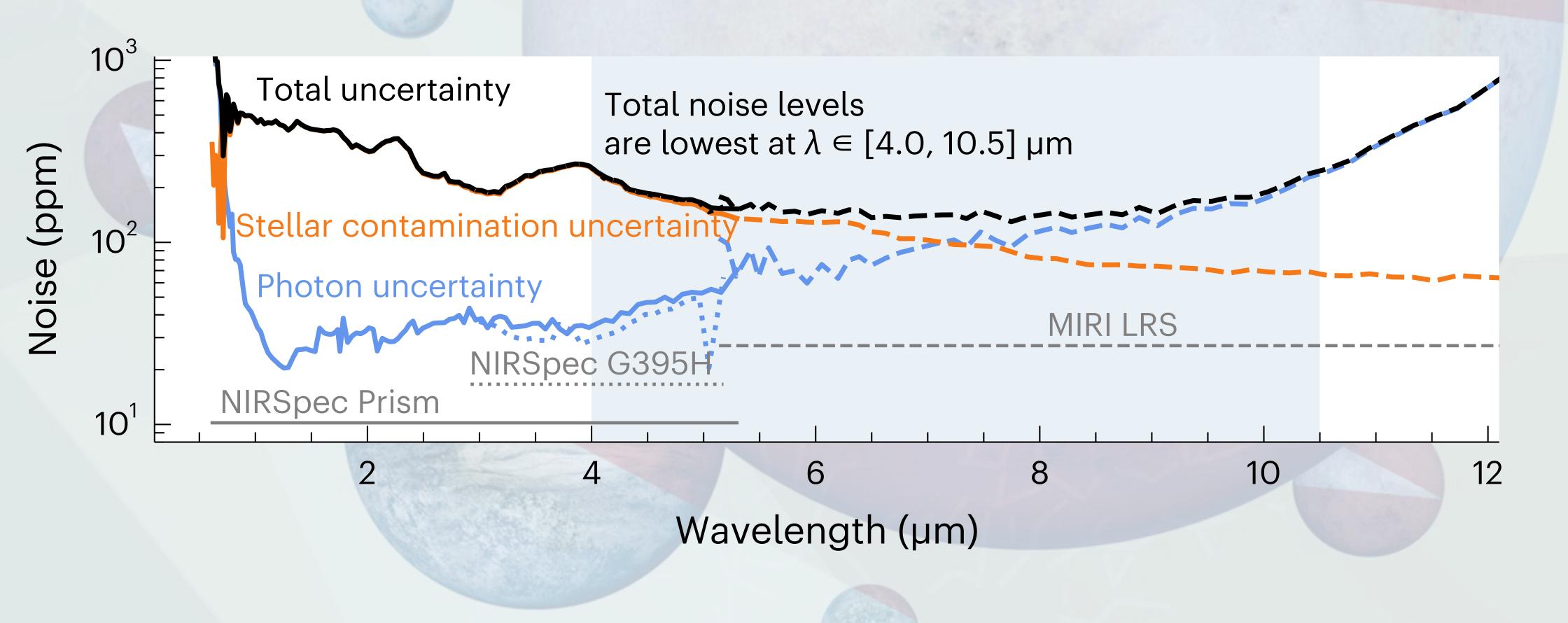
NIRSpec also sensitive to CH4 and CO, for other carbon reservoir



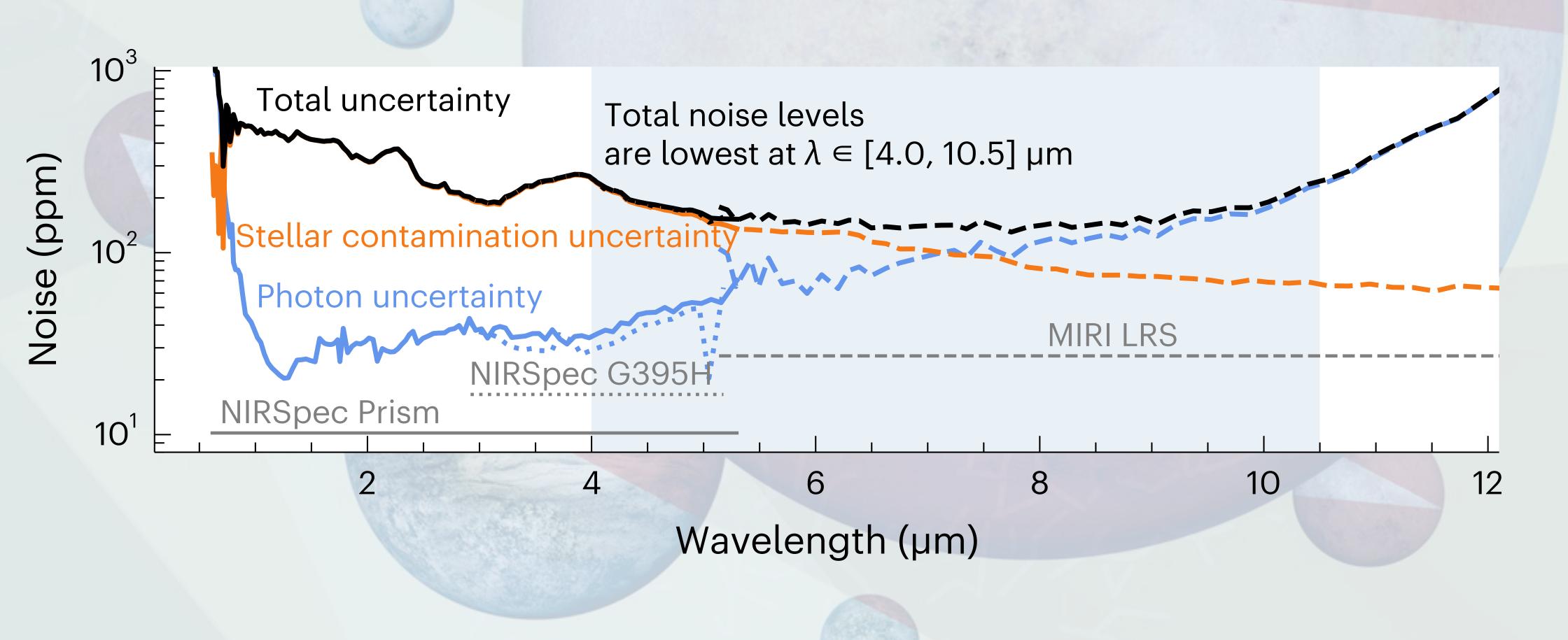
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Triaud, de Wit + 2023



MIRI band is where stellar contamination ~ photon noise



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Summary

Defining a concept of hab/aqua-signature is important to support and frame further work into empirical tracers of a hydrosphere.

Using a depleted feature is rarely used (e.g. as a biosignature). Depletion works if we calibrate (thus we need > 1 planet)

dCO2 is a likely habsignature, to be investigated further to verify

Of all molecules, CO_2 is the easiest to seek for rocky planets. I-find planet 2-detect CO_2 3-measure CO_2 abundance 4-seek biosignatures

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