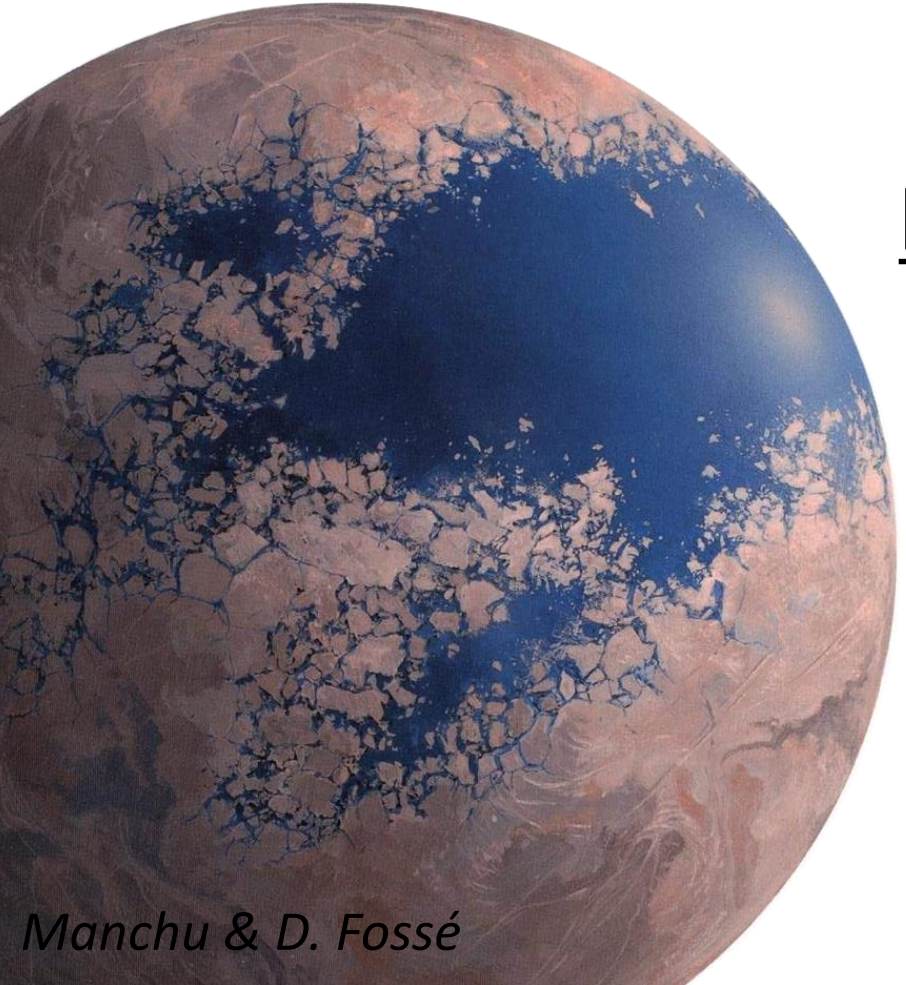
À la recherche d'océans sur les exoplanètes

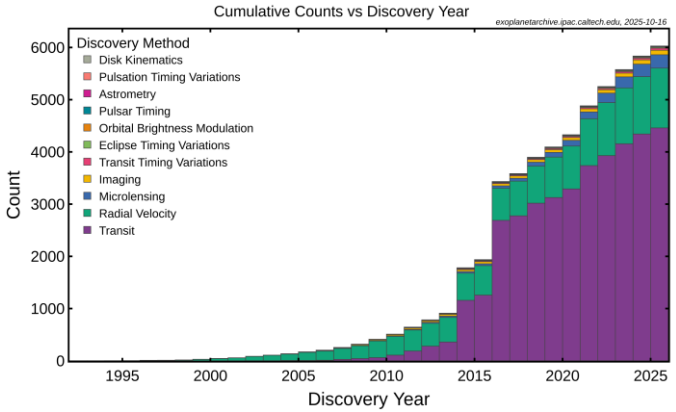


Manchu & D. Fossé

Martin Turbet, chargé de recherche au CNRS
Laboratoire de Météorologie Dynamique (LMD), IPSL
Laboratoire d'Astrophysique de Bordeaux (LAB)

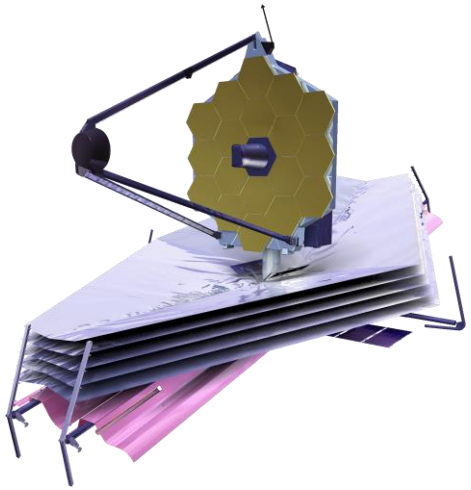
Context – Where do we stand in exoplanet research?

- Over **6,000 exoplanets** detected
- Most are very hot and/or large, a consequence of observational biases



- About ~ 50 known exoplanets could, in theory, host liquid water oceans (neither too hot nor too cold ; neither too small nor too large)

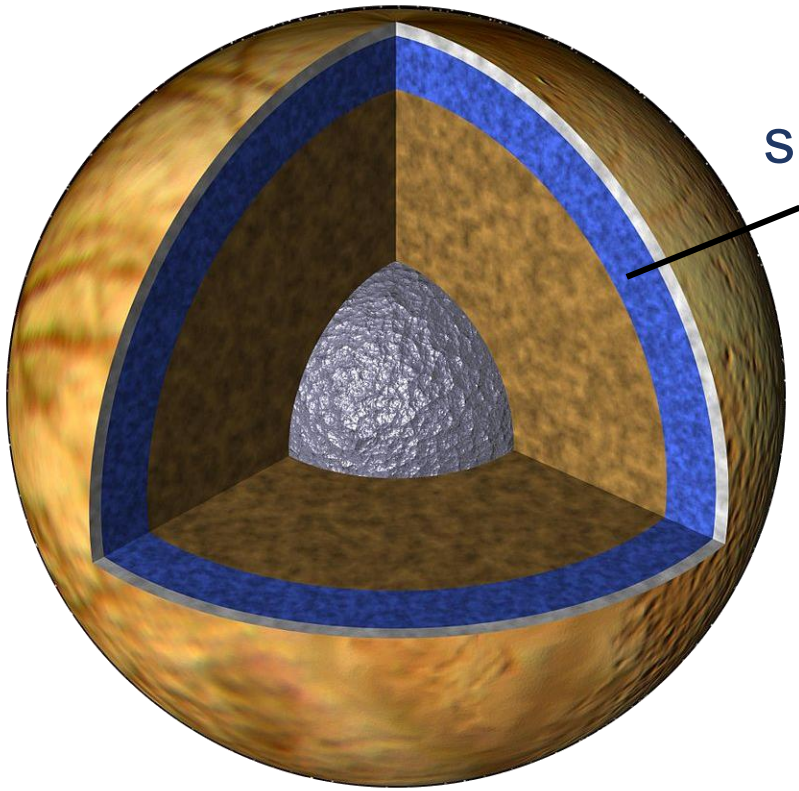
- Only ~ 10 are within reach of our best telescopes (e.g., JWST) to find out if they have atmospheres and maybe even oceans



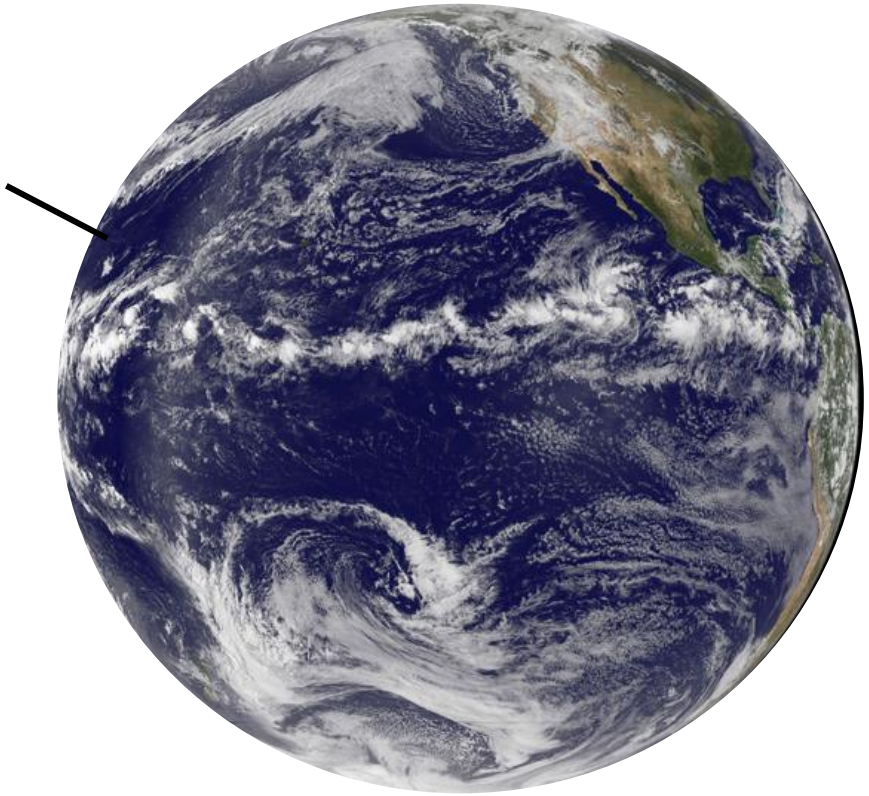
JWST
(James Webb Space Telescope)

What types of oceans on exoplanets?

Sub-surface oceans

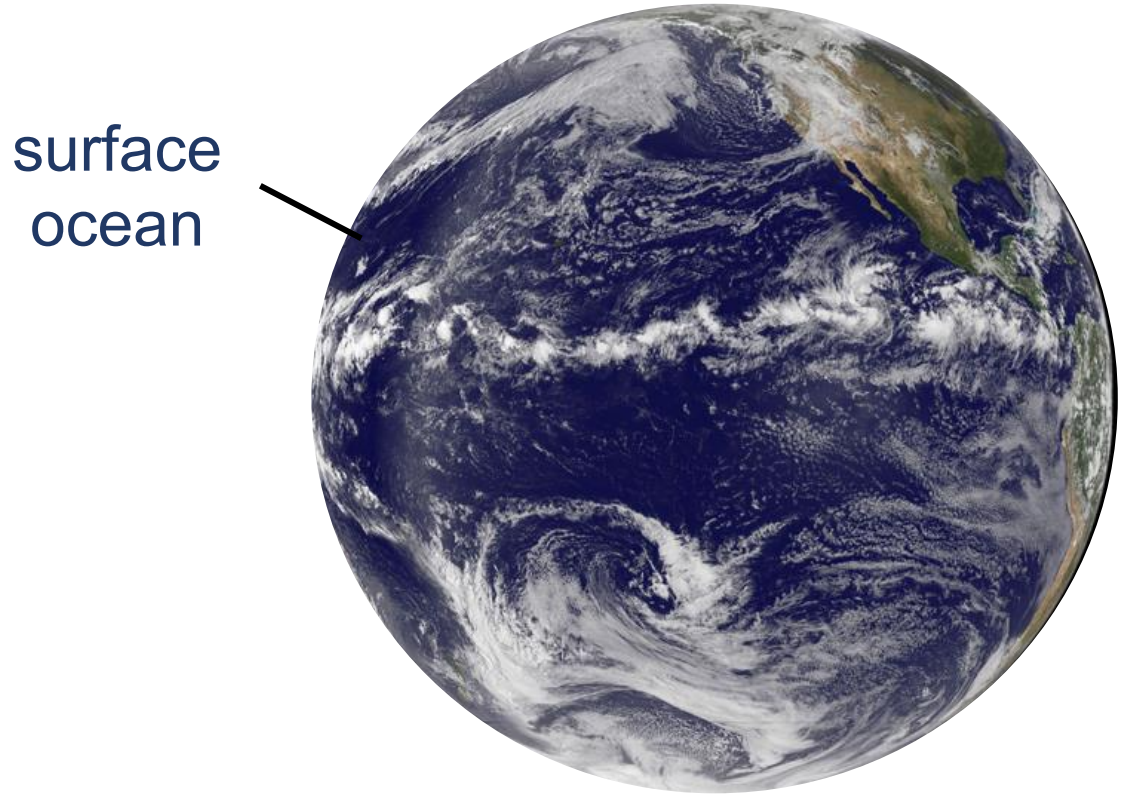


Surface oceans

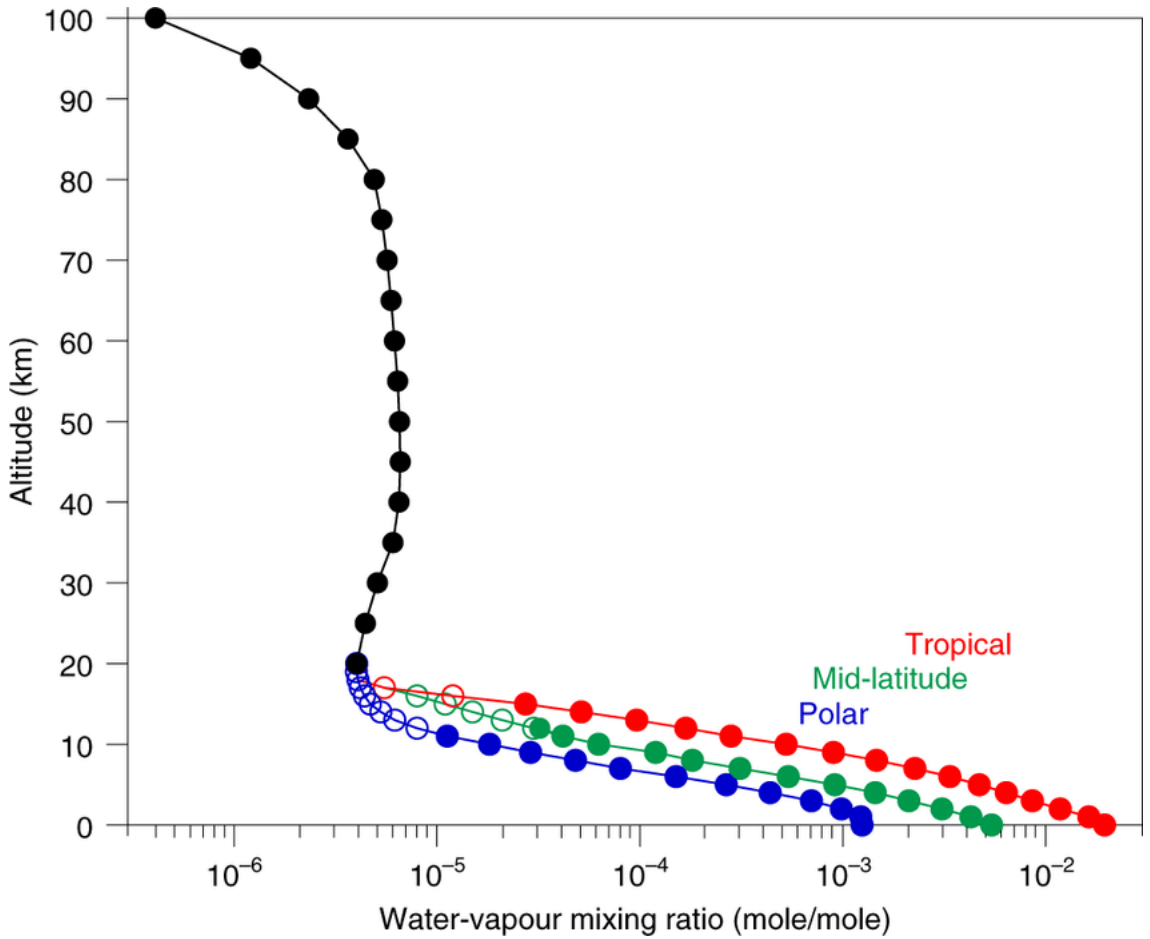


How to detect oceans on exoplanets?

Surface oceans



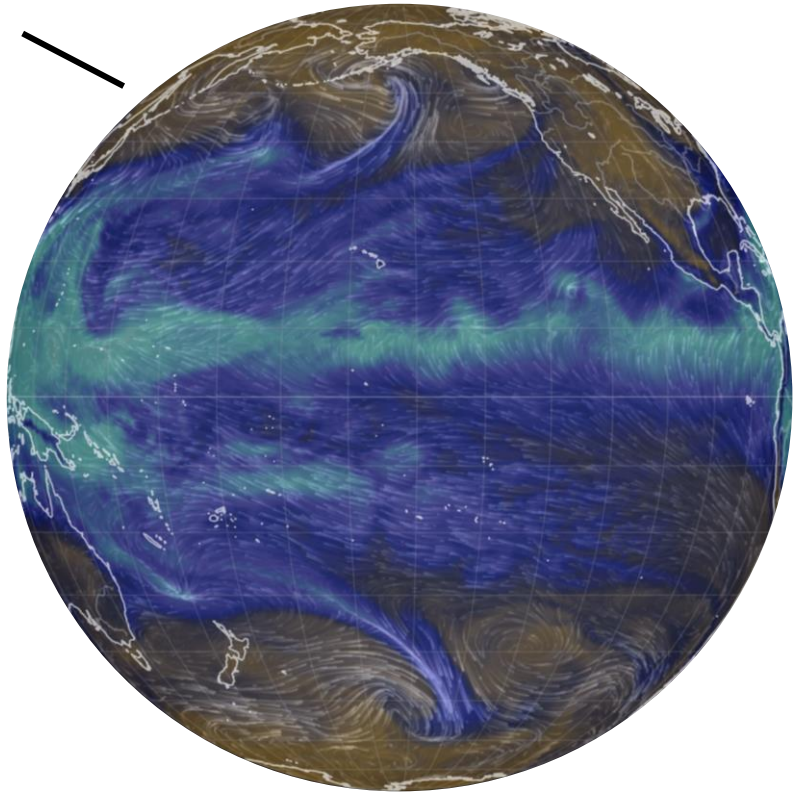
How to detect oceans on exoplanets?



Hallsworth et al. 2021

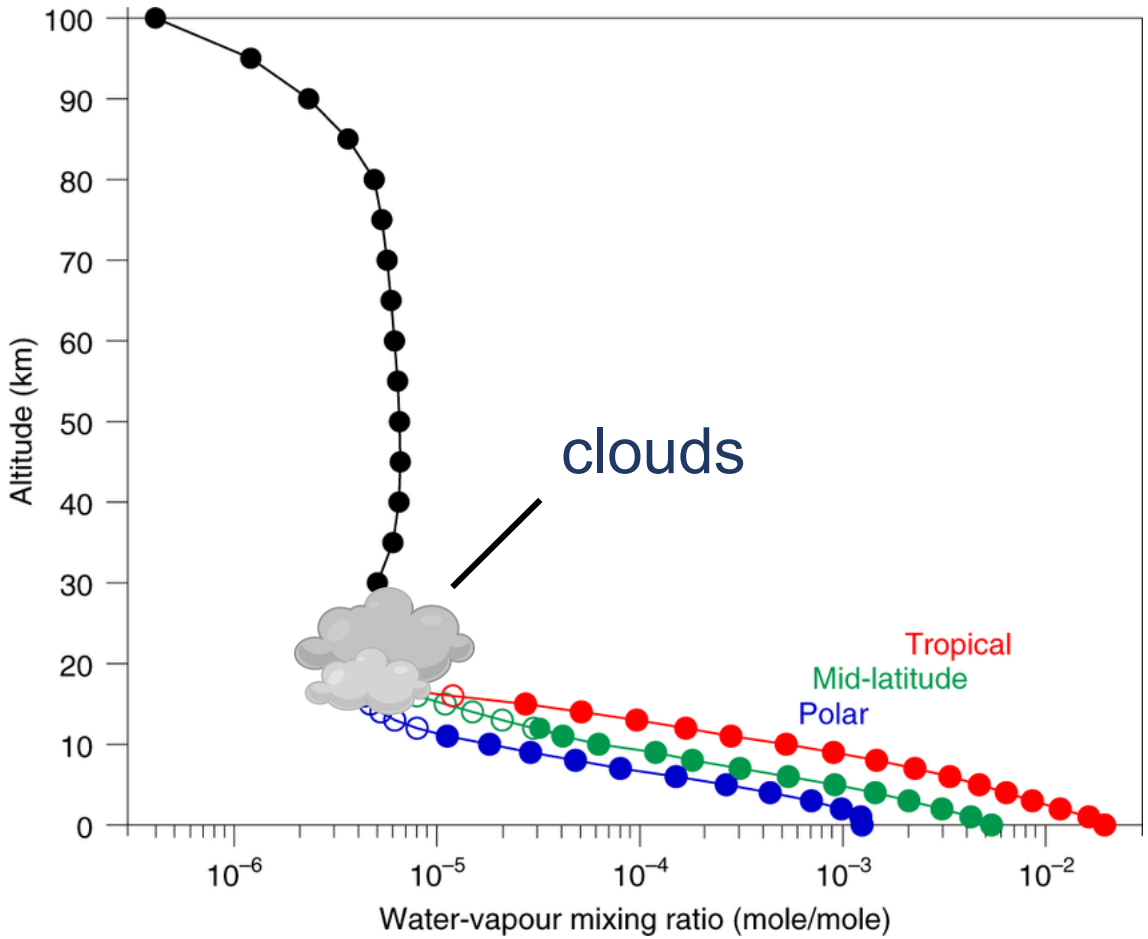
Surface oceans

Water vapor map
(GFS / NCEP)



up to a few centimeters precipitable water vapor

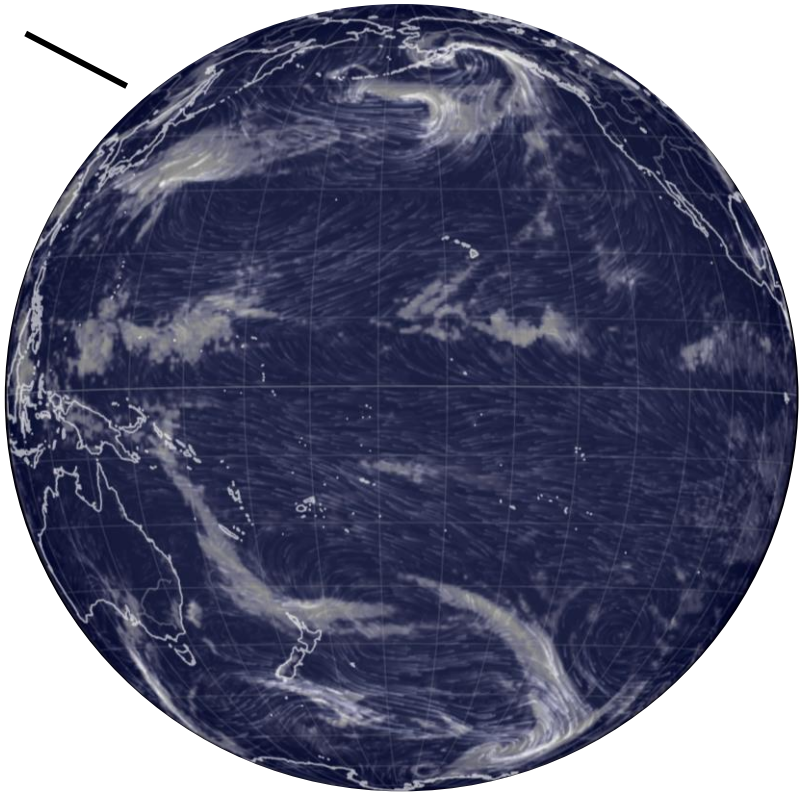
How to detect oceans on exoplanets?



Hallsworth et al. 2021

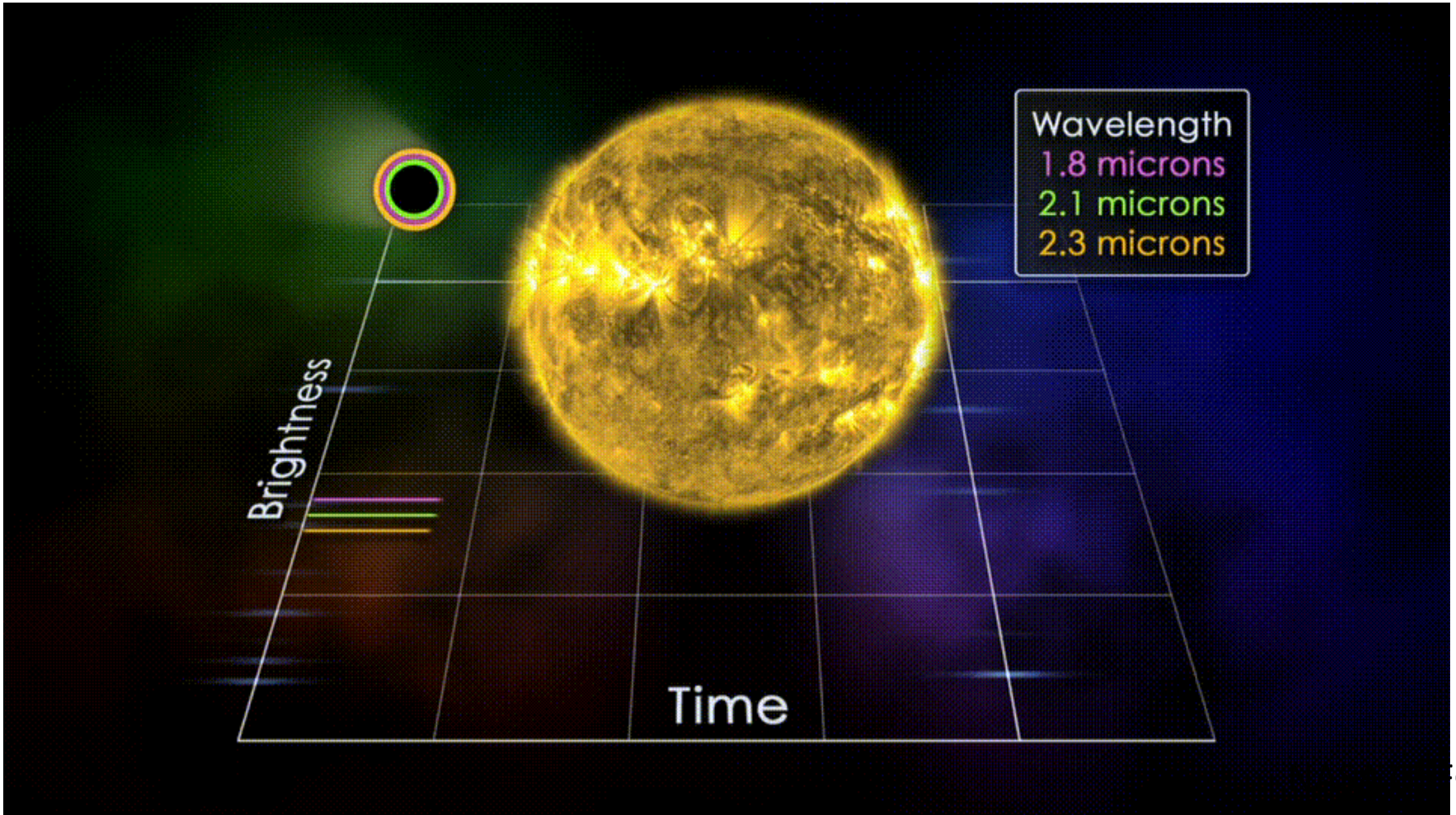
Surface oceans

Water cloud map
(GFS / NCEP)

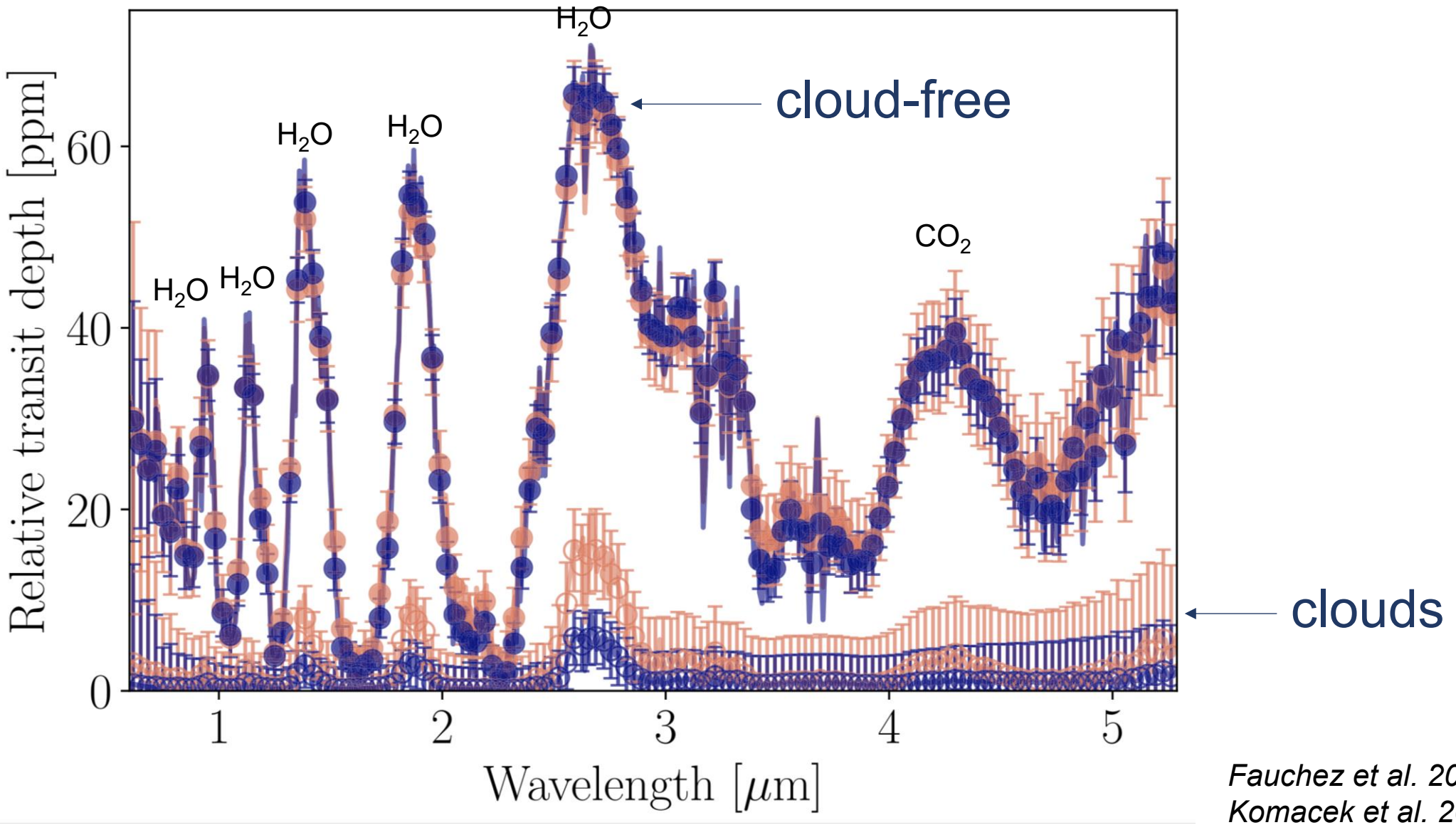


up to a few millimeters precipitable water cloud content

TRANSIT SPECTROSCOPY



How to detect oceans on exoplanets?



Fauchez et al. 2019
Komacek et al. 2020

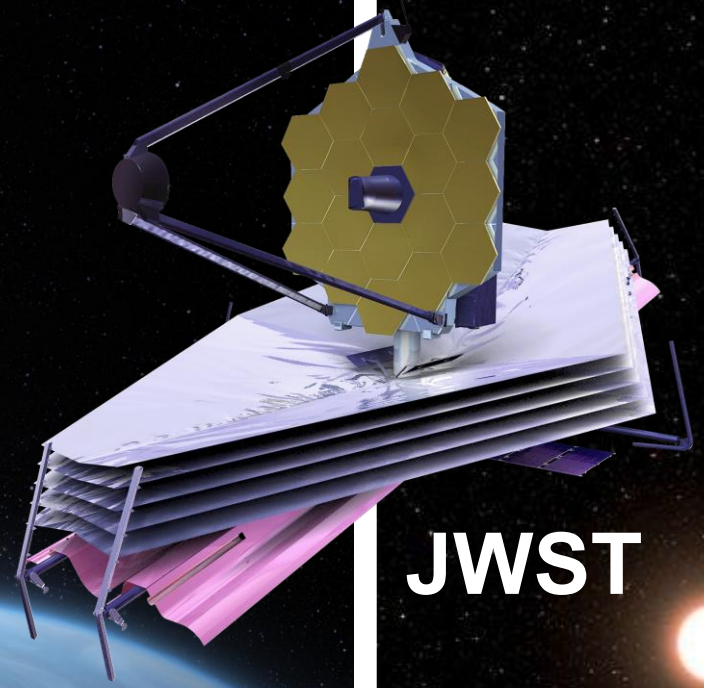
So … How to detect oceans on exoplanets?

So … How to detect oceans on exoplanets?

K2-18b

- 8.6 Earth mass
- 2.6 Earth radius
- ~ 1 Earth insolation

ESA – Artist View



JWST

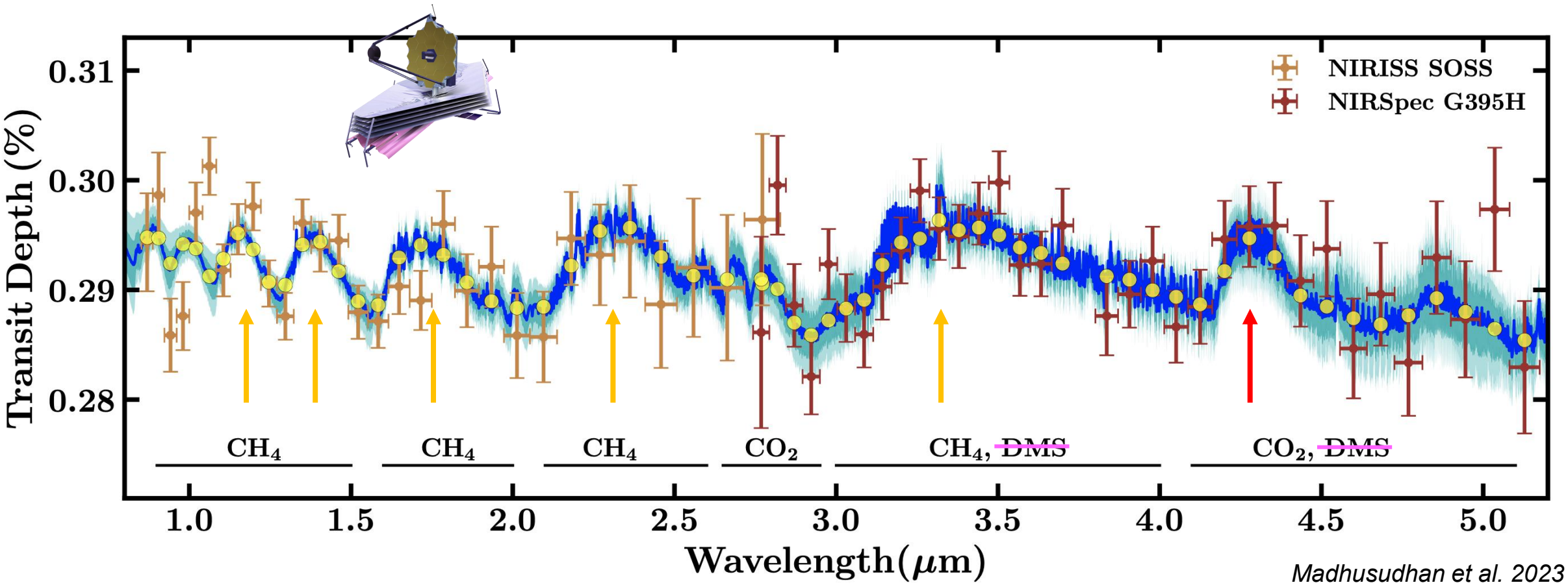
LHS1140b

- 5.6 Earth mass
- 1.7 Earth radius
- ~ 0.4 Earth insolation

STScI – Artist View

K2-18b: A temperate exoplanet with a H_2-rich atmosphere

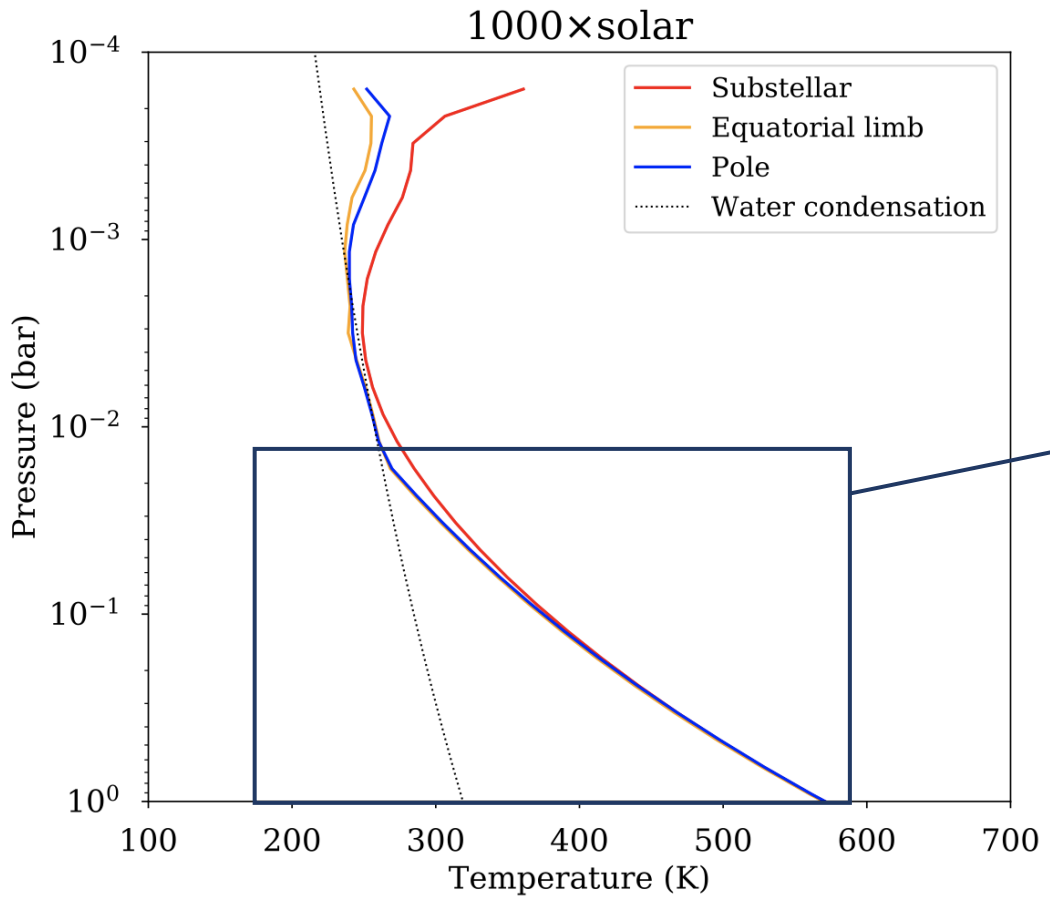
- Previous observations with Hubble revealed a H_2-dominated atmosphere
- **Where is ammonia (NH_3) ????**



Madhusudhan et al. 2023

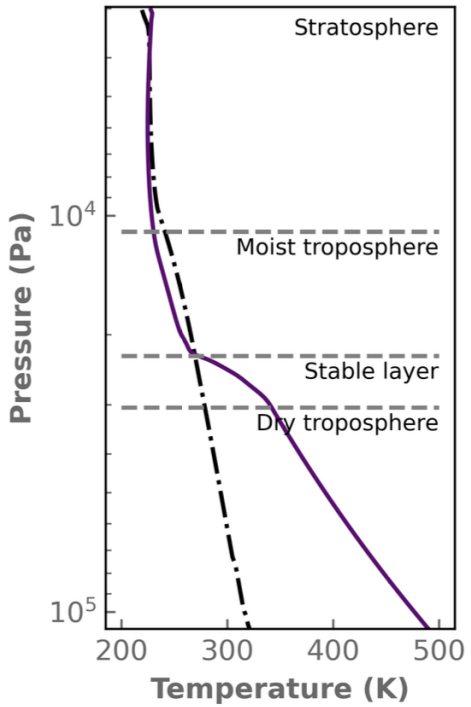
Could K2-18b be an ocean planet? ➔ most likely no!!

3D Global Climate model simulations



Charnay et al. 2021, A&A

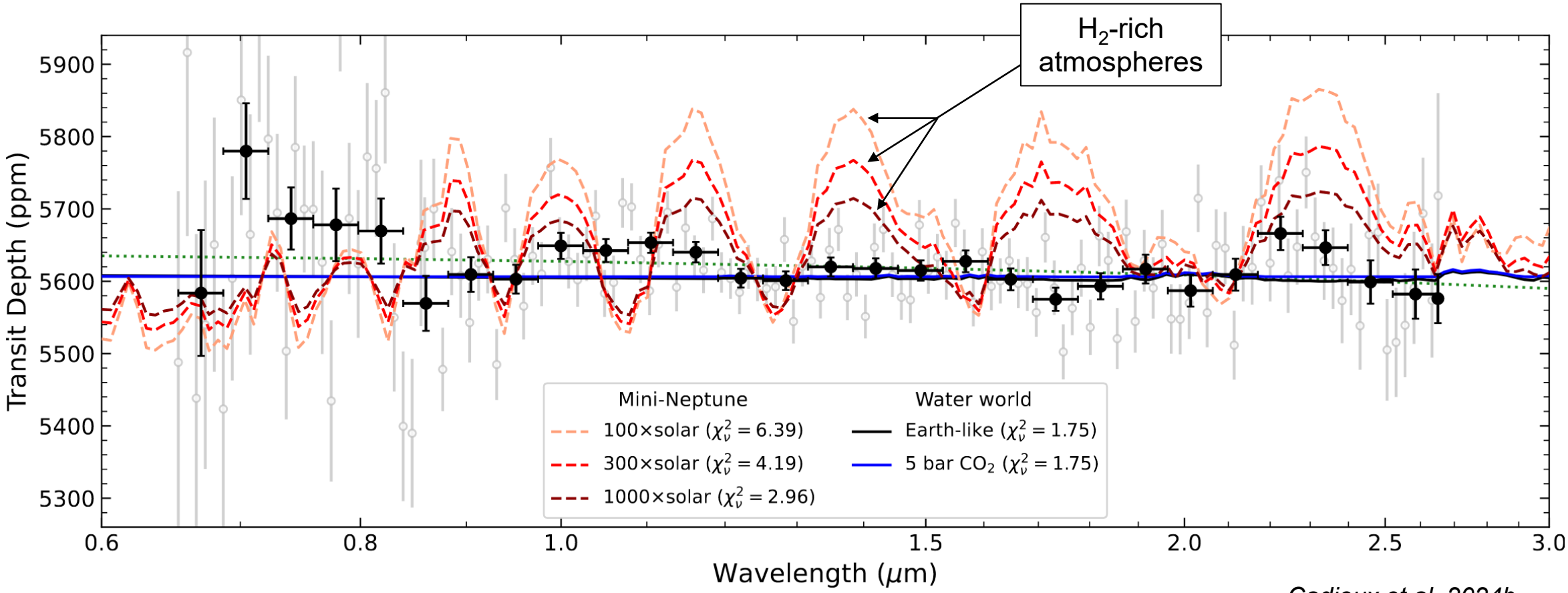
3D Cloud Resolving model simulations



Leconte et al. 2024, A&A

LHS1140b: Temperate super-Earth or mini-Neptune?

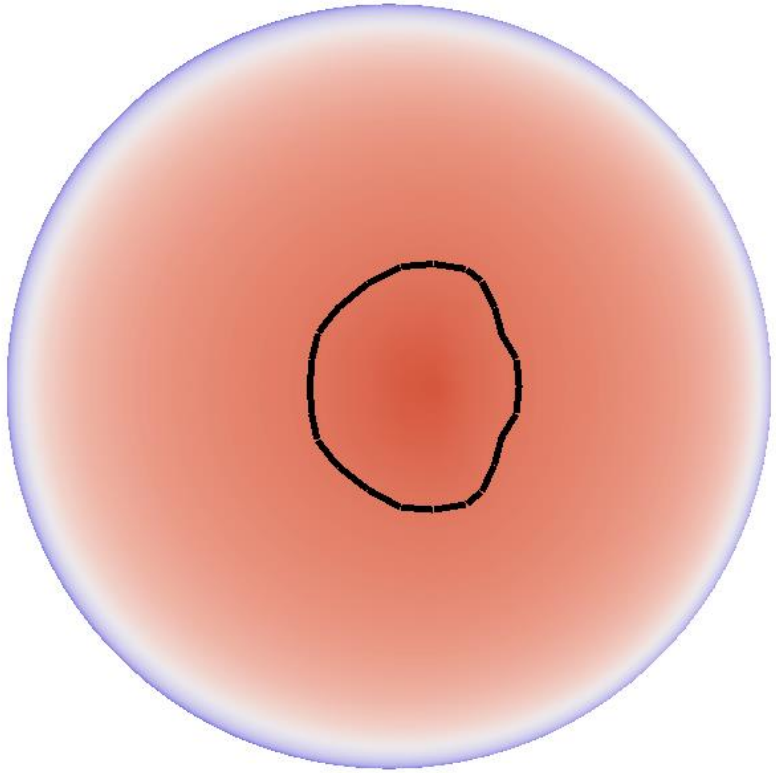
- Previous observations (Spitzer, VLT, etc.) revealed a low-density, compatible with a H_2-rich atmosphere or water-rich composition.



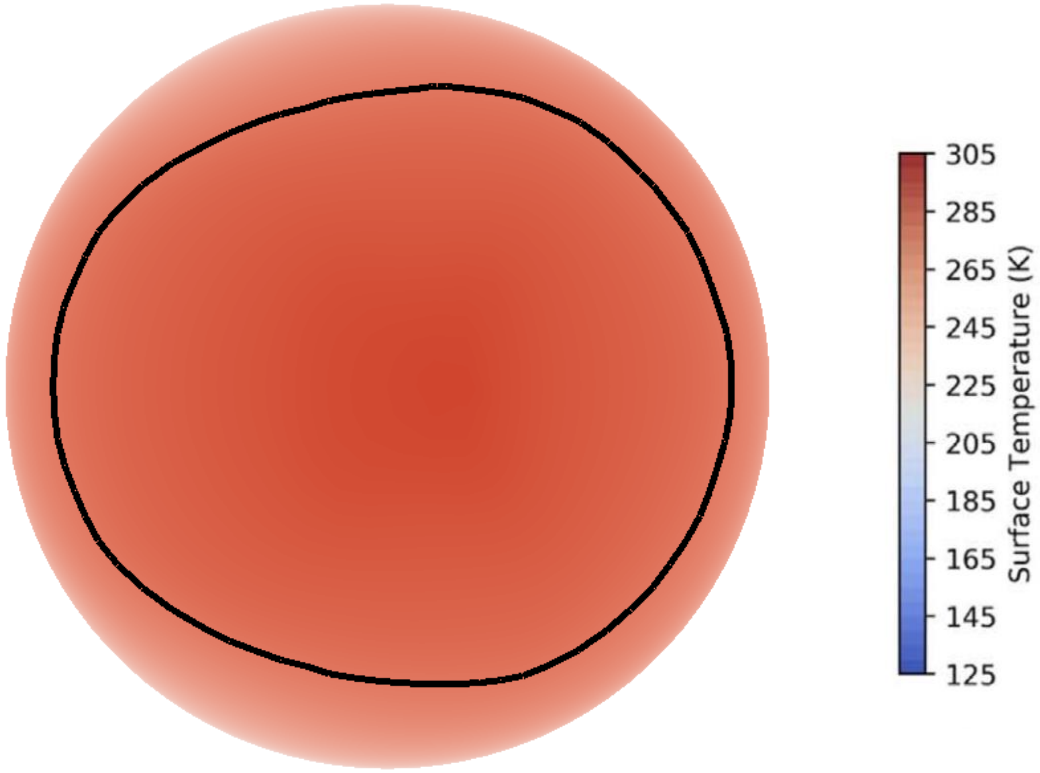
Cadieux et al. 2024b

Could LHS1140b be an ocean planet? ➔ **Possibly yes!**

Earth-like atmosphere with oceans



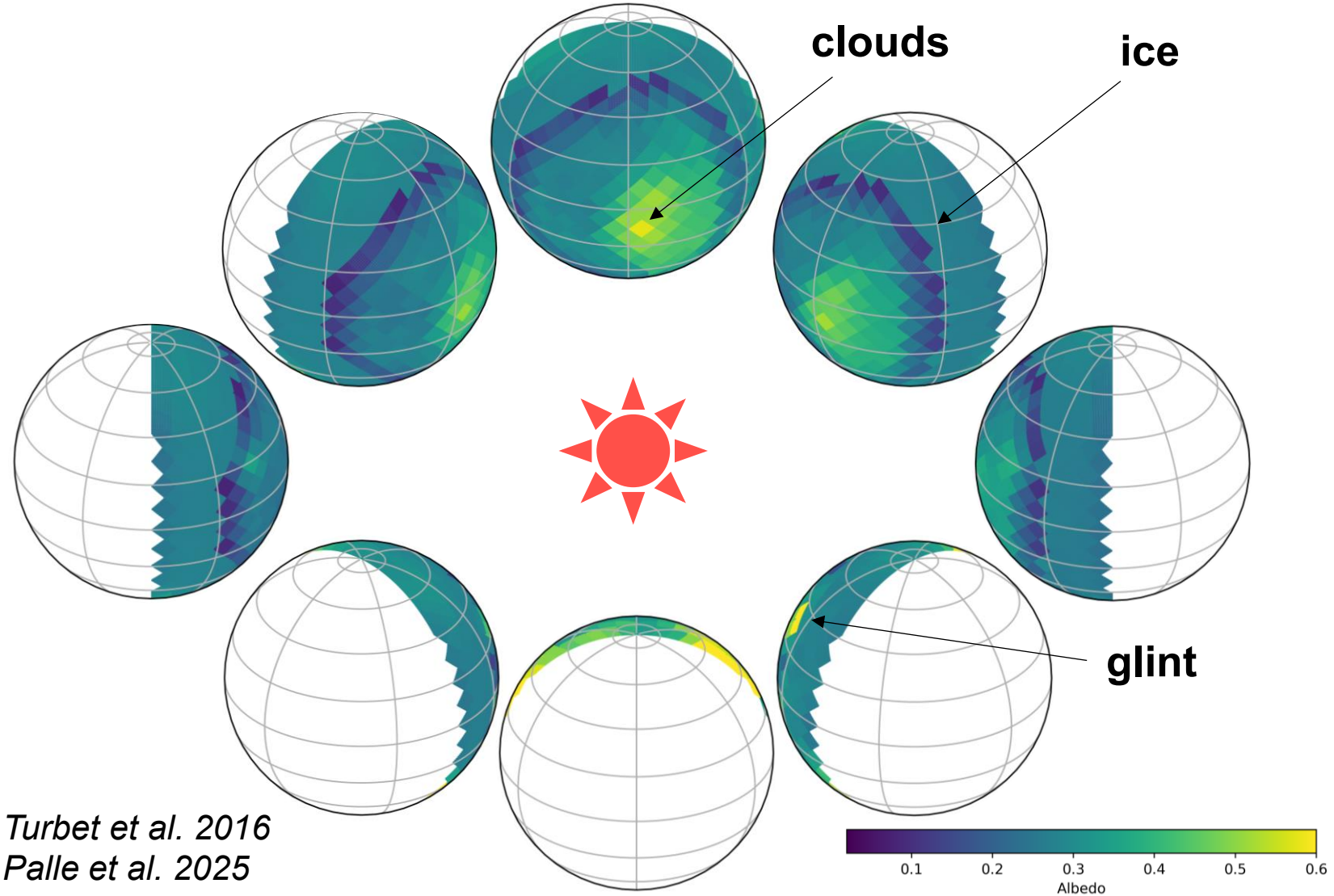
CO_2-rich atmosphere with oceans

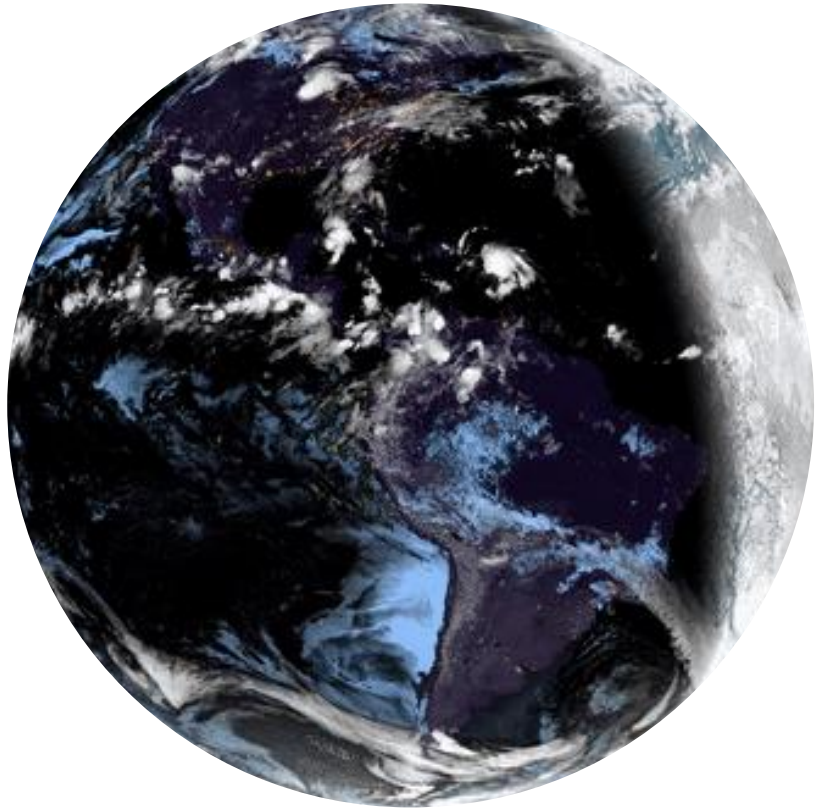


Cadieux et al. 2024ab

Detecting oceans on exoplanets: what's next?

3D Simulations of Proxima b with an Earth-like atmosphere and global ocean





Turbet et al. 2016
Palle et al. 2025

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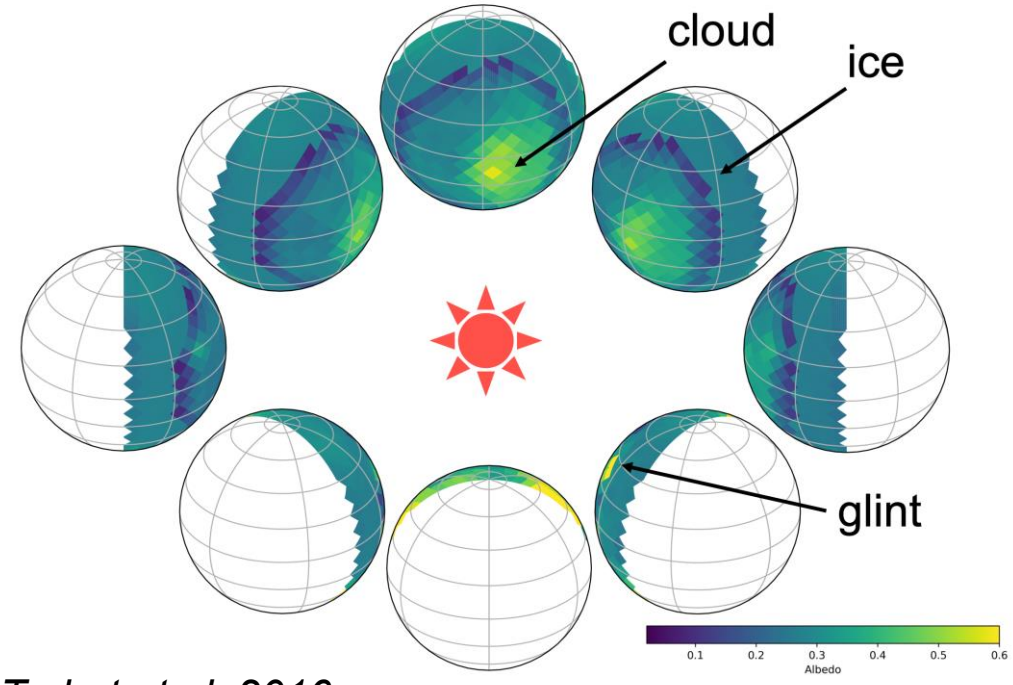
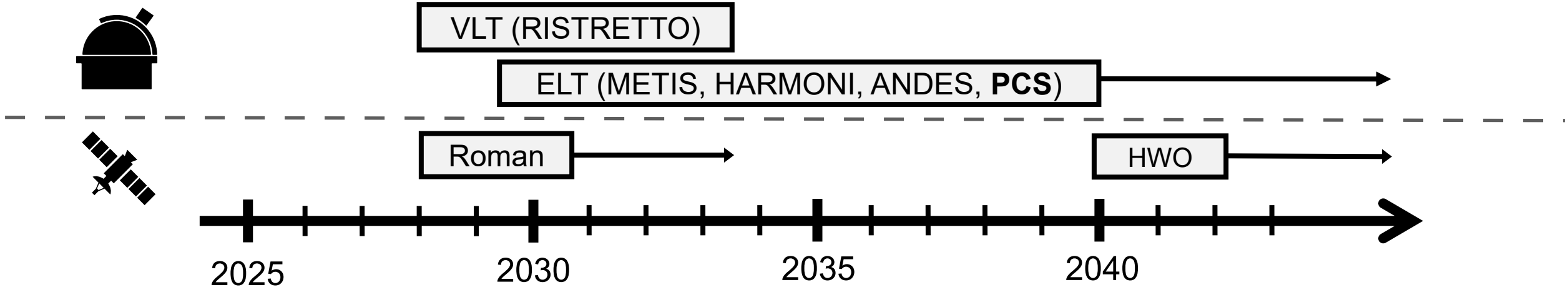


Turbet et al. 2016
Palle et al. 2025

BUT:

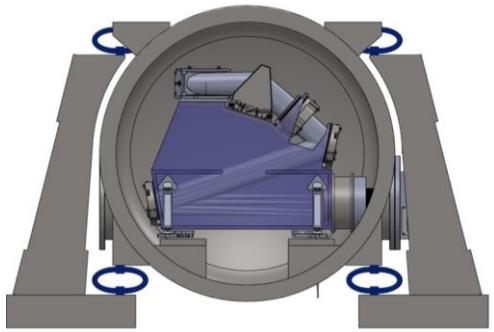
- Detecting Proxima b's reflected light requires a **planet-to-star contrast ratio of ~10^{-7}** (0.1ppm).
- Detecting ocean glint requires **~10^{-8}**.
- For ocean-bearing planets around Sun-like stars, the required contrast reaches **10^{-9} to 10^{-11}**.
- **These contrast levels are extremely difficult to achieve and demand dedicated high-contrast instrumentation**.

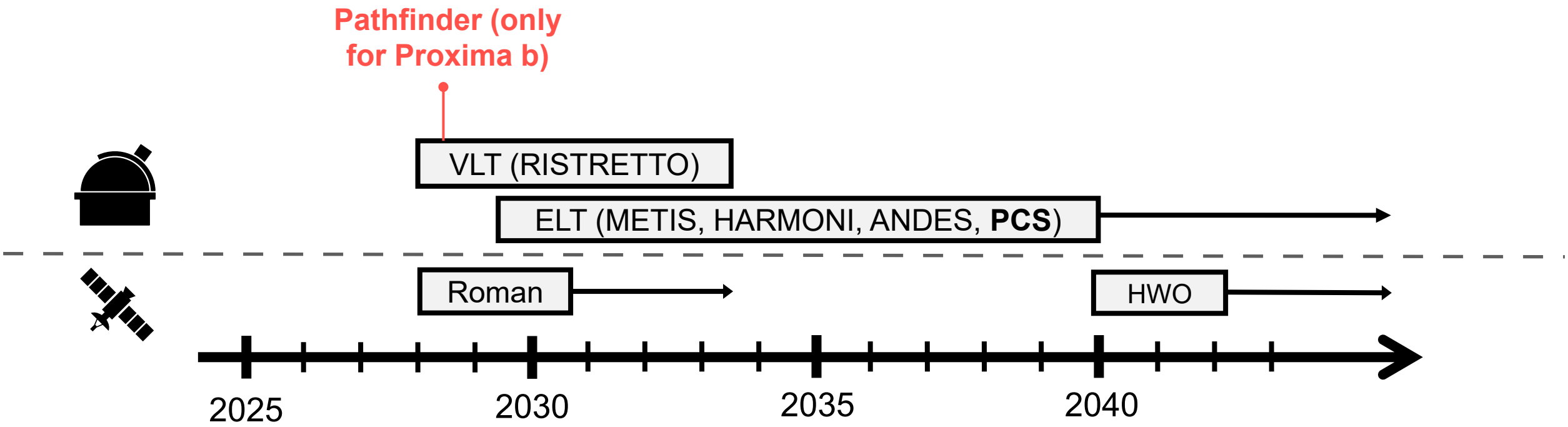
Future instrumentation for high-contrast reflected-light imaging



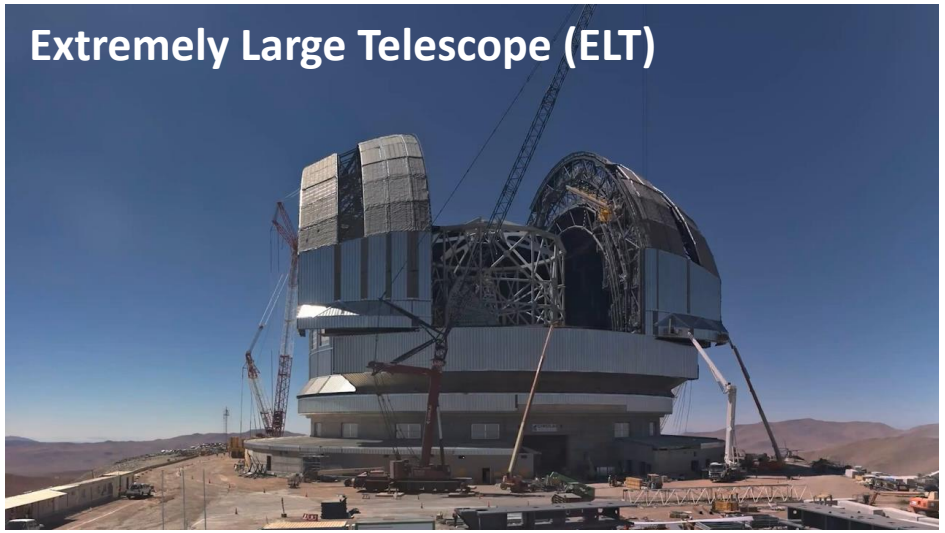
Future instrumentation for high-contrast reflected-light imaging

RISTRETTO





Future instrumentation for high-contrast reflected-light imaging



ESO (Nov. 2025)

Many Earth/super-Earth mass planets around M and K stars

Pathfinder (only for Proxima b)

VLT (RISTRETTO)

ELT (METIS, HARMONI, ANDES, **PCS**)

Roman

HWO

2025 2030 2035 2040

Future instrumentation for high-contrast reflected-light imaging

Roman Space Telescope

Many giant planets

Many Earth/super-Earth mass planets around **M** and K stars

Pathfinder (only for Proxima b)

VLT (RISTRETTO)

ELT (METIS, HARMONI, ANDES, **PCS**)

Roman

HWO

2025 2030 2035 2040

Future instrumentation for high-contrast reflected-light imaging

Habitable Worlds Observatory (HWO)

Many giant planets

Many Earth/super-Earth size planets around Sun-like stars

Many Earth/super-Earth mass planets around **M** and K stars

Pathfinder (only for Proxima b)

VLT (RISTRETTO)

ELT (METIS, HARMONI, ANDES, **PCS**)

Roman

HWO

2025 2030 2035 2040