Image: Pablo Budassi

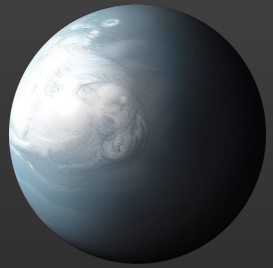
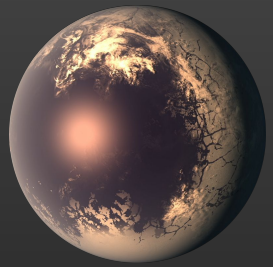


Image: NASA/JPL-Caltech



Atmospheric Characterization of the Temperate Planet LHS 1140 b with JWST/NIRISS

Is LHS 1140 b a Mini-Neptune or a Water World?

Charles Cadieux | CRAQ Annual Meeting | 8 May 2024

CRAQ
Comprendre l'Univers

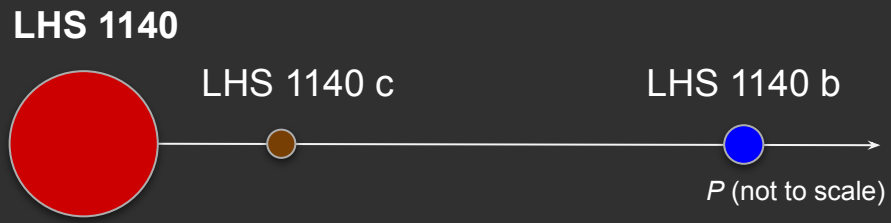
iREx

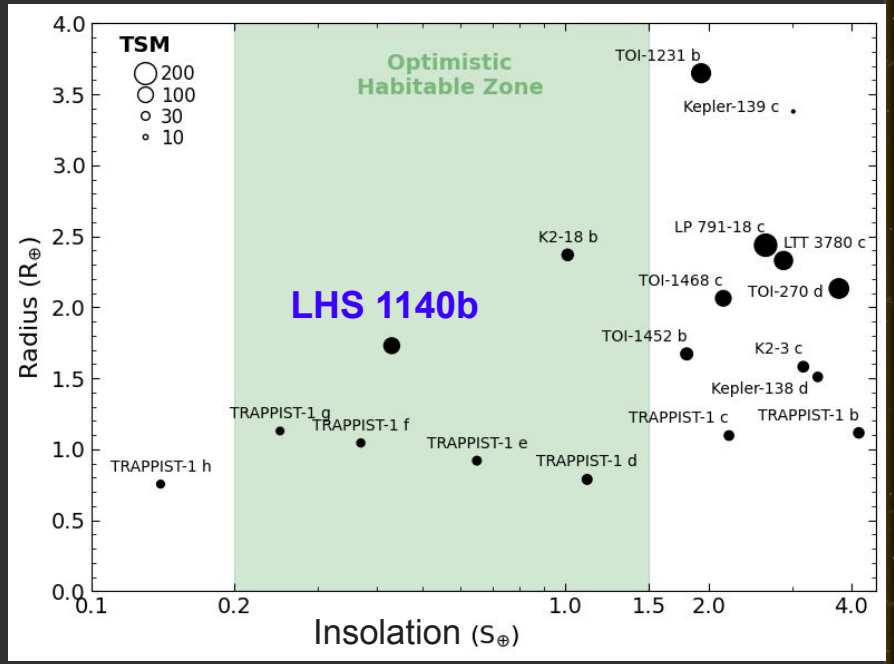
Université de Montréal

Context: The LHS 1140 System

Two-planet transiting system around an old (> 5 Gyr) and relatively inactive (P_{rot} = 131 d) M4.5 dwarf:

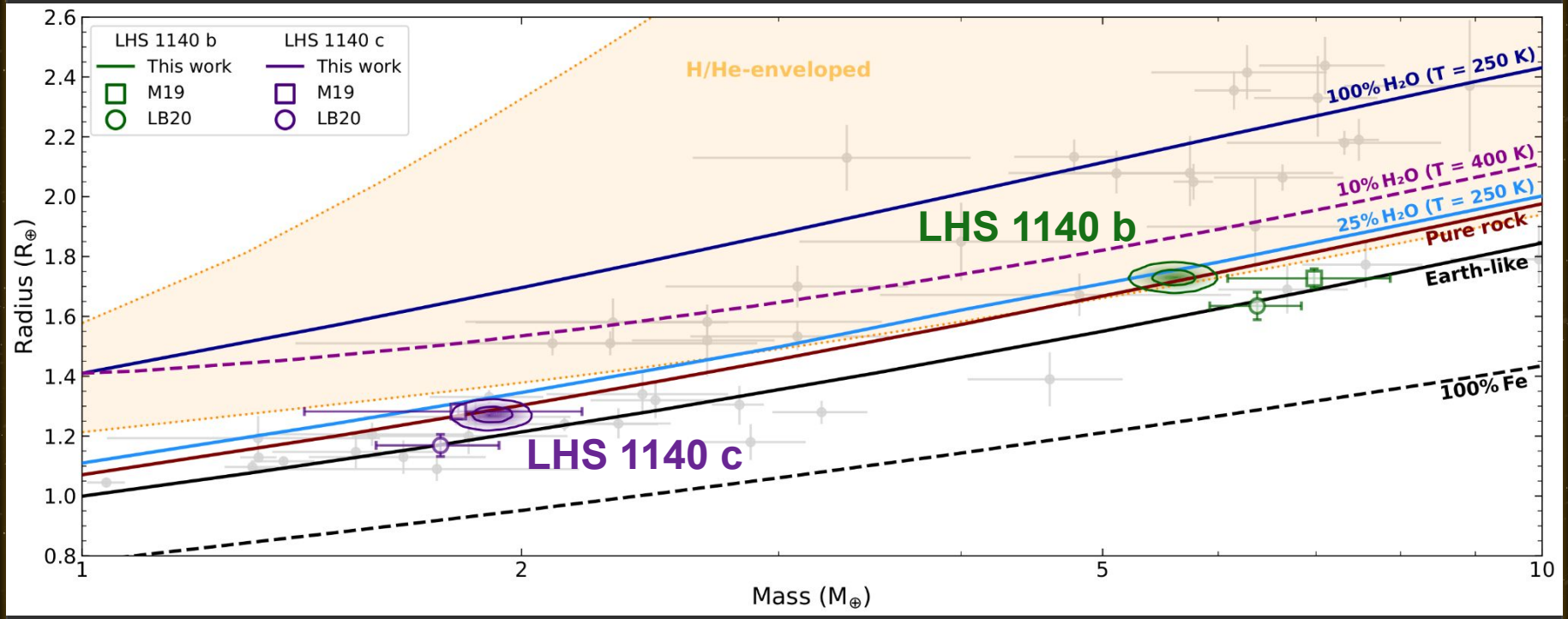
- **LHS 1140 b**, a **temperate** 1.73 $R_\oplus$ planet with ambiguous composition (H_2O-rich?, H_2-rich?)
- LHS 1140 c, an inner 1.27 $R_\oplus$ rocky super-Earth





Well-characterized (ΔR_p, ΔM_p < 30%) transiting planets

Revised Mass and Radius



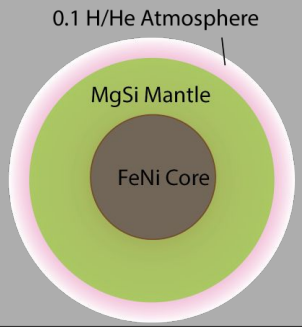
$\sigma_{R_p}/R_p \sim 2\%$

Cadieux et al. 2024

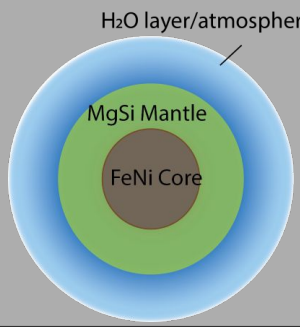
$\sigma_{M_p}/M_p \sim 3\%$

Interior Scenarios for LHS 1140 b

1. **Mini-Neptune**



2. **Water world**

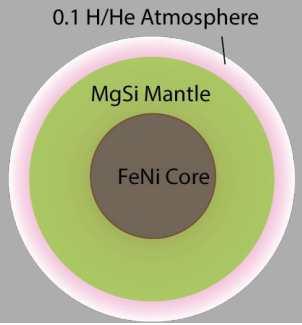


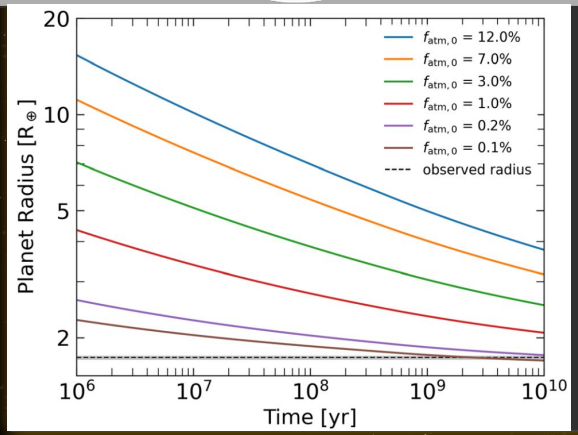
3. **Fe-depleted/Coreless Planet**

Cadieux et al. 2024

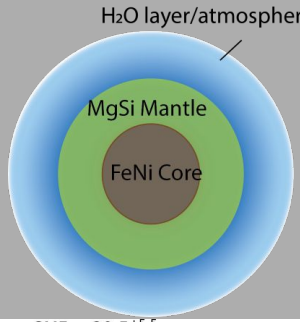
Interior Scenarios for LHS 1140 b

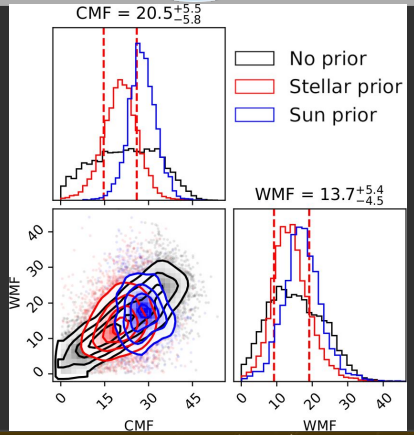
1. Mini-Neptune



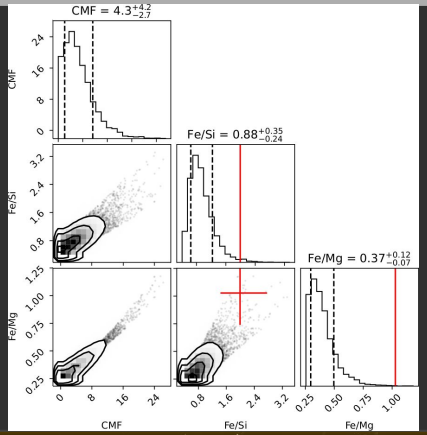


2. Water world





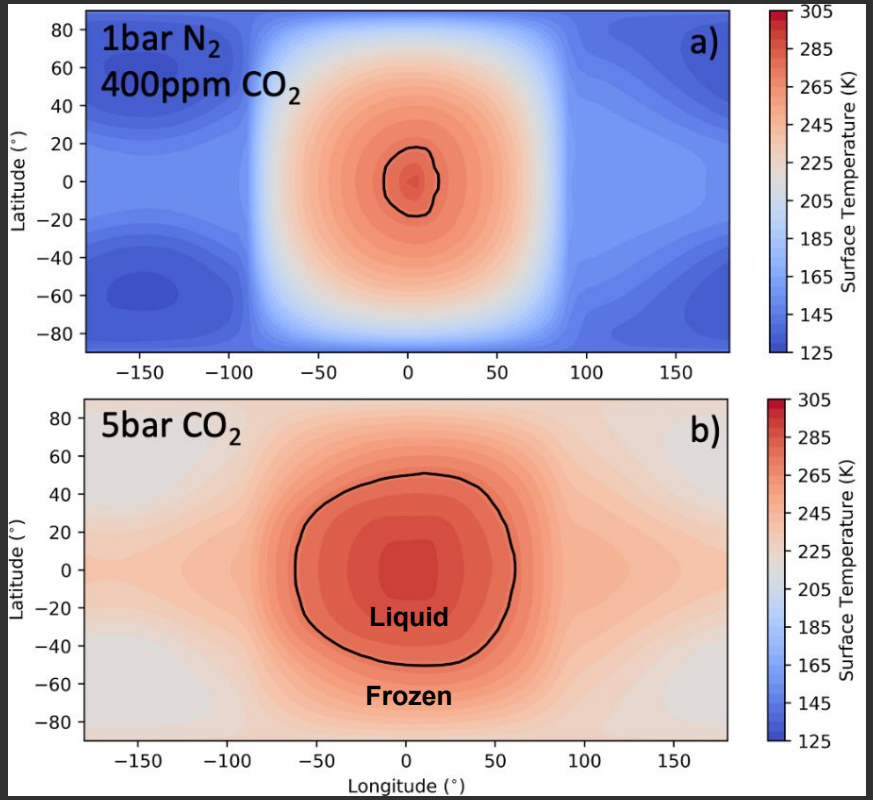
3. Fe-depleted/Coreless Planet



Work by M. Plotnykov, C. Cherubim; Cadieux et al. 2024

3D Global Climate Models

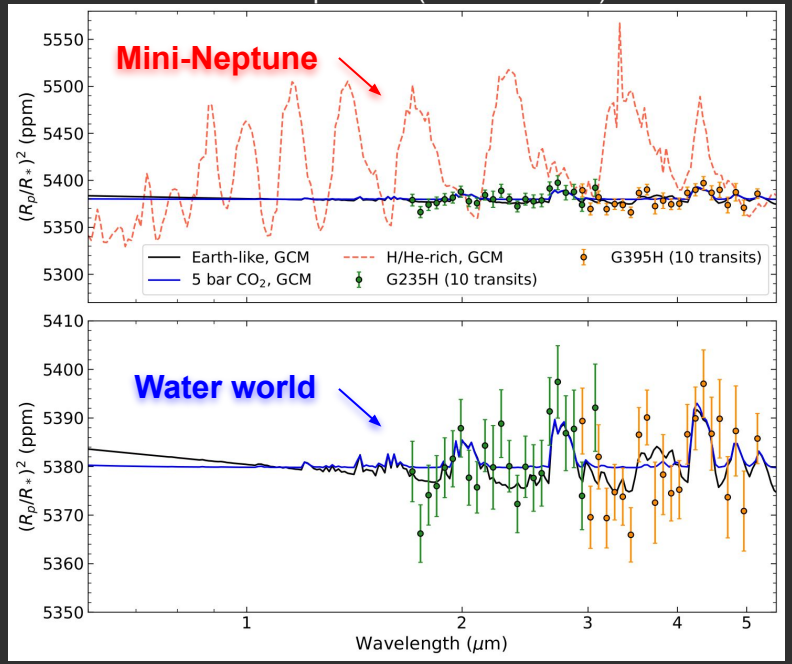
- For the water world case, the planet could be in a **snowball** configuration with:
  - Patch of liquid water whose size depends on CO_2 concentration
  - H_2O and CO_2 clouds



Work by M. Turbet, B. Charnay; Cadieux et al. 2024

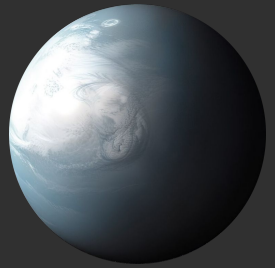
LHS 1140 b: A Mini-Neptune or a Water World?

Simulated transmission spectrum (Cadieux+2024)



~100 ppm

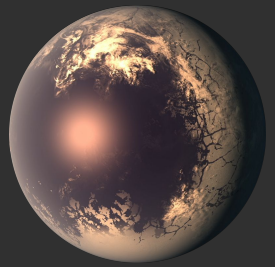
1 visit



Mini-Neptune (H_2, CH_4, NH_3)

~15 ppm

12 visits



Water world (N_2?, CO_2)

LHS 1140 b: A Mini-Neptune or a Water World?

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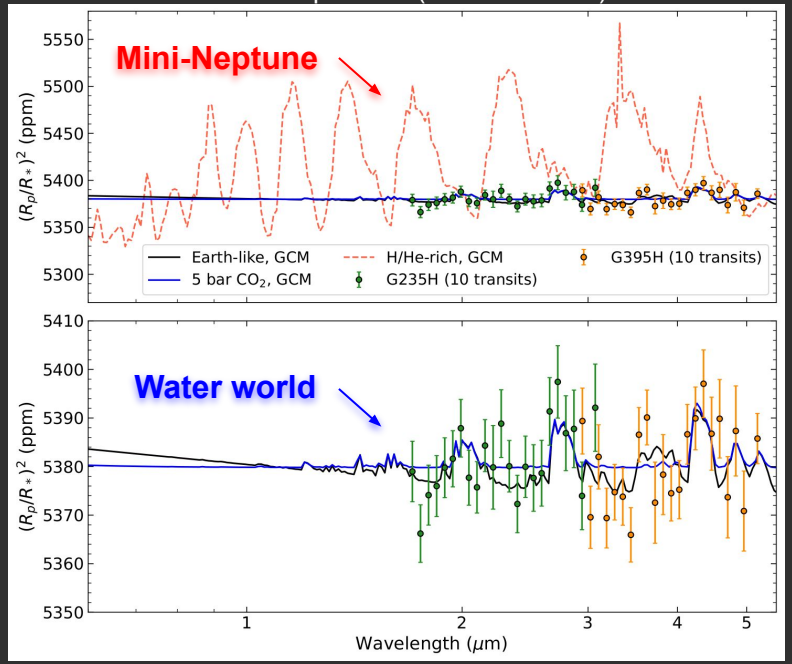
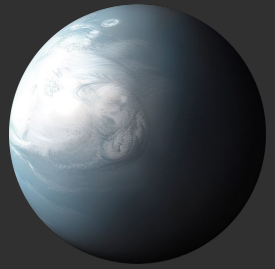


~100 ppm

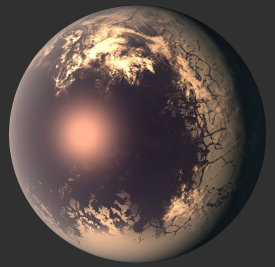
1 visit



Mini-Neptune (H_2, CH_4, NH_3)

~15 ppm

12 visits

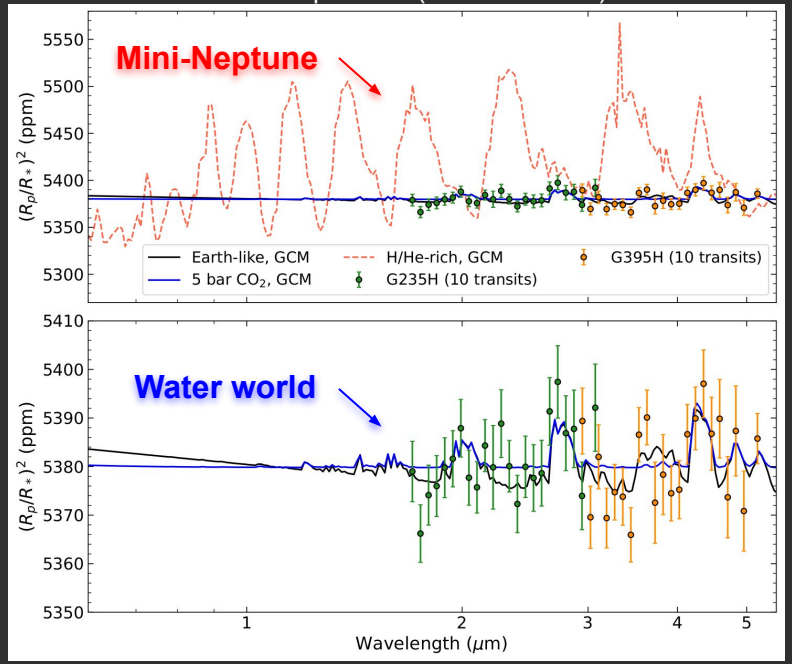


Water world (N_2?, CO_2)

Transit spectroscopy can discriminate the two scenarios*

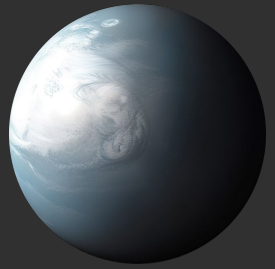
LHS 1140 b: A Mini-Neptune or a Water World?

Simulated transmission spectrum (Cadieux+2024)



~100 ppm

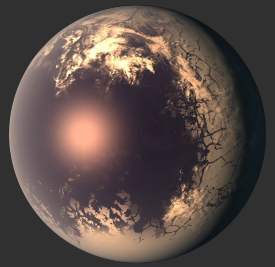
1 visit



Mini-Neptune (H_2, CH_4, NH_3)

~15 ppm

12 visits

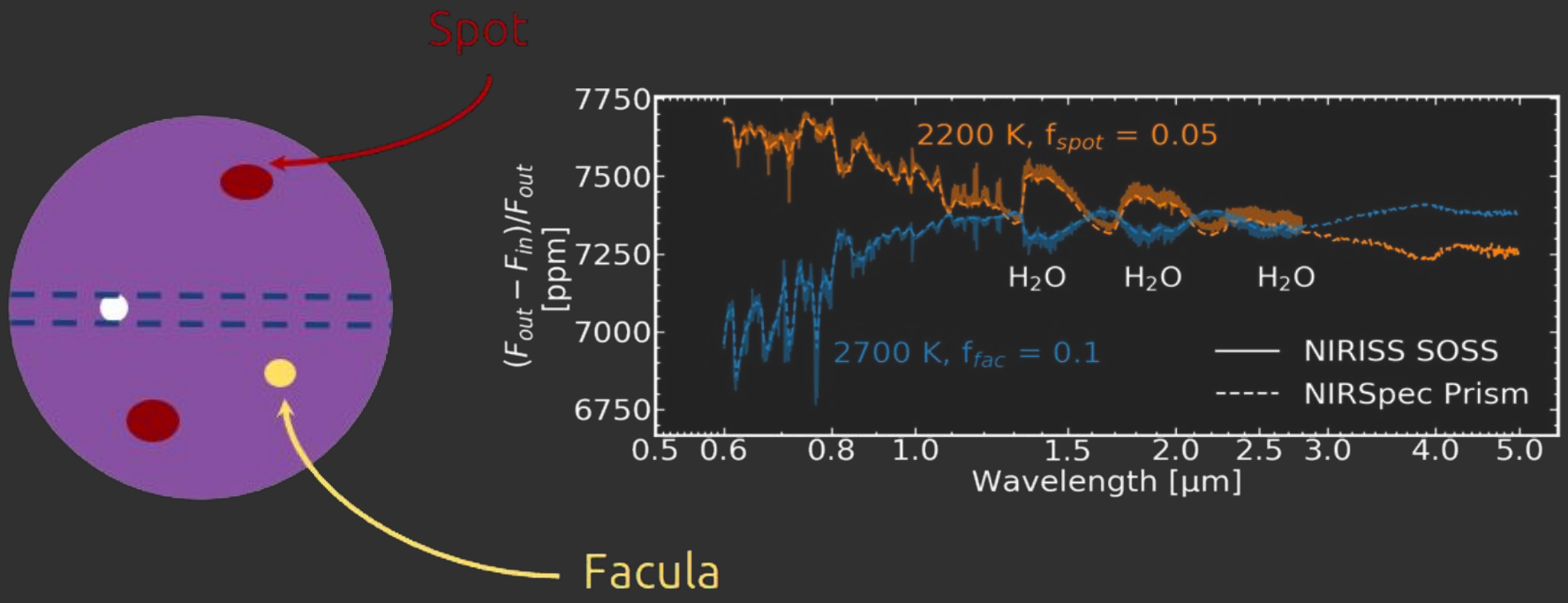


Water world (N_2?, CO_2)

Transit spectroscopy can discriminate the two scenarios*

*provided that stellar contamination can be properly treated

The Transit Light Source (TLS) Effect

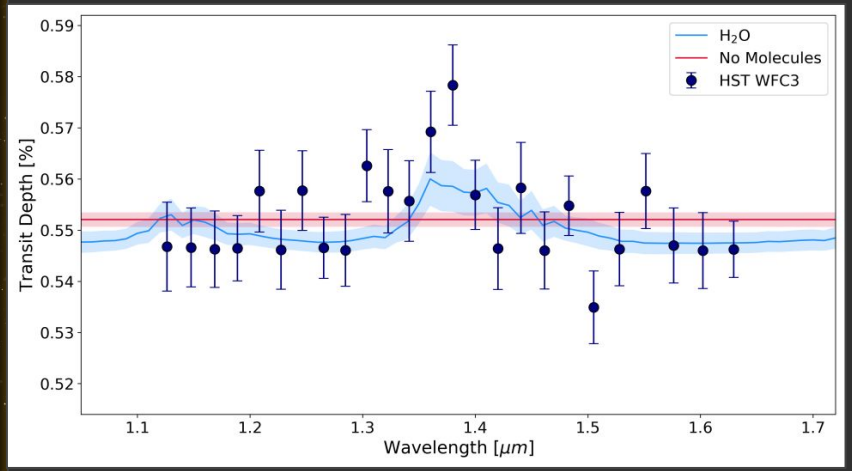


Ghost atmospheric signal induced by stellar activity

Credit: Olivia Lim

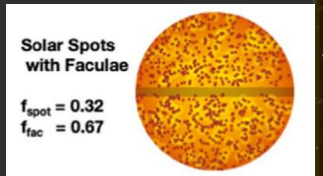
Transit Spectroscopy with HST/WFC3

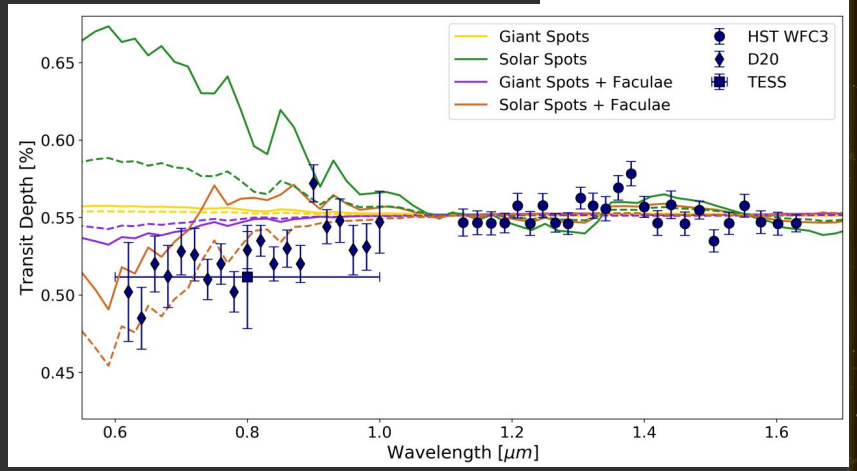
Tentative detection of H_2O near 1.4 μm (~100 ppm) in a hydrogen-dominated atmosphere (μ ~ 2.3)



Edwards+2021

A combination of **unocculted** spots (32%) and faculae (67%) could also explain the data





Diamond-Lowe+2020; Edwards+2021

Crédit : NASA GSFC/CIL/Adriana Manrique Gutierrez

Enters JWST

- **LHS 1140 has limited visibility** (only 4 observable transits per year)
- Cycle 1 NIRSpec (1.7–5.2 μm) program GO2334 (PI: Damiano & Hu) with 2 transits in July 2023
- **We obtained 2 transits in Dec. 2023 as part of program DD6543 (PI: Cadieux & Doyon)**
- NIRISS/SOSS (0.6–2.8 μm) to:
  - Repeat the HST observations
  - Characterize levels of stellar activity
  - Confirm/reject the mini-Neptune scenario for LHS 1140 b

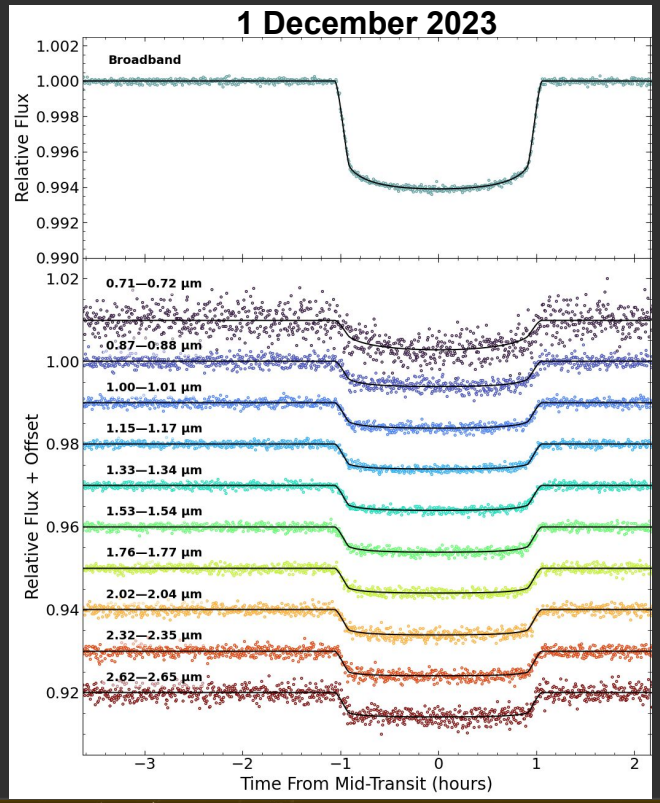
Transit Spectroscopy with JWST/NIRISS

(DD6543, PI: Cadieux & Doyon)

Quiet star

No variability

No flares



Cadieux et al. in prep.

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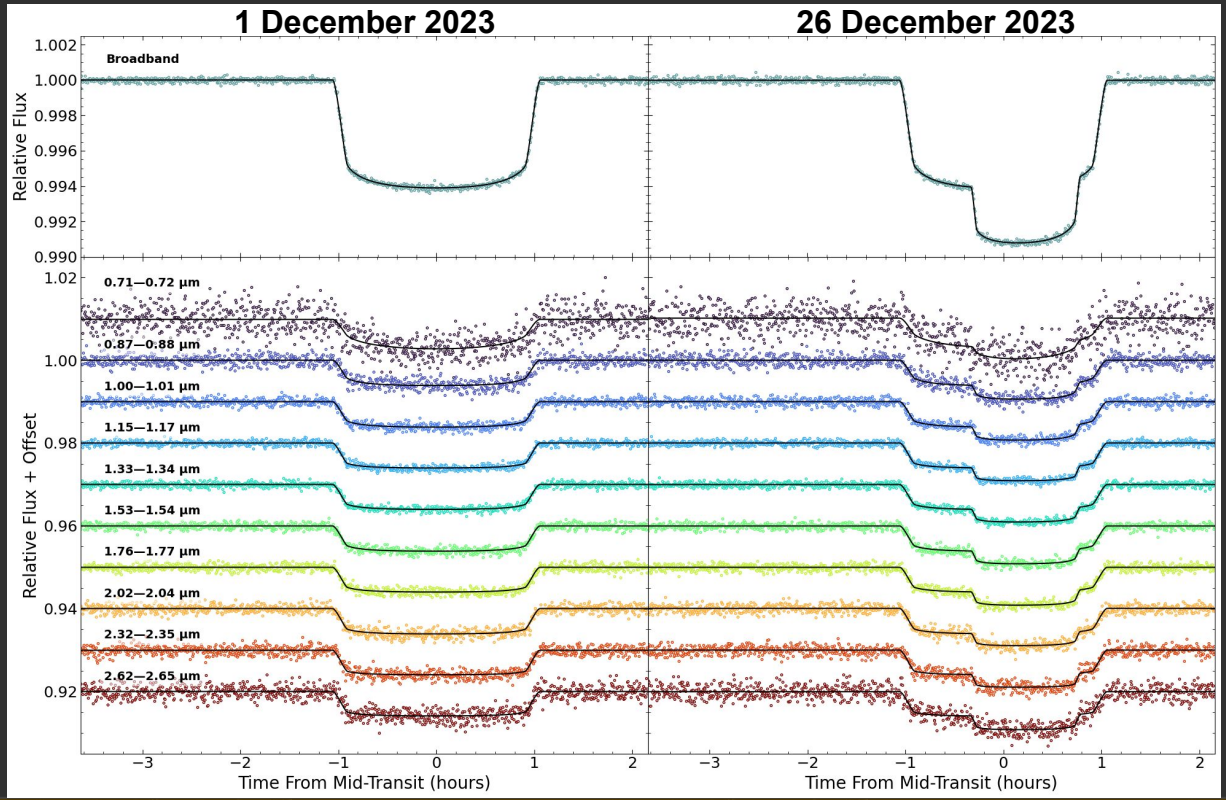
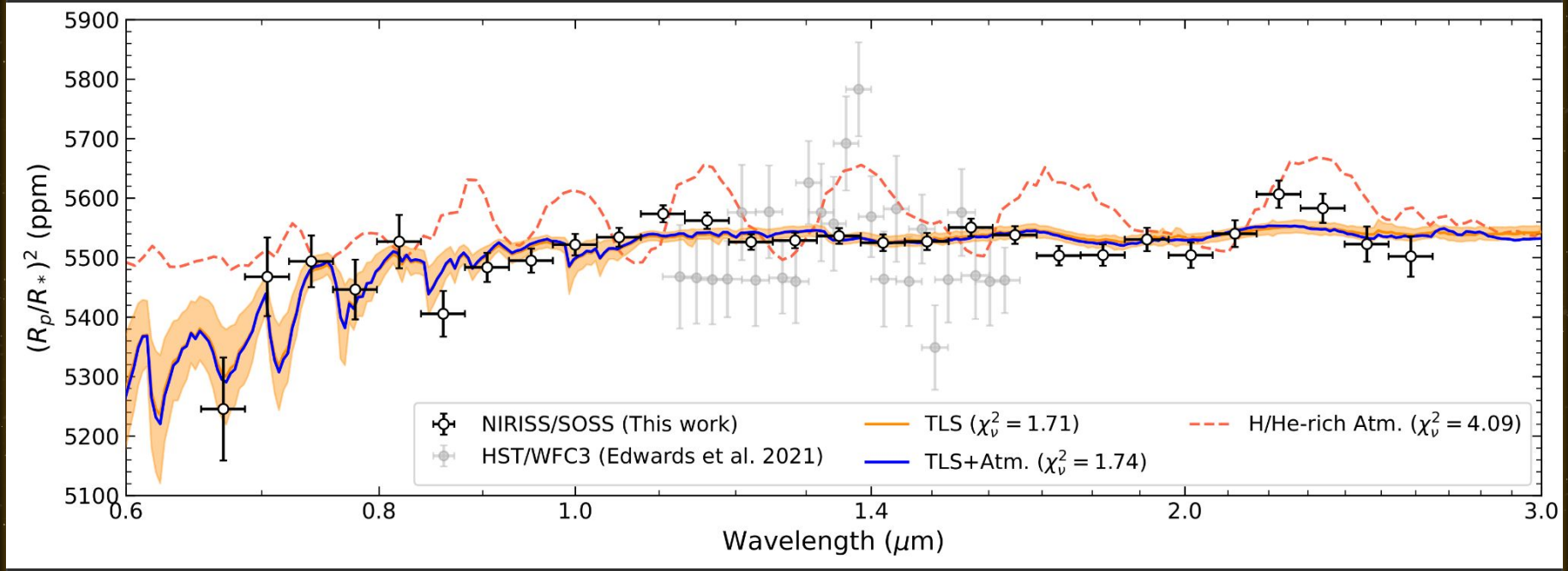


A double transit of LHS 1140 c!

Cadieux et al. in prep.

Transit Spectroscopy with JWST/NIRISS

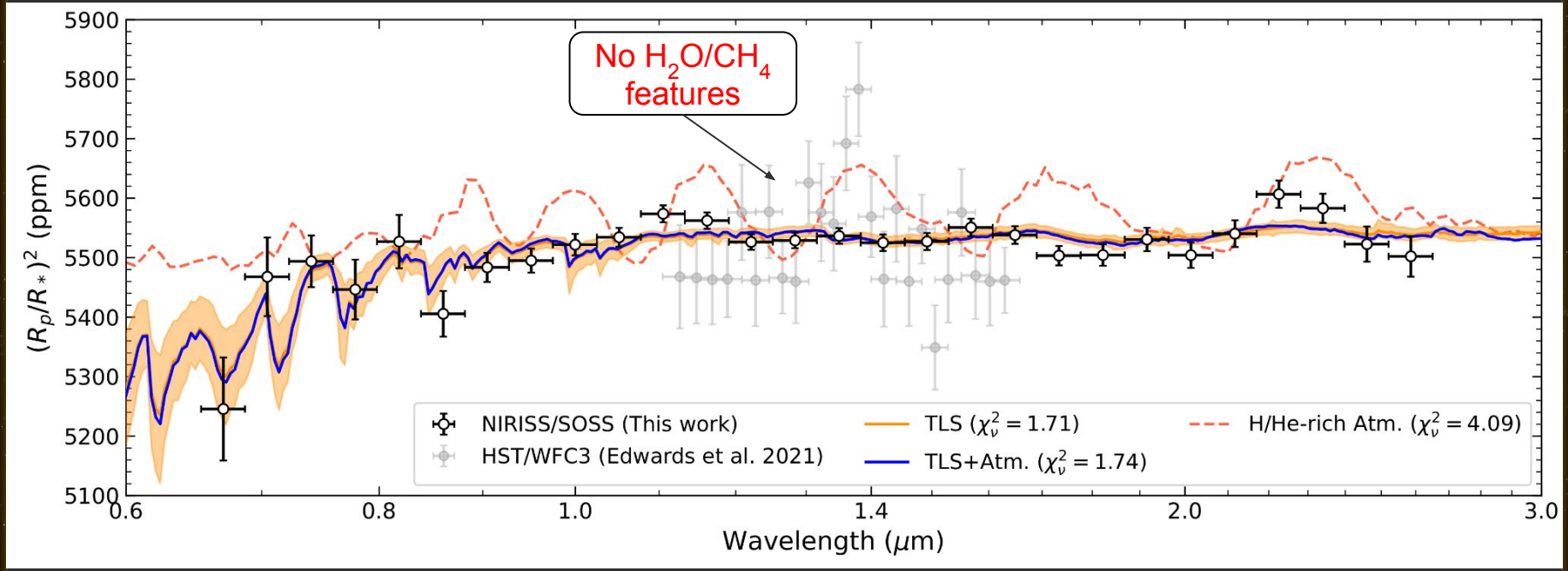
(DD6543, PI: Cadieux & Doyon)



Doyon (PAS proceedings, 2024); Cadieux et al. in prep.

Transit Spectroscopy with JWST/NIRISS

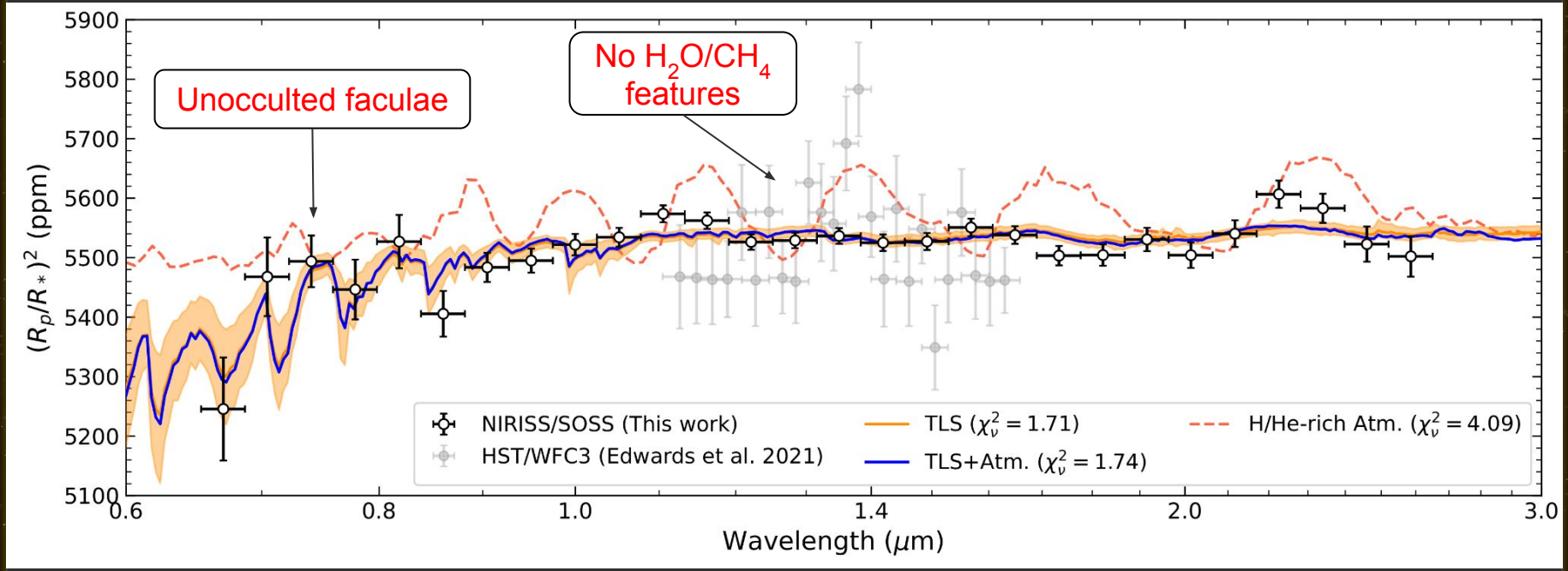
(DD6543, PI: Cadieux & Doyon)



Doyon (PAS proceedings, 2024); Cadieux et al. in prep.

Transit Spectroscopy with JWST/NIRISS

(DD6543, PI: Cadieux & Doyon)



Doyon (PAS proceedings, 2024); Cadieux et al. in prep.

Transit Spectroscopy with JWST/NIRISS

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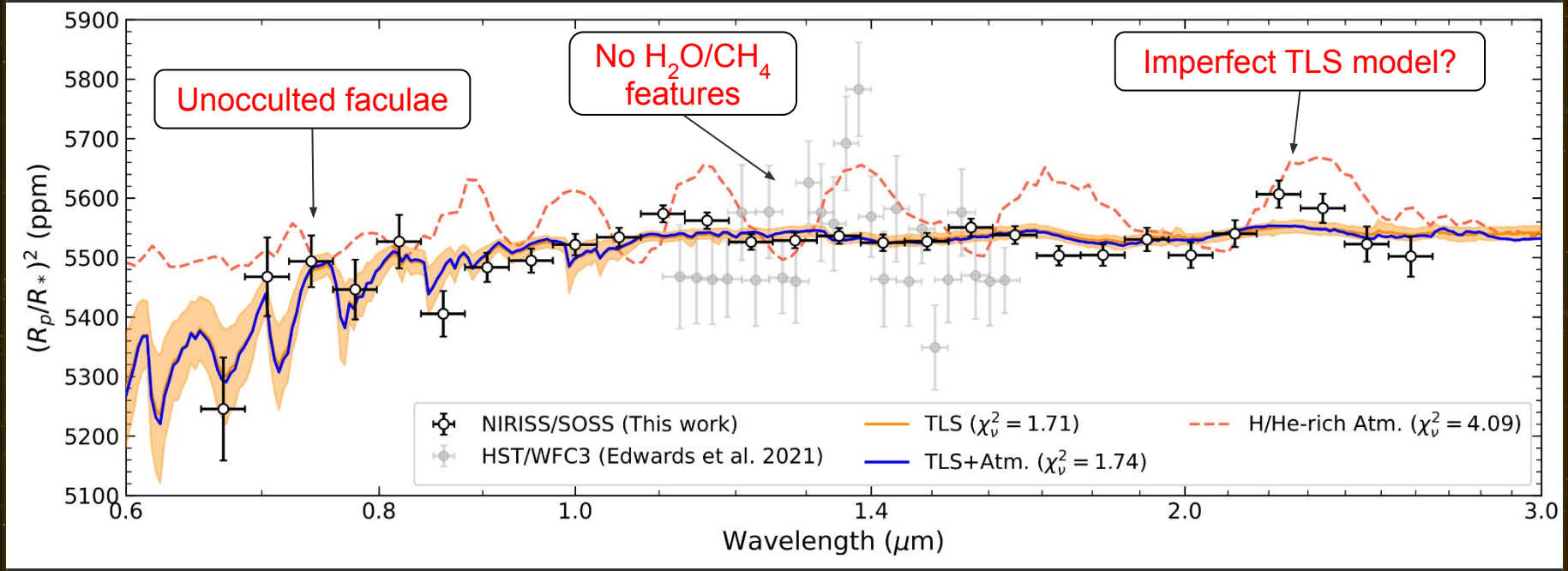
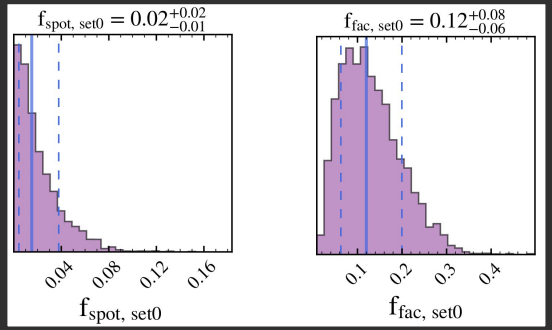
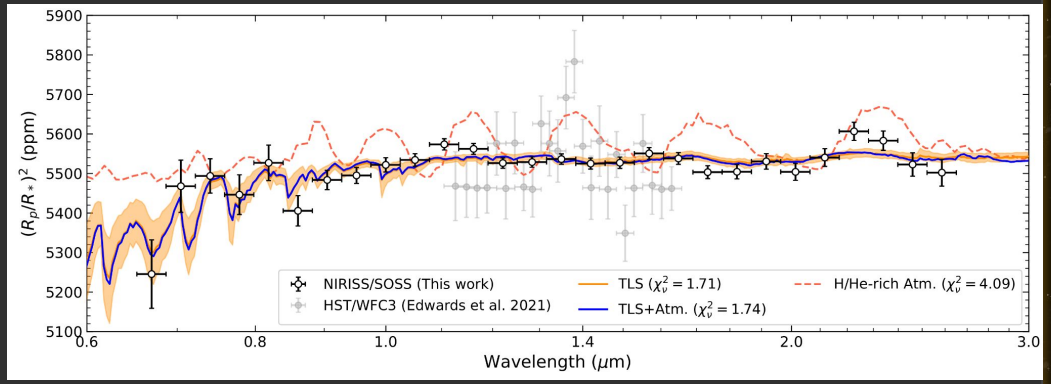


Doyon (PAS proceedings, 2024); Cadieux et al. in prep.

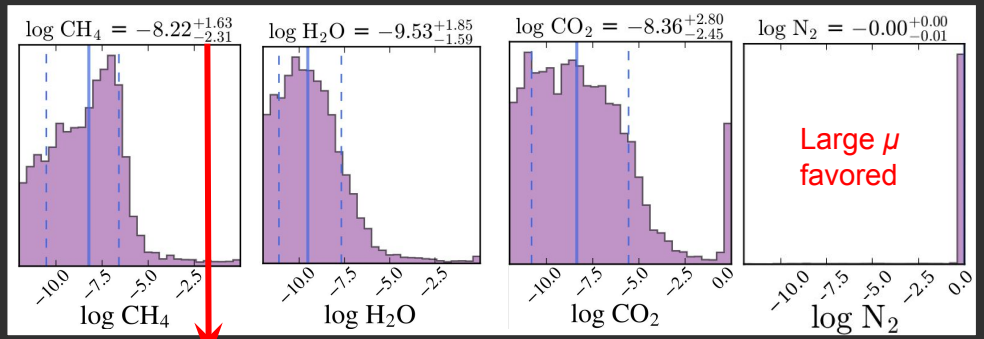
Free Chemistry Atmospheric Retrieval

Stellar contamination model





Atmospheric abundances



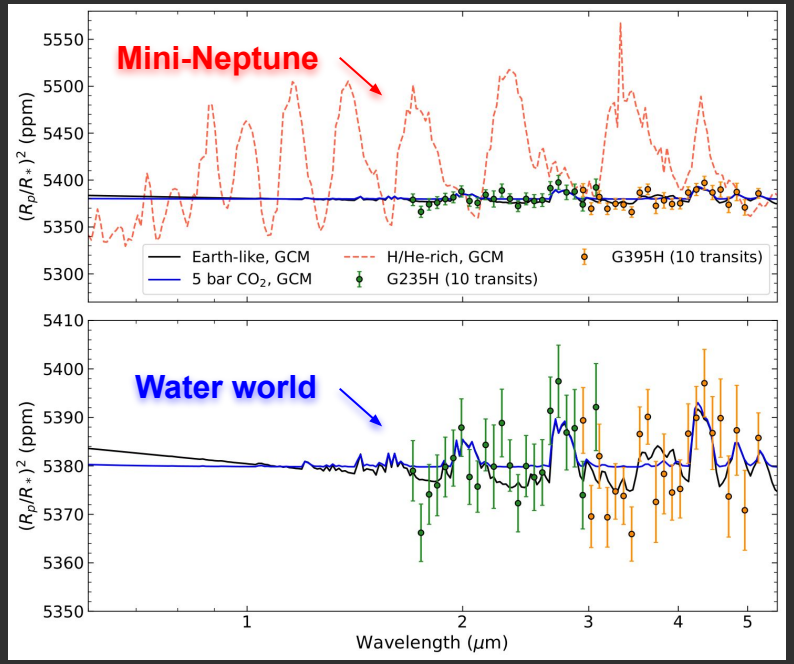
~1% for K2-18 b (Madhusudhan+2023)

- Evidence (~2σ) of **unocculted faculae**
- No molecular absorption (upper limits inferred)
- A **featureless spectrum** is preferred over the mini-Neptune prediction (>10σ)

Work by R. MacDonald, O. Lim; Cadieux et al. in prep.

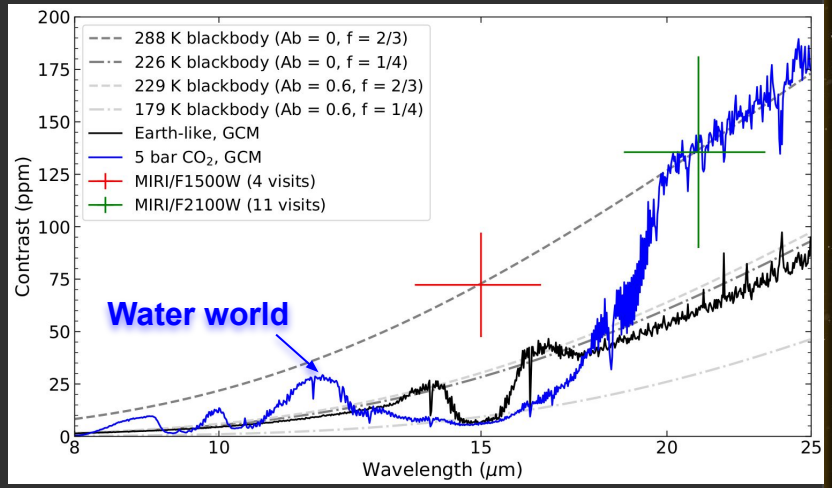
What's next? … More data!

Transit spectroscopy (NIRISS+NIRSpec)



~12 visits (3 years) needed to constrain CO_2

Eclipse photometry (MIRI)

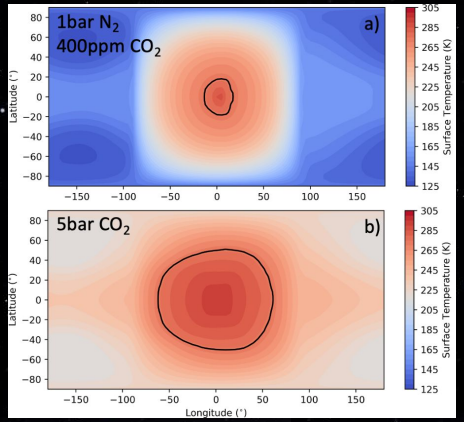


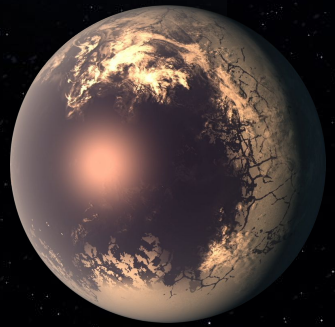
- 15 microns: 1 year to rule out the airless case
- 21 microns: 3 years to detect a CO_2-dominated atmosphere

Figure by S. Salhi; Cadieux et al. in prep.

Summary & Conclusion

- The **JWST/NIRISS** transmission spectrum of LHS 1140 b reveal:
  - LHS 1140 b ***is not*** a lower-mass version of K2-18 b; the spectrum is **incompatible (>10σ) with the mini-Neptune scenario**
  - Evidence (2σ) of TLS from **unocculted faculae**, even for this quiet star
- ***LHS 1140 b is a strong water world candidate, probably the best target for inferring surface liquid water through atmospheric detection of CO_2***
- Transmission+eclipse data ***urgently*** needed to constrain an atmosphere





Merci!