

Ground and space-based observatories: the feasibility of measuring D/H in exoplanet atmospheres

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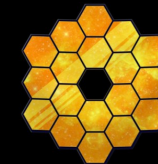
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D/H as a probe for atmospheric evolution



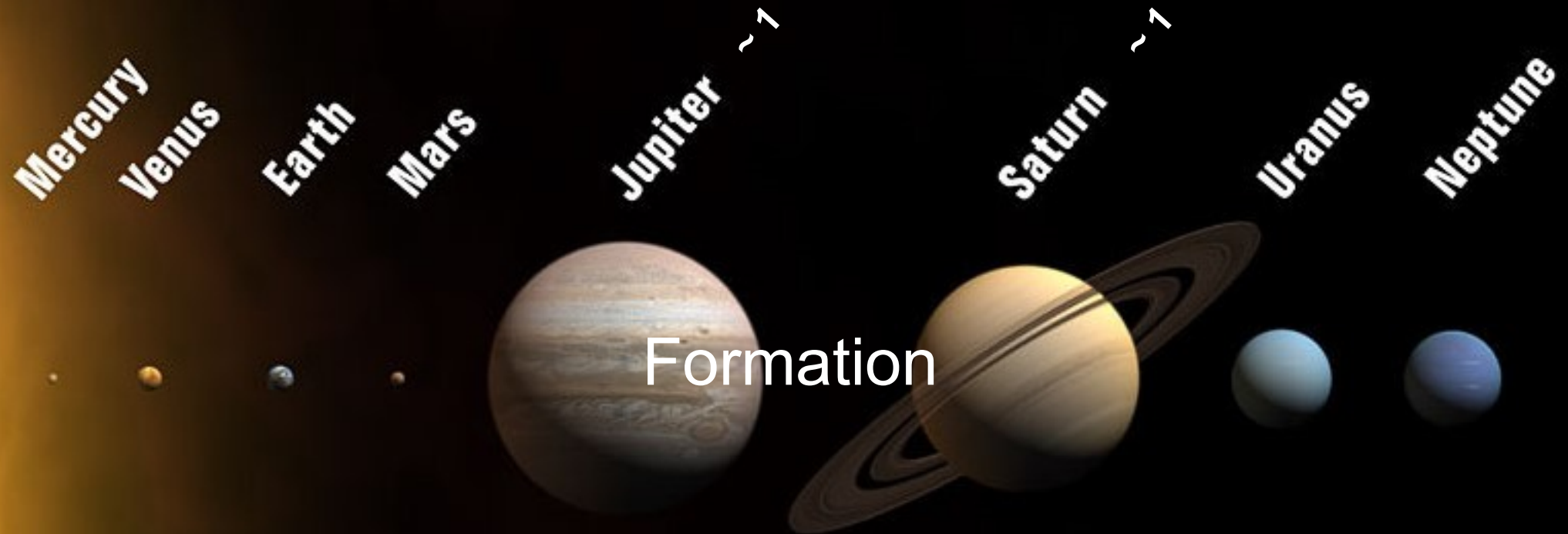
1. Solar system and the deuterium/hydrogen ratio (D/H)
2. Molecular absorption constrained using state-of-the-art databases
3. Space-based: Trappist-1b in primary transit
4. Ground-based: Emission from a hot Jupiter





D/H in the Solar System

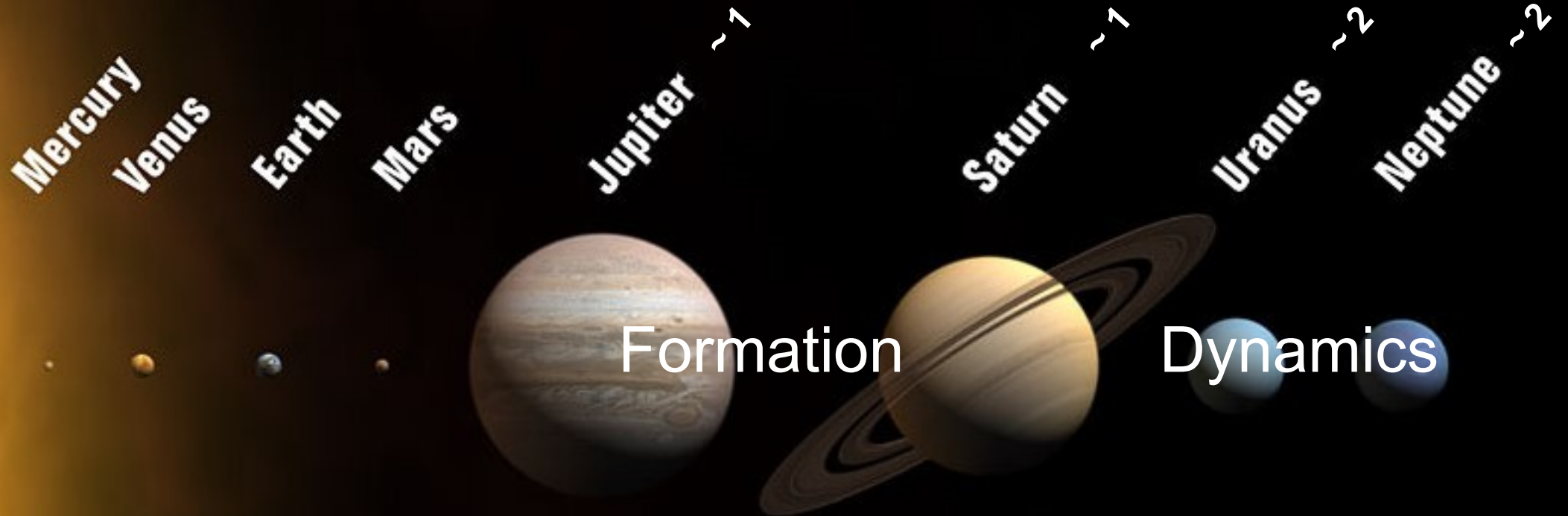
D/H vs. protosolar value of $2 \cdot 10^{-5}$





D/H in the Solar System

D/H vs. protosolar value of $2 \cdot 10^{-5}$





D/H in the Solar System

D/H vs. protosolar value of $2 \cdot 10^{-5}$



Evolution

Formation

Dynamics



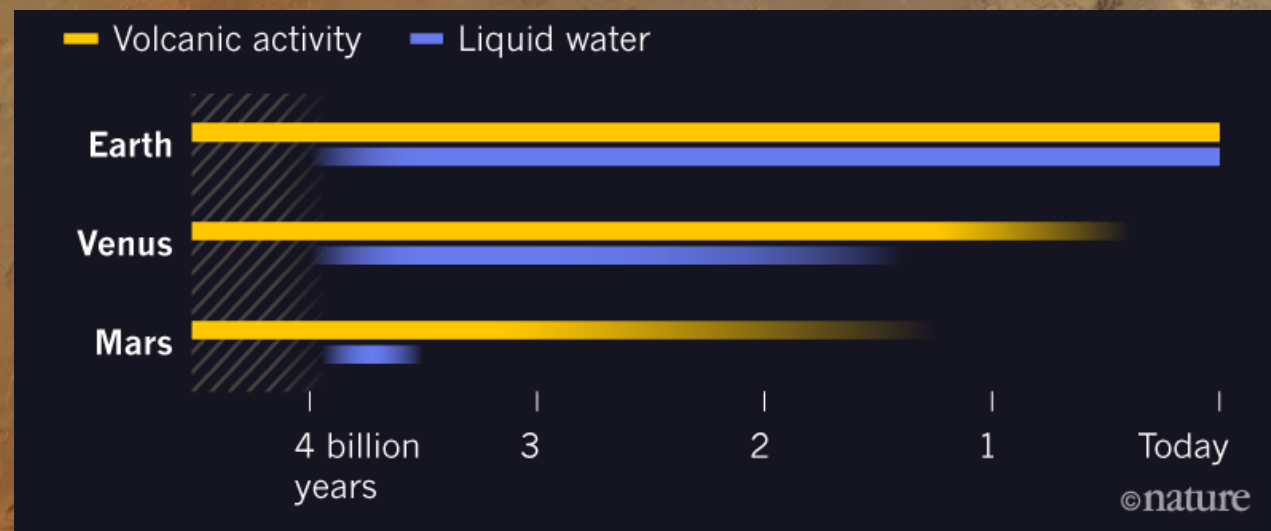
Atmospheric escape and D/H

Both thermal and suprathermal escape result in loss of lighter isotopes:

- 1) Higher velocity
- 2) More abundant at higher altitudes

Effects are the strongest in D/H (not seen in $^{12}\text{C}/^{13}\text{C}$ or O isotopes)

For Venus and Mars, the D/H ratios indicate significant water loss

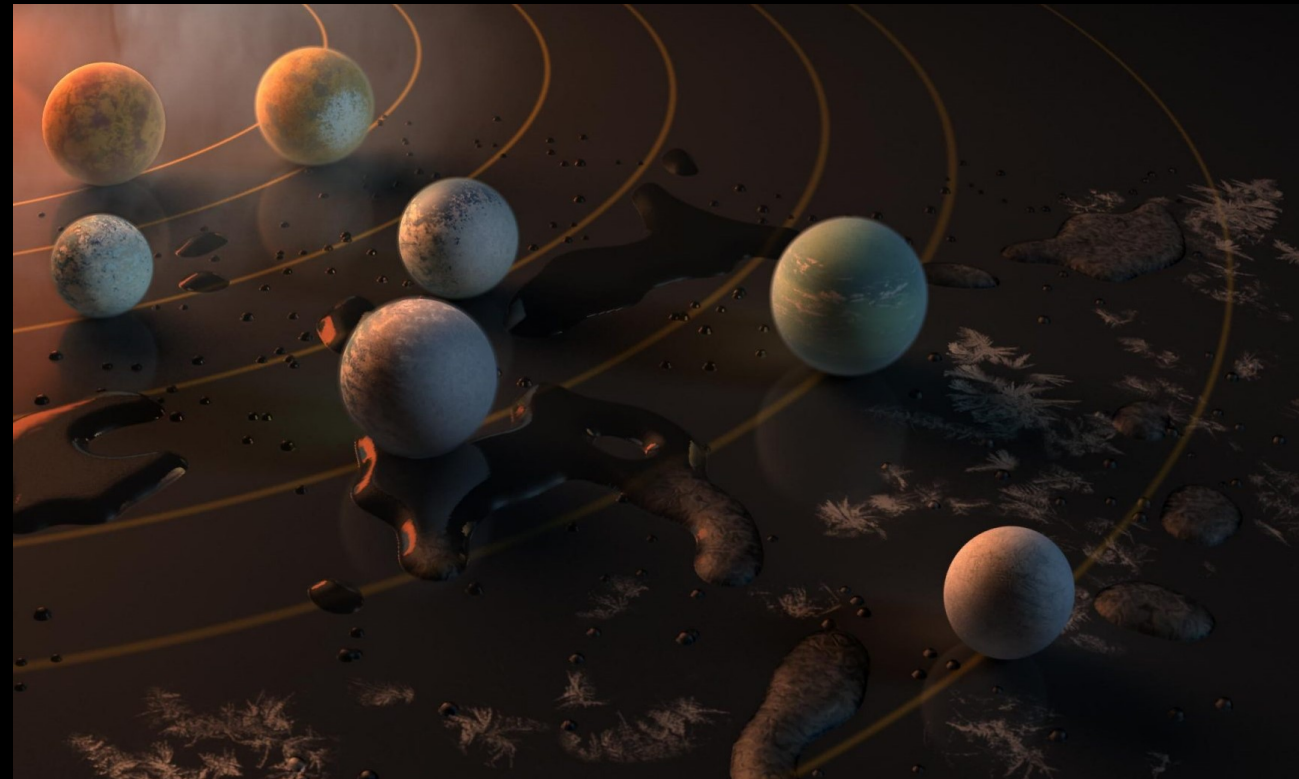




Why the D/H ratio in exoplanets?

Constraints on the D/H reveal parts of the history of the atmosphere

1. Formation and dynamics
2. Atmospheric evolution
 - Runaway greenhouse
 - Loss of magnetic field?
 - Stellar output?
 - Presence or loss of liquid water
→ habitability?

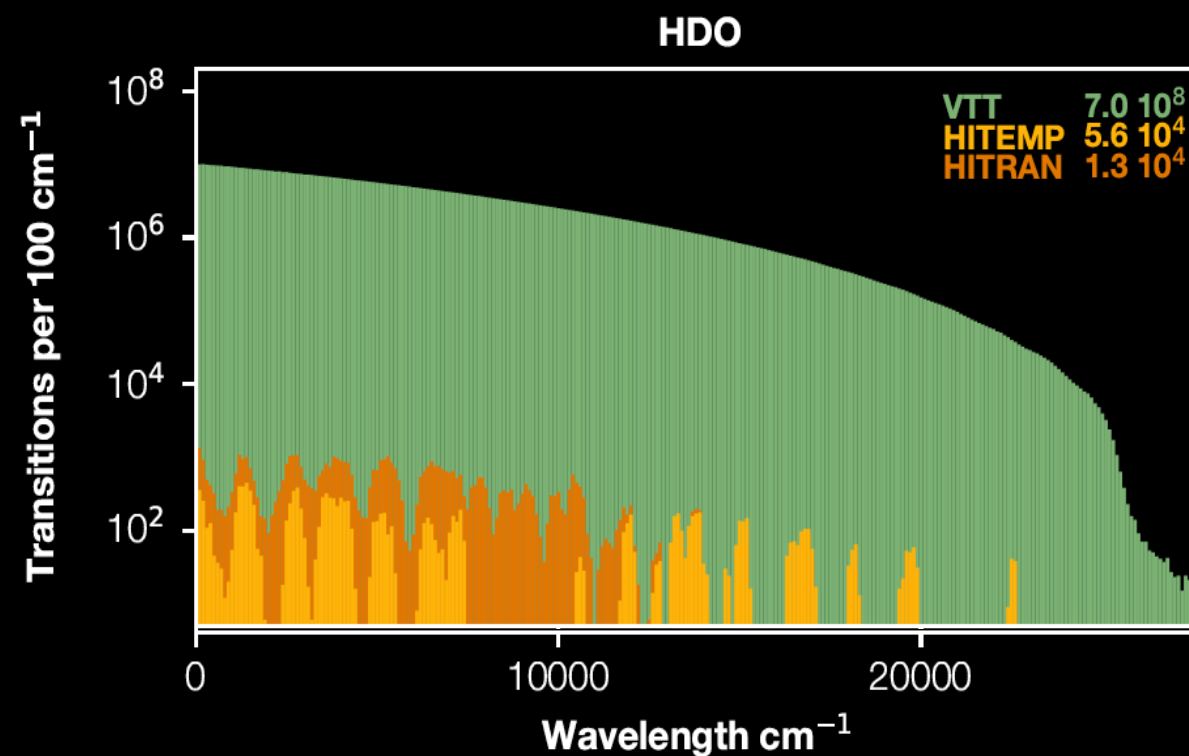




The need for state-of-the-art spectroscopy

Diversity of exoplanets demands complete and accurate spectroscopic data

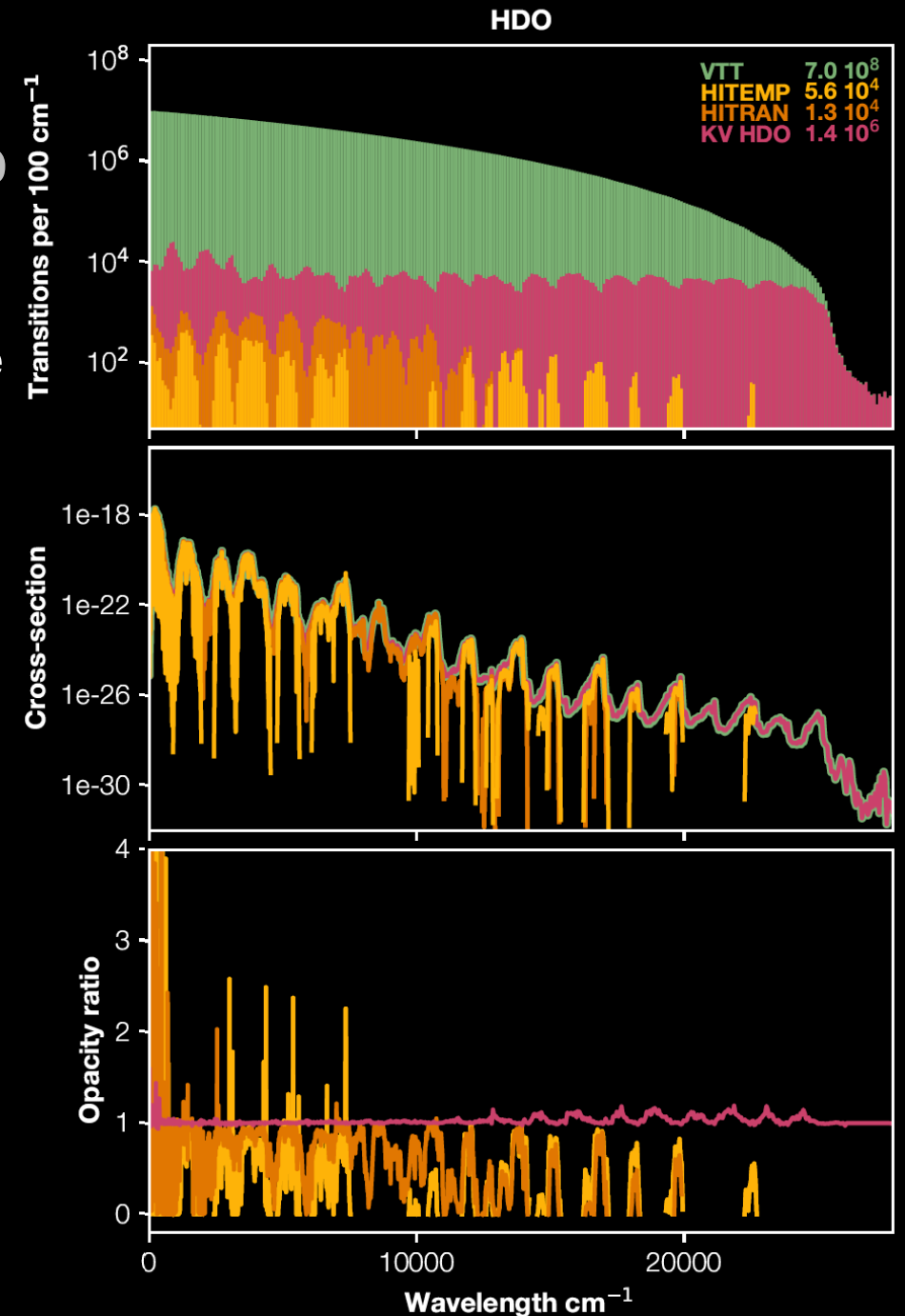
- HITRAN/HITEMP:
 - Incomplete in wavelength coverage
 - Not applicable for higher temperatures
- VTT (ab initio line lists) are complete:
 - Too large for RT
 - Line shape info missing



The need for state-of-the-art spectroscopy

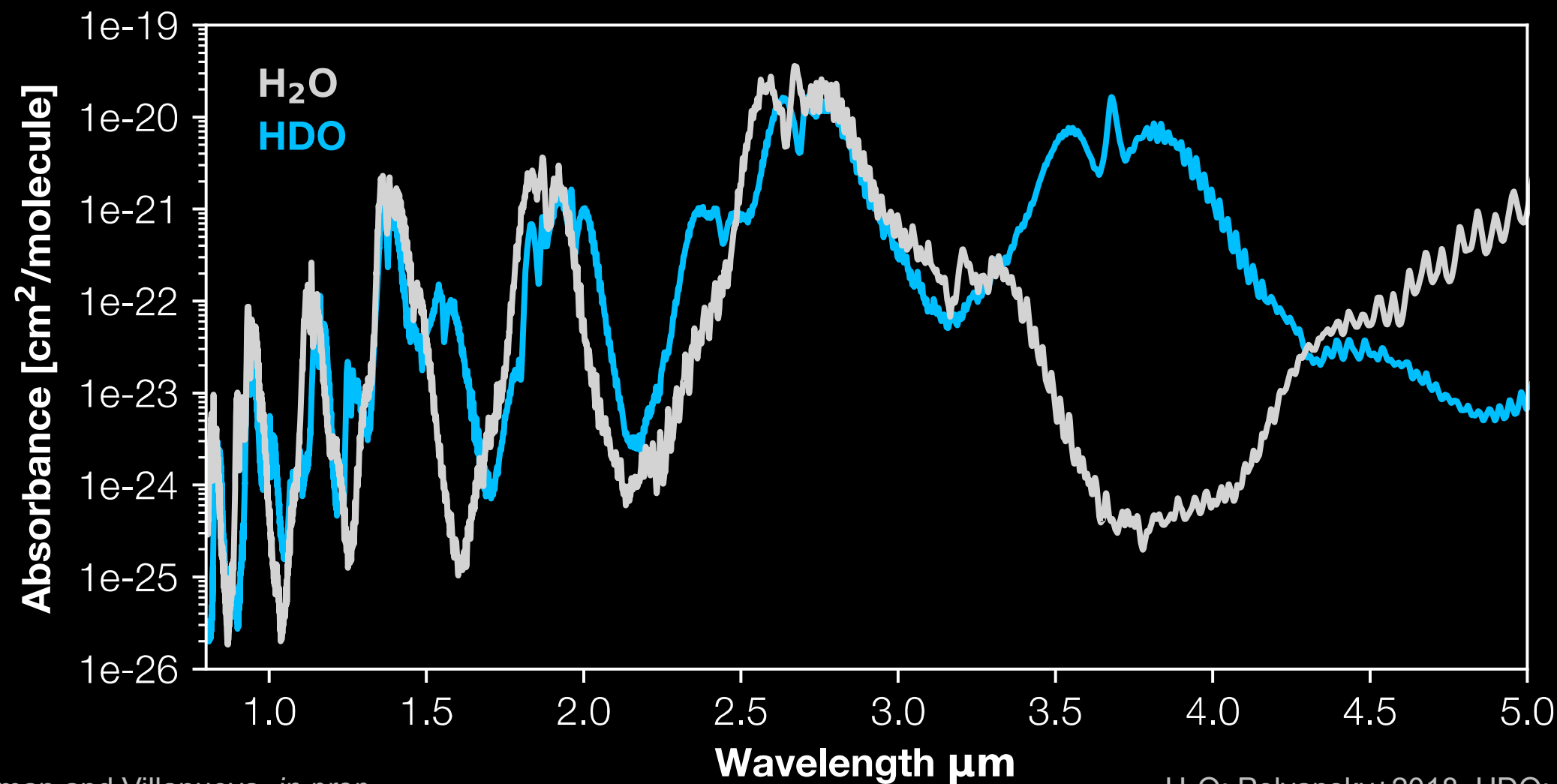
Diversity of exoplanets demands complete and accurate

- HITRAN/HITEMP:
 - Incomplete in wavelength coverage
 - Not applicable for higher temperatures
- Ab initio lists are complete:
 - Too large for RT
 - Line shape info missing
- Our hybrid database:
 - Complete coverage
 - Line shape information
 - Minimal loss of opacity





Water at 3.7 μm





Atmospheric escape and D/H using space-based observatories

- Space-based observatories telluric free and accurate photometric spectra
- Access to wavelength all wavelength ranges

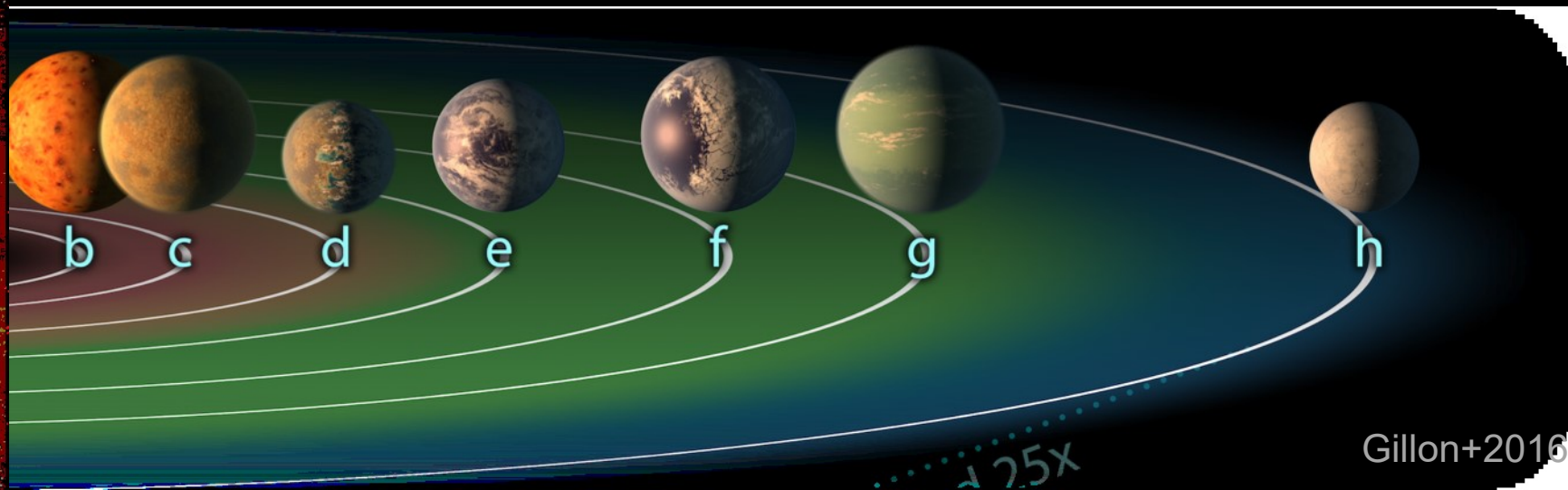




Simulations of the Trappist-1 system:

- Trappist-1 system favorable for atmospheric studies:
 - Strong infrared output
 - Relatively small host star
 - Planets are close in

Resulting in deep and frequent transits

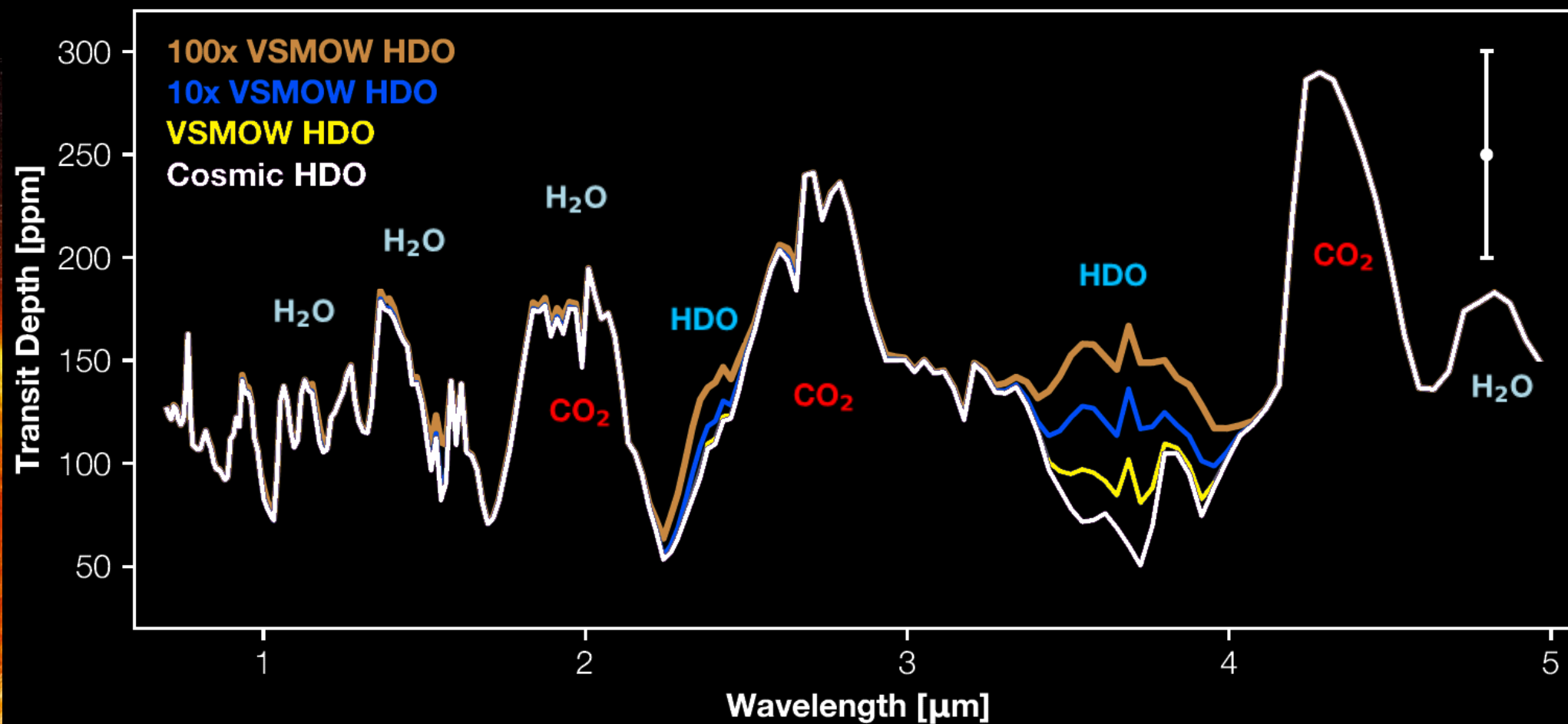


Gillon+2016



Simulations of the Trappist system:

Primary transit of Trappist 1b



O_2 dominated
 H_2O 500 ppm





Atmospheric escape and D/H using ground-based observatories

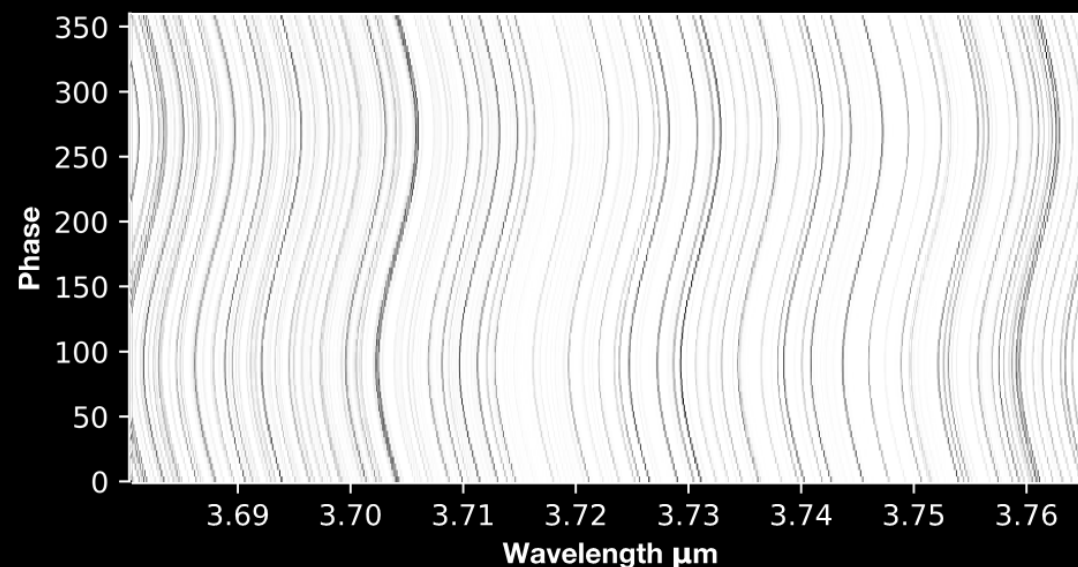
- High-resolution studies possible ($R \sim 50,000 - 100,000$)
- Larger collecting areas



Example: H₂O detection in HD 189733b

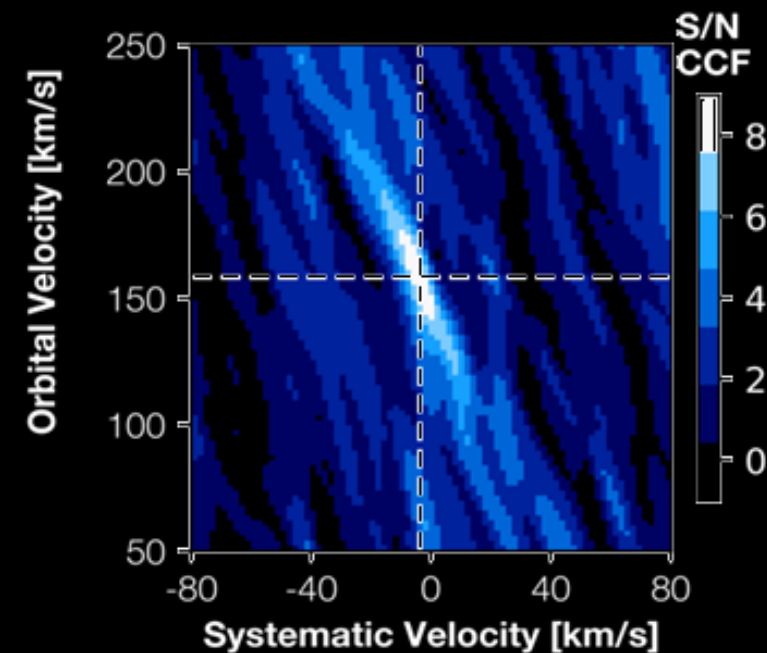
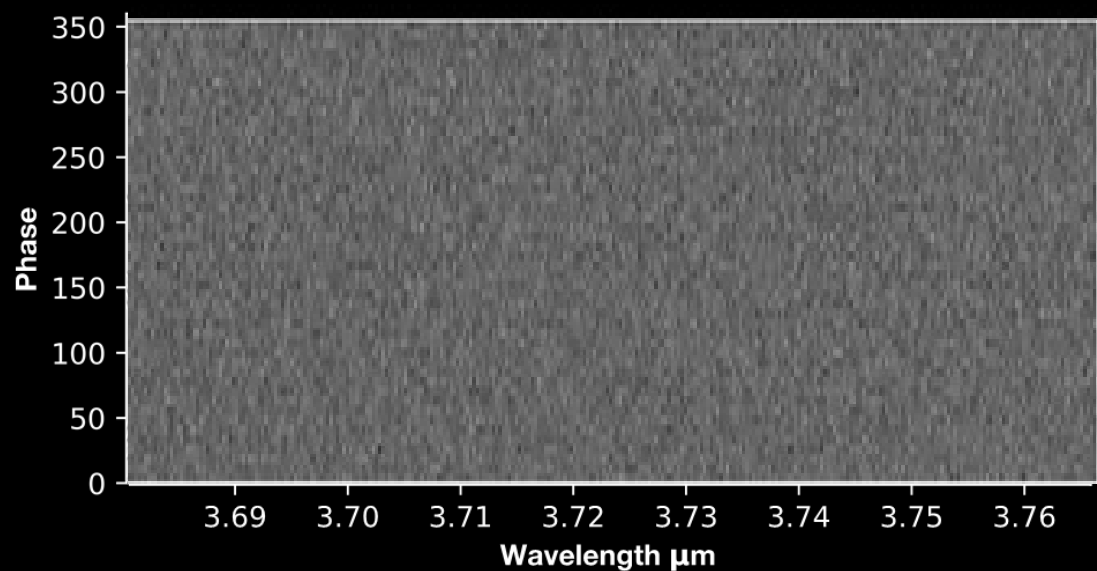


- High-resolution observations of bright and close in planets
- Changing Doppler shift of planetary spectra during observations allows separation from telluric and stellar features

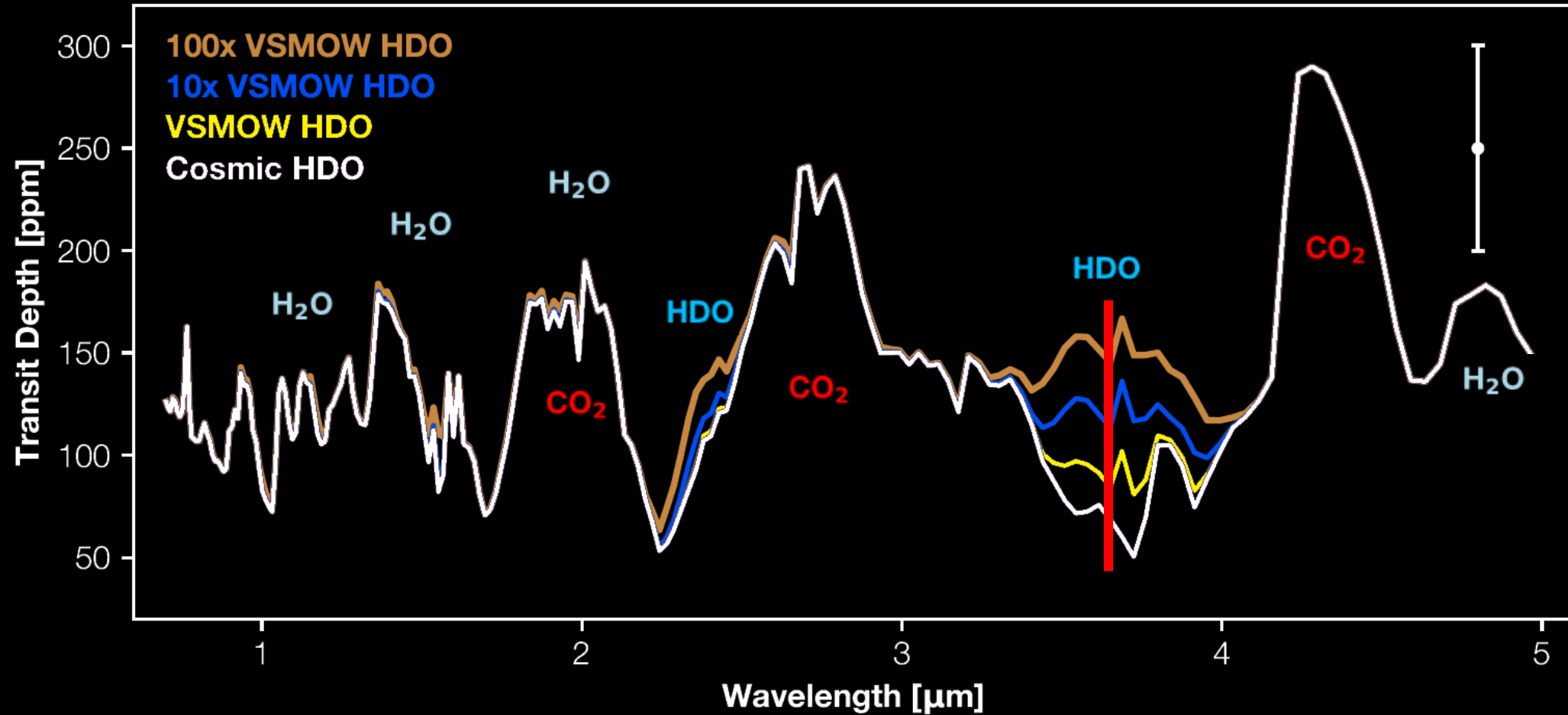


Example: H₂O detection in HD 189733b

Observer view



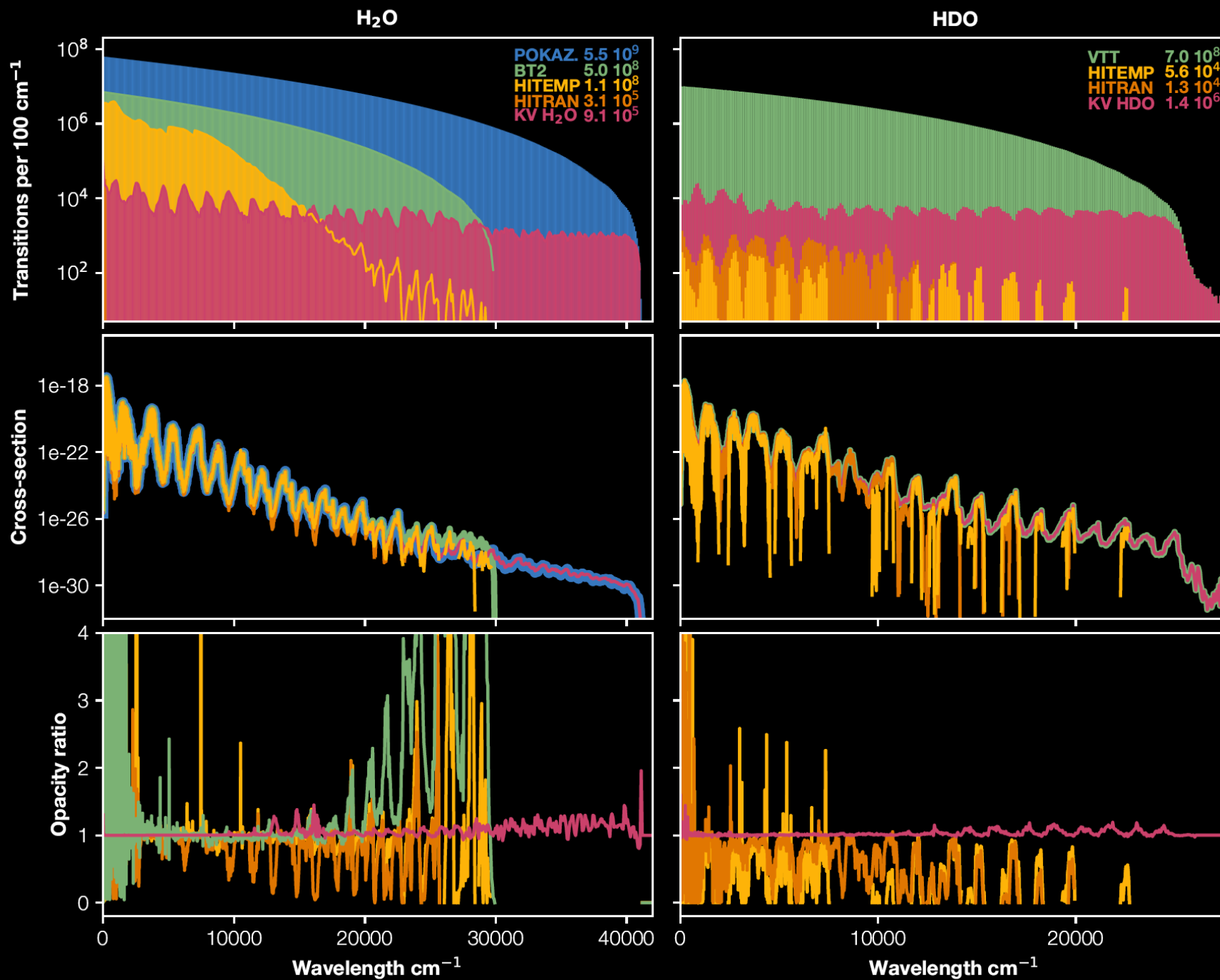
Leveraging the advantages of both techniques?

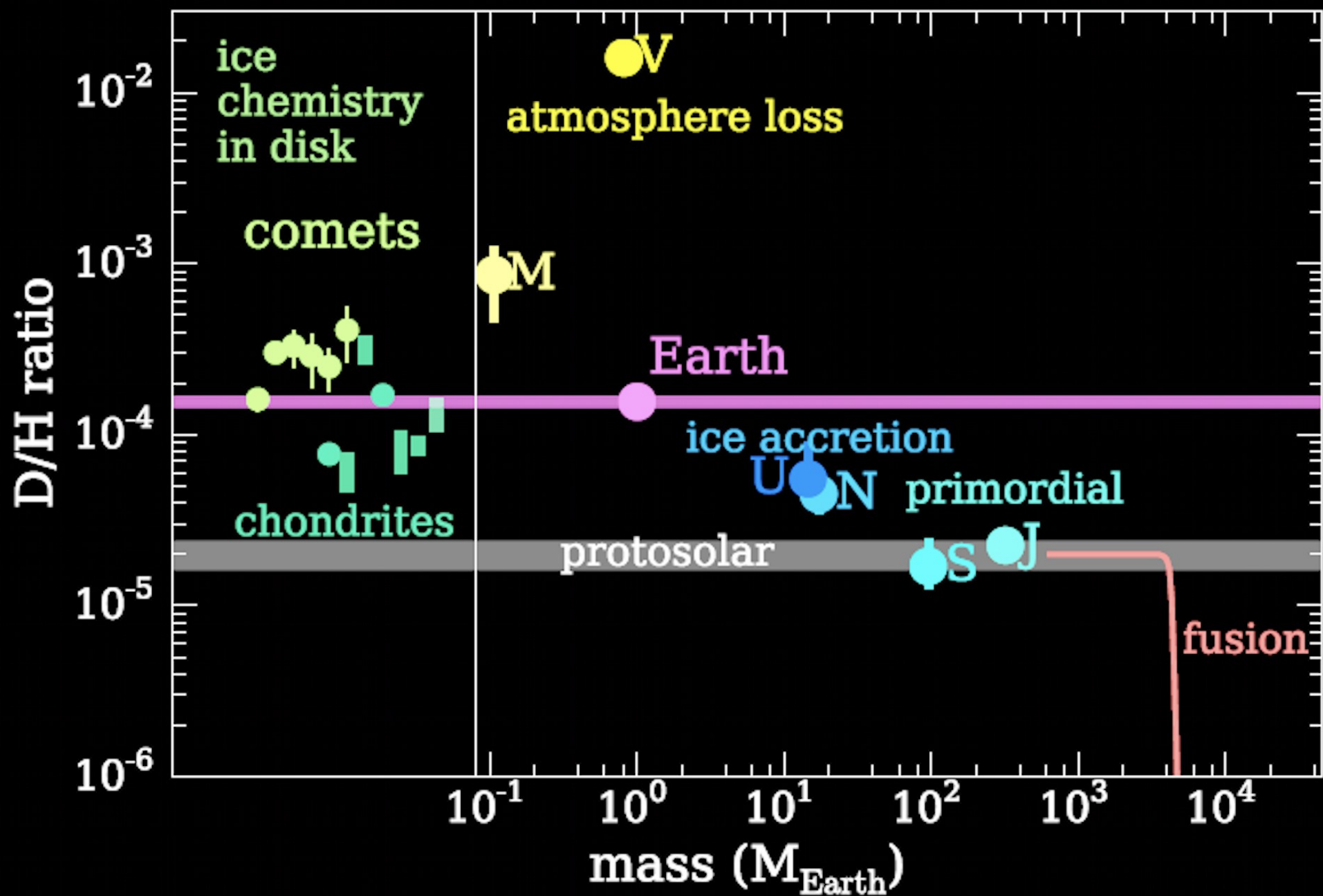




Take away points

- New line list soon available in PSG
 - Both space-based and ground-based detections of HDO are possible, but require favorable atmospheric conditions
 - Ground and space-based observatories each hold their advantages
- Applied together yield significantly more information





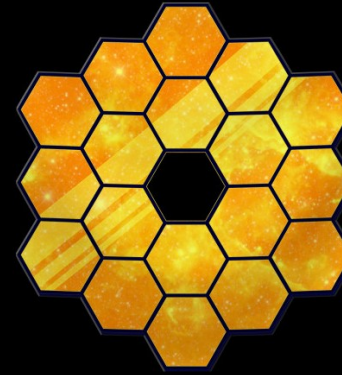
Observation strategies

- Space-based observations

Telluric free

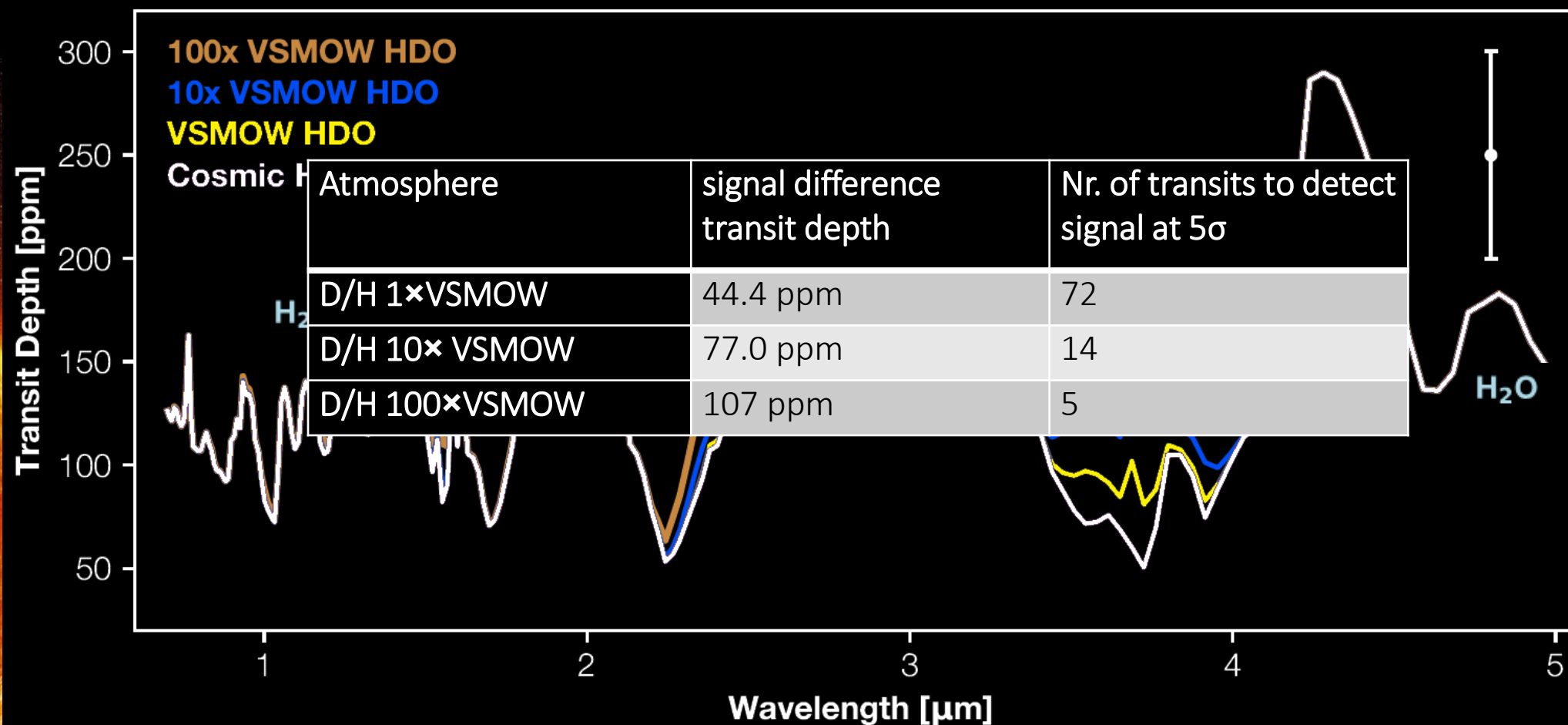
- Ground

High-resolution



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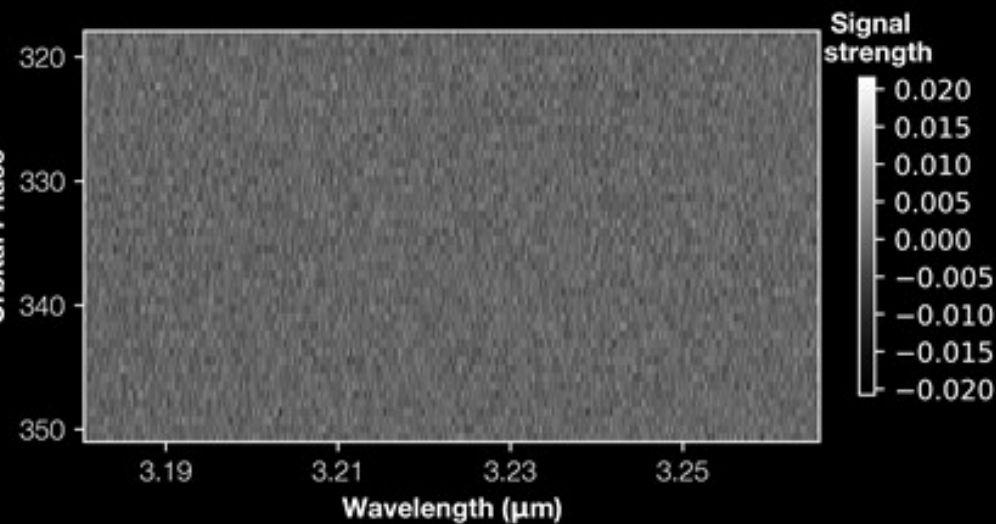
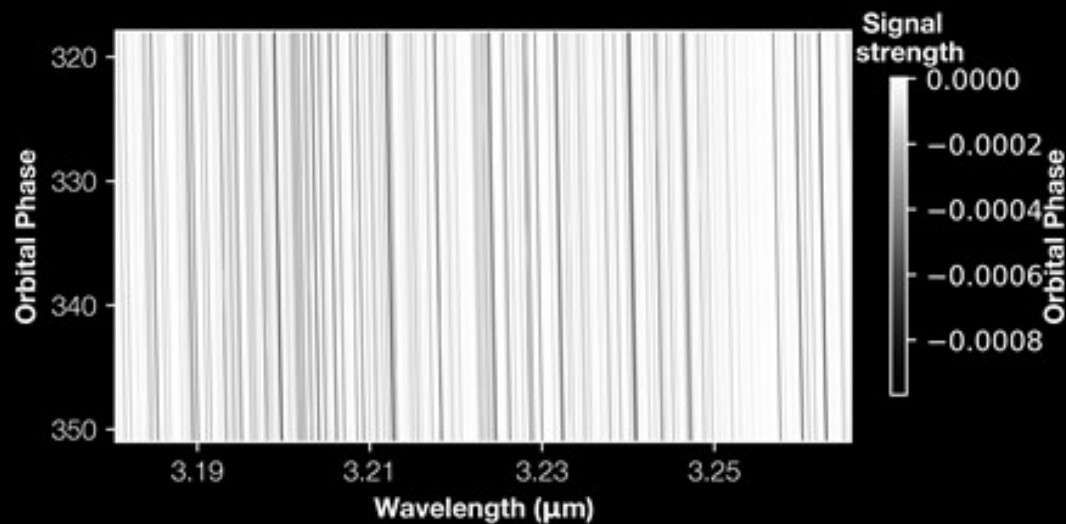


Example:

H₂O detection in HD189733b



5 hours of observation with VLT



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H₂O detection in HD189733b



5 hours of observation with VLT

