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Ions in the Thermosphere: Observational Constraints to Probe Habitability of Exoplanets

J. Bourgalais, N. Carrasco, Q. Changeat, O. Venot, P. Pernot, J. Tennyson, K. Chubb, S. Yurchenko, G. Tinetti

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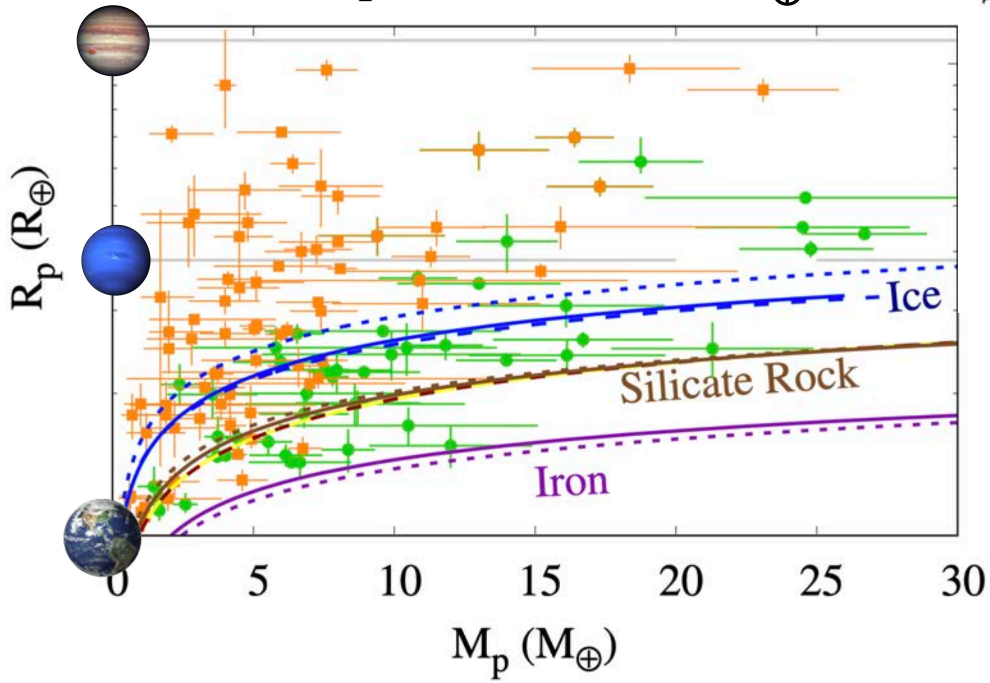
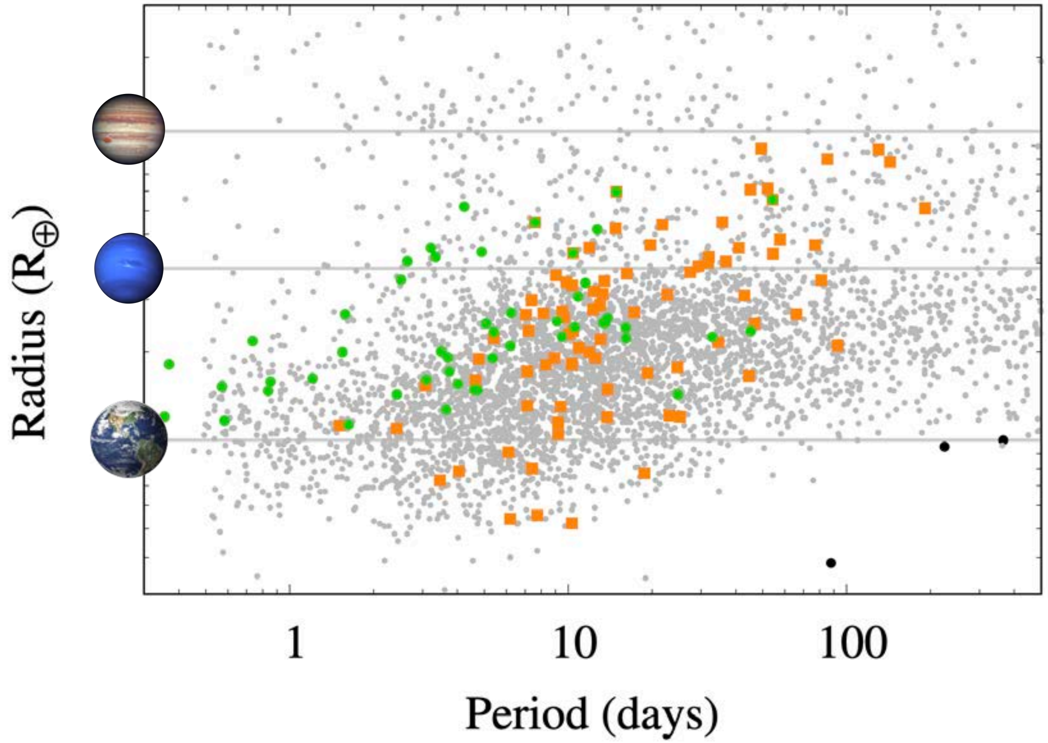
Super-Earth & Mini-Neptune

- Most of the 4,000 transiting exoplanet candidates discovered by the *Kepler* mission are between Earth and Neptune in size.

Mass-radius diagram for exoplanets below 30$M_\oplus$



Planetary Radii and Orbital Periods of Transiting Exoplanets in the *Kepler* Field



- Clear diversity in the compositions of low-mass exoplanets (rocky and gas-rich).

Jontof-Hutter, D. (2019). *Annual Review of Earth and Planetary Sciences*, *47*, 141-171.

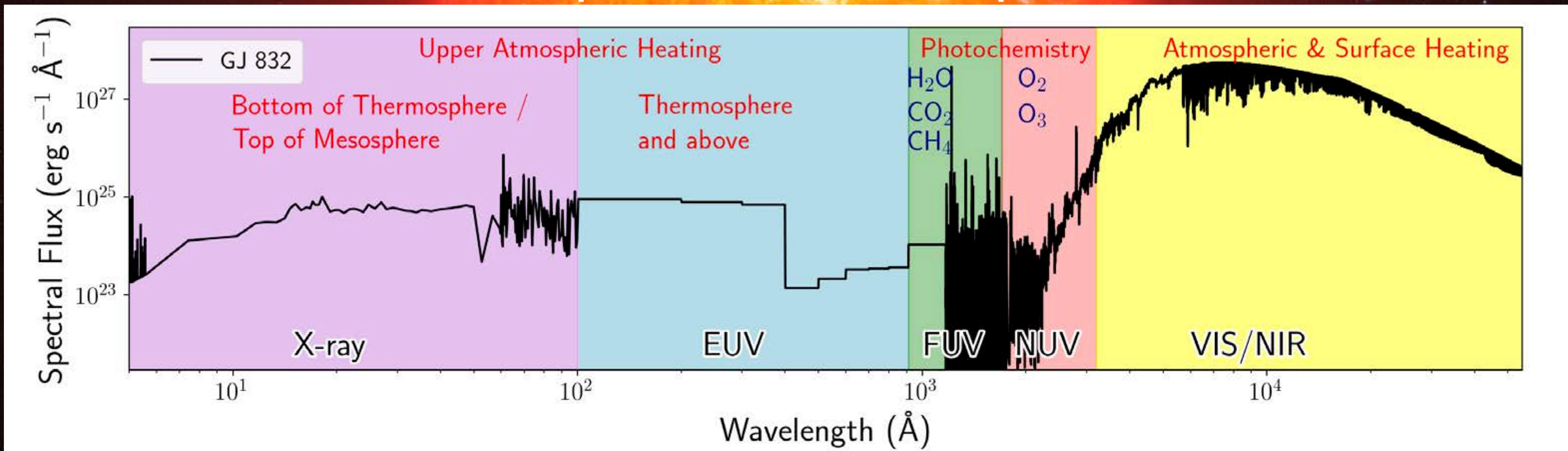
Photochemistry in the Thermosphere of Exoplanets

- Stellar UV environment around M stars strongly impacts the formation, evolution, and chemistry of close-in exoplanet atmospheres

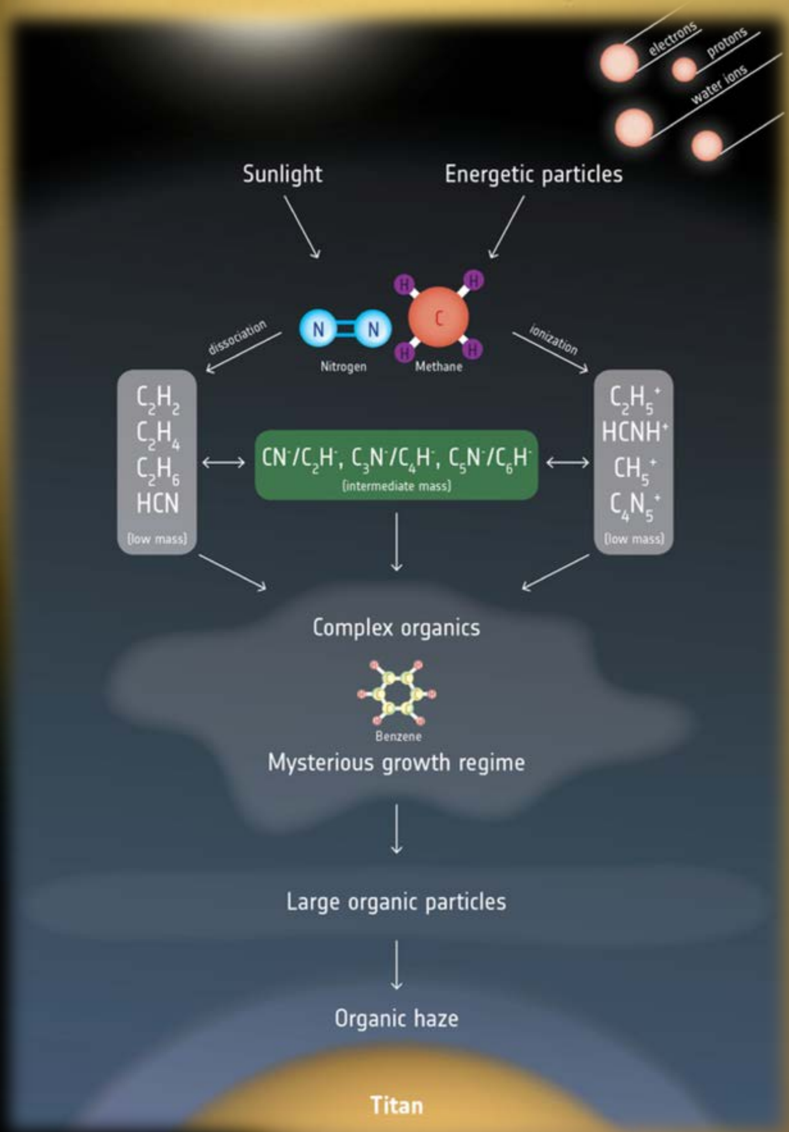
Ionization & dissociation

Youngblood et al. (2019) *arXiv preprint arXiv:1903.05718.*

MUSCLES Treasury Survey

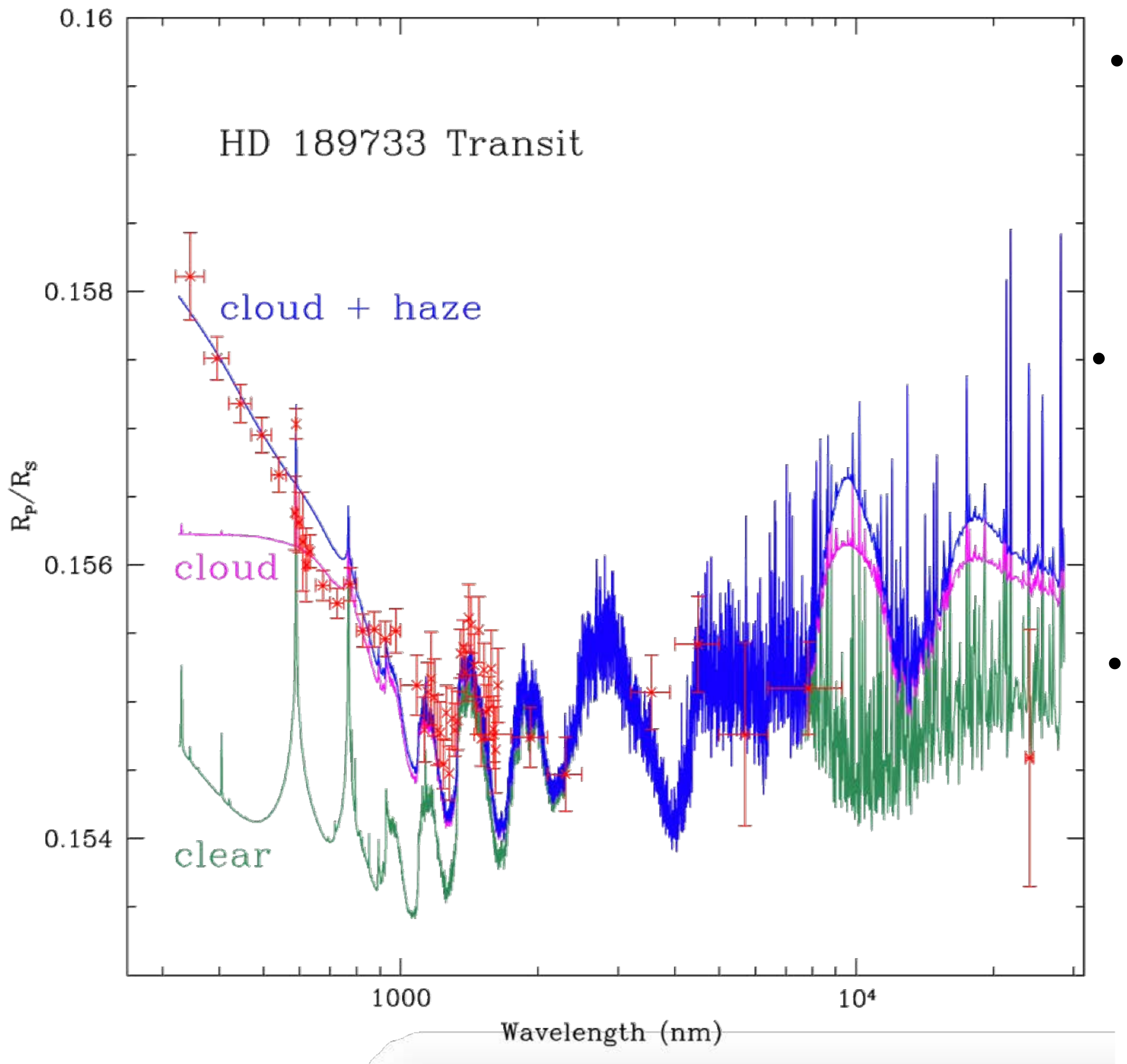


Efficient Ion-Neutral chemistry in Solar System Bodies



- Complex ion and neutral composition of the thermosphere
- Ion-neutral chemistry is a key element toward the formation of photochemical organic aerosols

Photochemical hazes in Exoplanets



- Photochemical hazes have been detected in the atmosphere of hot-Jupiters

  Bailey, J., et al. (2018). *MNRAS*, *480*(2), 1613-1625.

- Expected presence of suspended particulate matter in the atmospheres of Super-E/mini-Neptune

  Crossfield, I. J., & Kreidberg, L. (2017). *arXiv preprint arXiv:1708.00016.*

- Transmission spectra of low-mass exoplanets in IR:

  Which transmission is blocked by clouds and hazes ?

  Inventory of atmospheric molecules present ?

Thermospheres: Complex Chemical Environments

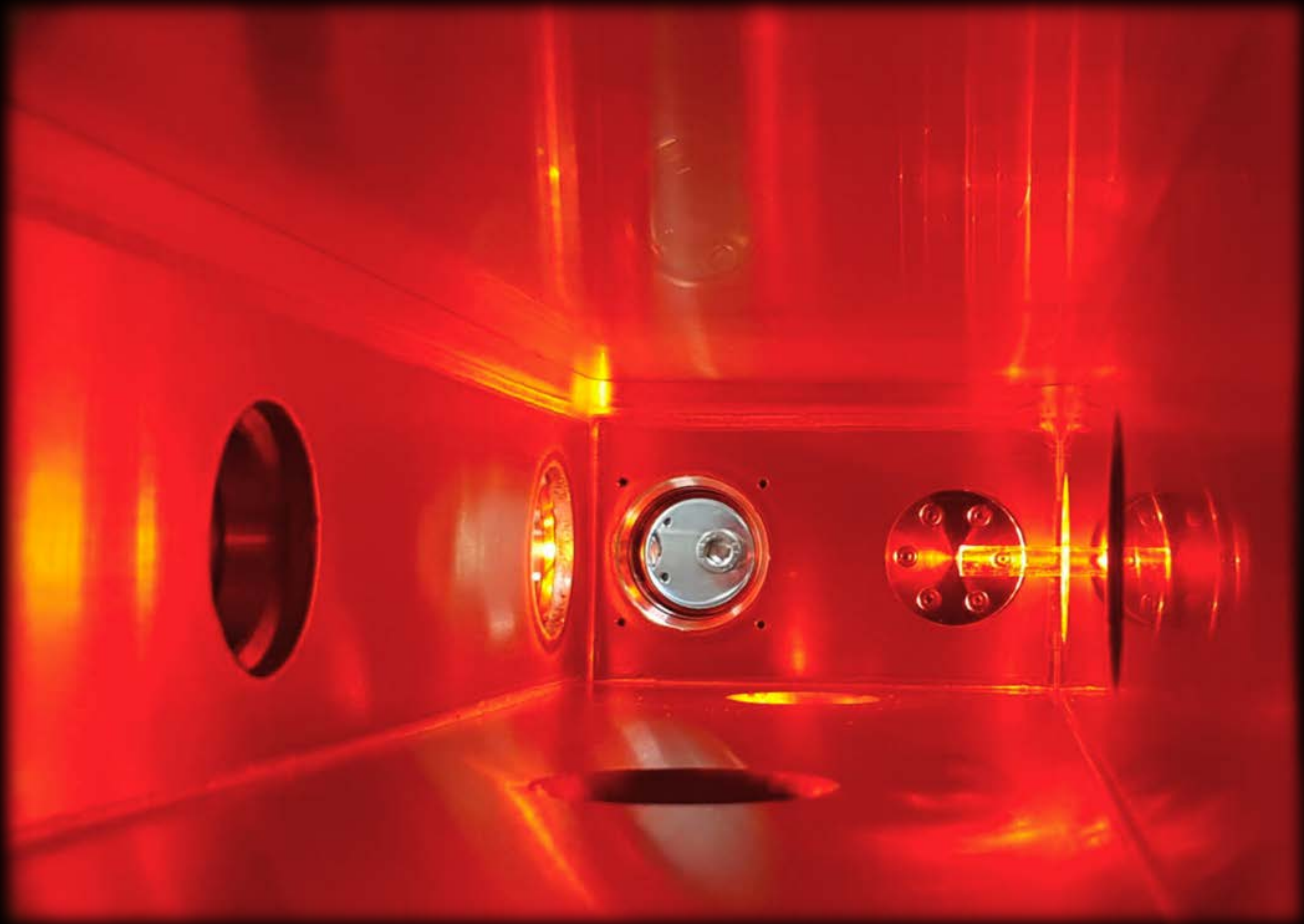
- Need detailed atmospheric model coupling dynamics and complex chemical networks.
- Identification of the main species and description of the dominant reaction pathways
- Laboratory experiments like photochemical-driven molecular growth are required

Aim of this work:

What could be the main expected ions in the thermospheres of warm exoplanets ?

NASA's Goddard Space Flight Center/Duberstein)

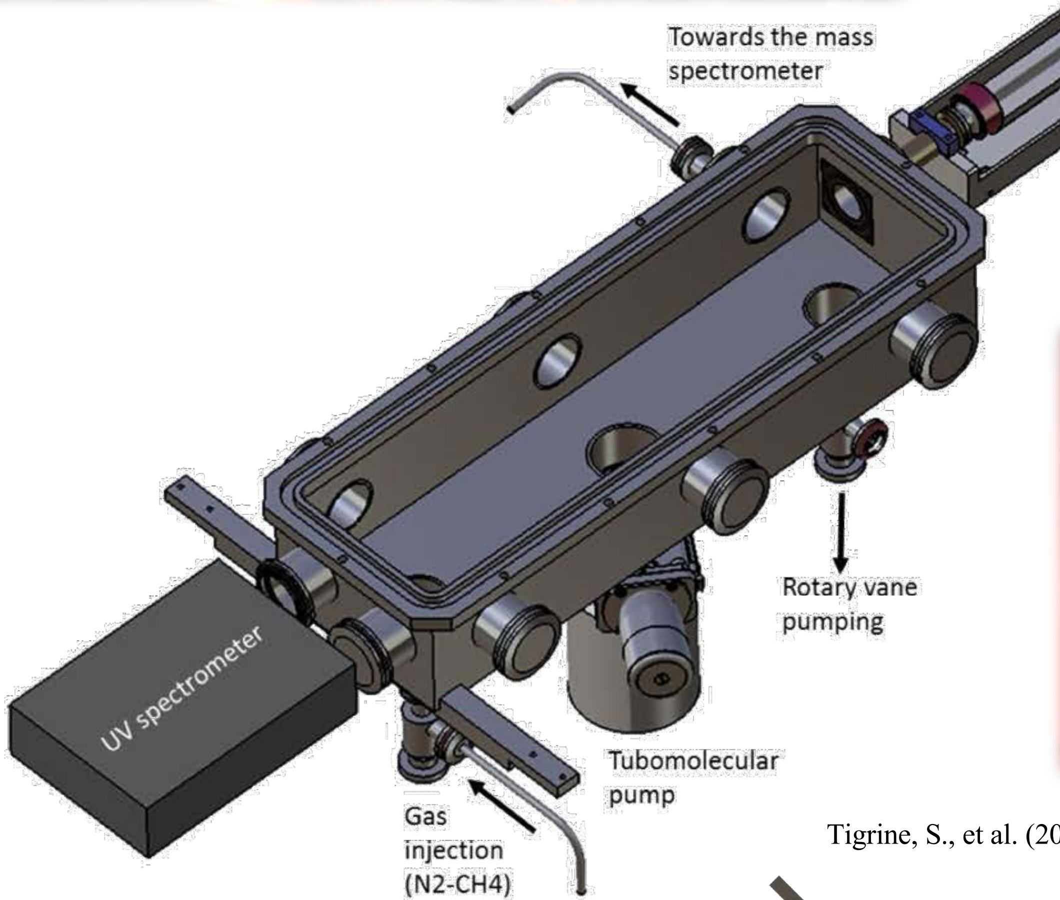
Laboratory experiments on thermospheric chemistry



Experimental Method

- How to reproduce a simplified exoplanetary's upper atmosphere in laboratory ?

An EUV photon source



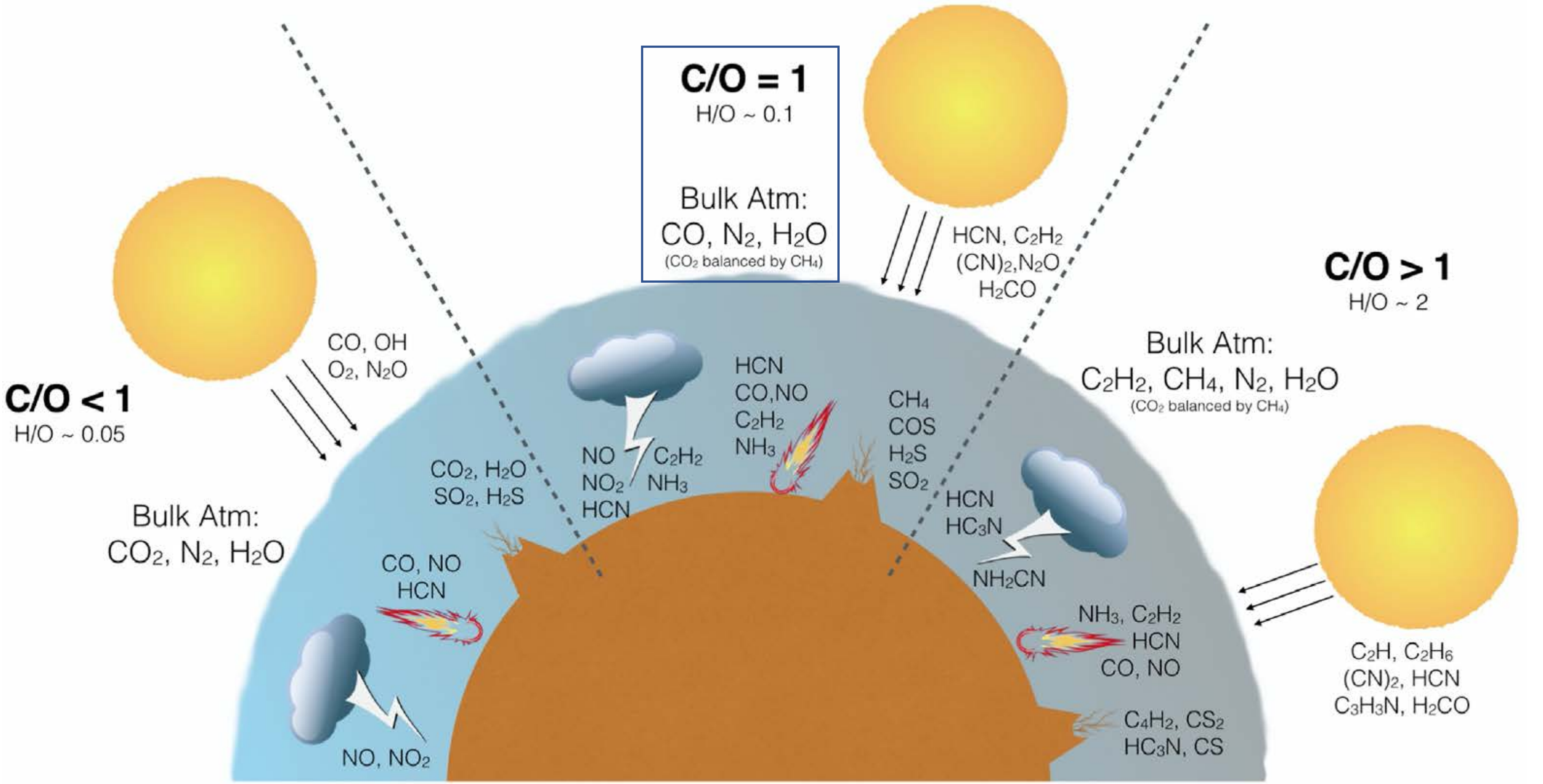
A simplified thermosphere

Tigrine, S., et al. (2016). *Journal of Physics D: Applied Physics*, *49*(39), 395202.

Experimental Parameters

- Irradiation at 73.6 nm (16.8 eV)
- P= 0.9 mbar and room temperature
- Relevant gas mixtures ($CO – N_2 – H_2$) w/ H_2O traces (ppm lvl)

H_2-poor (1%) → % H_2 → H_2-rich (96%)



Rimmer, P. B., & Rugheimer, S. (2019). *Icarus*, *329*, 124-131.

Preliminary Results: MS Analysis

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- P= 0.9 mbar and room temperature
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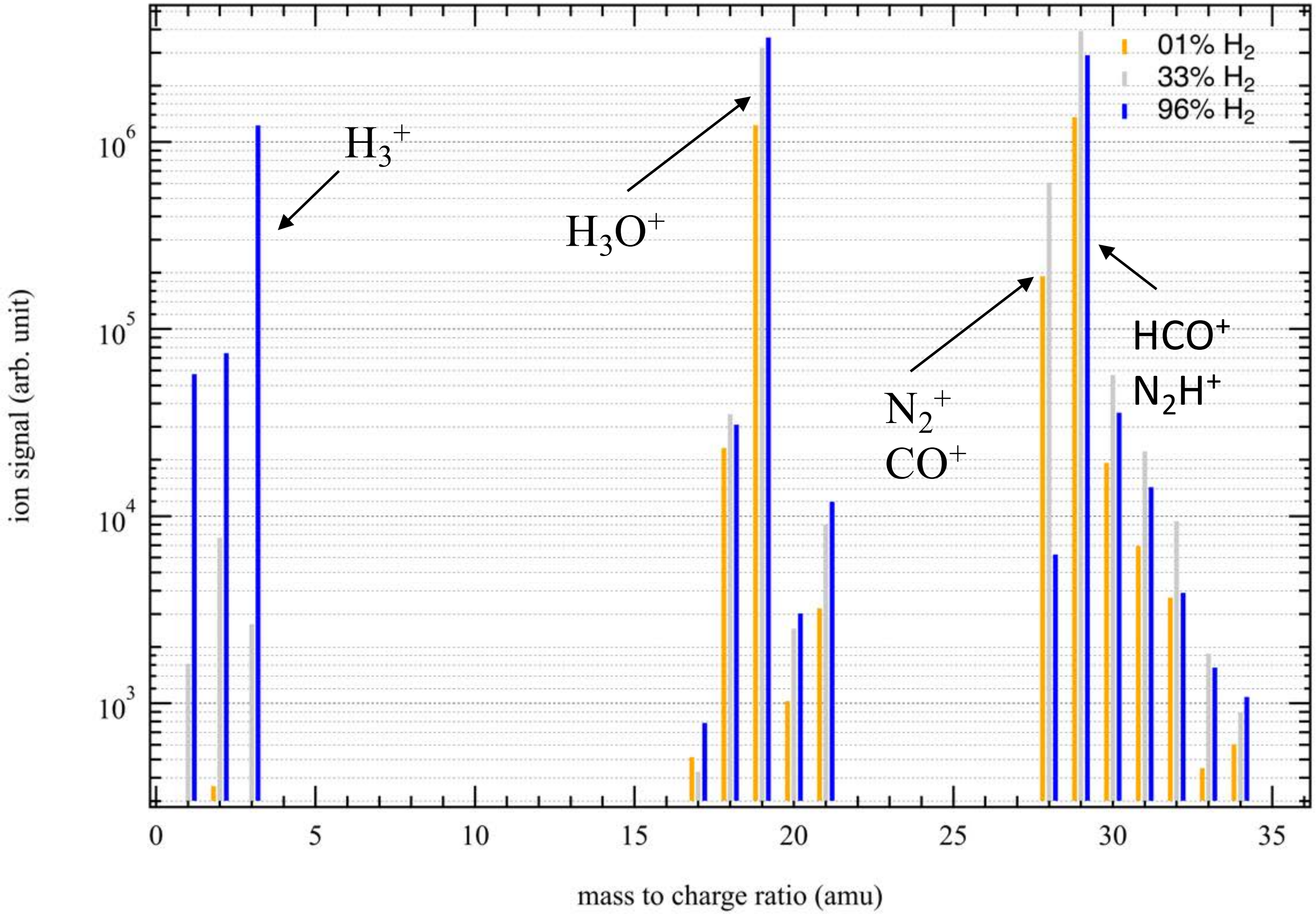
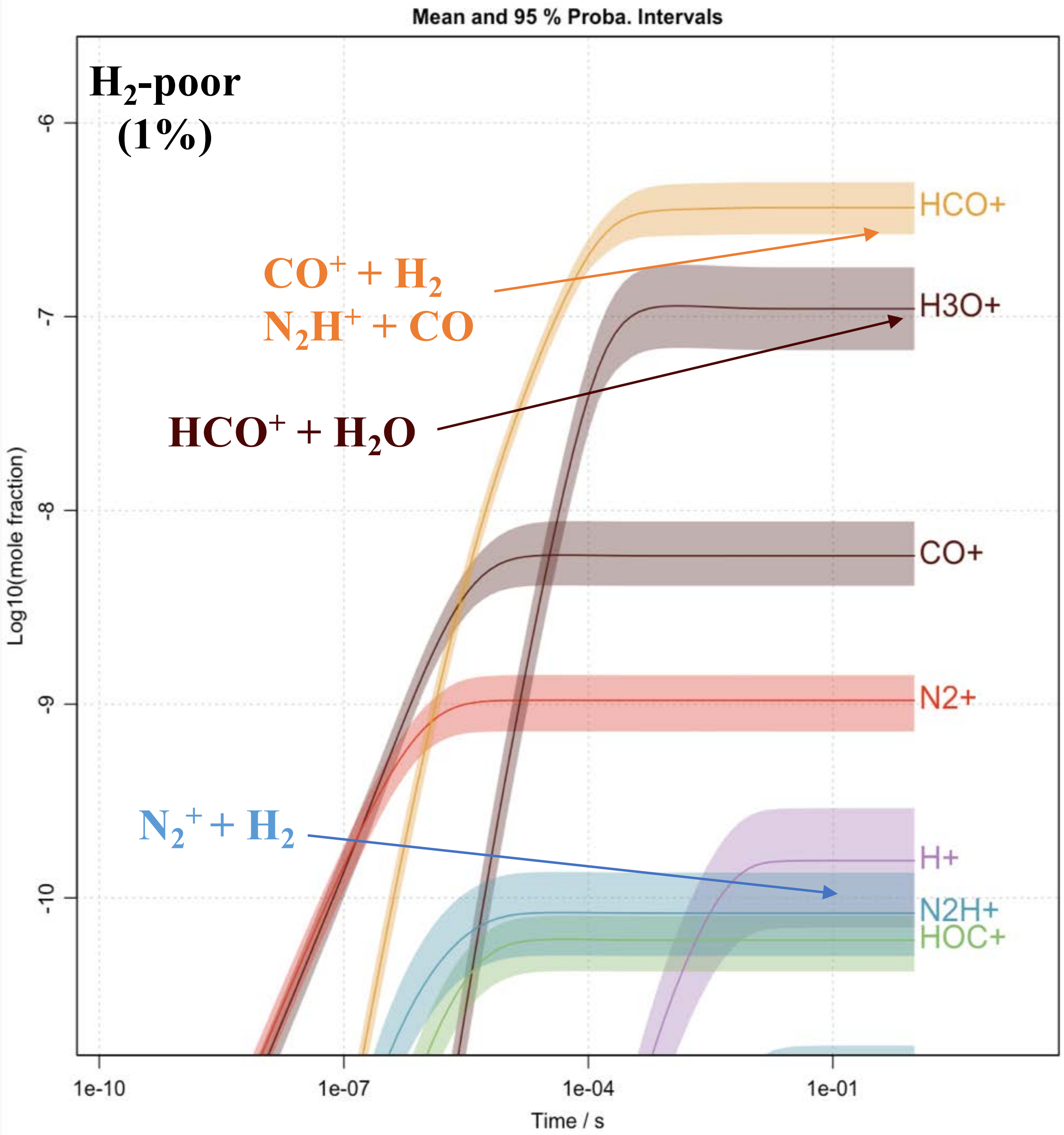


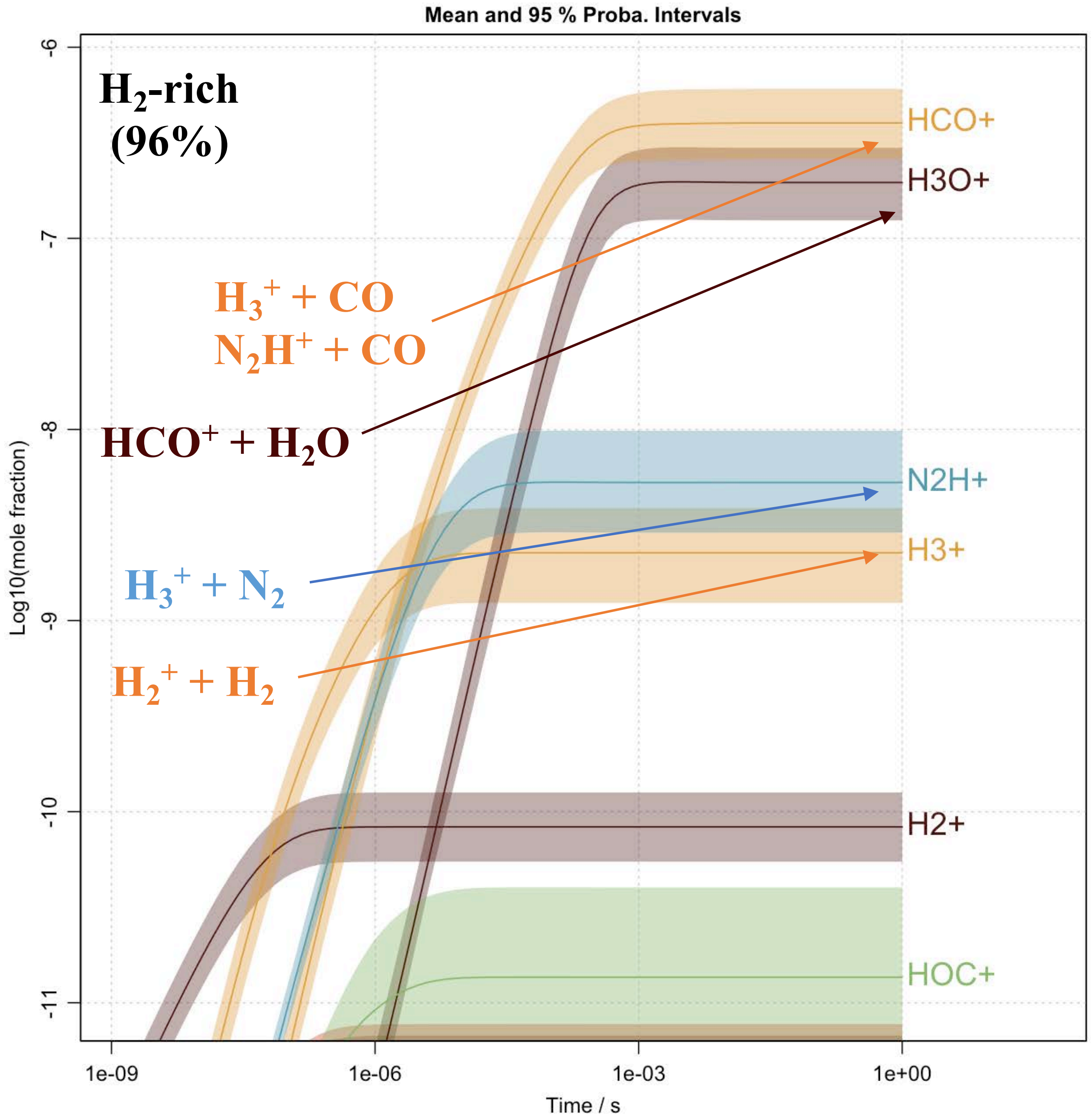
Preliminary Results: 0D-Photochemical Model

- Primary ions formed at 73.6 nm: H_2^+, N_2^+ and CO^+ trigger the molecular growth
- H-transfer reactions leading to the stable protonated ions observed
- The abundance of N_2H^+ is much smaller than HCO^+
- The formation of H_3^+ is negligible



Preliminary Results: 0D-Photochemical Model

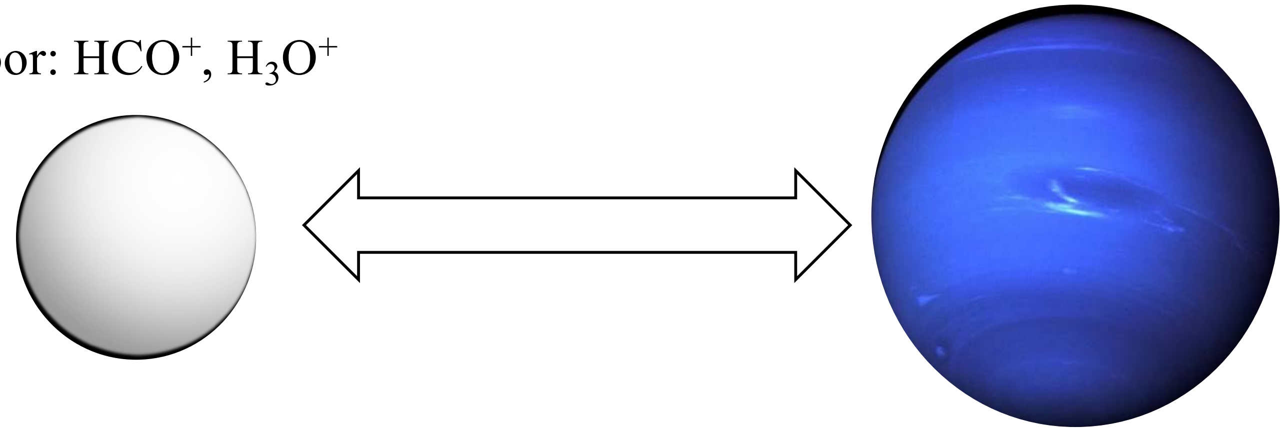
- H_3O^+ and HCO^+ remain the most abundant ions
- H_3O^+ is formed through HCO^+ in both environments
- Increase in N_2H^+ shows the propensity of CO to destroy N_2H^+
- H_3^+ is an important ion contributor driving the ionic chemistry



H_2-rich: HCO^+, H_3O^+, H_3^+

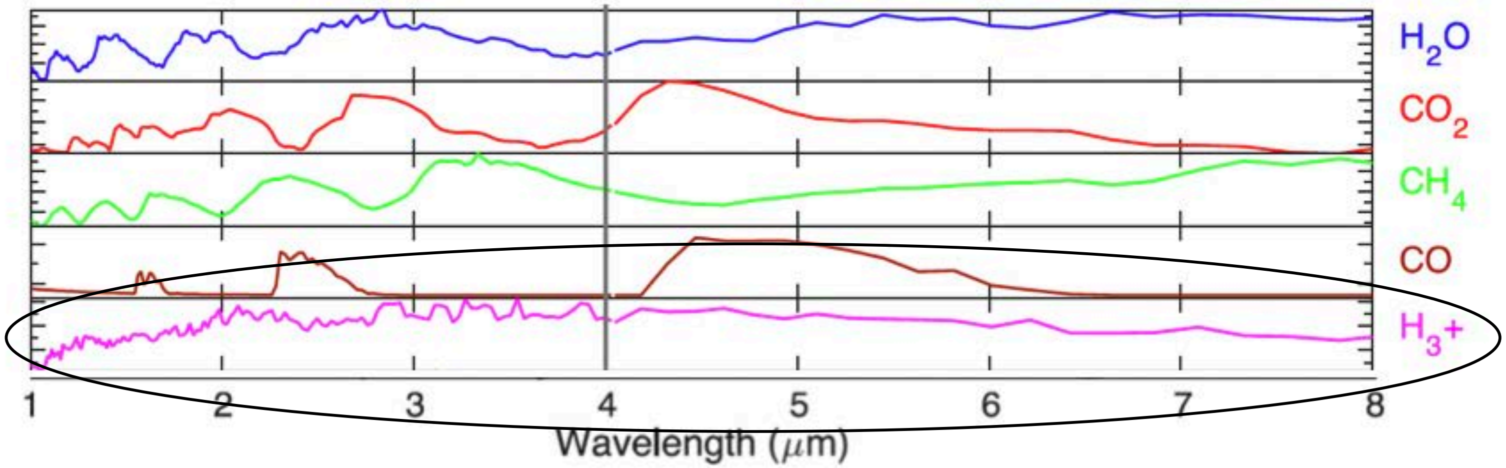
H_2-poor: HCO^+, H_3O^+

super-Earth



mini-Neptune

Can we detect those ions in such bodies ?

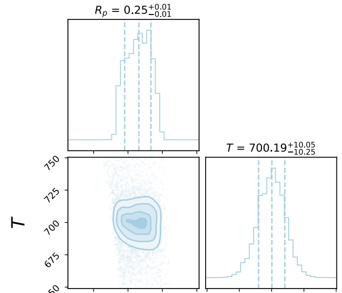


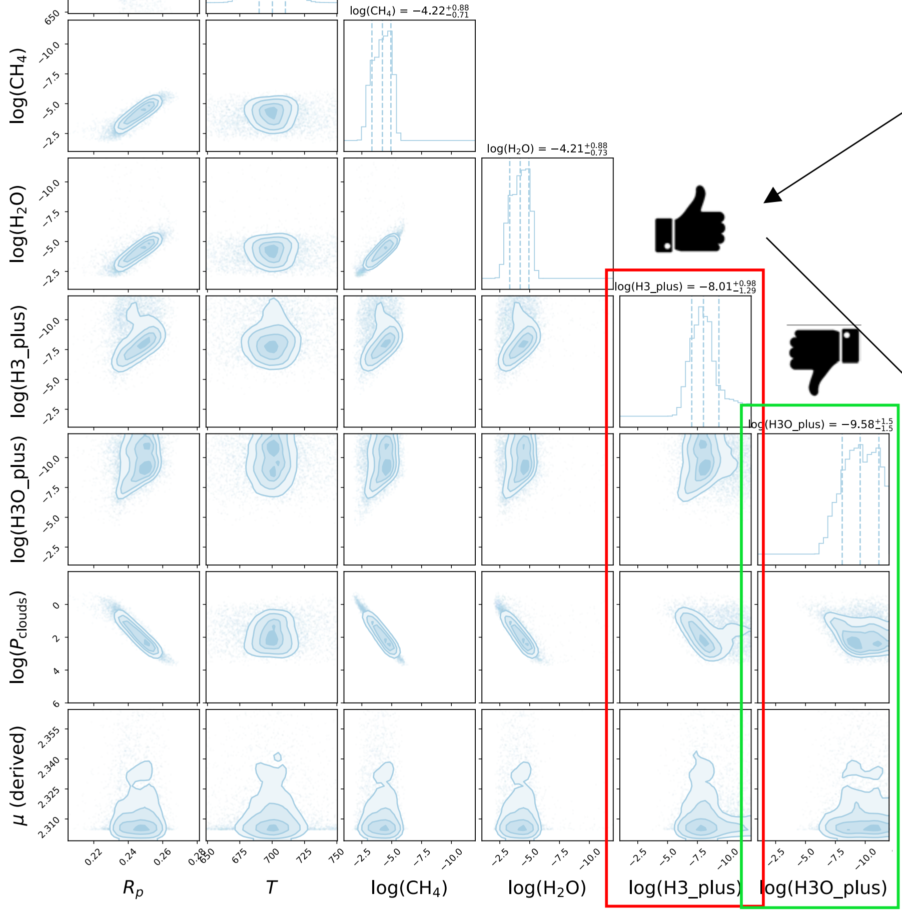
Hot Jupiter

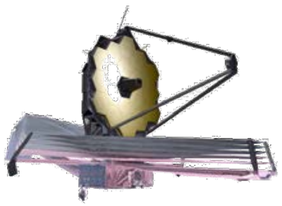
Lenz, L. F., et al. (2016). *Astronomy & Astrophysics*, *589*, A99.

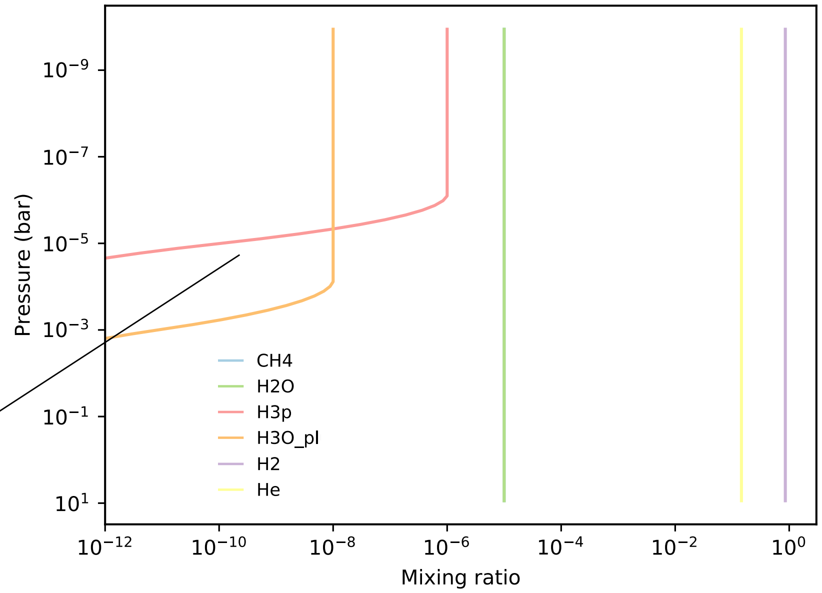
Simulations of Transmission Spectra of sub-Neptune GJ1214b

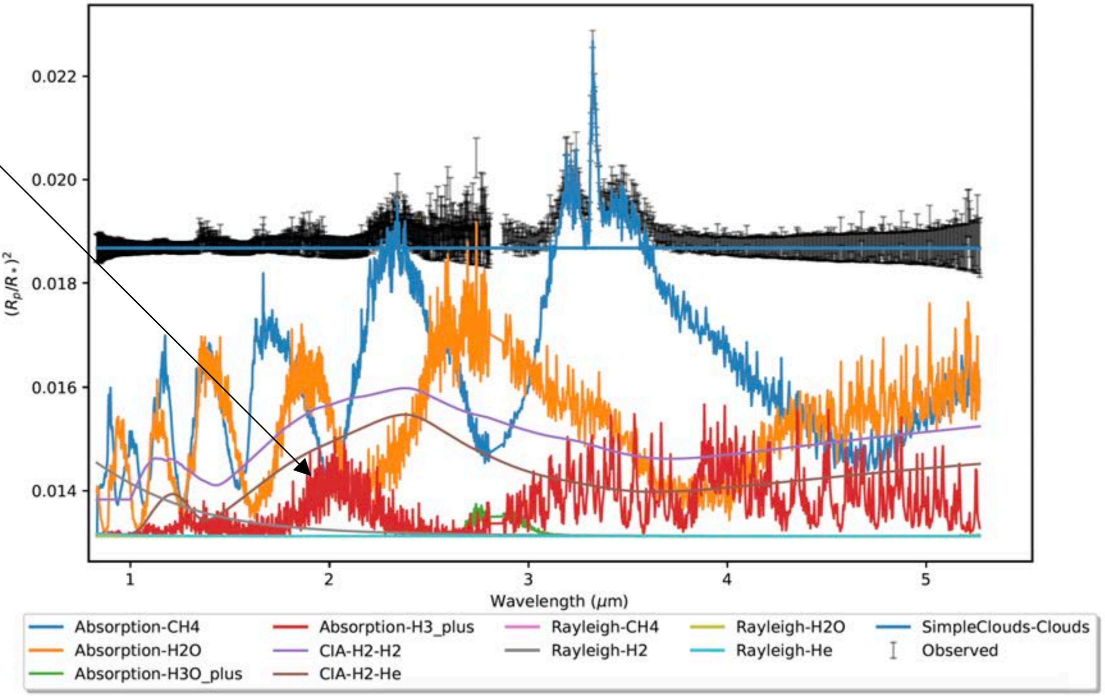
- JWST NIRISS-NIRSpec 2 transits





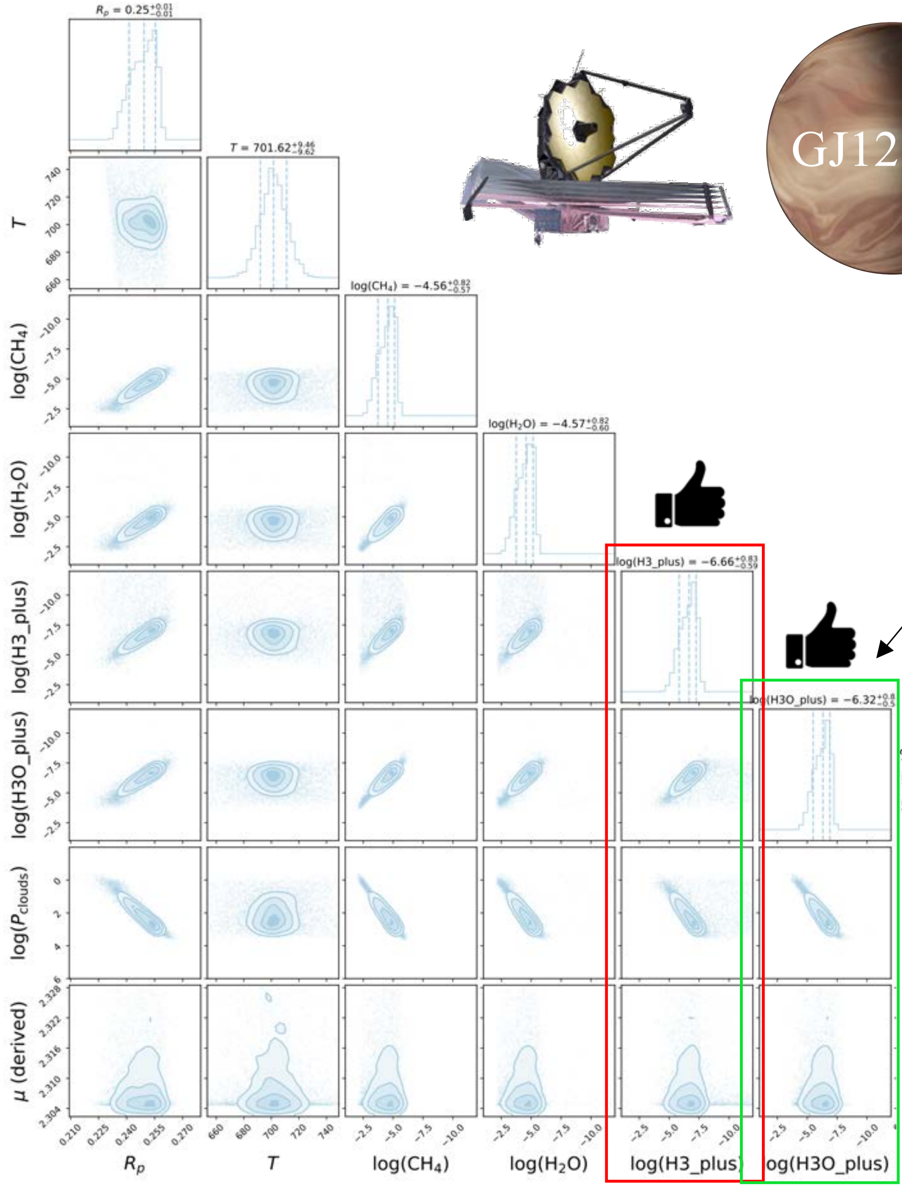


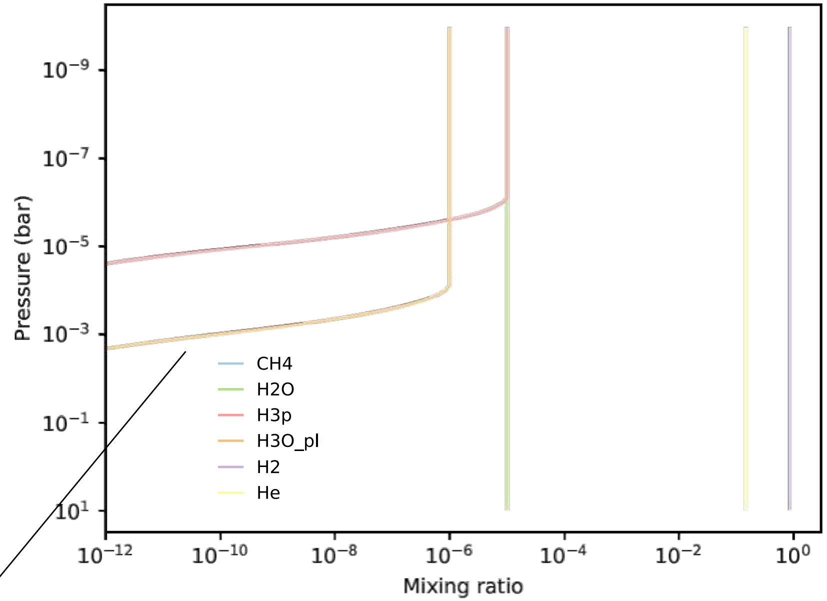


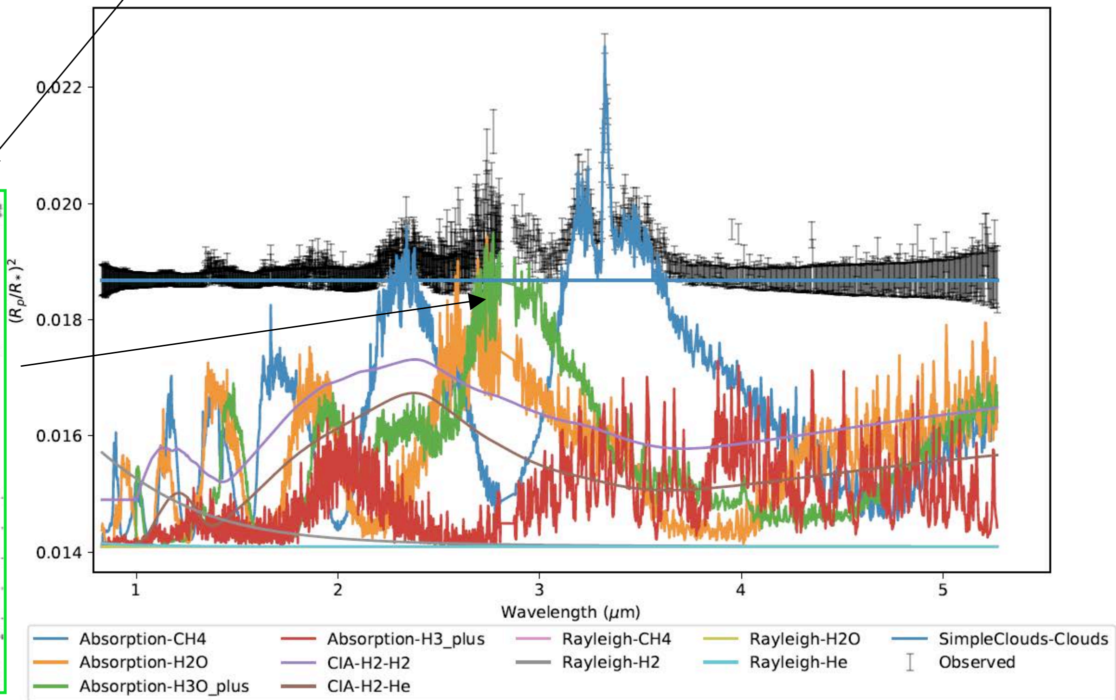


Simulations of Transmission Spectra of sub-Neptune GJ1214b

- JWST NIRISS-NIRSpec 2 transits

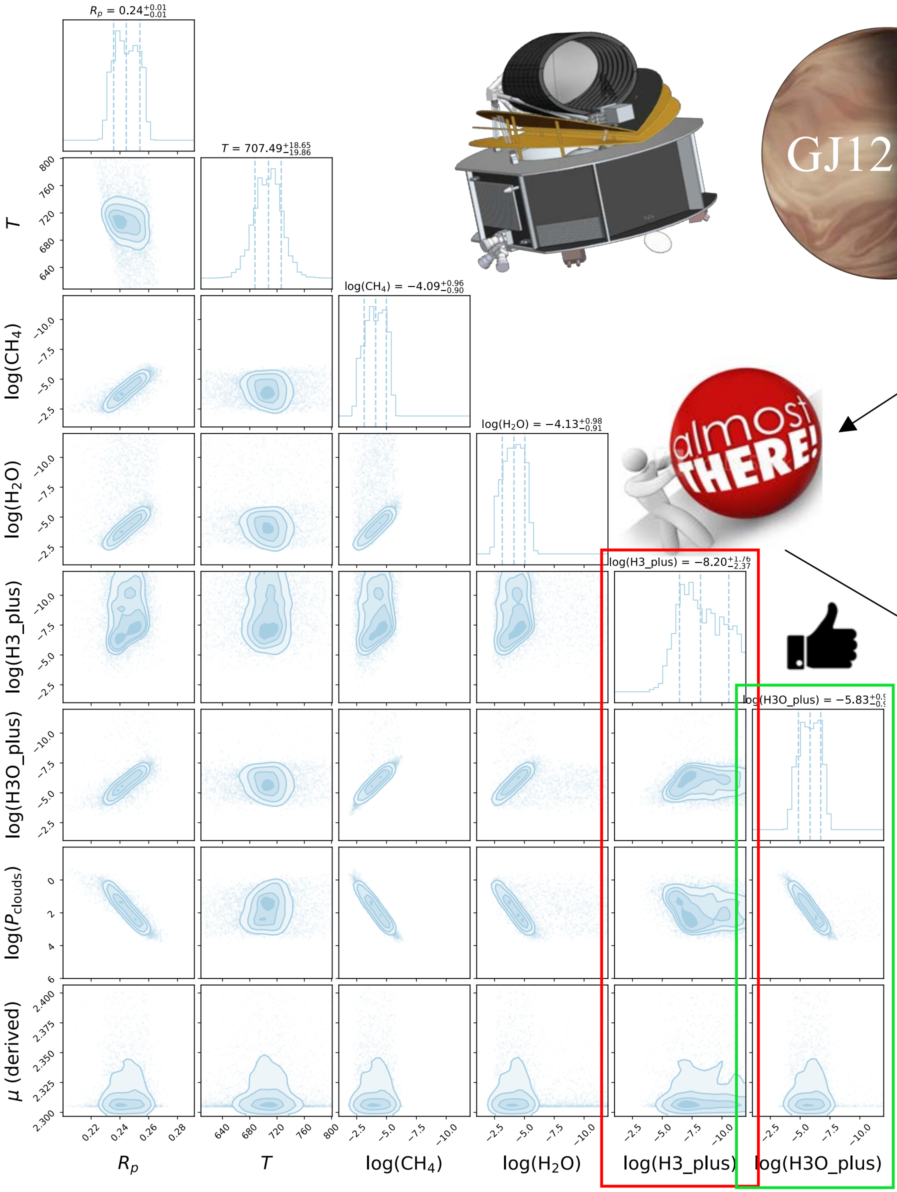


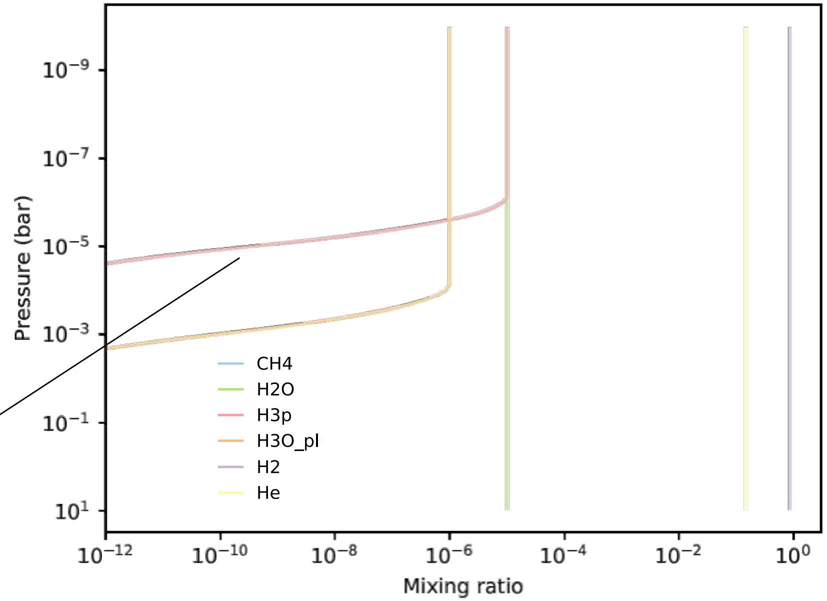


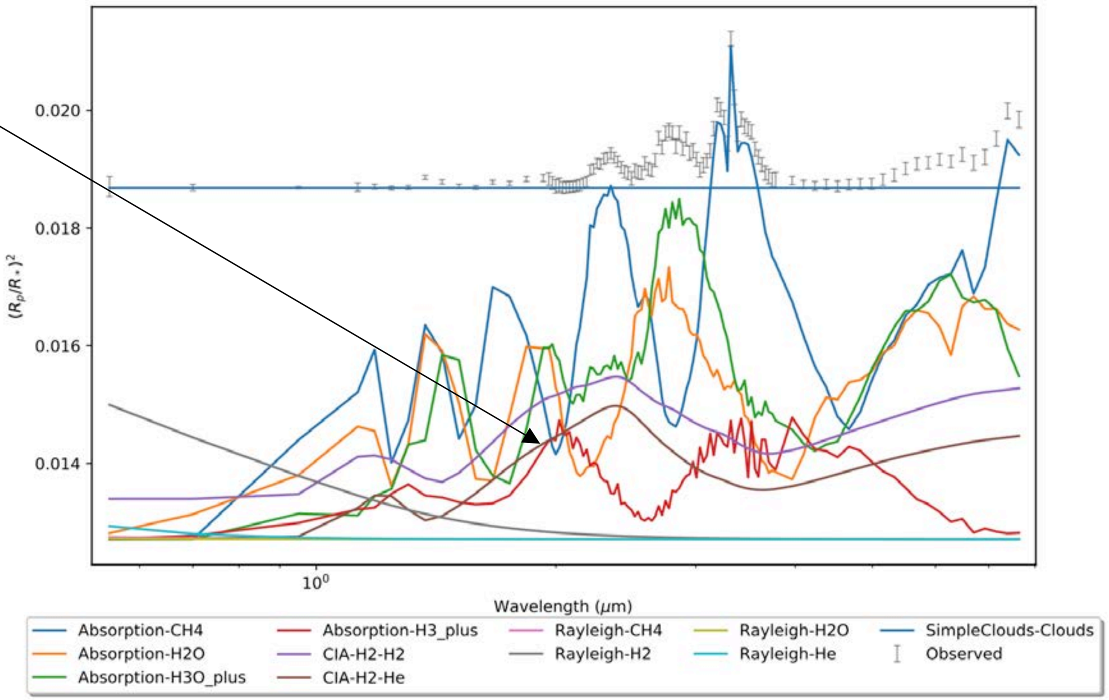


Simulations of Transmission Spectra of sub-Neptune GJ1214b

- ARIEL Tier 3 - 15 transits

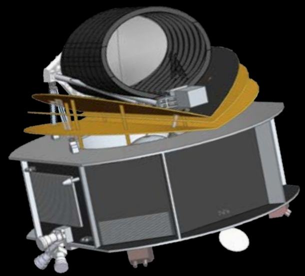


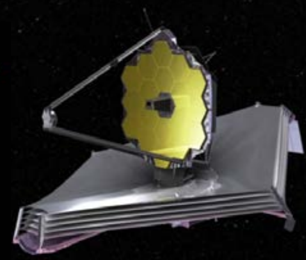




Conclusion

- Sub-Neptunes could be good candidates for the direct detection of H_3^+ and should be coupled with the observation of its ionic product, H_3O^+





- Additional information for the classification of planets in the transition between super-Earths and mini-Neptunes.


N. Carrasco
O. Venot
P. Pernot
G. Tinetti
Q. Changeat
To be continued …
ExoMol
S. Yurchenko
J. Tennyson
K. Chubb