Exploring the ARIEL Capabilities to Constrain Exoplanet Atmospheres

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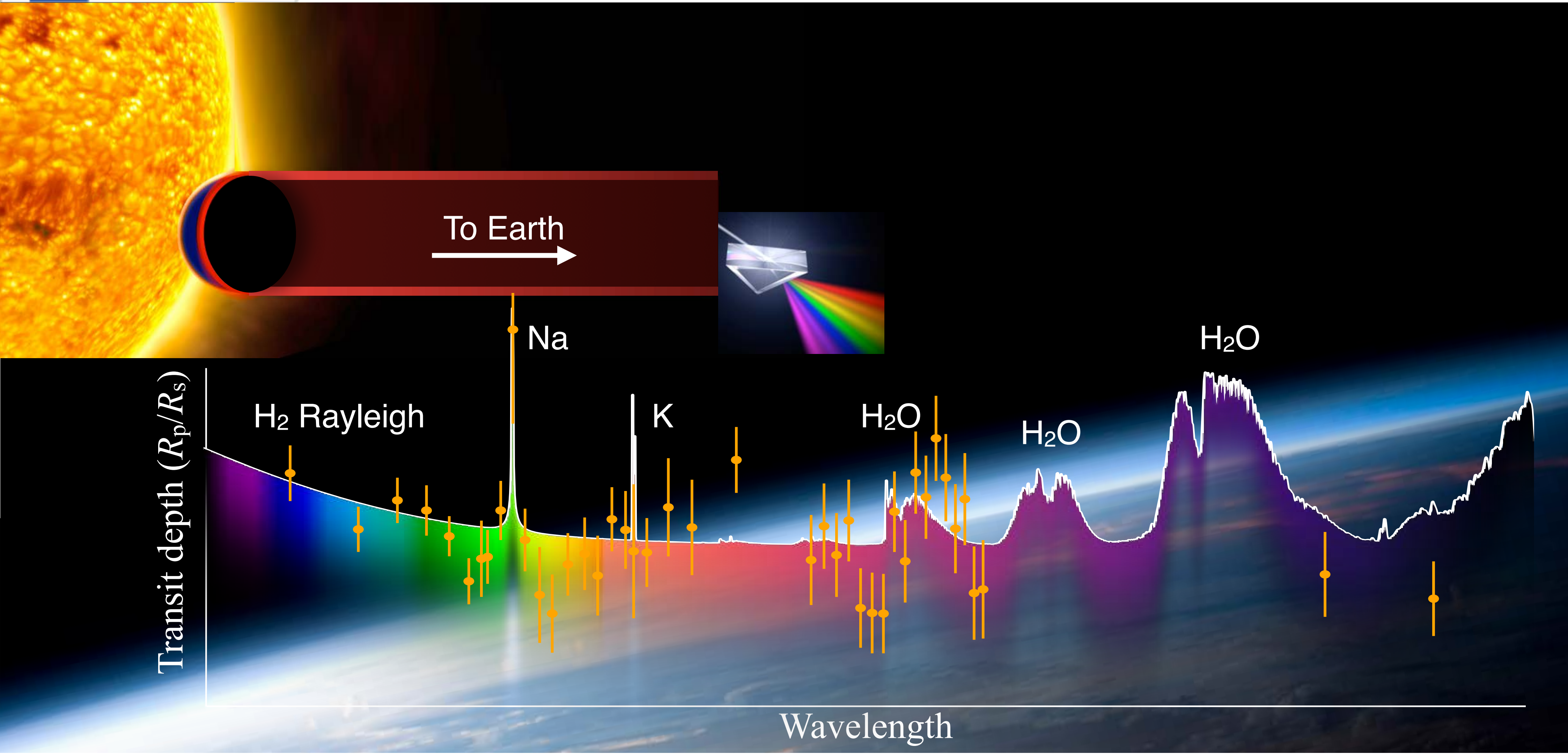
Space Research Institute (IWF), Austrian Academy of Sciences

Photo credit: NASA

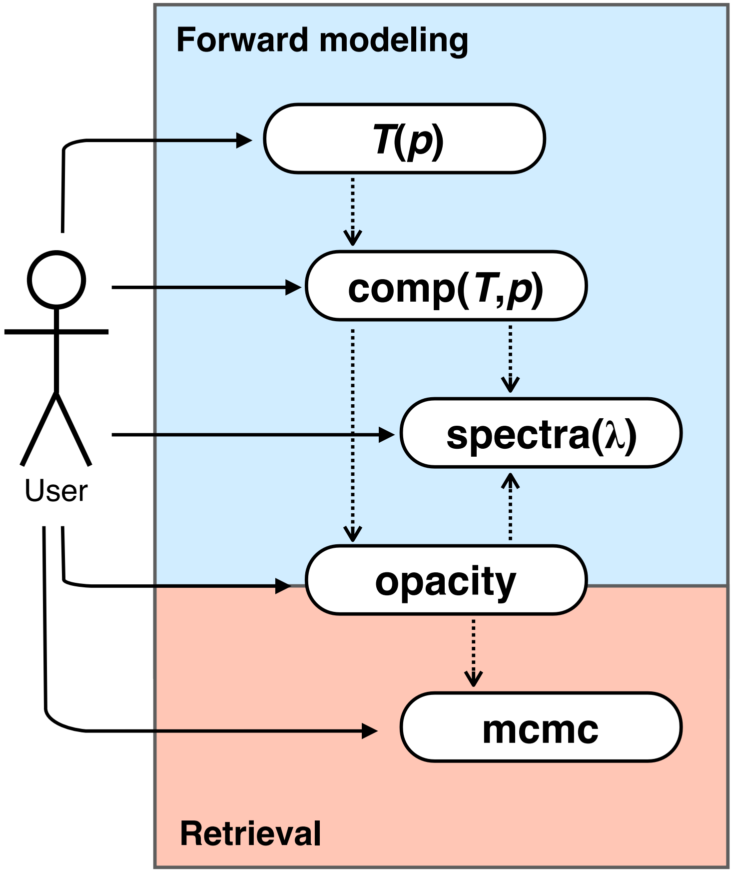
ARIEL Science, Mission & Community 2020 conference
16.01.2019

Transiting Exoplanet Characterization



Atmospheric Retrieval Framework

Python **Ra**diative **T**ransfer in a **Bay**esian framework: (Cubillos & Blecic, in prep.)



Atmospheric modeling

Radiative transfer

MCMC

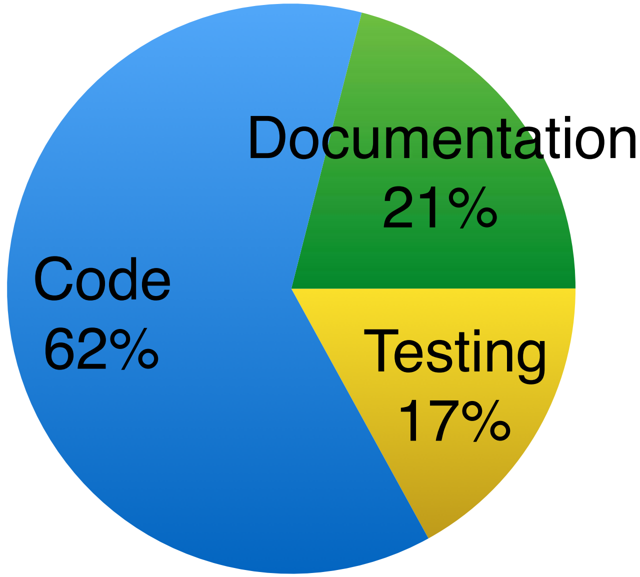
Used in retrieval comparison:
Kilpatrick et al. (2019),
Venot et al. (2020).

Follow best-coding practices
(e.g., PEP 8, PEP 20, PEP 257)

Read the Docs

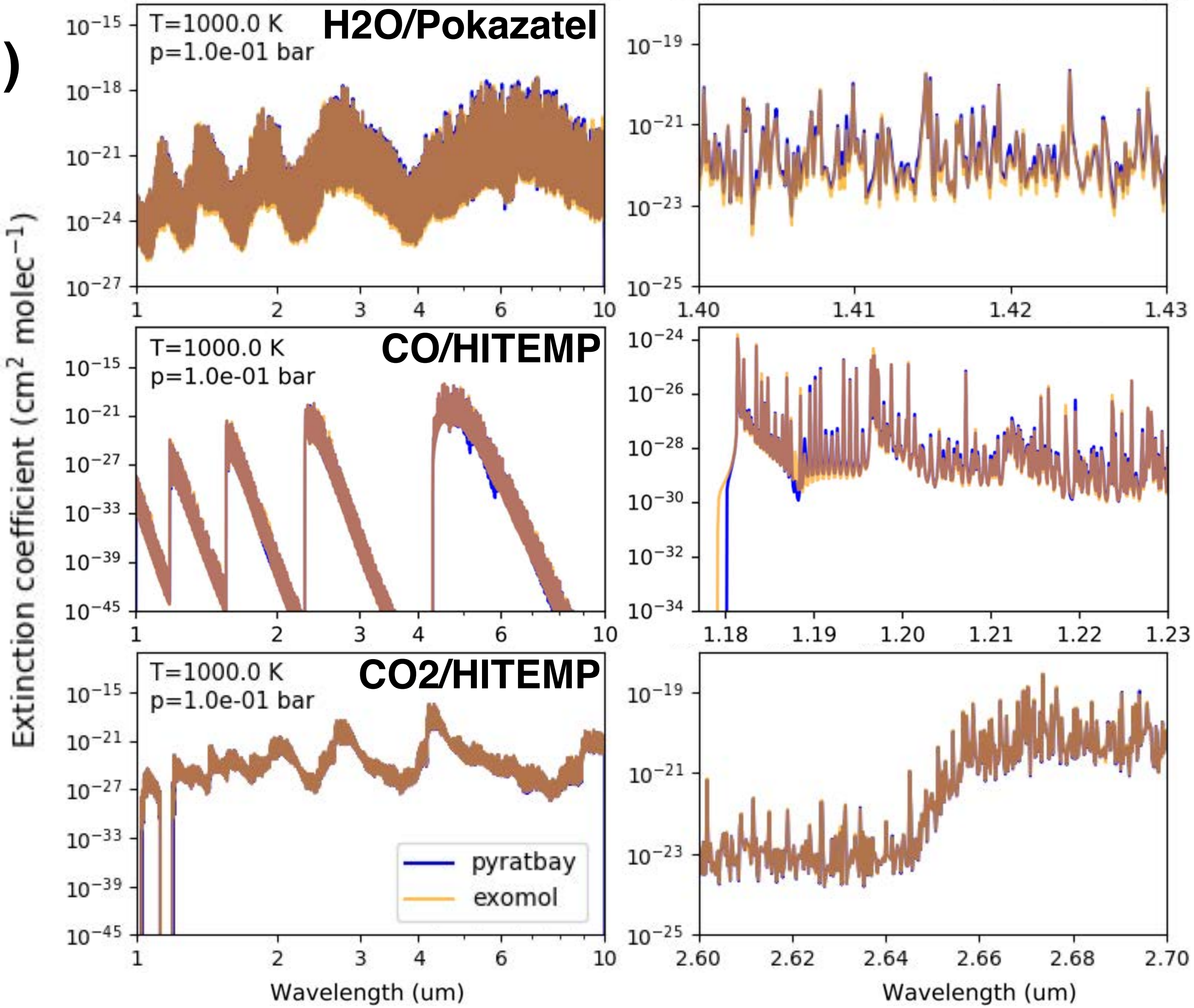
pytest

Travis CI



Validation (1)

Compare against ExoMol/TauREx opacities (Chubb et al, in prep)

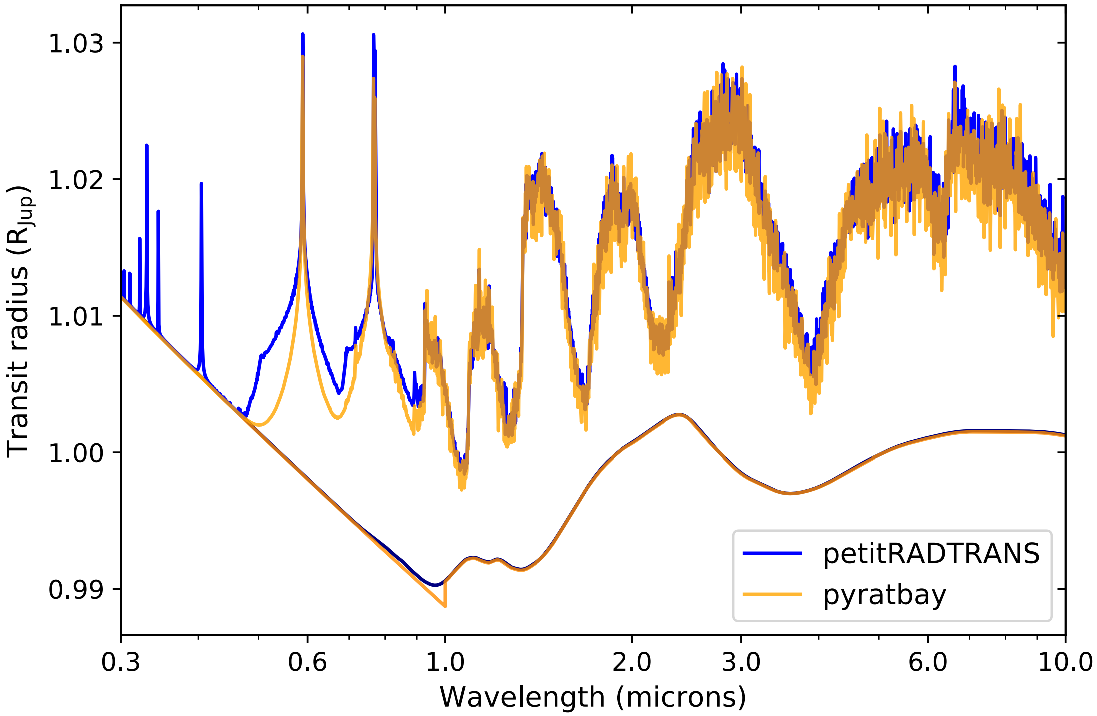


Validation (2)

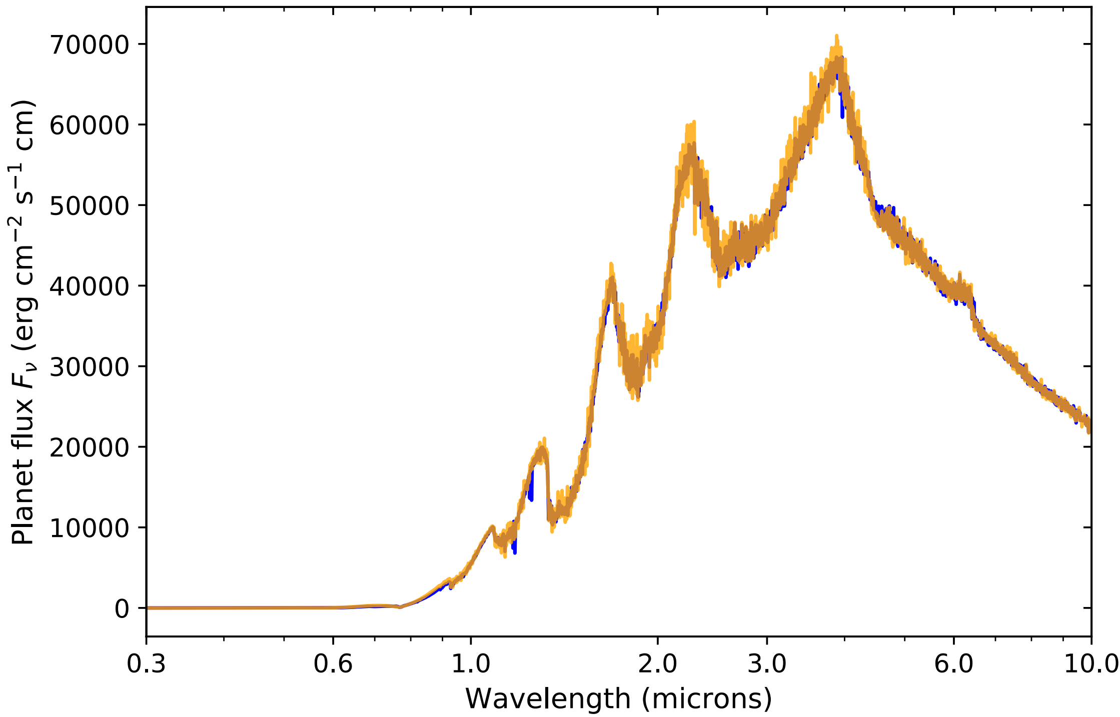
Compare against petitDARTRANS spectra (Molliere et al, 2019)

https://petitradtrans.rtfd.io/

Transmission spectra

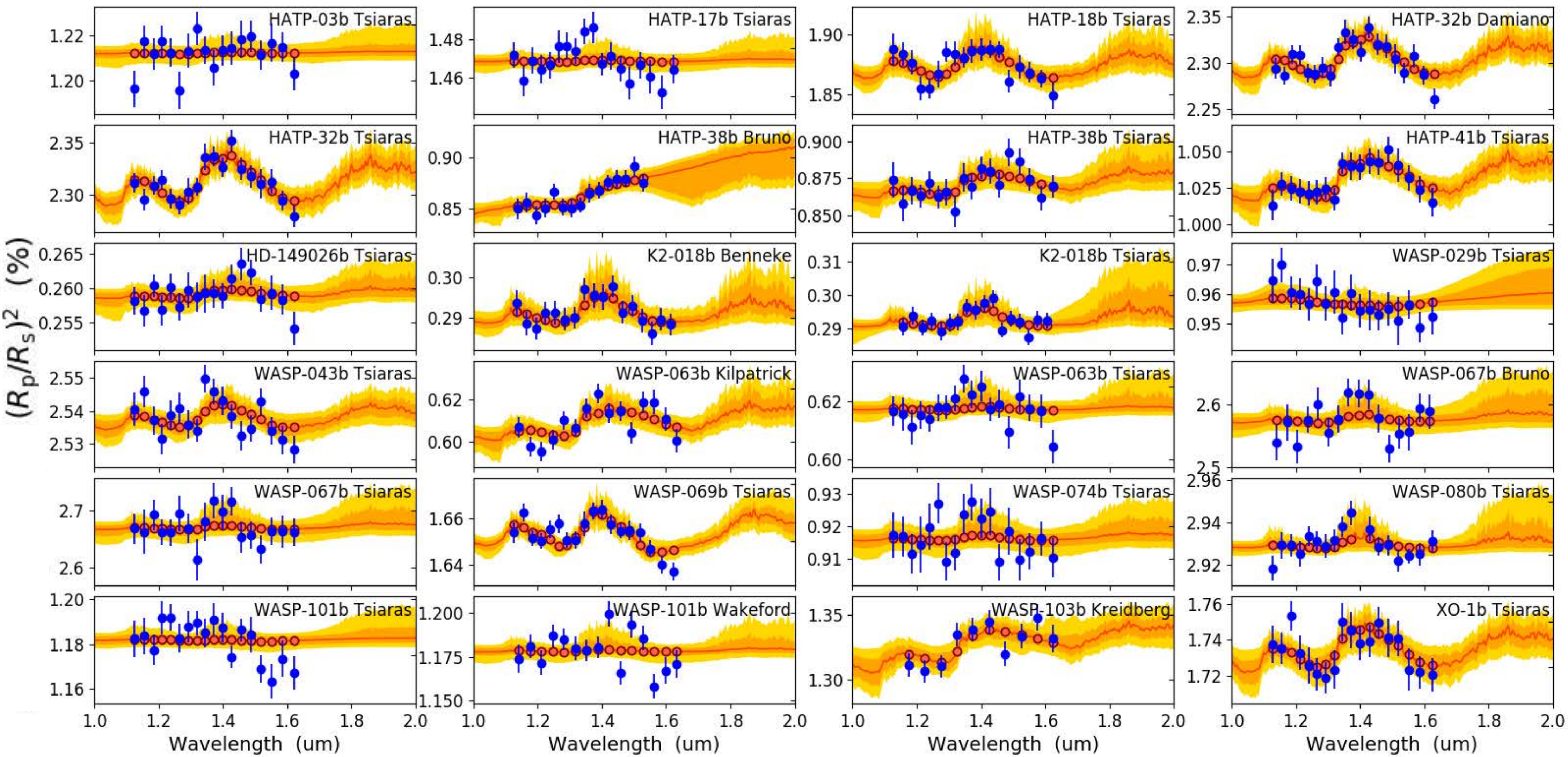


Emission spectra

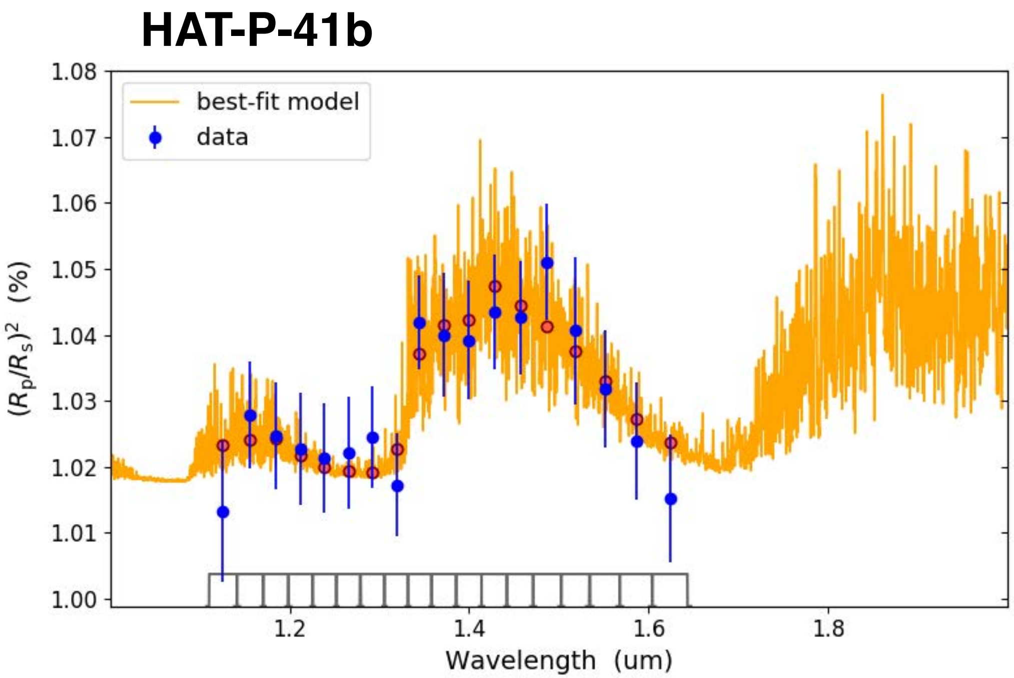


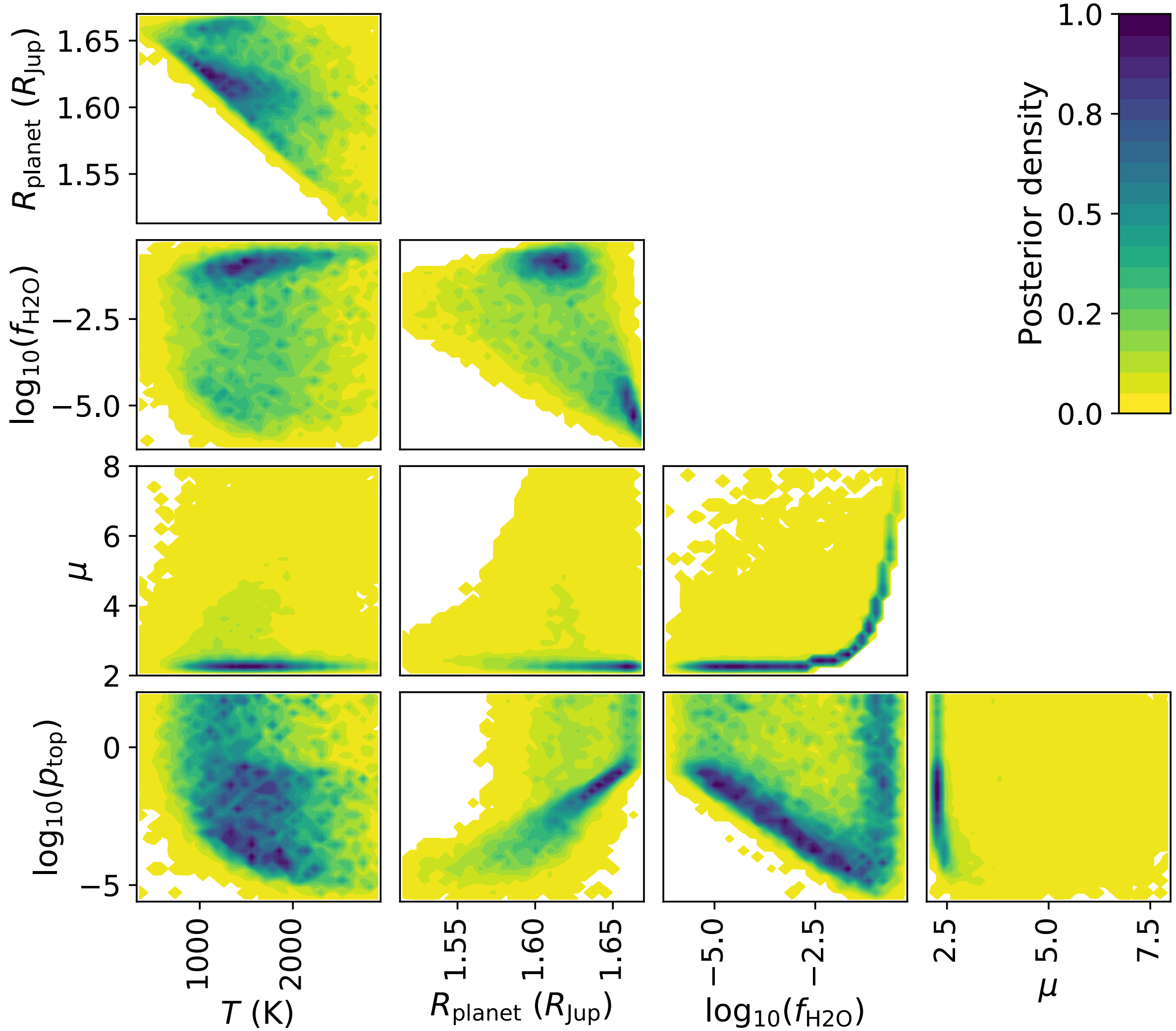
The HST/WFC3 Transmission Sample

(Cubillos & Blecic, in prep.)



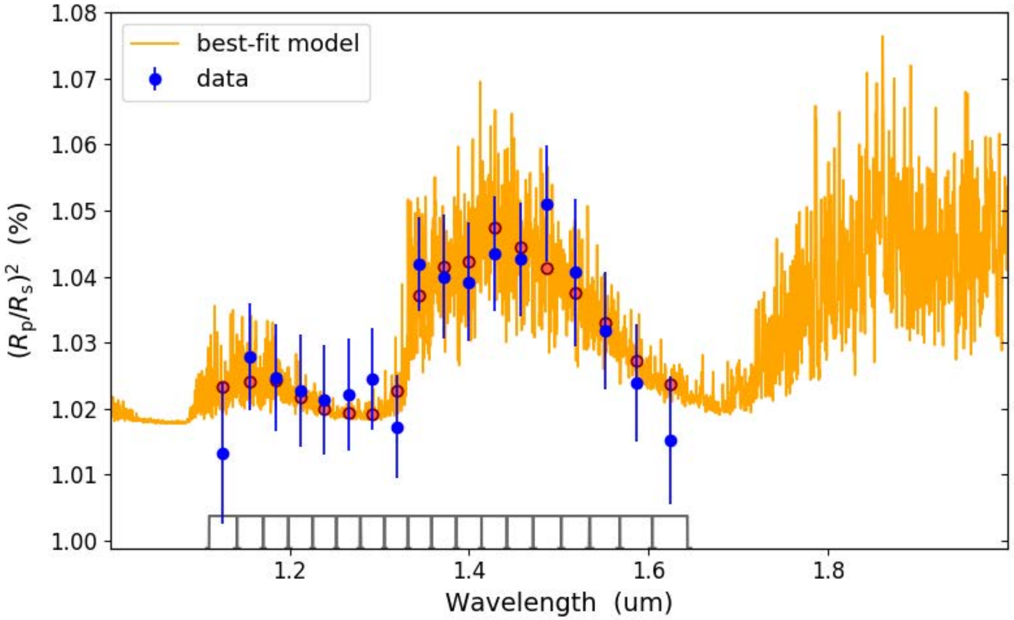
Degenerate/multi-modal Posteriors



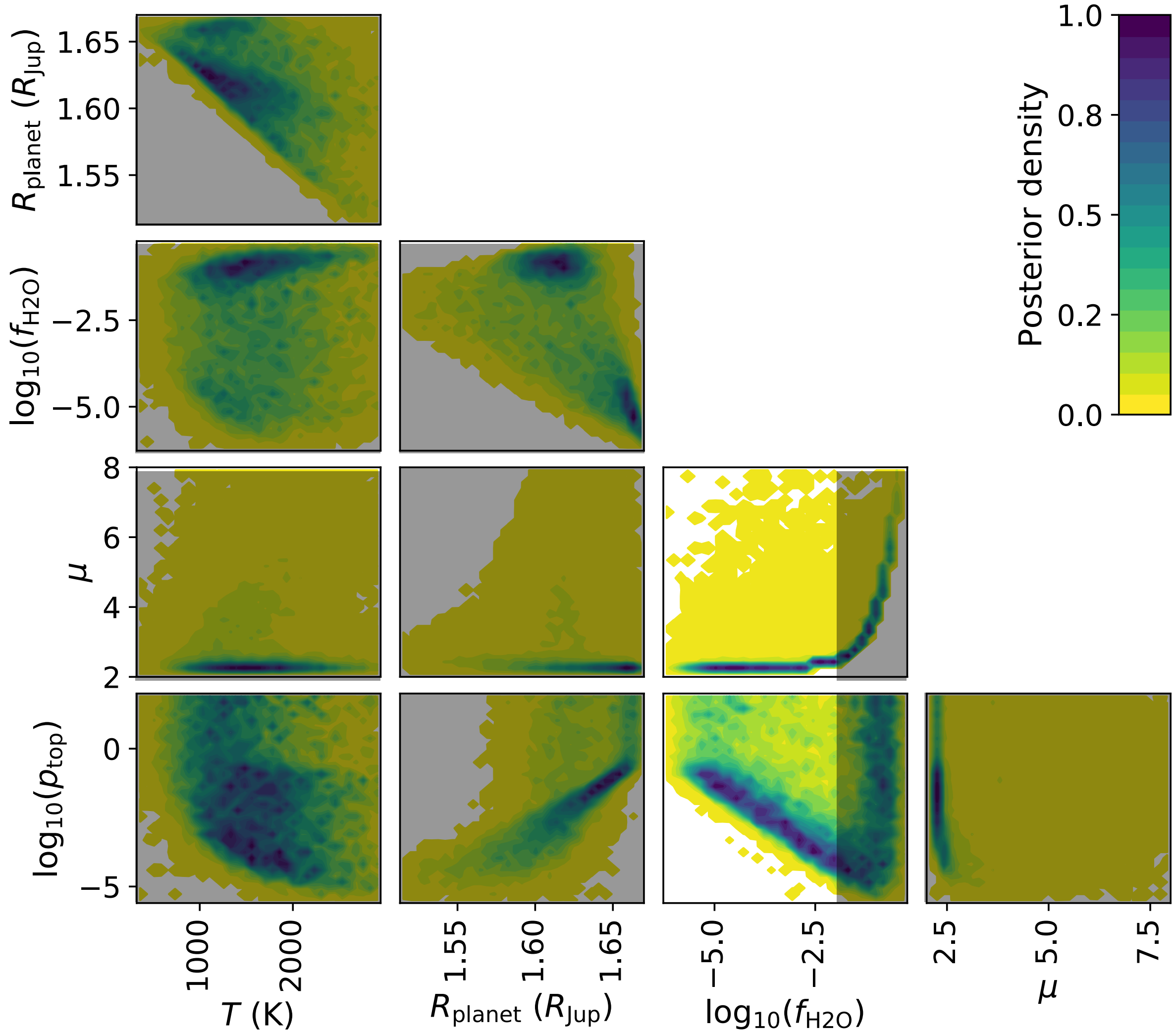


Degenerate/multi-modal Posteriors

HAT-P-41b



- **Cloudy mode:** H2O correlates with cloud top pressure



Degenerate/multi-modal Posteriors

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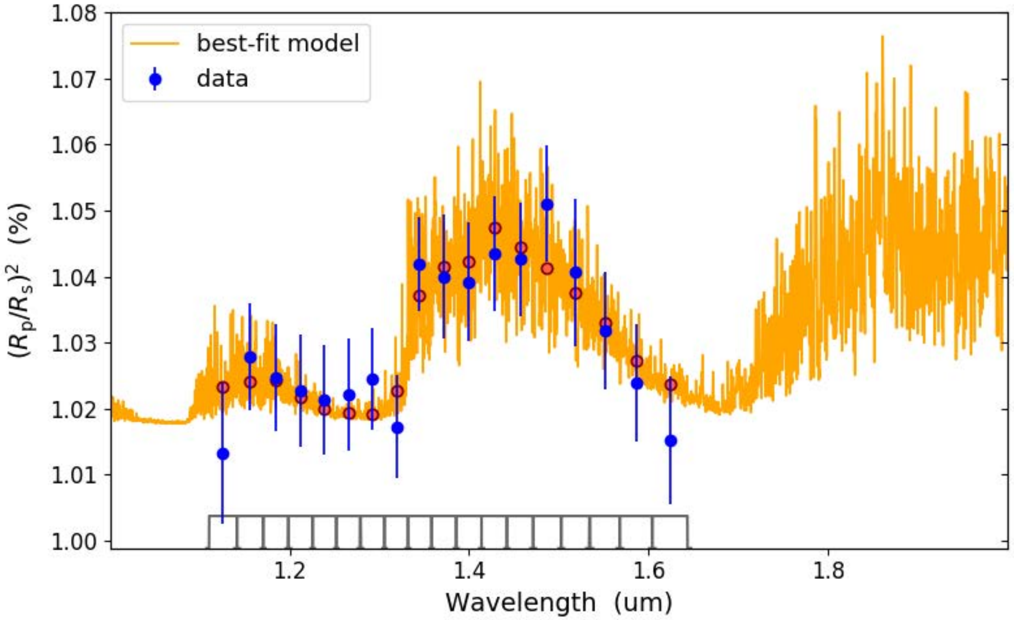
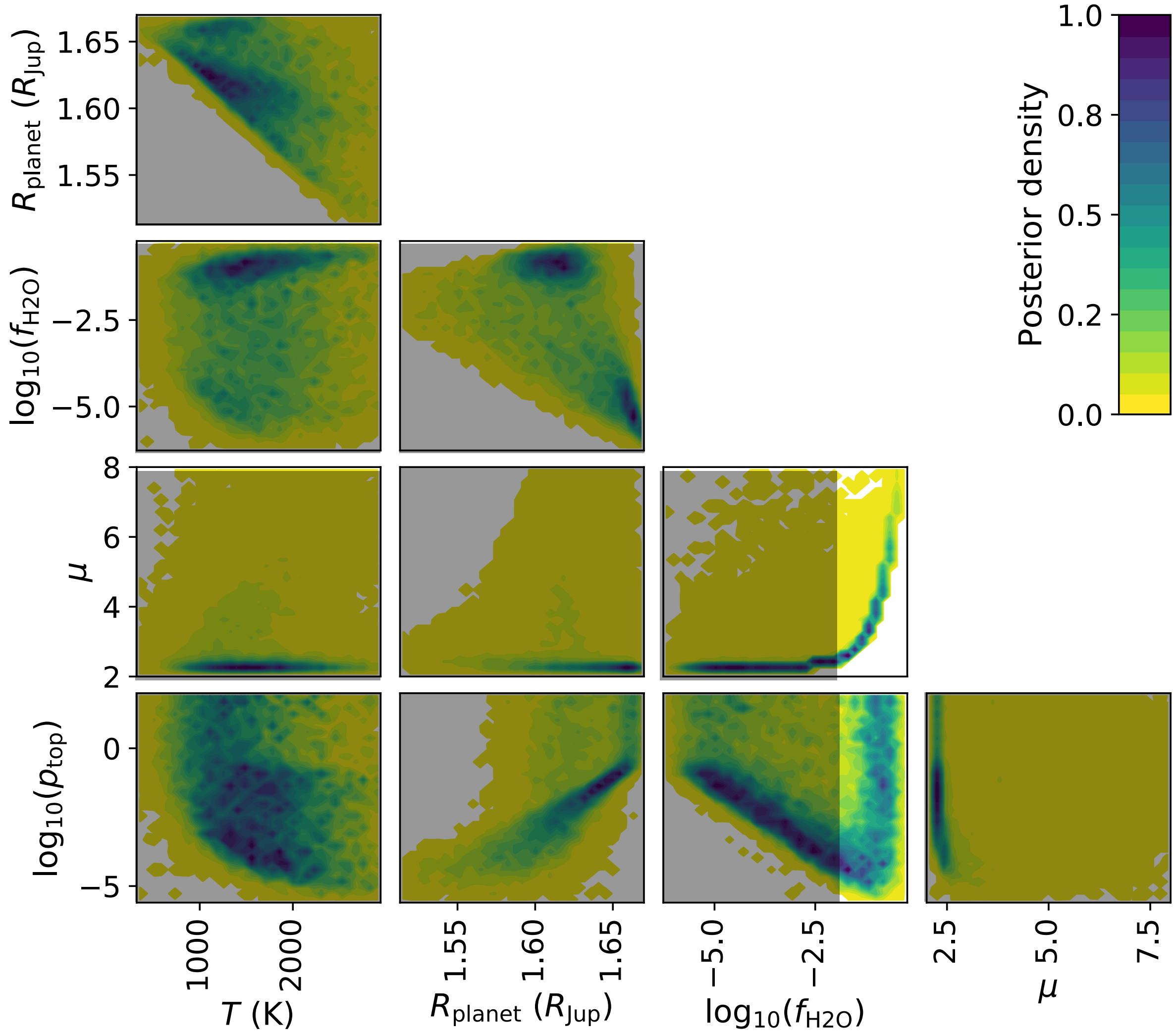
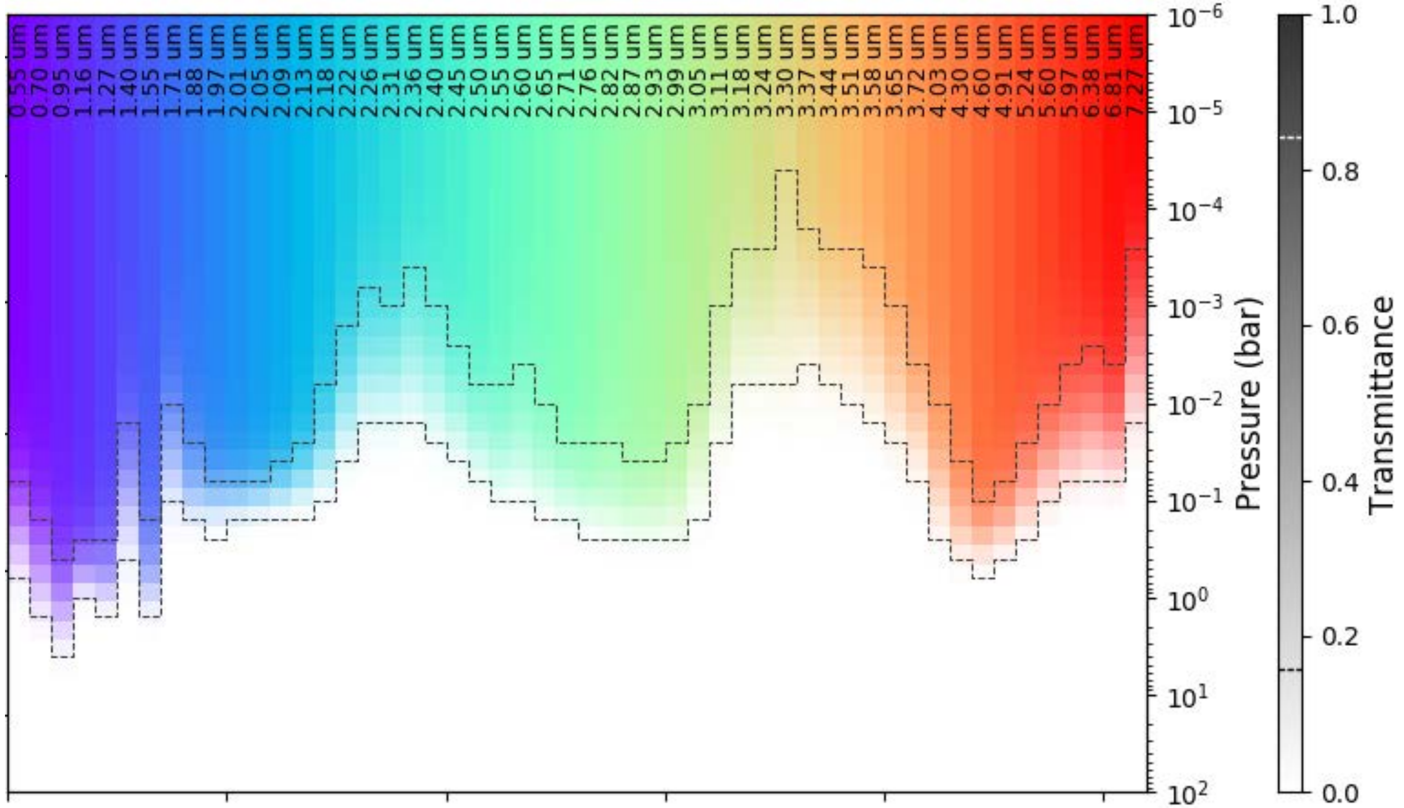
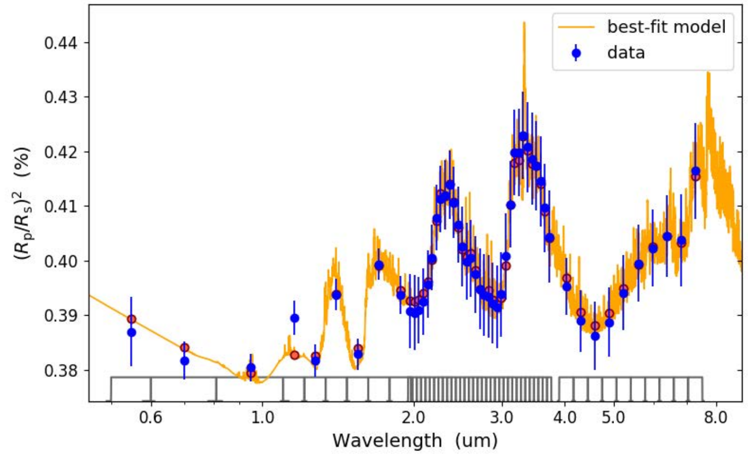




- **Cloudy mode:** H2O correlates with cloud top pressure
- **High-*μ* mode:** H2O in high mean-molecular-mass atmosphere

Degenerate/multi-modal Posteriors





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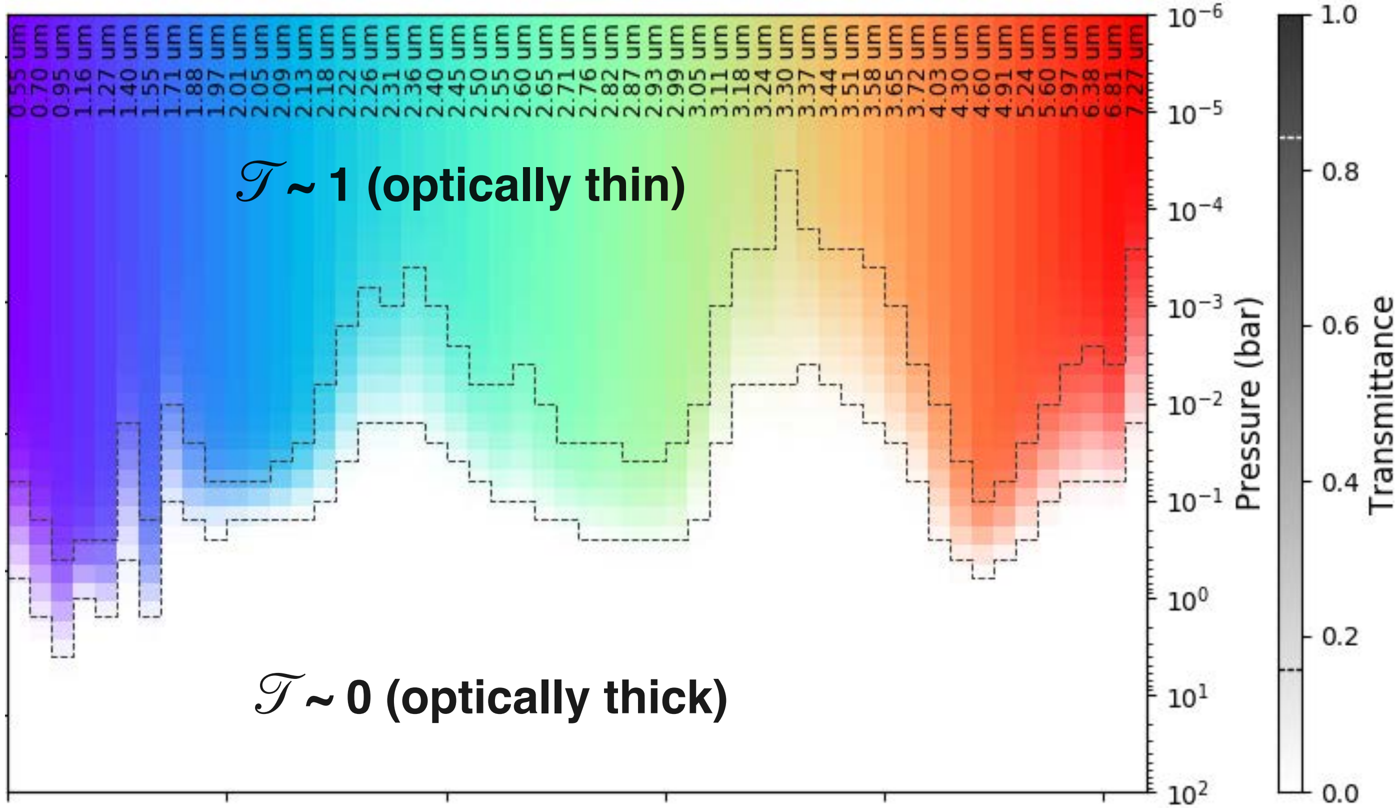
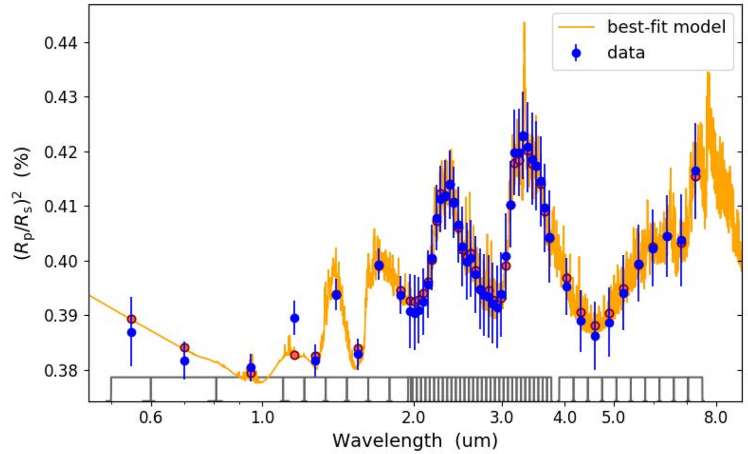
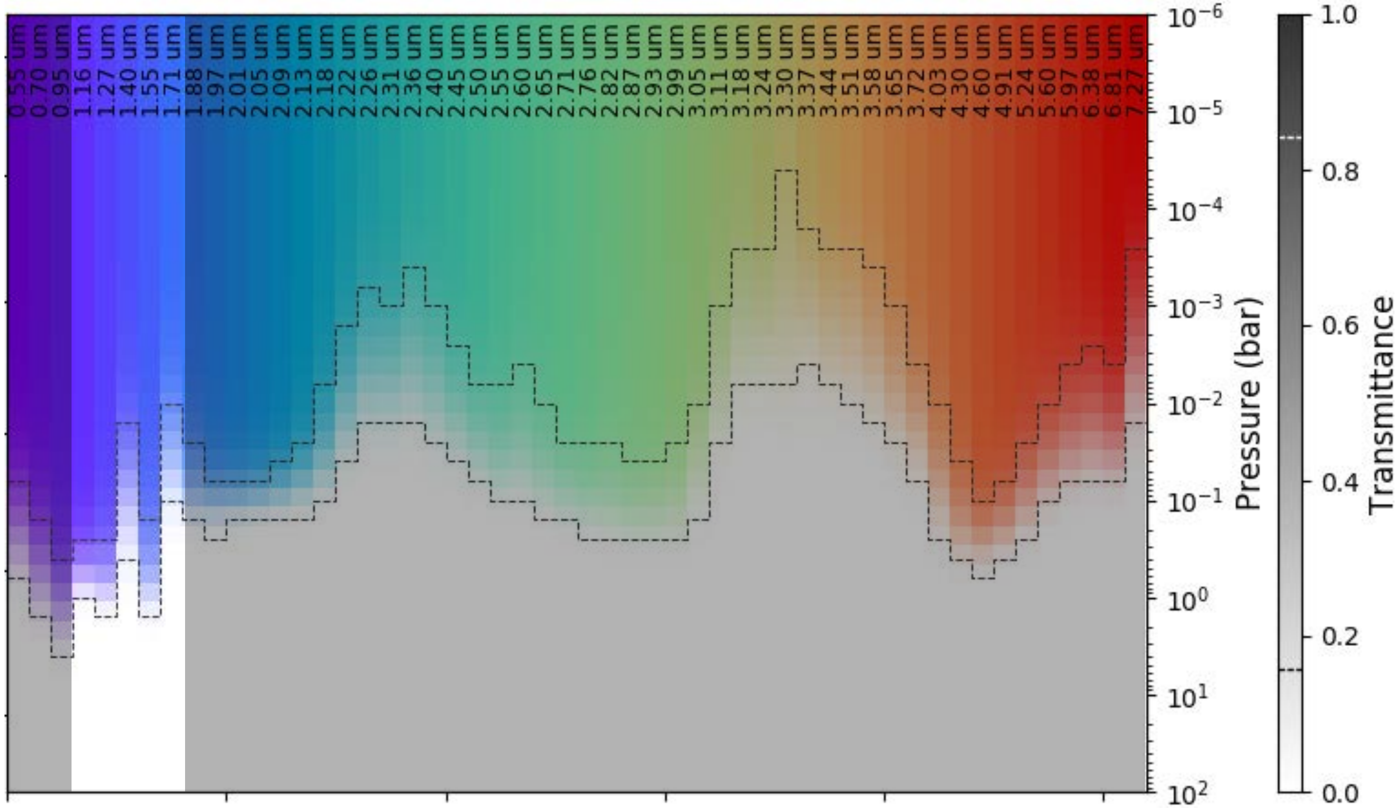
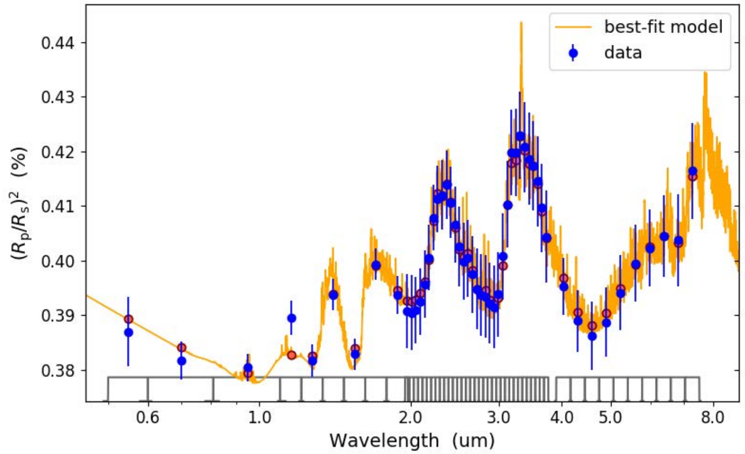




Degenerate/multi-modal Posteriors

WFC3 band





Degenerate/multi-modal Posteriors

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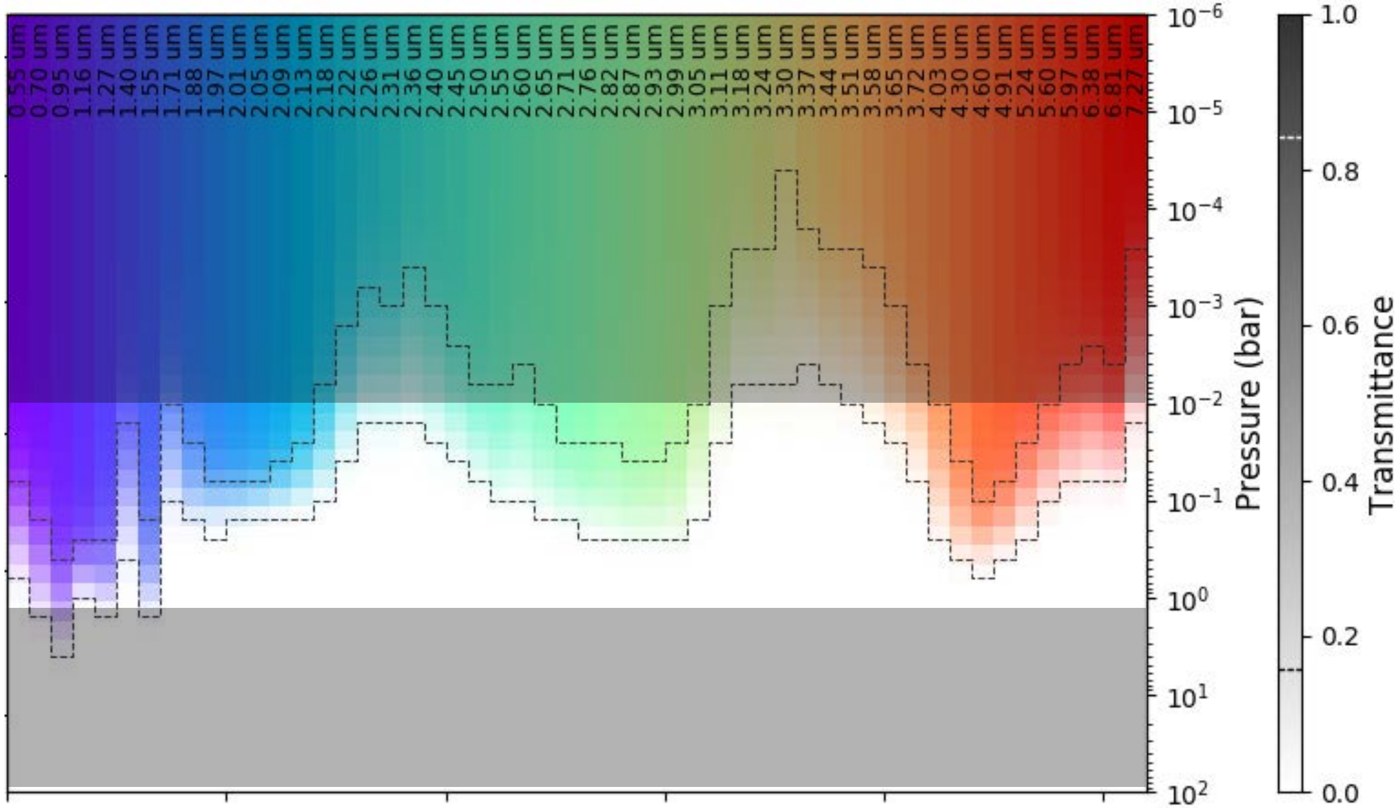
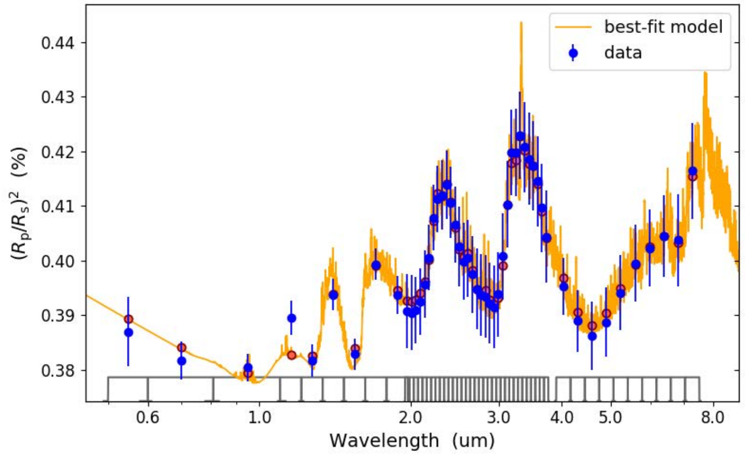
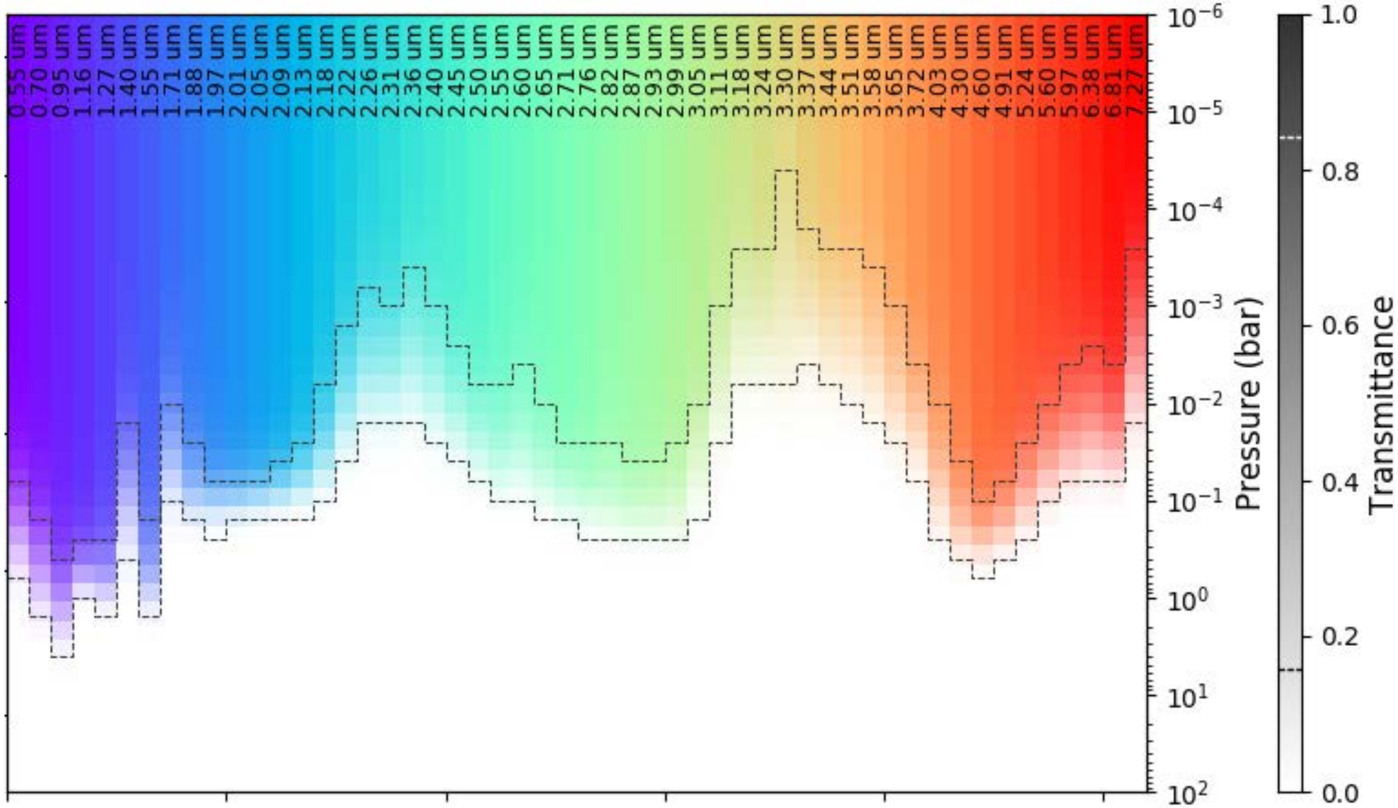


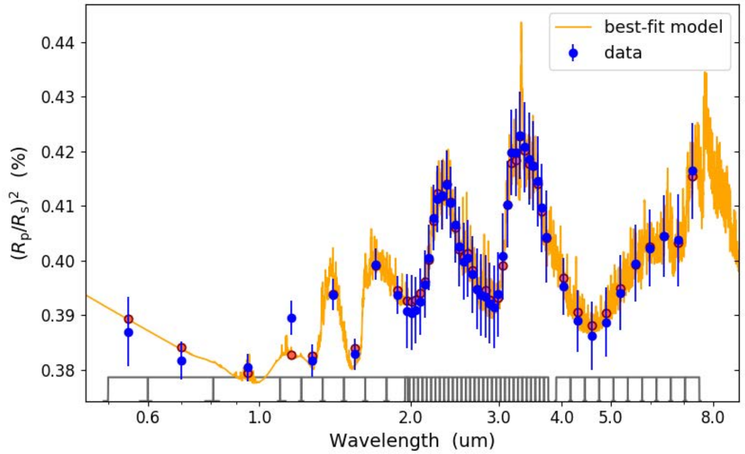


WFC3 probes narrow pressure range
(isothermal/isobaric OK-ish)

Degenerate/multi-modal Posteriors

ARIEL: wide simultaneous coverage





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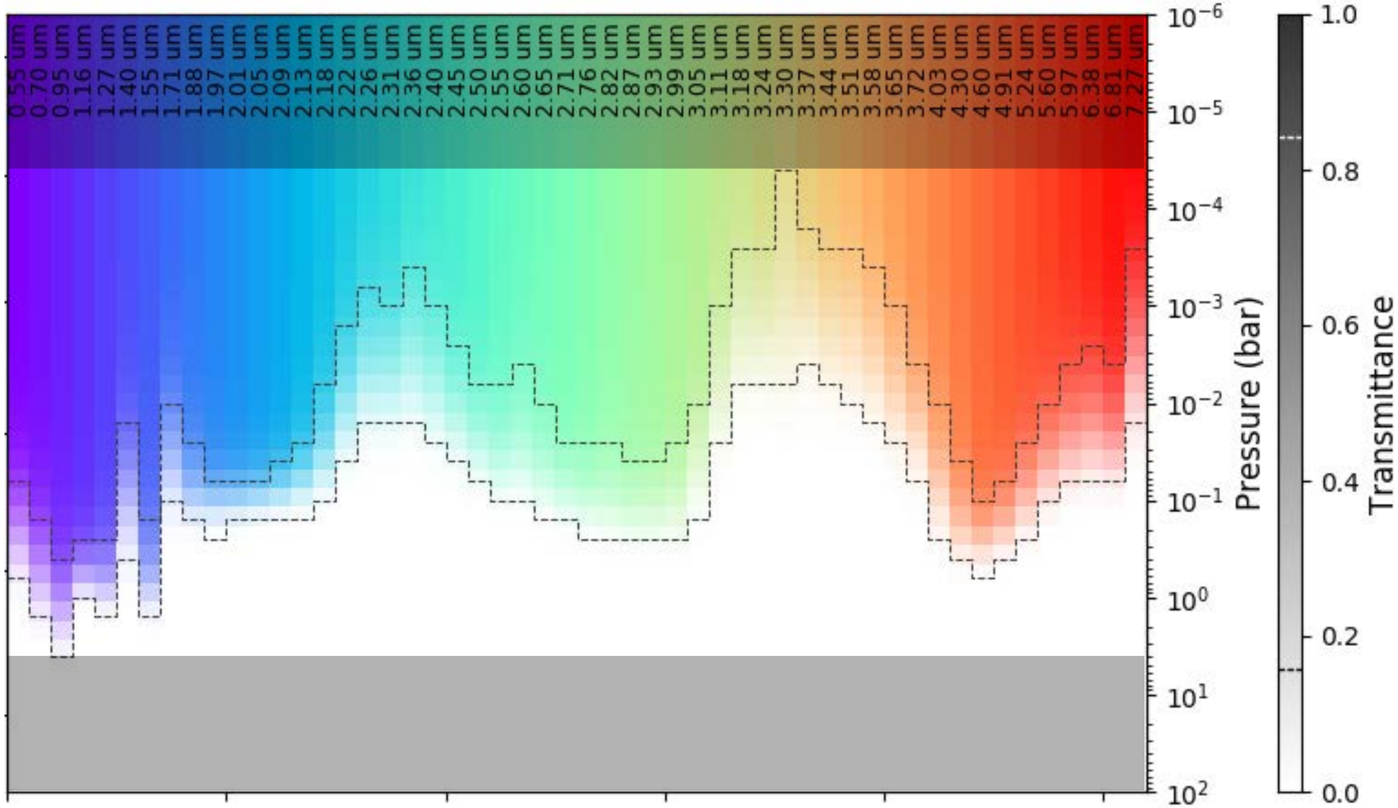
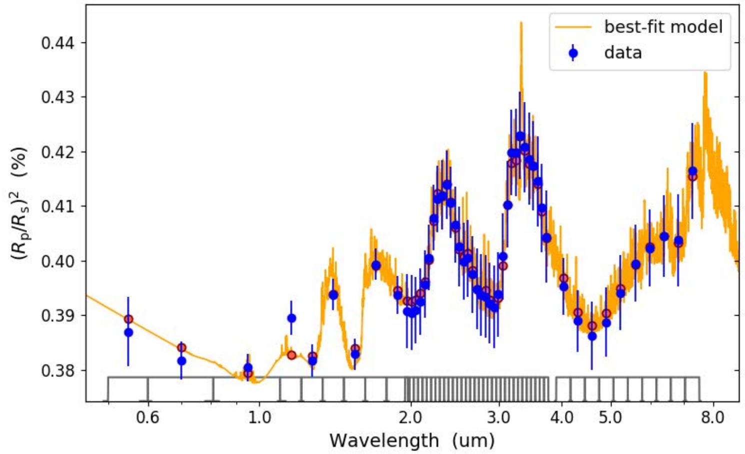




WFC3 probes narrow pressure range (isothermal/isobaric OK-ish)

ARIEL will probe much wider pressure range!

ÖAW IWF

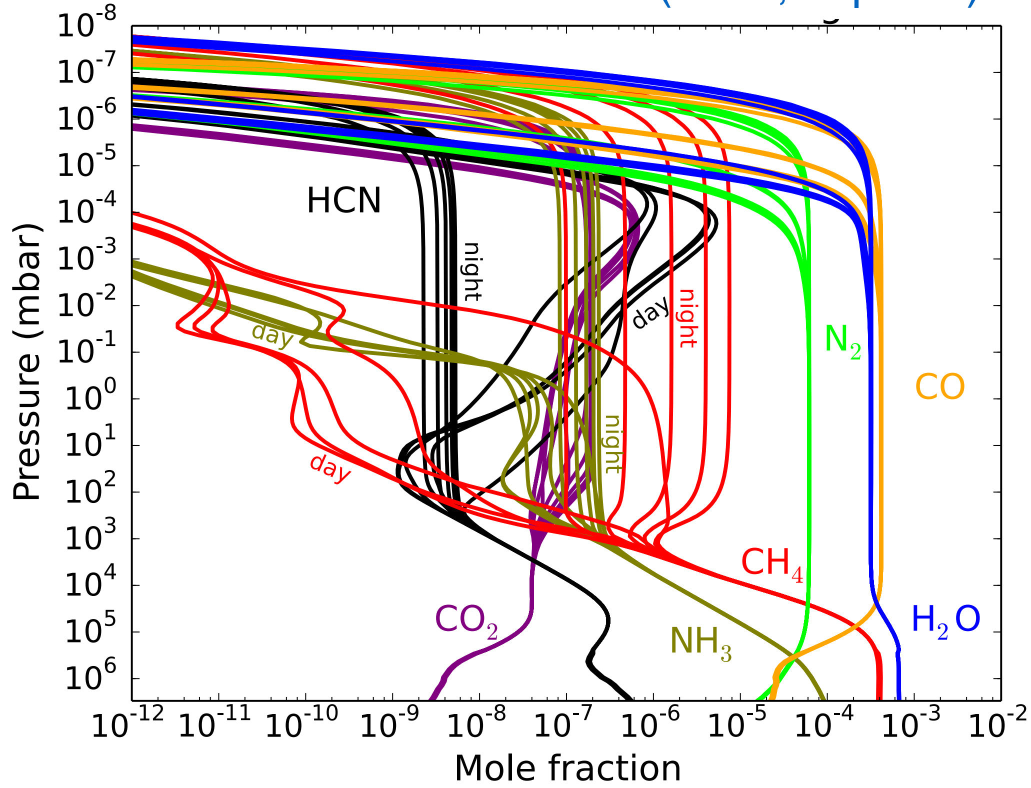
The Challenge

We wish to increase complexity:
- Non-isothermal profiles
- Non-isobaric abundances (Changeat et al., 2019)
- > 1D geometry (Taylor et al.; Irwin et al., 2019)
- Complex clouds (Blecic et al., in prep)

But, restrained by data quality:
- Unwieldy parameter space
- Unconstrained posteriors
- **Modeling choices impact outcome**
  physics
  data bases
  what to include/exclude

Restrained by CPU power
GPU no longer (e.g., Al-Refaie, Zalesky, Malik)

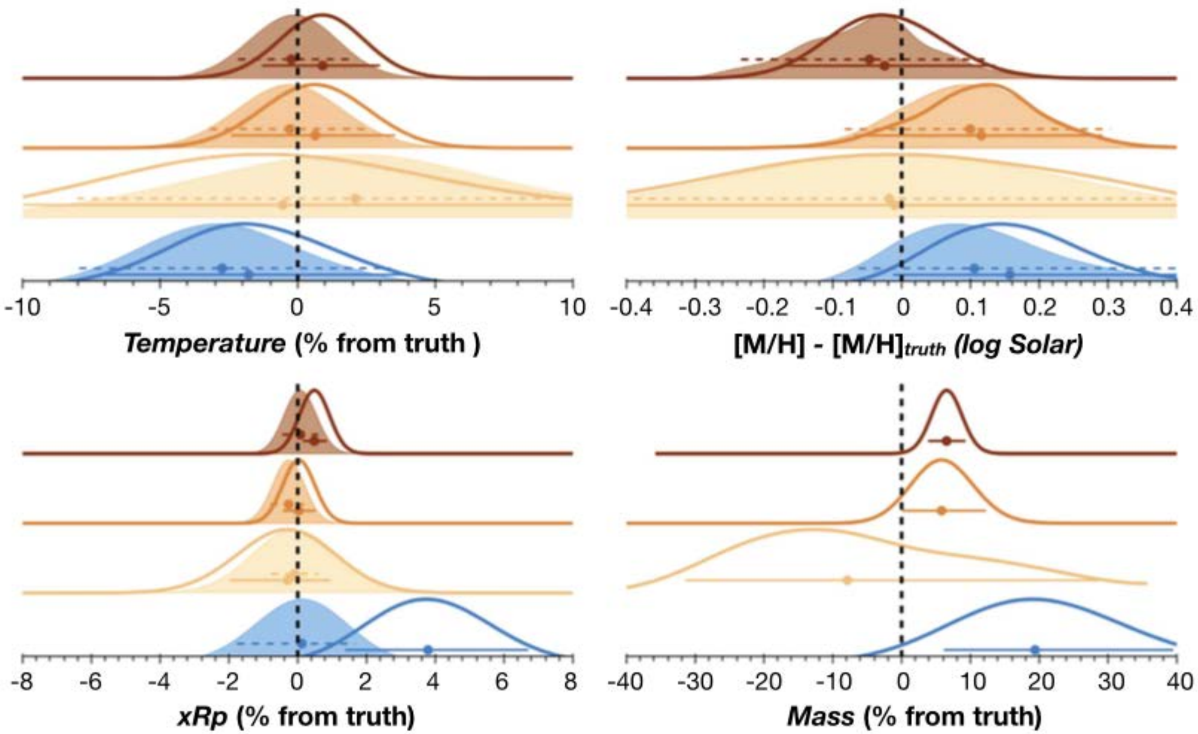
Venot et al. (2020, in press)



Increase complexity,
be aware of assumptions,
keep results insightful

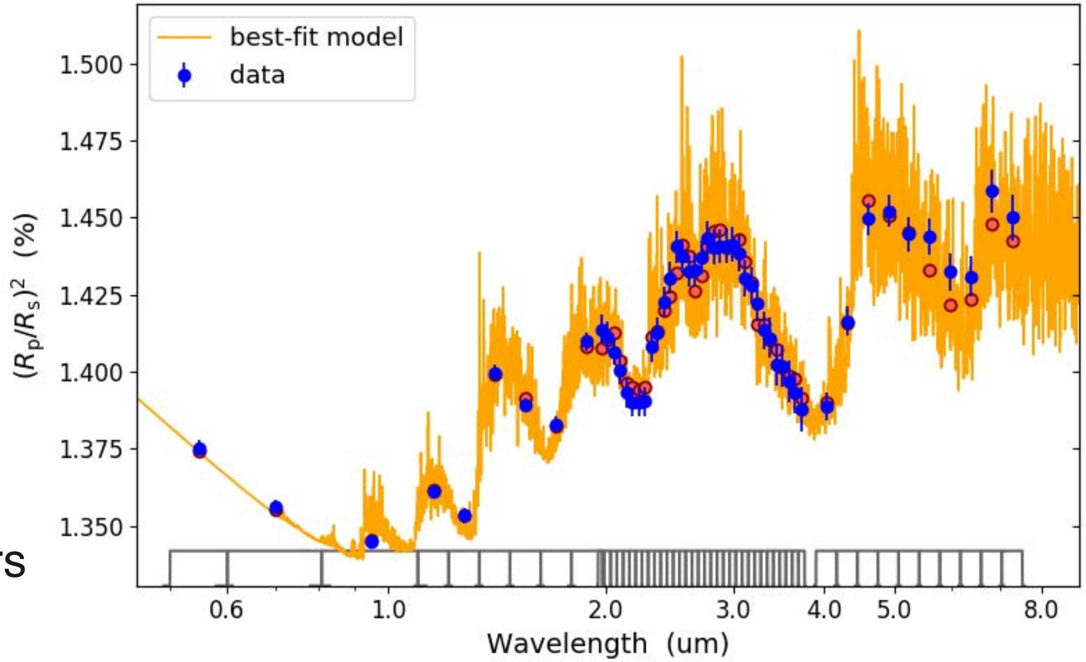
The Precision of Mass Measurements Required for Robust Atmospheric Characterization of Transiting Exoplanets

Natasha E. Batalha[1], Taylor Lewis[1], Jonathan J. Fortney[1], Natalie M. Batalha[1], Eliza Kempton[2], Nikole K. Lewis[3], Michael R. Line[4]



Mass-retrieval Setup

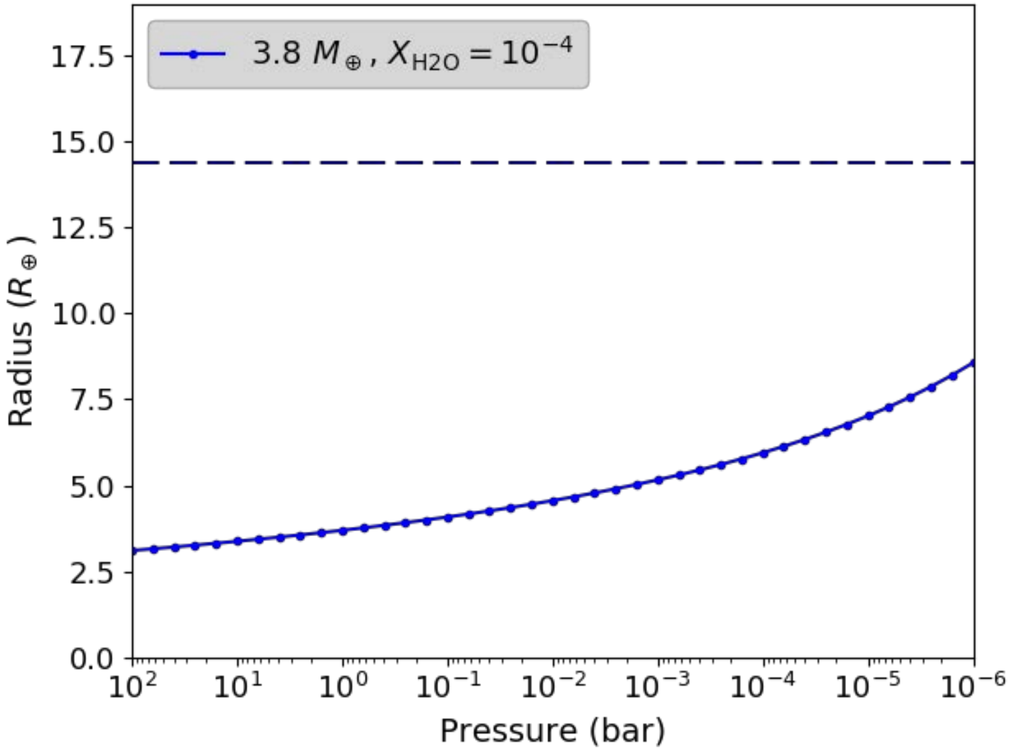
Same assumptions as retrieval challenge:
- Isothermal profile
- Isobaric abundances (H2O, CO, CO2, CH4, TiO)
- Radius at 10 bar
- Gray cloud deck



Additionally:
- Retrieve planetary mass, assuming Gaussian priors
- Test multiple mass-uncertainties

What's the impact on the *abundance* posteriors?

ARIEL Mass-retrieval Setup

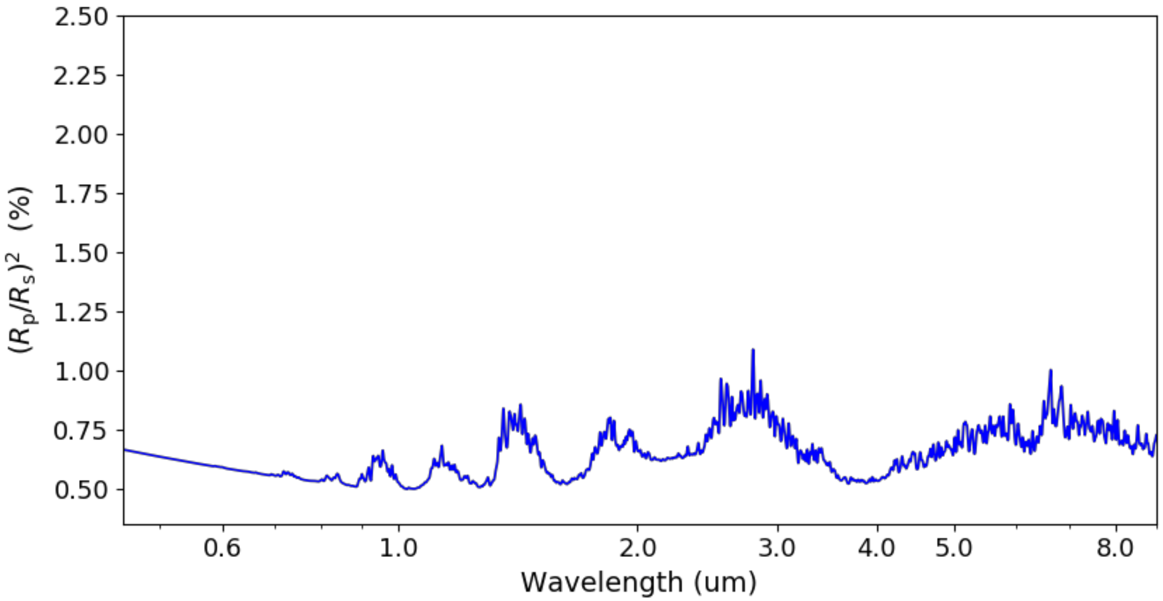


Hydrostatic equilibrium:

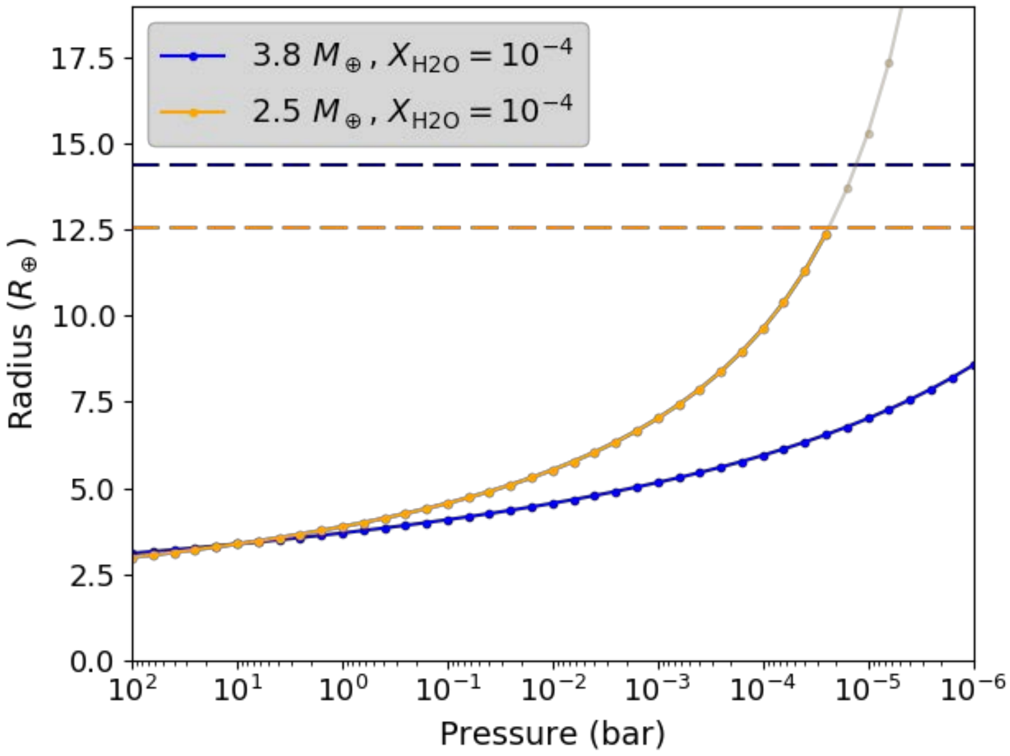
$$\frac{\mathrm{d}r}{r^2} = -\frac{kT}{\mu G M_\mathrm{p}} \frac{\mathrm{d}p}{p}$$

Hill Radius:

$$R_\mathrm{H} = a \sqrt[3]{\frac{M_\mathrm{p}}{3M_\mathrm{s}}}$$



ARIEL Mass-retrieval Setup



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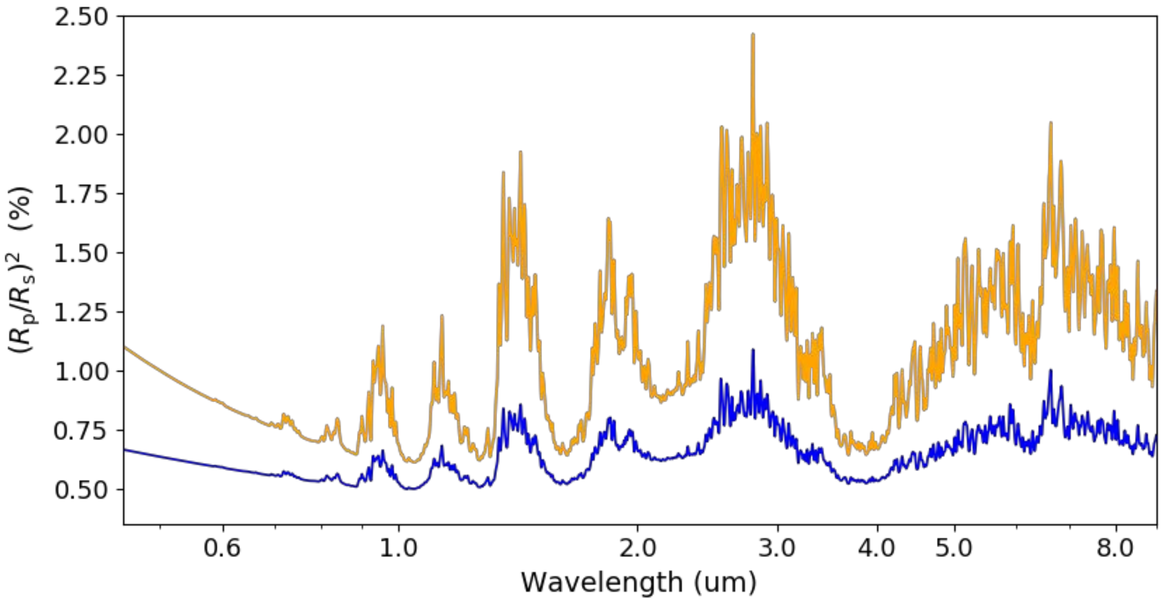

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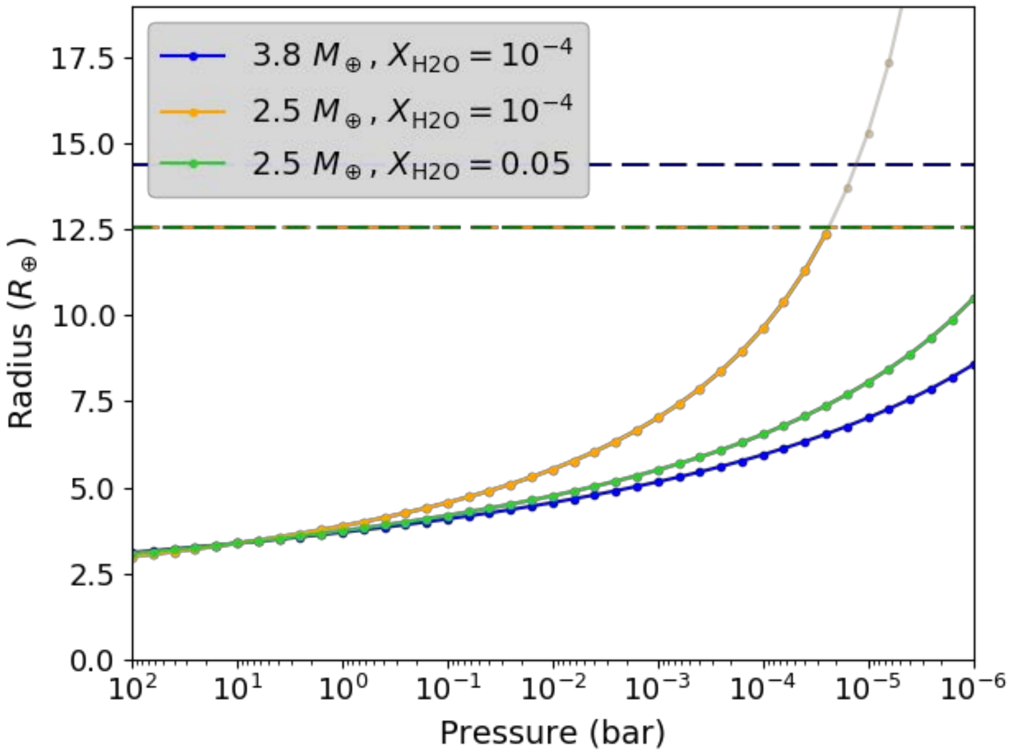

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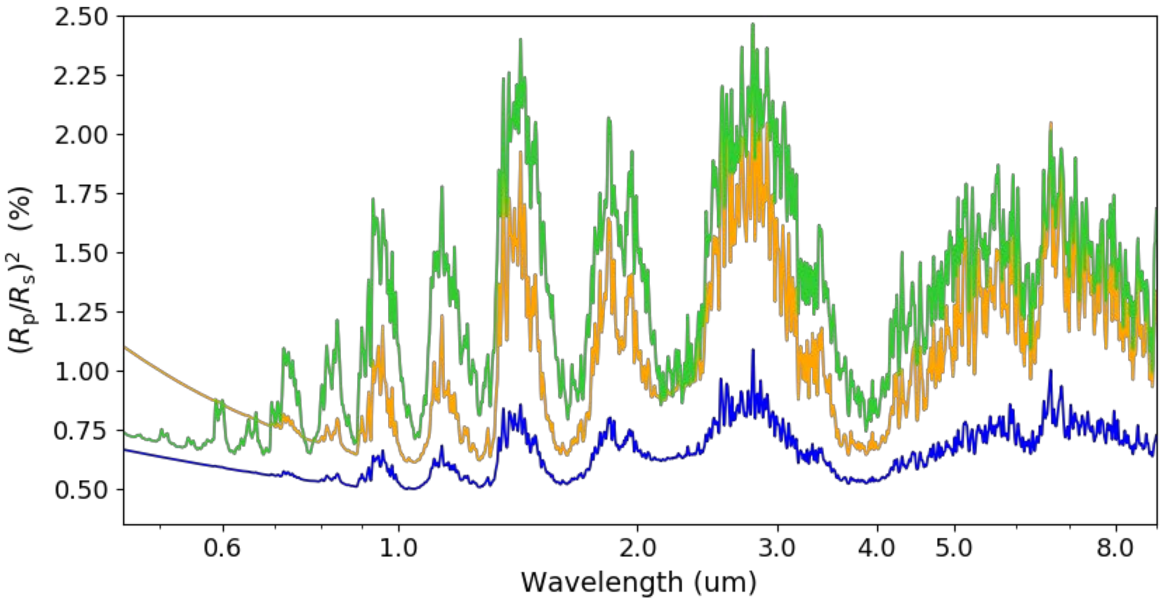
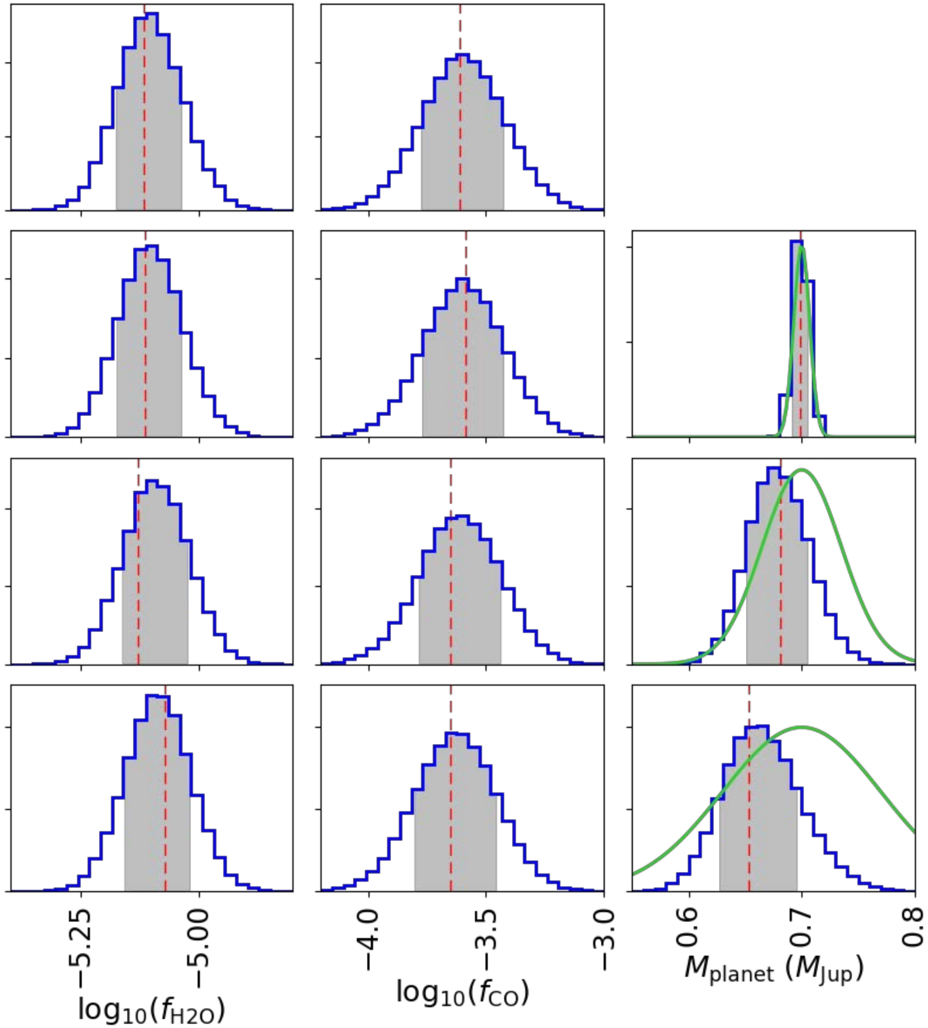


Hot Jupiter (0.7 M_{Jup})

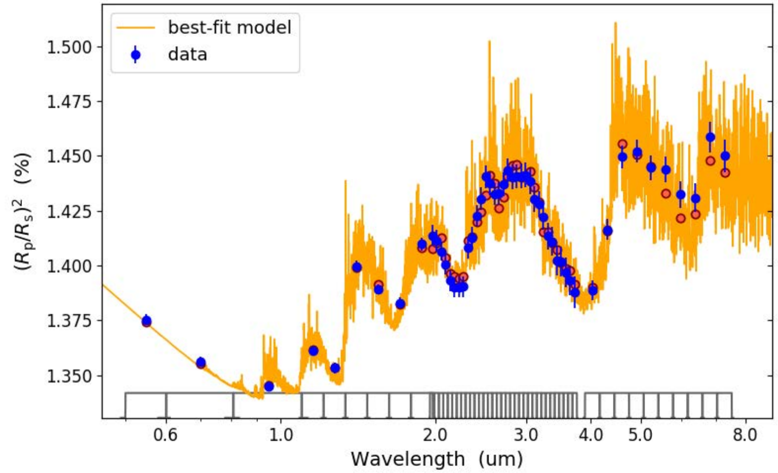


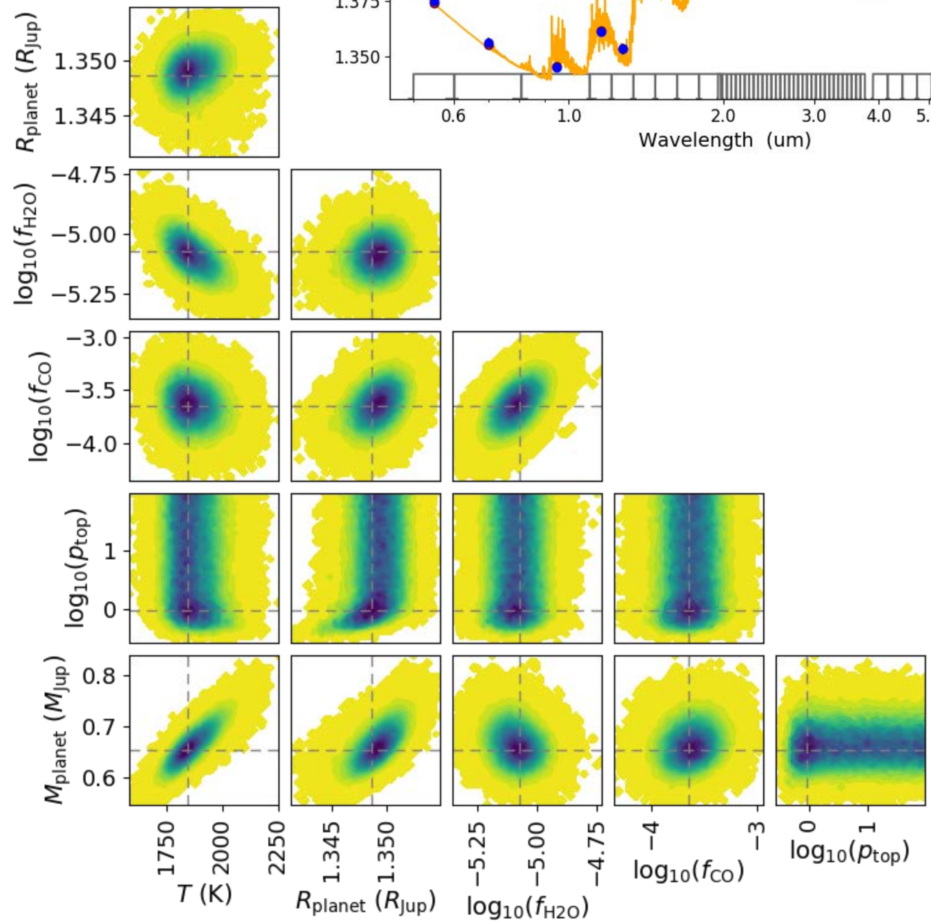
$\sigma_M = 0$

σ_M/M_{p}=1%

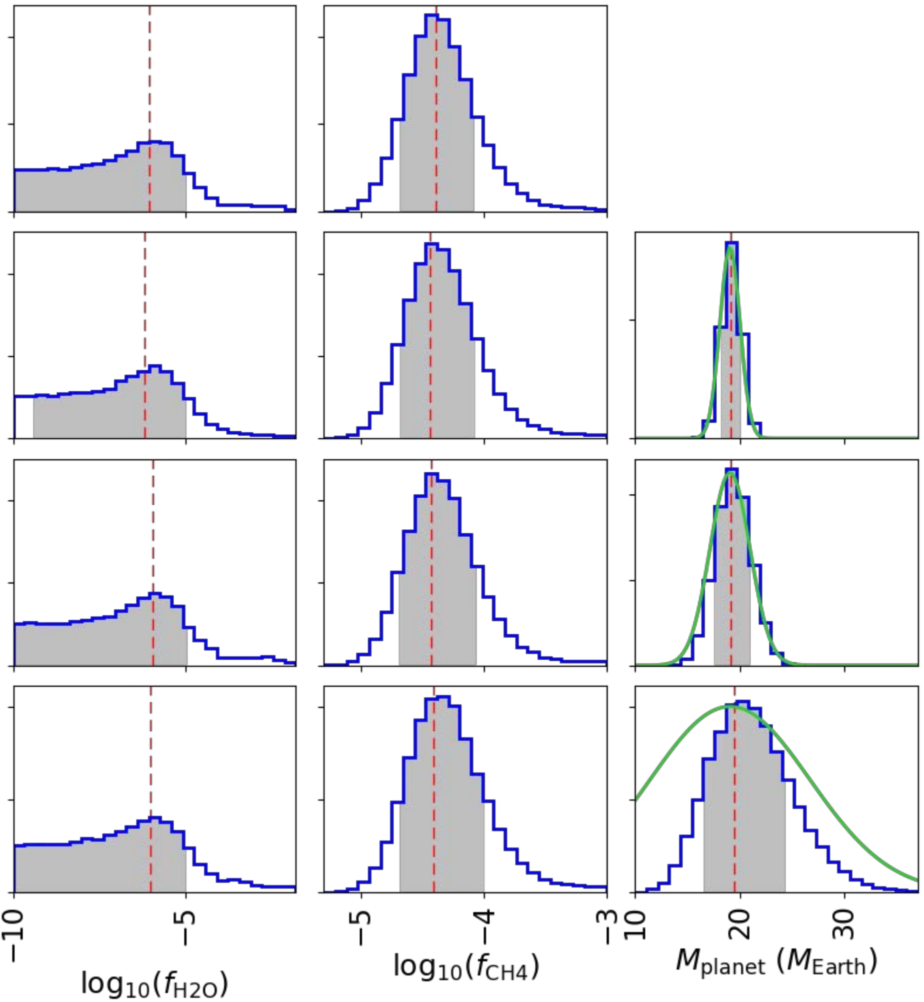
σ_M/M_{p}=5%

σ_M/M_{p}=10%





Mini-Neptune 1 (20 M_{Earth})

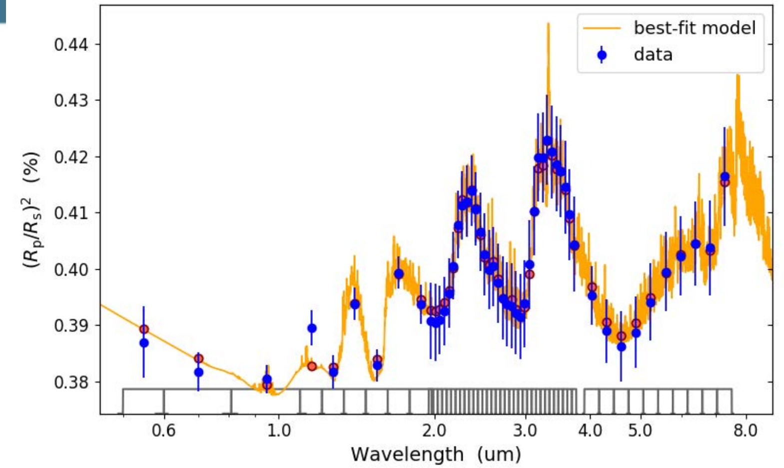


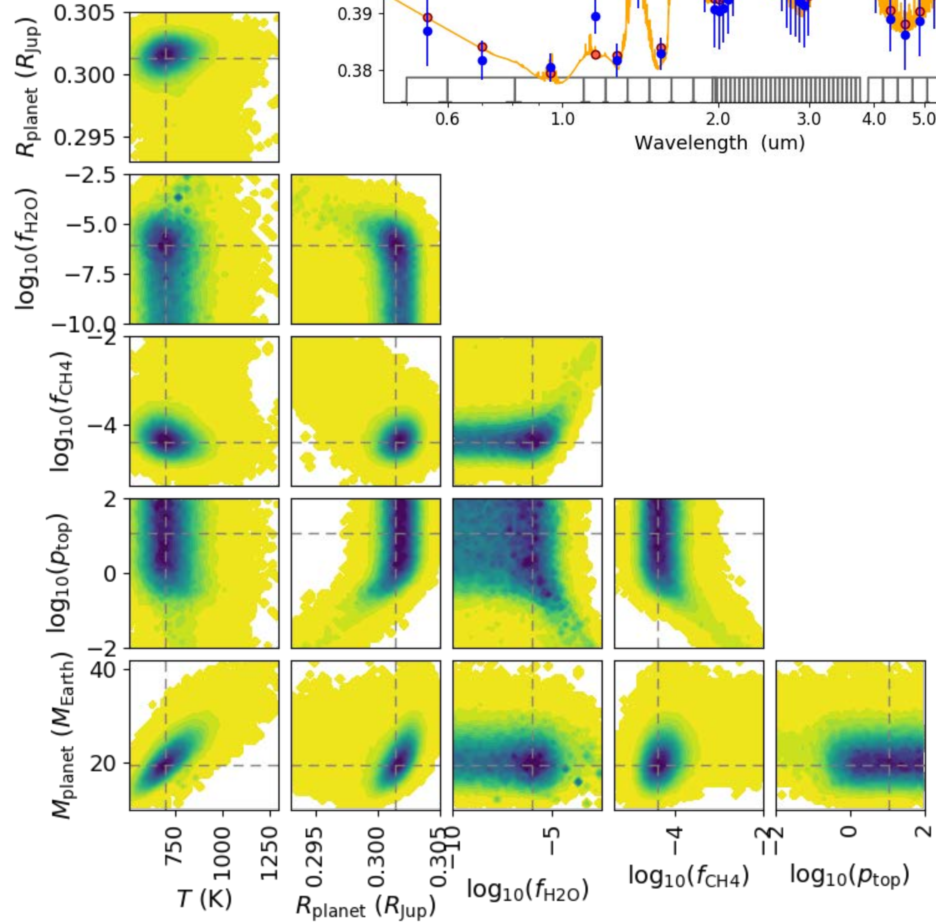
$\sigma_M = 0$

σ_M/M_p=5%

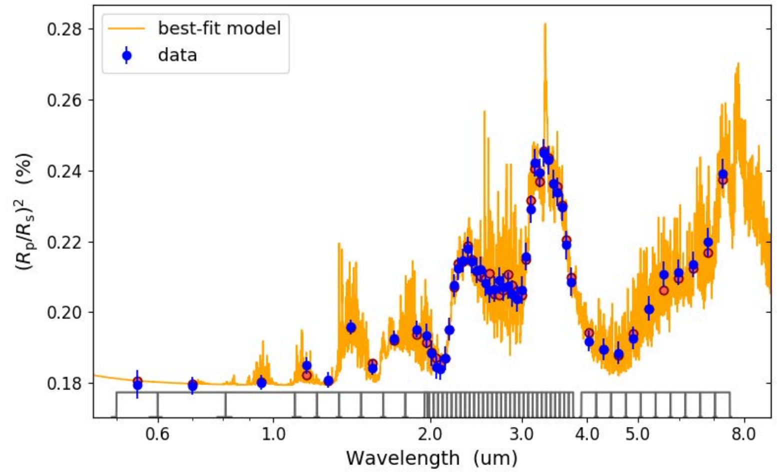
σ_M/M_p=10%

σ_M/M_p=40%





Mini-Neptune 2 (3.2 M_{Earth})

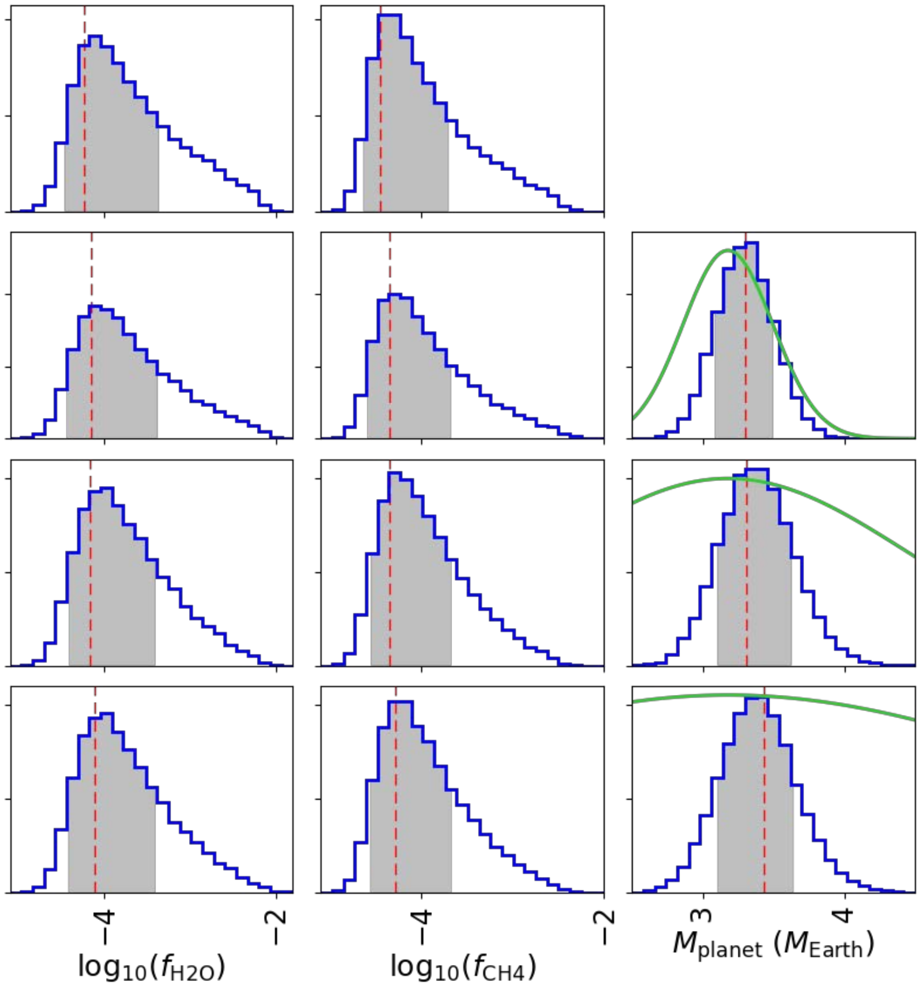


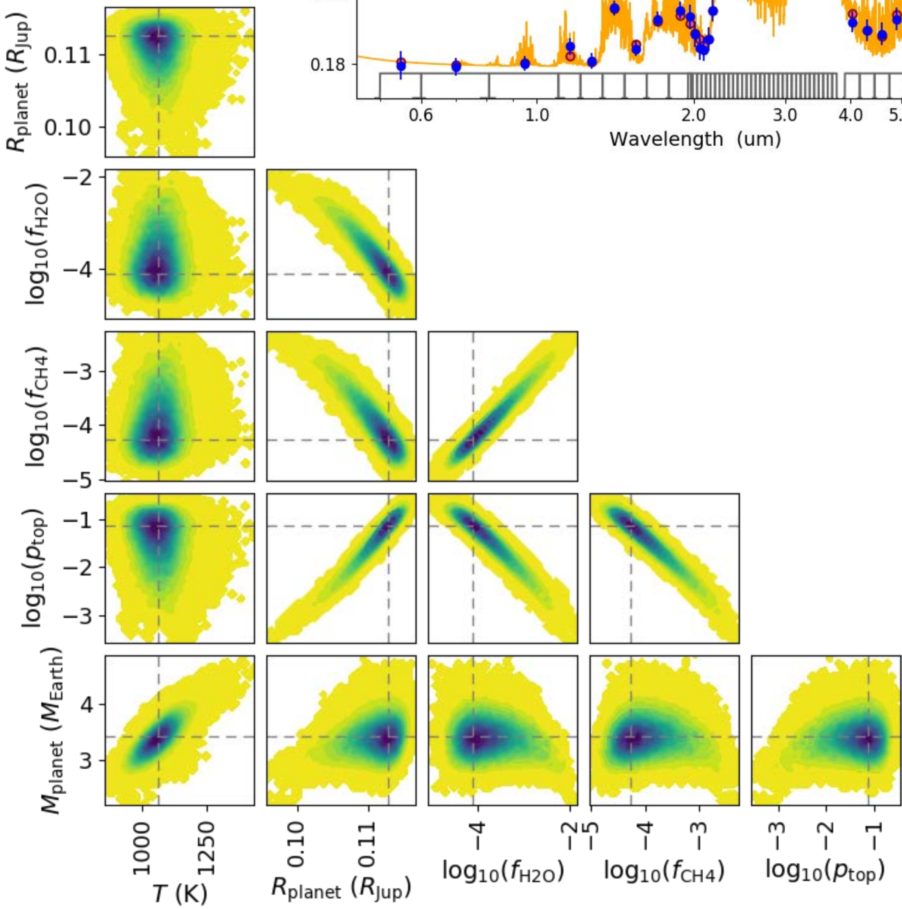
$\sigma_M = 0$

σ_M/M_p=10%

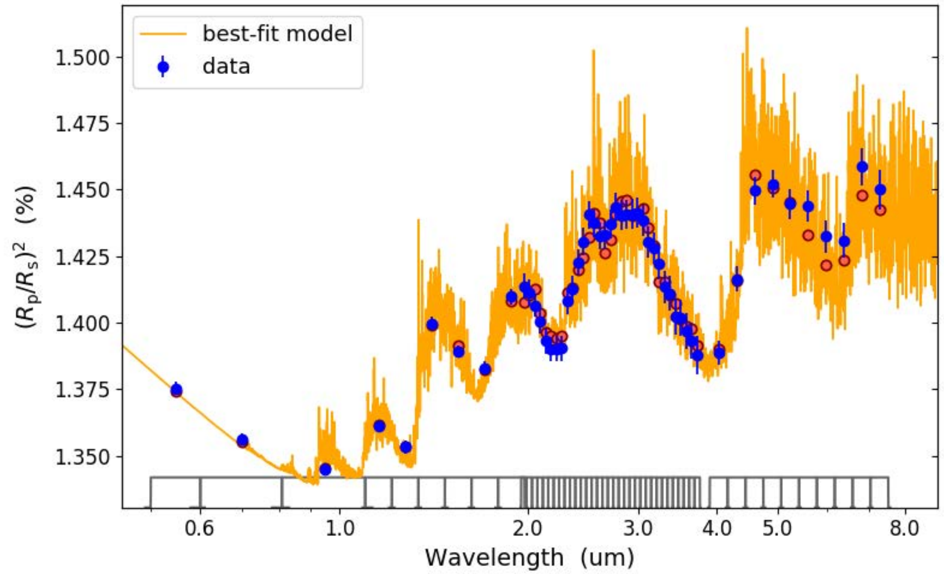
σ_M/M_p=40%

σ_M/M_p=80%





Conclusions



The broader simultaneous spectral coverage of ARIEL will let us aim for an increased model/retrieval complexity.

Mass uncertainties might not have a large impact in abundance retrievals of H/He planets.

There's a long list of improvements for retrieval (2D/3D, consistent equilibrium/disequilibrium chemistry, advanced cloud schemes, etc).

We must be aware of assumptions. Open-source code will help to understand impact.