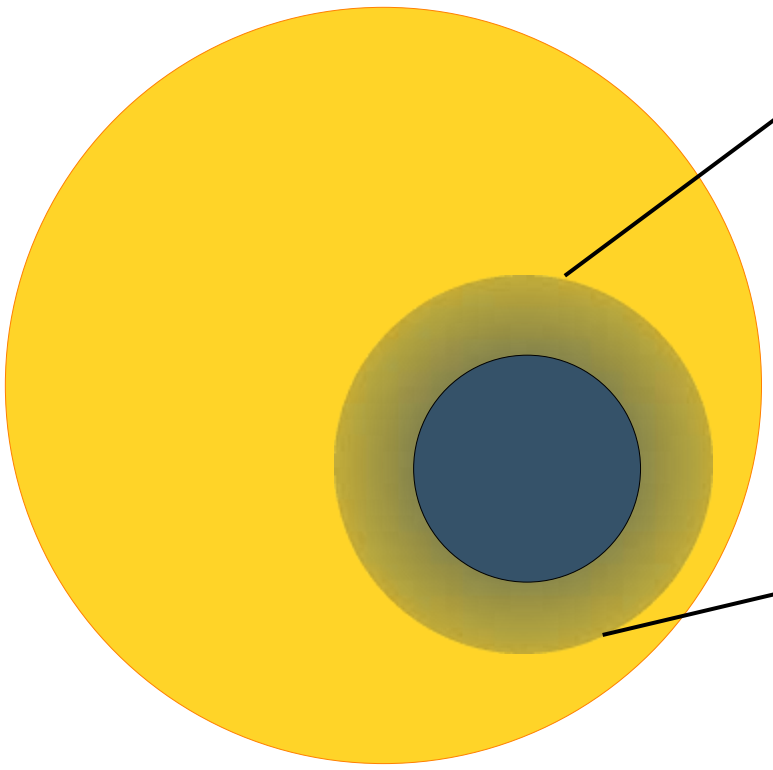
Speeding up Exoplanet Atmospheres Modeling with Neural-Network Emulators

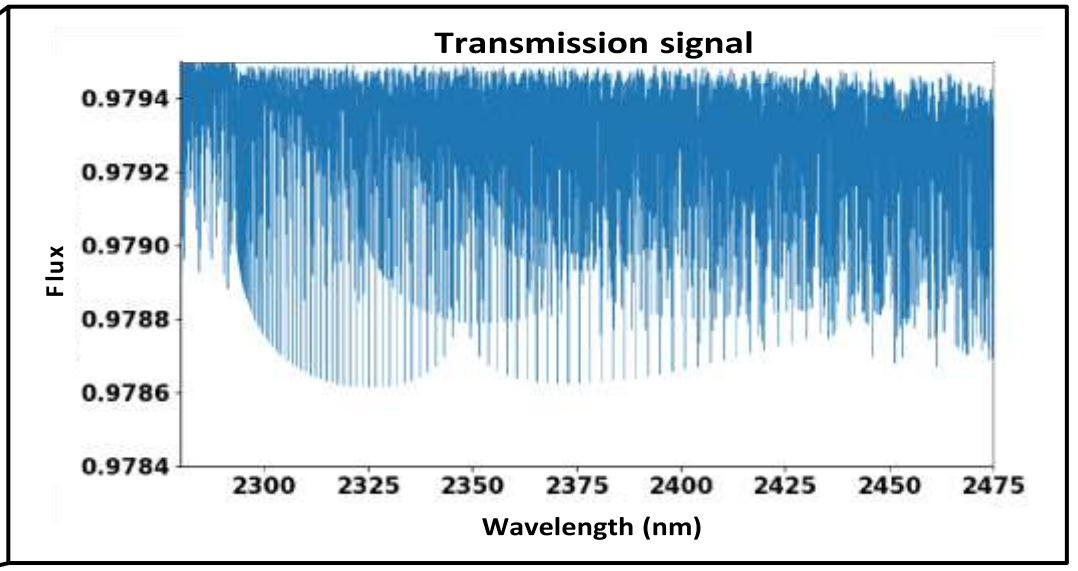
Adrien Masson

Postdoc at Centro de Astrobiología (CAB), Madrid, Spain

High-resolution modeling is expensive !



Your favorite **star** and **planet**



Atmospheric characterisation with HRS

- Thermal profile
- Species detection, abundances (H_2O, CO...)
- Atmospheric dynamics
- **But expensive modeling !**

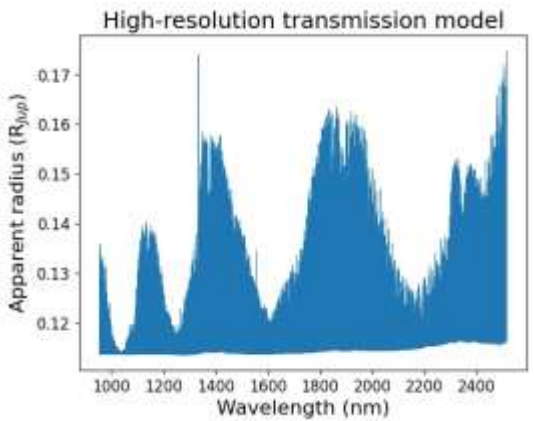
(T_{iso}, $[H_2O]$, $[CO]$, $[CH_4]$, P_{clouds})

High-resolution modeling is expensive !

petitRADTRANS code

Mollière et al. 2019

- 1D radiatif transfer
- line-by-line



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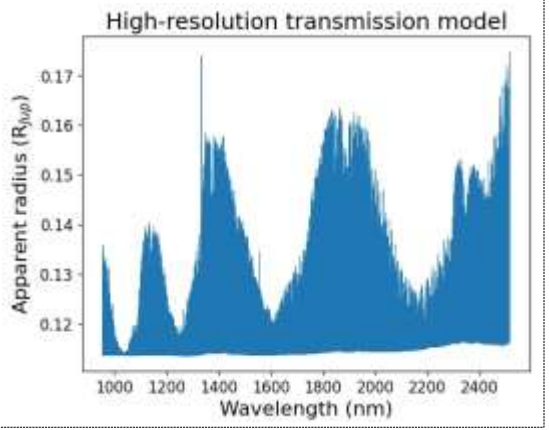

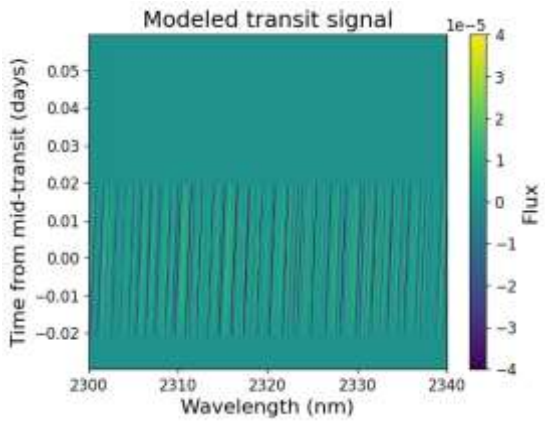

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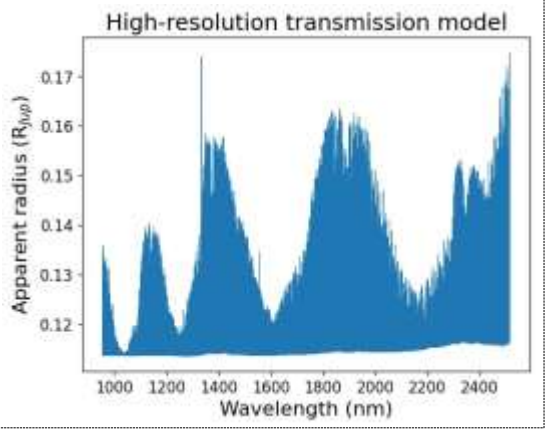
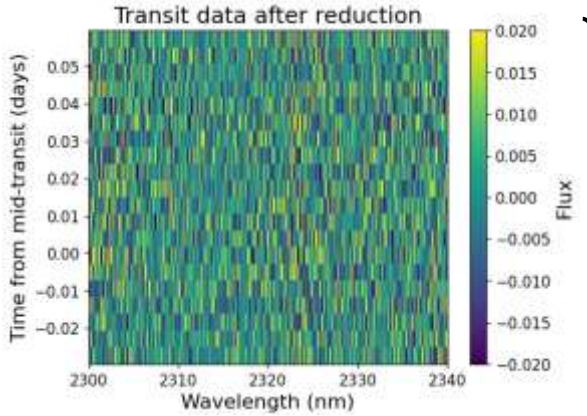
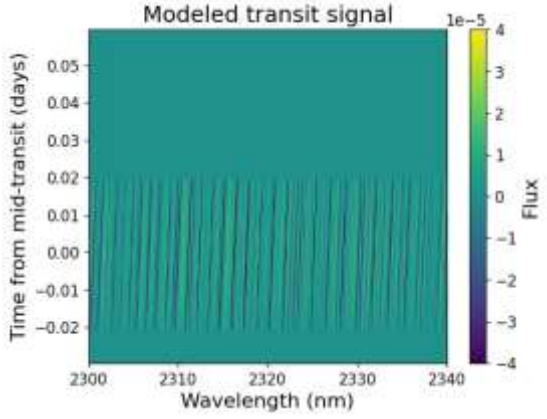
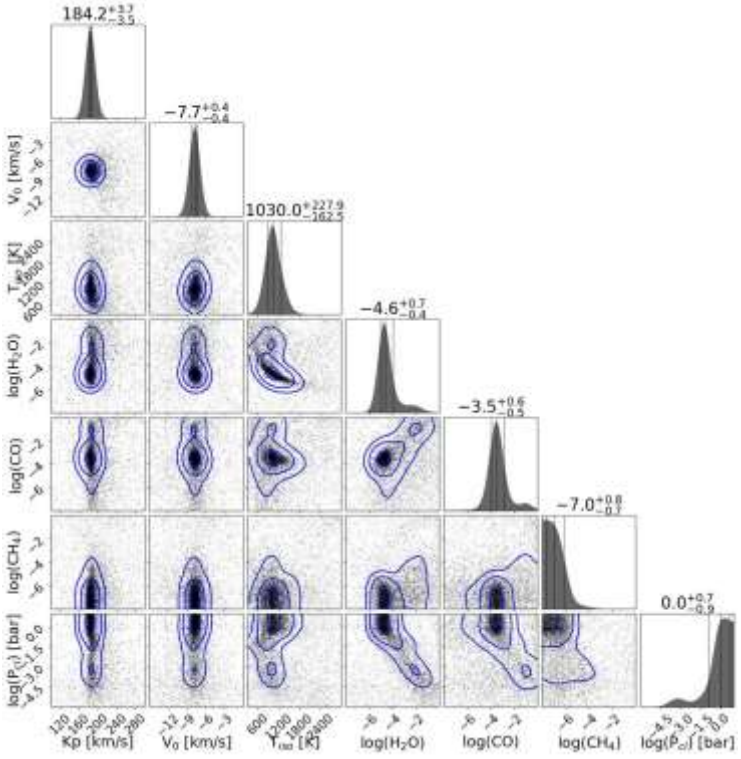






Bayesian Inference analysis

(MCMC, Nested Sampling..)



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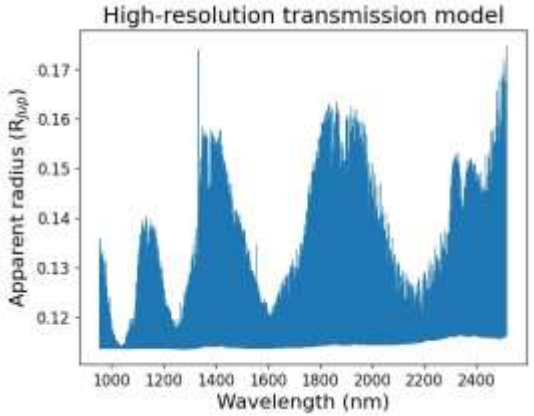

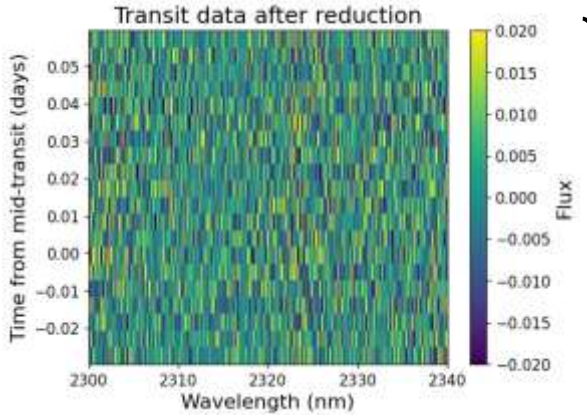

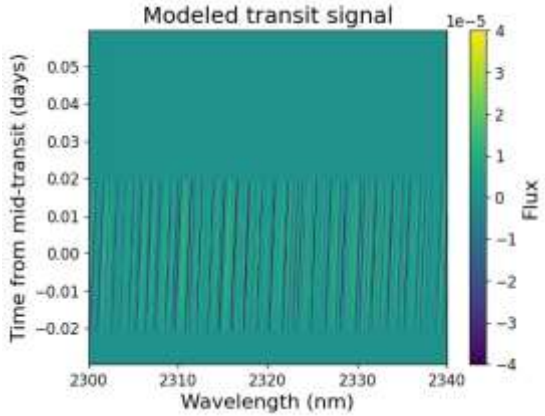

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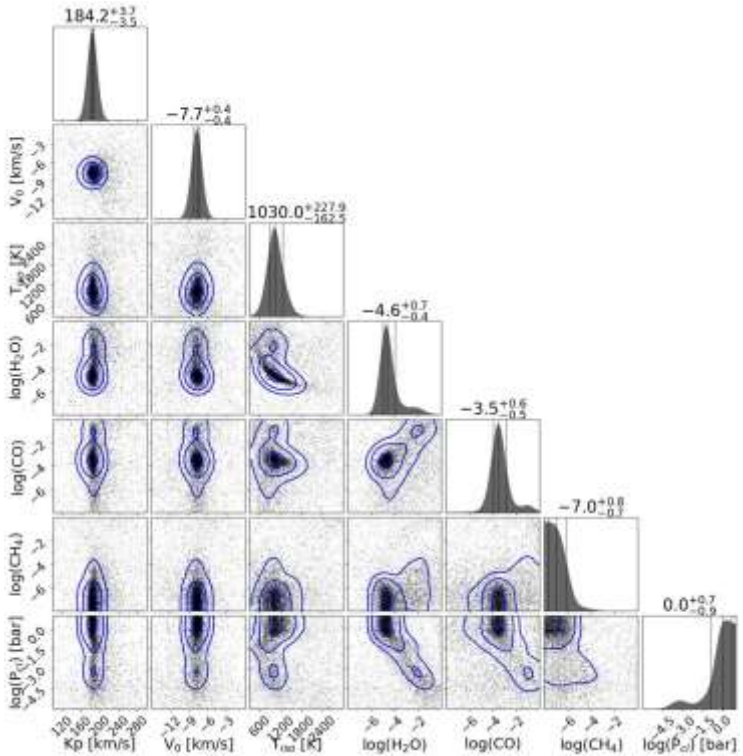

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~ 1 - 10s

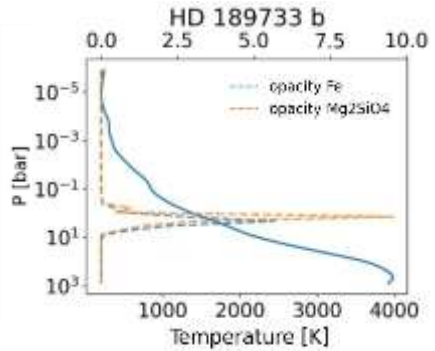
from days to months !

expensive !

Forces model simplification...

Real planets have :

- Varying thermal profile (e.g. inversion)



Exo-REM models *(Baudino+15,17, Charnay+18, Blain+21)*

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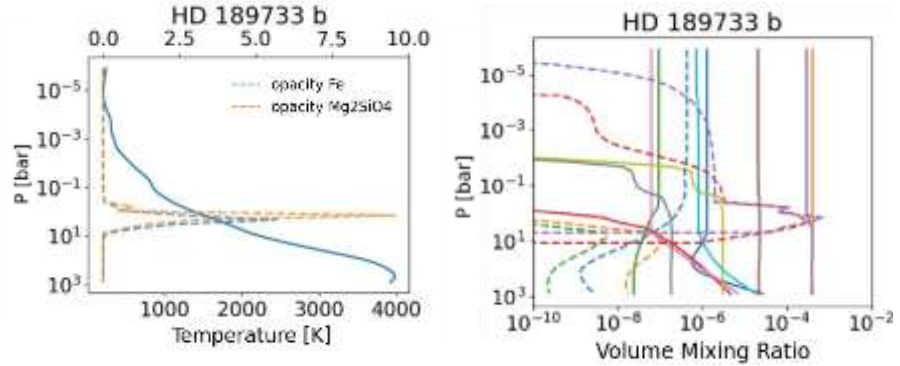

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- 3D geometry (hotspot offset, cloud formation on limbs/nightside…)

→ We're limited in the number of species to include and in profiles parametrization...

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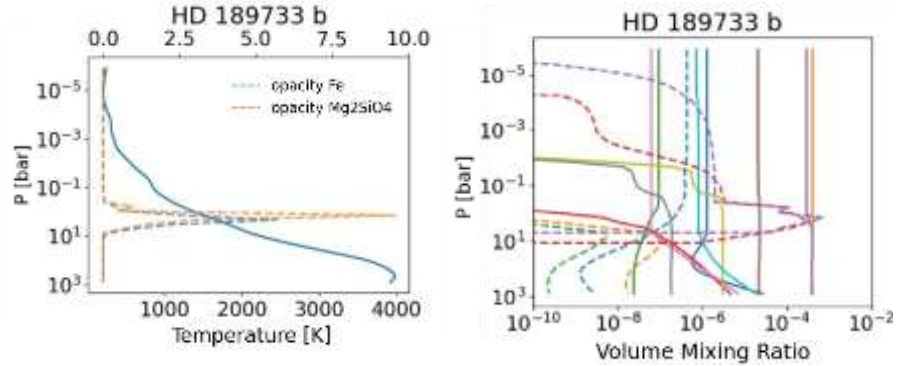

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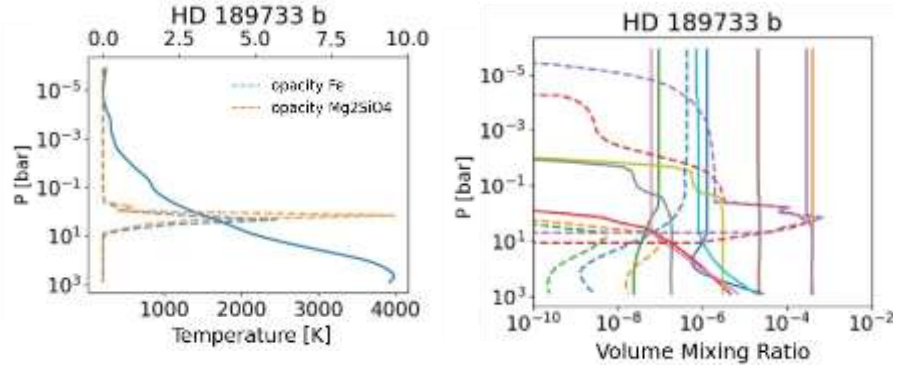

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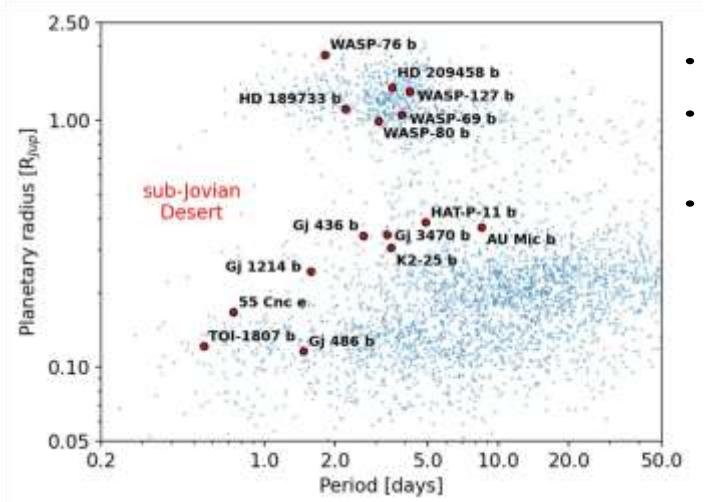
Limits population-level studies...



-
- **50 SPIRou**
- **1D model :**

- Rotation broadening
- Cloud pressure deck

Masson et al. 2026 (submitted to A&A)

Why not use interpolation

Real planets have :

- Varying thermal profile (e.g. inversion)
- Varying abundances profile (e.g. chemical quenching) **14 targets**

transits

- 9 molecules
- Isothermale

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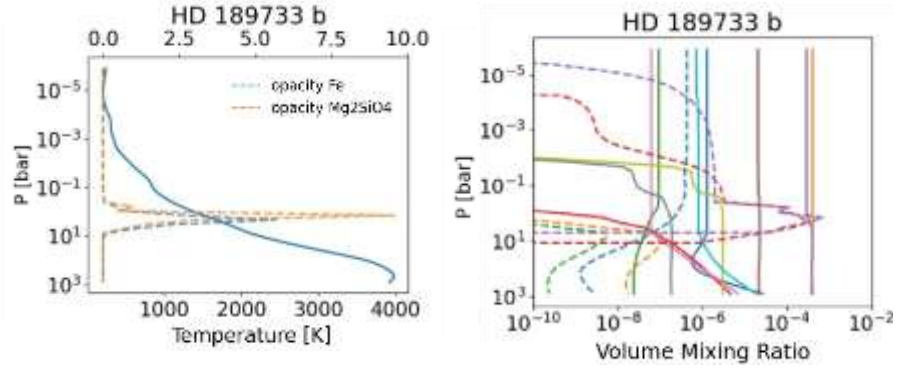

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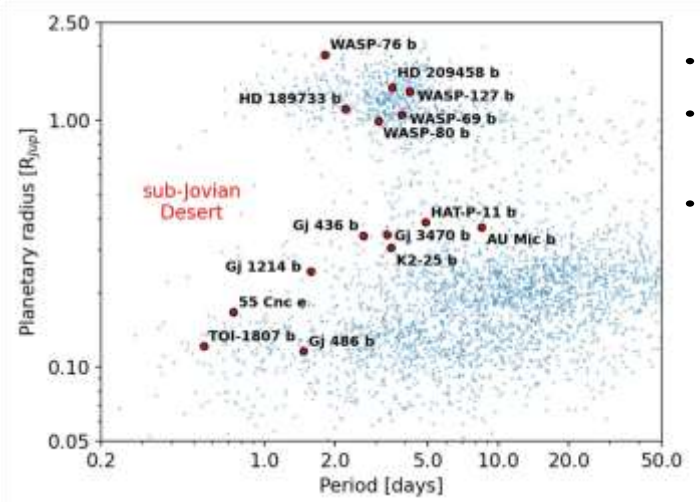

~2 months per full run. Now scale this to the expected Ariel (and JWST) outcome…

→ Faster modeling will be crucial for ground-based follow up !

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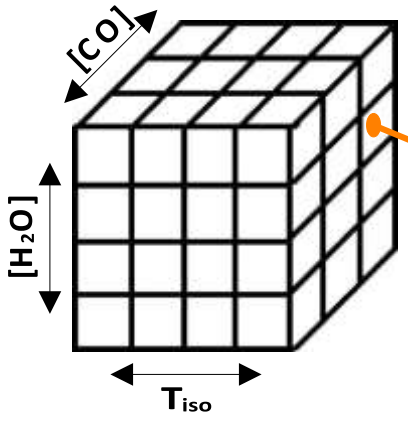
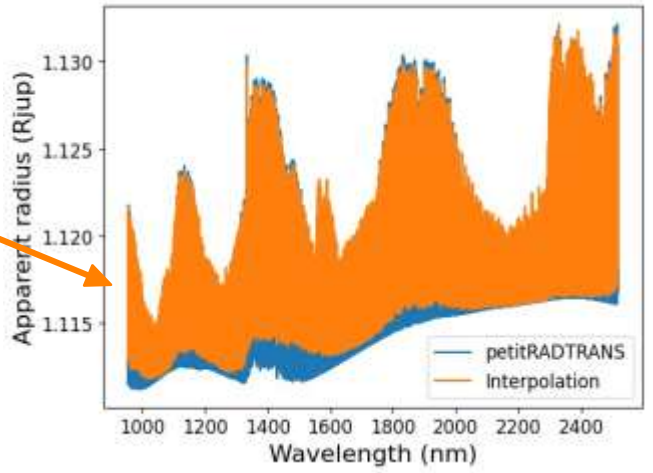
Precompute a grid of models and interpolate :

High-resolution modeling is expensive !





petitRADTRANS: ~1-10s

Interpolation : ~10-100ms

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Why not use interpolation grids ?

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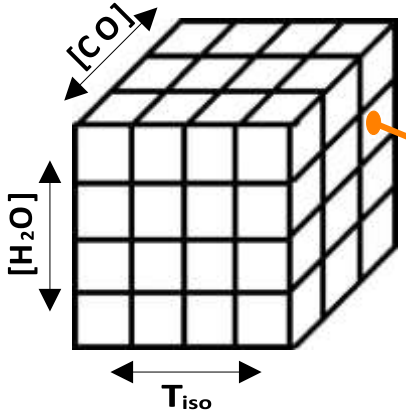

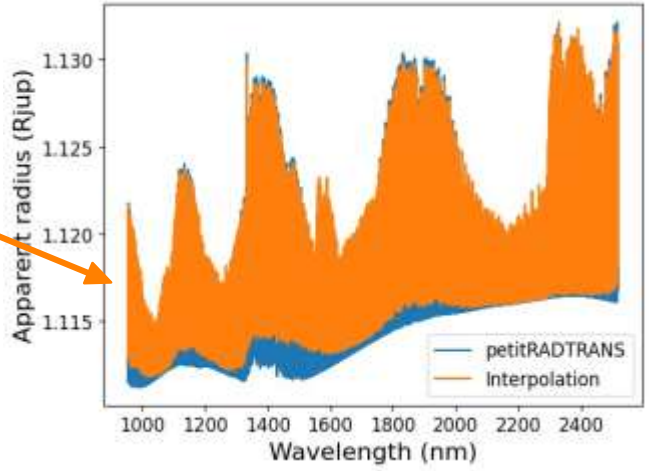

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BUT :

- High-resolution spectra are **heavy** (**~1Mb** per model)
- Sampling **10 points in 5D** (T_{iso}, [H2O], [CO], [CH4], P_{clouds}) 10→ ^{5} x 1Mb ~ **100Gb** (storage, RAM…)