f n r s
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Simulation-based inference for exoplanet characterization

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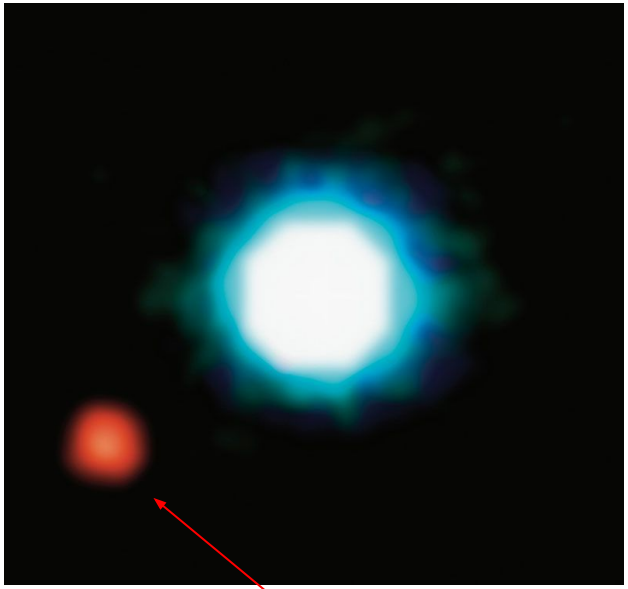
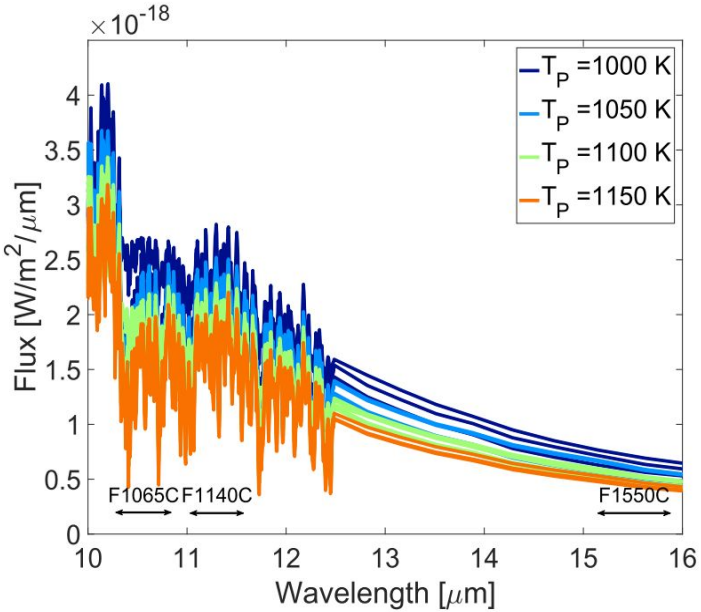
LIÈGE université

What's in an exoplanet?



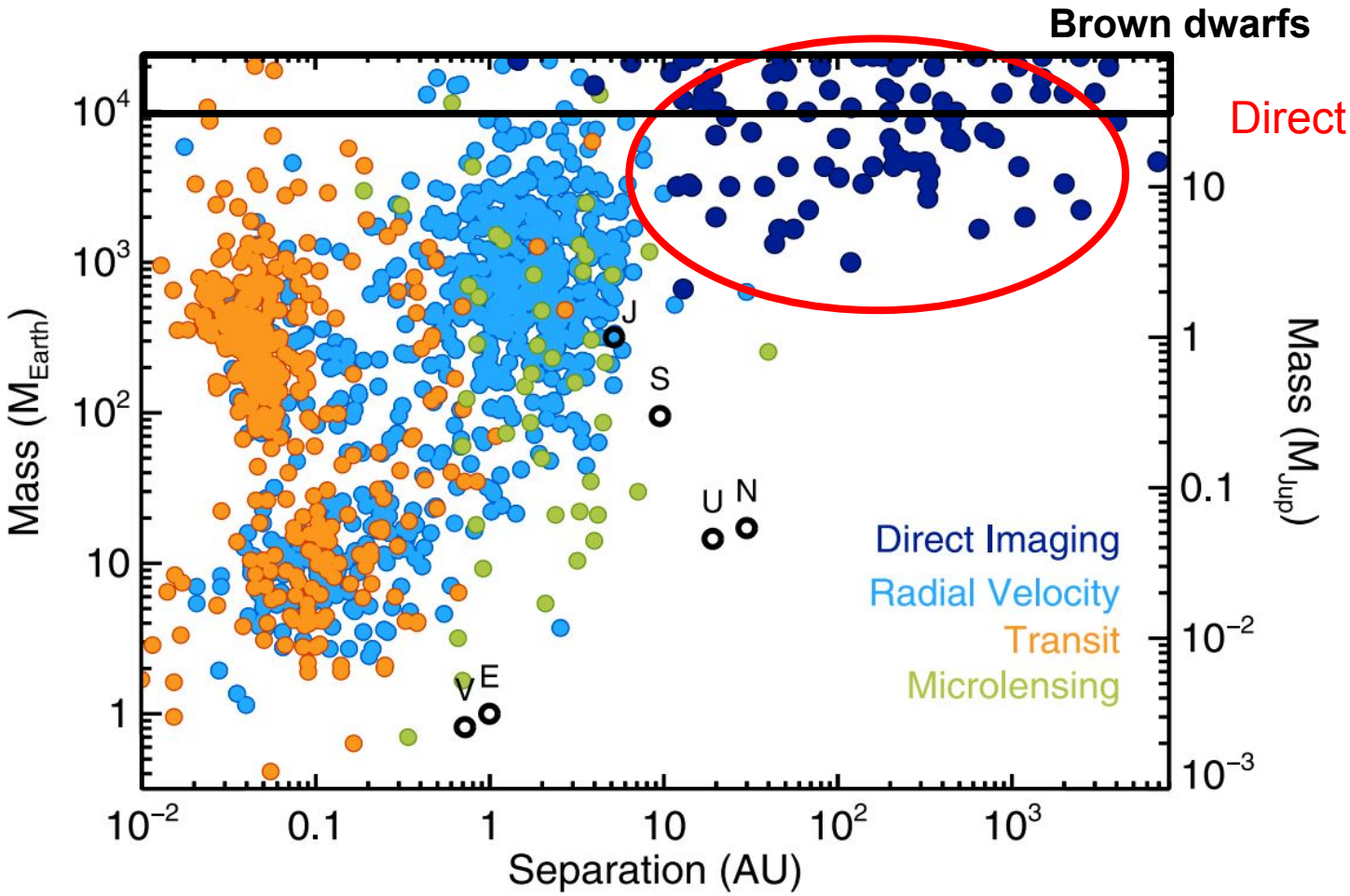
2M1207b

Direct imaging

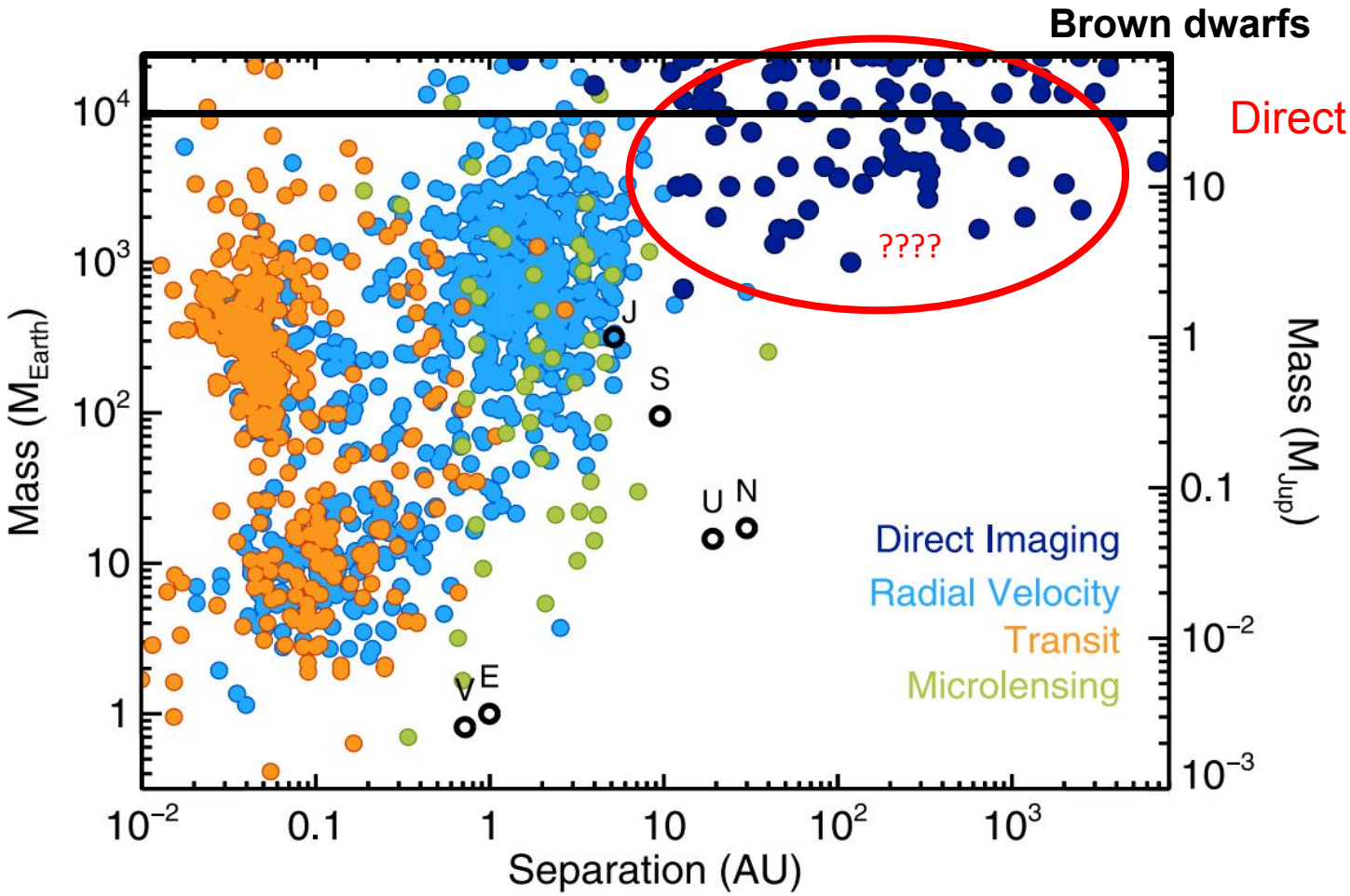


Emission spectra

Danielski et al 2018



Brendon. P. Bowler, Imaging extrasolar giant planets, 2016



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Motivation

Spectral retrieval, a best fit solution to the measured spectrum

Likelihood Prior

$$p(\theta|x) = \frac{p(x|\theta)p(\theta)}{p(x)}$$

Posterior

Evidence

Bayesian inference

Motivation

Spectral retrieval, a best fit solution to the measured spectrum

Current forward models: **explicit and tractable** likelihood.
(e.g, Gaussian distance measure/correlation coefficient)

Likelihood Prior

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Bayesian inference

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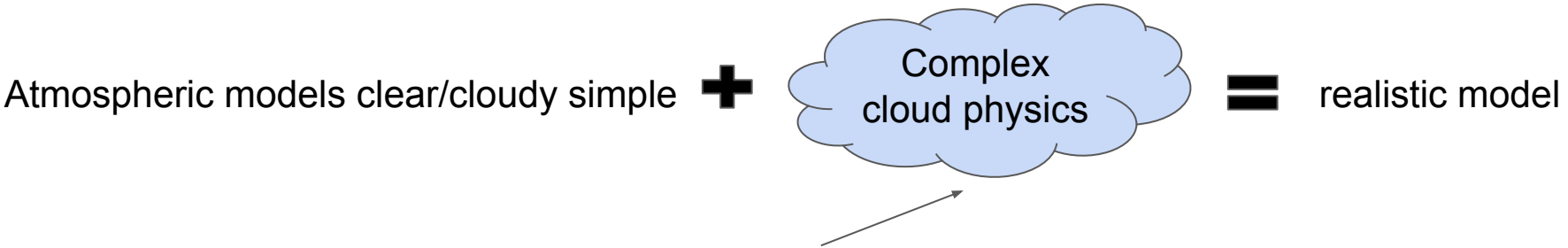

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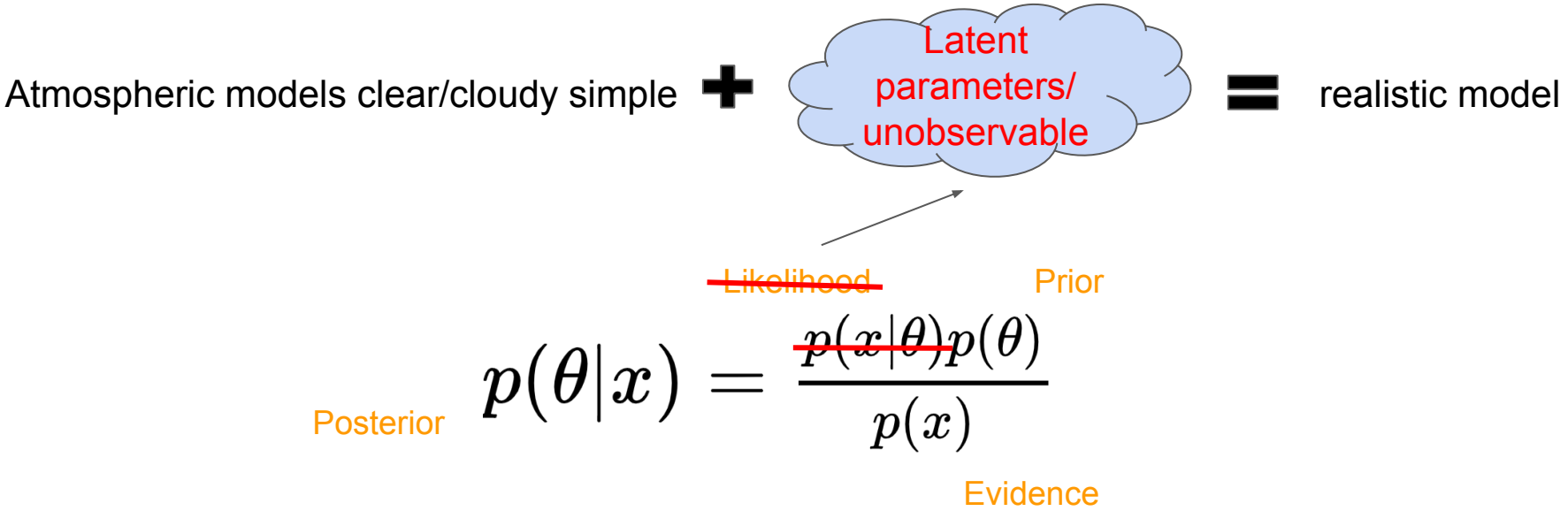

We suggest **simulation-based inference** to estimate the **posterior** without explicitly calculating a likelihood**.**

Proof of concept setup

(simple case without latent parameters for comparison)

Simulator: *petitRADTRANS*[a] for radiative transfer,

- line and collision opacities
- rayleigh scattering
- 2 clouds Fe and $MgSiO_3$
- 16 parameters- 3 cloud parameters,

a. https://petitradtrans.readthedocs.io/

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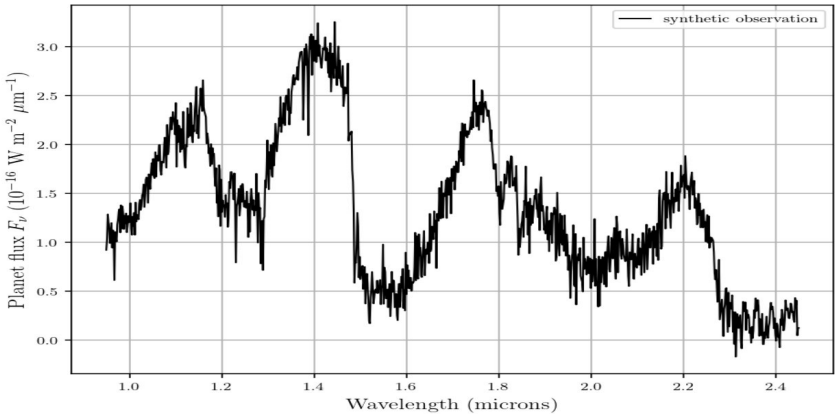

Synthetic **observation** spectra + $\mathcal{N}(0, \sigma^2)$
Mollière et al. (2020)

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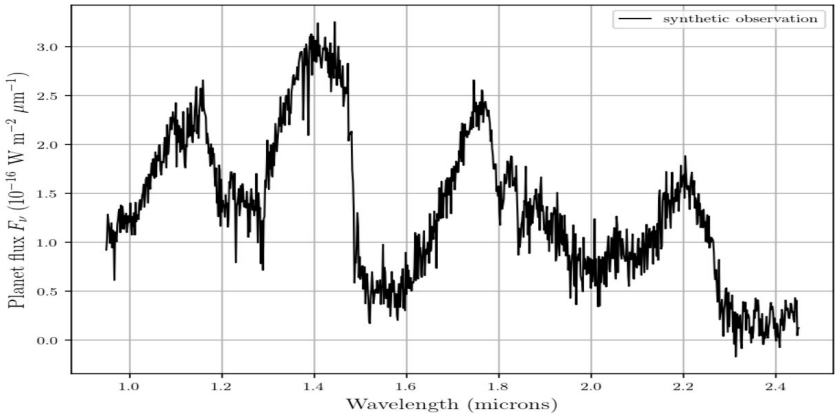
SBI package: *Lampe*[b]



Synthetic **observation** spectra + $\mathcal{N}(0, \sigma^2)$
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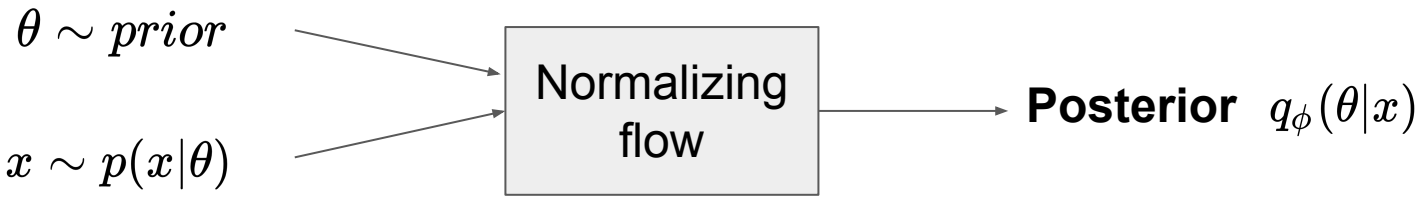
a. https://petitradtrans.readthedocs.io/
b. https://github.com/francois-rozet/lampe

Neural posterior estimation (NPE)

Embedding network : Res-MLP
NF: Masked autoregressive flow (MAF)



$$\phi^* = argmax_\phi \, \mathbb{E}_{p(\theta,x)} [log \, q_\phi(\theta|x)]$$

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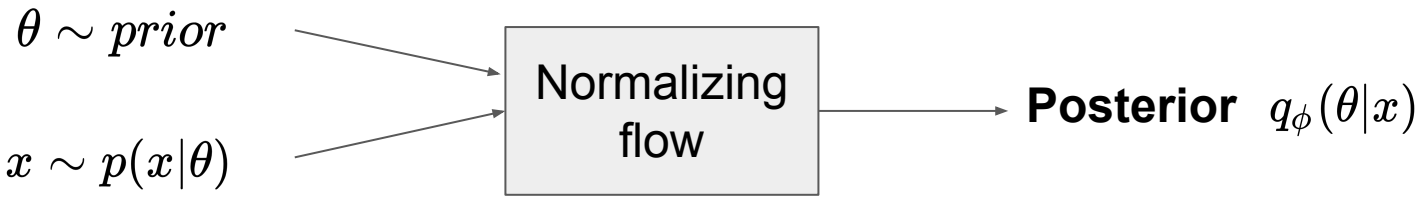

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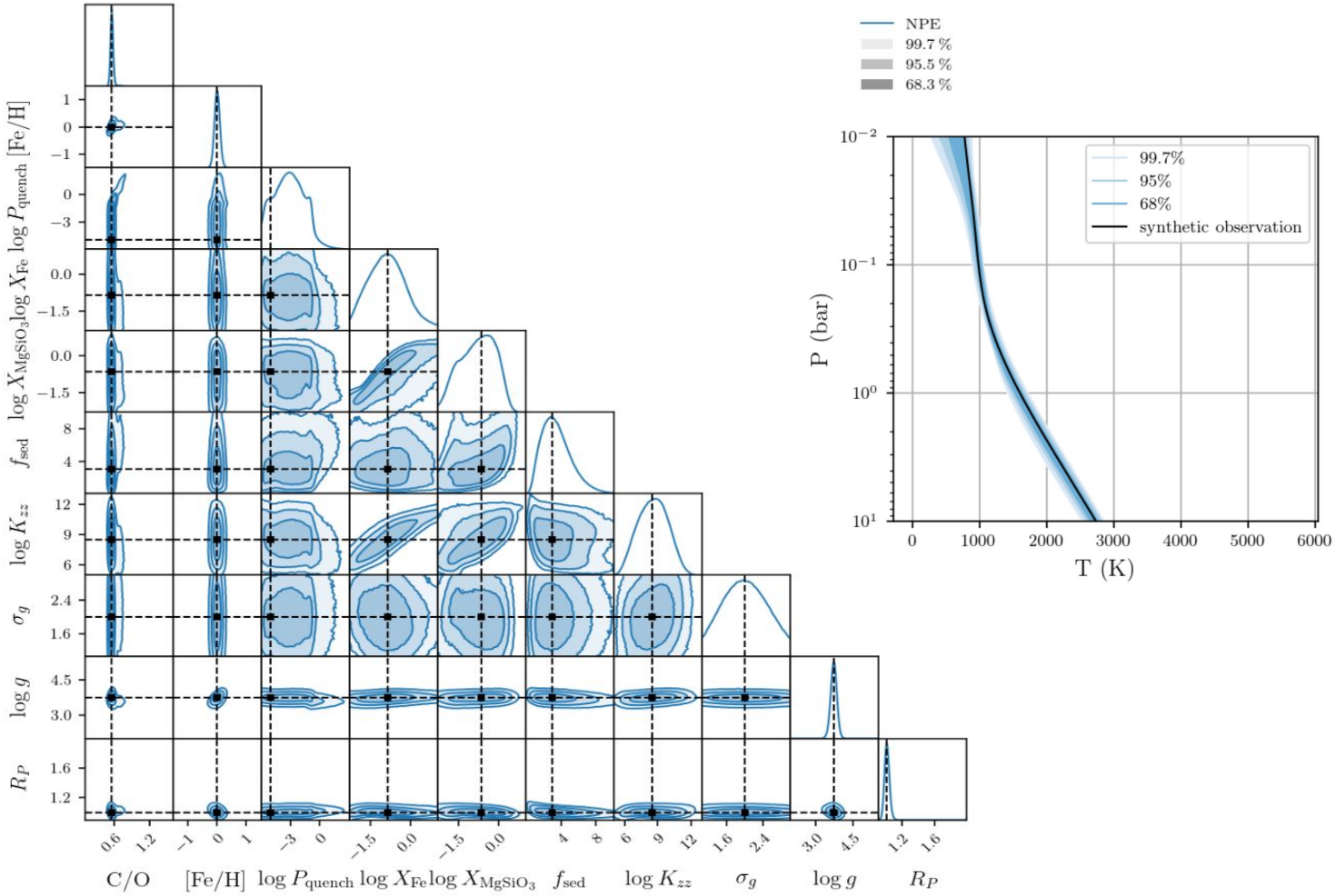
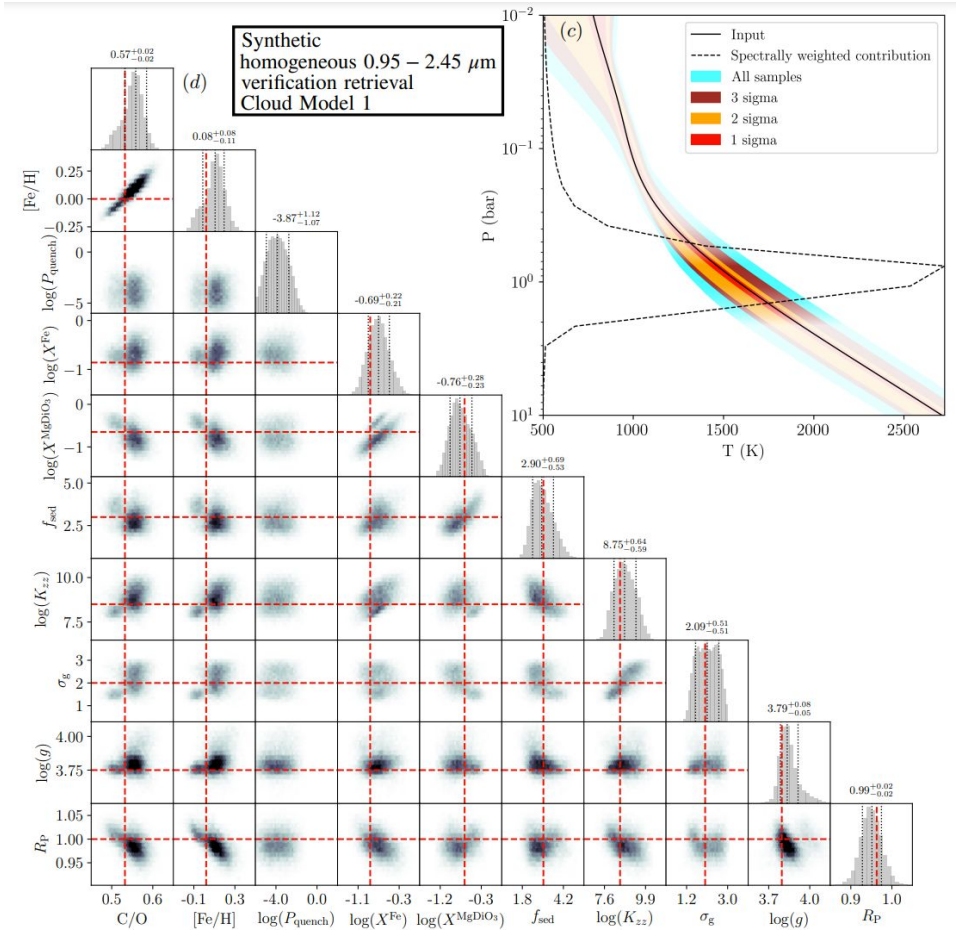
The estimator is amortized with respect to observations

Results

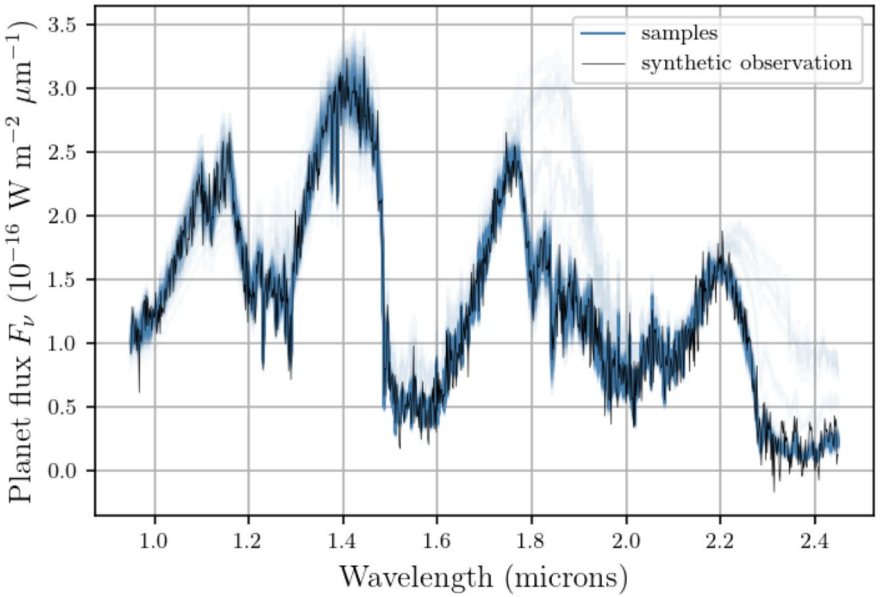

NPE
99.7 %
95.5 %
68.3 %
C/O
[Fe/H]
log $P_{\rm quench}$
log $X_{\rm Fe}$
log $X_{\rm MgSiO_3}$
$f_{\rm sed}$
log K_{zz}
σ_g
log g
R_P
99.7%
95%
68%
synthetic observation
P (bar)
T (K)

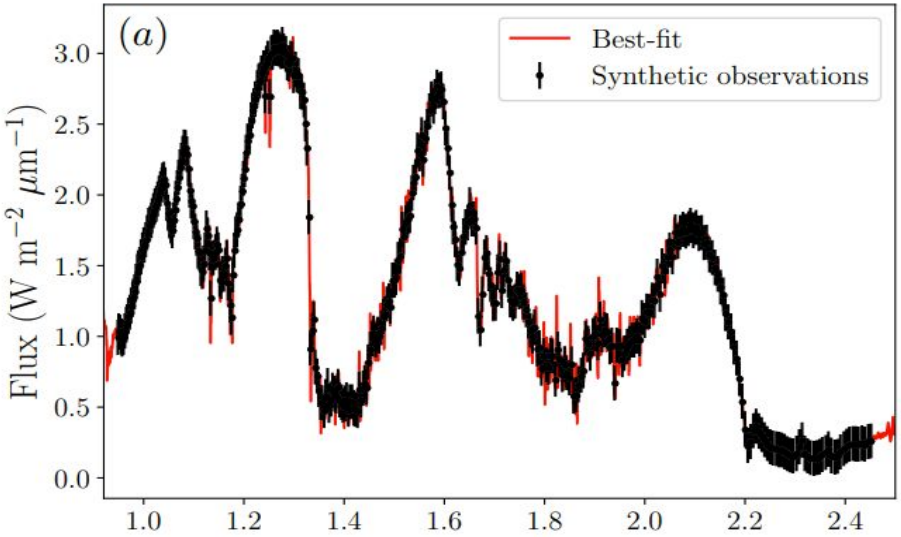
Results from Mollière et al 2020



Bayesian residuals

$$p(x'|x) = \int p(x'|\theta) q_\phi(\theta|x) d\theta$$



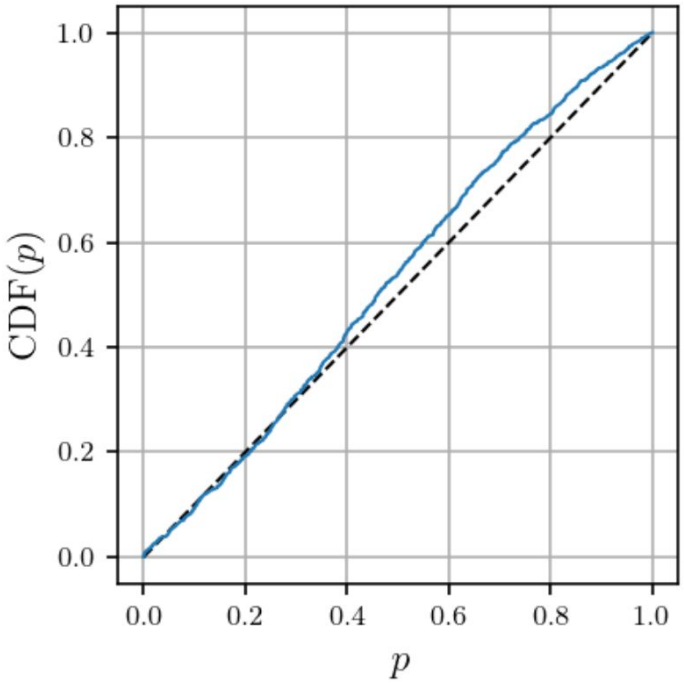


Consistent with synthetic observation

Coverage plot

Here we compare the **average of our estimated posterior** with the prior.

$$p(\theta) \approx \mathbb{E}_{p(x)} q_\phi(\theta|x)$$



Consistent with the prior

Conclusions

- The obtained results are **consistent with Nested Sampling** in Molliere et al 2020.

- SBI allows us to **characterize** exoplanet spectra **without** needing to explicitly **compute a likelihood**.

- It is **amortized** with respect to observations, hence faster and computationally less expensive.

- With this established proof of concept, this approach can be further used for **detailed atmospheric models** with complex cloud physics.

Thank You