

Flow Matching for Atmospheric Retrieval of Exoplanets: Where Reliability meets Adaptive Noise Levels

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Atmospheric Retrieval of Exoplanets

Goal: Efficiently and reliably infer atmospheric properties from spectra

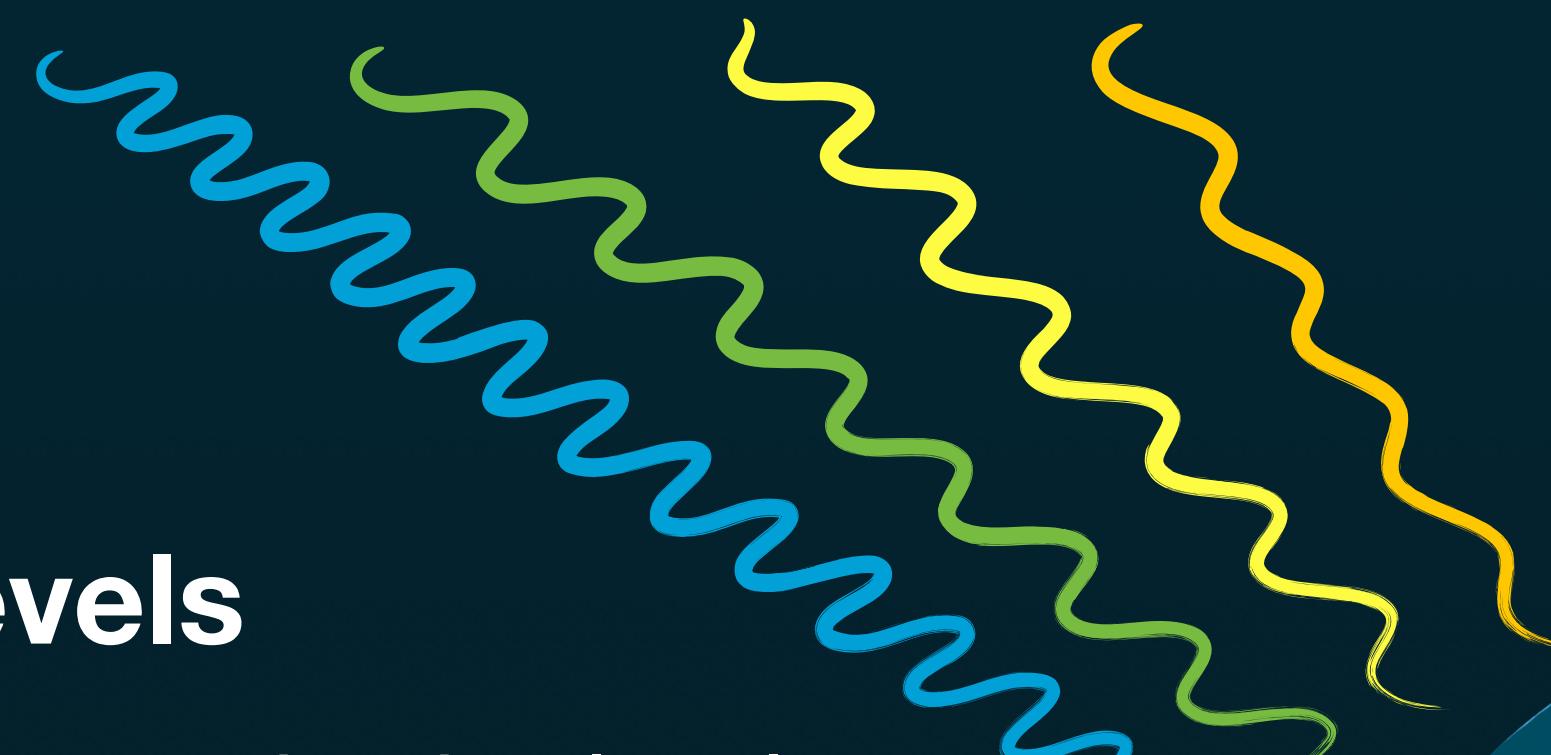
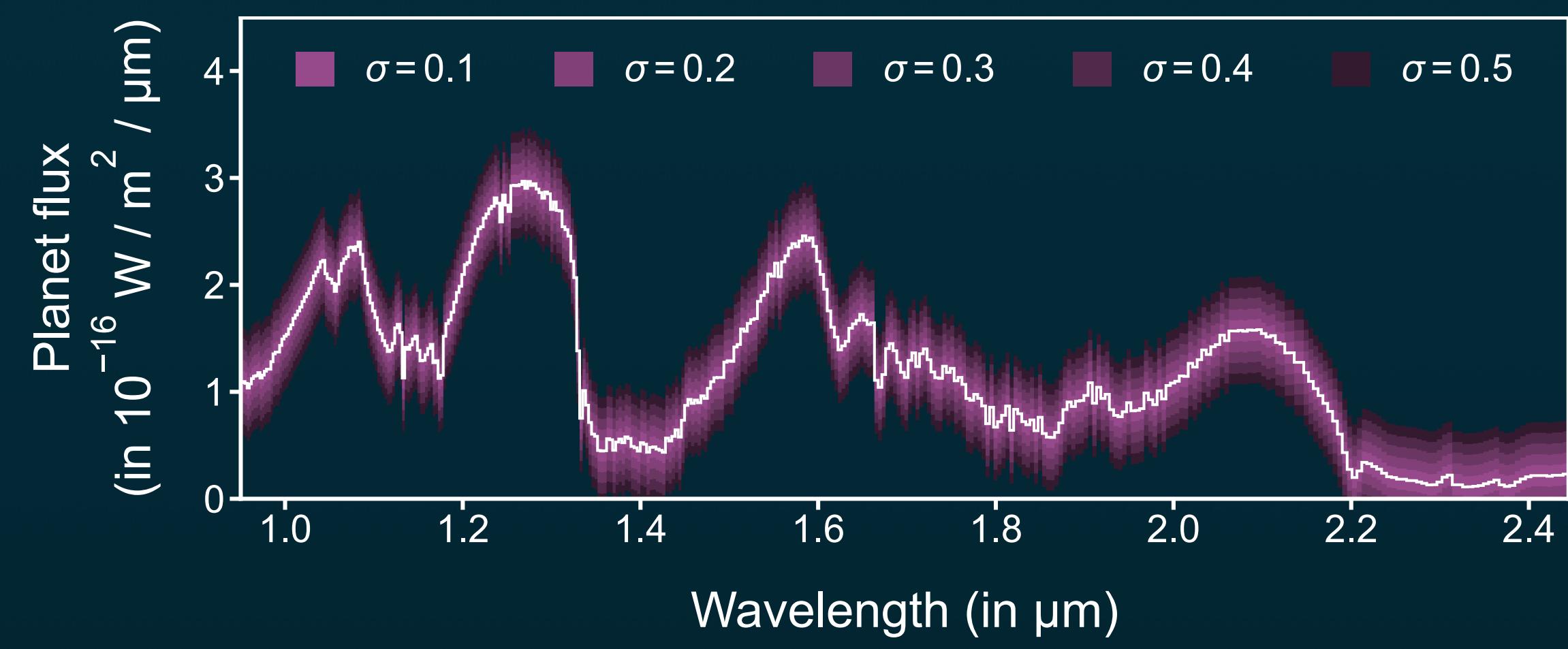
Problem: Traditional methods are slow; ML methods lack reliability

Solution: (1) Flow matching for scalability

(2) Importance sampling for verification/reliability

(3) Noise-level conditioning for adaptability/flexibility

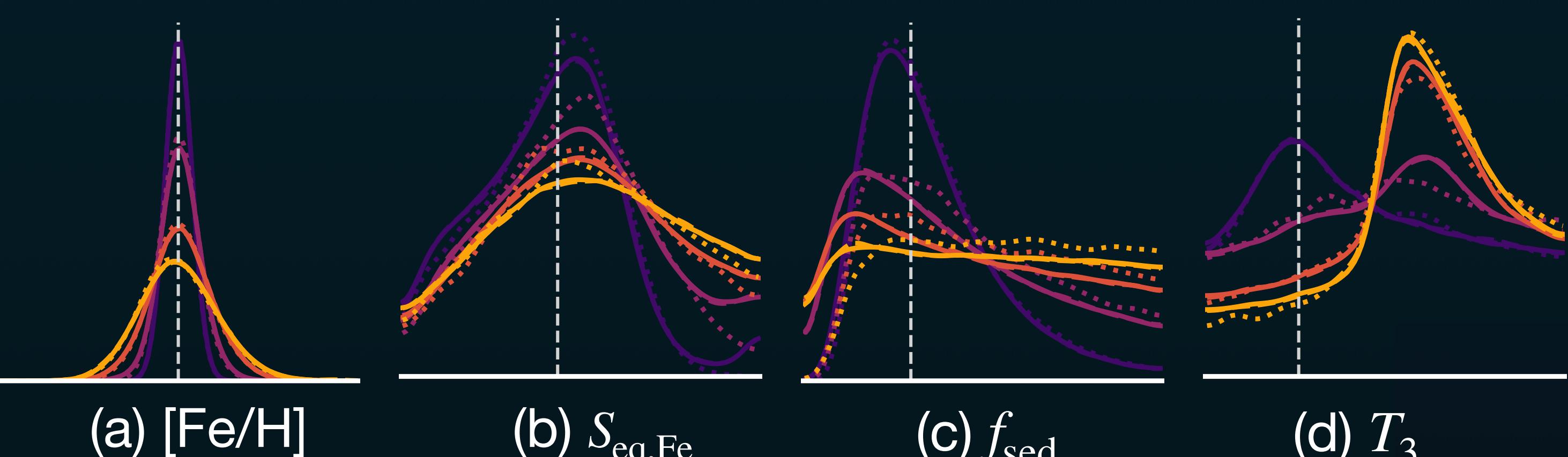
Data:



Adaptive Noise Levels

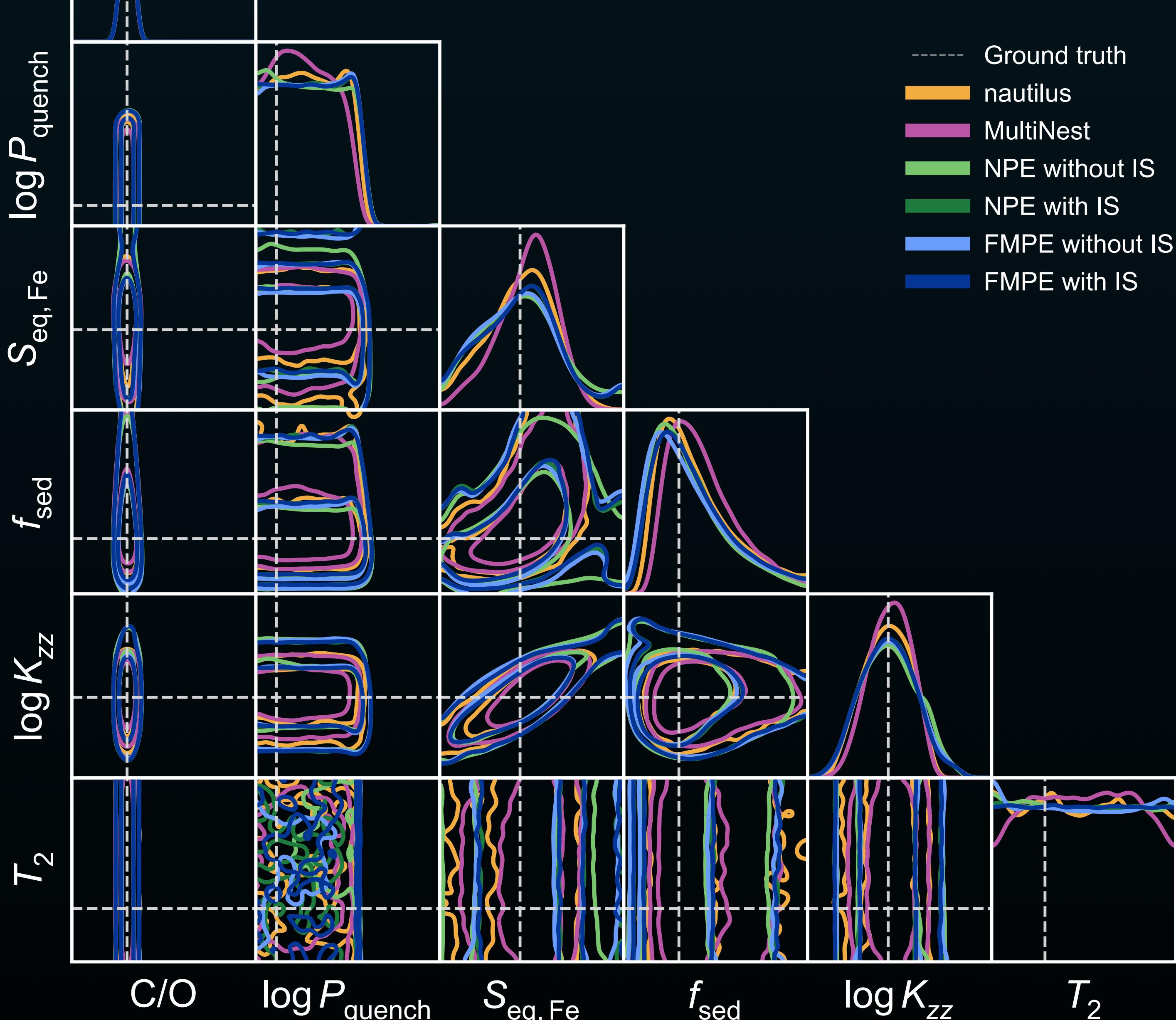
- Condition model on assumed noise level
- Vary noise level at inference time

Method	Noise Level (in $10^{-16} \text{ Wm}^{-2}\mu\text{m}^{-1}$)
FMPE-IS	$\sigma = 0.1$
NPE-IS	$\sigma = 0.2$
nautilus	$\sigma = 0.3$
	$\sigma = 0.4$

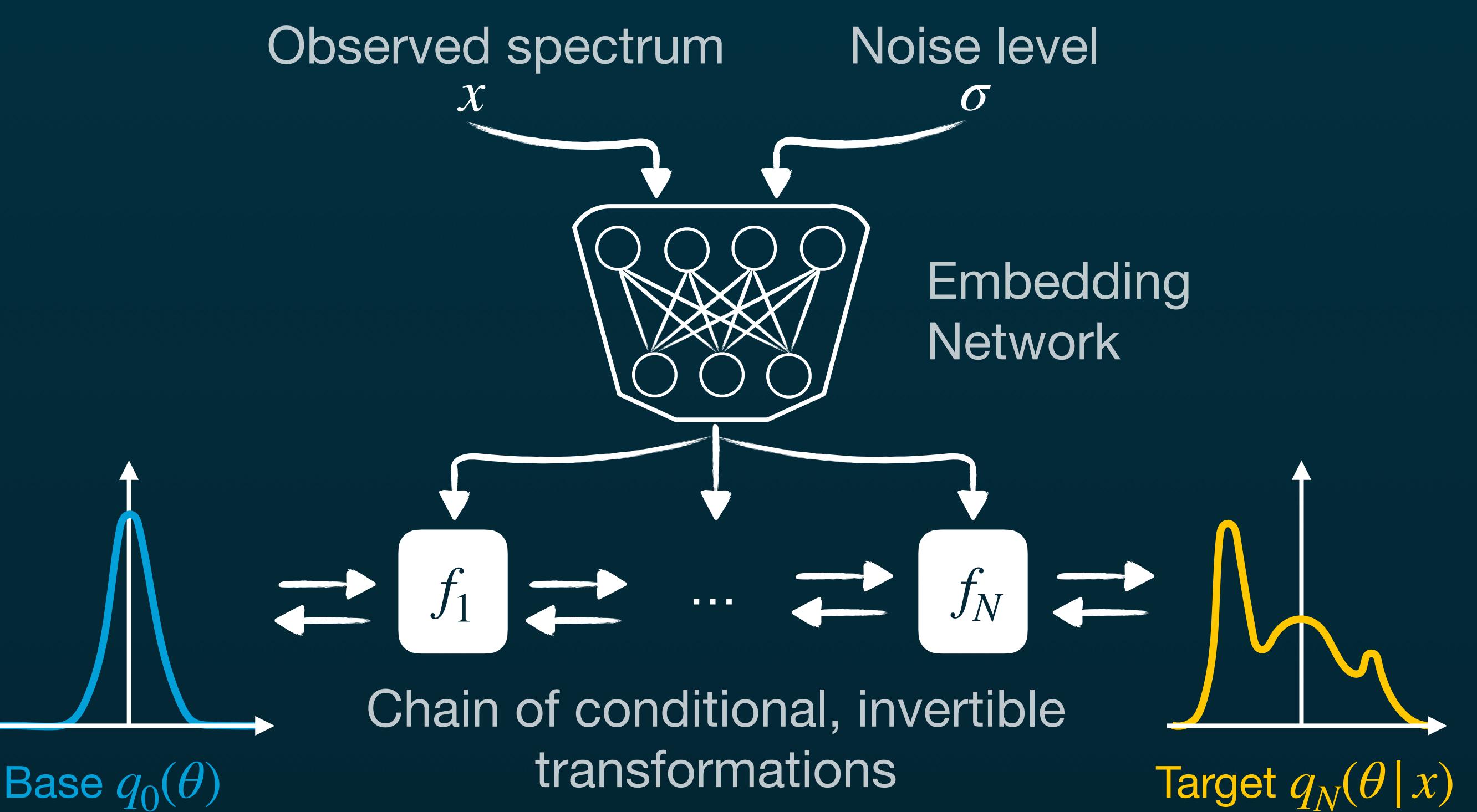


Results for Benchmark Spectrum

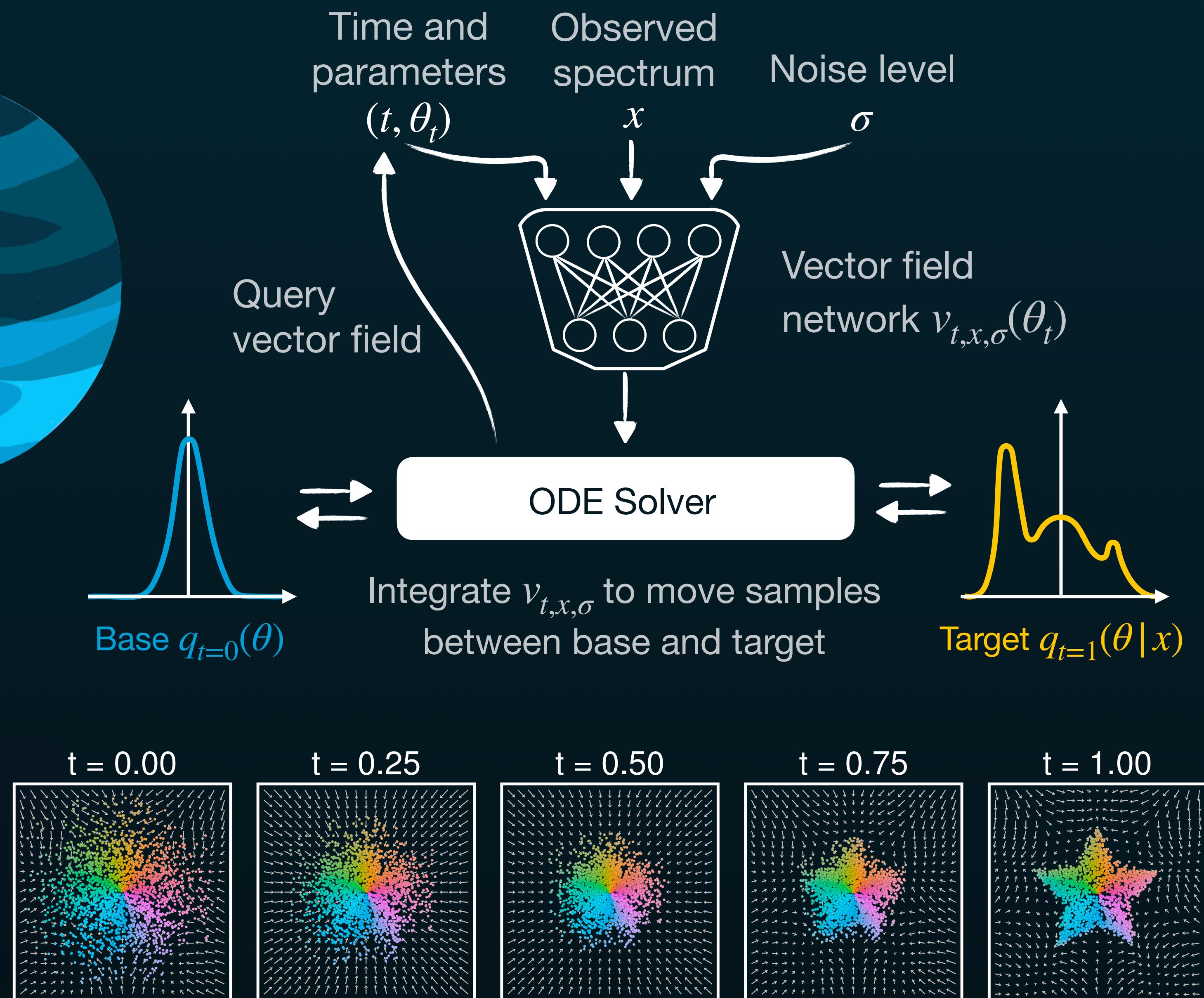
Subset: 6 out of 16 parameters



Neural Posterior Estimation (NPE) with Discrete Normalizing Flows



Flow Matching Posterior Estimation (FMPE) with Continuous Normalizing Flows

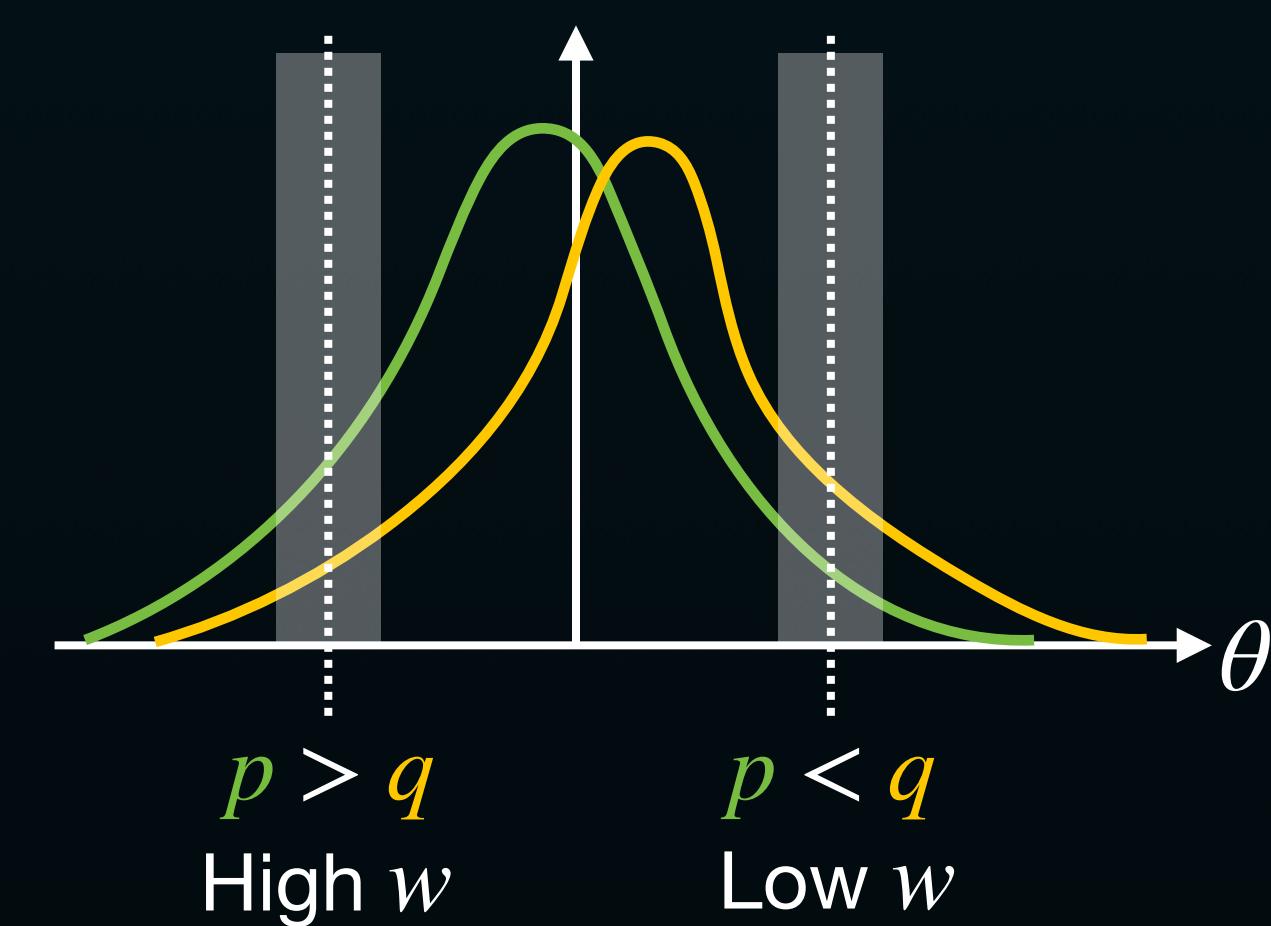


Reliability through Importance Sampling (IS)

Idea: Reweight model samples towards true posterior

$$w = \frac{\text{Likelihood} \cdot \text{Prior}}{q(\theta|d)} \propto \frac{p(d|\theta) \cdot p(\theta)}{q(\theta|d)}$$

True Posterior Proposal
 $p(\theta|d)$ From NPE/FMPE



Take-Aways

- FMPE allows less constrained, more scalable architecture (at the cost of slower inference)
- IS makes posteriors more reliable
- Conditioning on the noise level makes model more flexible

