# Precision searches for subhalos in strong lensing images with targeted inference networks

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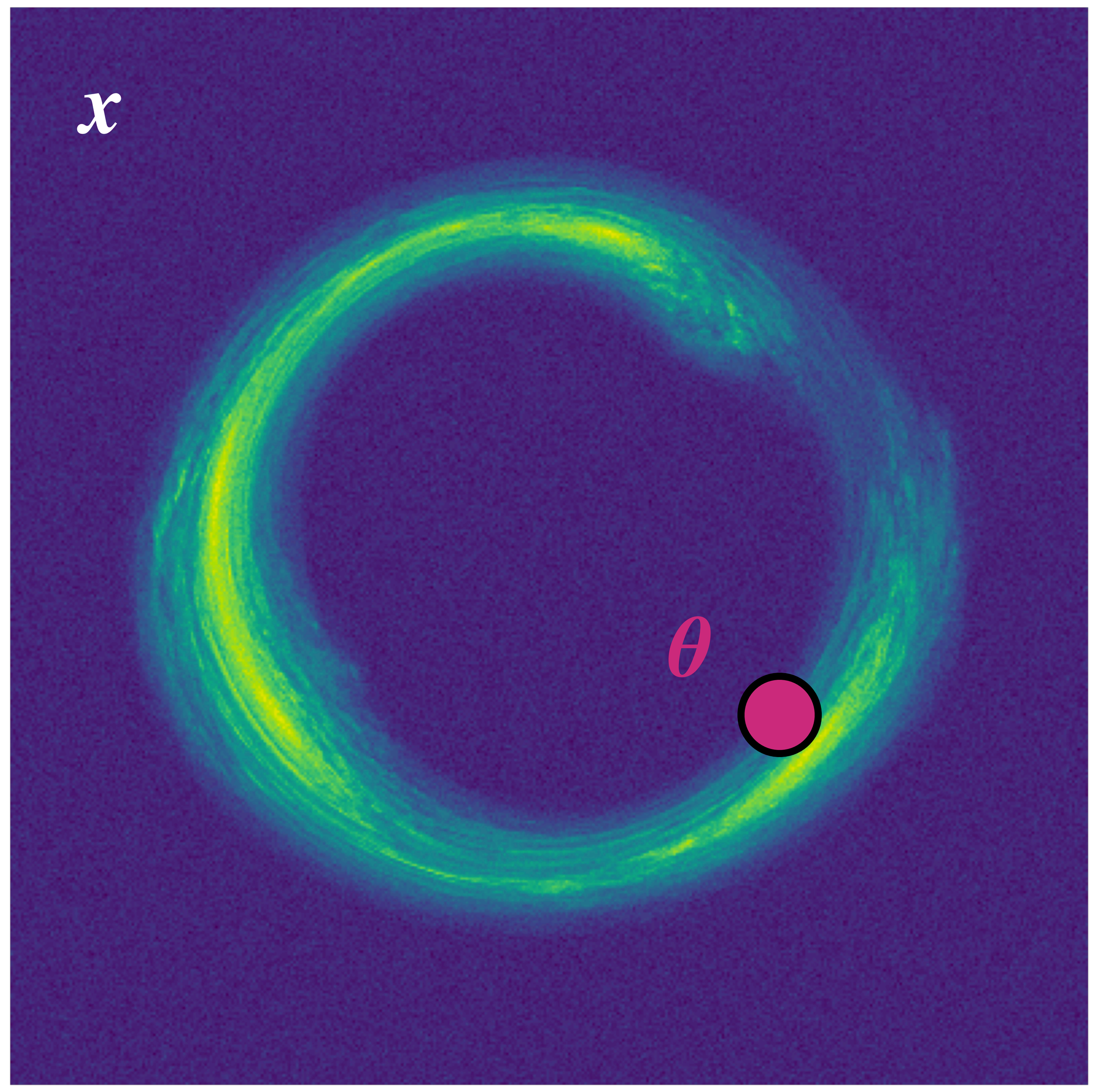
**Goal:** robustly measure individual dark matter subhalos' parameters

**Problem:** need to *marginalize* over $O(10^3\text{-}10^5)$ nuisance parameters

Observation — Source and lens parameters

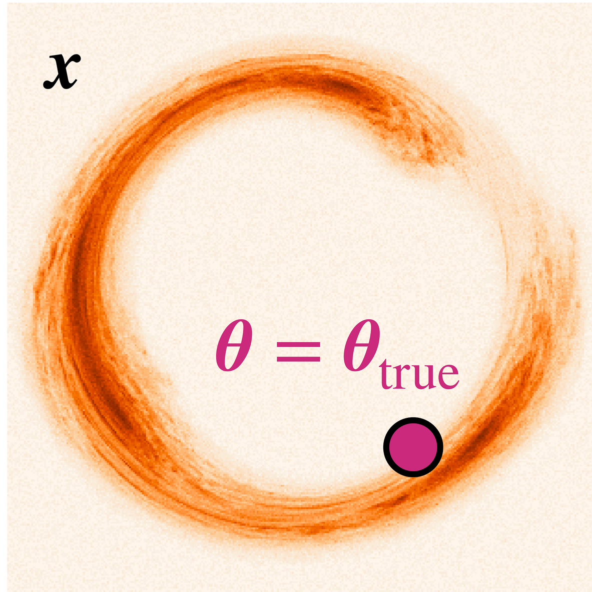
$$\underbrace{p(\boldsymbol{\theta}\,|\,\boldsymbol{x})}_{\text{Marginal posterior}} = \int d^n\boldsymbol{\eta}\, \underbrace{p(\boldsymbol{\theta},\boldsymbol{\eta}\,|\,\boldsymbol{x})}_{\text{Joint posterior}}$$




Techniques like MCMC and nested sampling sample the joint posterior.
**Intractable here due to high dimensionality.**

**Neural likelihood-to-evidence ratio estimation:** rephrases marginal posterior inference as equivalent *classification problem*

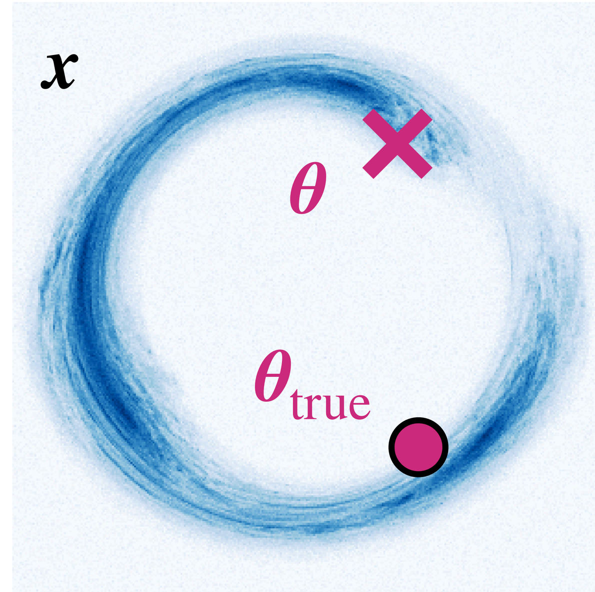
*"Given an (subhalo parameter, image) pair $(\boldsymbol{\theta}, \boldsymbol{x})$, does the subhalo in $\boldsymbol{x}$ actually have parameters $\boldsymbol{\theta}$?"*




**Class A**

Parameters *were* used to generate image

$p_A = p(\boldsymbol{\theta}, \boldsymbol{x})$




**Class B**

Parameters are *unrelated* to image

$p_B = p(\boldsymbol{\theta})\, p(\boldsymbol{x})$

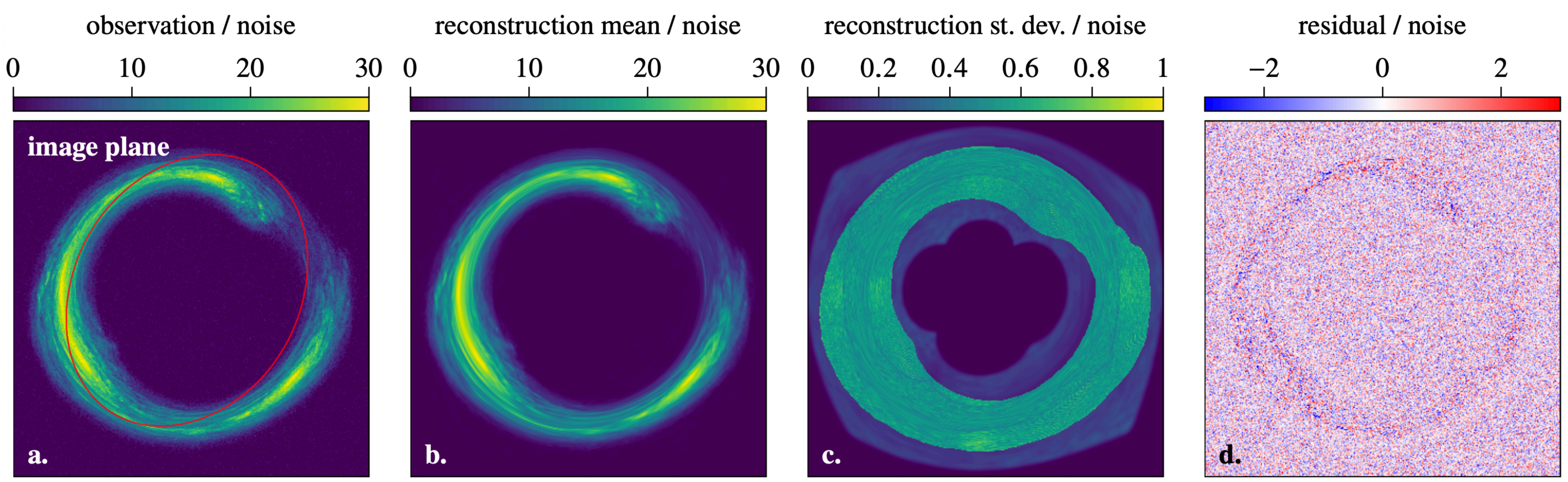
Classification network directly learns $\dfrac{p_A}{p_B} = \dfrac{p(\boldsymbol{\theta}\,|\,\boldsymbol{x})}{p(\boldsymbol{\theta})}$ ⟵ Marginal posterior

Nuisance parameters marginalized via *random sampling* during training

**Targeted inference:** sample nuisance params *consistent with observation*

We've developed a fast, differentiable lensing model using an approximate Gaussian process source and variational hyperparameter optimization. Enables fitting a variational posterior for $O(10^5)$ source and lens parameters using gradient-based optimization, then *sample from it to generate training data.*

→ ***See Konstantin Karchev's poster for more details***



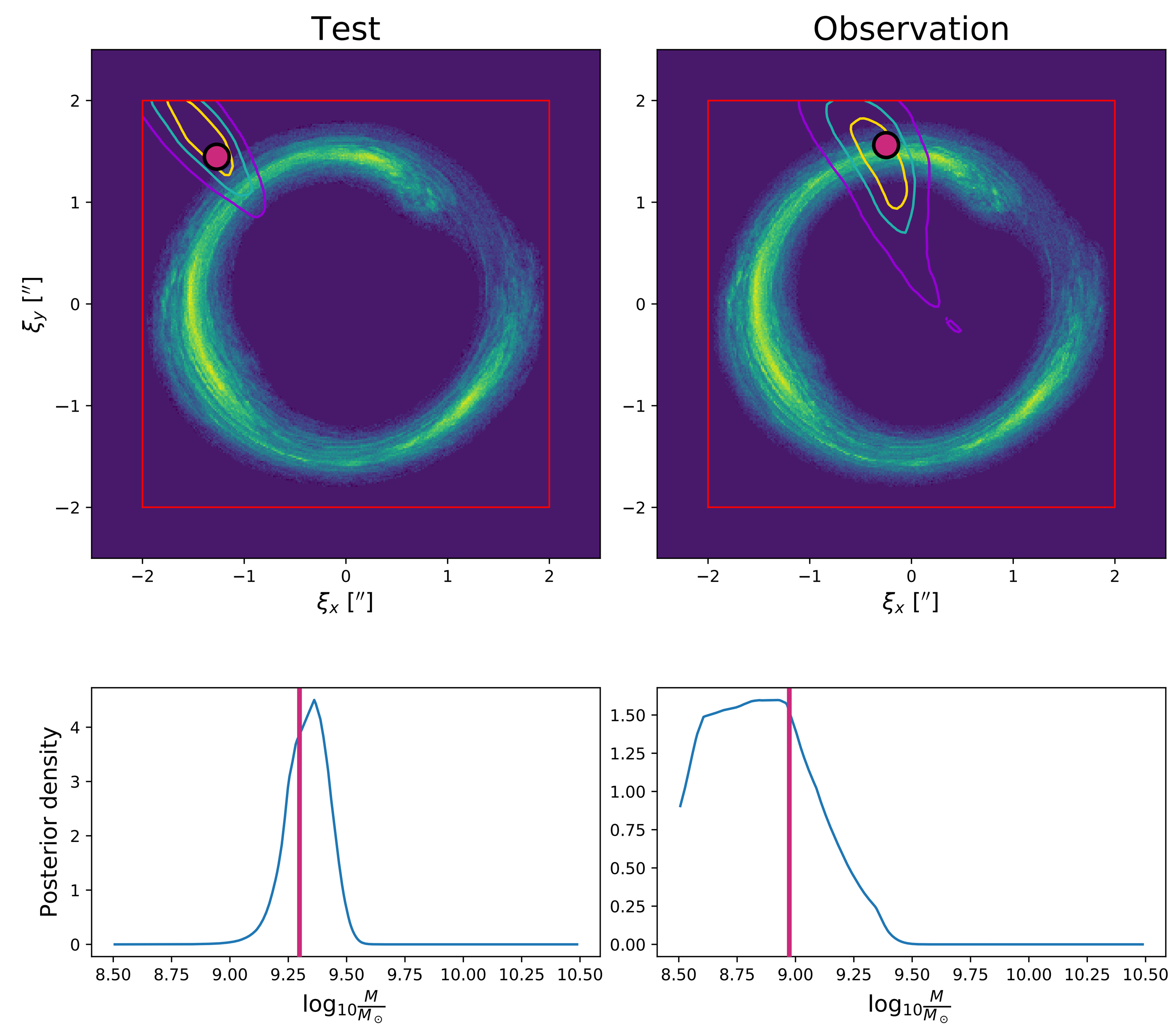

**Results**

Analysis of mock **high-resolution image**

**Accurate marginal posteriors for subhalo position and mass** from a simple inference network trained on just 10,000 targeted samples

**Posteriors are marginalized over 174,458 source and lens parameters!**

→ ***See Noemi Anau Montel's talk for extension to inferring parameters for a population of perturbers***




**Affiliations**

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**For details on this work:**
Coogan, Karchev & Weniger, NeurIPS 2020, arXiv:2010.07032 (full pipeline)
Karchev, Coogan & Weniger, arXiv:2105.09465 (lens modeling)

**For more on neural likelihood-to-evidence ratio estimation:**
Hermans, Begy & Louppe, ICML 2020, arXiv:1903.04057,
Miller, Cole, Louppe & Weniger, NeurIPS 2020, arXiv:2011.13951
and accompanying code, swyft