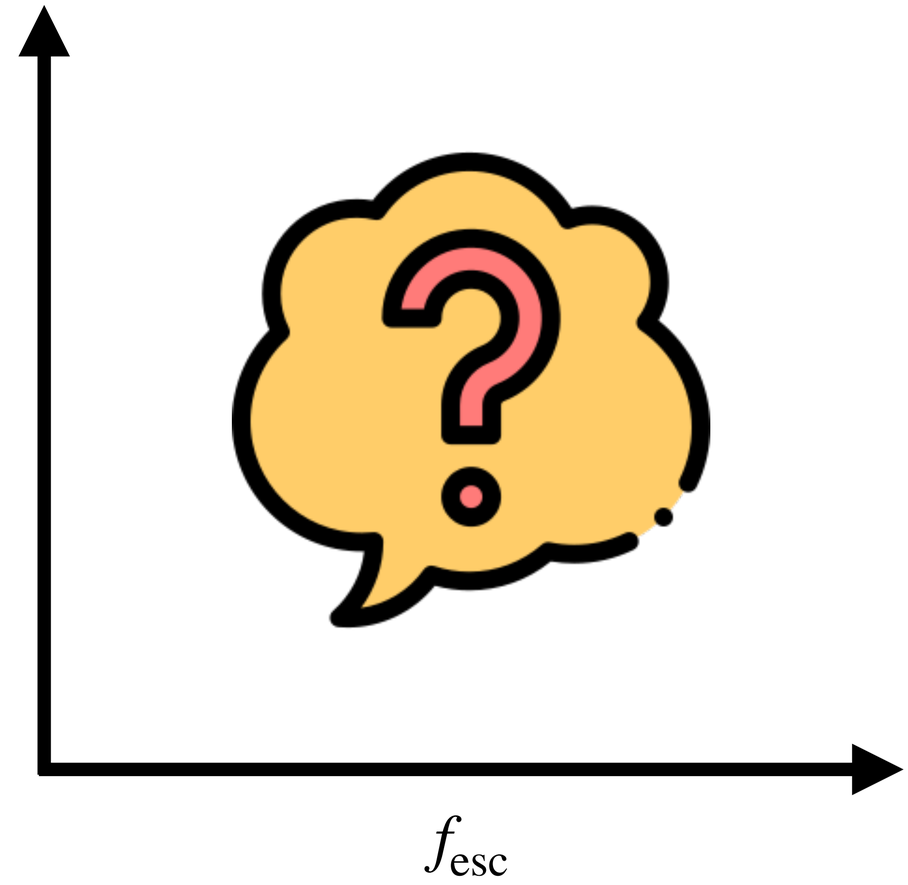
Inferring the Distribution of the Ionising Photon Escape Fraction

Kimi C. Kreilgaard, Charlotte A. Mason,
Fergus Cullen, Ryan Begley & Ross J. McLure

arXiv: 2405.10364



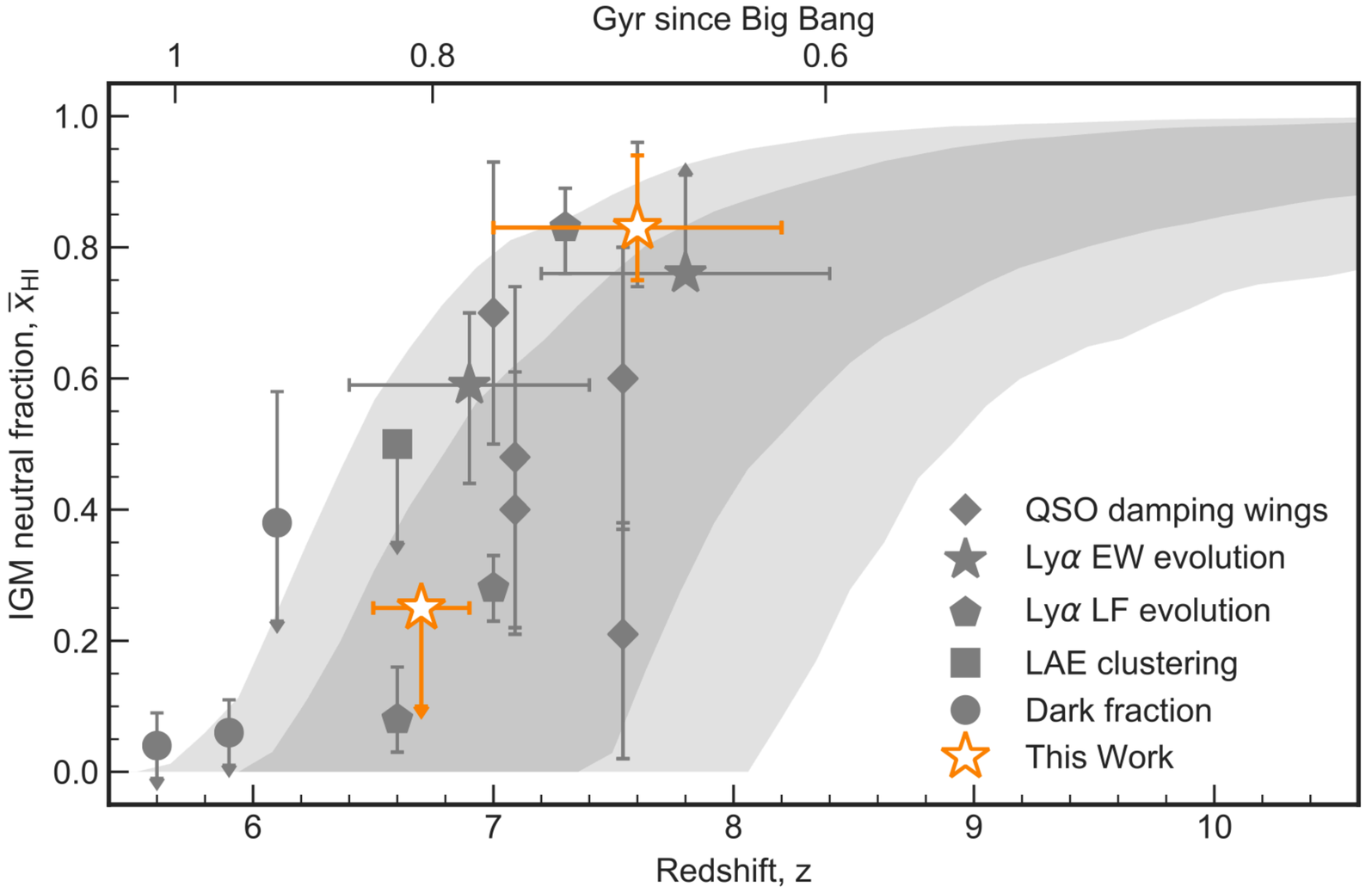
DAWN

UNIVERSITY OF COPENHAGEN

Cosmic Dawn at High Latitudes, Stockholm, June 2024

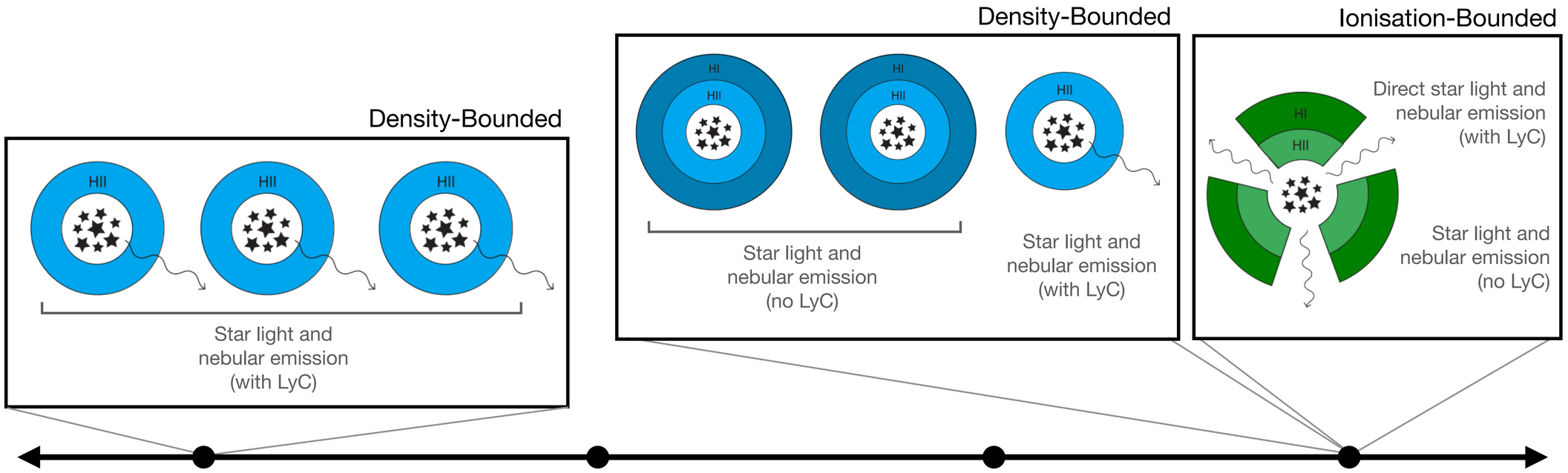
The reionisation history

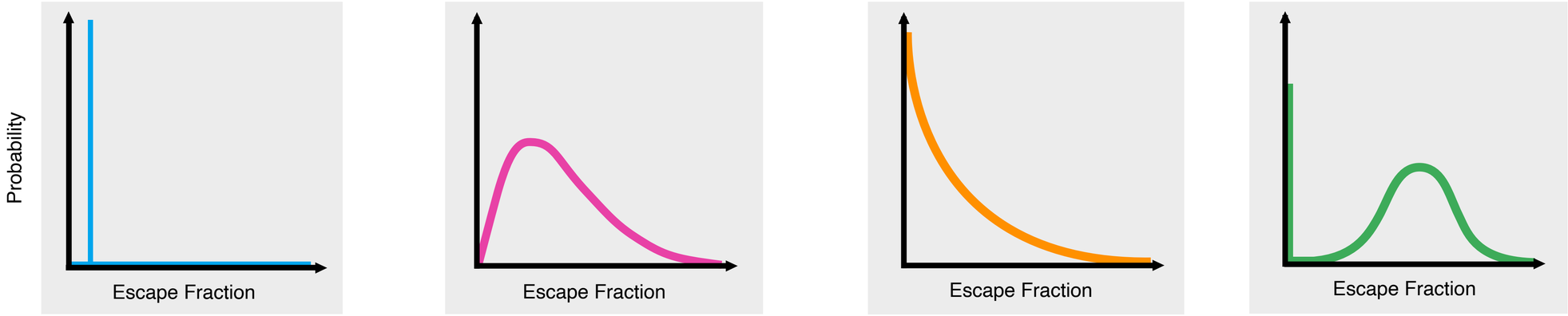
- Number of sources producing ionising photons
- Ionising photon production efficiency
- The ionising photon escape fraction **distribution**



Bolan+2022

How does the distribution connect to the physical picture?



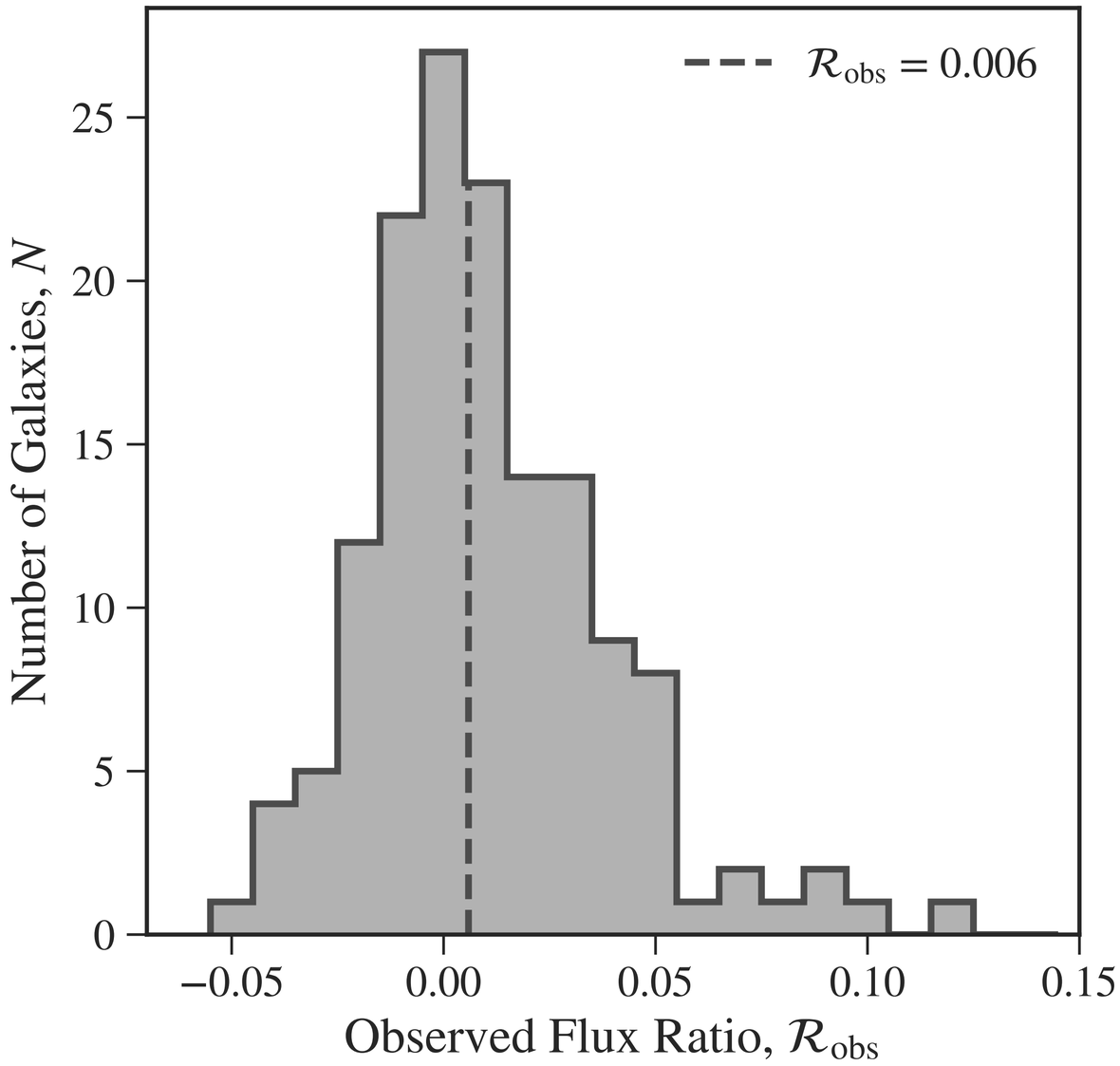


Constant Model **Log-Normal Model** **Exponential Model** **Bimodal Model**

The Data

- Selection of **148 star-forming galaxies from VANDELS survey**
  - **Spectroscopic redshift:** 3.35 < z < 3.95
  - **LyC photometry** (VIMOS U-band)
  - **Non-ionising UV photometry.** (HST F606W)

$$\mathcal{R}_{\rm obs} = \left(\frac{L_{\rm LyC}}{L_{\rm UV}}\right)_{\rm obs} = \left(\frac{\langle f_{\rm U}\rangle}{\langle f_{\rm V606}\rangle}\right)_{\rm obs}$$



Sample presented in Begley+2022

Linking the escape fraction to the data

Intrinsic flux ratio of UV to LyC photons

Escape fraction

UV Dust attenuation from the galaxy's ISM

Transmission through the IGM and CGM

Observed flux ratio of UV to LyC photons

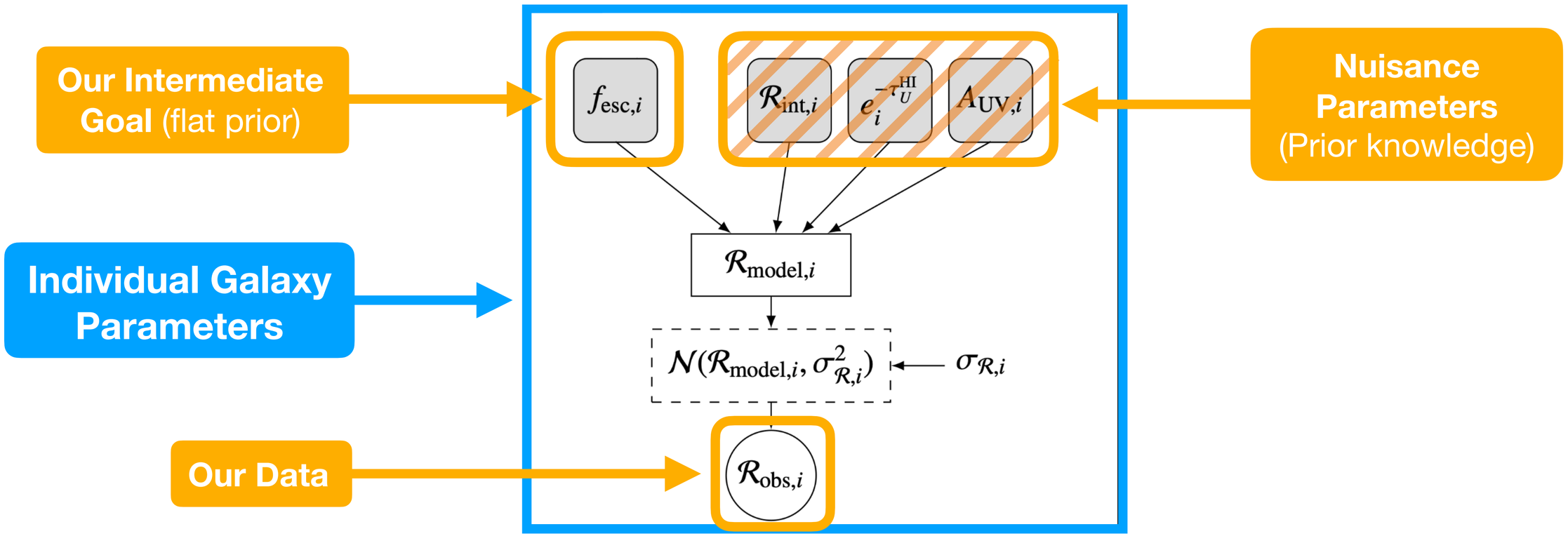
$$\mathscr{R}_{\rm int} \times f_{\rm esc} \times 10^{0.4(A_{\rm UV})} \times e^{-\tau_{\rm U}^{\rm HI}} = \mathscr{R}_{\rm obs}$$

Our goal

Our Data

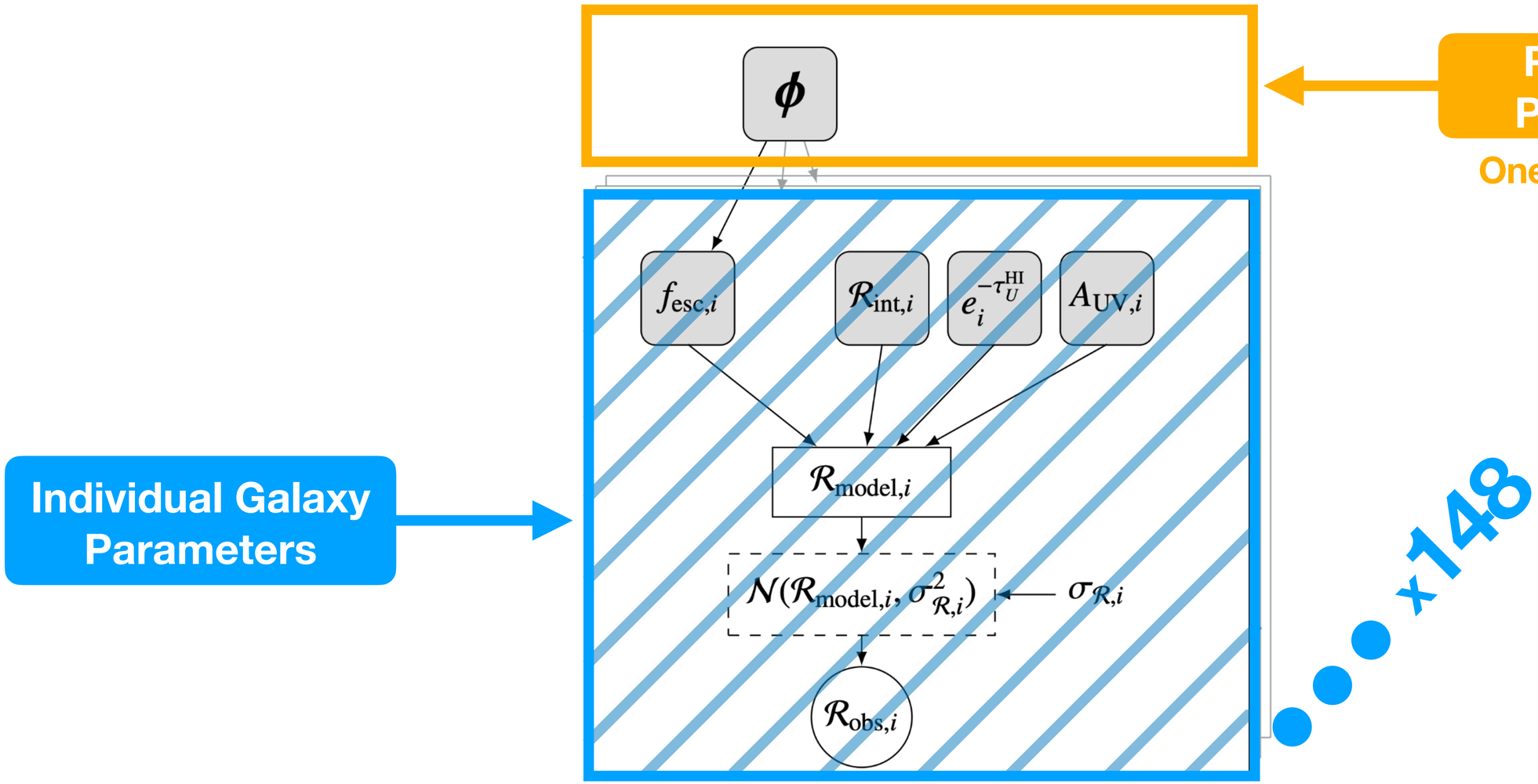
Forward model from Begley+2022

How do we infer the population distribution?



Kreilgaard+2024

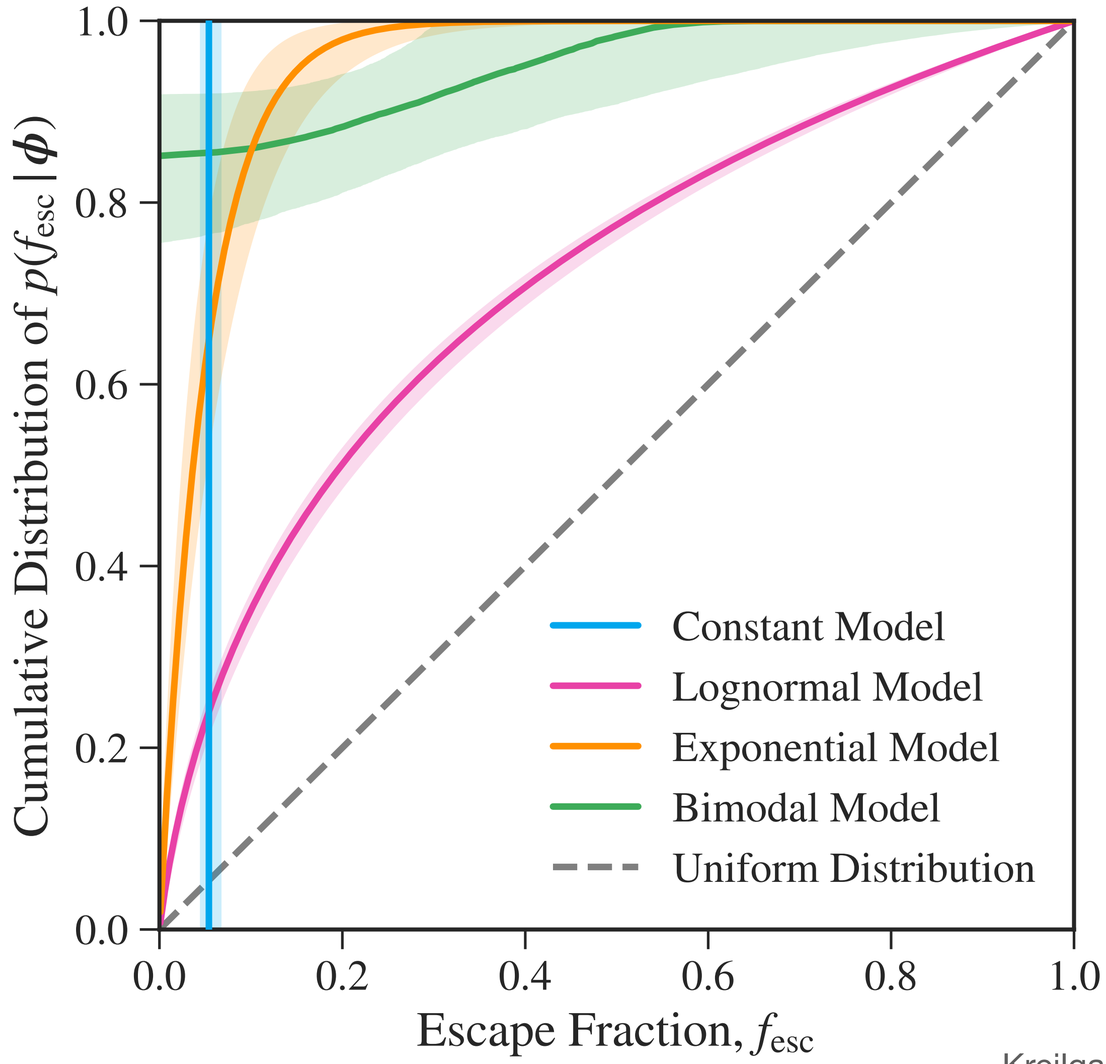
How do we infer the population distribution?



Kreilgaard+2024

What does the distribution look like?

- Most distributions predict the majority of galaxies with: $f_{\rm esc} < 0.1$



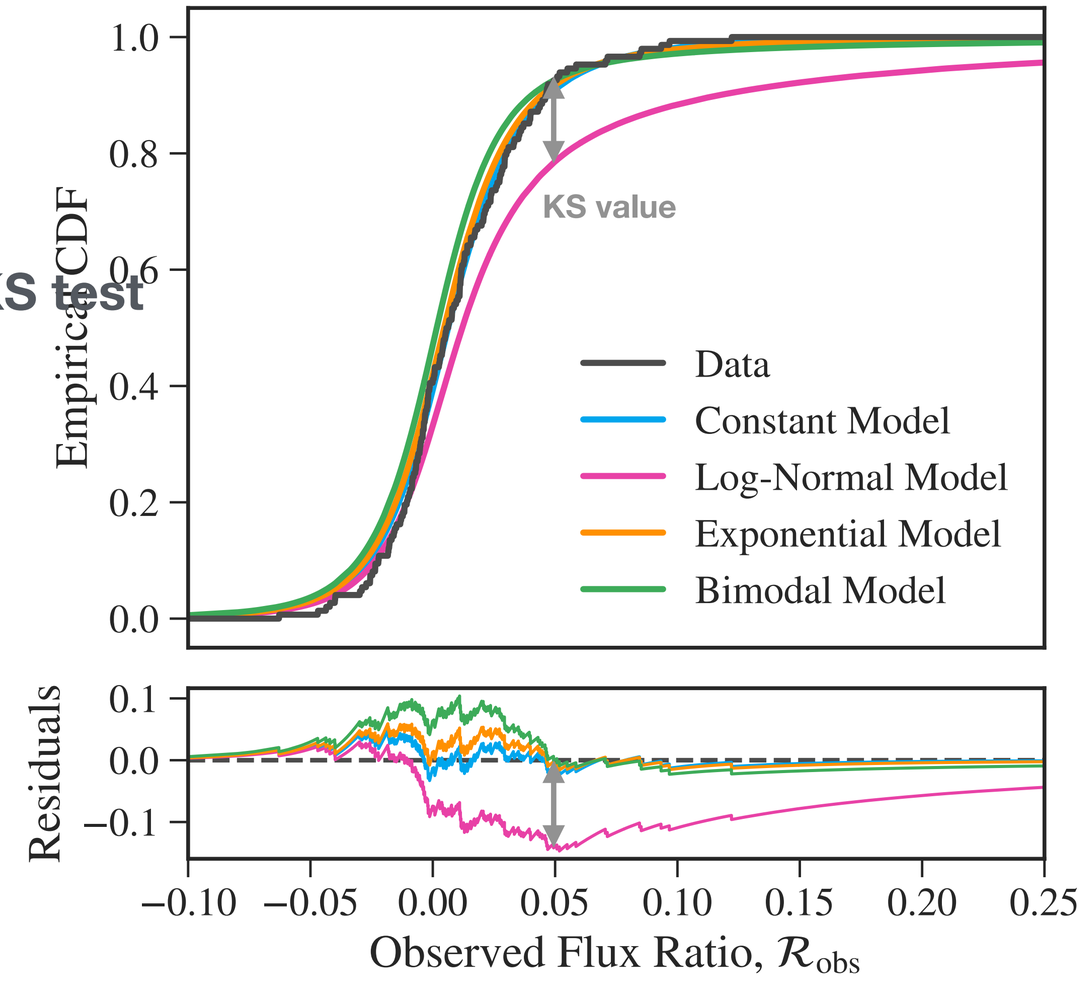
Kreilgaard+2024

Which distribution is best?

Posterior Predictive Test

Sample $f_{\rm esc}$ from distribution → Simulate $\mathcal{R}_{\rm obs}$ distribution → Does the simulated $\mathcal{R}_{\rm obs}$ match the observed $\mathcal{R}_{\rm obs}$?

} KS test

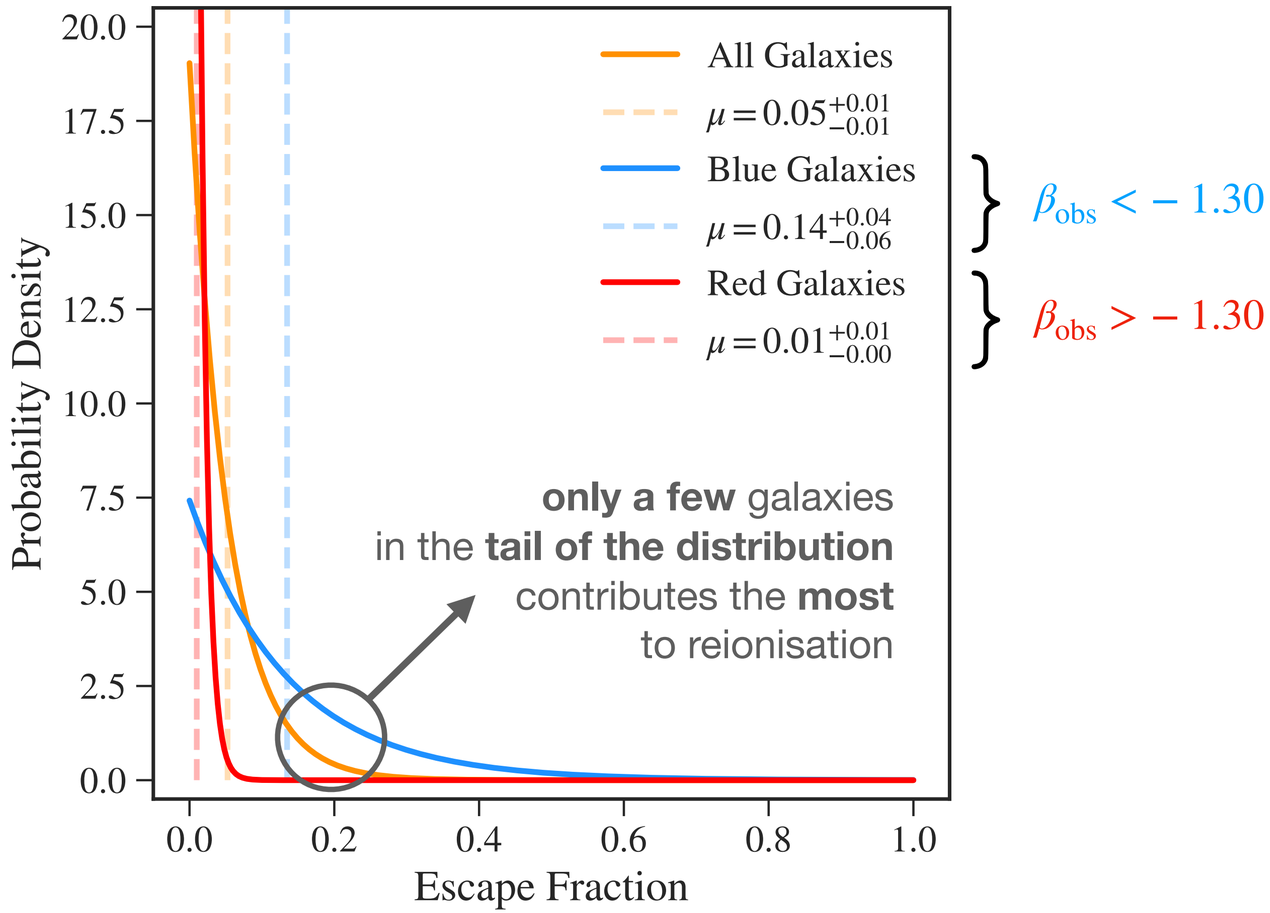


- We reject the log-normal + bimodal models.
- The constant model is inconsistent with individual measurements
- **The exponential distribution of $f_{\rm esc}$ is best**

Kreilgaard+2024

What does the exponential PDF look like?

… it correlates with the UV beta slope



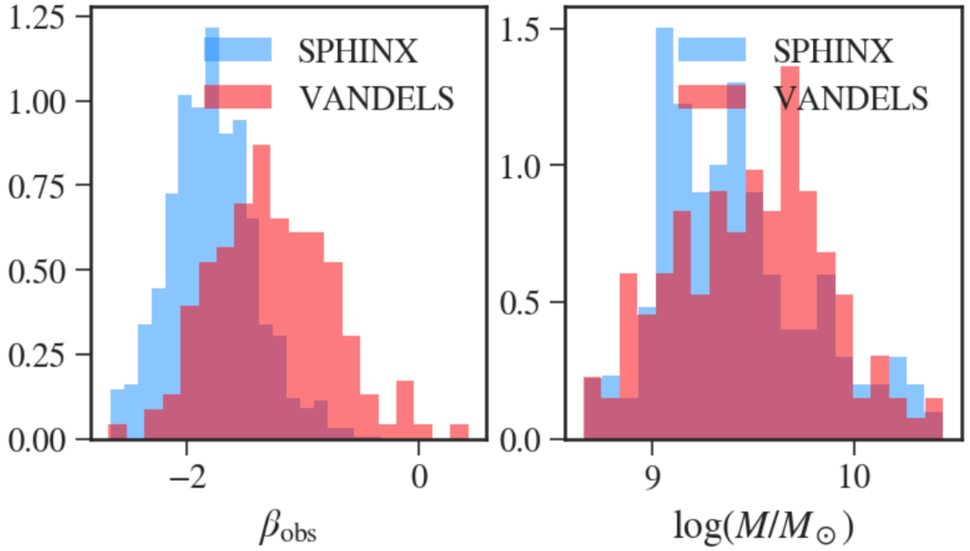
Kreilgaard+2024

Comparing with simulations

… is challenging, but important!

- Fair comparison requires similar galaxies (redshift, mass, beta-slope, …)
- Simulations and observations measure $f_{\rm esc}$ differently
- Sight line $f_{\rm esc}$ versus angle averaged $f_{\rm esc}$

- SPHINX Galaxies
  - 4.64 < z < 5.5
- VANDELS Galaxies
  - 3.35 < z < 3.95



SPHINX sample from Katz+2023

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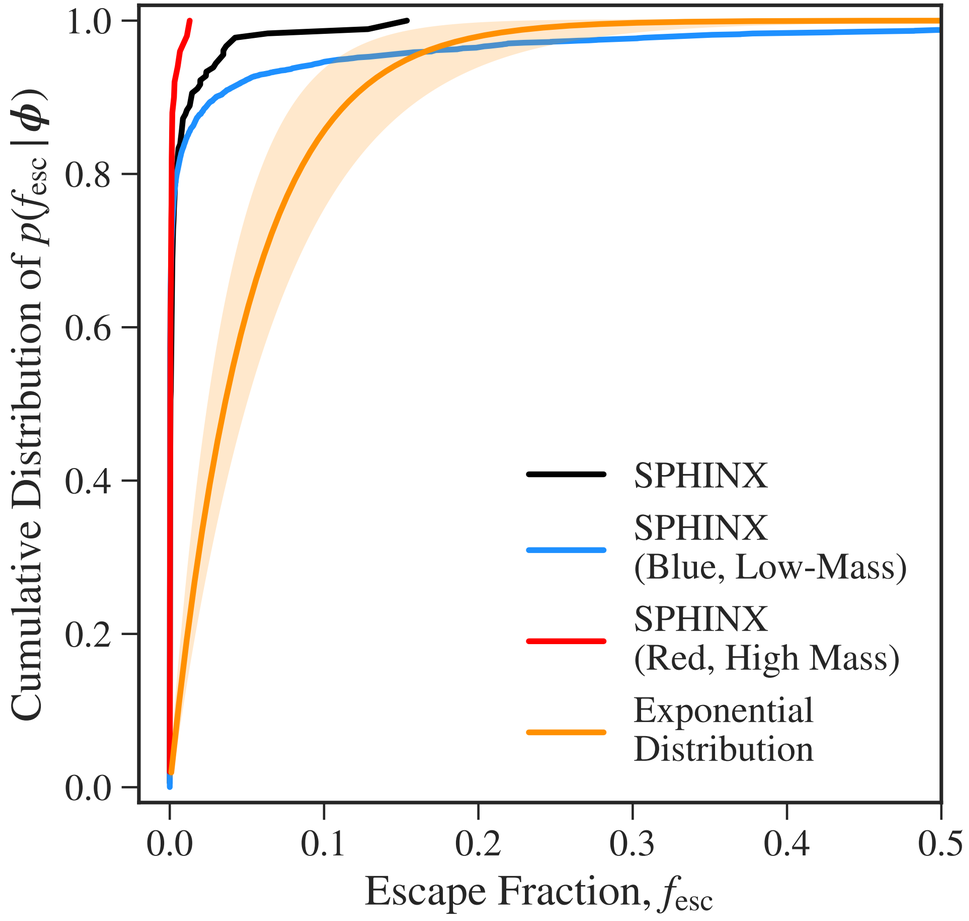


Somewhat similar shape, but the simulation under-predicts the escape fraction.

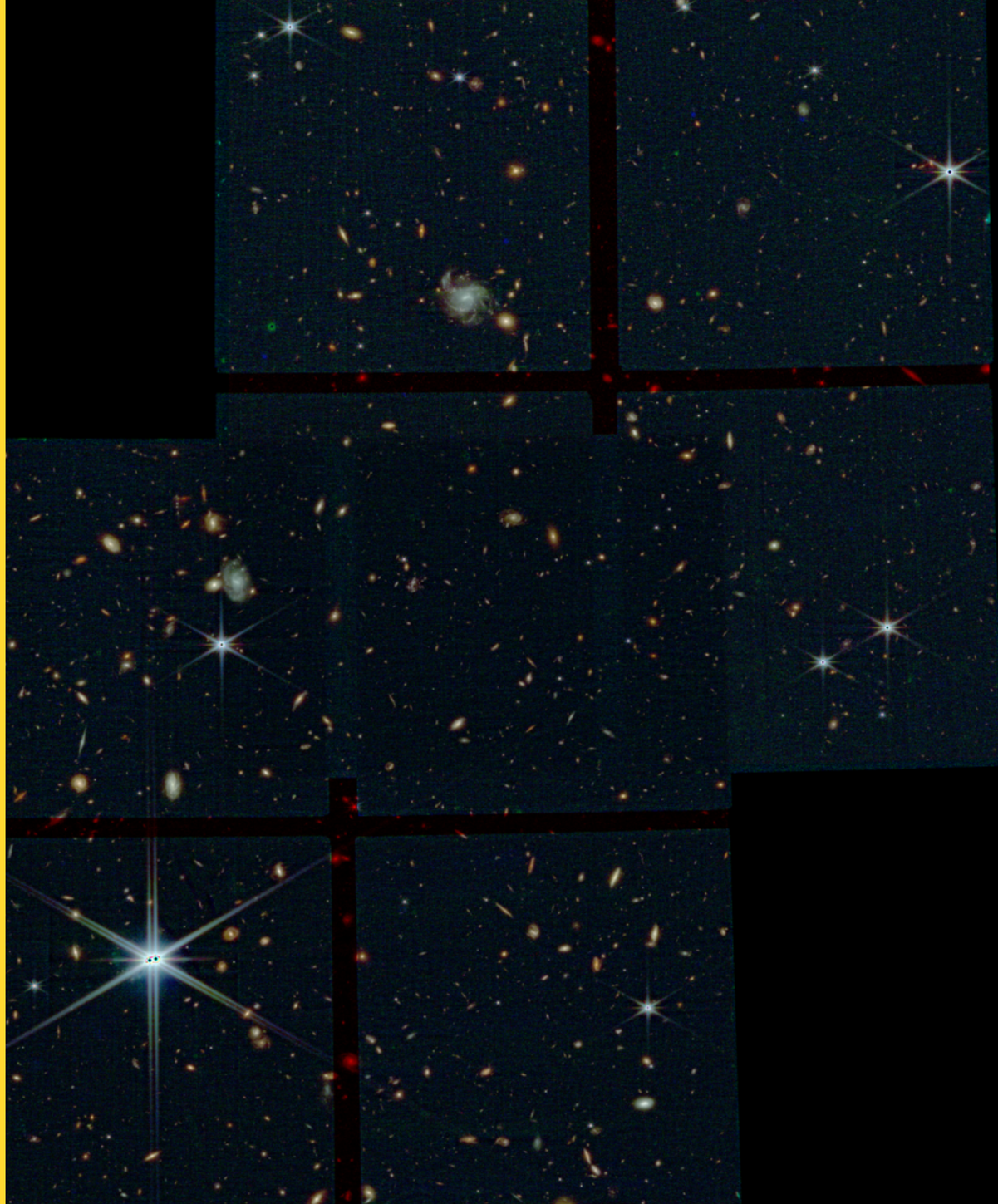
SPHINX sample from Katz+2023

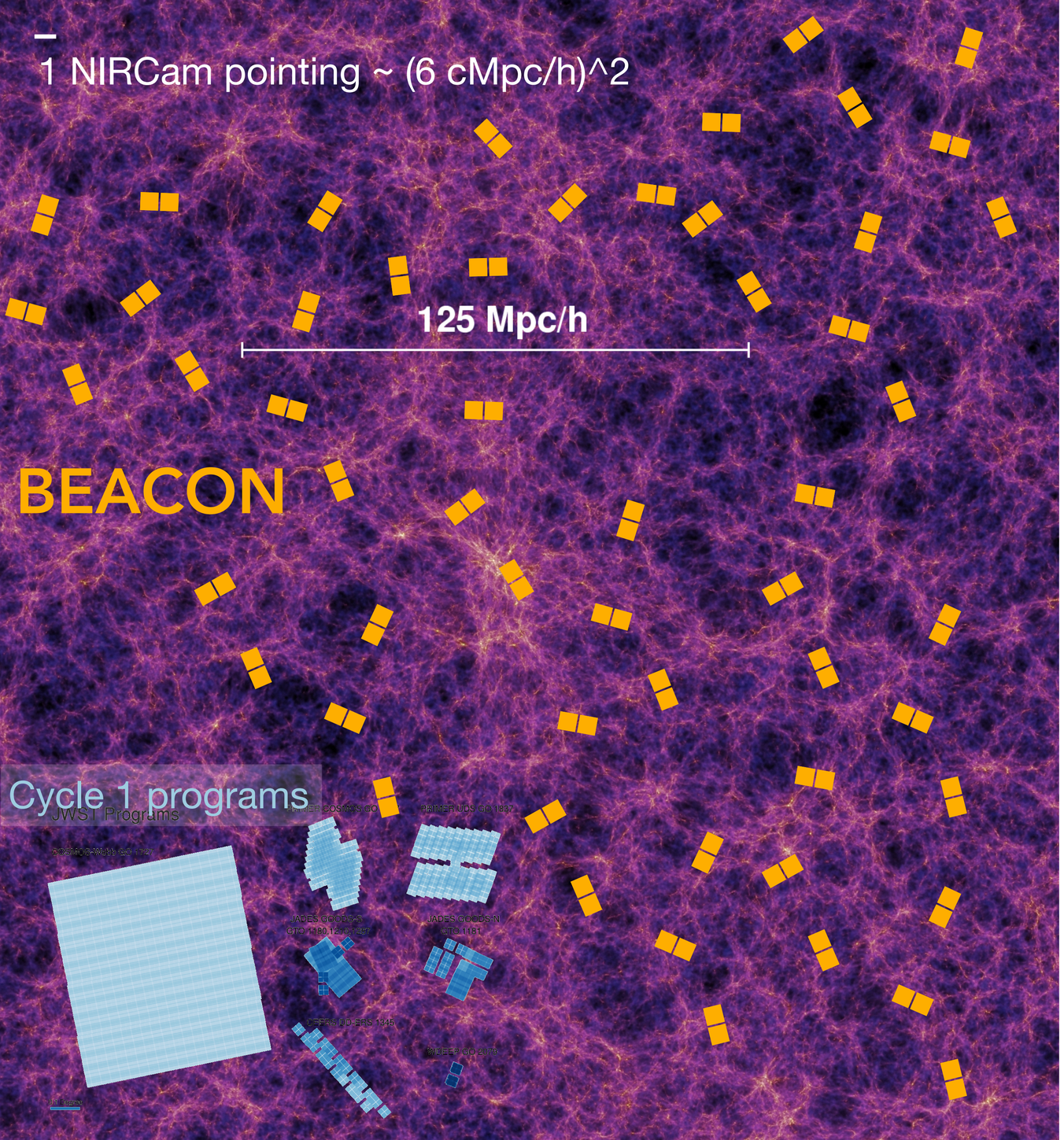
BEACON

Bias-free Extragalactic Analysis for Cosmic Origins with NIRCam

PI: Takahiro Morishita,
Co-PIs: Charlotte Mason, Michele Trenti, Tommaso Treu

Survey Paper: Morishita+ in prep.





BEACON is:

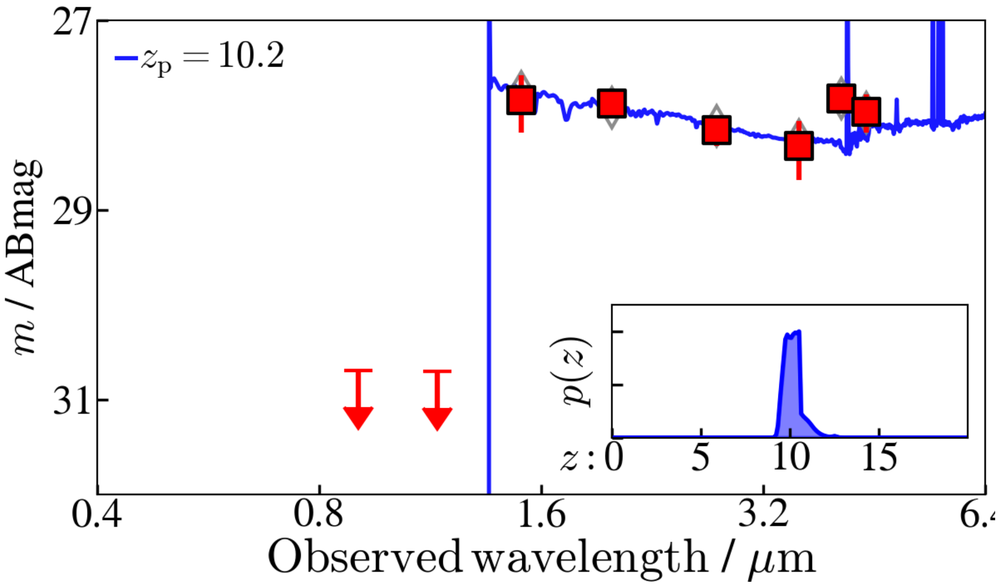
- Pure-parallel multi-band imaging survey
- ~ 220 sightlines
- ~ 0.6 square degrees total area
- Awarded ~ 600 hours

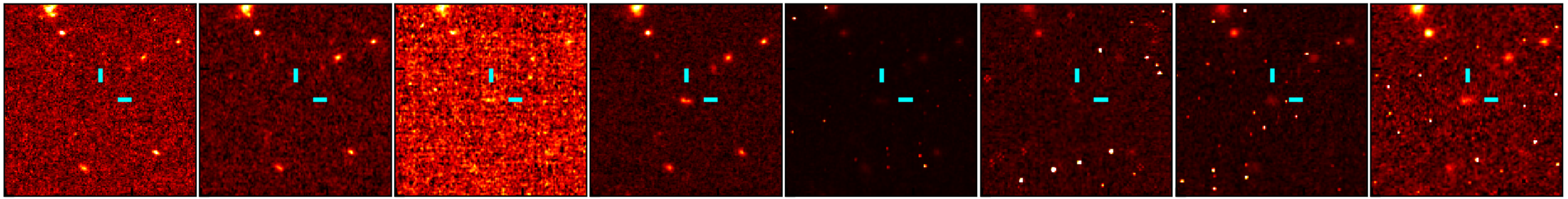
BEACON will find:

- N > 1e3 galaxies at z = 7-9
- N ~ 100 galaxies at z = 10 - 12
- N ~ 1-100 galaxies at z > 13

A good z~10 candidate

- NIRCAM 8-band imaging provides robust photometric redshift determination
- With our 8 band filter configurations we can determine redshifts at z~2 up to z > 10





Take Aways

FESC DISTRIBUTION

arXiv: 2405.10364

- We recover **expected values of** $f_{\rm esc} = 0.05$ consistent w. previous work (Begley+2022)
- We argue the distribution is exponential: **only a small fraction of sources may be the main contributers to reionisation at a given time.**
- **Correlation with physical galaxy properties is possible** with more data, useful for constraints within EoR

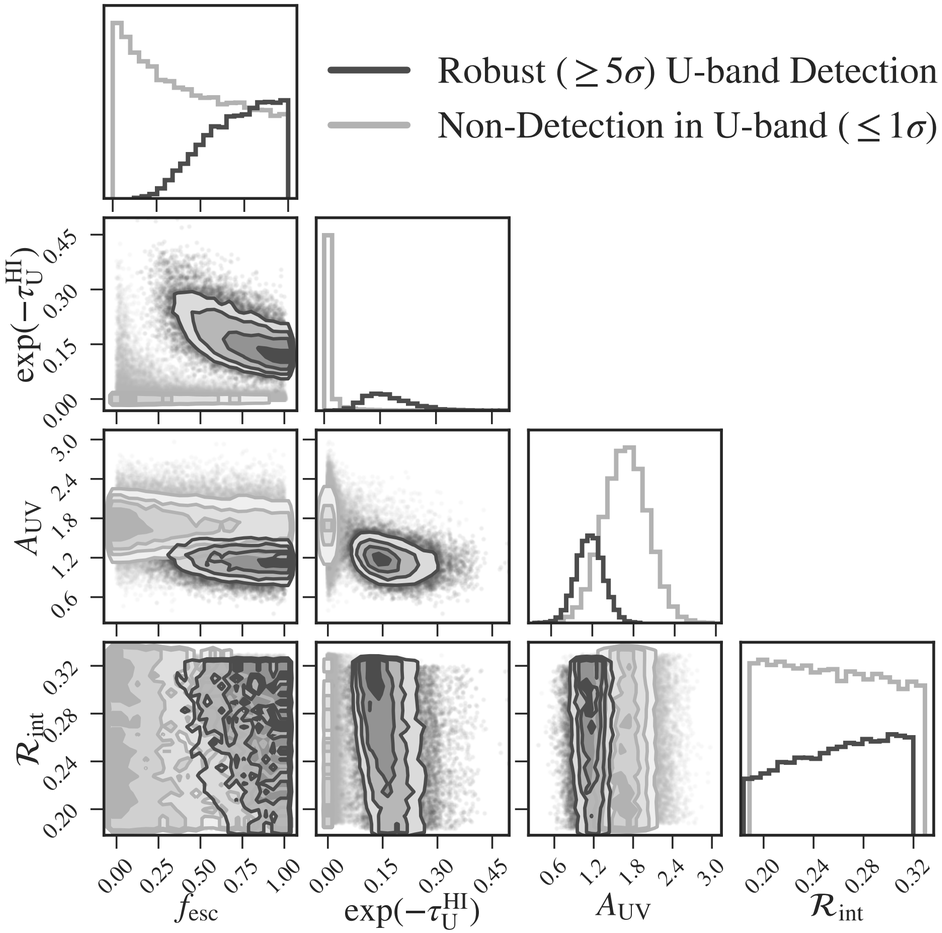
BEACON SURVEY

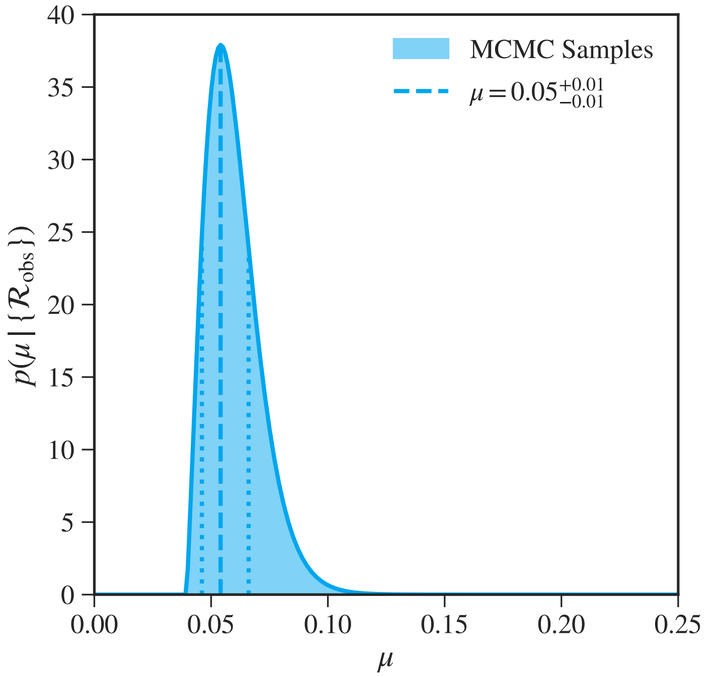
Morishita+ in prep.

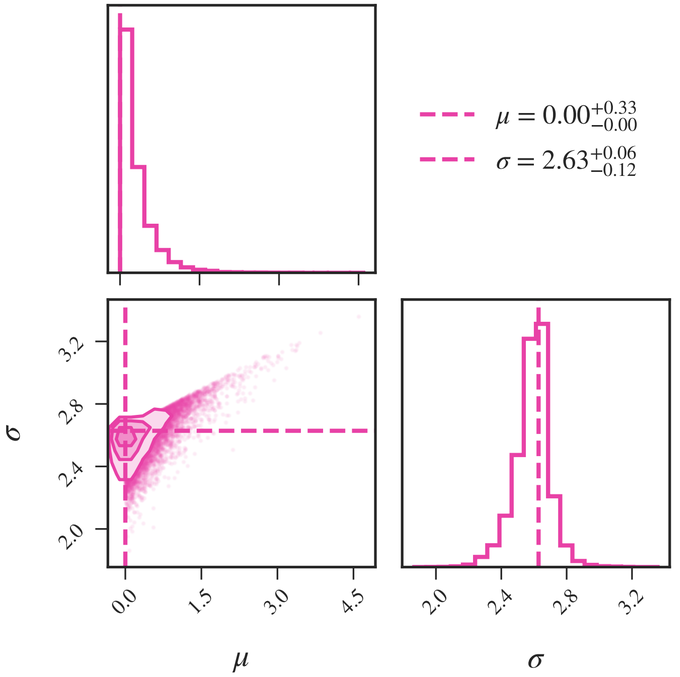
- **Unbiased** view of the Universe
- **Robust photometric redshifts**
- Candidates for spectroscopic follow-up
- Pure-Parallel is “free”

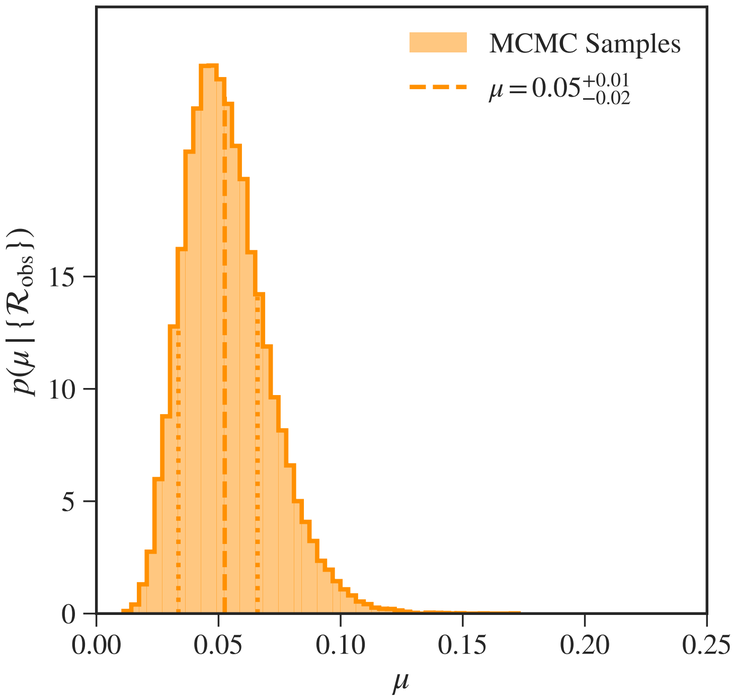
BEACON

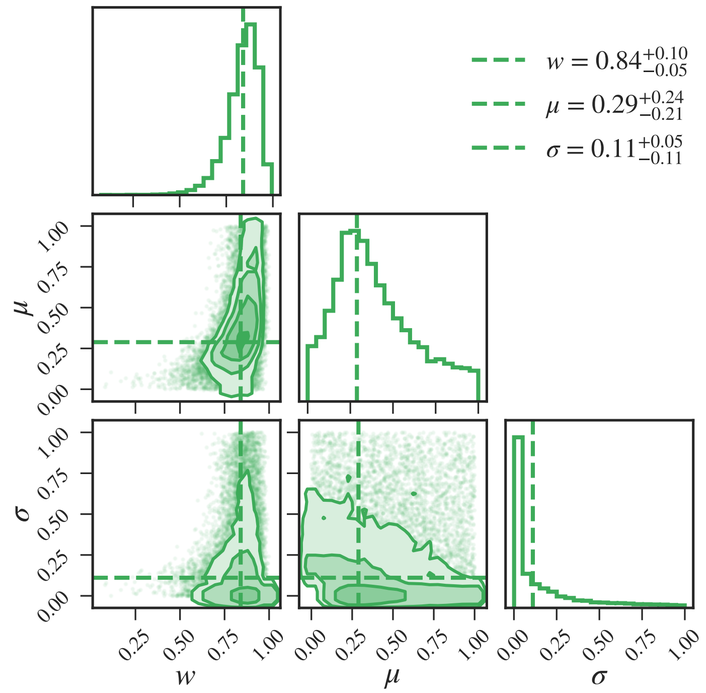
EXTRA
SLIDES

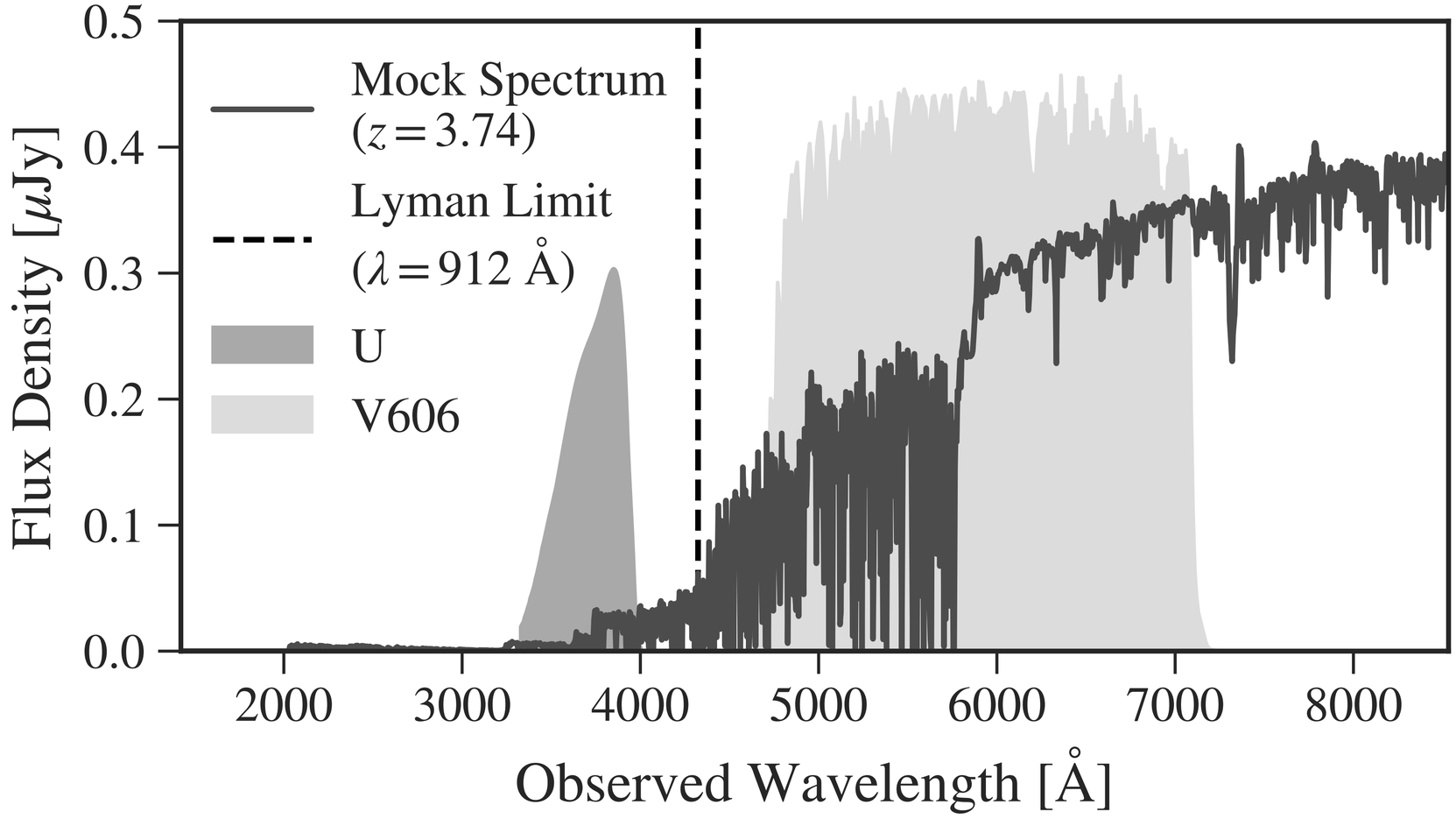

Robust ($\geq 5\sigma$) U-band Detection
Non-Detection in U-band ($\leq 1\sigma$)
$\exp(-\tau_U^{HI})$
A_{UV}
$\mathcal{R}_{int}$
f_{esc}

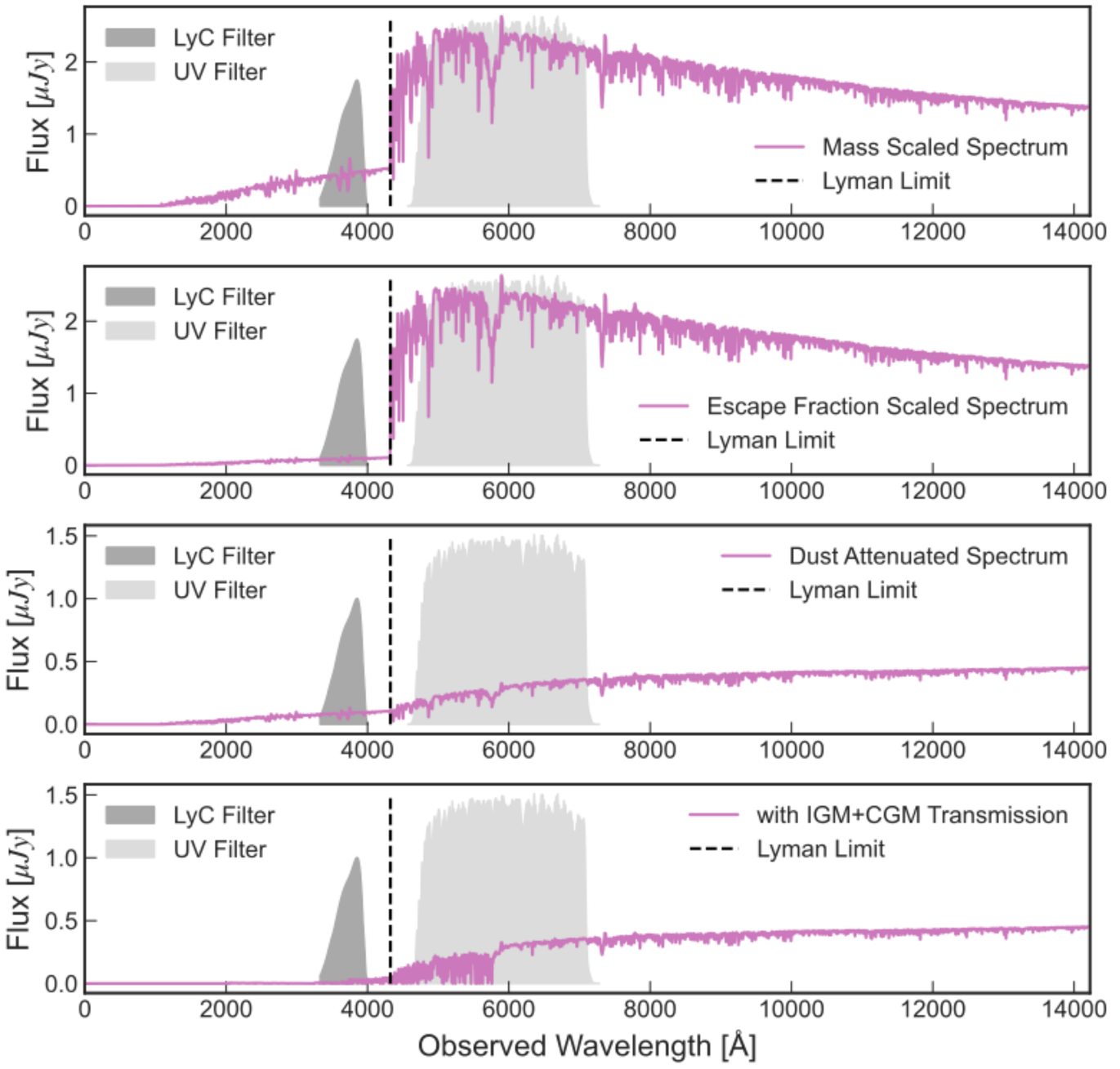
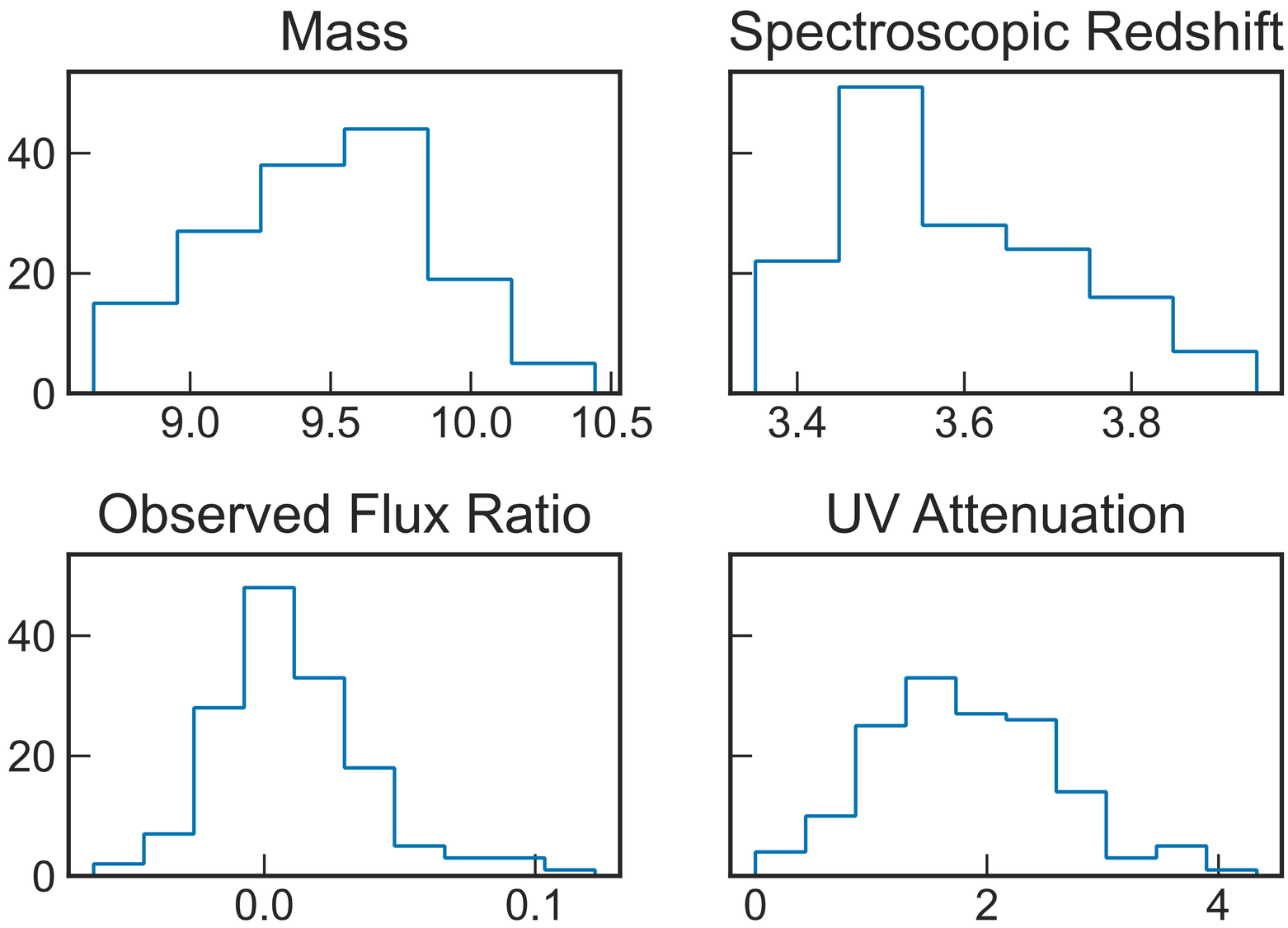

MCMC Samples
$\mu = 0.05^{+0.01}_{-0.01}$
$p(\mu \mid \{\mathcal{R}_{obs}\})$
μ


$\mu = 0.00^{+0.33}_{-0.00}$
$\sigma = 2.63^{+0.06}_{-0.12}$
σ
μ


MCMC Samples
$\mu = 0.05^{+0.01}_{-0.02}$
$p(\mu \mid \{\mathcal{R}_{obs}\})$
μ


$w = 0.84^{+0.10}_{-0.05}$
$\mu = 0.29^{+0.24}_{-0.21}$
$\sigma = 0.11^{+0.05}_{-0.11}$
w
μ
σ


Mock Spectrum
($z = 3.74$)
Lyman Limit
($\lambda = 912$ Å)
U
V606
Flux Density [μJy]
0.0
0.1
0.2
0.3
0.4
0.5
2000
3000
4000
5000
6000
7000
8000
Observed Wavelength [Å]


LyC Filter
UV Filter
Mass Scaled Spectrum
Lyman Limit
Escape Fraction Scaled Spectrum
Dust Attenuated Spectrum
with IGM+CGM Transmission
Flux [μJy]
Observed Wavelength [Å]

VANDELS Sample