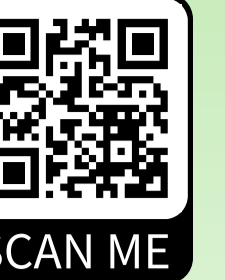


Probing cosmology with large-scale radio galaxy clustering

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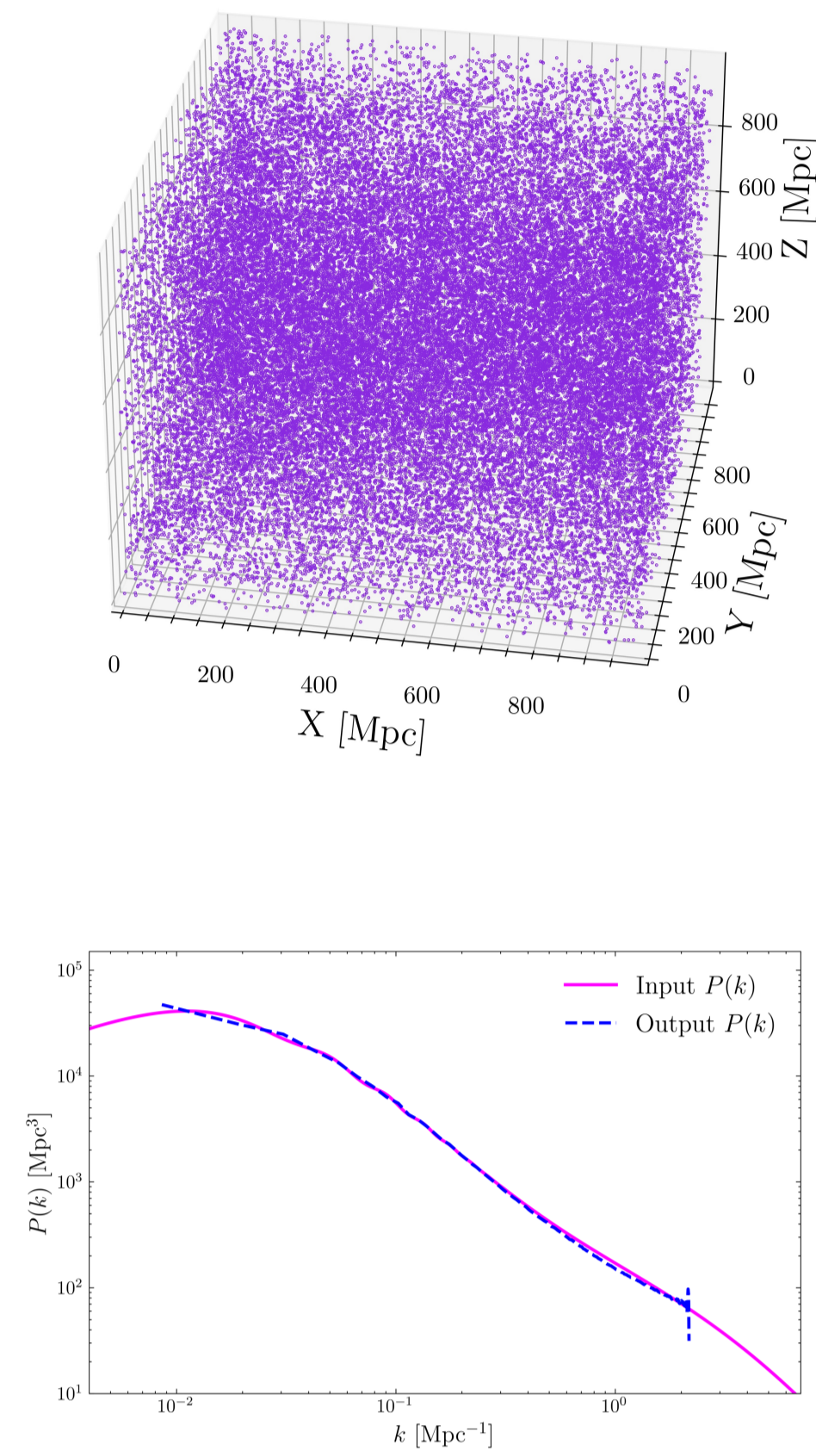


Motivation

Inferring cosmological parameters from galaxy surveys is a central goal of observational cosmology. Conventional inference methods require an explicit likelihood for the data, which becomes difficult when dealing with real surveys with irregular sky coverage and complicated noise models. Simulation-Based Inference (SBI) offers a fast and robust alternative by directly learning the mapping from data to parameters via forward simulations, thereby bypassing the need for an analytic likelihood. In this work, we create an SBI pipeline for the LOFAR Two-metre Sky Survey (LoTSS DR2), using fast log-normal galaxy simulations and conditional Invertible Neural Networks (cINNs) to perform posterior inference on real radio survey data.

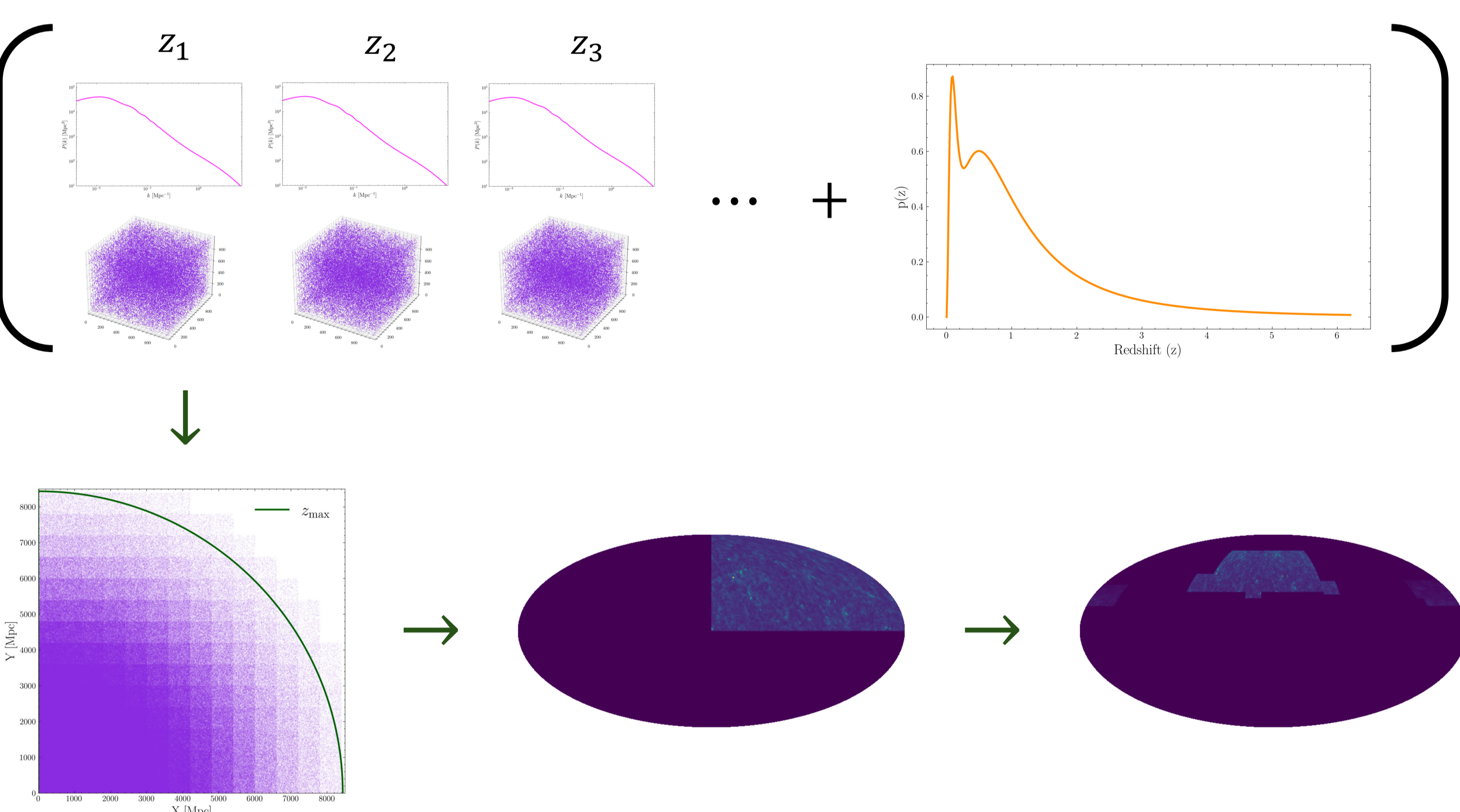
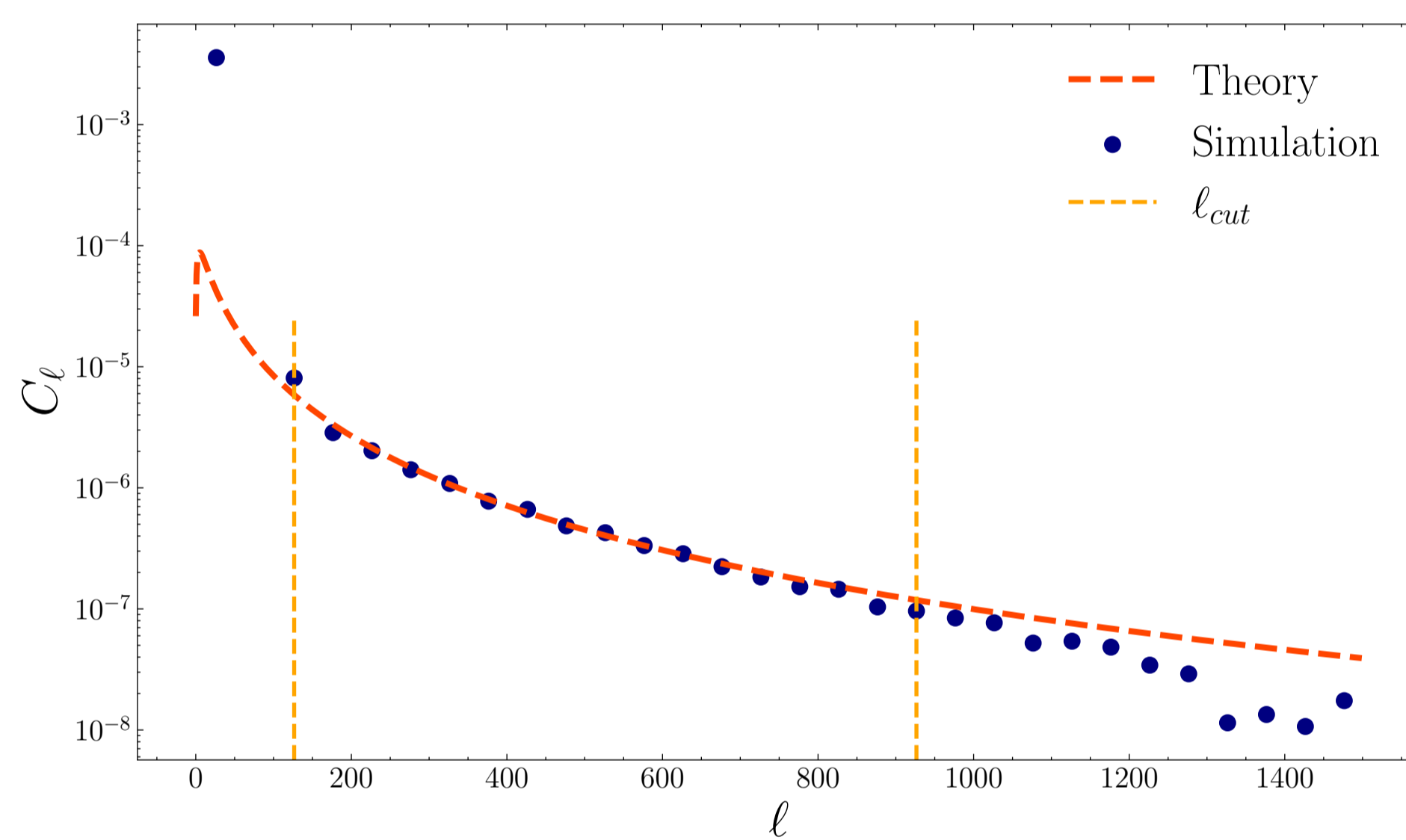
1) Log-normal Galaxy Simulations

- Log-normal fields [1] provide a fast forward model for generating mock galaxy catalogues (~seconds per realisation), allowing the large simulation numbers required for SBI
- Input galaxy power spectrum $P_{gg}(k) = b^2 P_{mm}(k)$ computed using pyccl (linear theory, CAMB)
- Gaussian field sampled in Fourier space, exponentiated to generate log-normal density contrast; galaxies placed via Poisson sampling
- Input parameters: cosmology, redshift (z), galaxy bias (b), amplitude of matter fluctuations (σ_8), box size (L), mesh resolution (N_{mesh}), and expected number of galaxies (N)
- Underlying log-normal generator written in C++; SIMPLE [2] provides a Python wrapper for the code



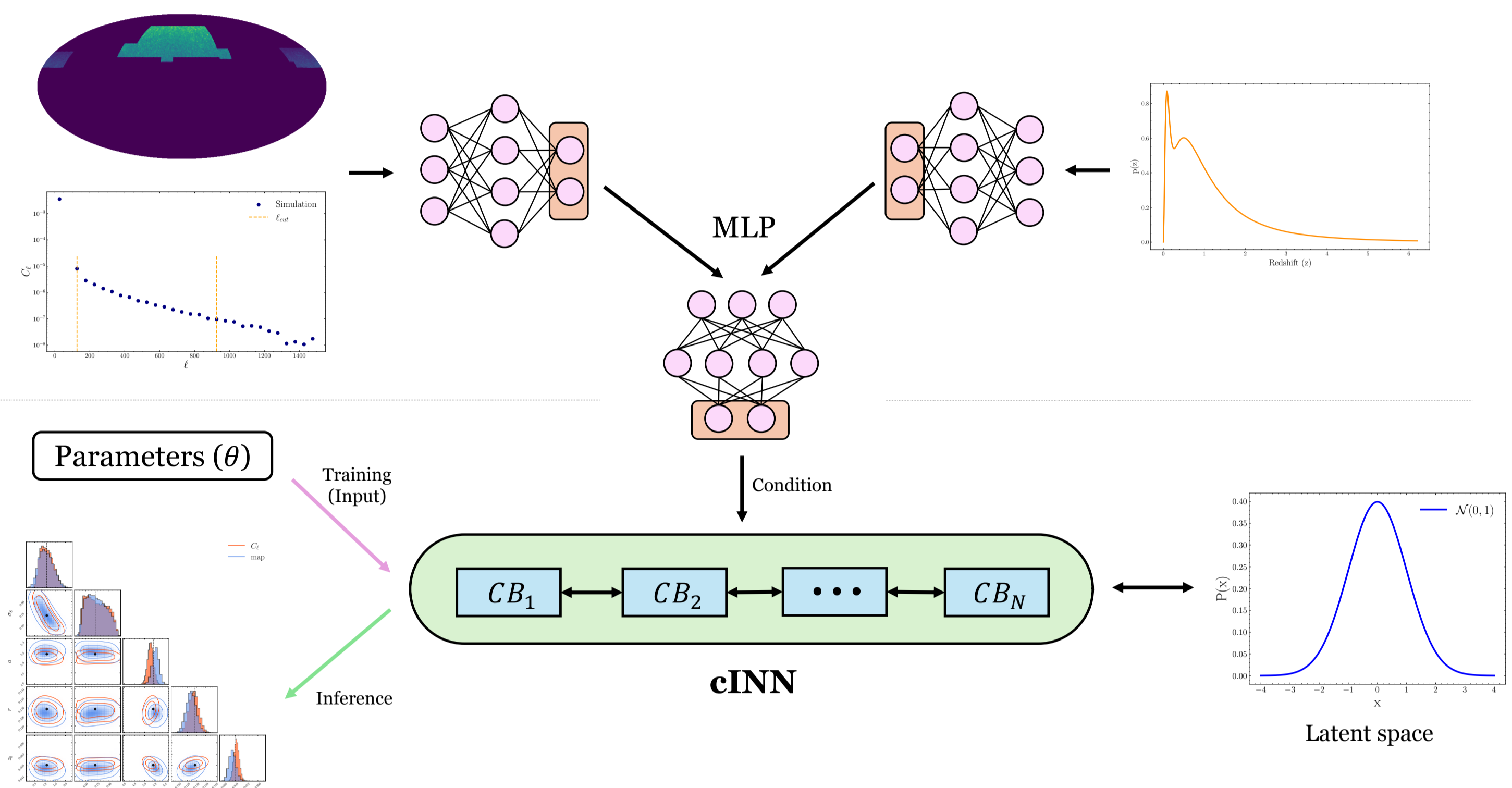
2) Sky Maps

- Each box is generated with its own $P(k, z)$ at the box's central redshift; $z \in [0, 6]$
- Redshift distribution $p(z; a, r, z_0)$ parametrised to match LoTSS source counts
- Boxes stitched into a quarter-sky light cone
- Two non-overlapping regions were extracted and remapped to the LoTSS DR2 footprint
- Galaxy positions projected onto Hierarchical Equal Area isoLatitude Pixelation (HEALPix) maps ($N_{side} = 256$)
- Angular power spectrum C_ℓ computed with NaMaster on masked sky
- ~20,000 simulations with five parameters: b, σ_8, a, r, z_0



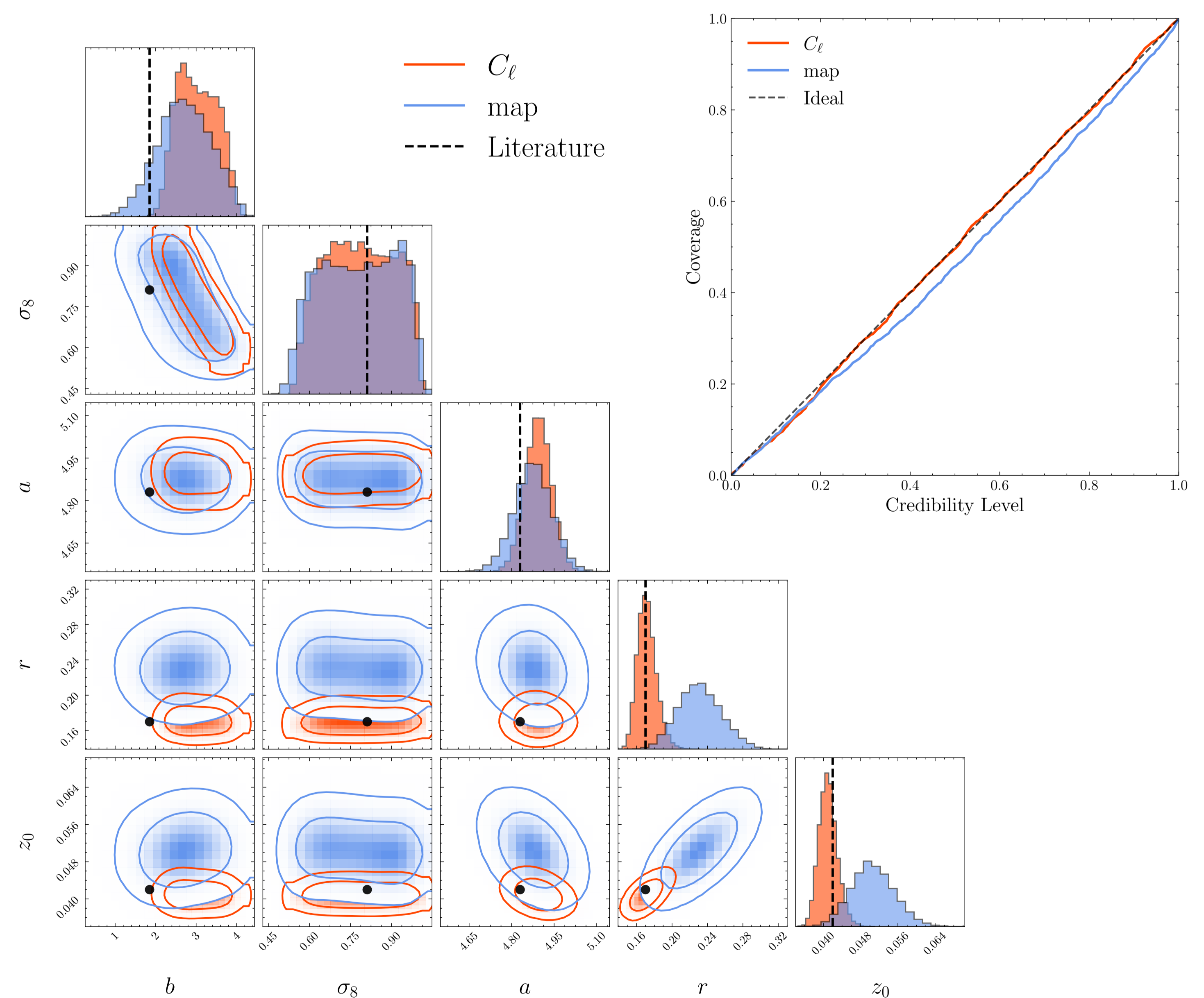
3) SBI with cINNs

- cINNs learn a bijective mapping
 - Training: maps $\theta \rightarrow z$ (latent Gaussian)
 - Inference: draws $z \sim N(0, I)$ and inverts to $\theta = f^{-1}(z | x)$.
- Implemented using FrEIA [3]
- Two architectures tested:
 - $C_\ell + p(z)$
 - full HEALPix map $+p(z)$



4) Results

- TARP confirms that both architectures have well-calibrated posteriors
- Both models applied to real LoTSS DR2 [4,5] data give consistent, physically reasonable posteriors
- Inferred values consistent with literature expectations



Summary & Outlook

This work shows an SBI pipeline for inferring cosmological parameters from radio galaxy survey data. The simulations can be further improved by including non-linear corrections and by adding realistic observational effects such as noise and survey completeness. The framework can be readily applied to newer data releases such as LoTSS DR3, which will cover a significantly larger sky area. Finally, extending the analysis to other cosmological parameters and including cross-correlations with other probes offers a promising path toward more robust constraints.

Ref:

- Log-normal, Agrawal et al. 2017, arXiv:1706.09195
- SIMPLE, Niemeyer et al. 2023, arXiv:2307.08475
- FrEIA, url: <https://github.com/vislearn/FrEIA>
- LoTSS DR2, Shimwell et al. 2022, arXiv:2202.11733
- Cosmology from LOFAR, Hale et al. 2023, arXiv:2310.07627



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