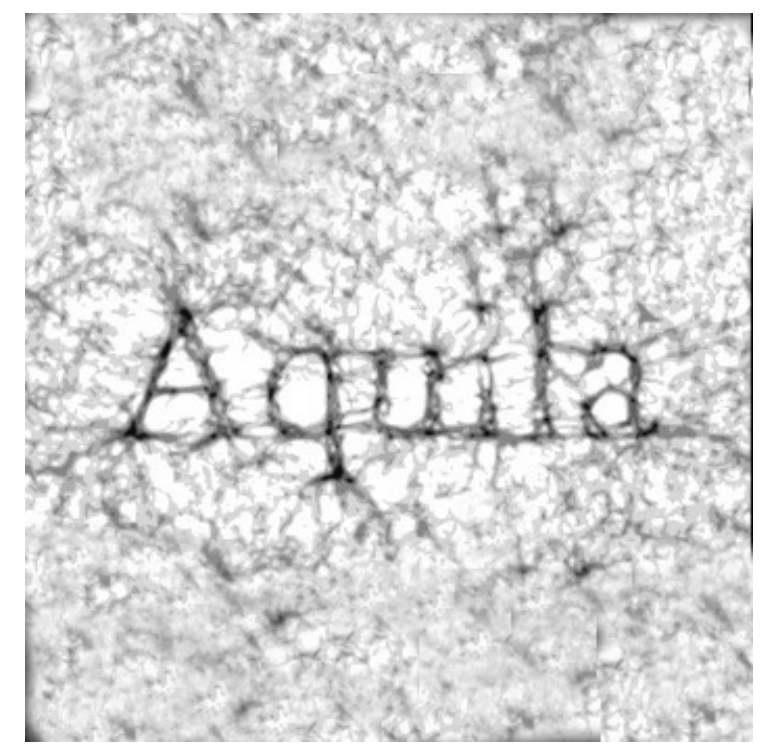




**INAF**  
ISTITUTO NAZIONALE  
DI ASTROFISICA

**OAS**  
BOLOGNA

SIMONS FOUNDATION



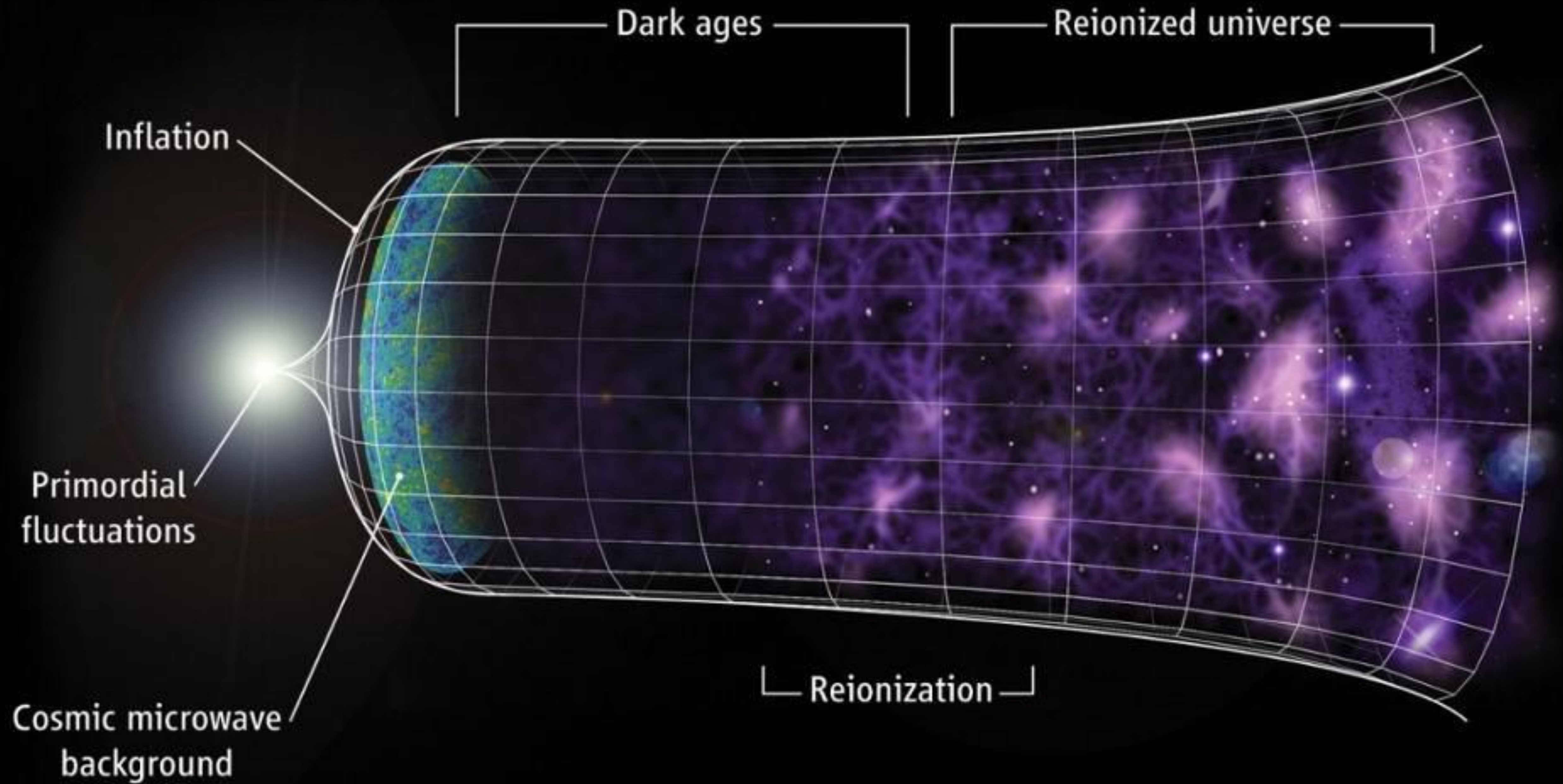
# Field-level inference of primordial non-Gaussianity, using next-generation galaxy surveys

Adam Andrews

*ML-IAP/CCA 2023, November 28th*

arxiv: 2203.08838





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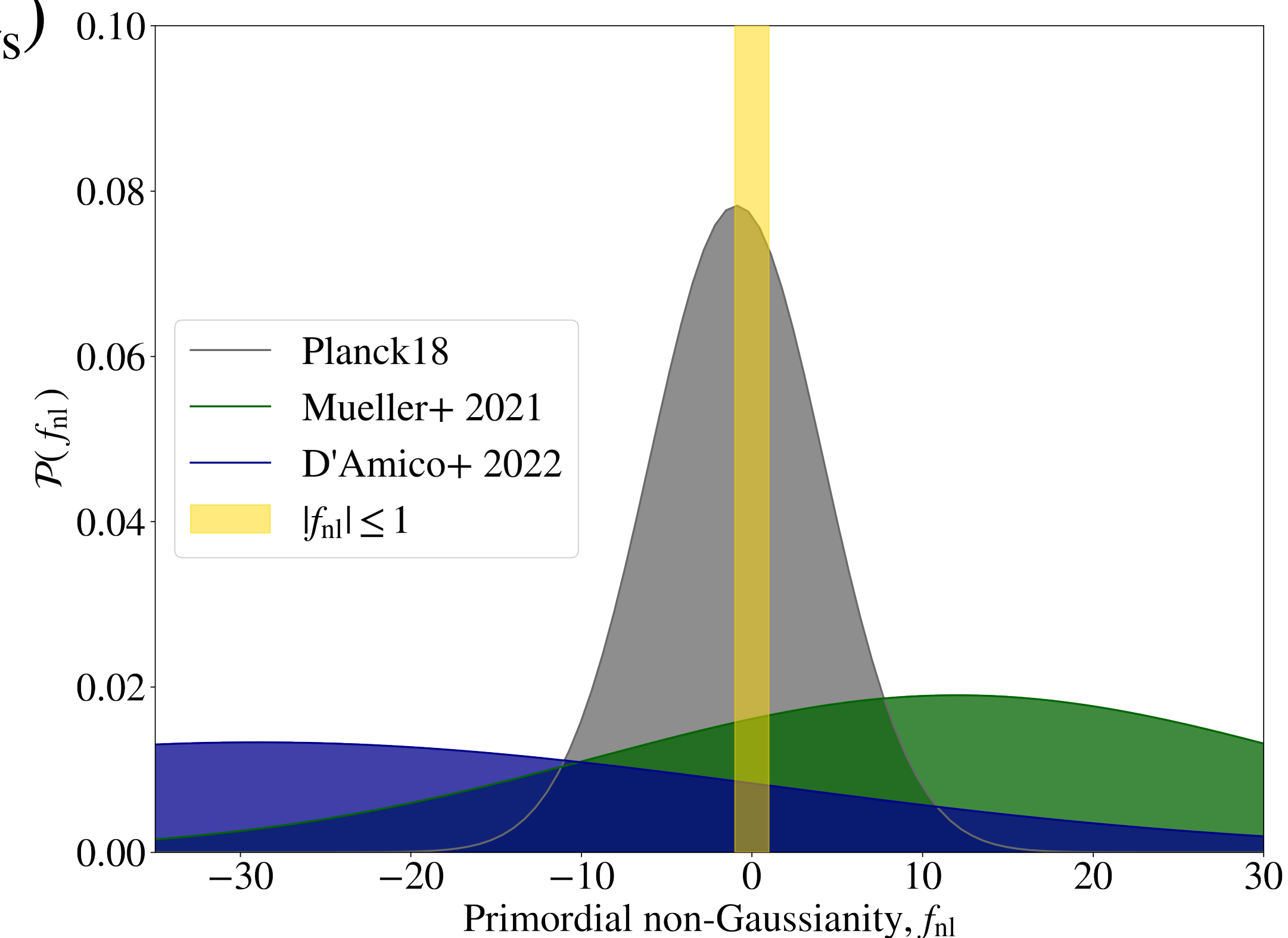
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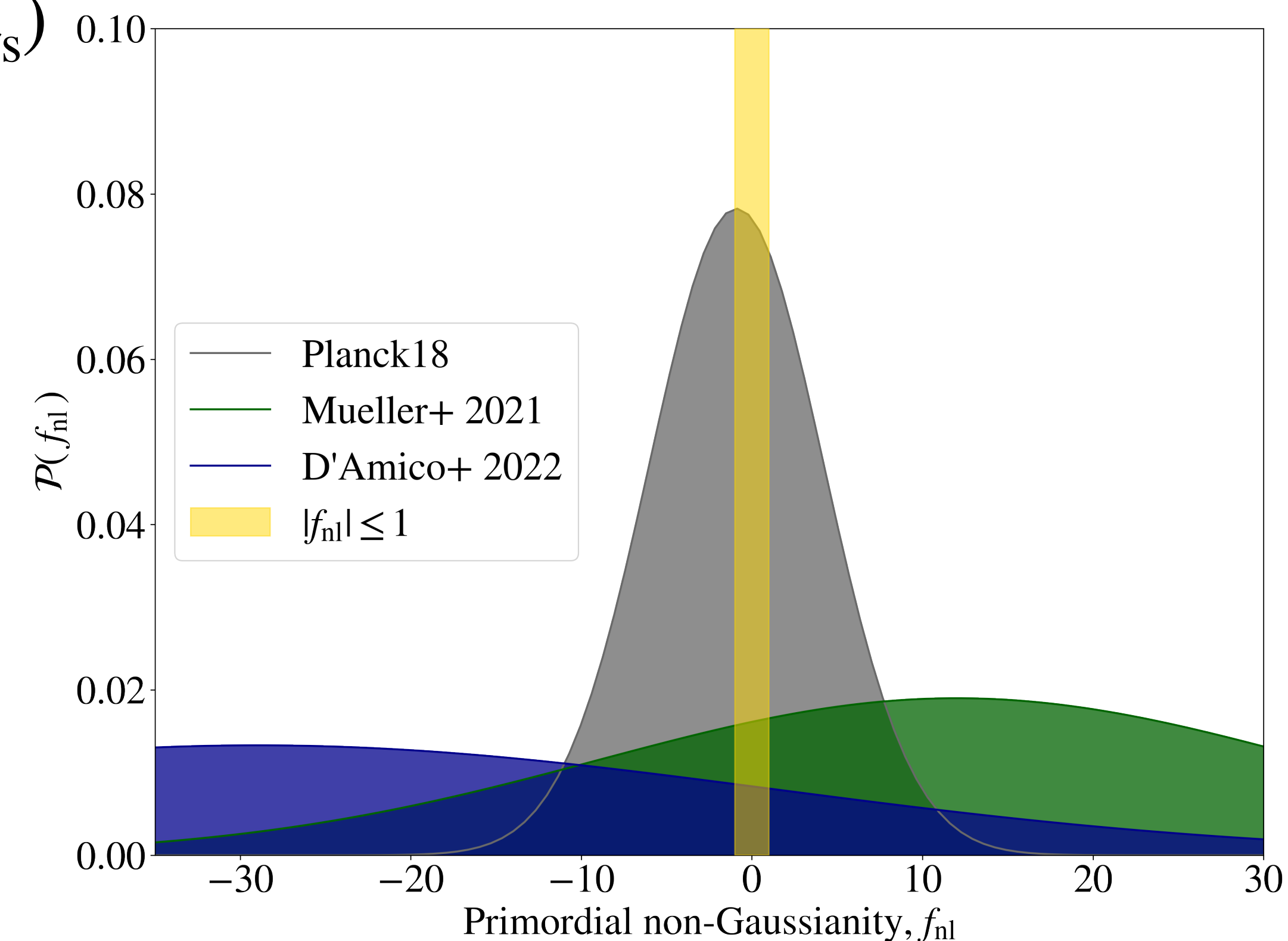
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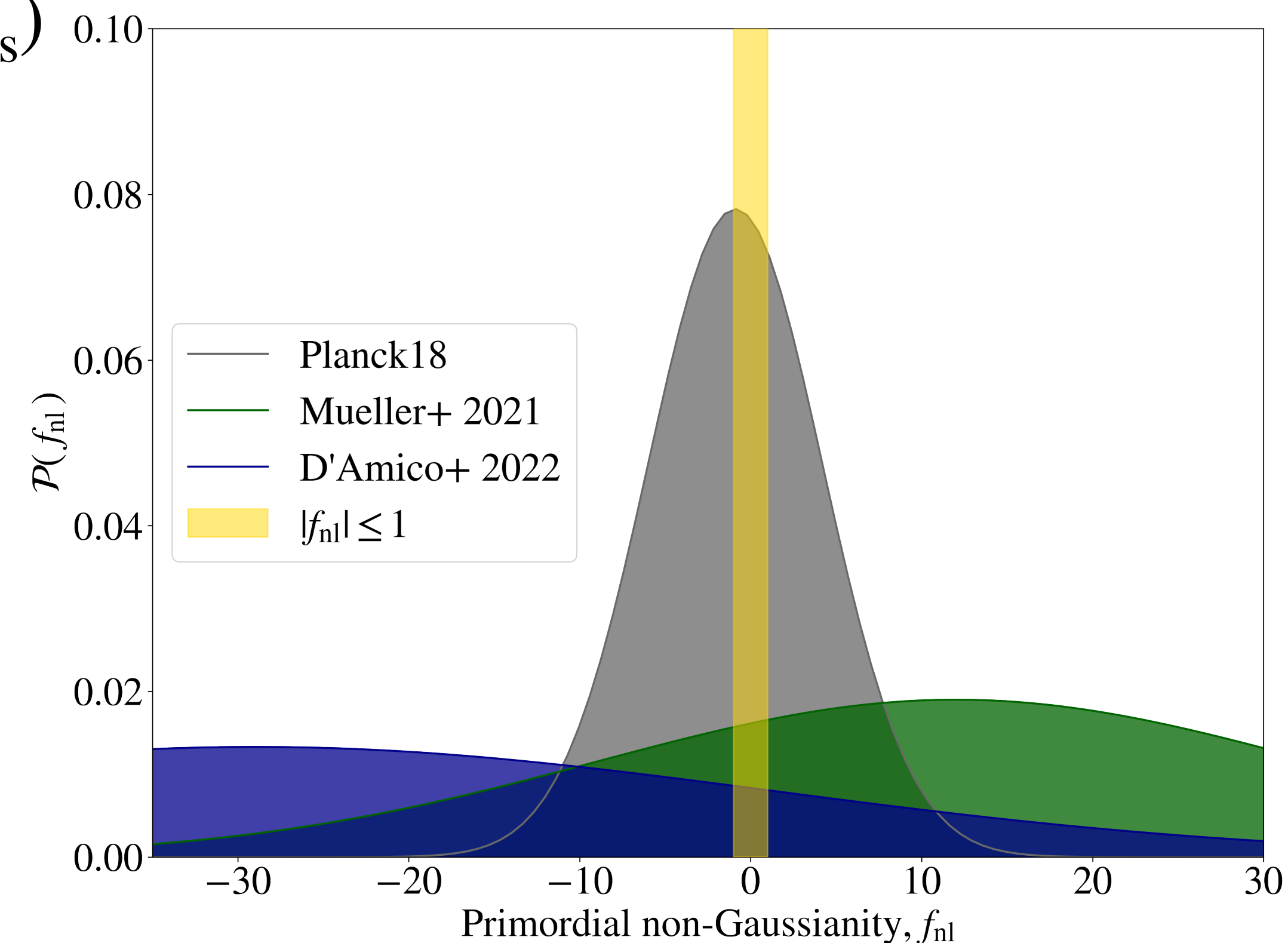
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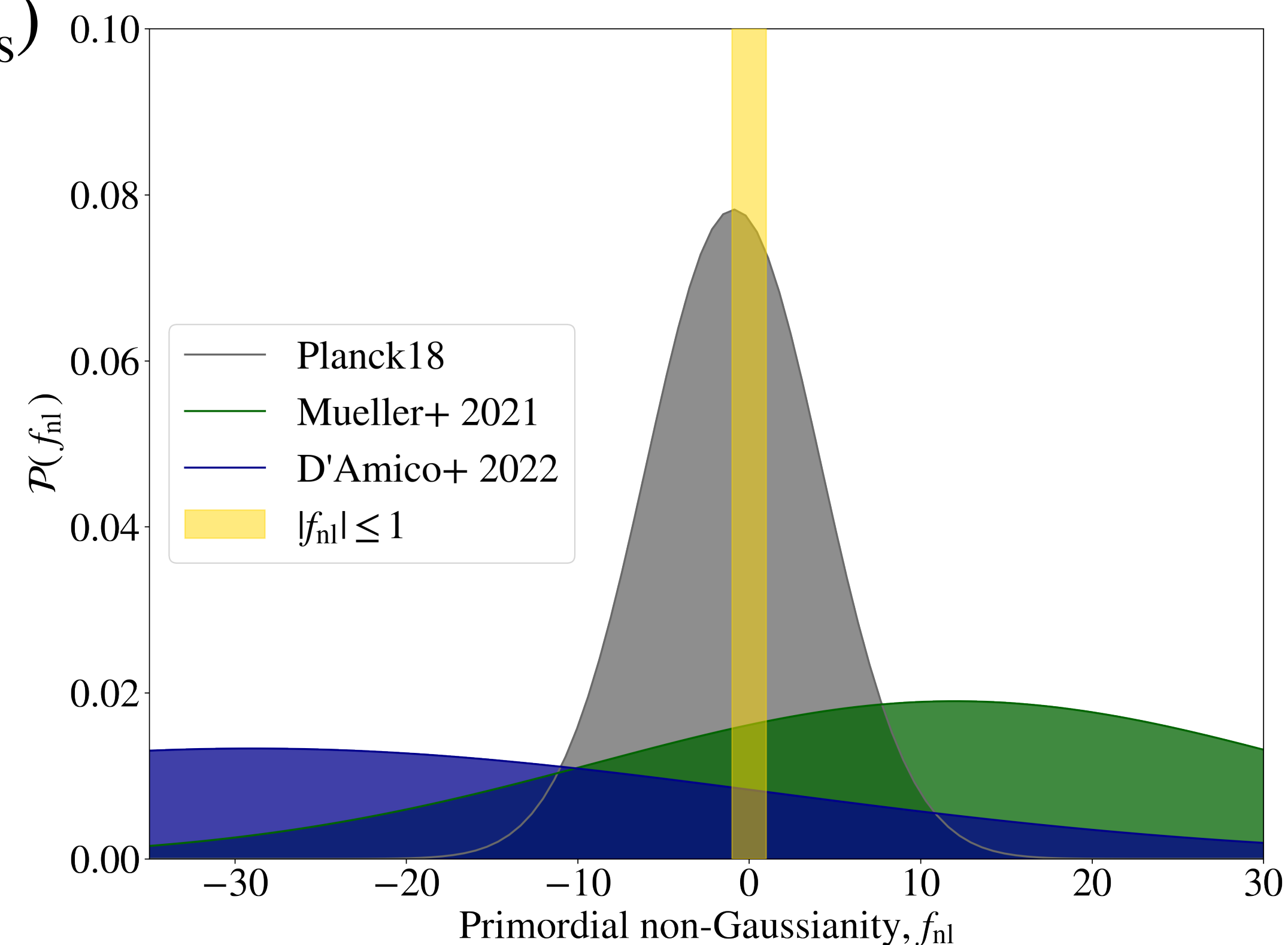
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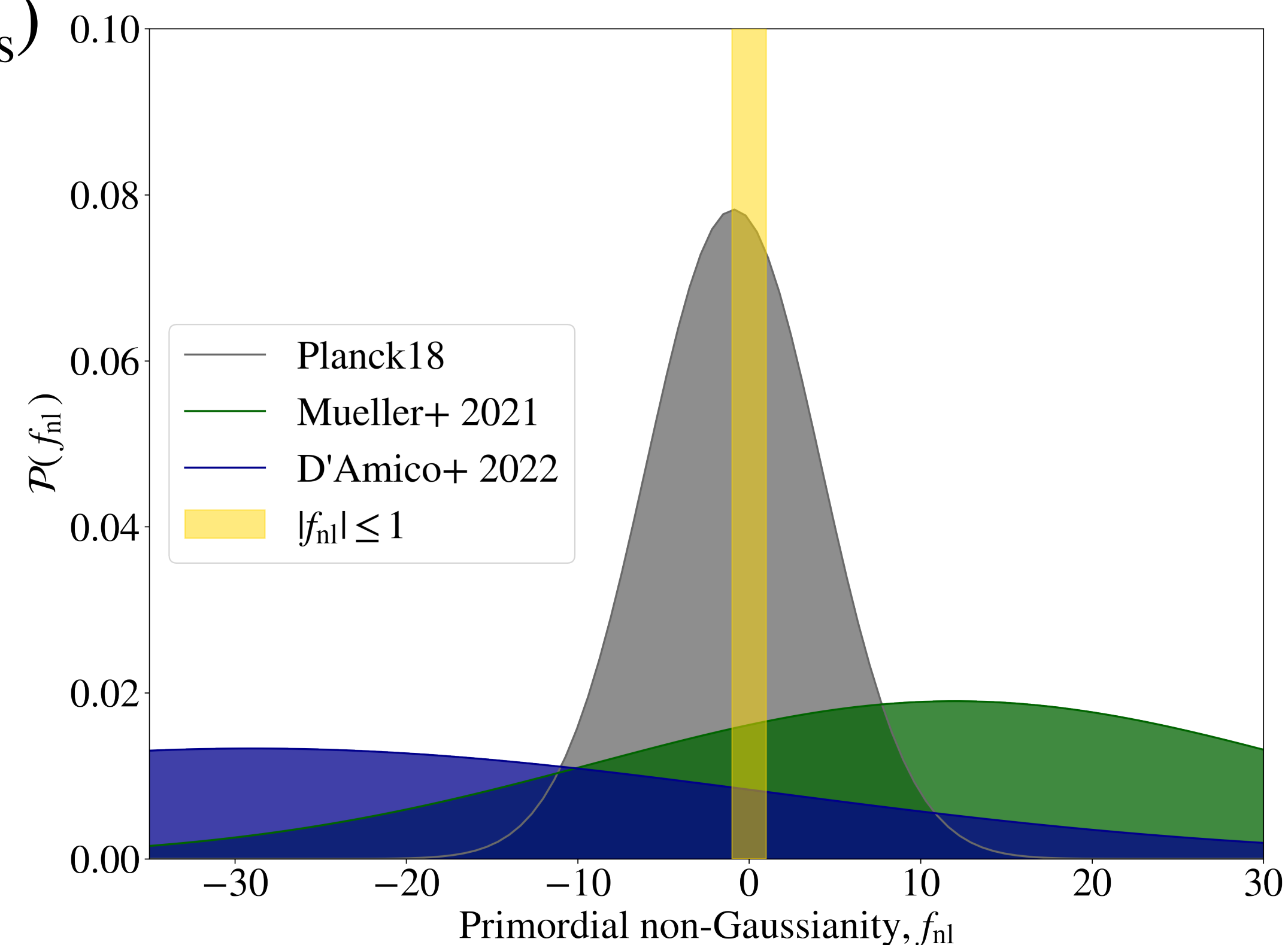
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(Bispectrum + Power spectrum)\*\*:

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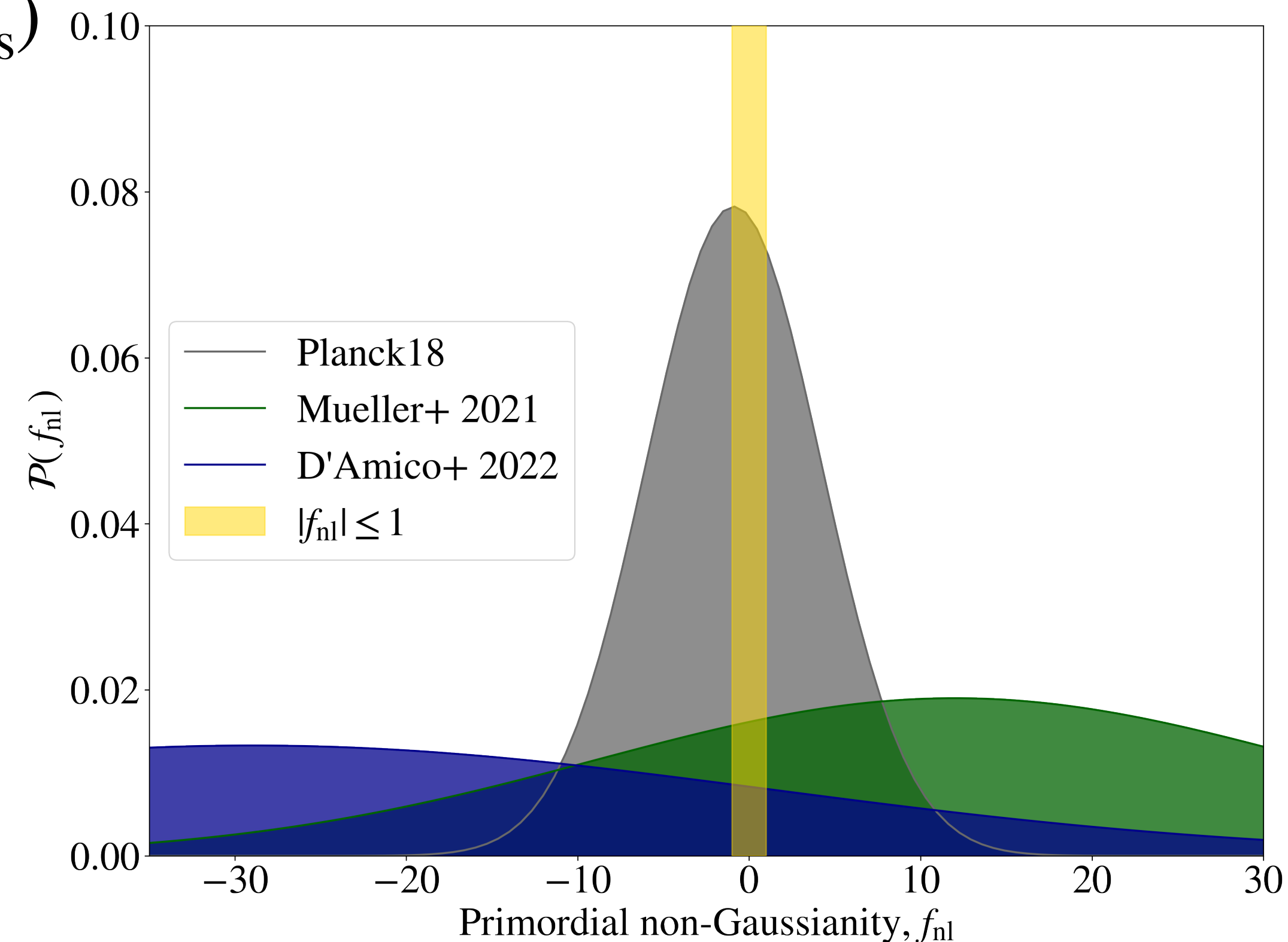
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*Can we do better?  
Can we use the full field?*



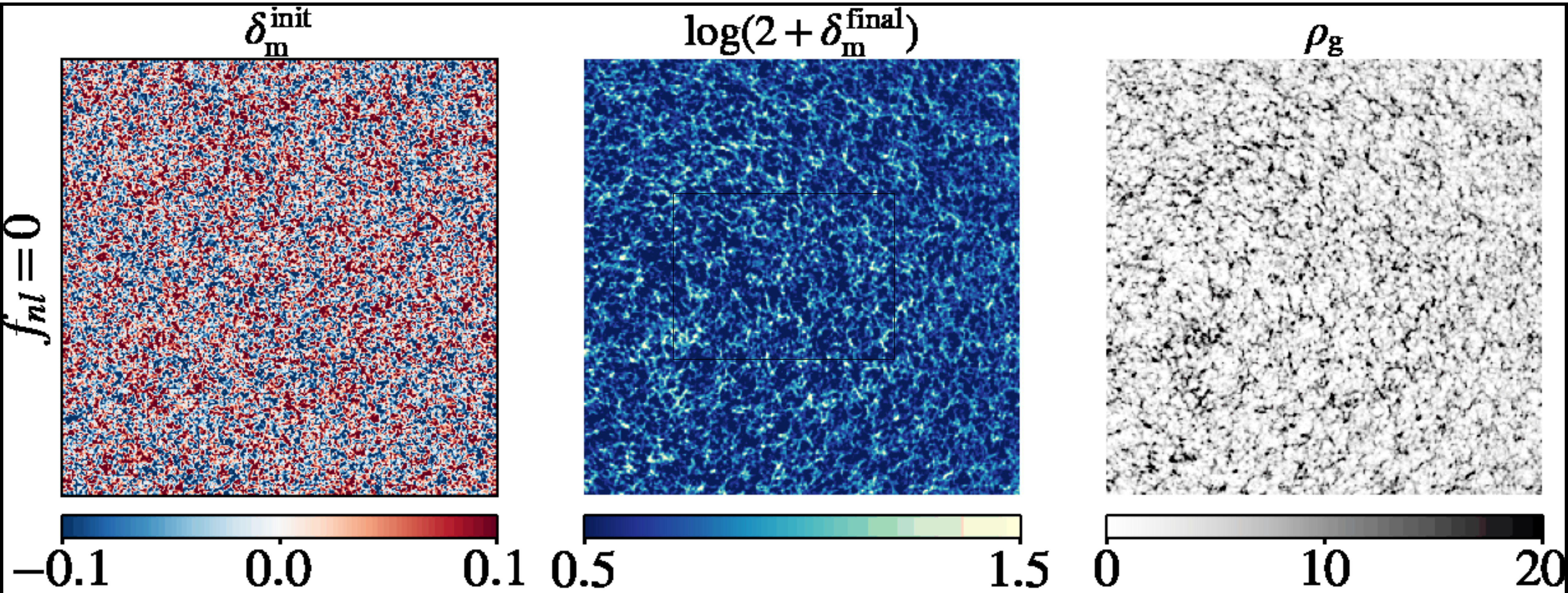
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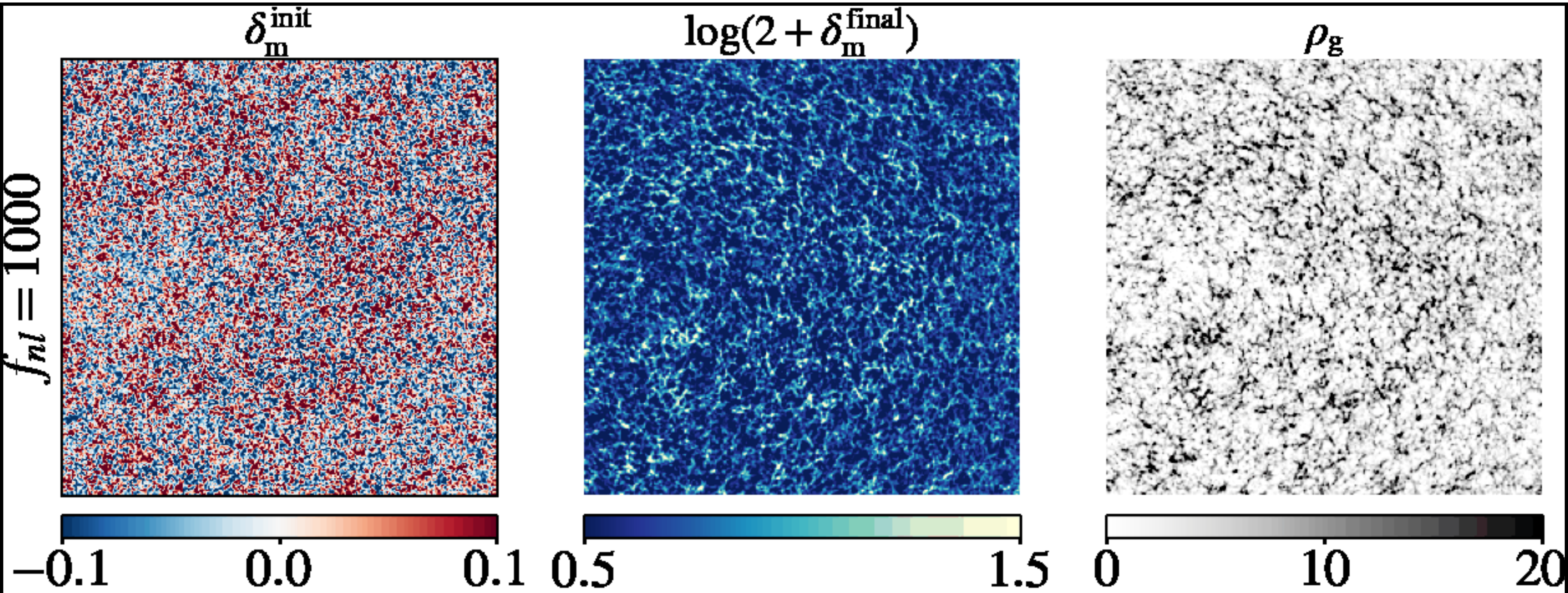
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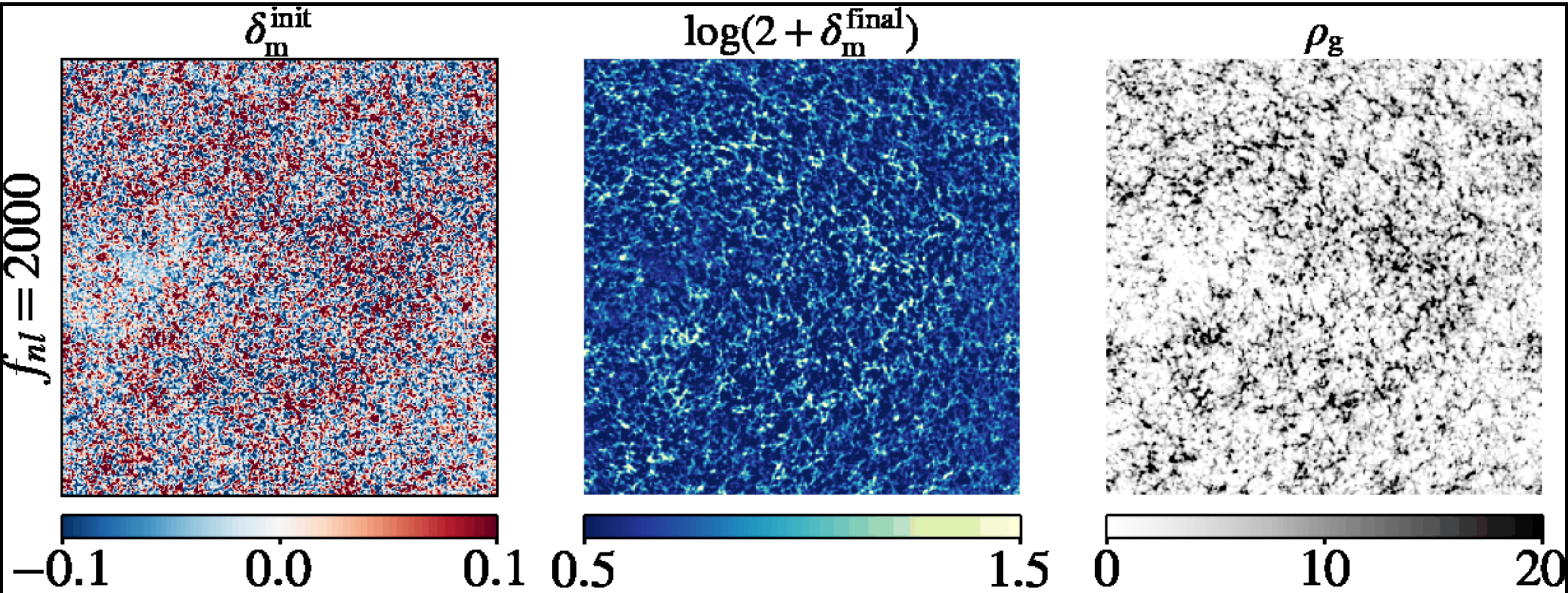
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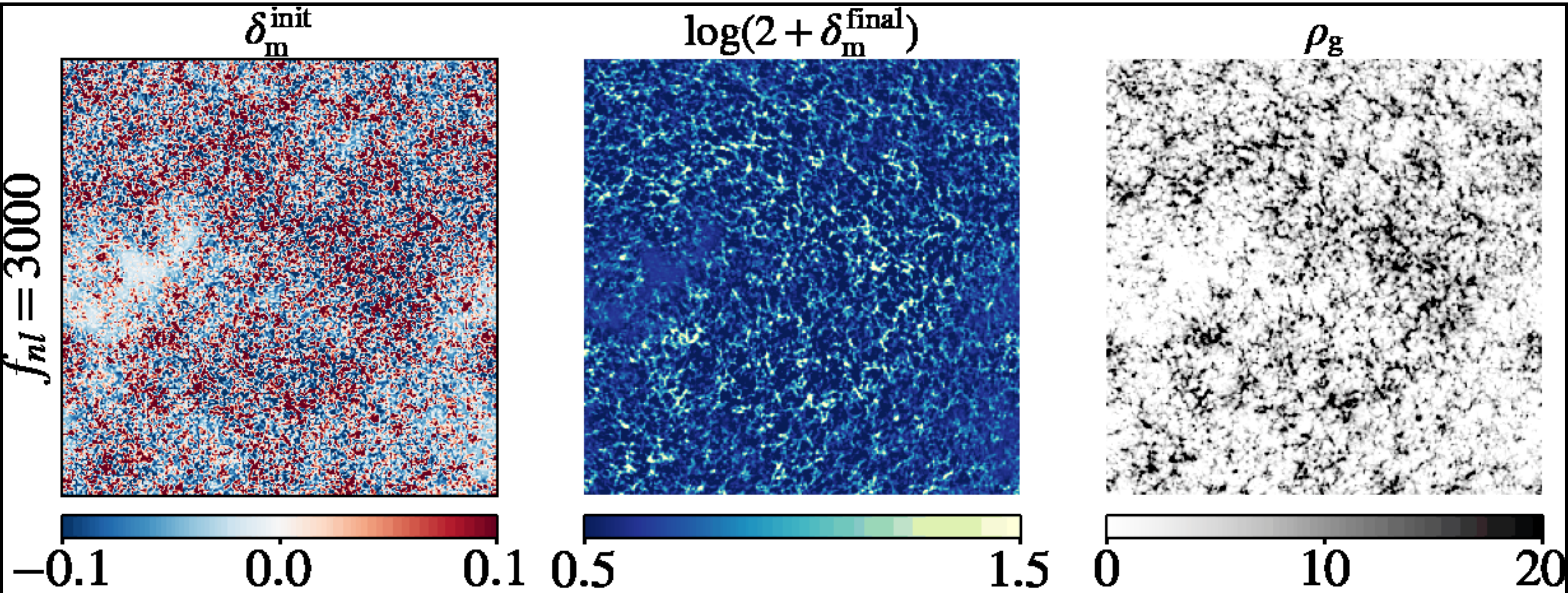


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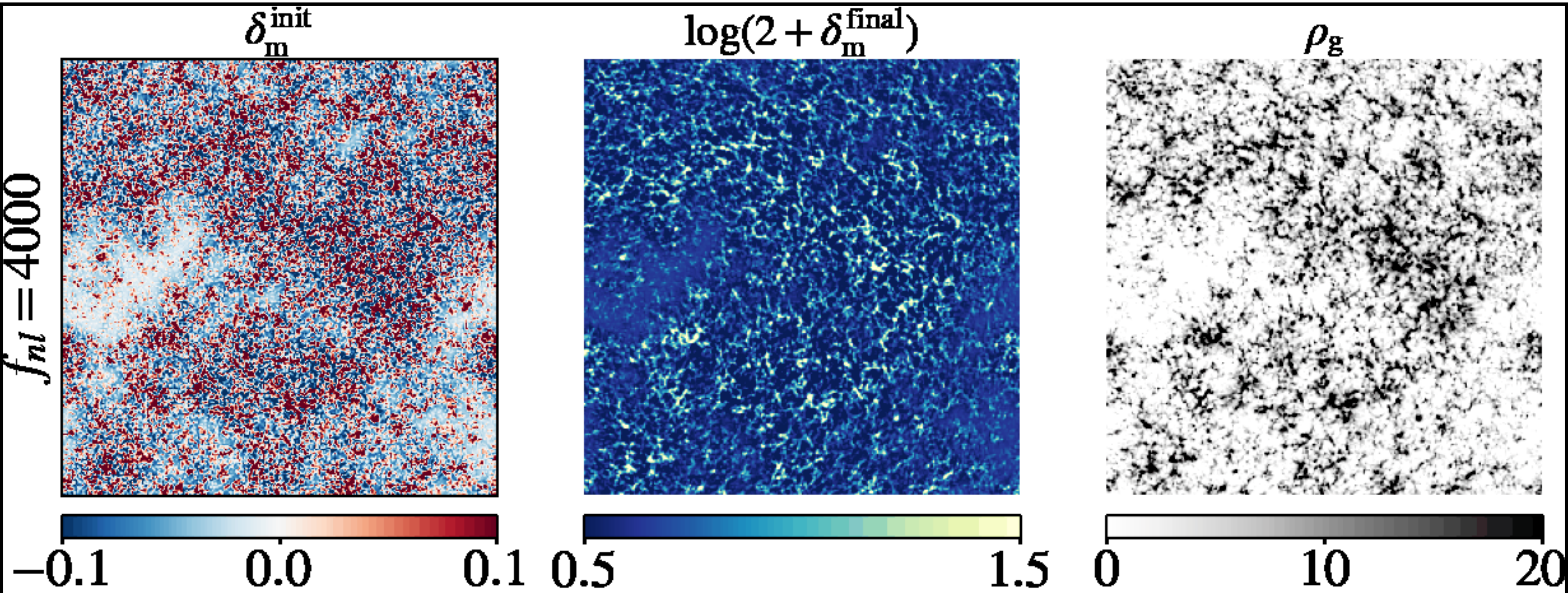




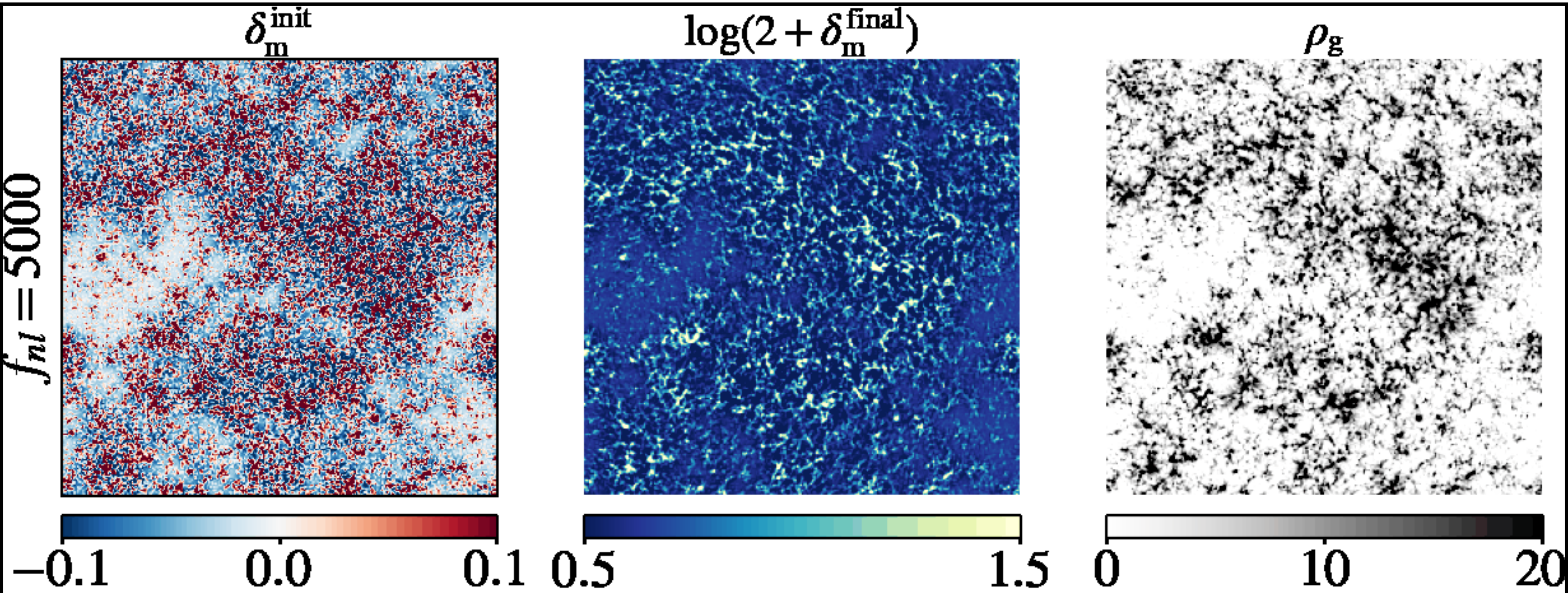
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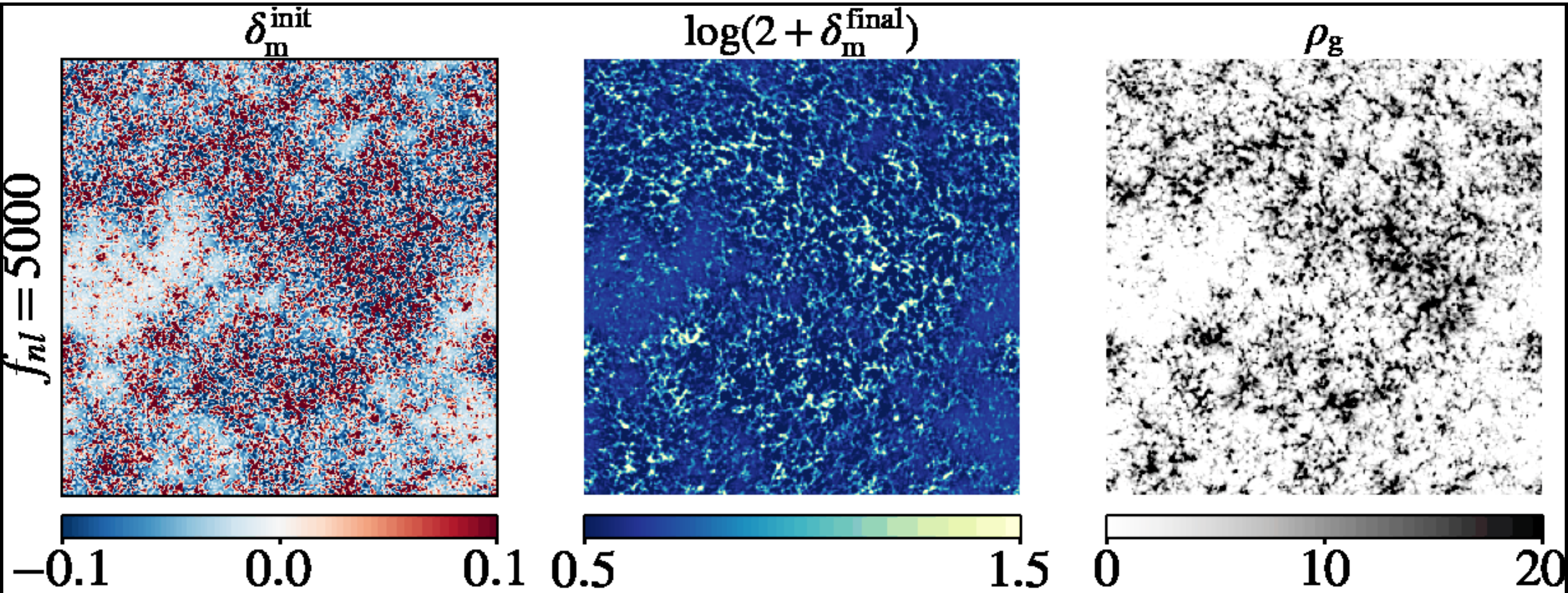
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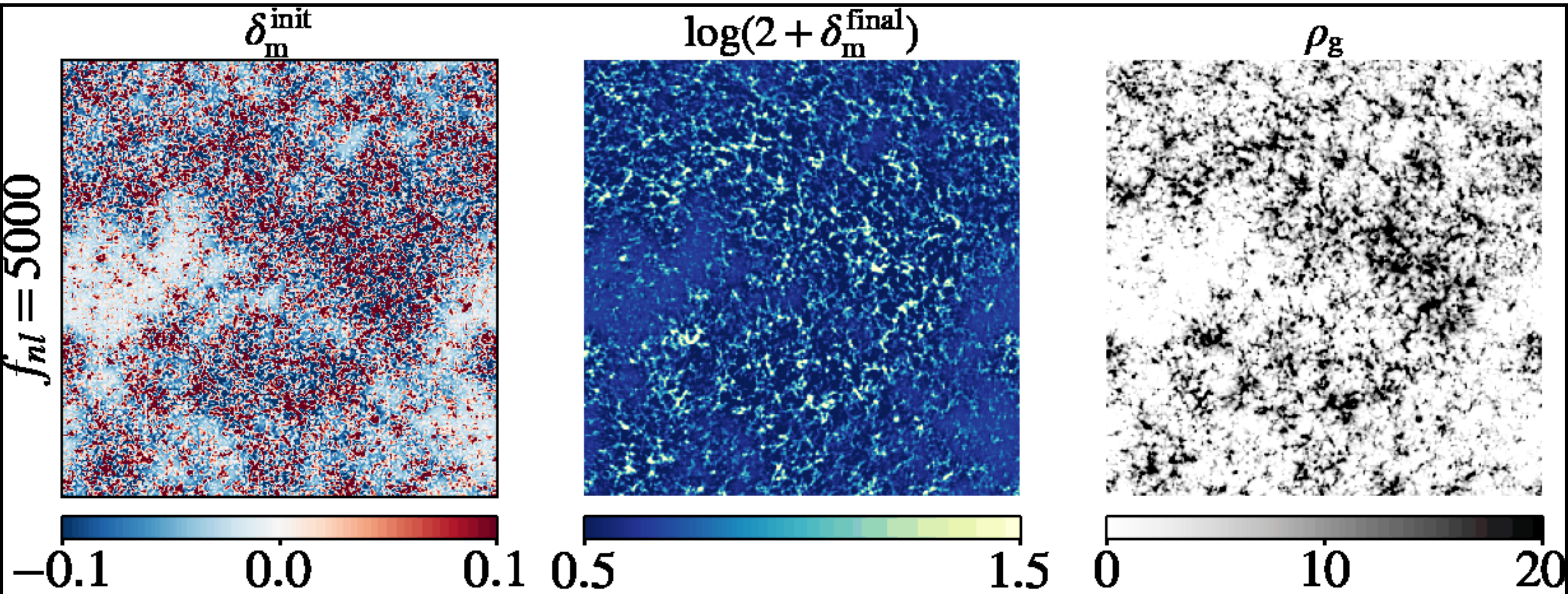


# How does $f_{nl}$ affect the cosmic matter field?



**Summary statistics:**

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**Summary statistics:**

**Goal: *Fit the full cosmic field***

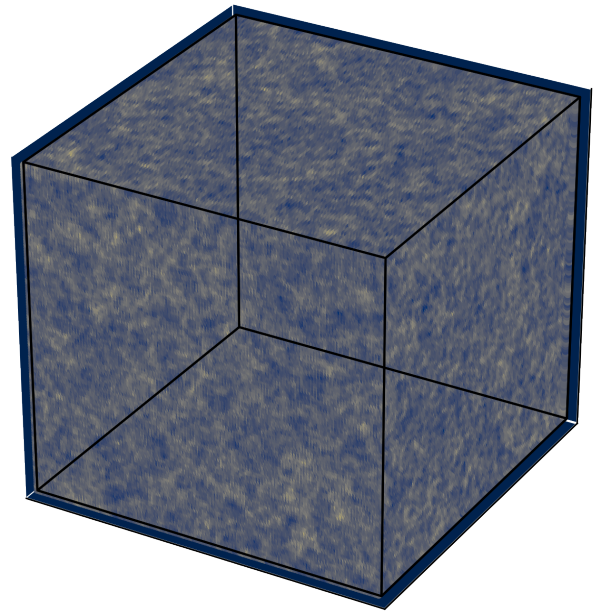
# Field-level inference

**1) Forward model**

**2) Statistical inference**

# Field-level inference

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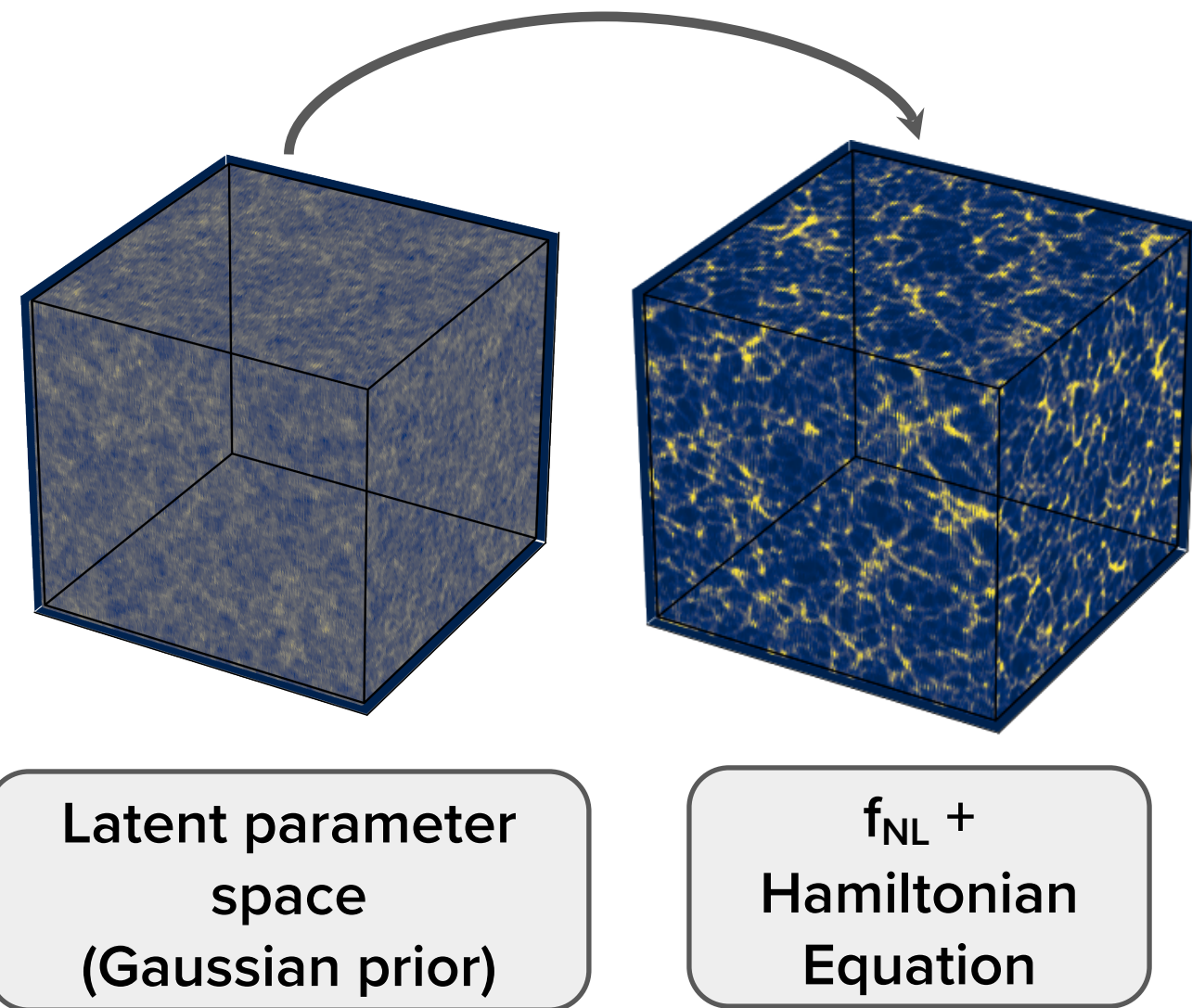


Latent parameter  
space  
(Gaussian prior)

## 2) Statistical inference

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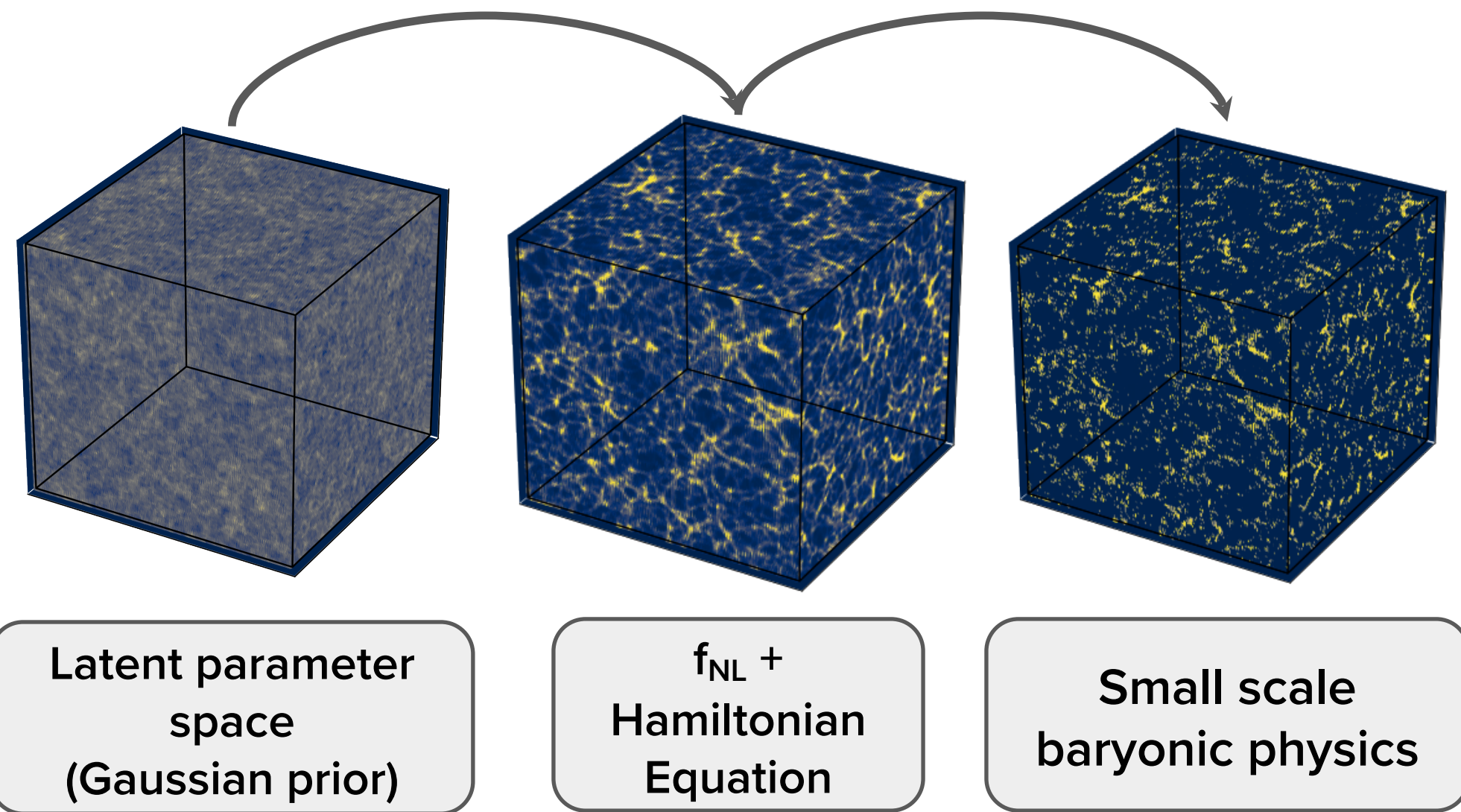


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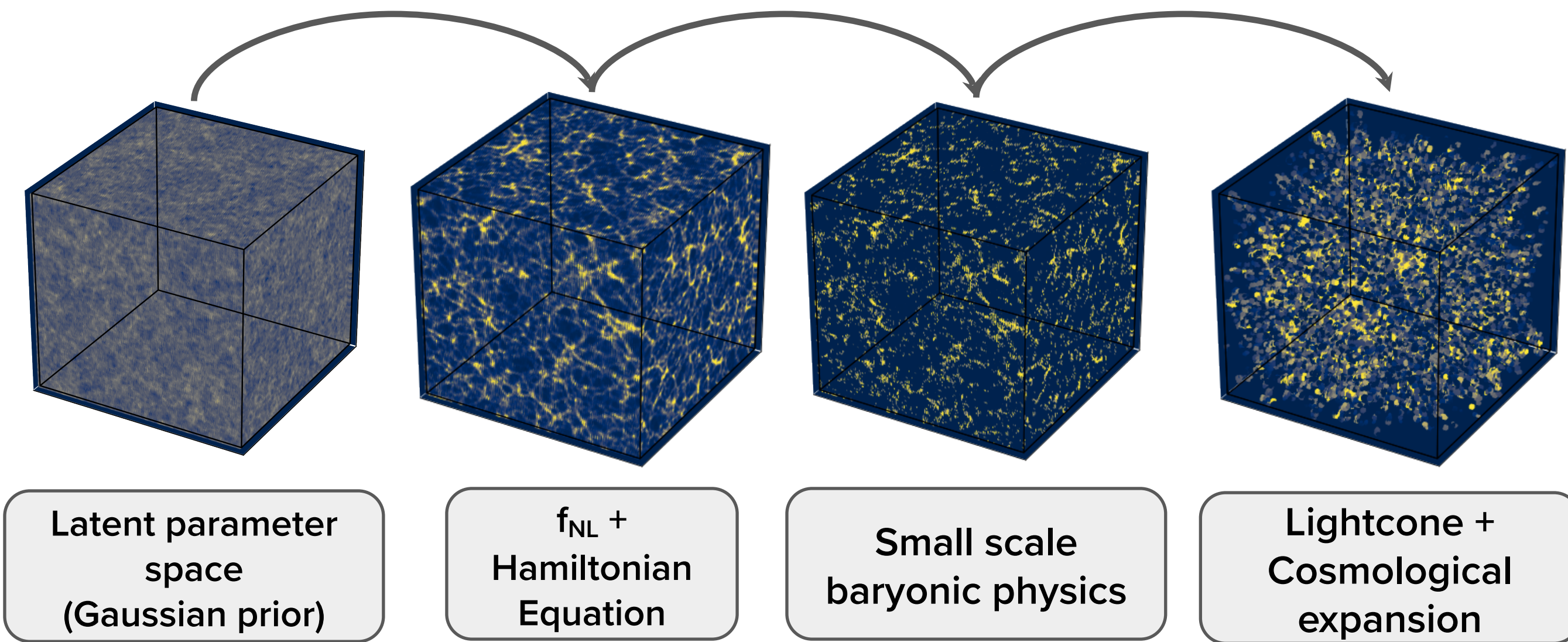
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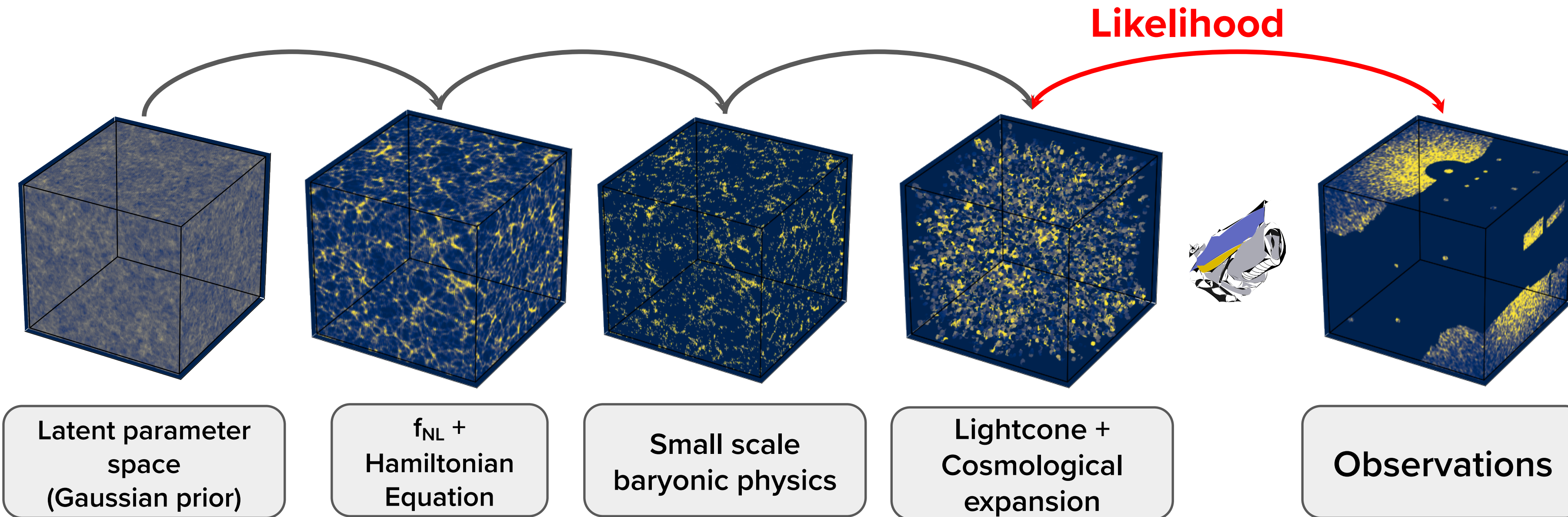
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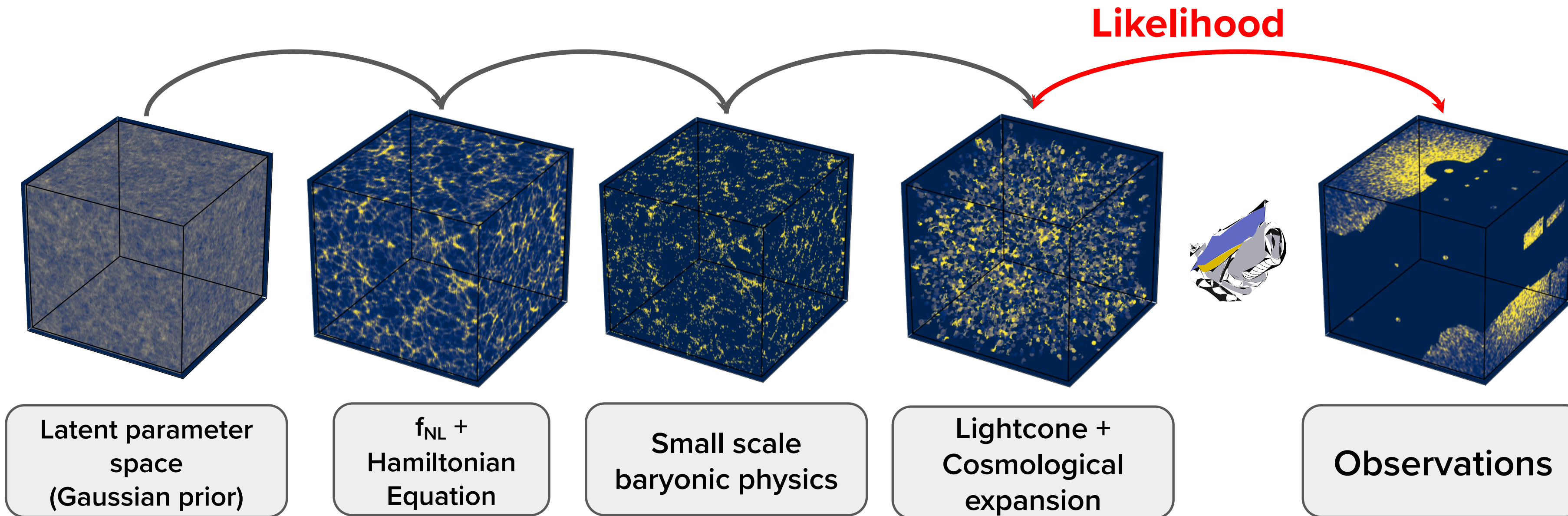
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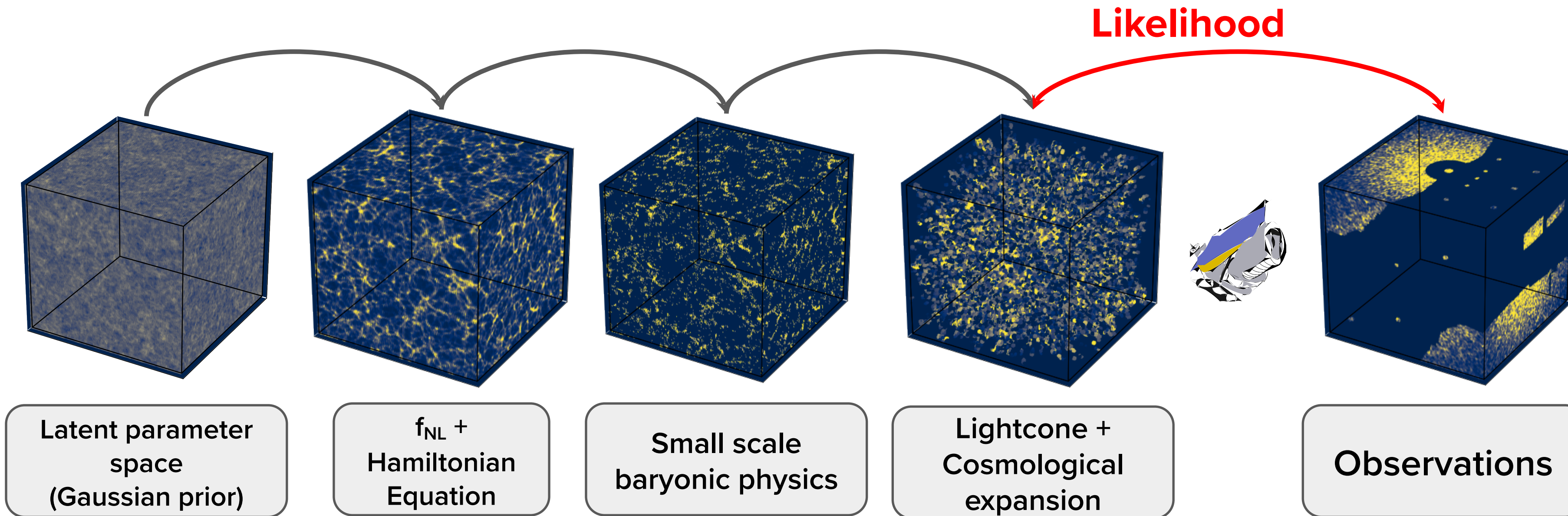


- Hierarchical Bayesian framework

## 2) Statistical inference

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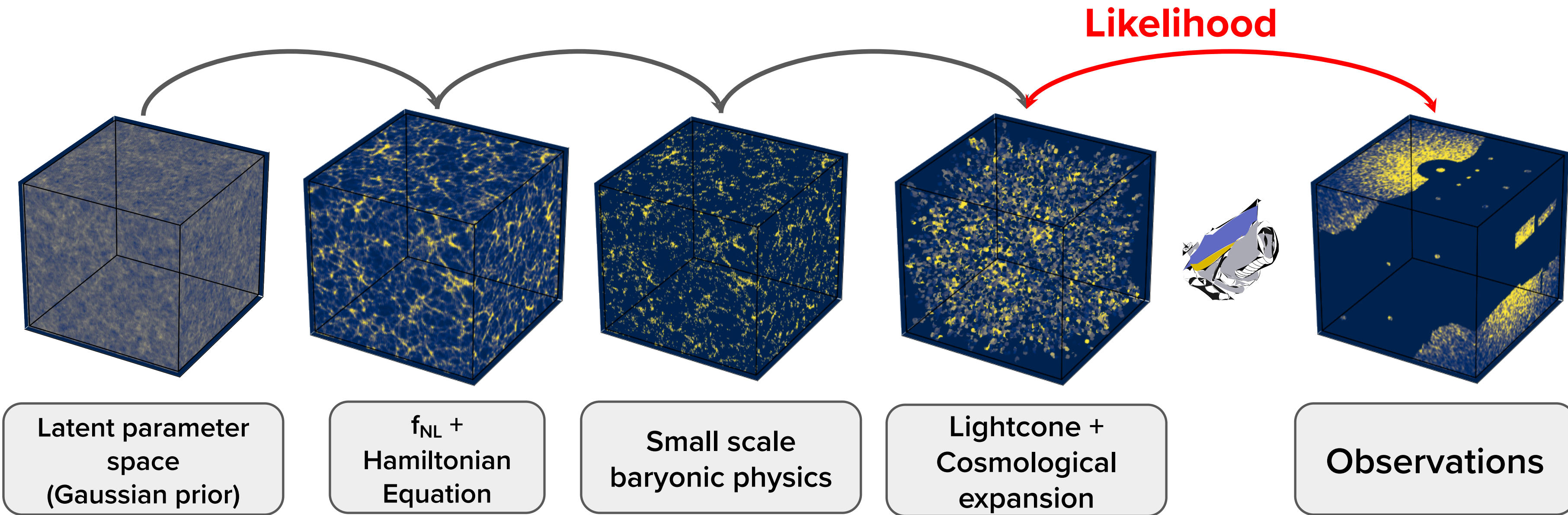


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- Explicit likelihood

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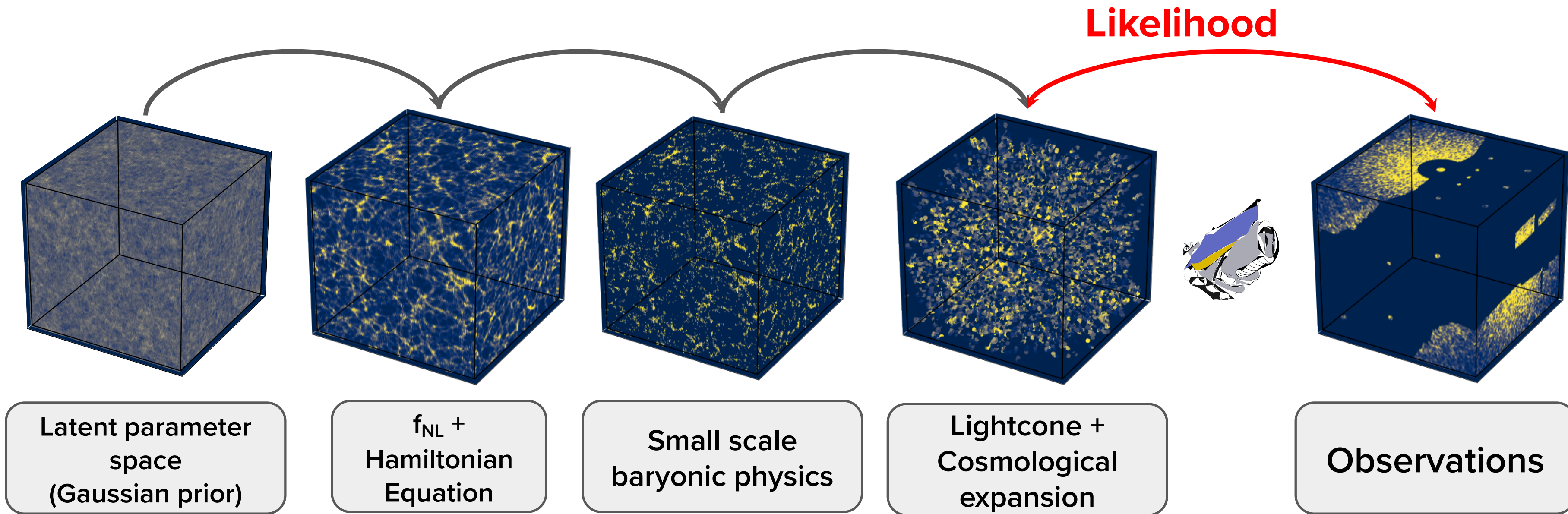


- Hierarchical Bayesian framework
- Explicit likelihood
- Differentiable data model at the field level

## 2) Statistical inference

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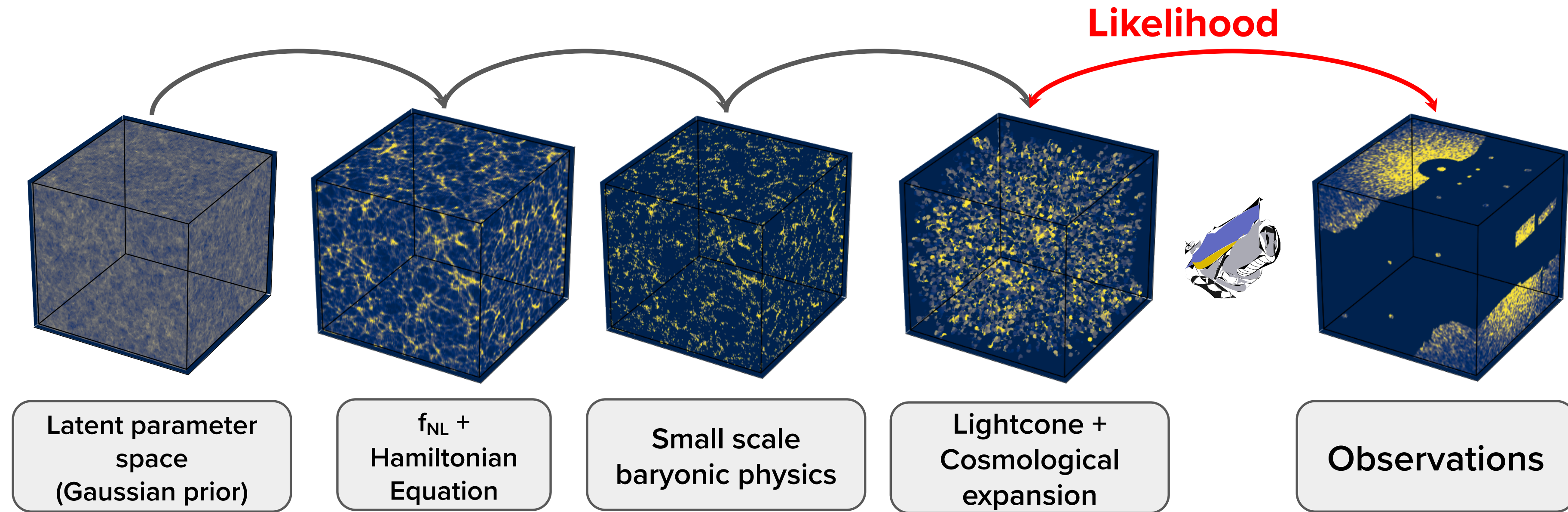


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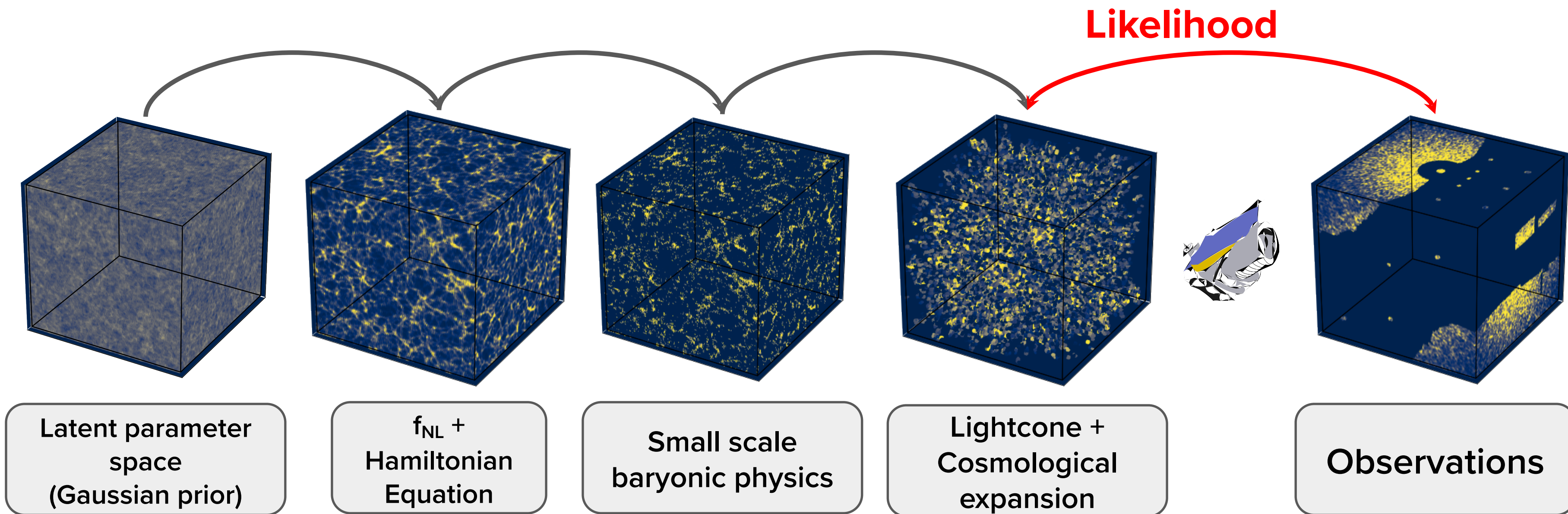
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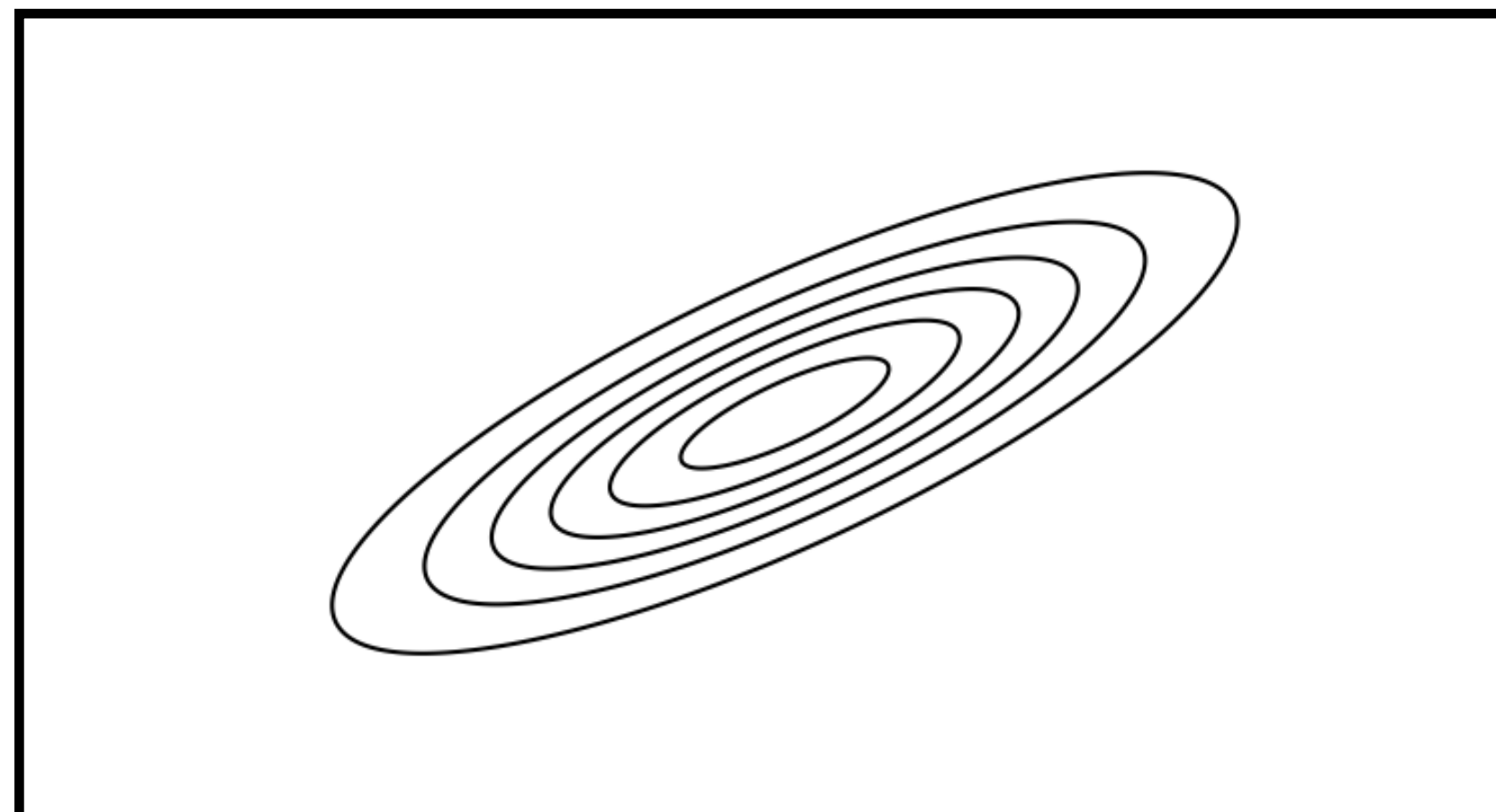


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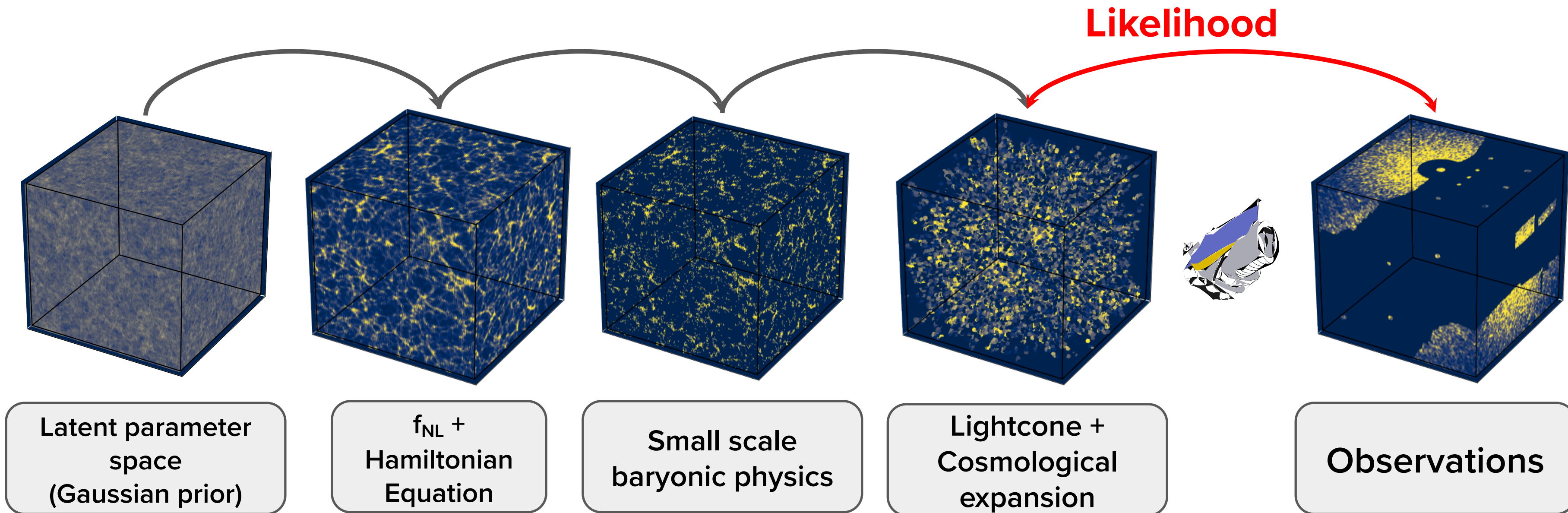
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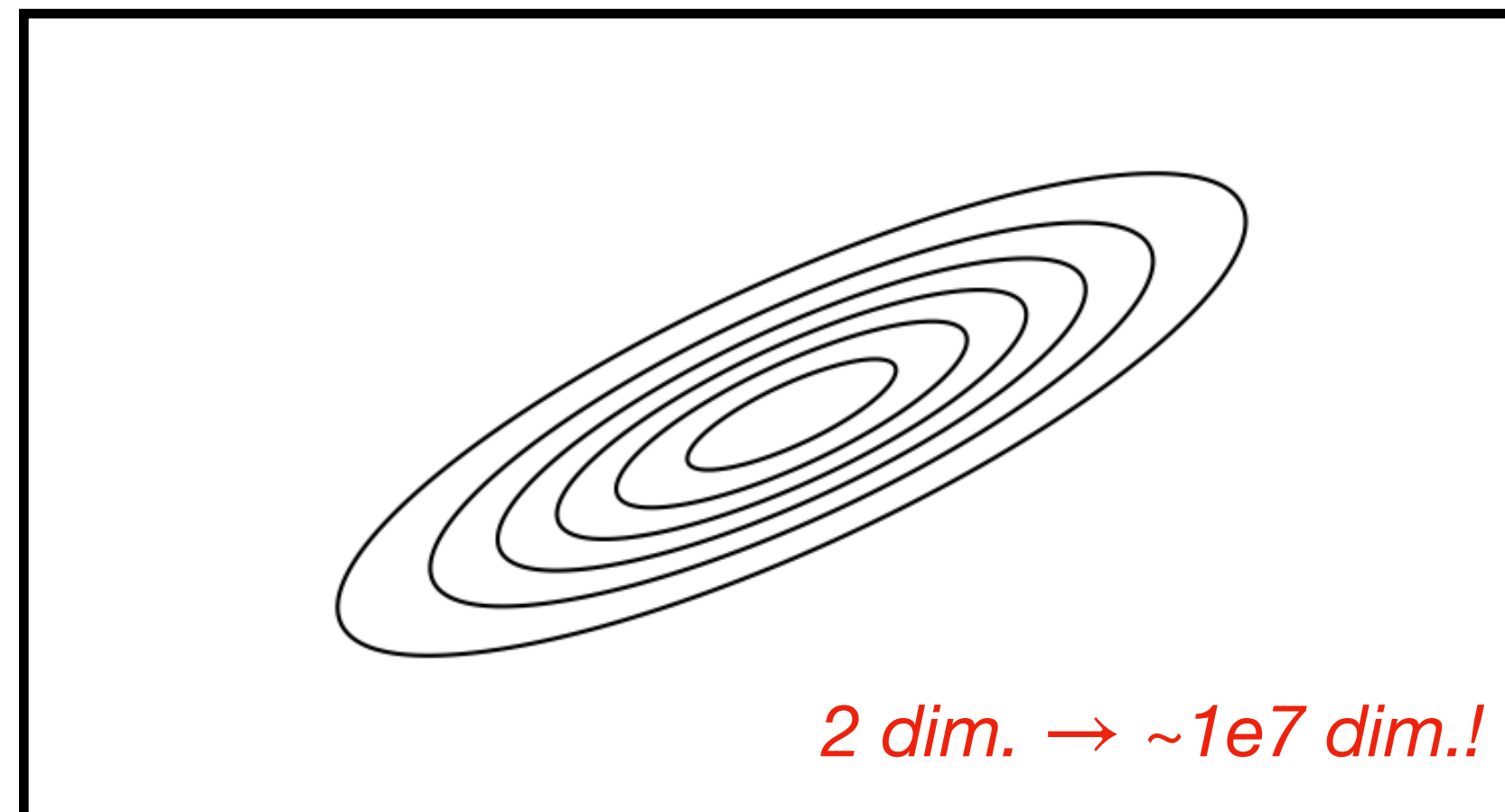


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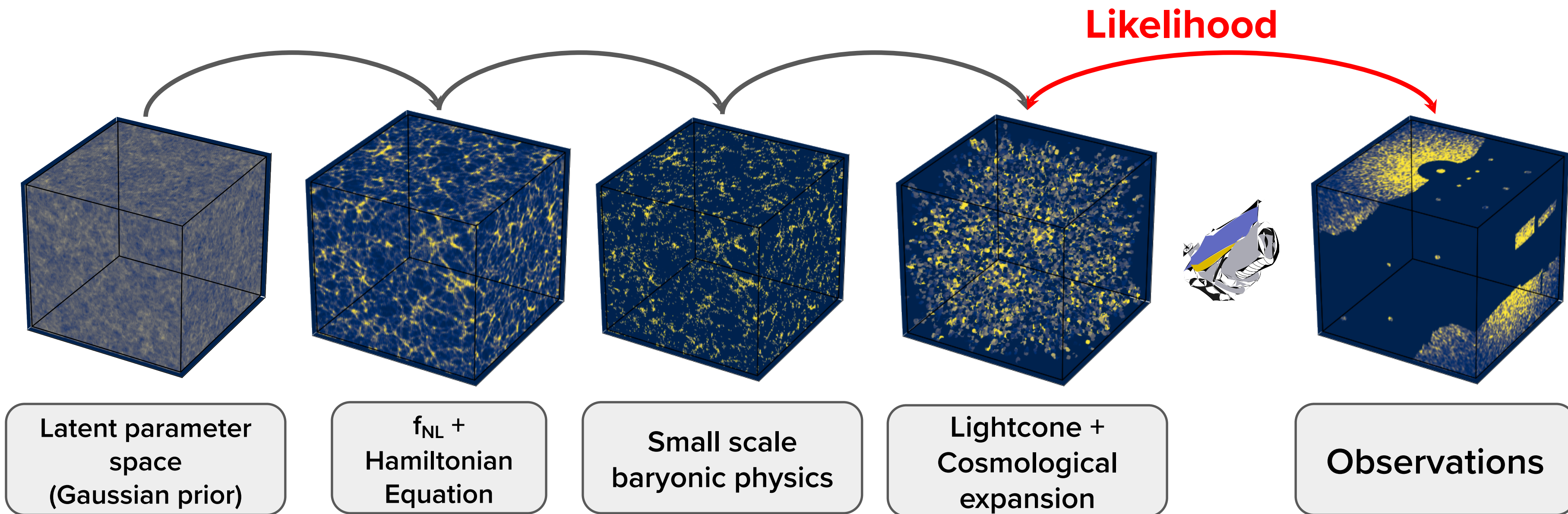
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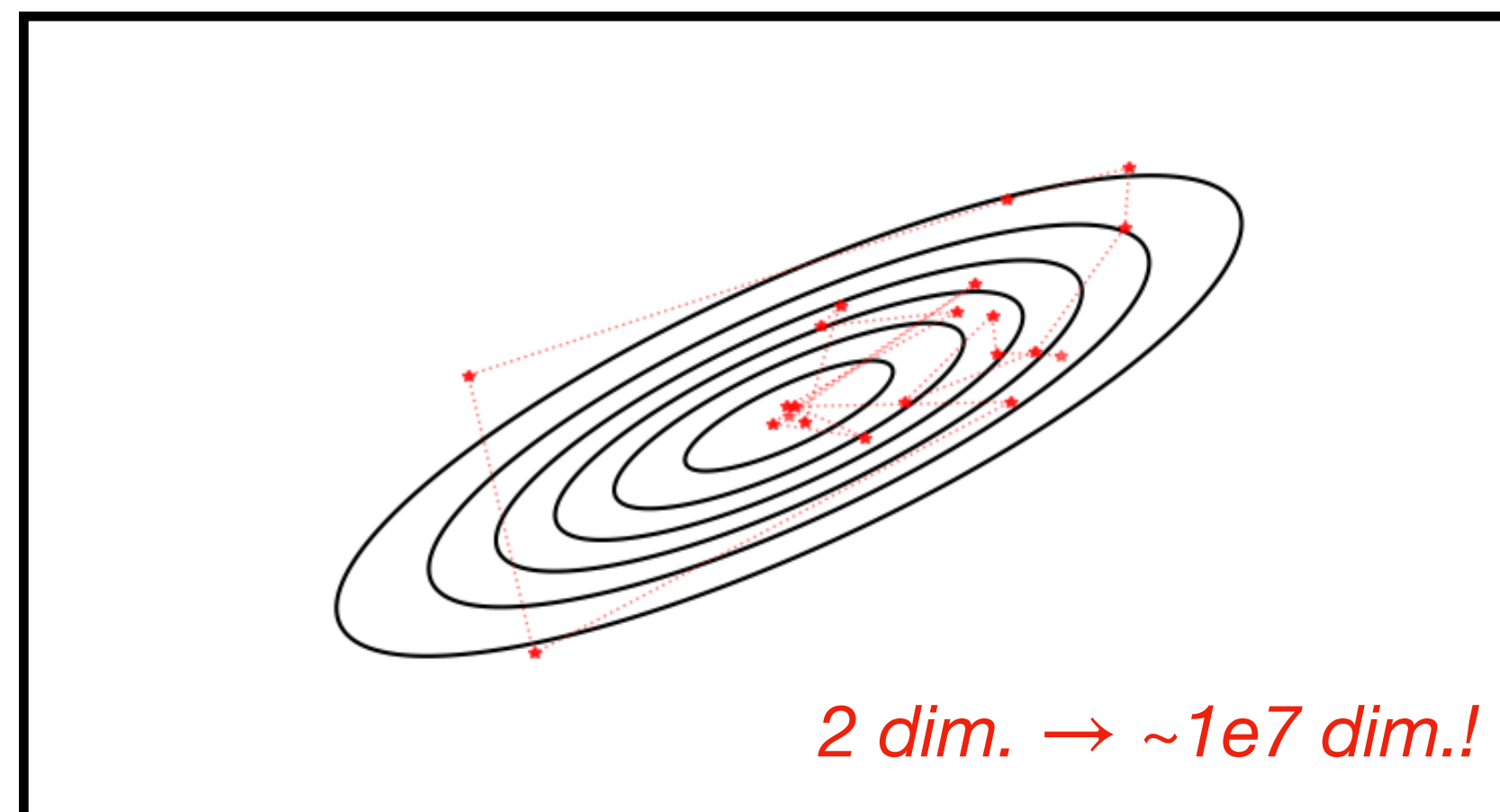


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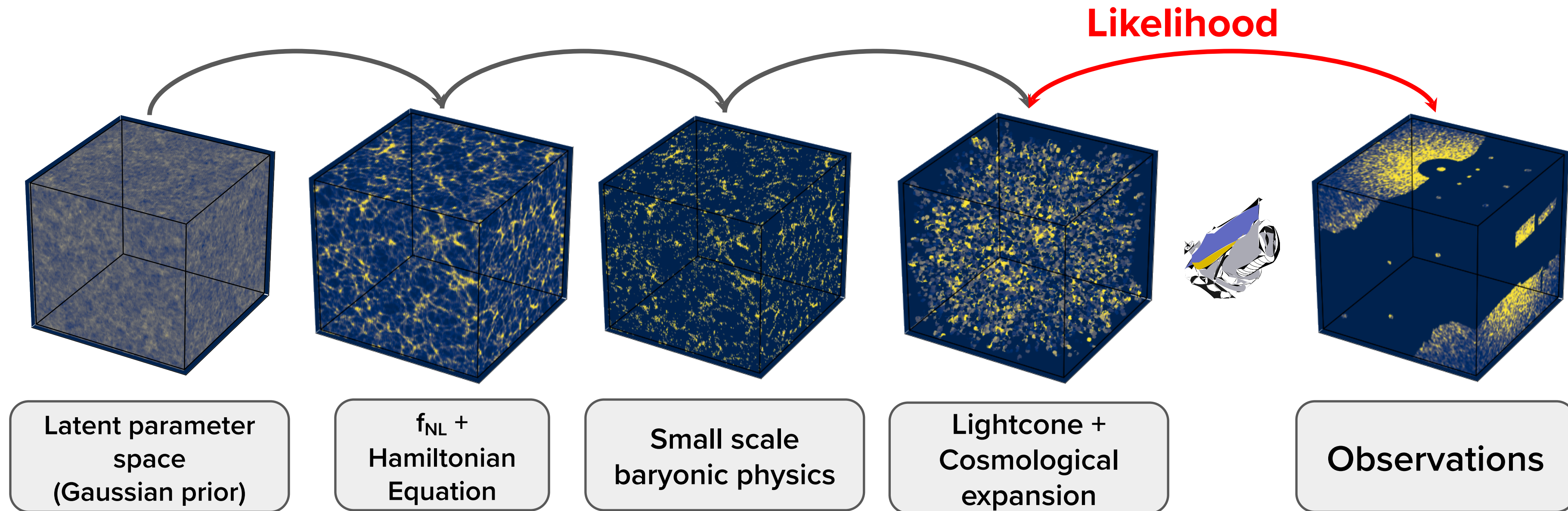
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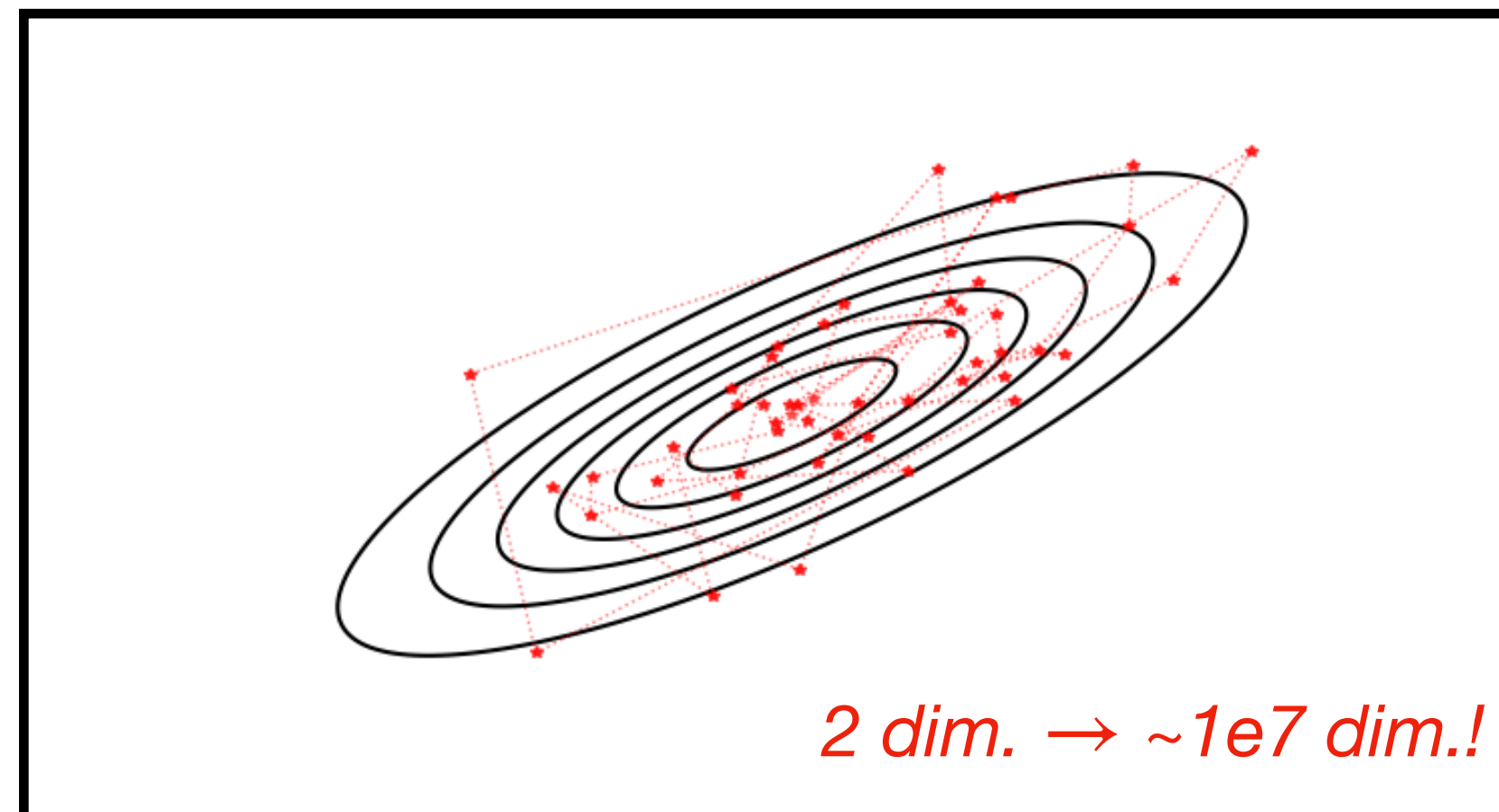


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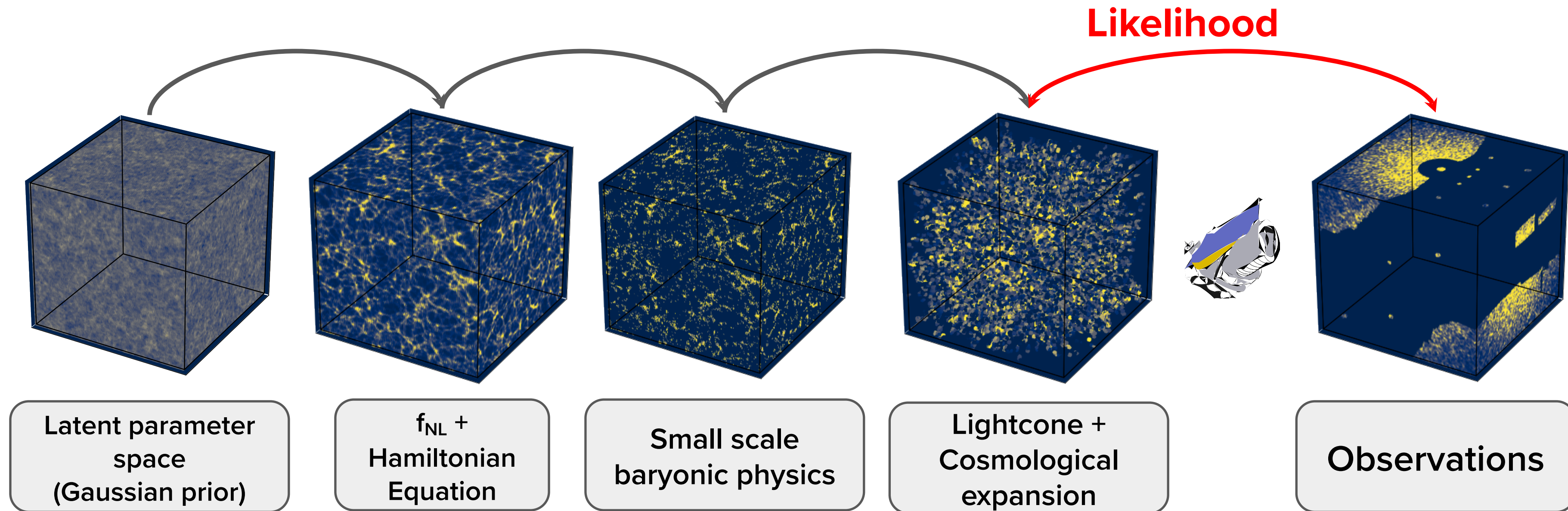
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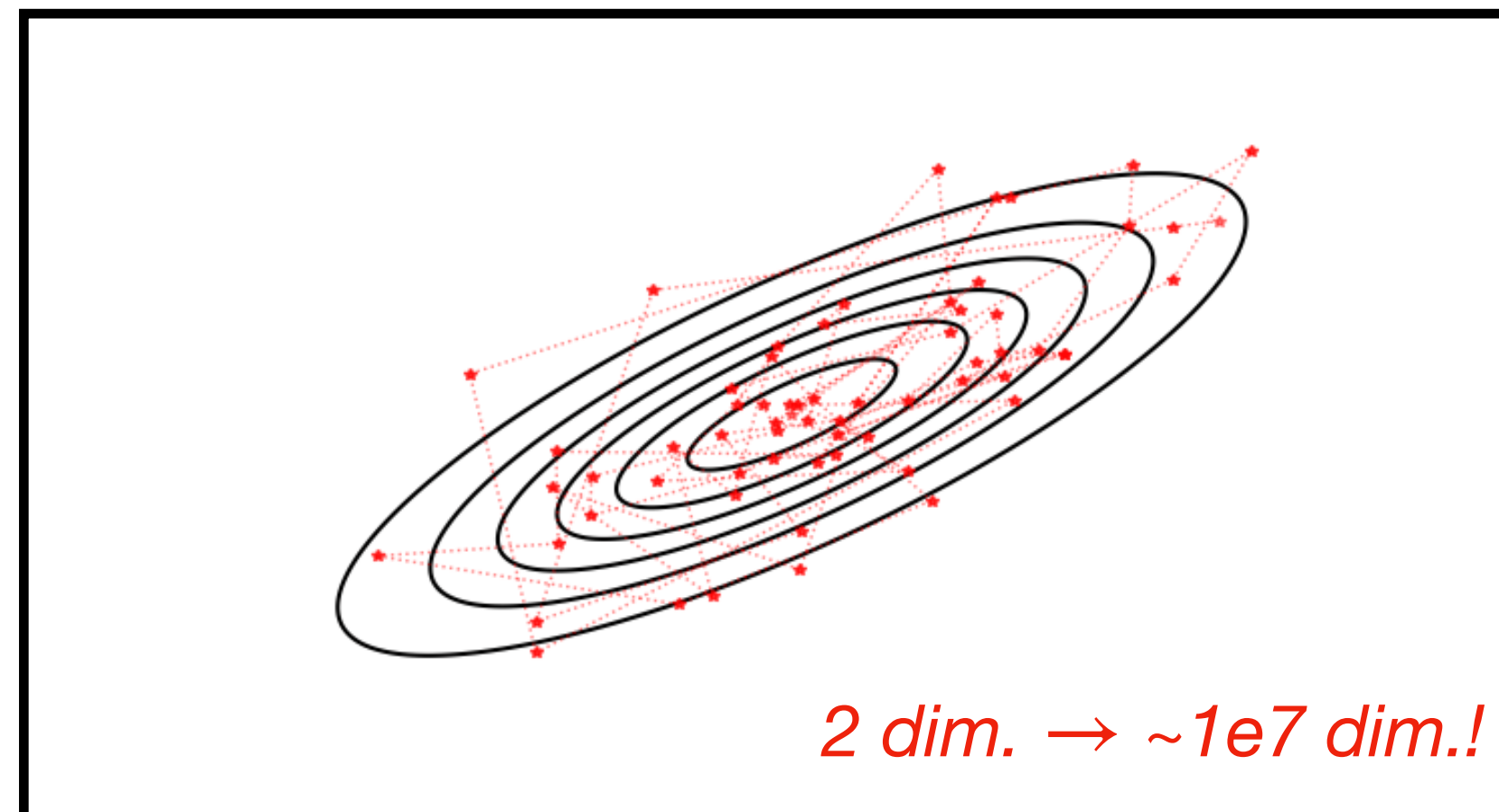


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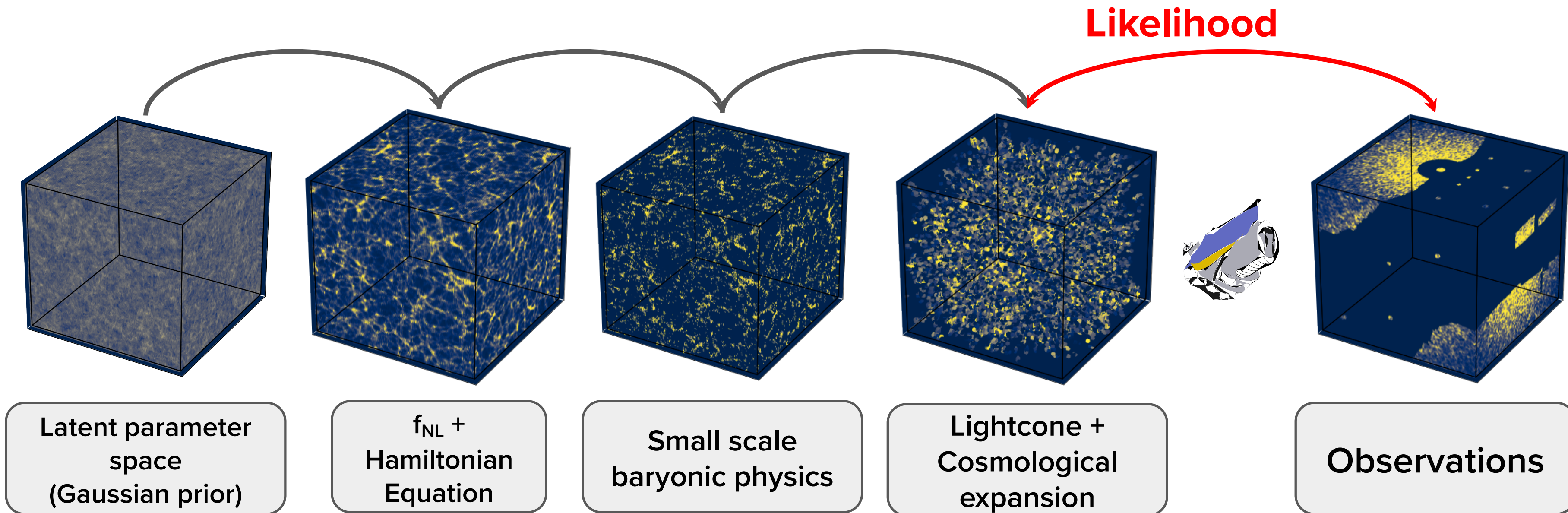
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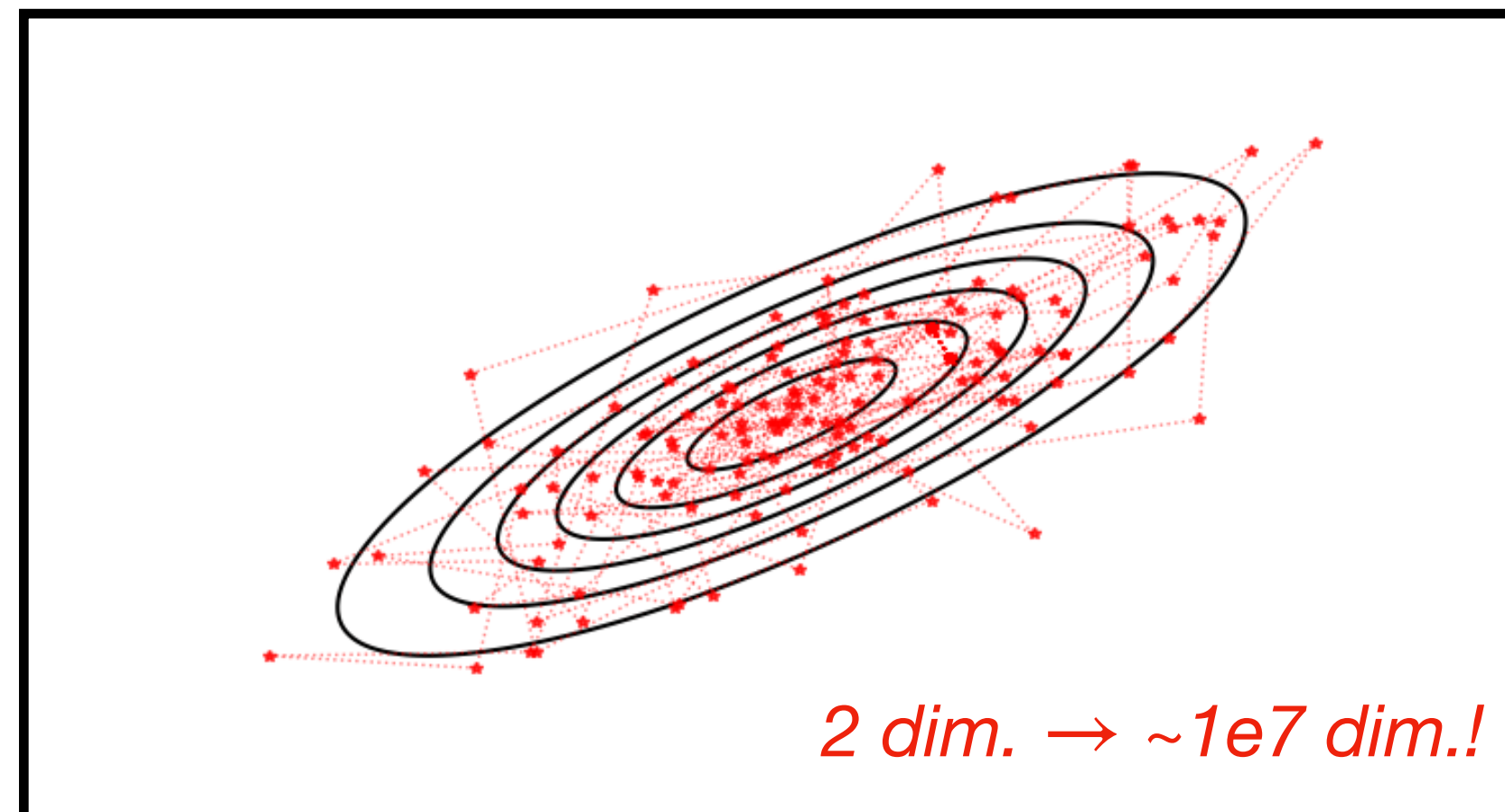


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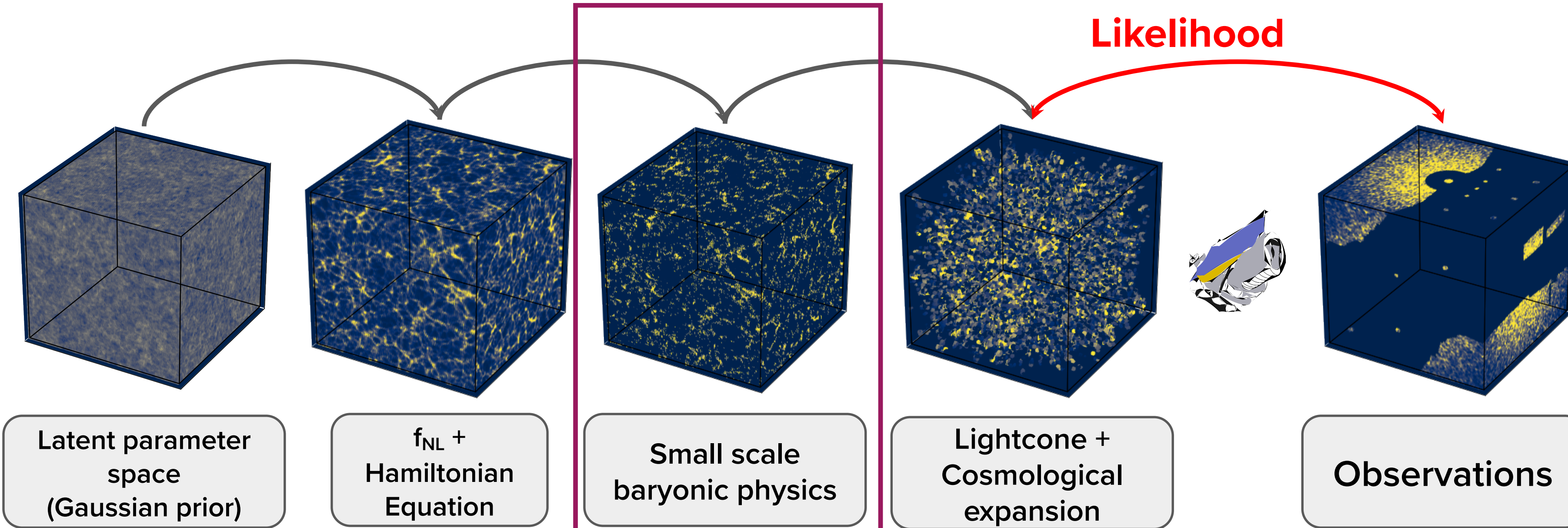
### Key Features of Field-Level Inference

- Handle survey systematics
- Combine all probes
- Inference of initial conditions

# Field-level inference

## 1) Forward model

See Ludvig Doerer's talk

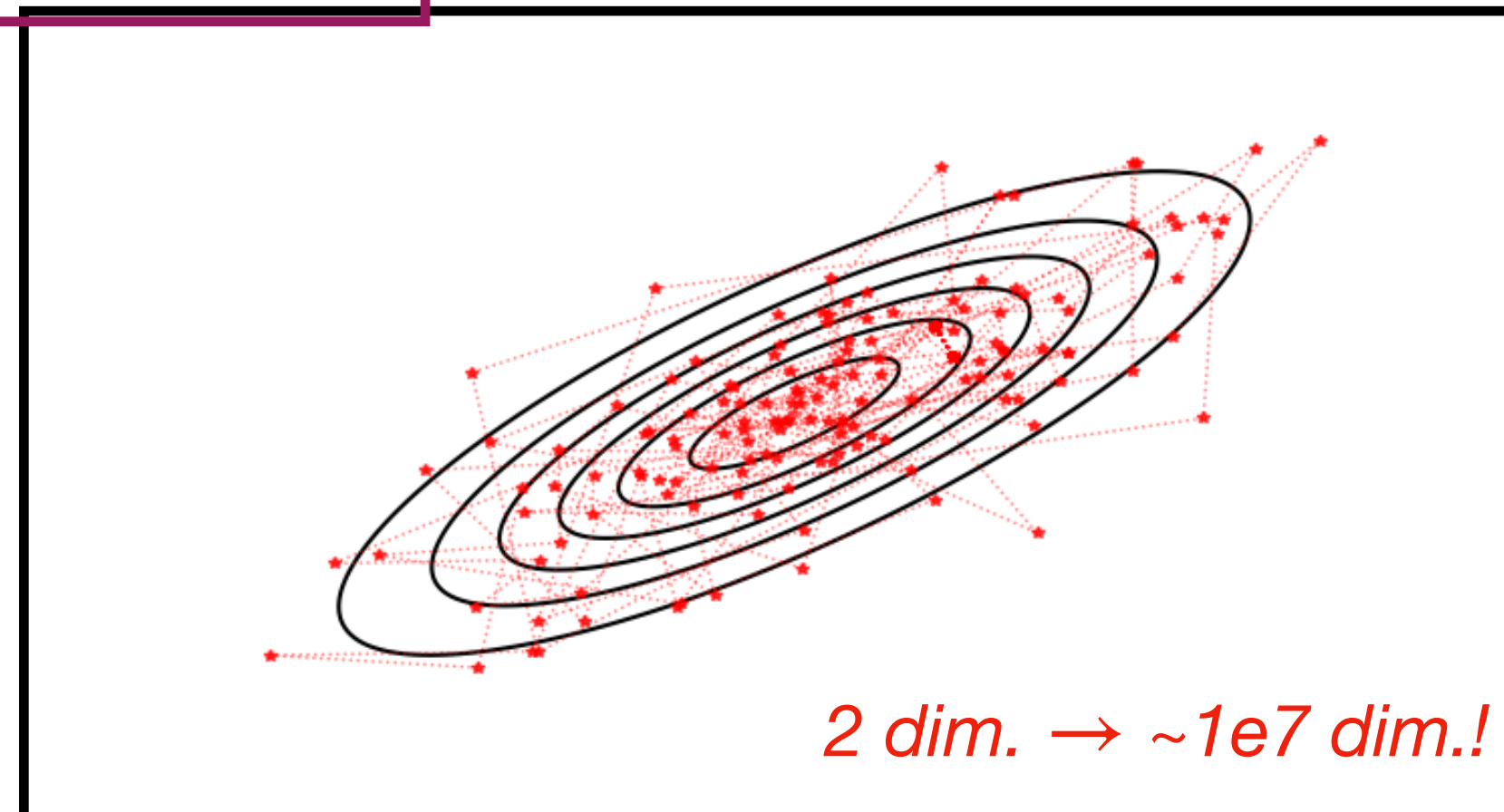


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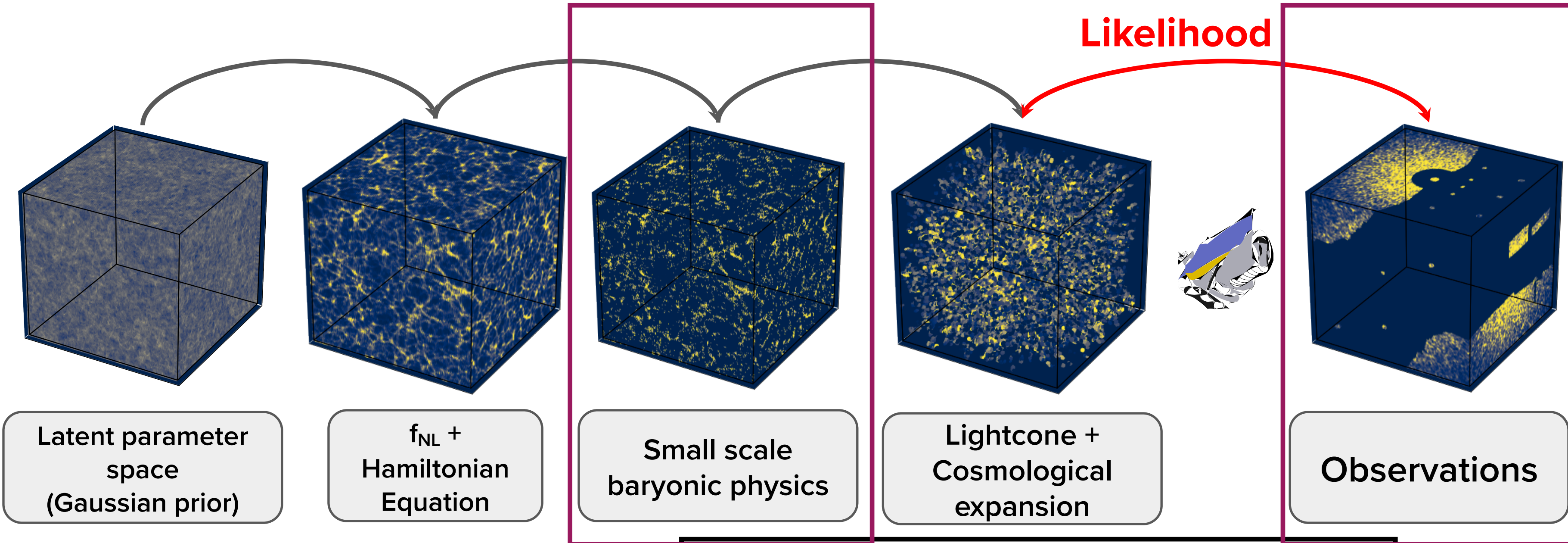
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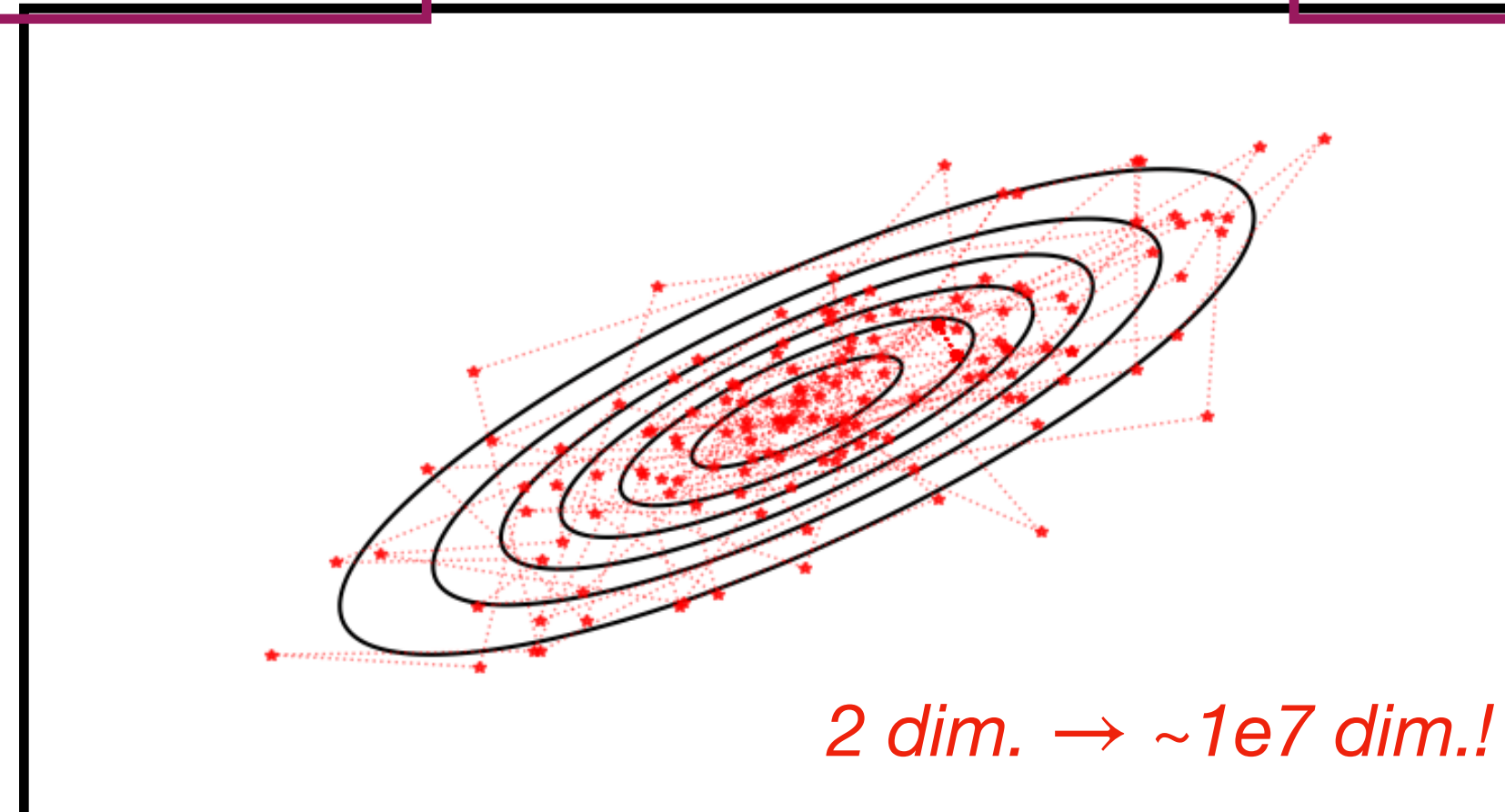


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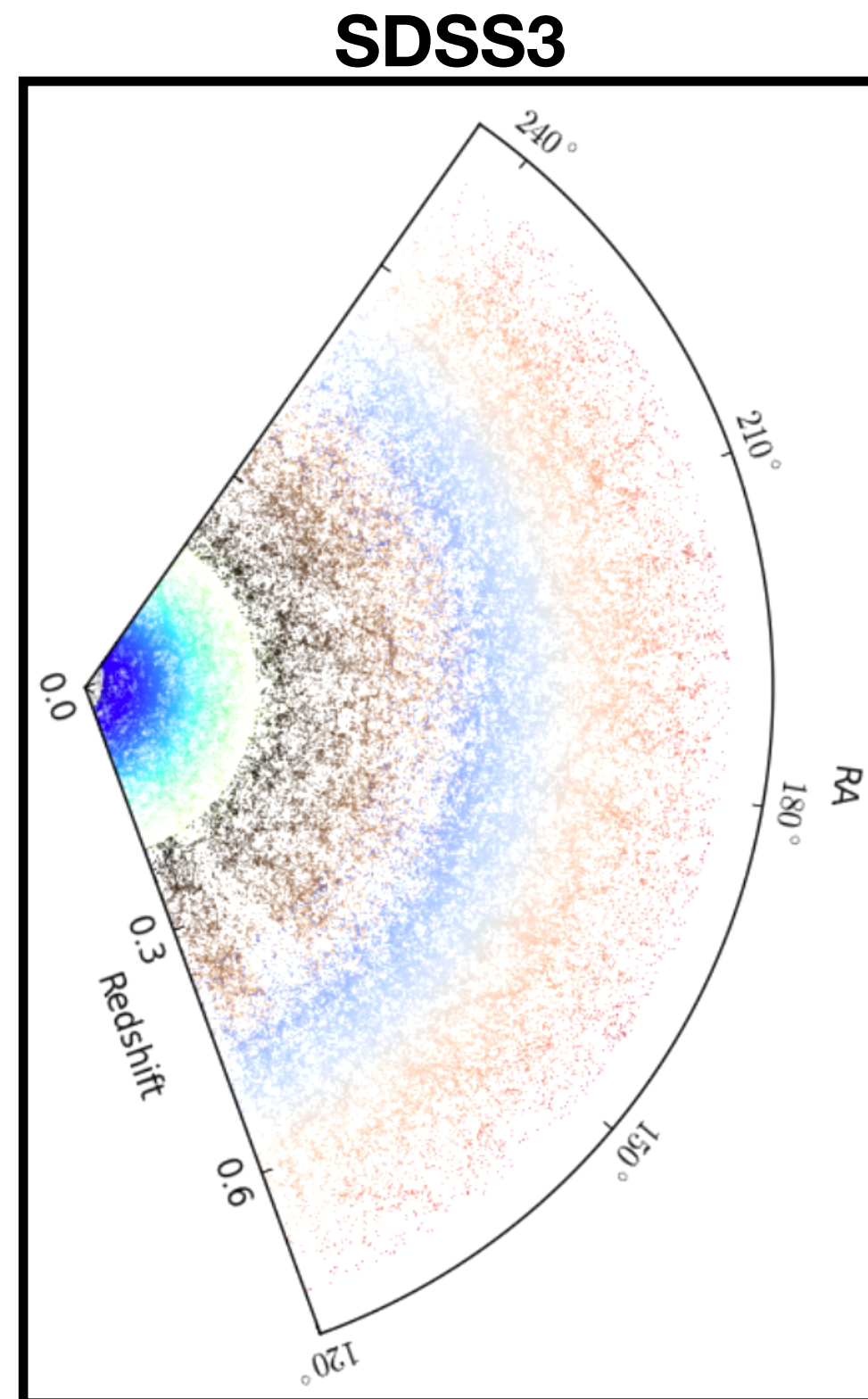
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# Proof-of-Concept

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**Figure Credit: Guilhem Lavaux**

# Proof-of-Concept

## Radial Selection

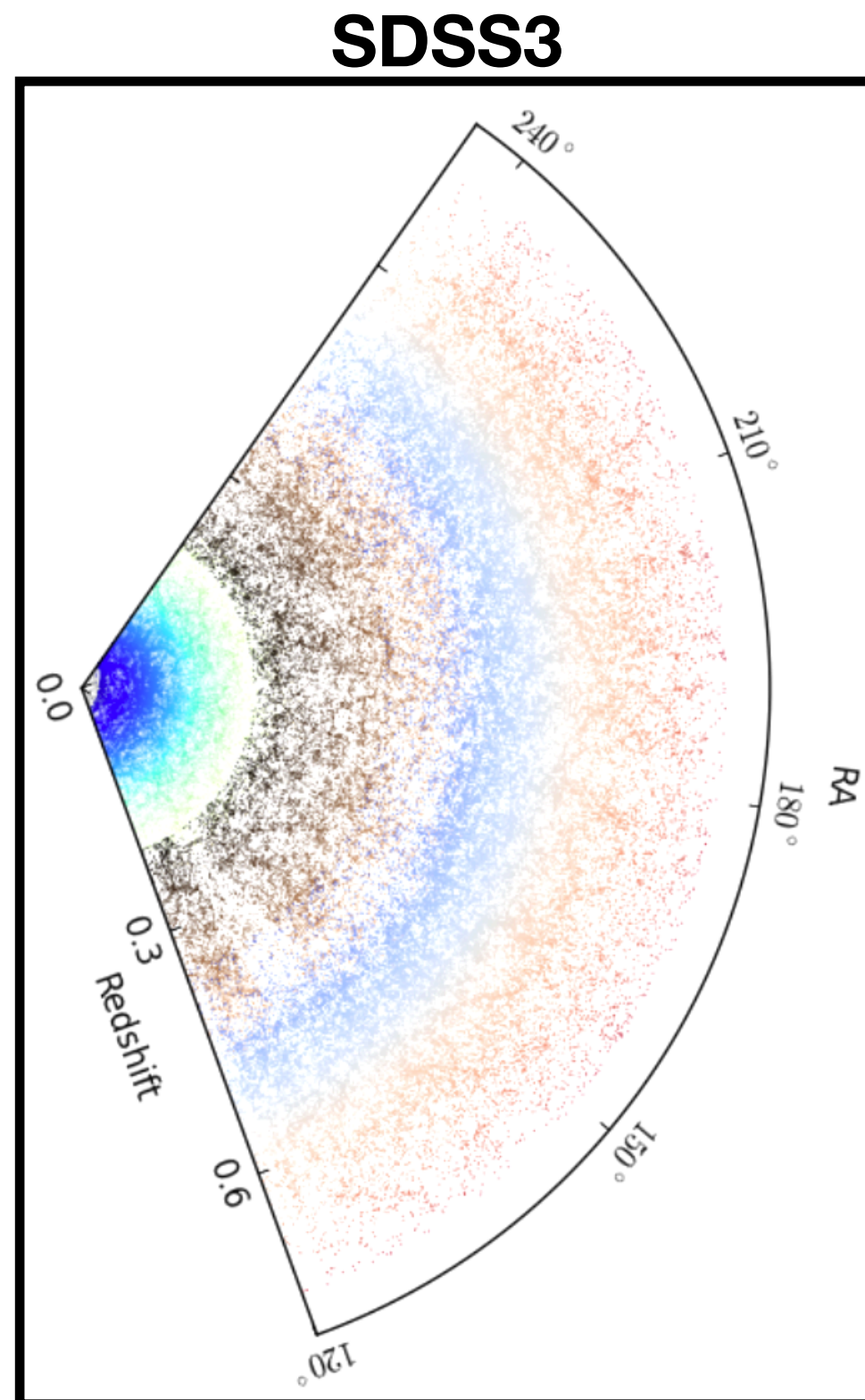
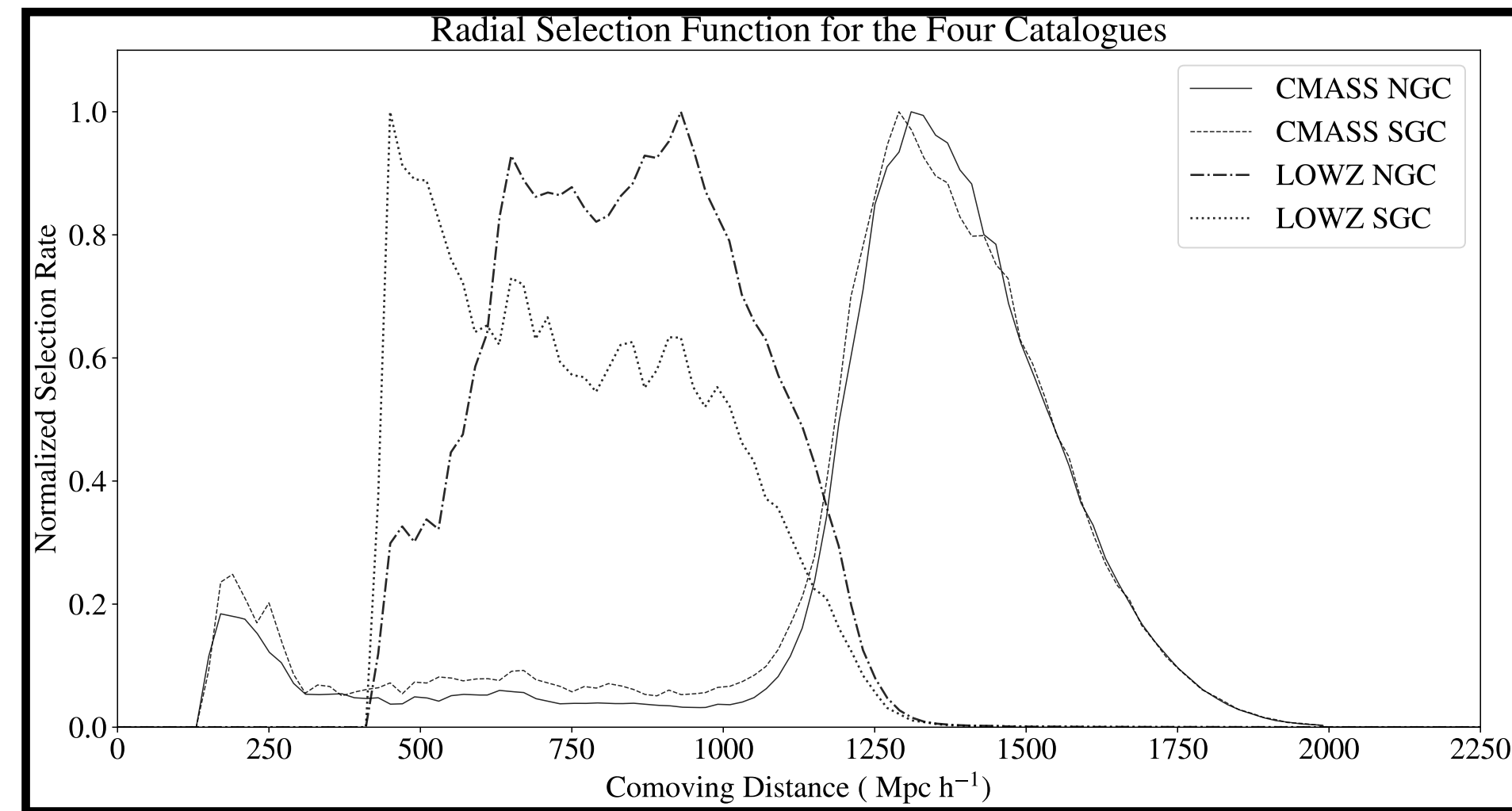


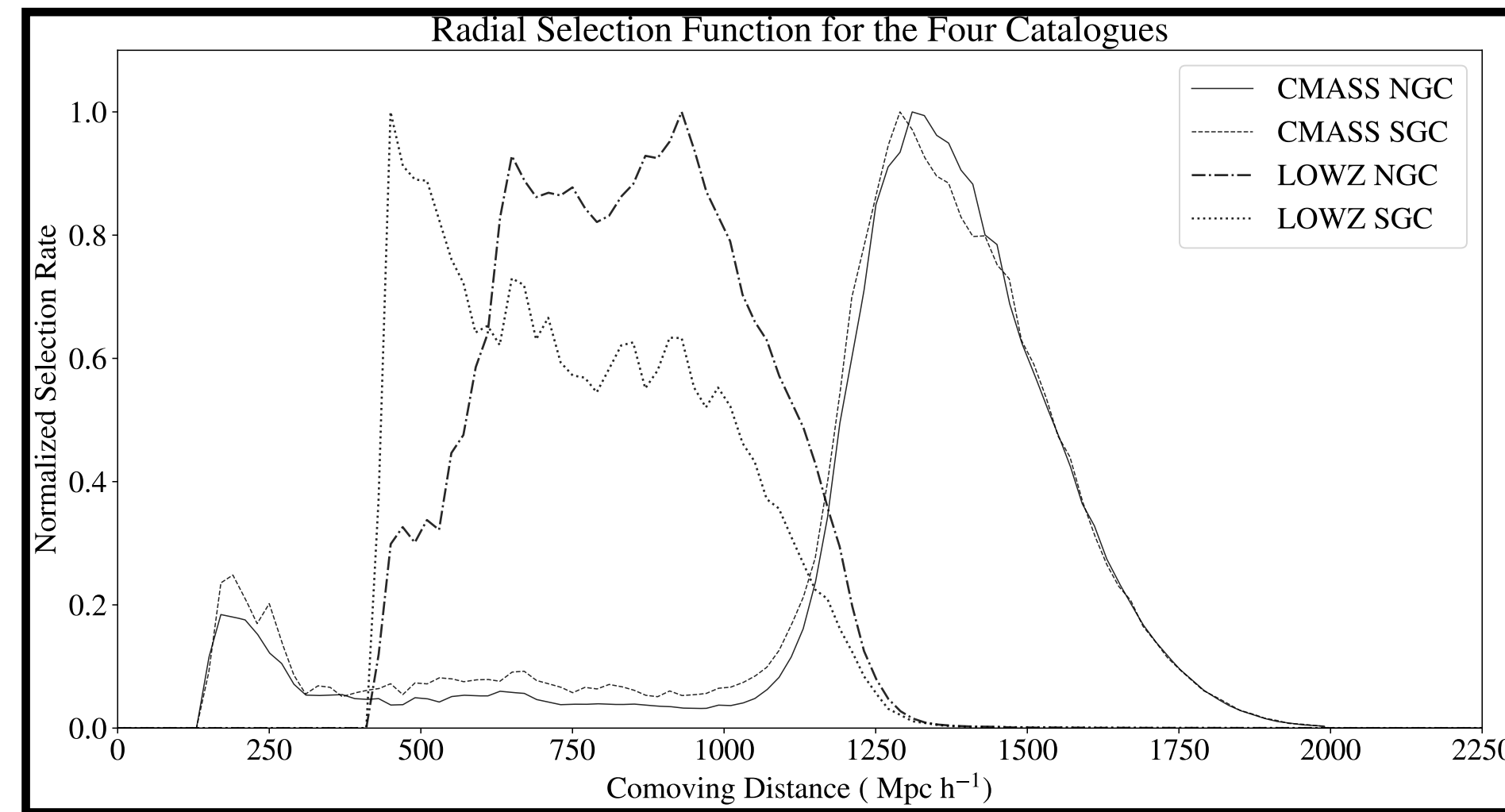
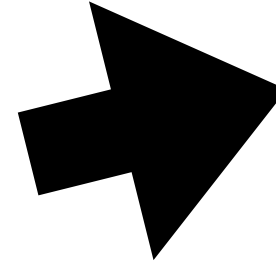
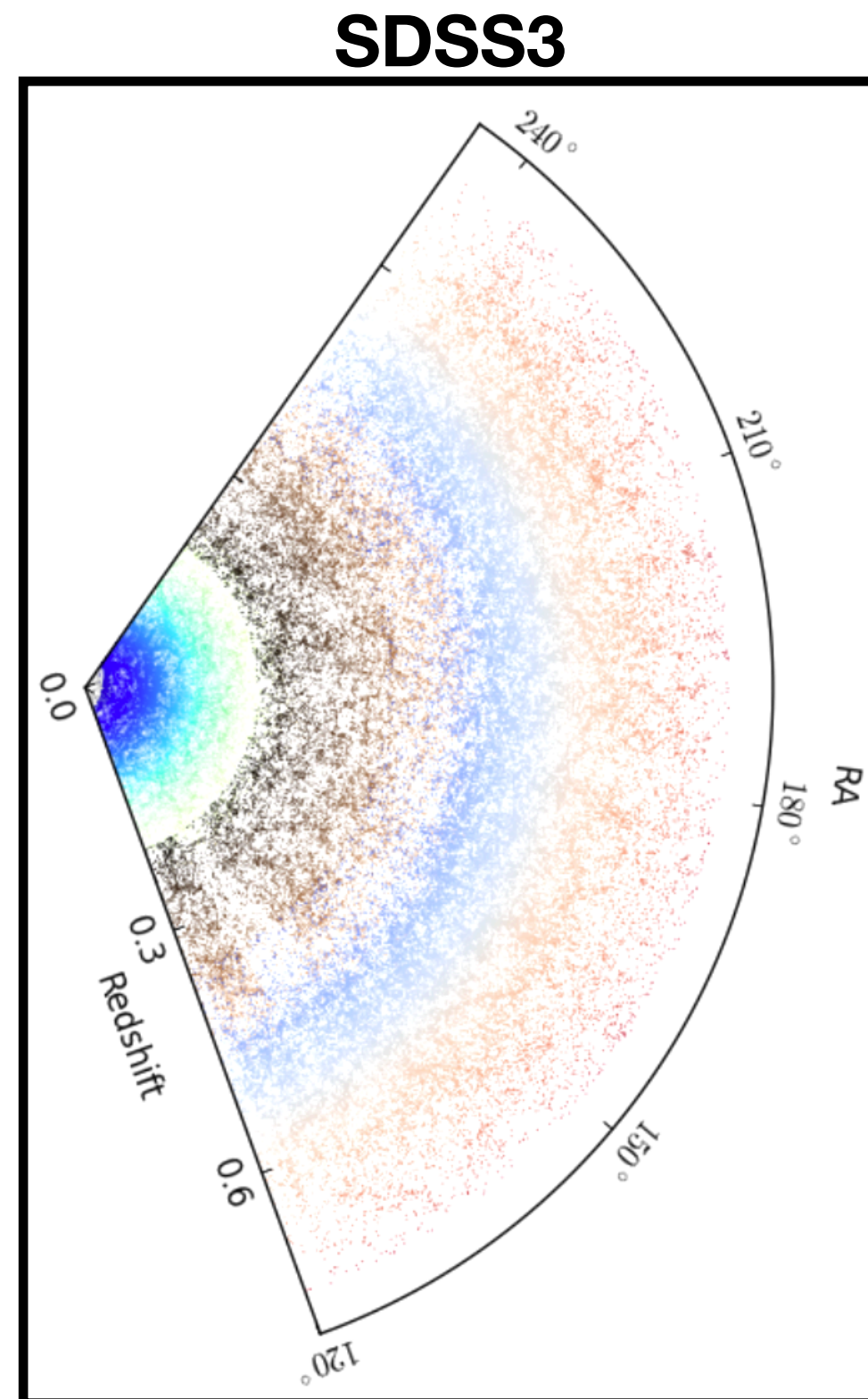
Figure Credit: Guilhem Lavaux



Andrews et al. 2022

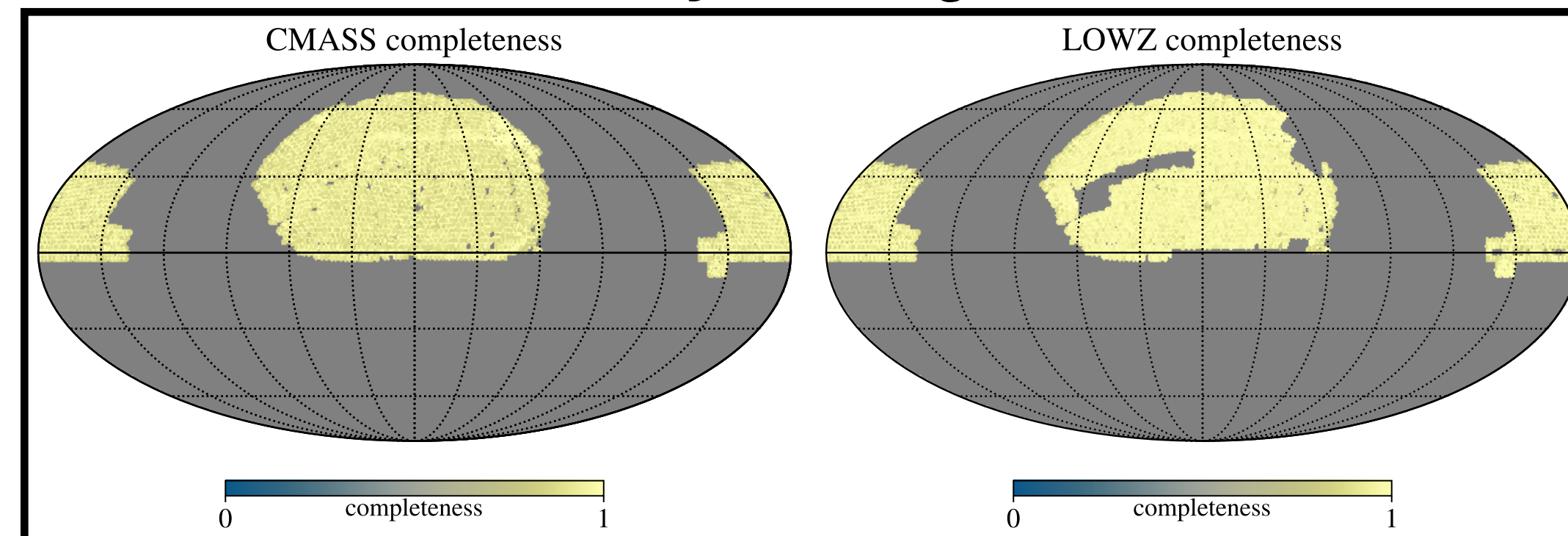
# Proof-of-Concept

## Radial Selection



Andrews et al. 2022

## Sky Coverage

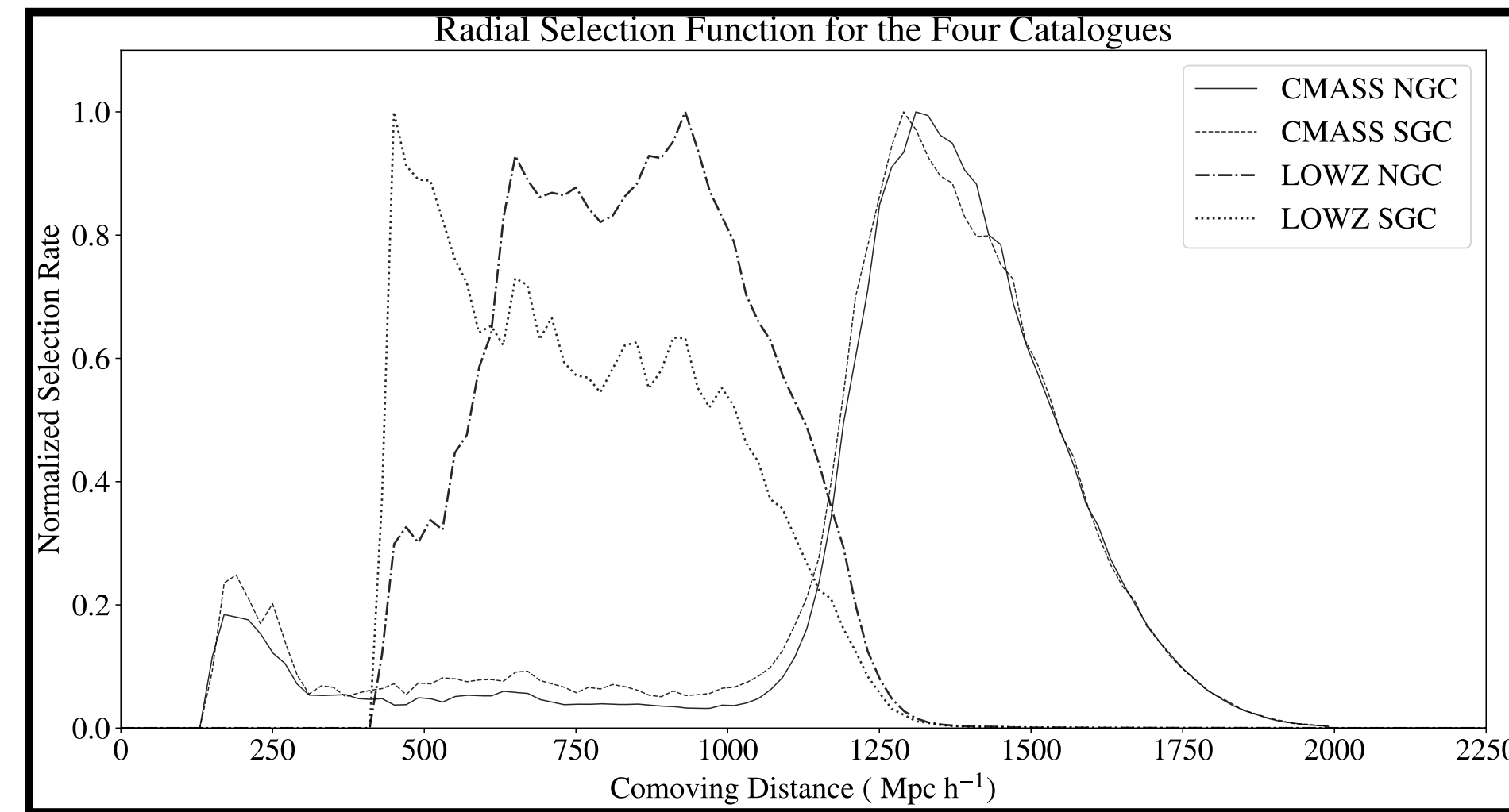
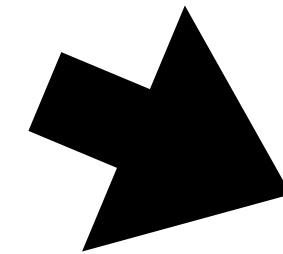
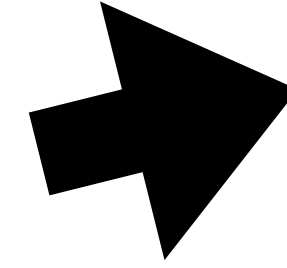
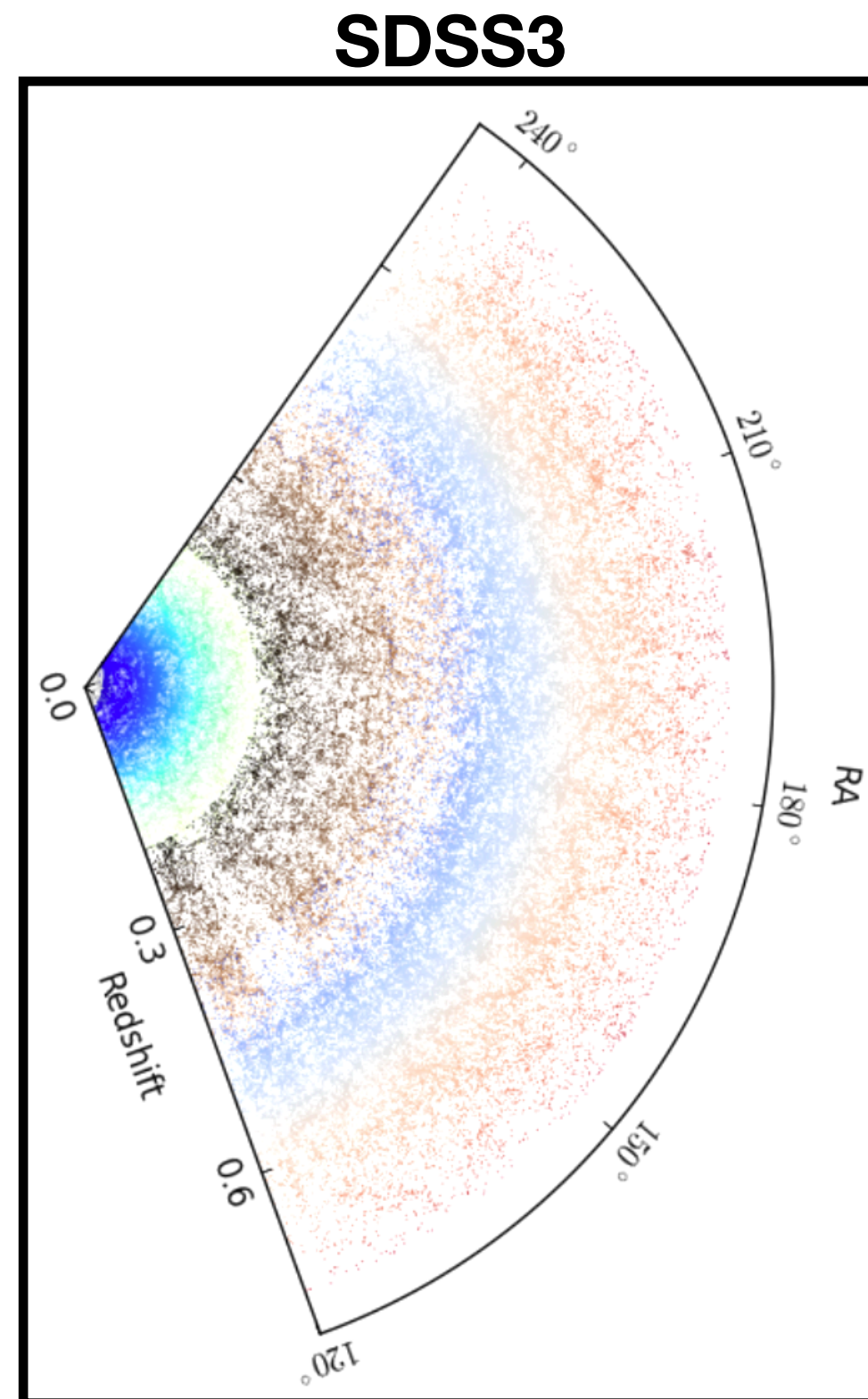


Andrews et al. 2022

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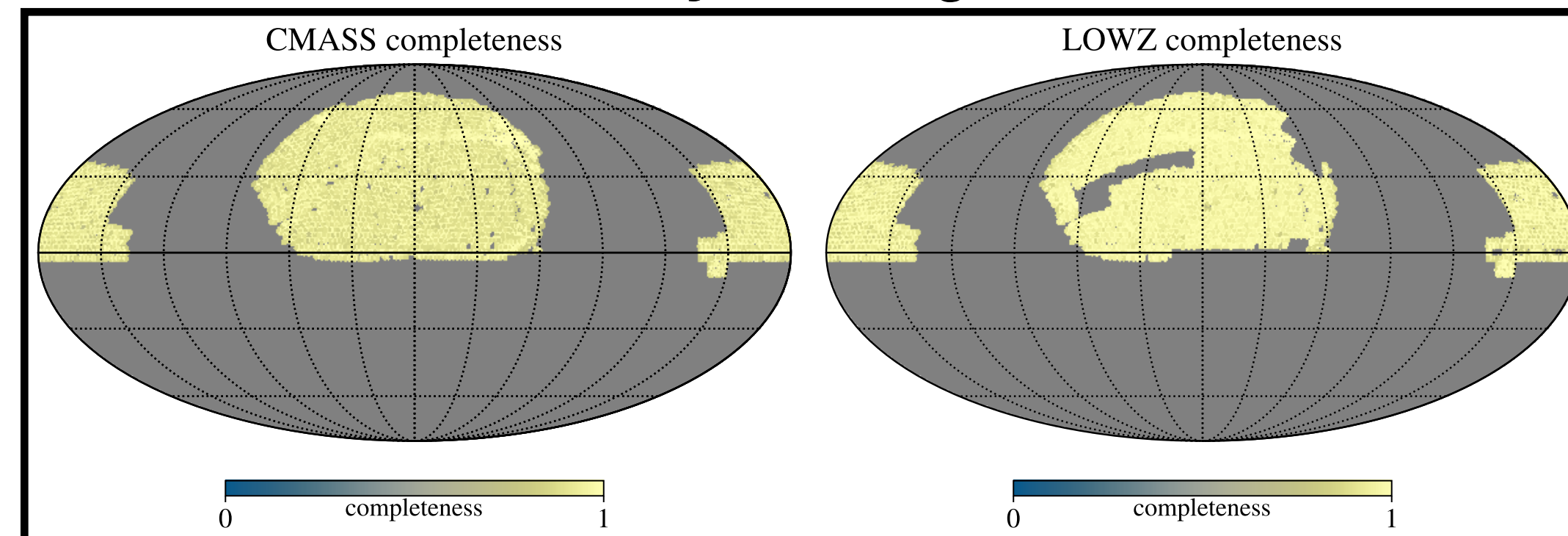
# Proof-of-Concept

## Radial Selection



Andrews et al. 2022

## Sky Coverage



Andrews et al. 2022

$$f_{\text{nl}} = 5$$

Figure Credit: Guilhem Lavaux

# Proof-of-Concept

## Radial Selection

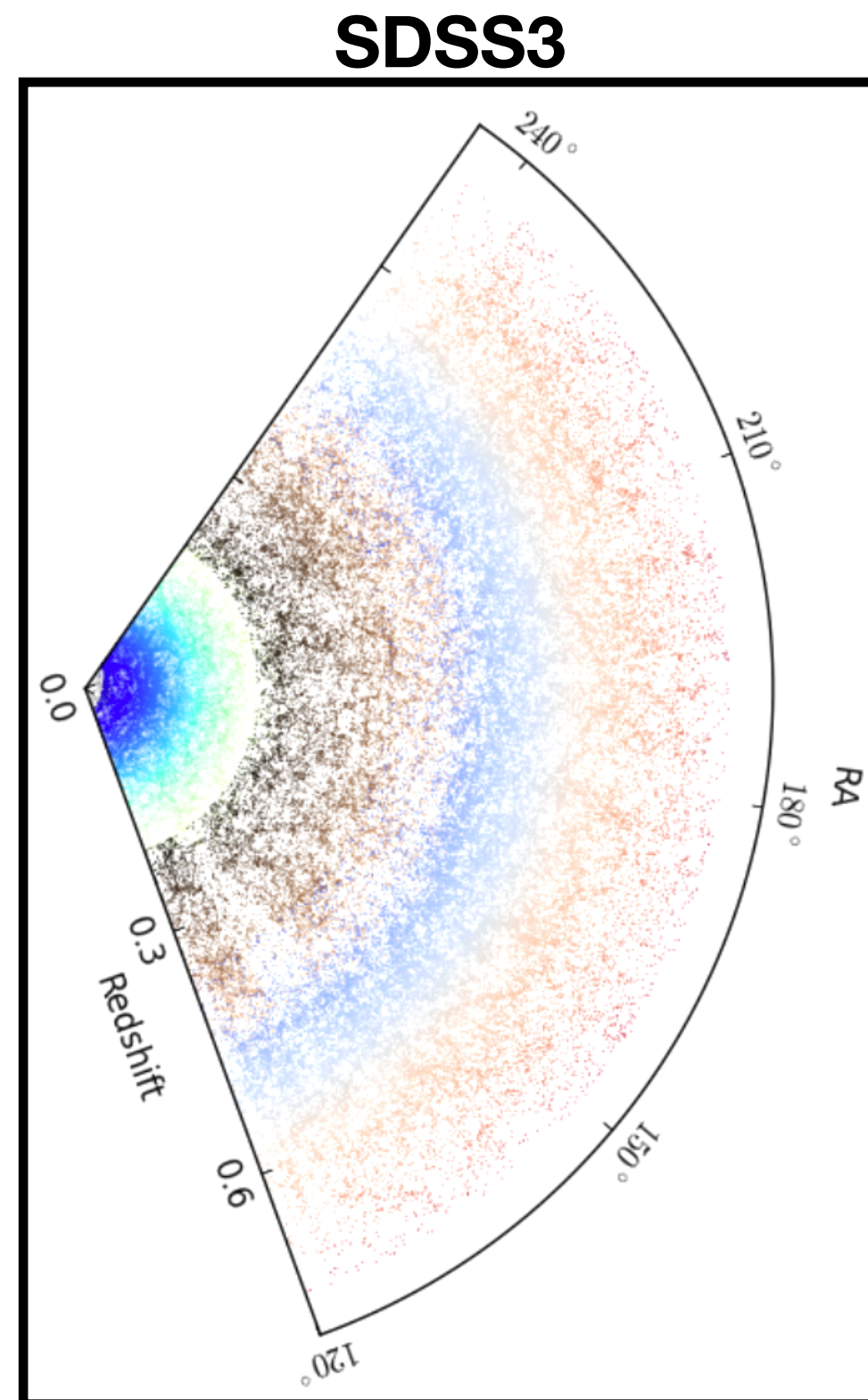
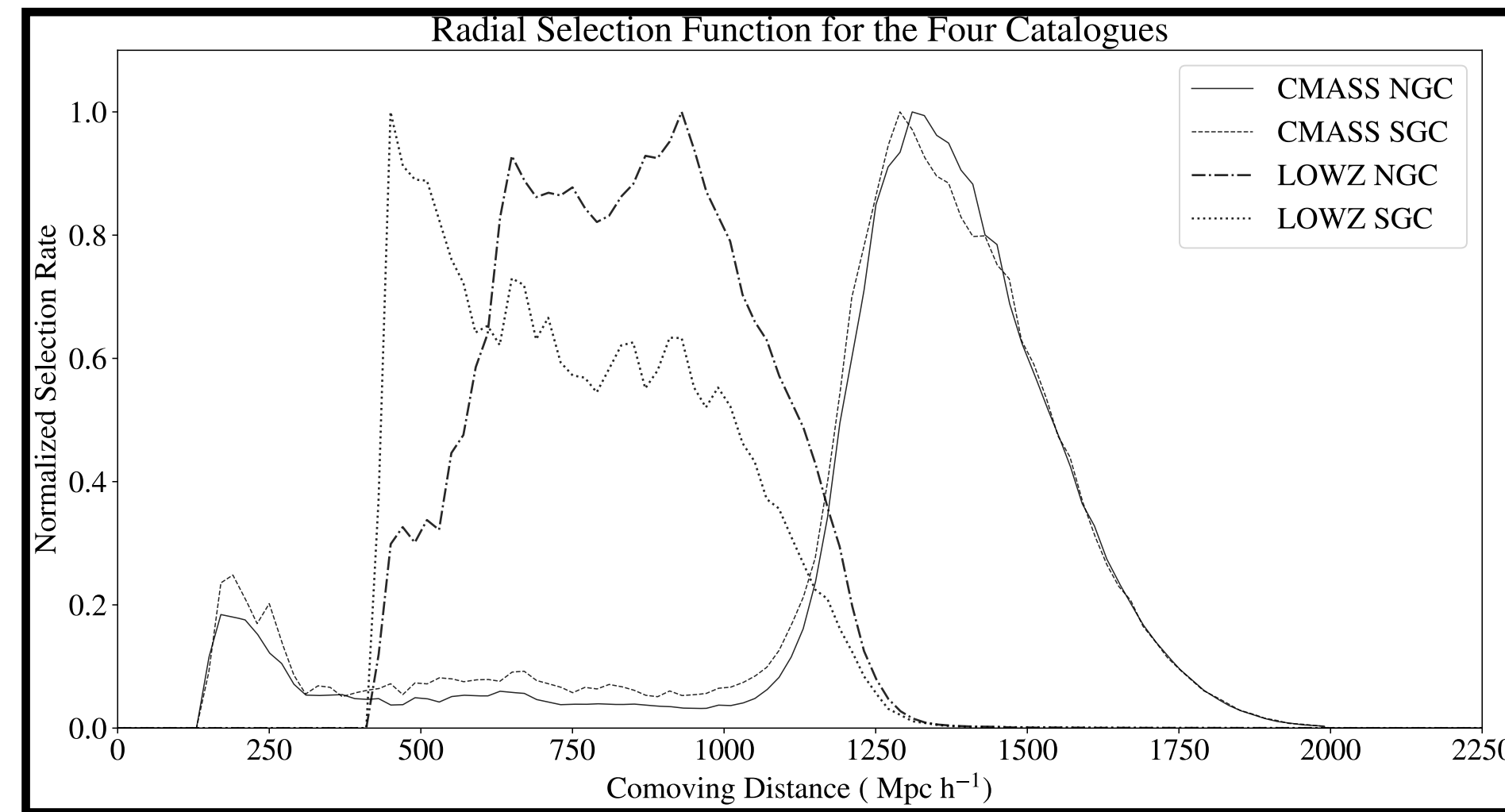
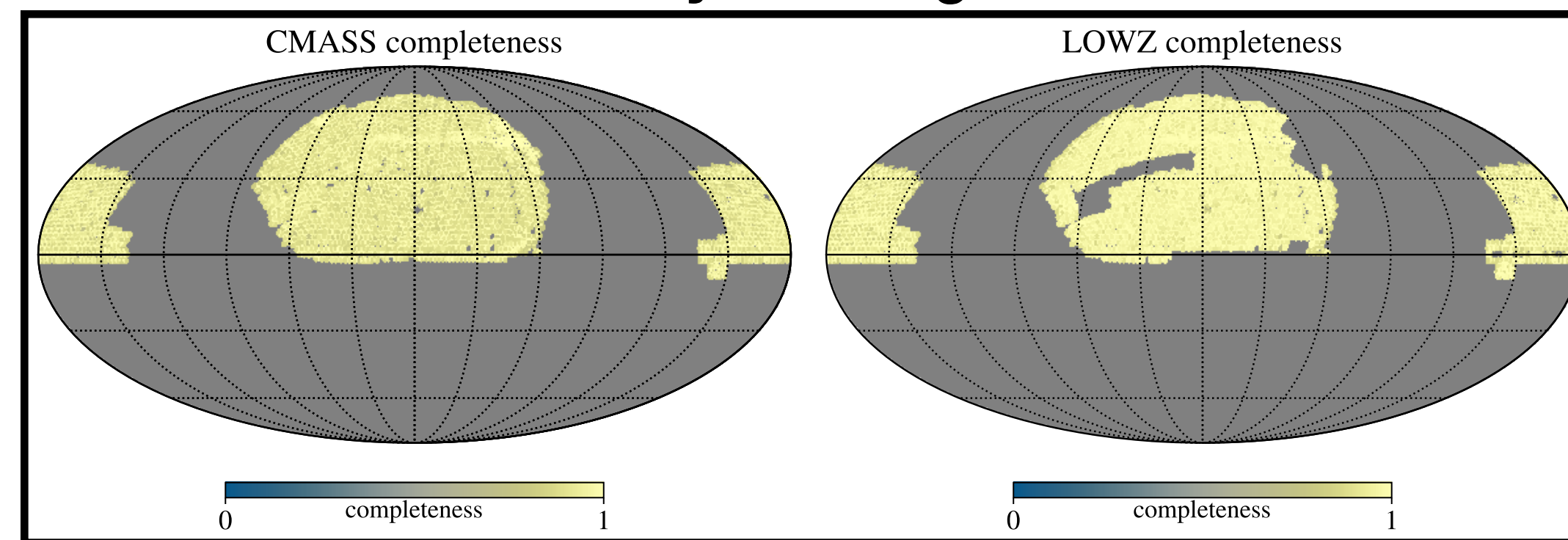


Figure Credit: Guilhem Lavaux



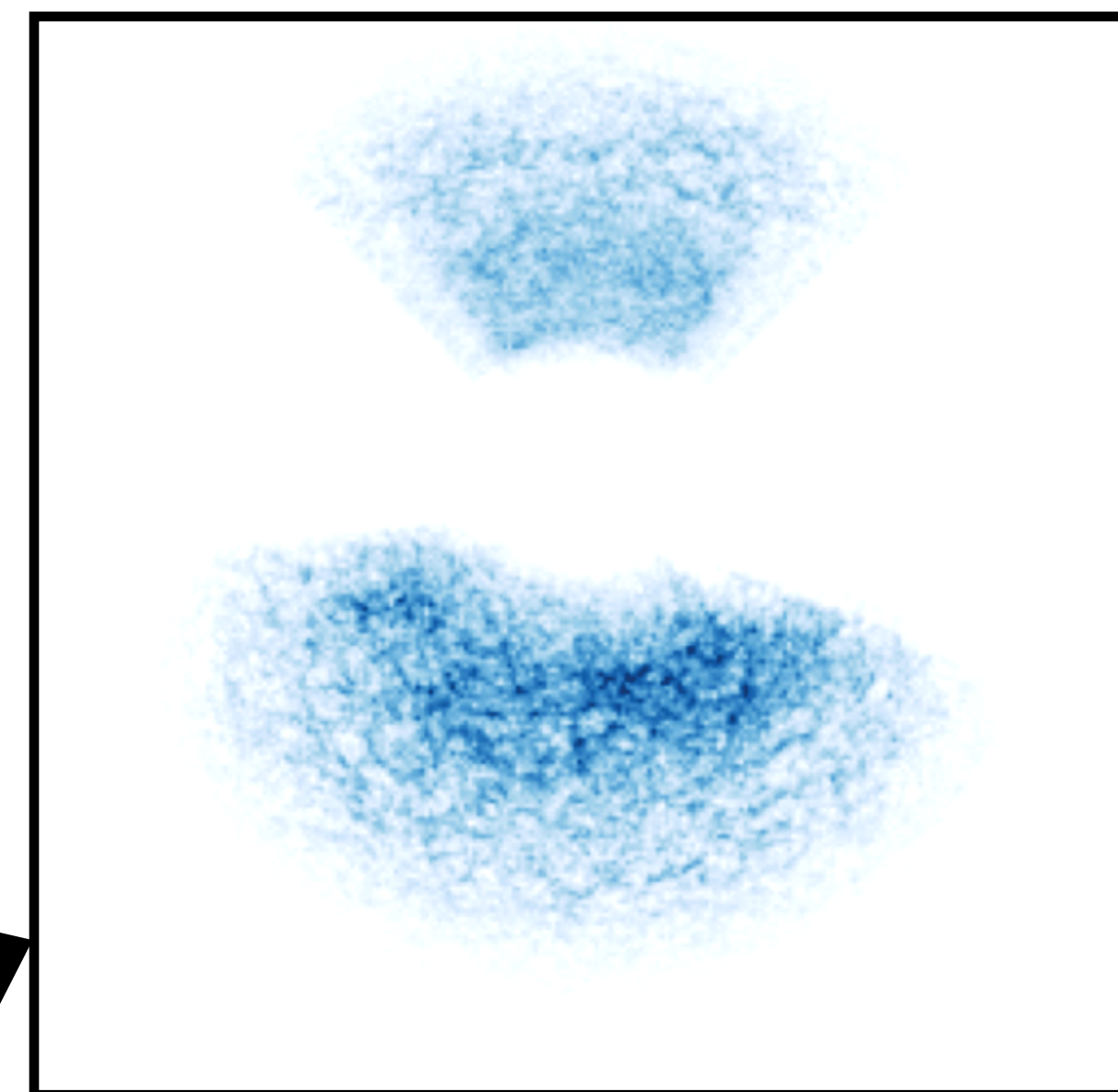
Andrews et al. 2022

## Sky Coverage



Andrews et al. 2022

## Mock Data

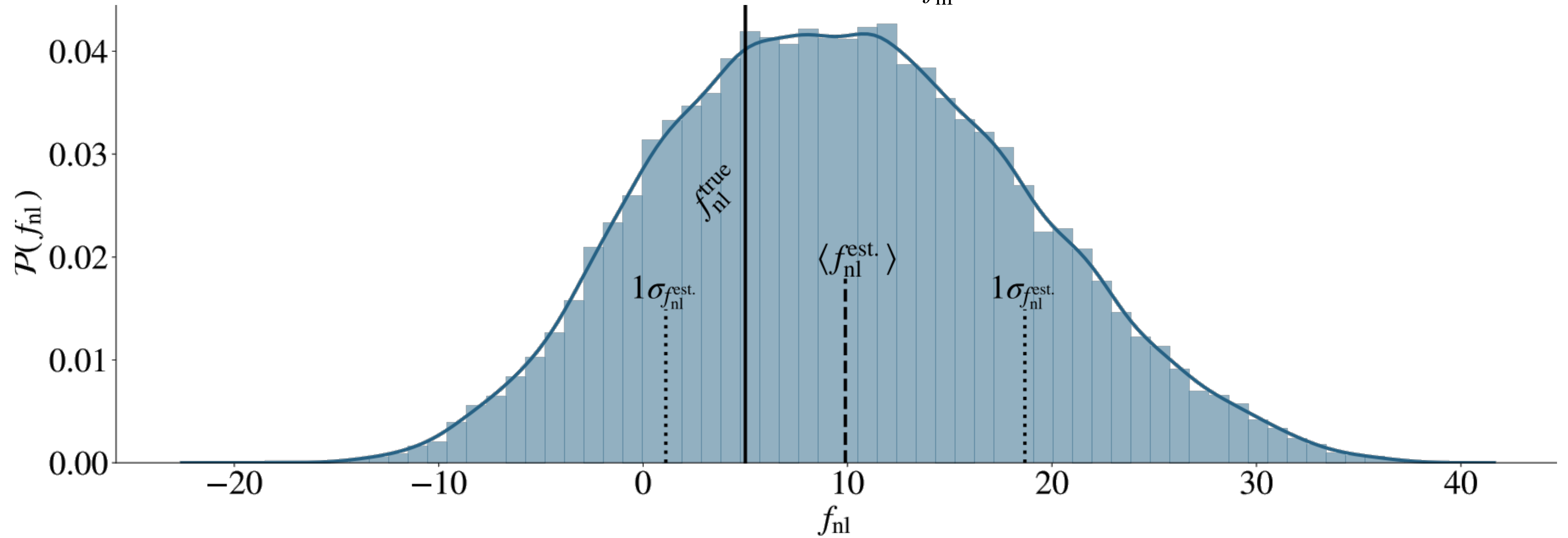


$f_{nl} = 5$

# Main results

# Main results

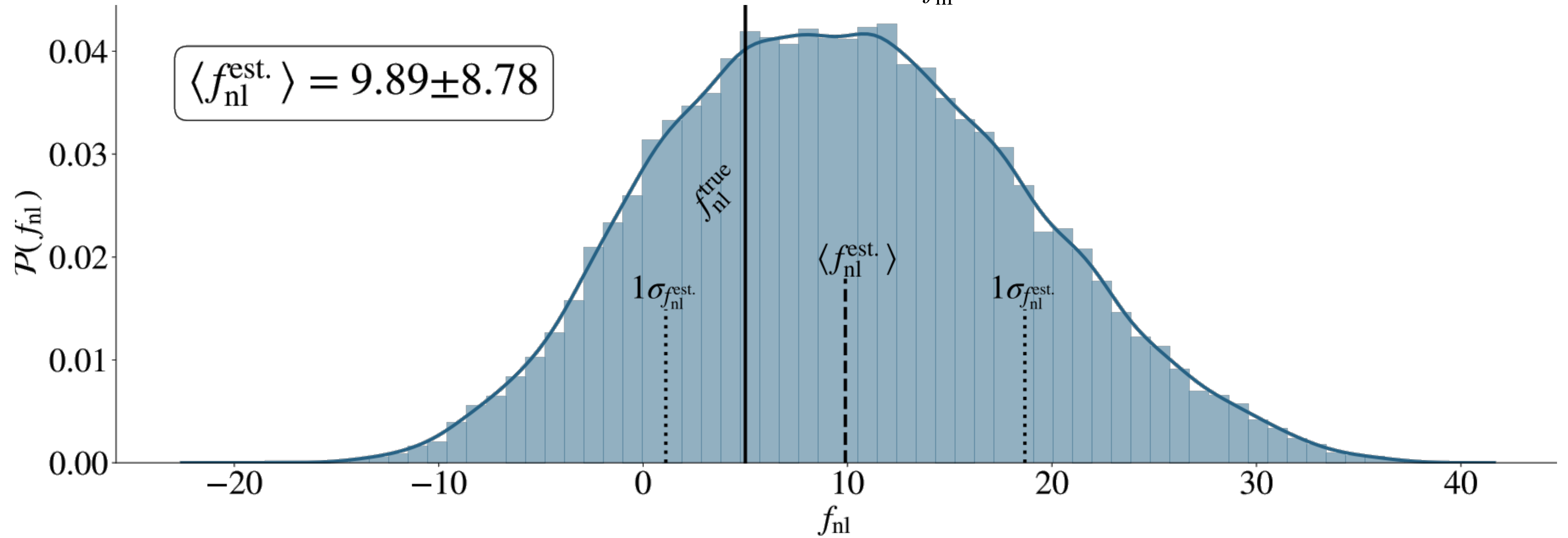
Posterior distribution of  $f_{nl}$





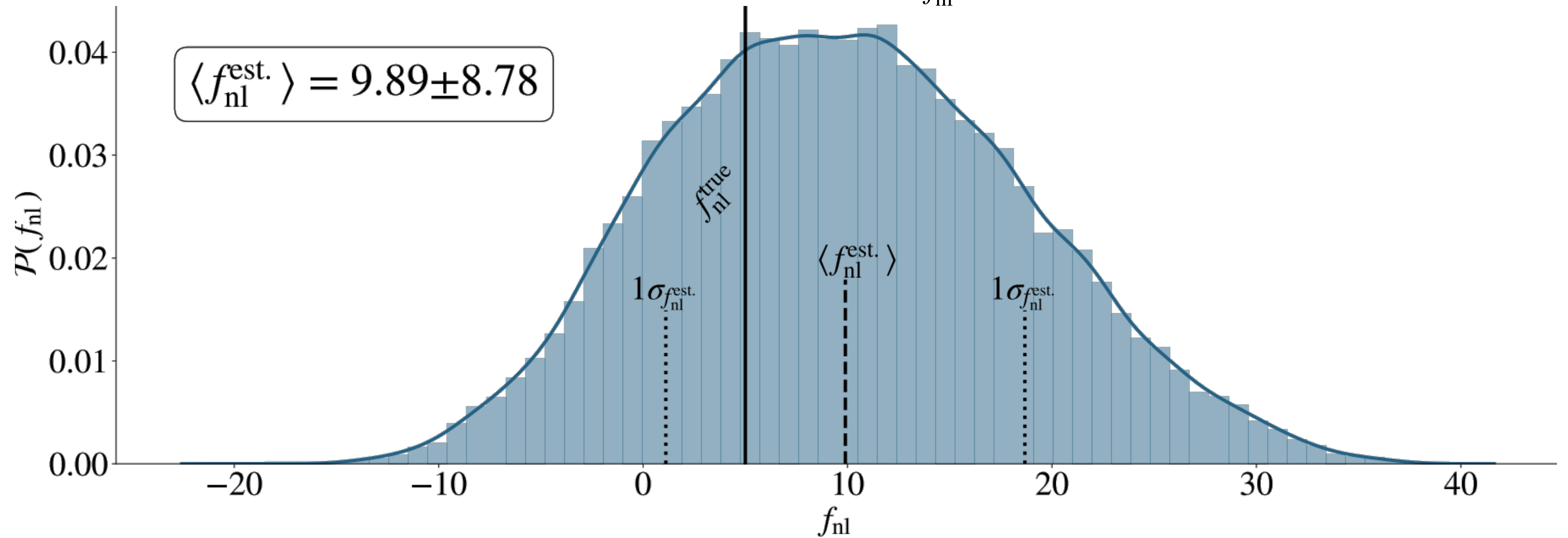
# Main results

Posterior distribution of  $f_{\text{nl}}$



# Main results

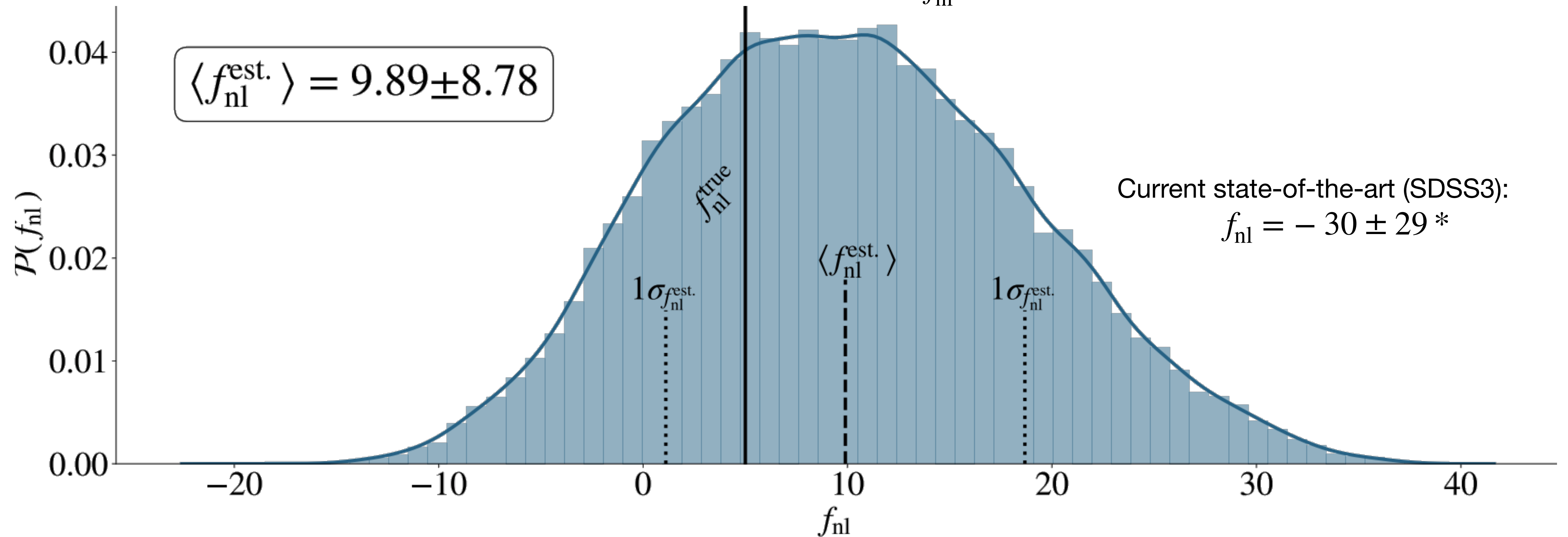
Posterior distribution of  $f_{\text{nl}}$



**Full statement on the information content available in the data!**

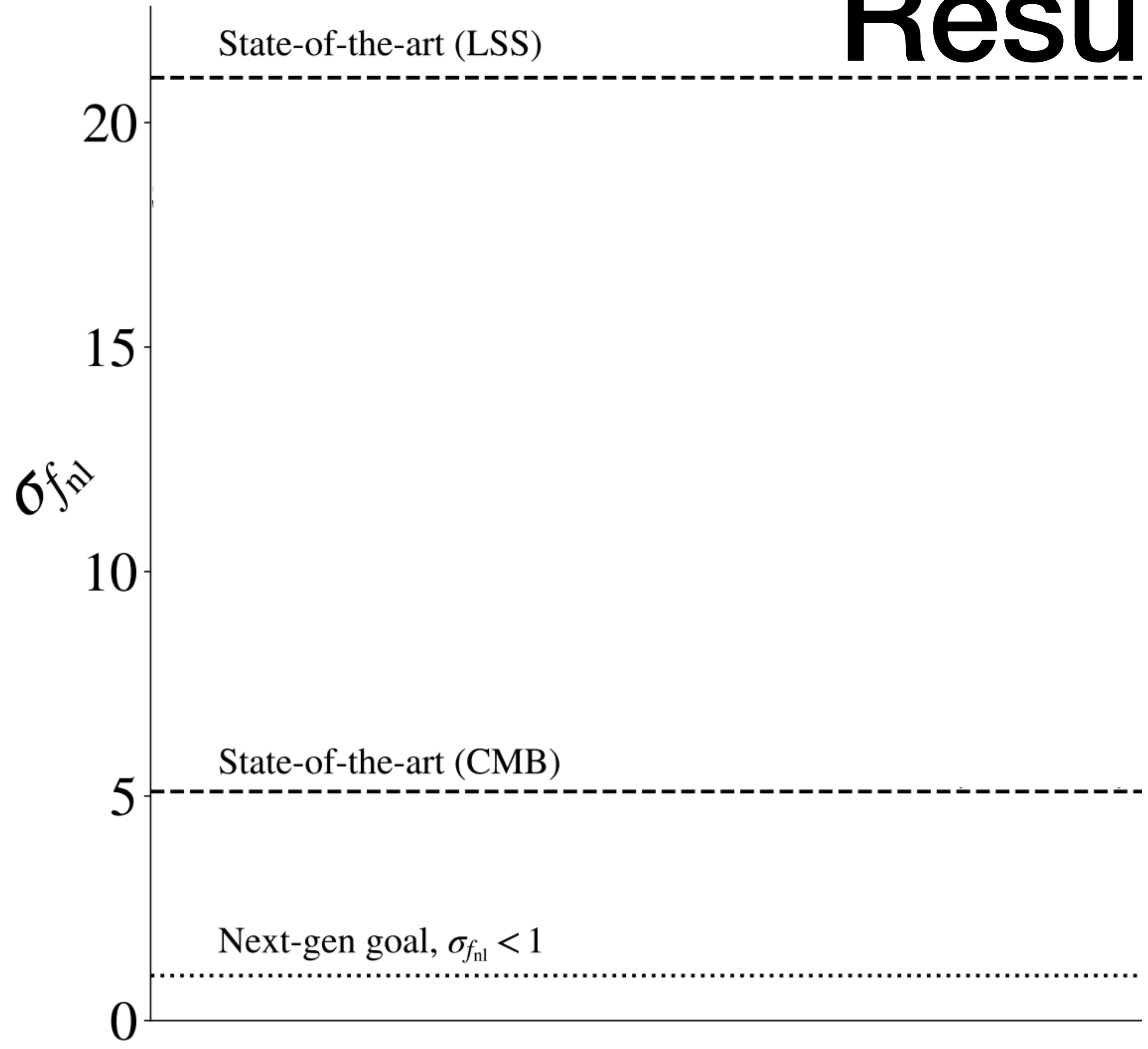
# Main results

Posterior distribution of  $f_{\text{nl}}$

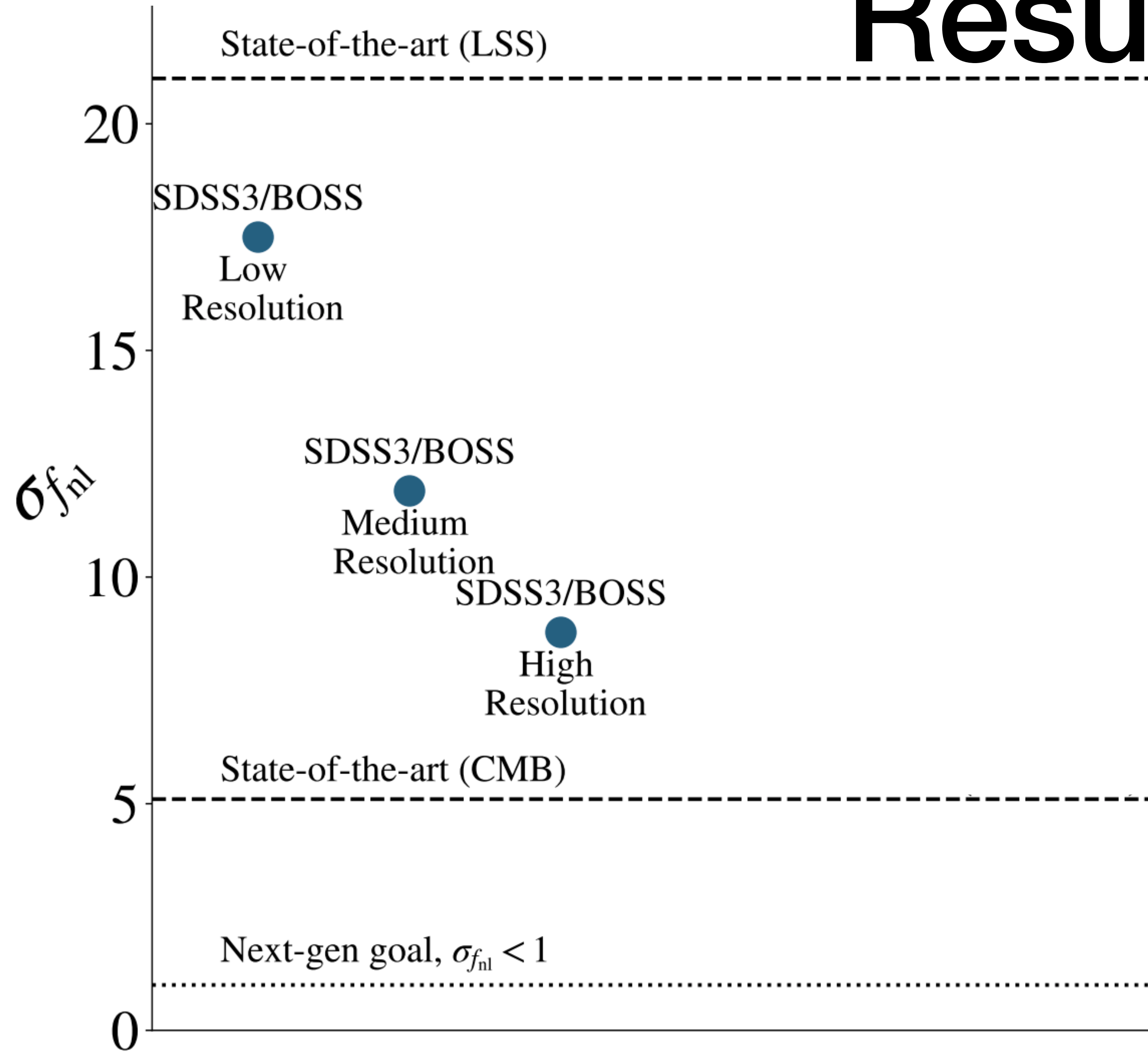


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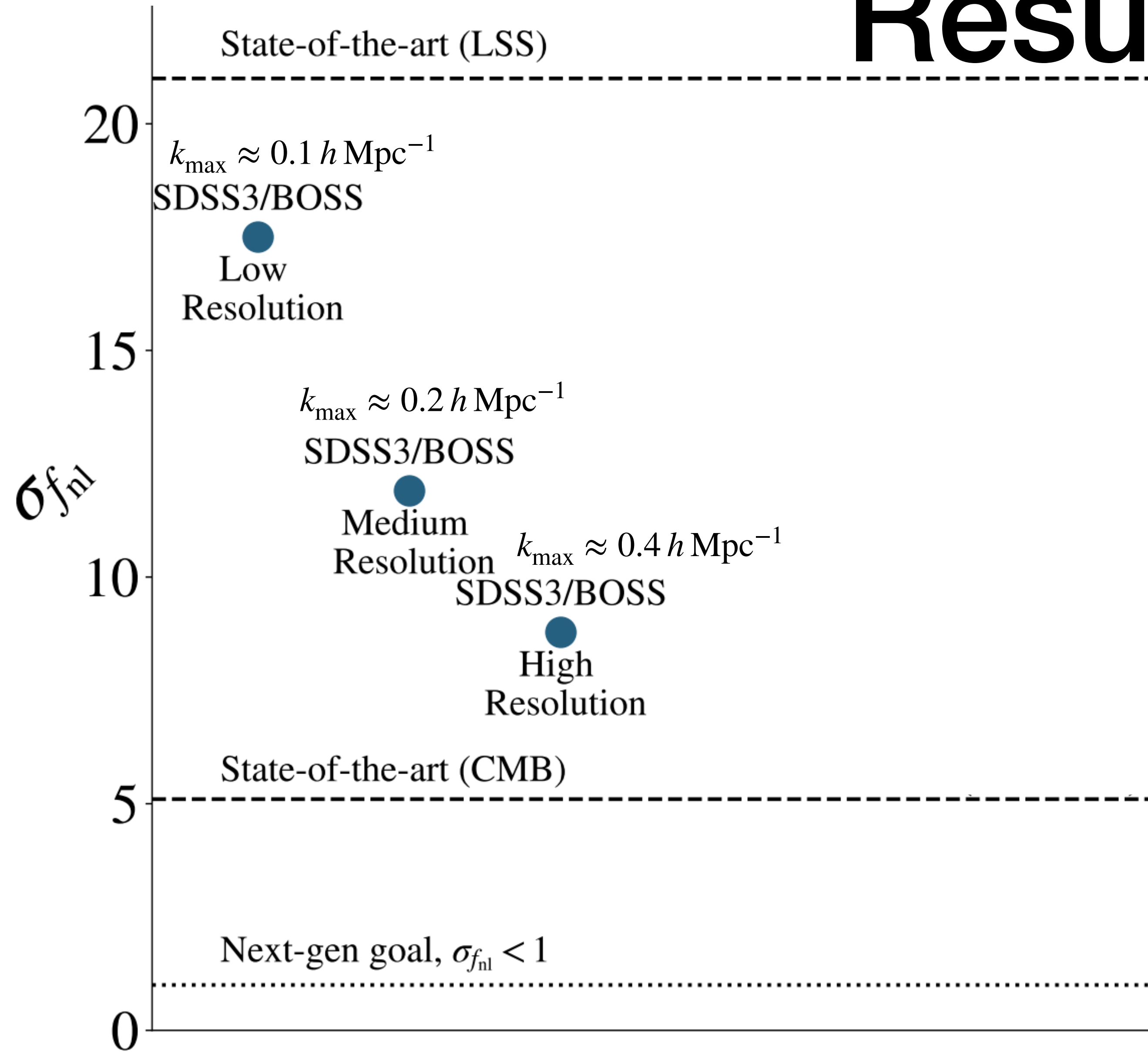
# Results



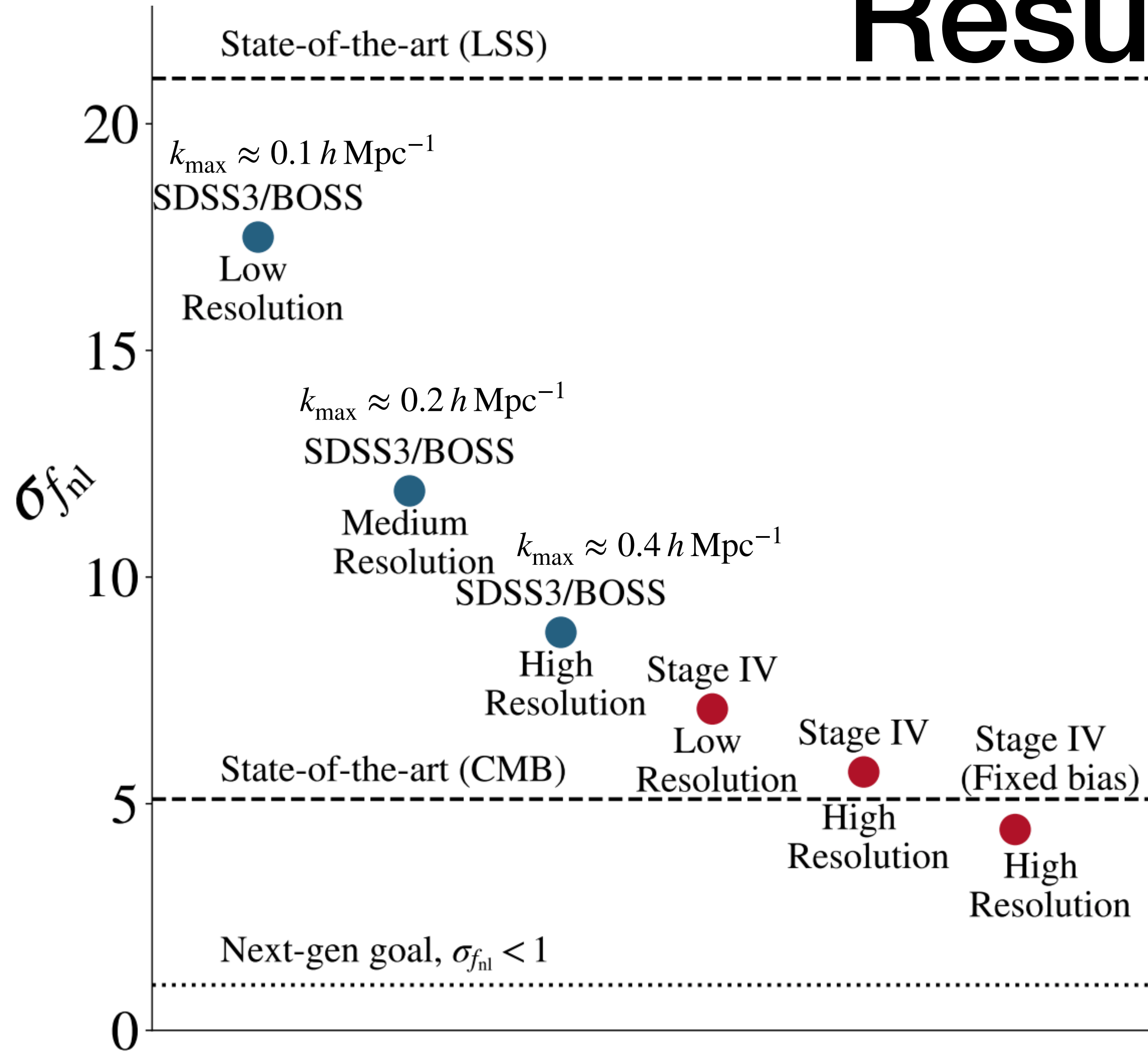
# Results



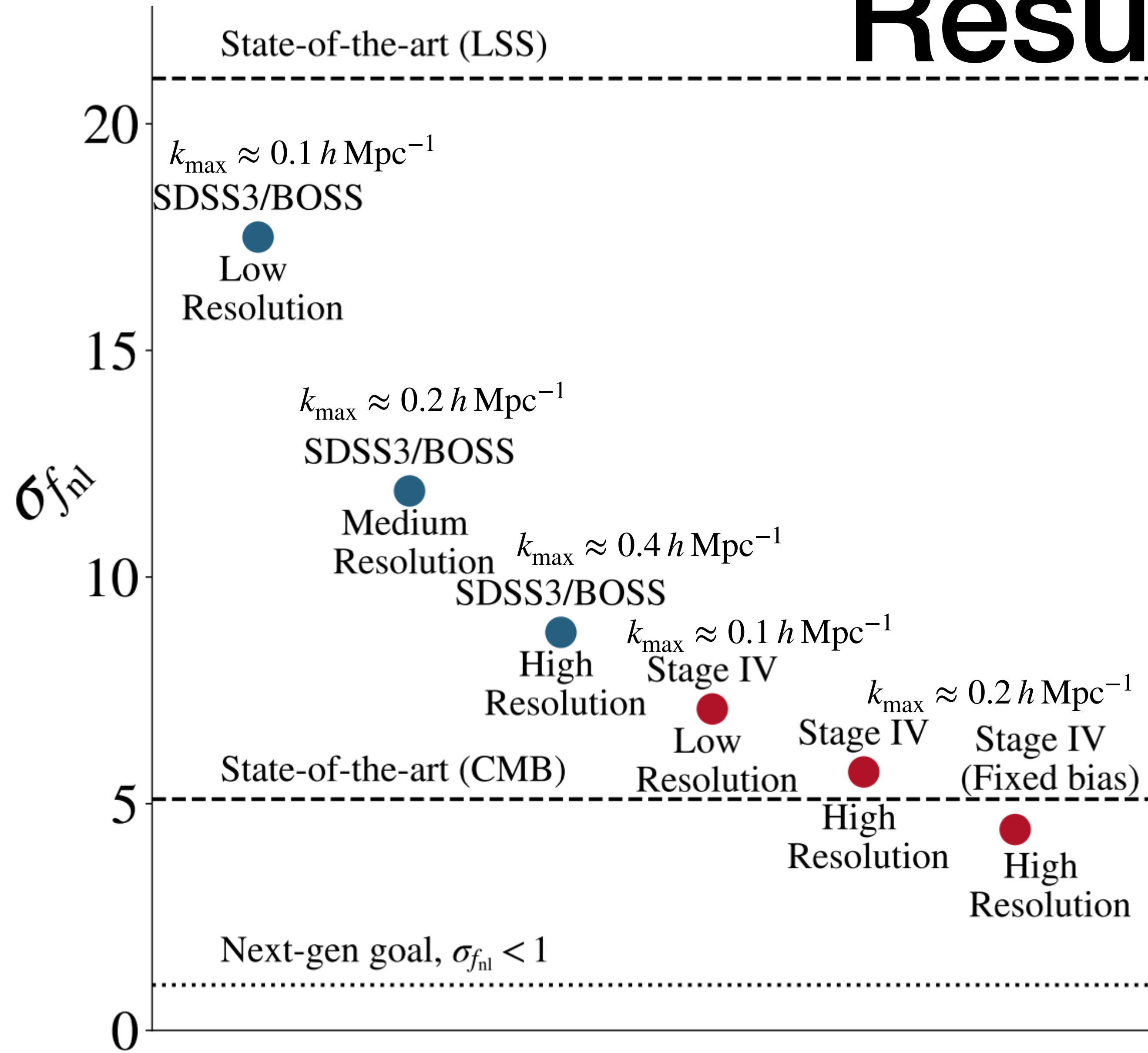
# Results



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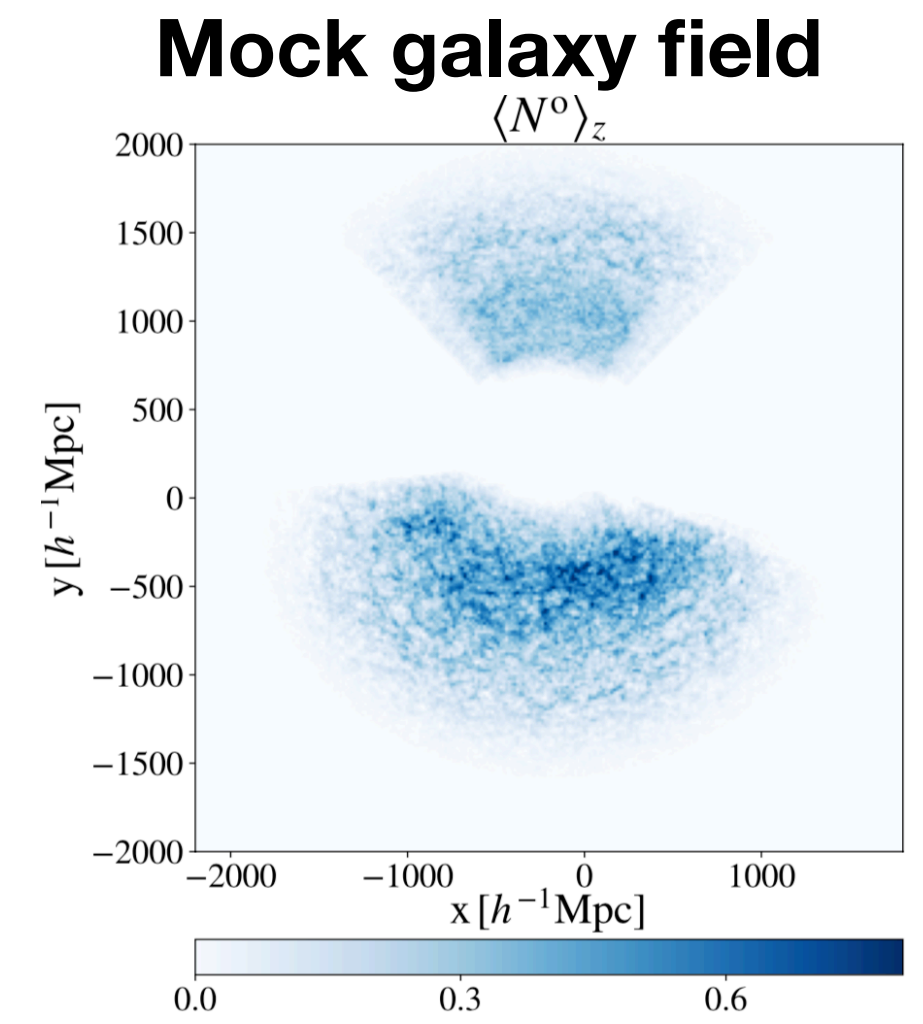
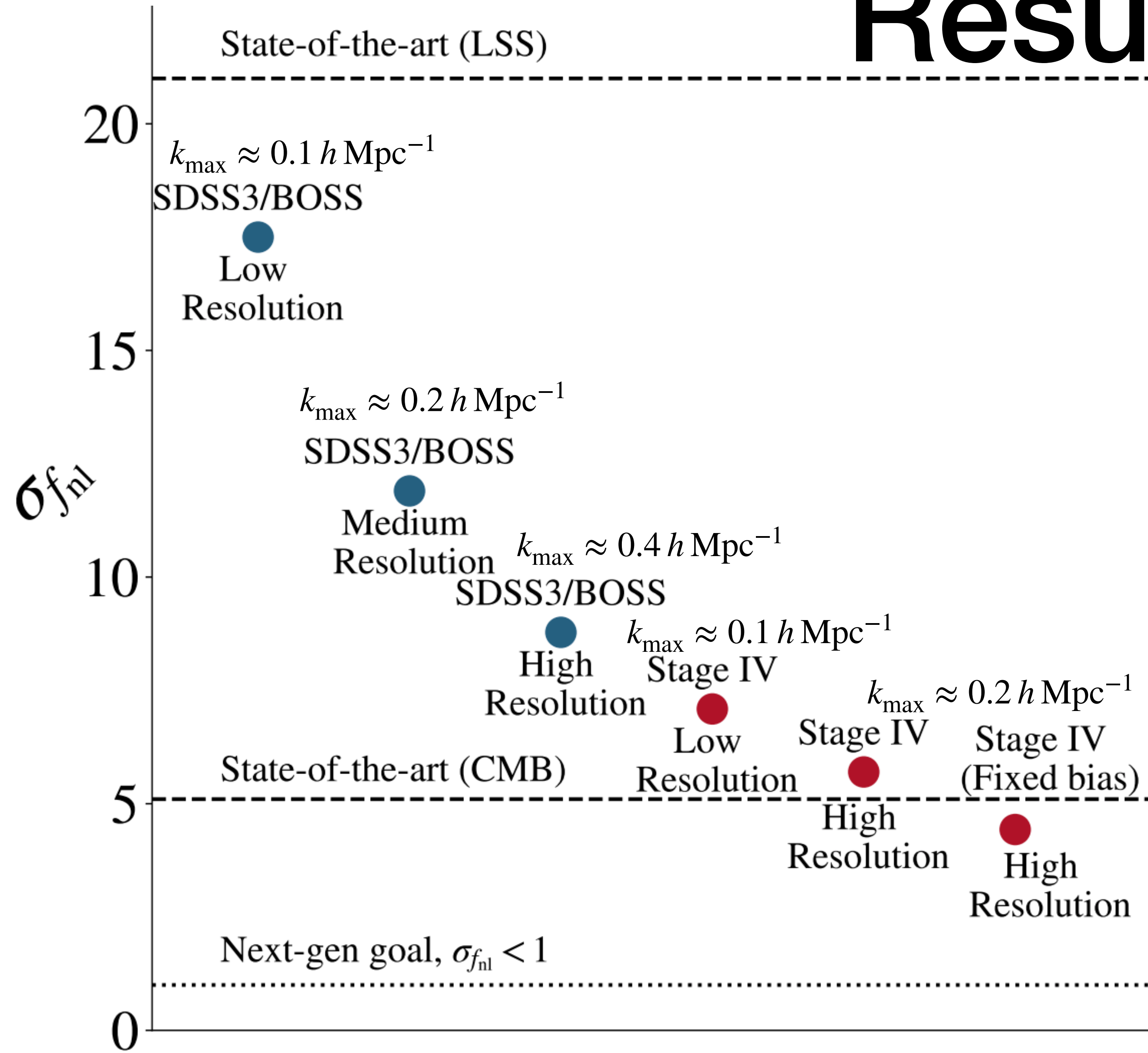


# Results

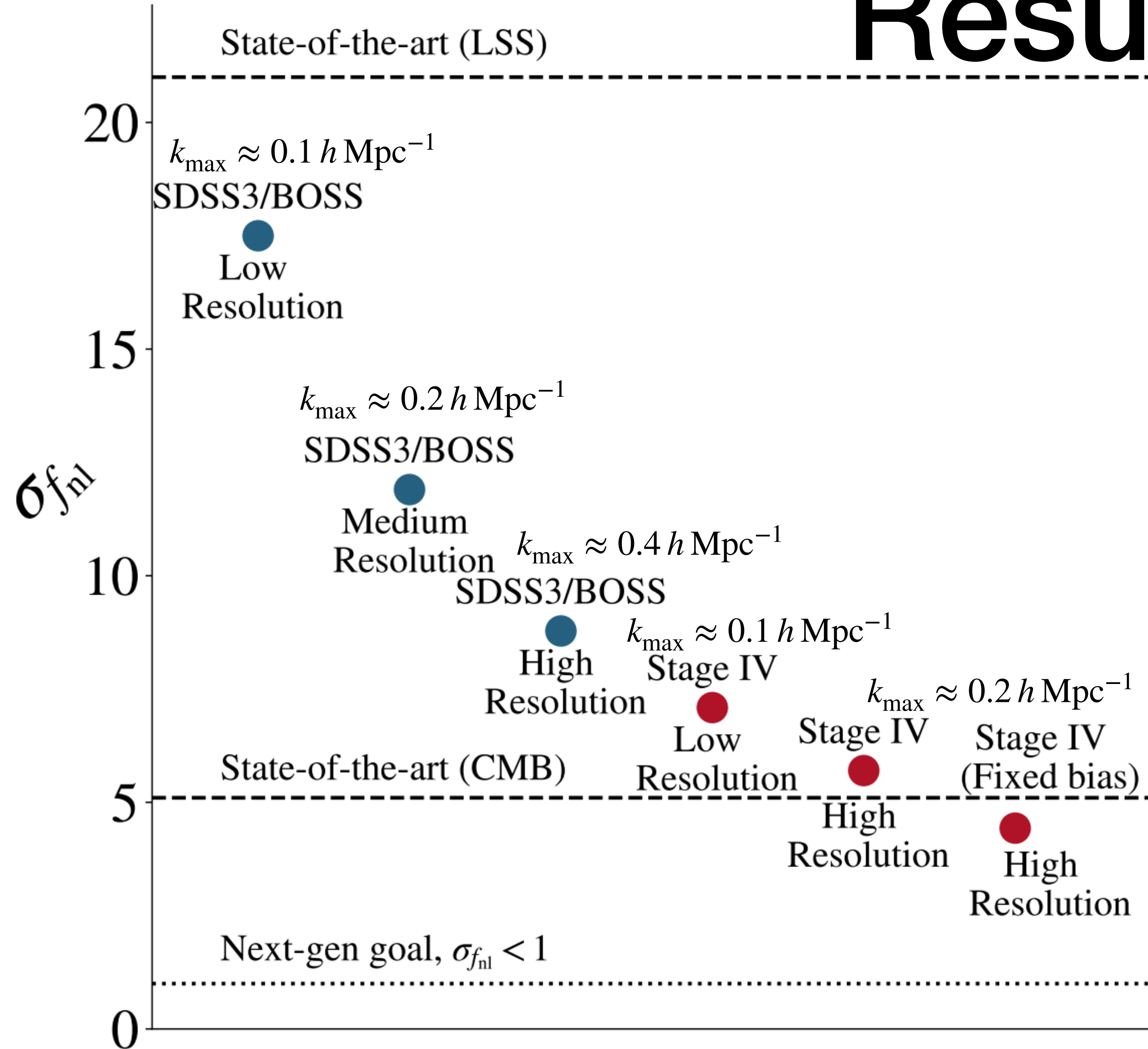




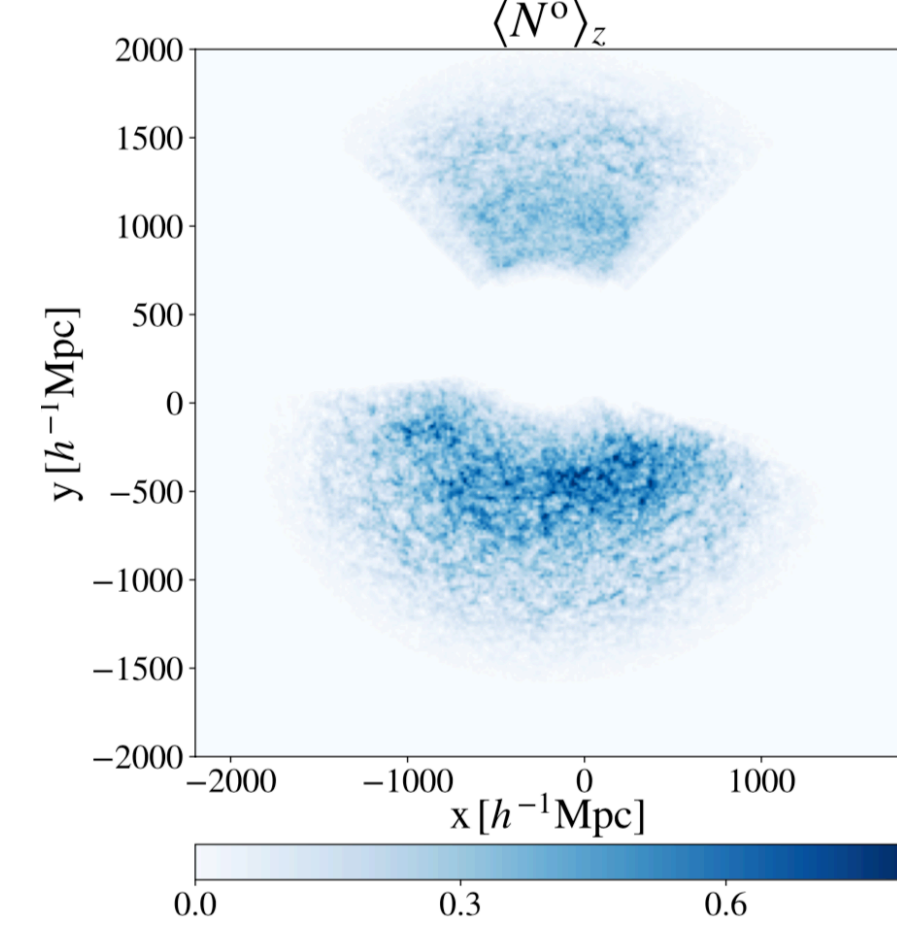
# Results



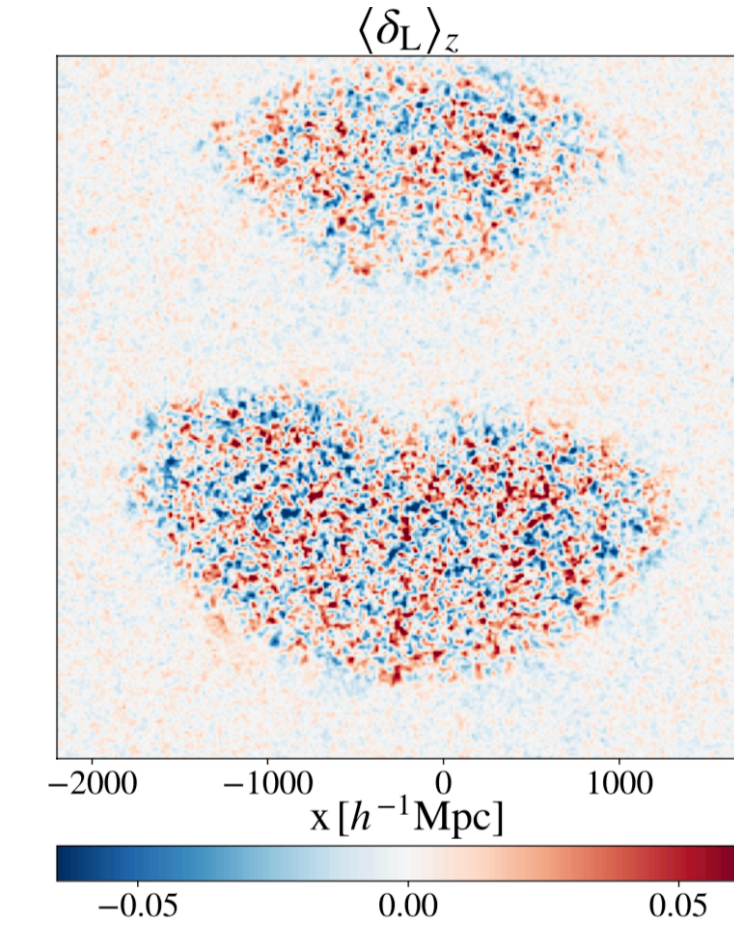
# Results



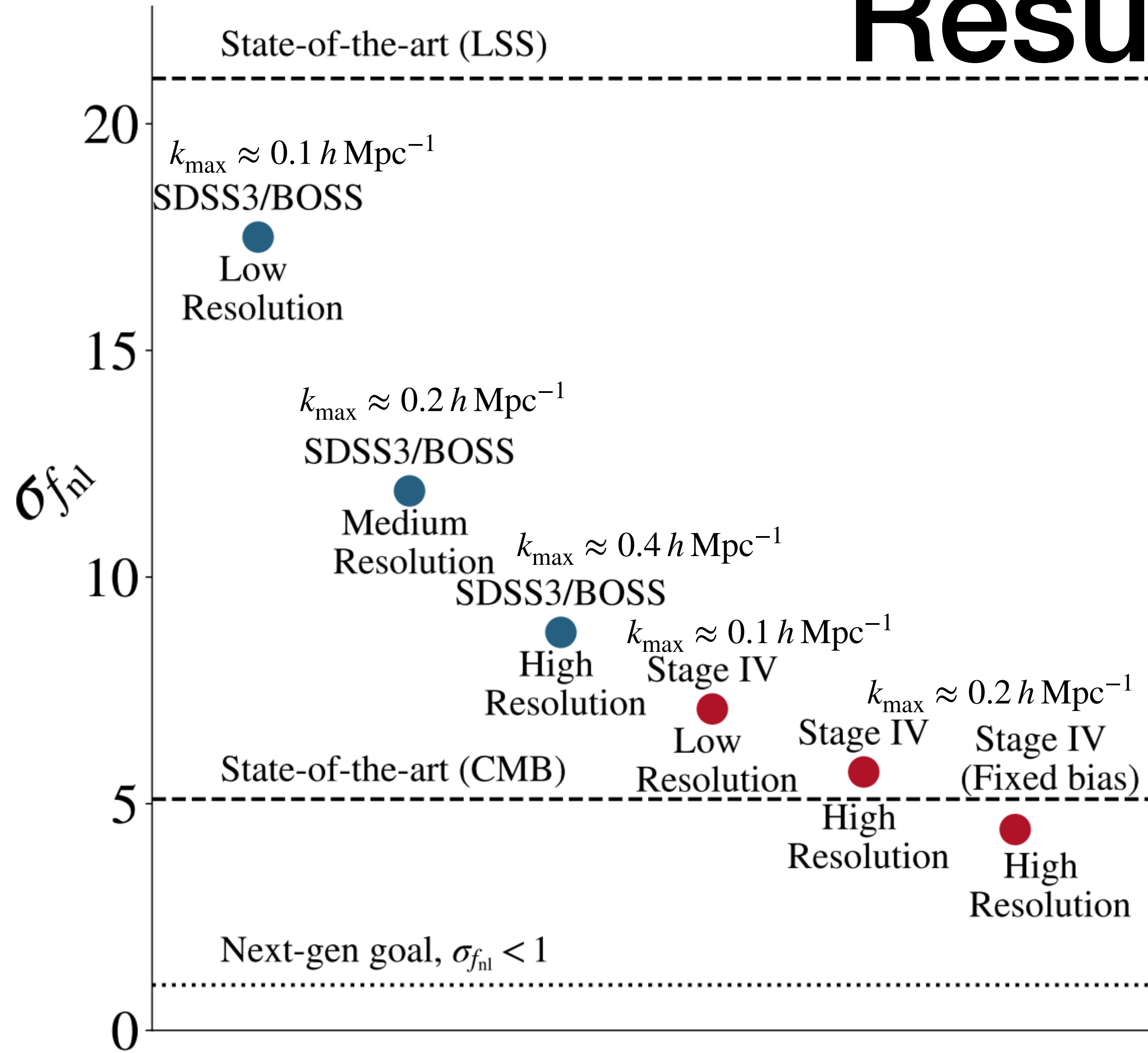
Mock galaxy field



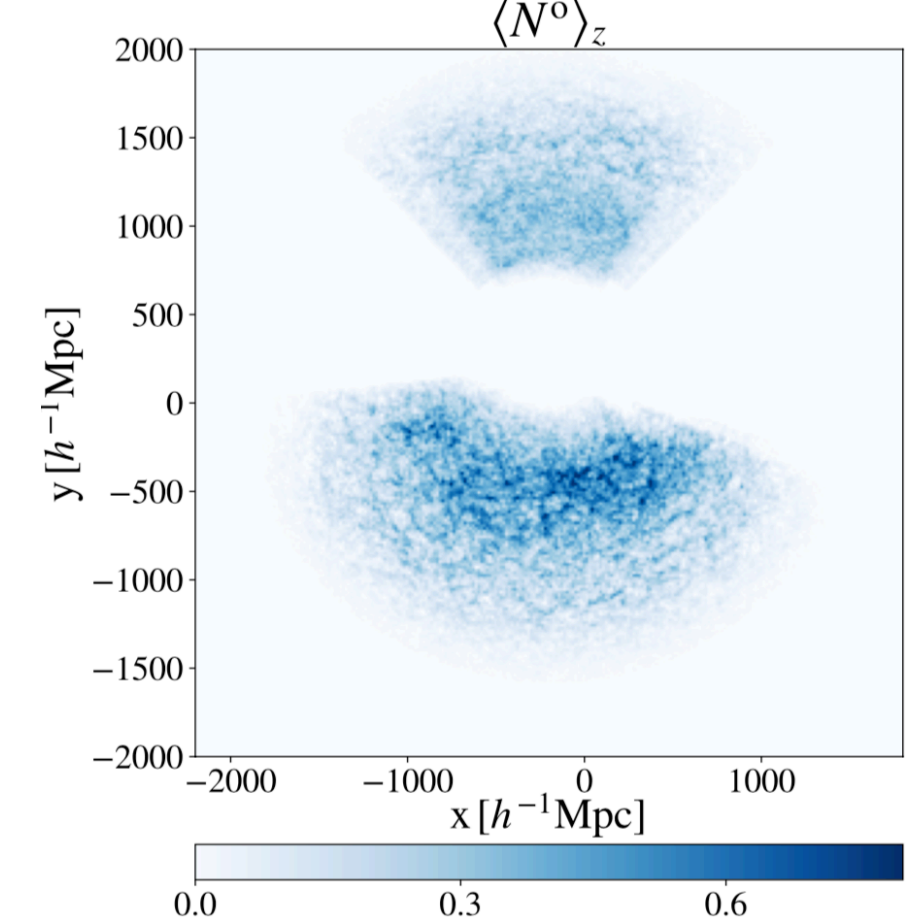
Inferred density field



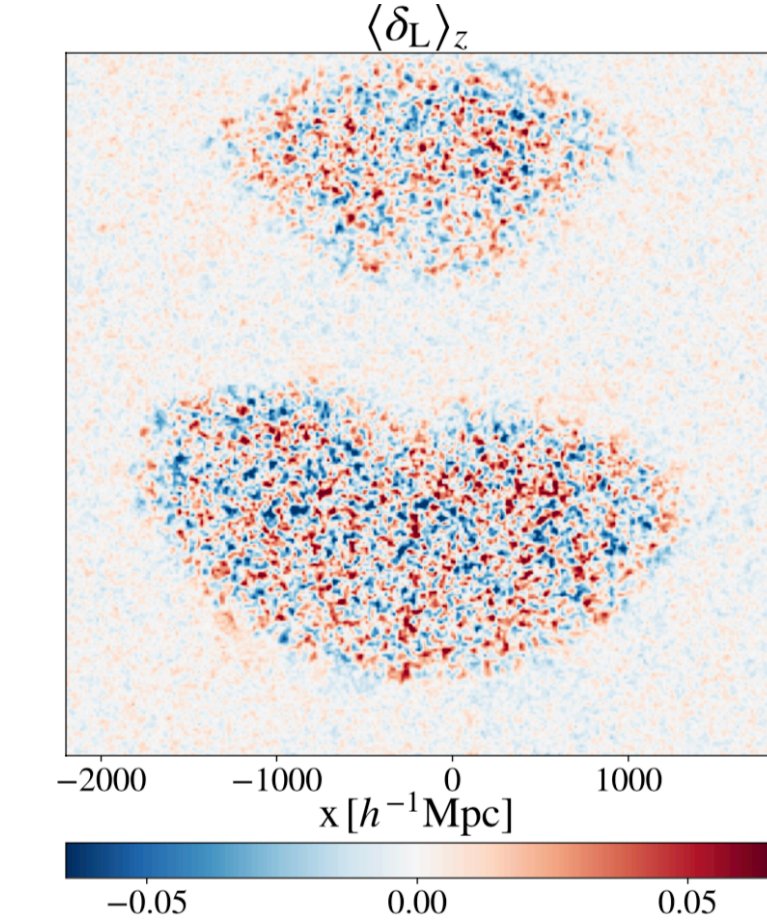
# Results



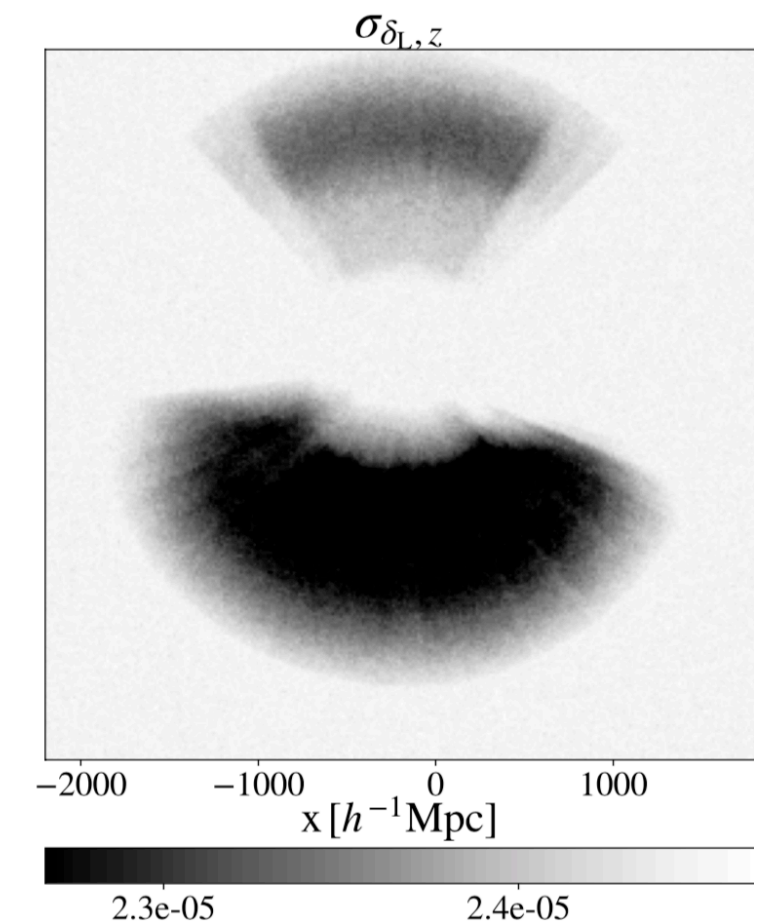
Mock galaxy field



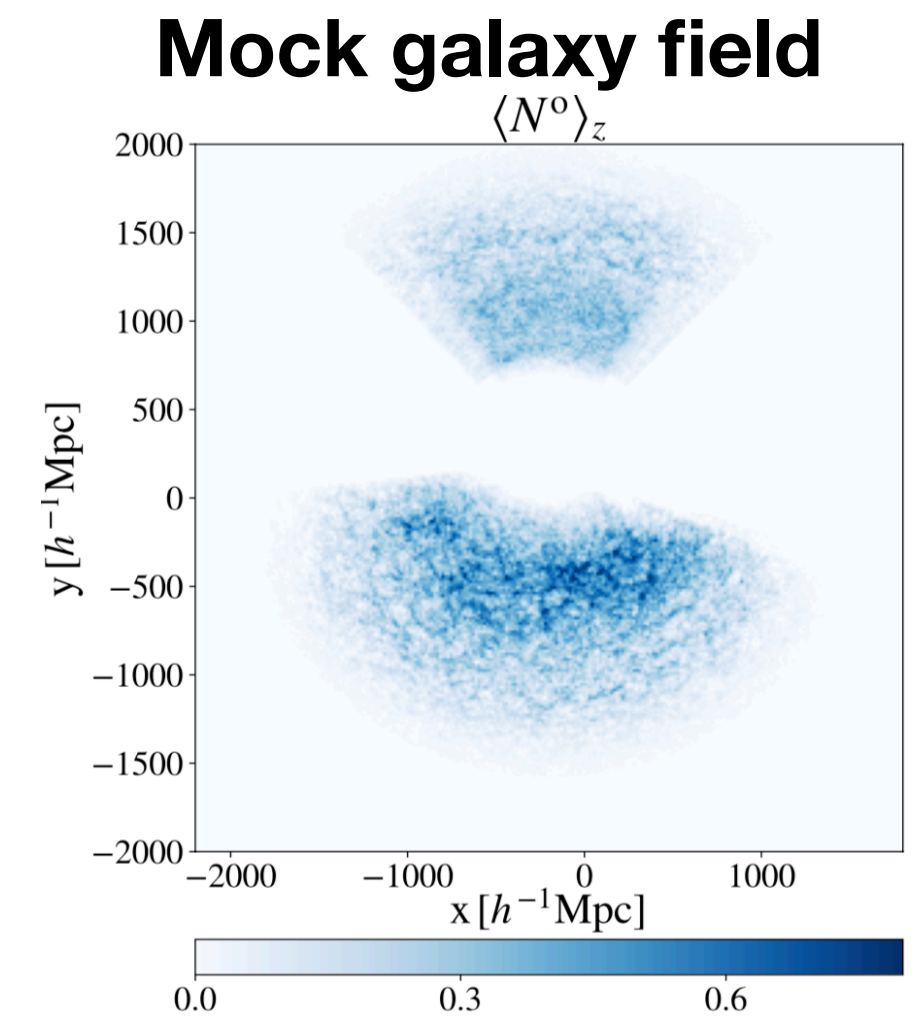
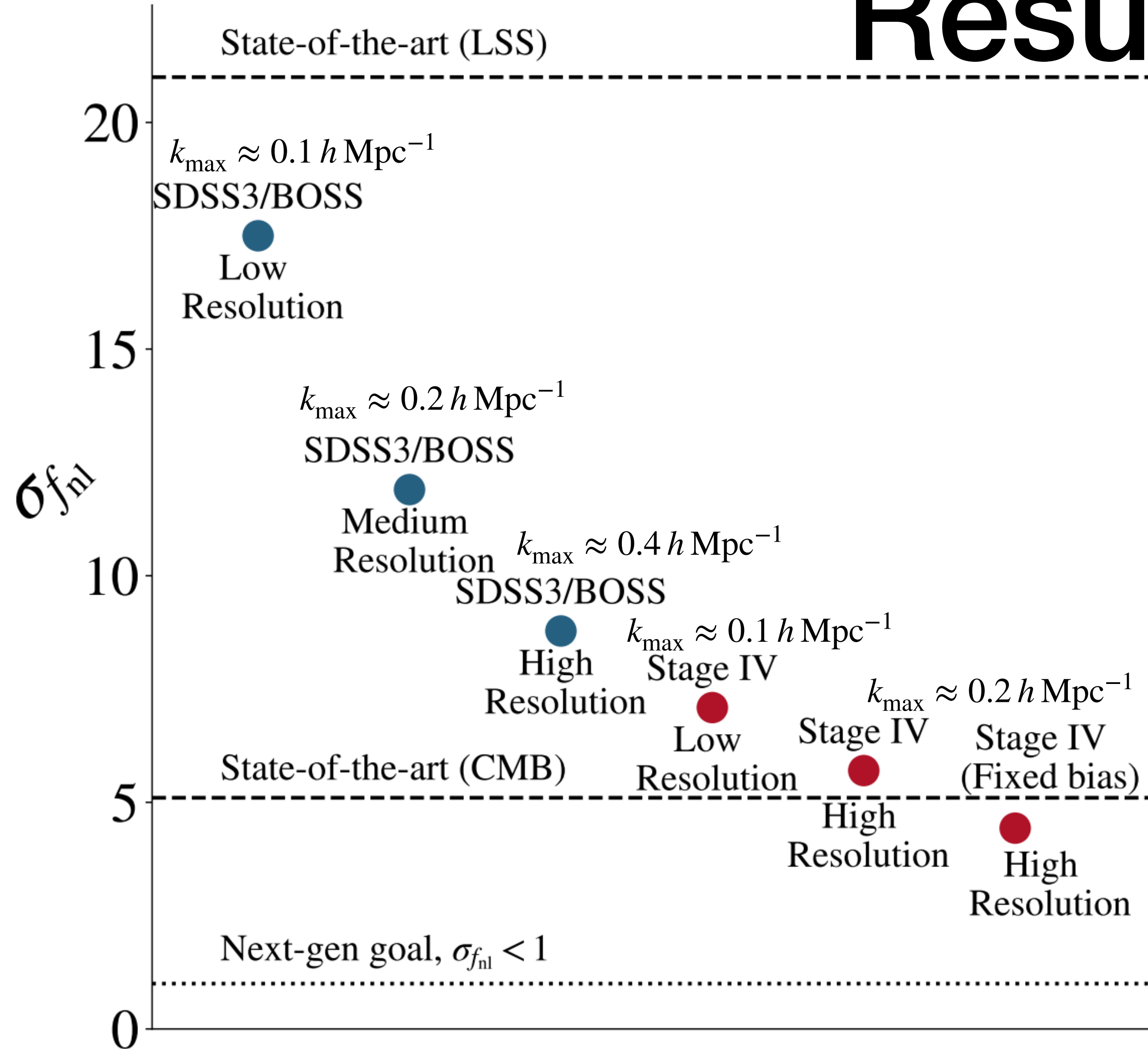
Inferred density field



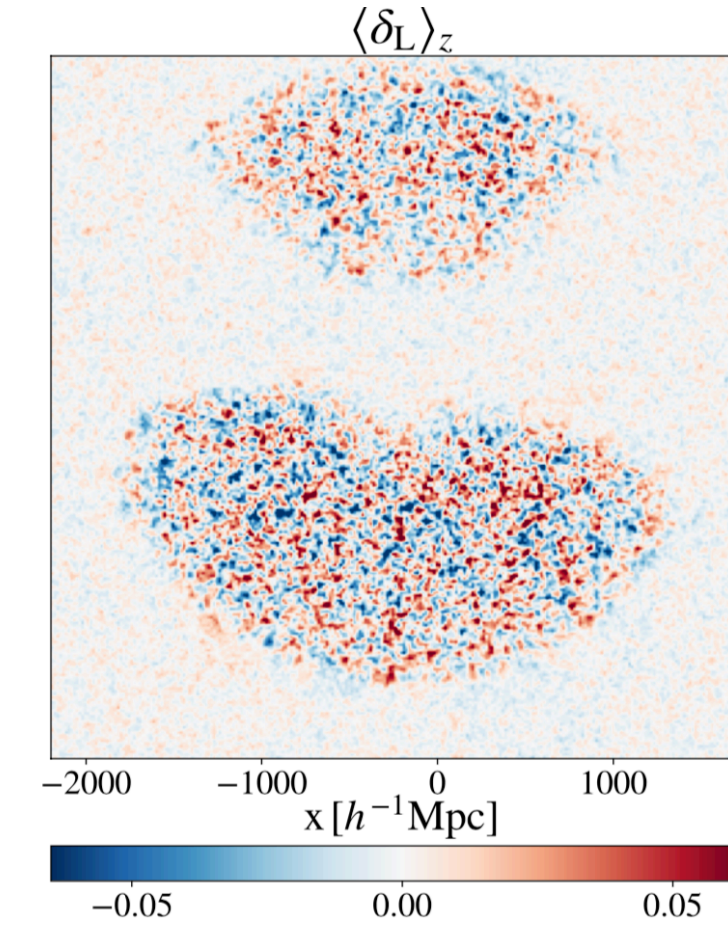
Uncertainty



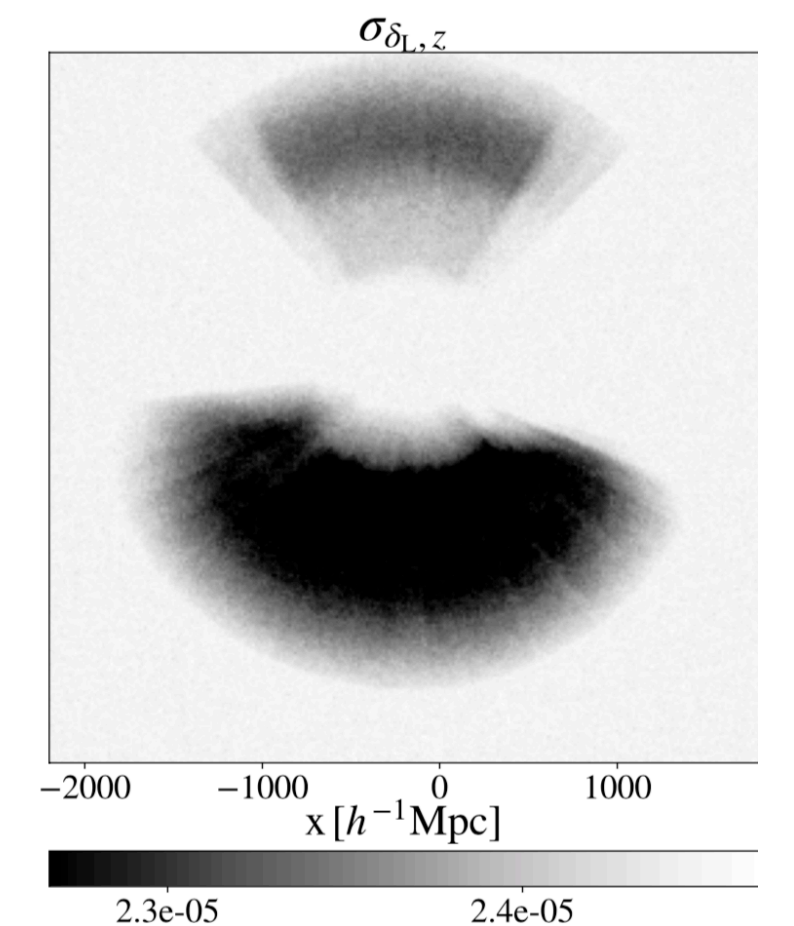
# Results



Inferred density field

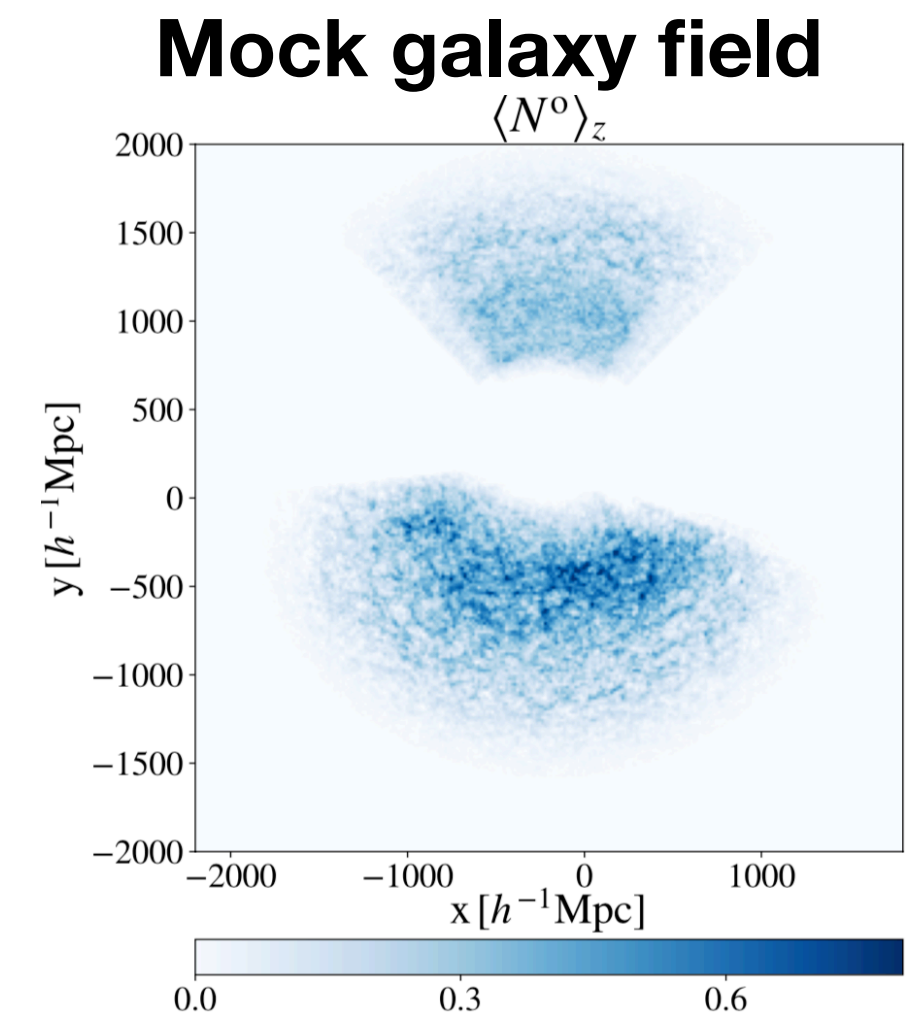
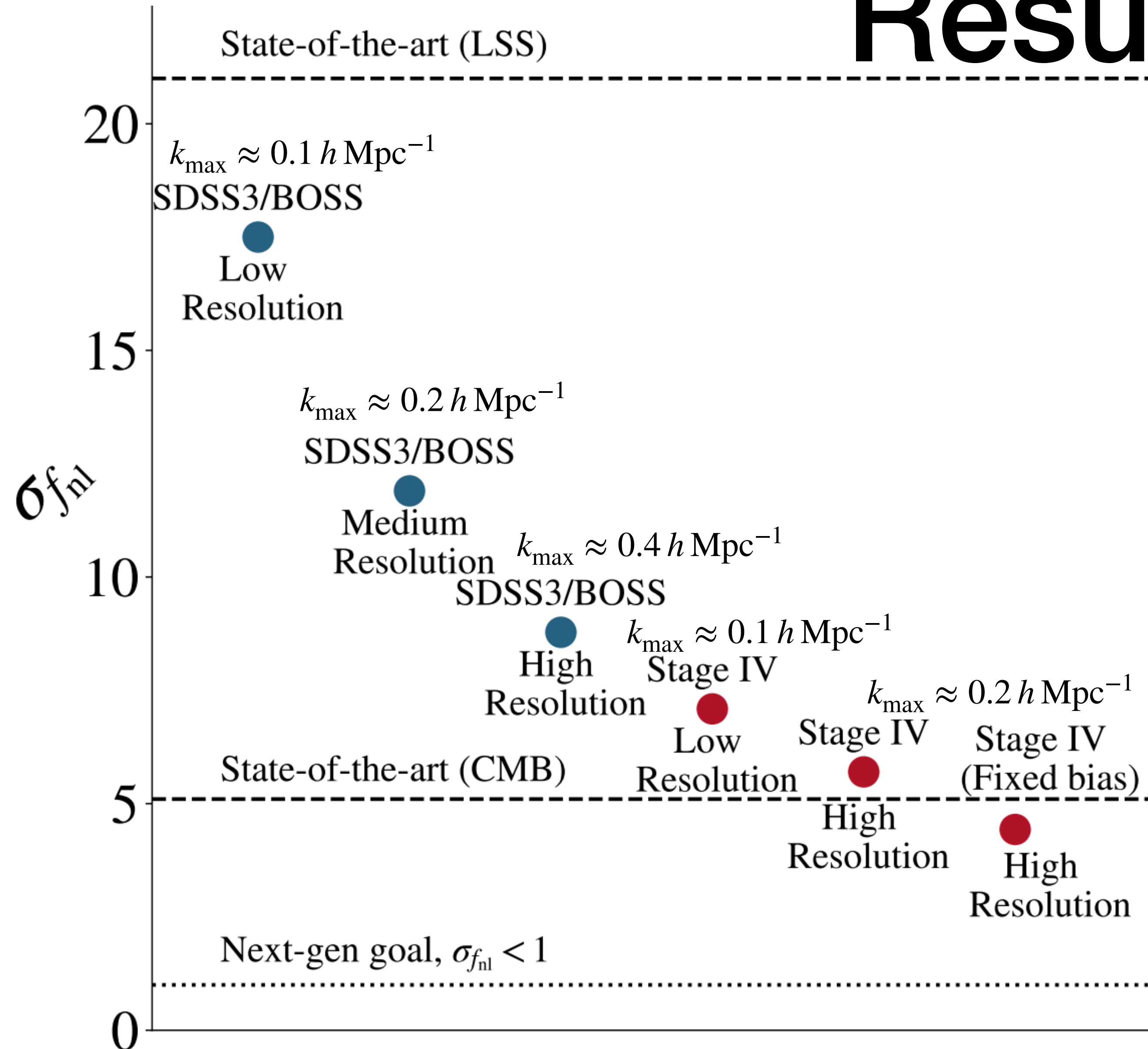


Uncertainty

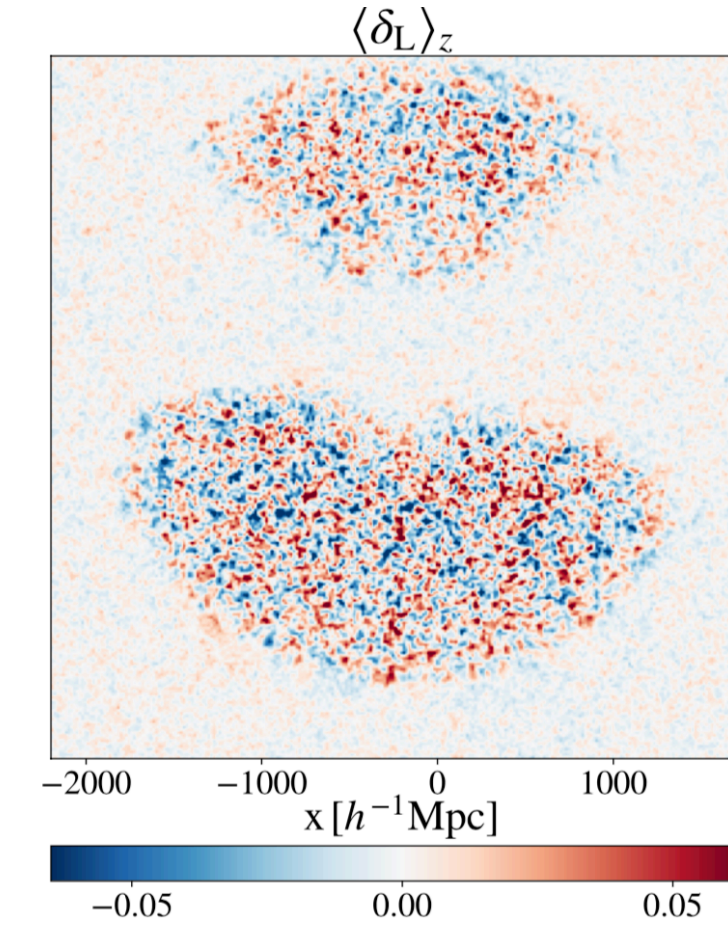


- Go beyond and extract additional information\*

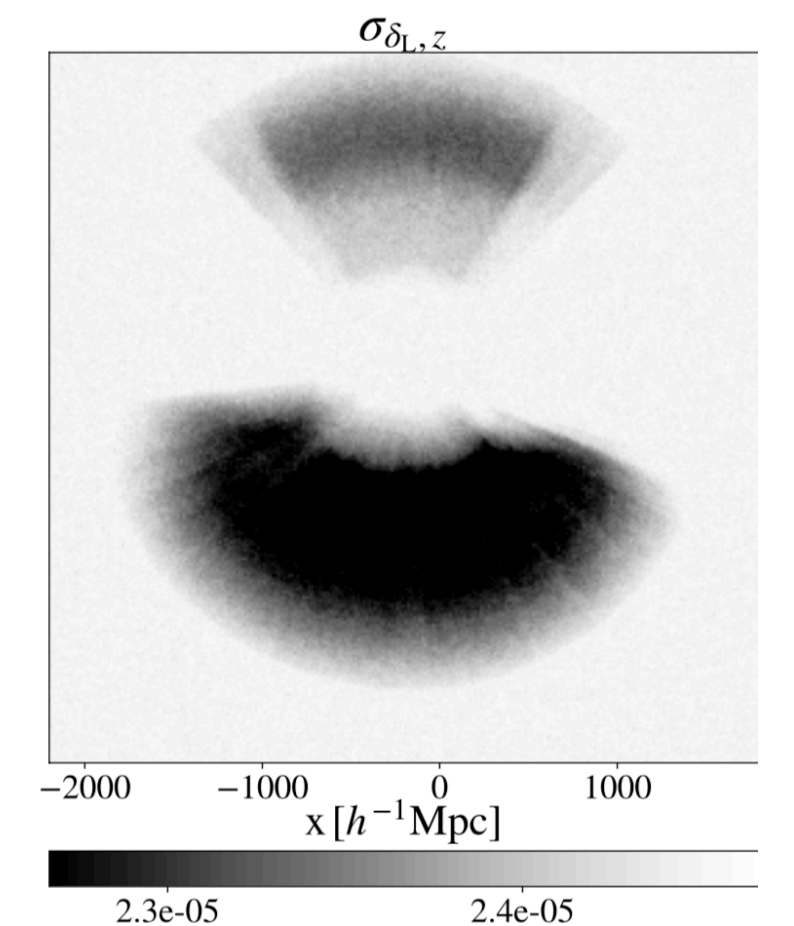
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Inferred density field



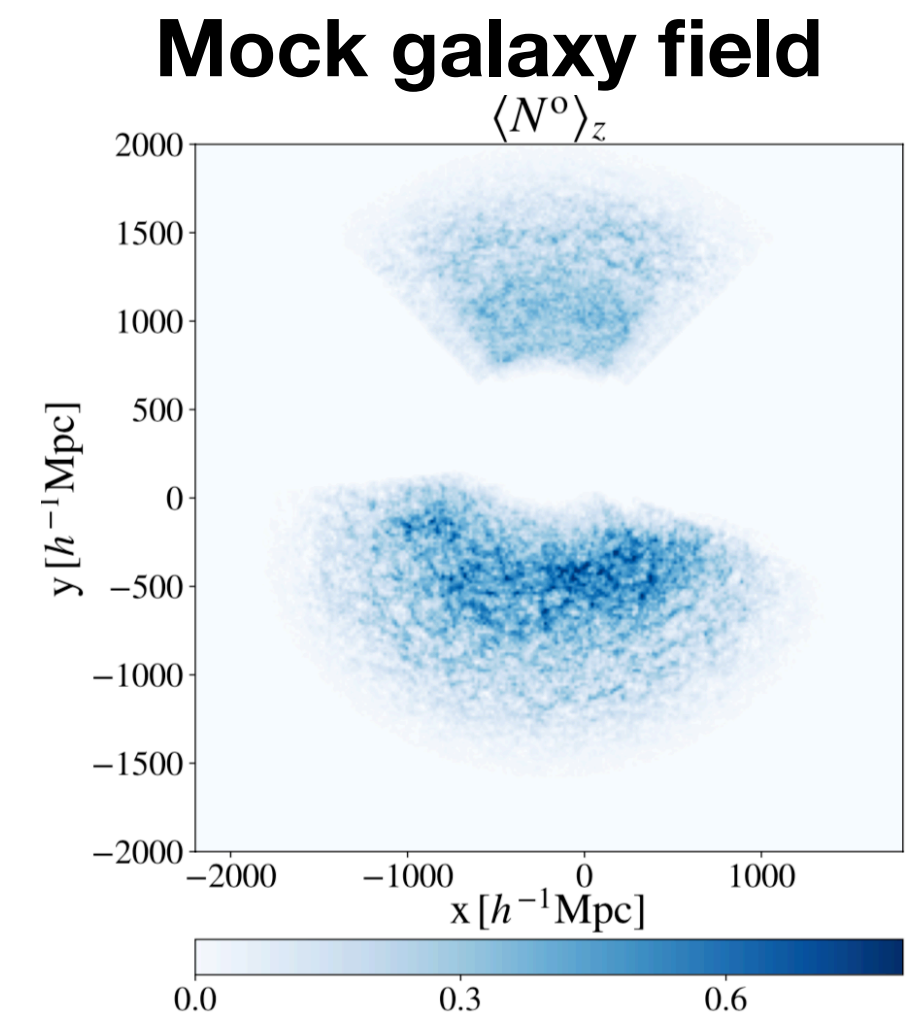
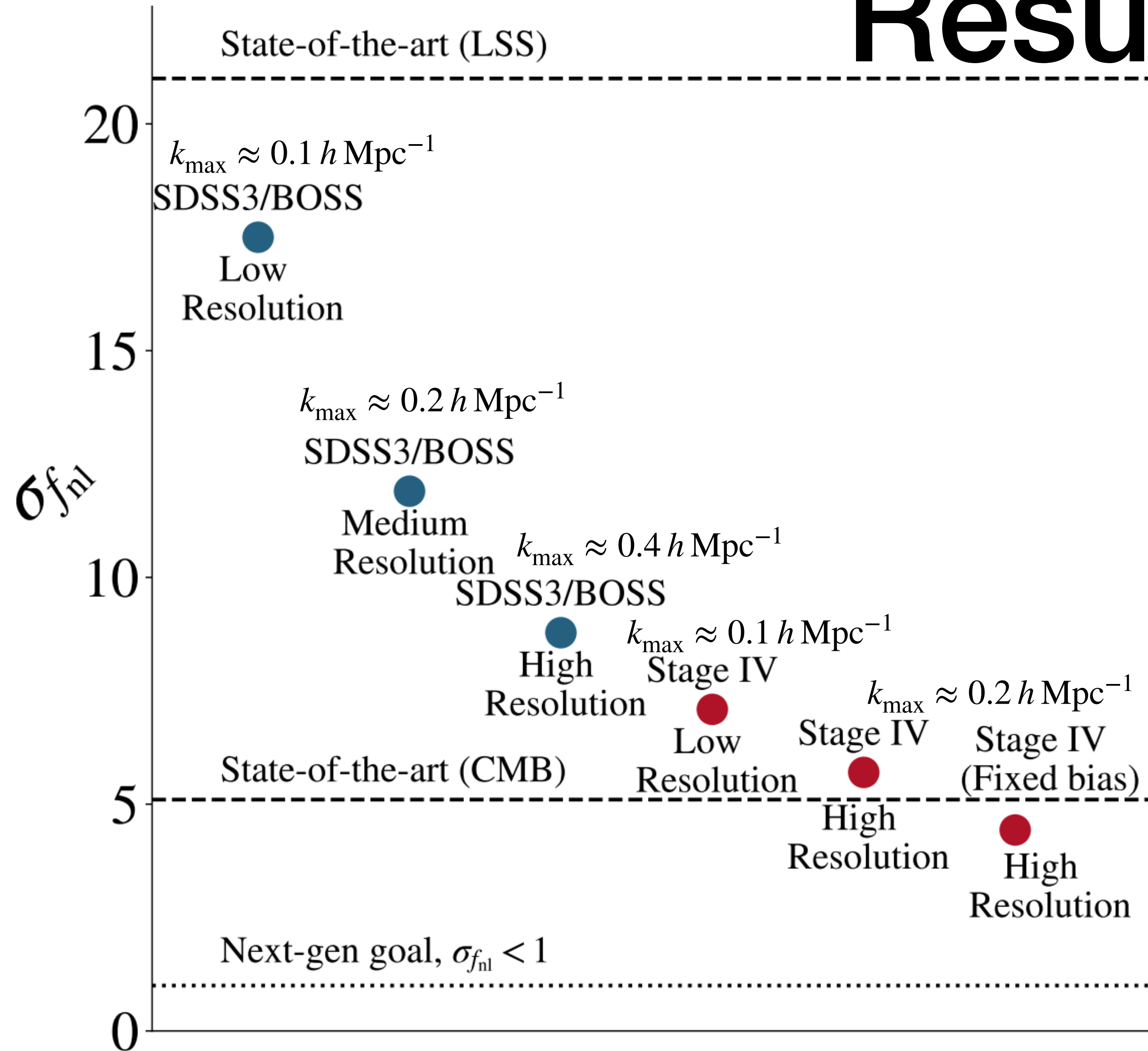
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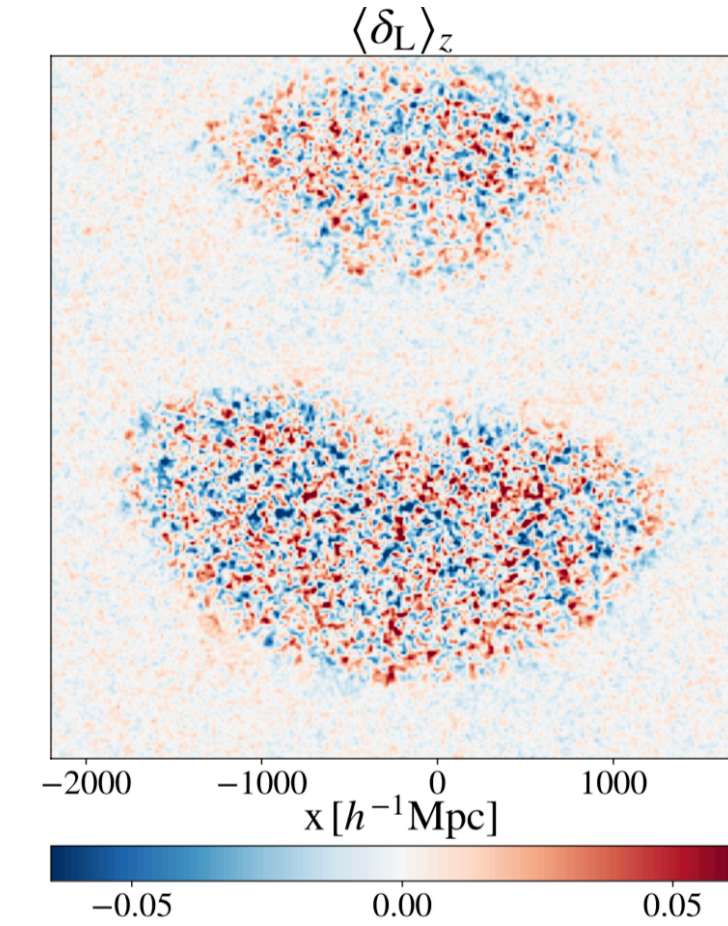
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\*D. Ramanah et al. (2018), N. Porqueres (2021), F. Leclercq & A. Heavens (2021)

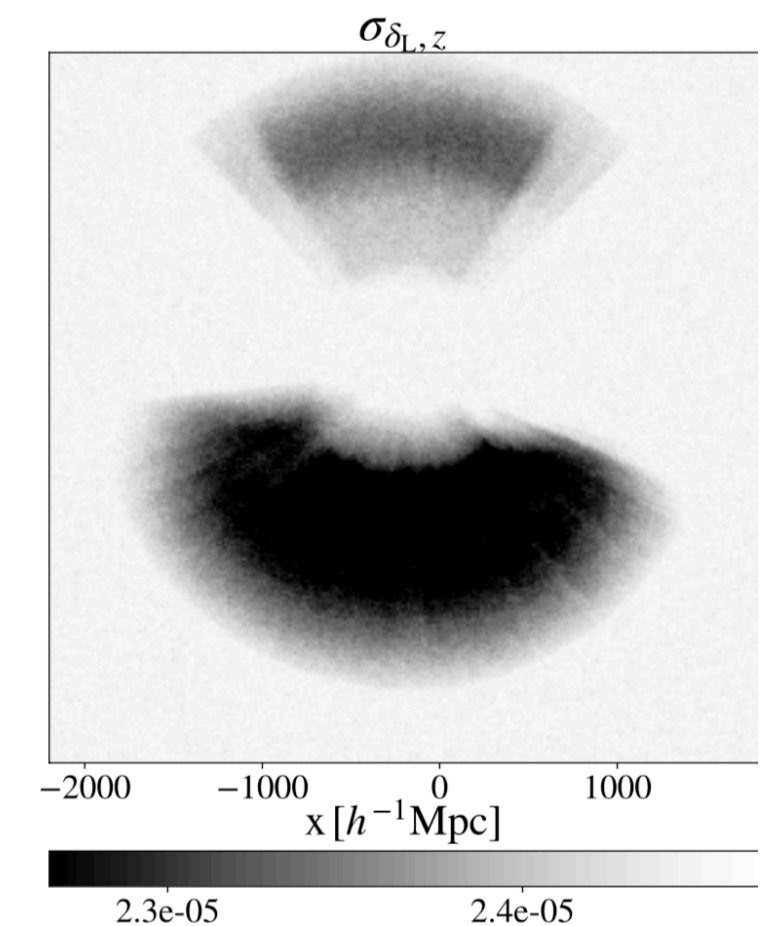
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Inferred density field



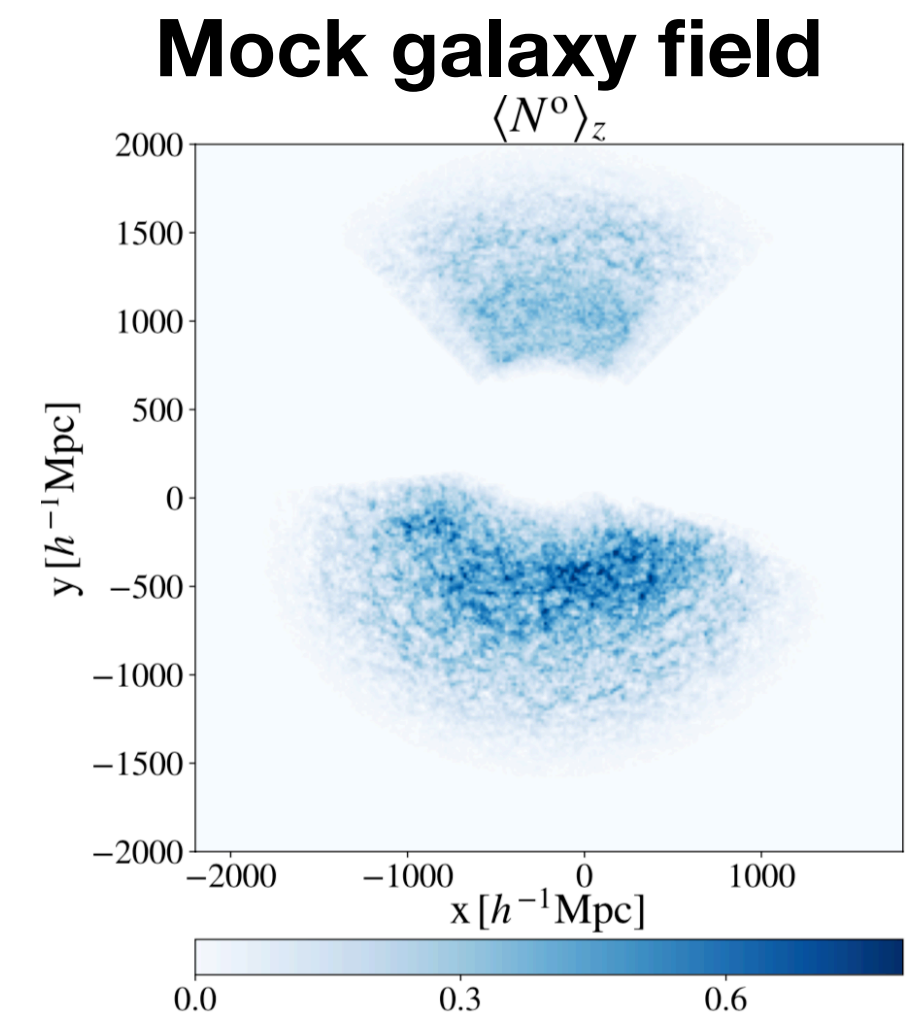
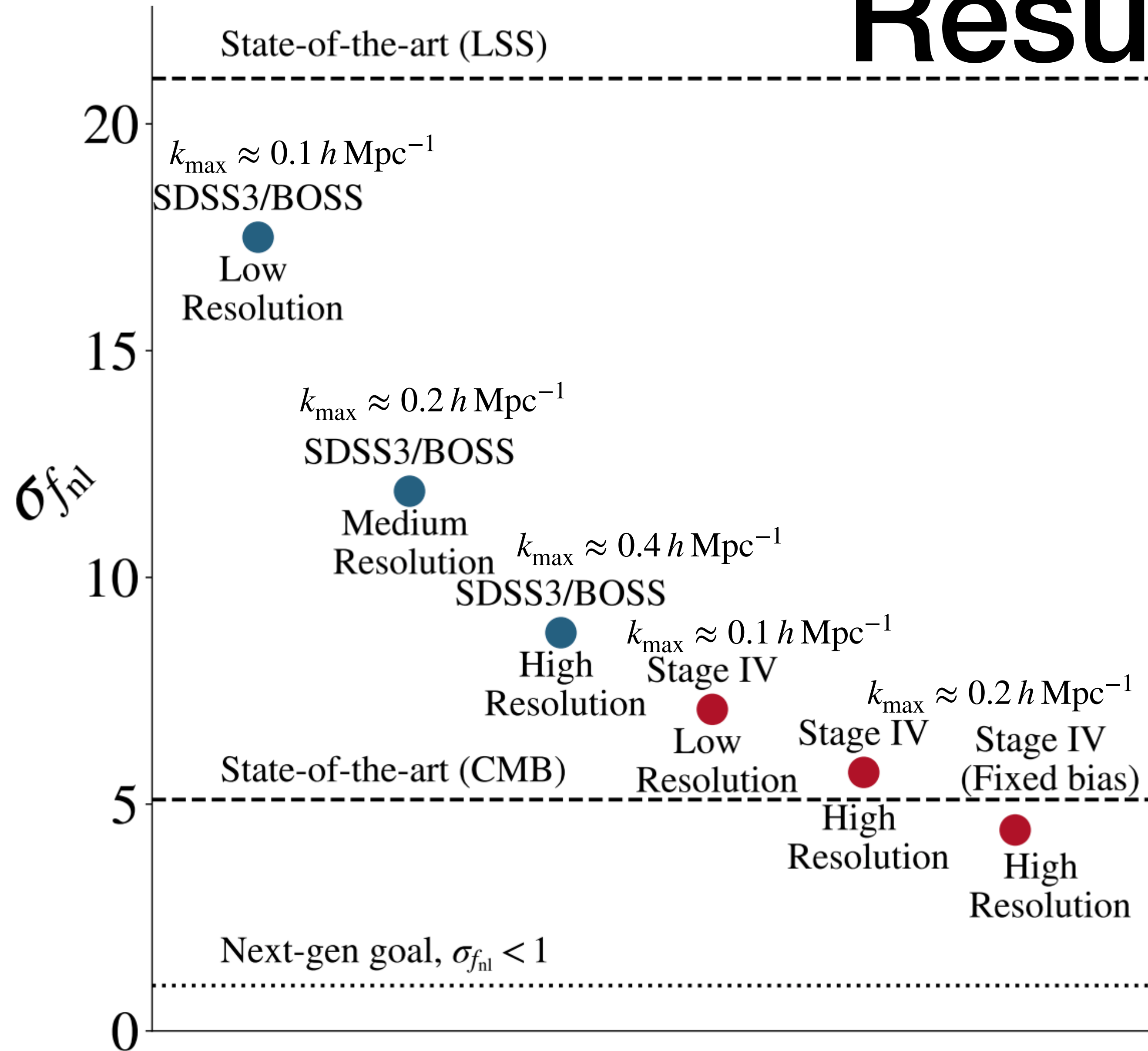
Uncertainty



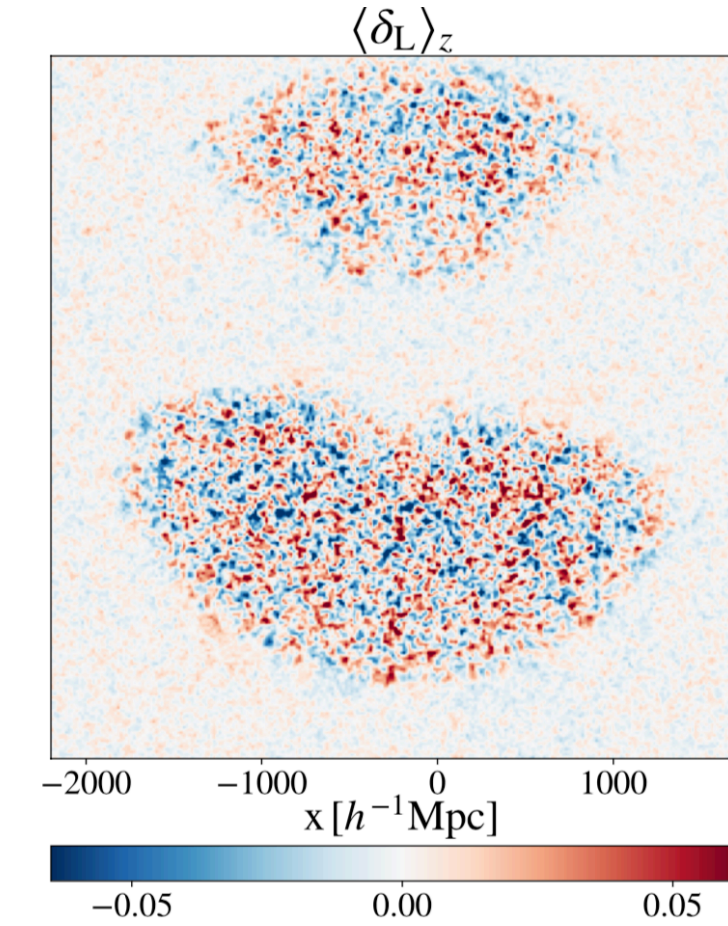
- Go beyond and extract additional information\*
- Disentangle effects and incorporate non-trivial physics

\*D. Ramanah et al. (2018), N. Porqueres (2021), F. Leclercq & A. Heavens (2021)

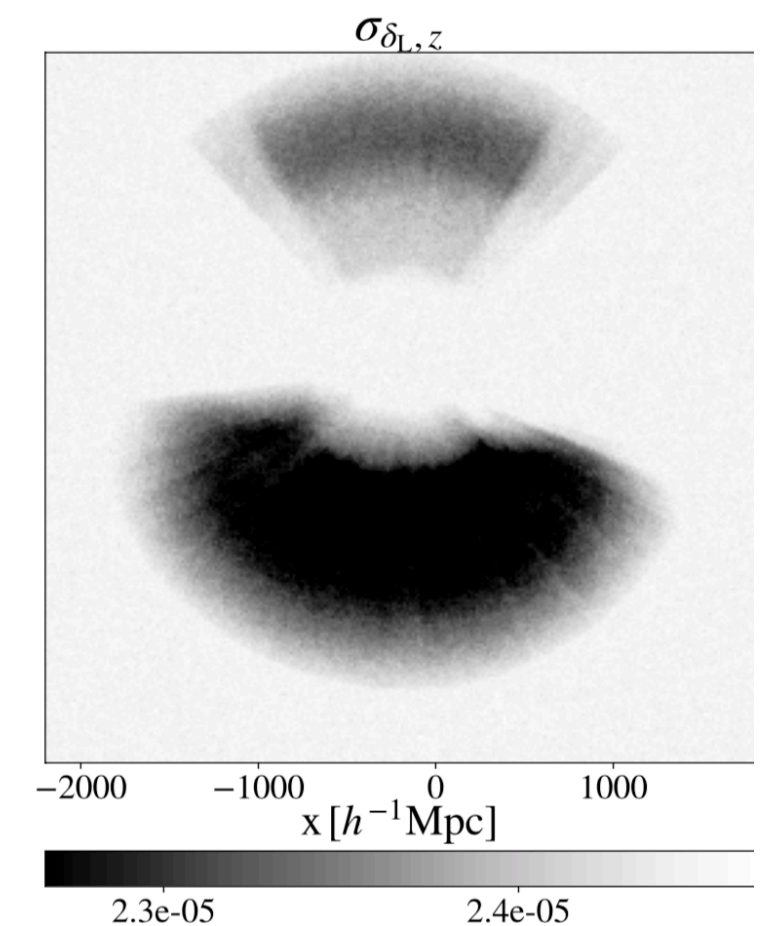
# Results



Inferred density field



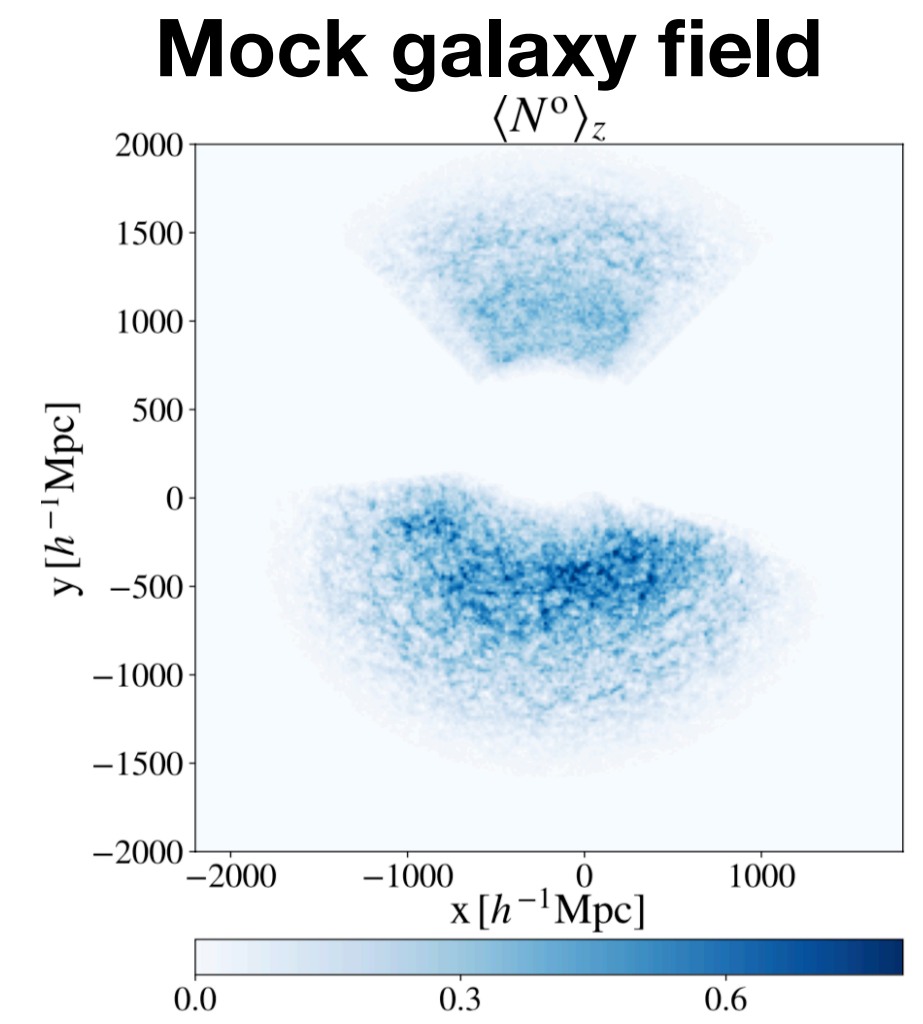
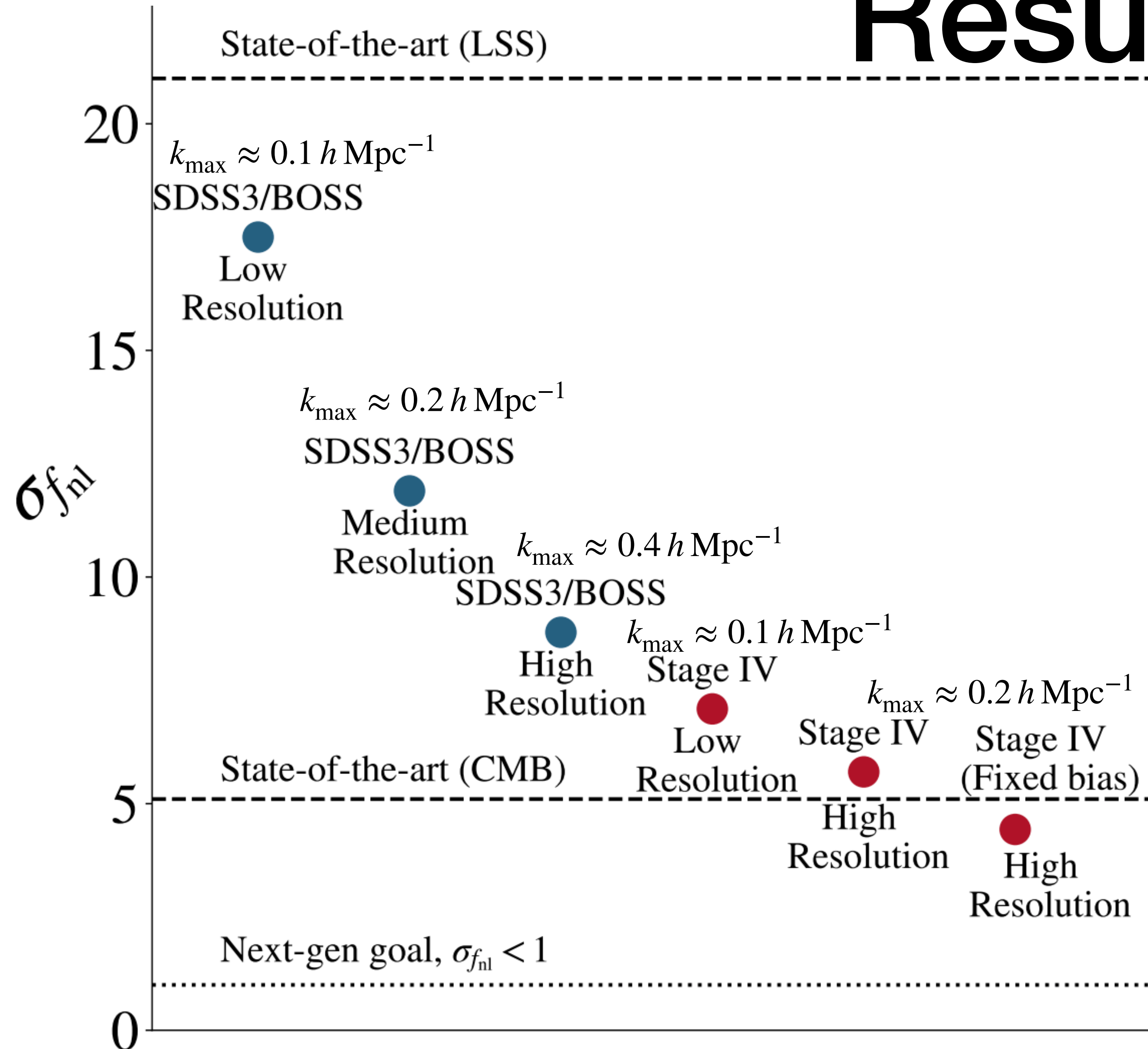
Uncertainty



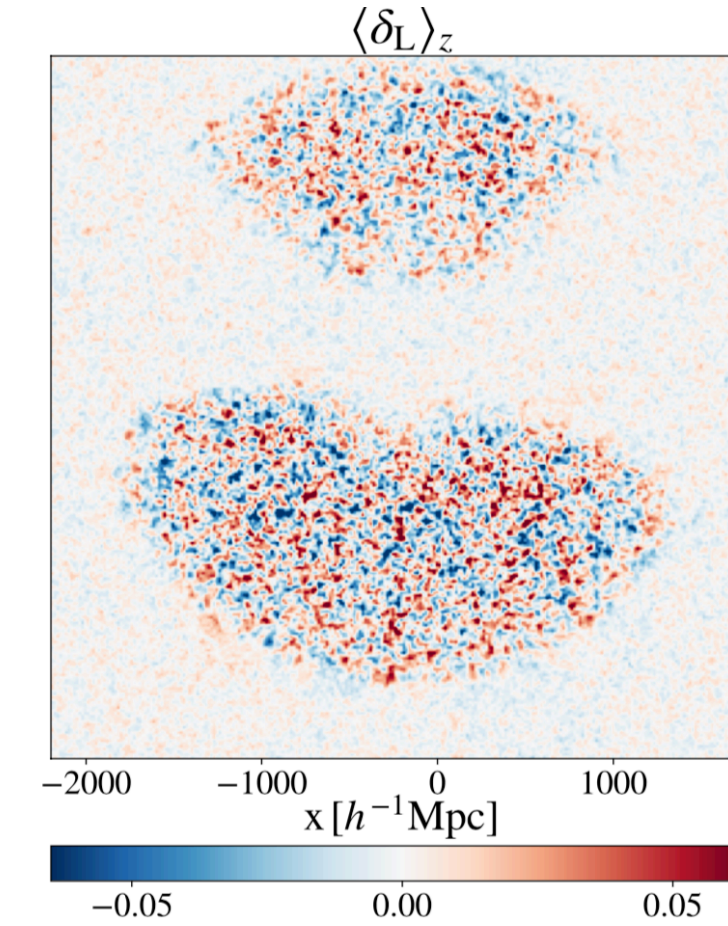
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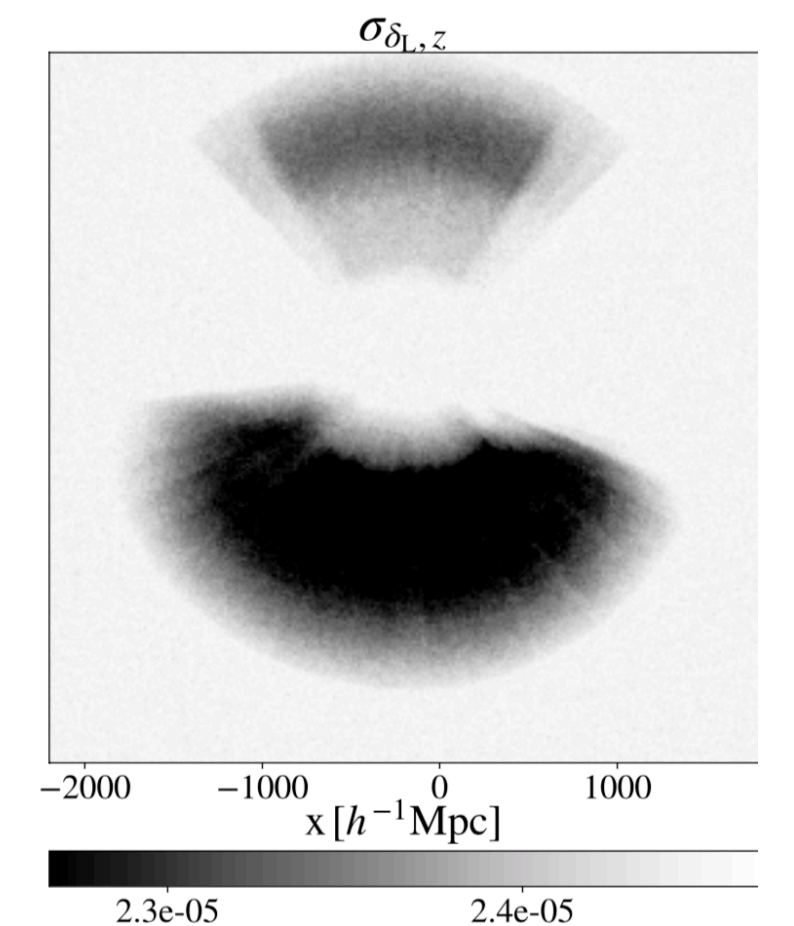
# Results



Inferred density field



Uncertainty



- Go beyond and extract additional information\*
  - Disentangle effects and incorporate non-trivial physics
  - Robustness to systematic effects\*\*
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- \*\*G. Lavaux et al. (2019)



# Opportunities for field-level inference

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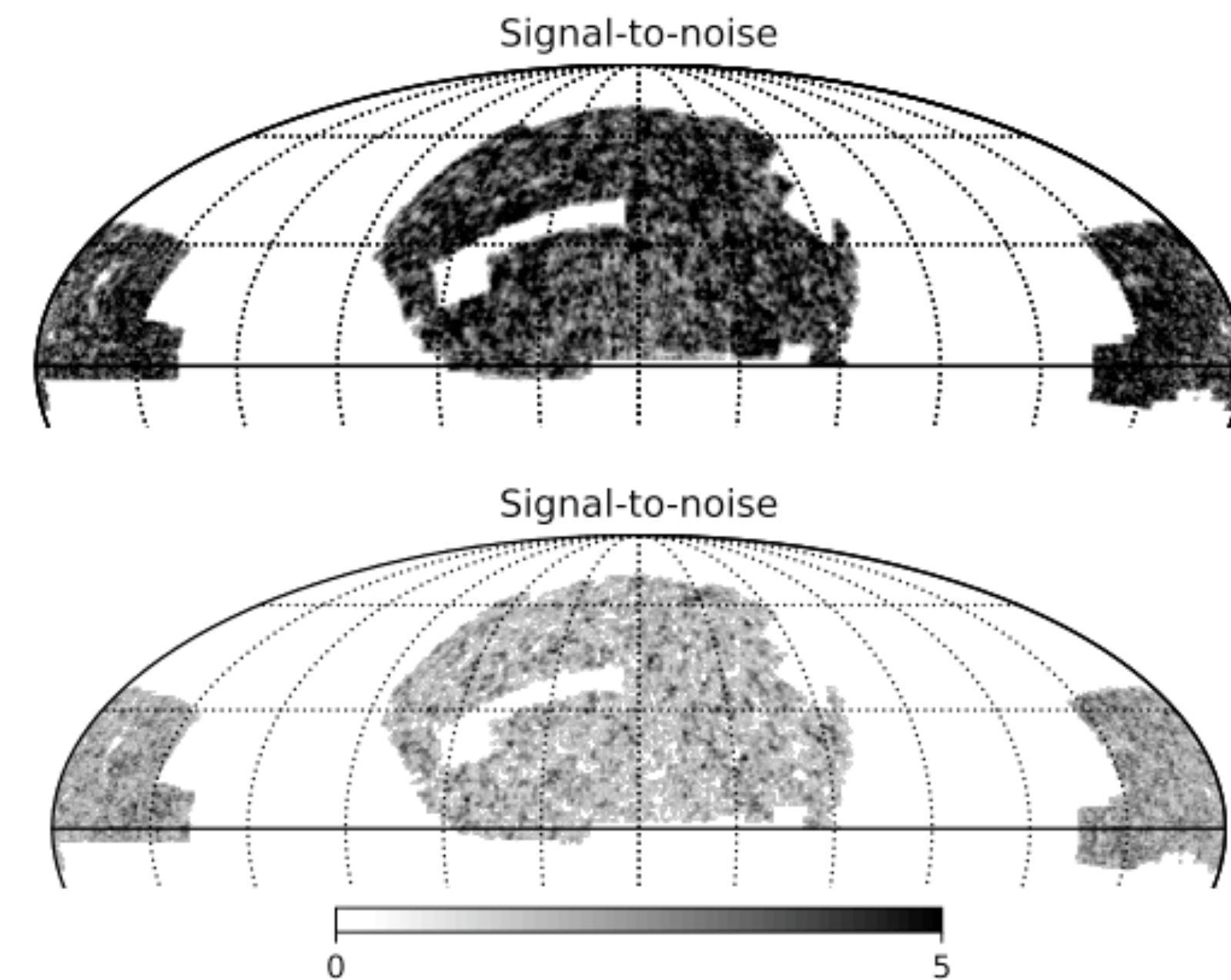
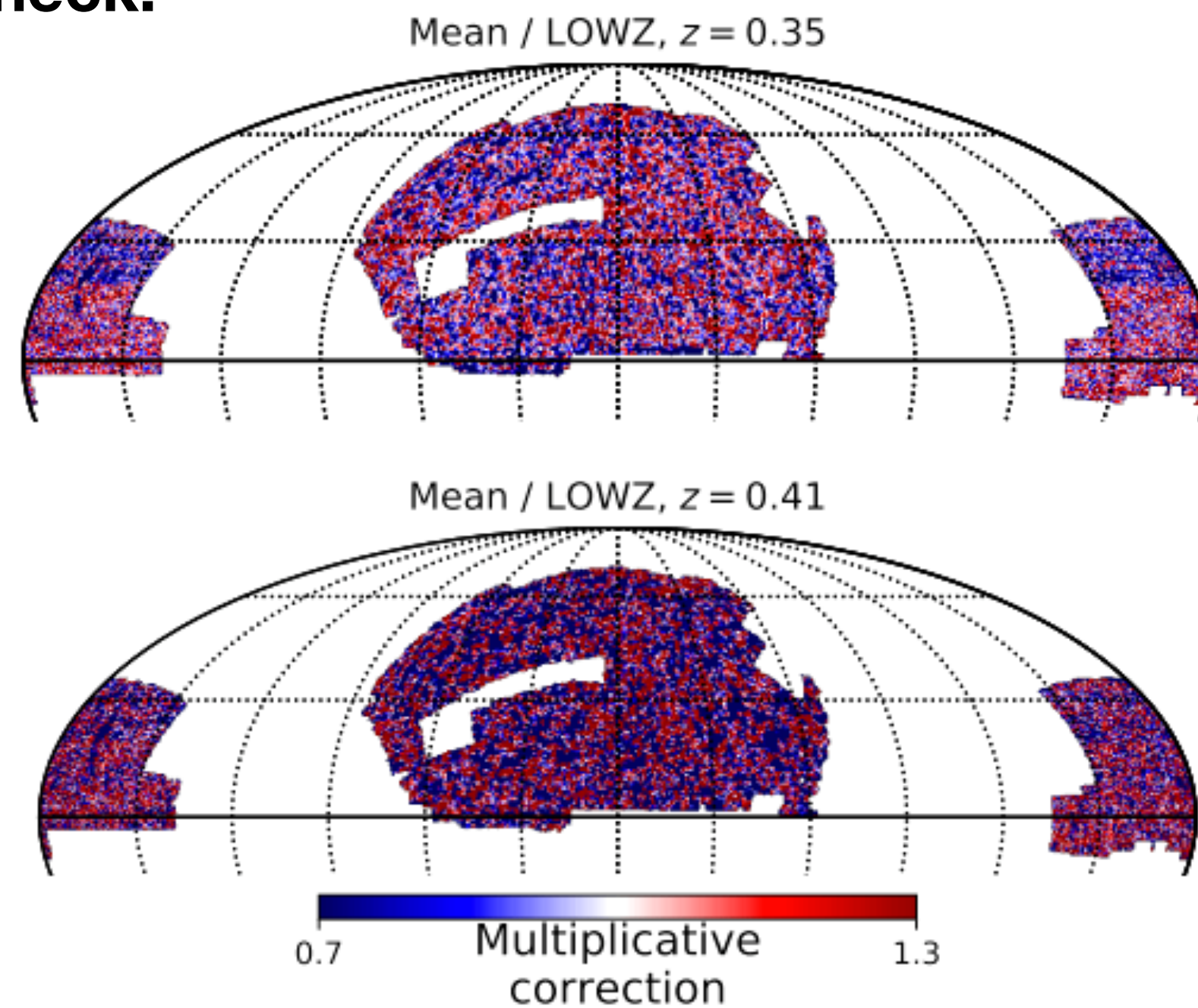
**Handle large-scale survey systematics?**

- Physics-informed model**
- Integrate out unphysical signals**
- Go back and check:**

# Opportunities for field-level inference

Handle large-scale survey systematics?

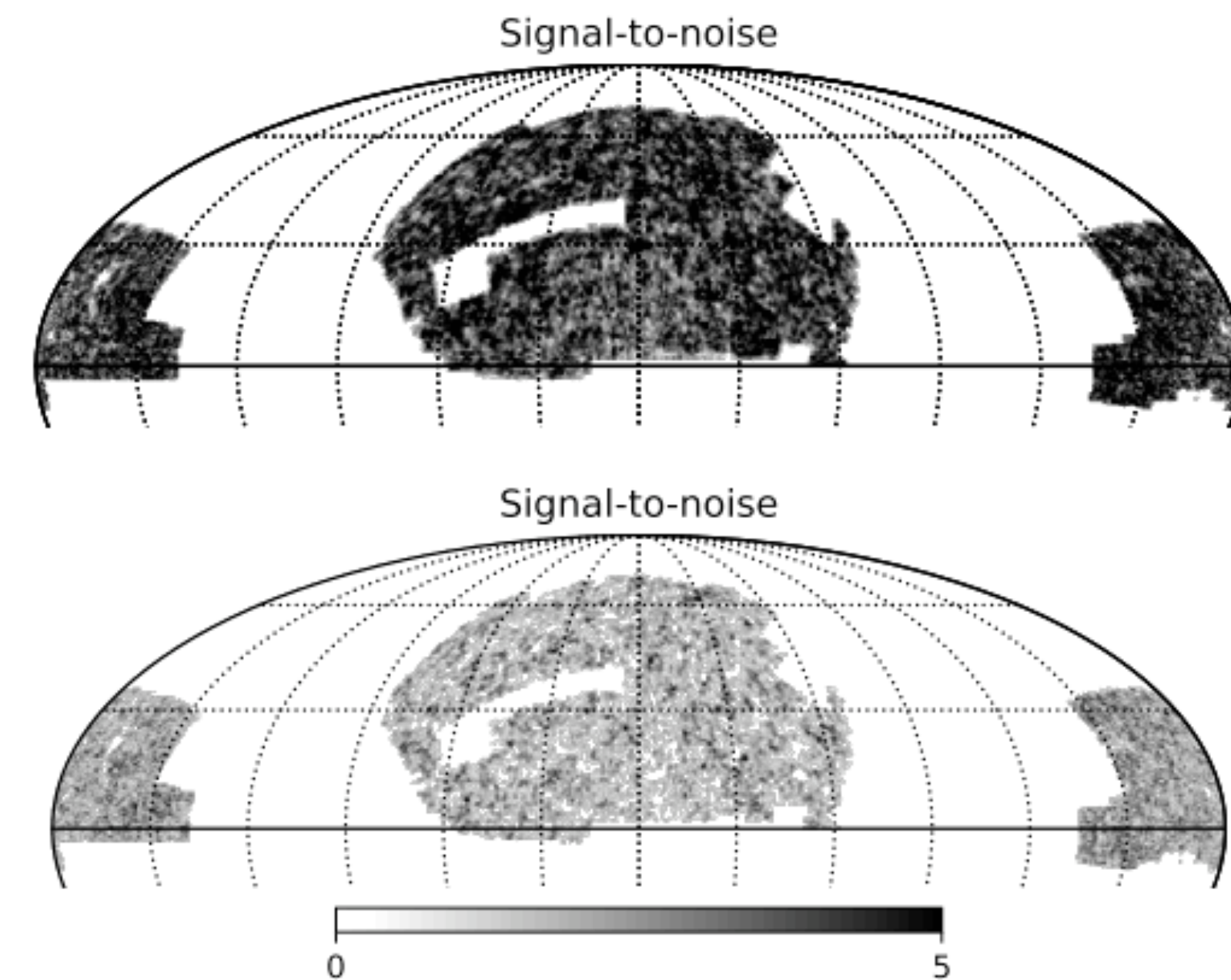
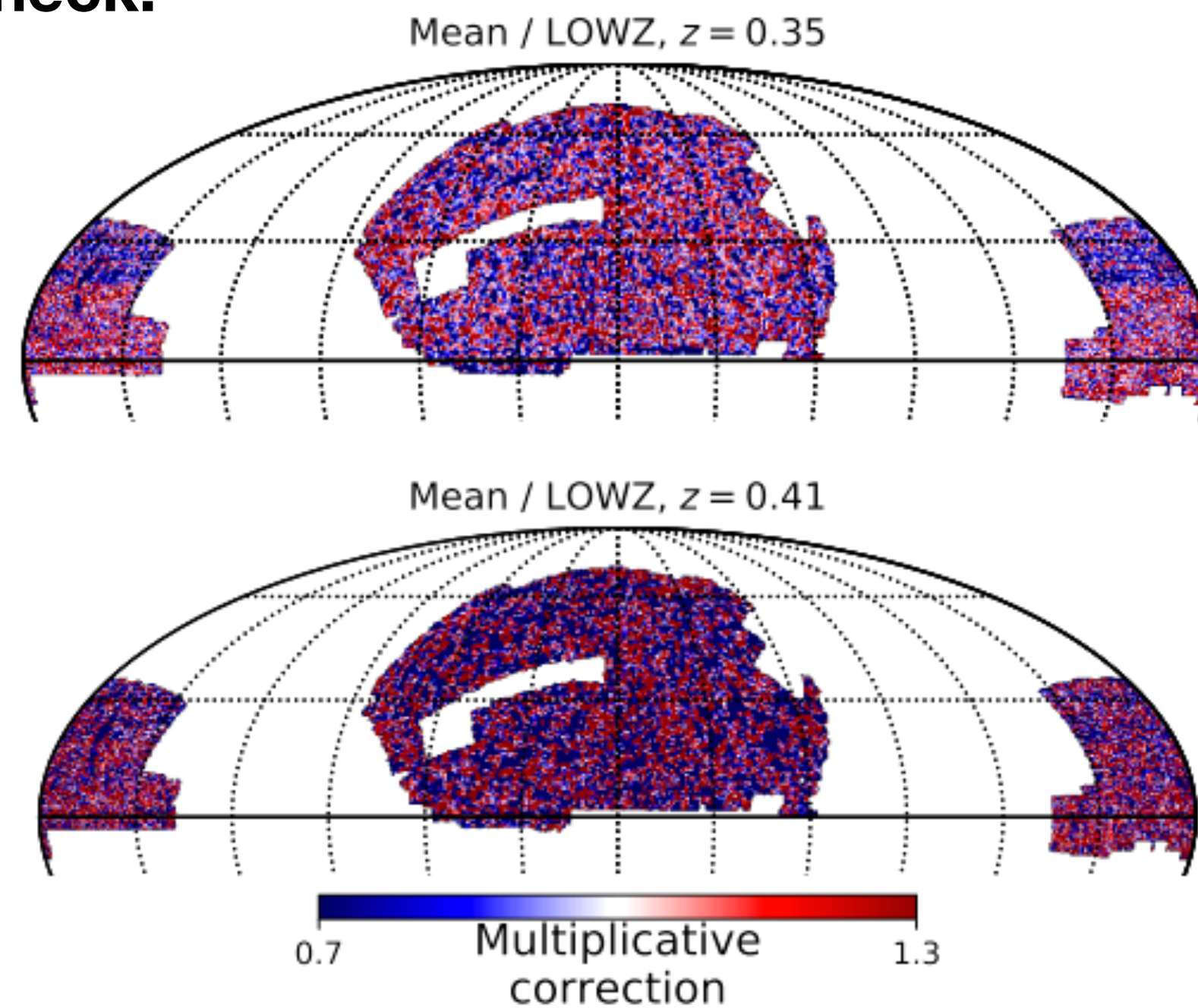
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# Opportunities for field-level inference

Handle large-scale survey systematics?

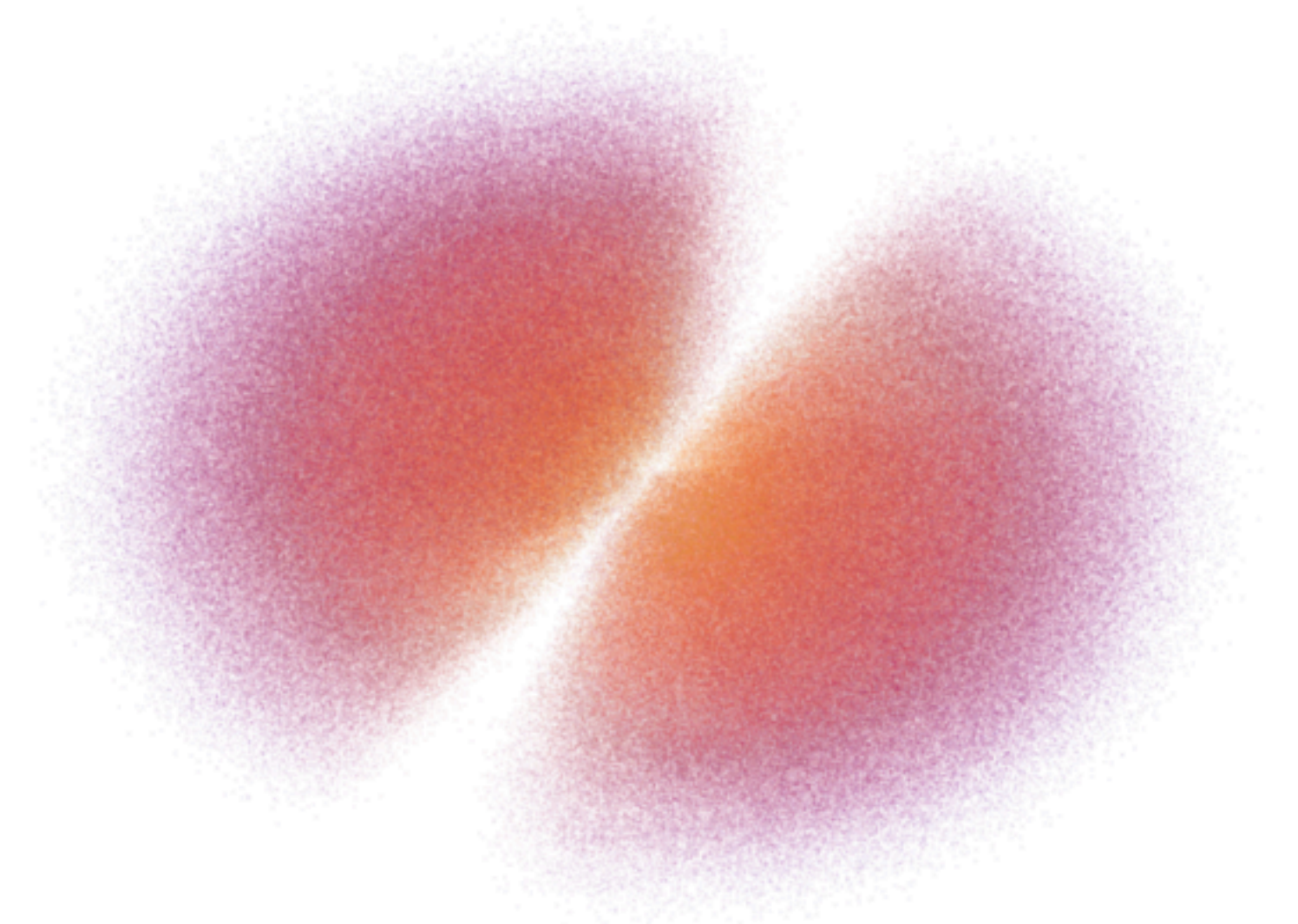
- Physics-informed model
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See Florent Leclercq's talk

# Preliminary work: Quiaia analysis

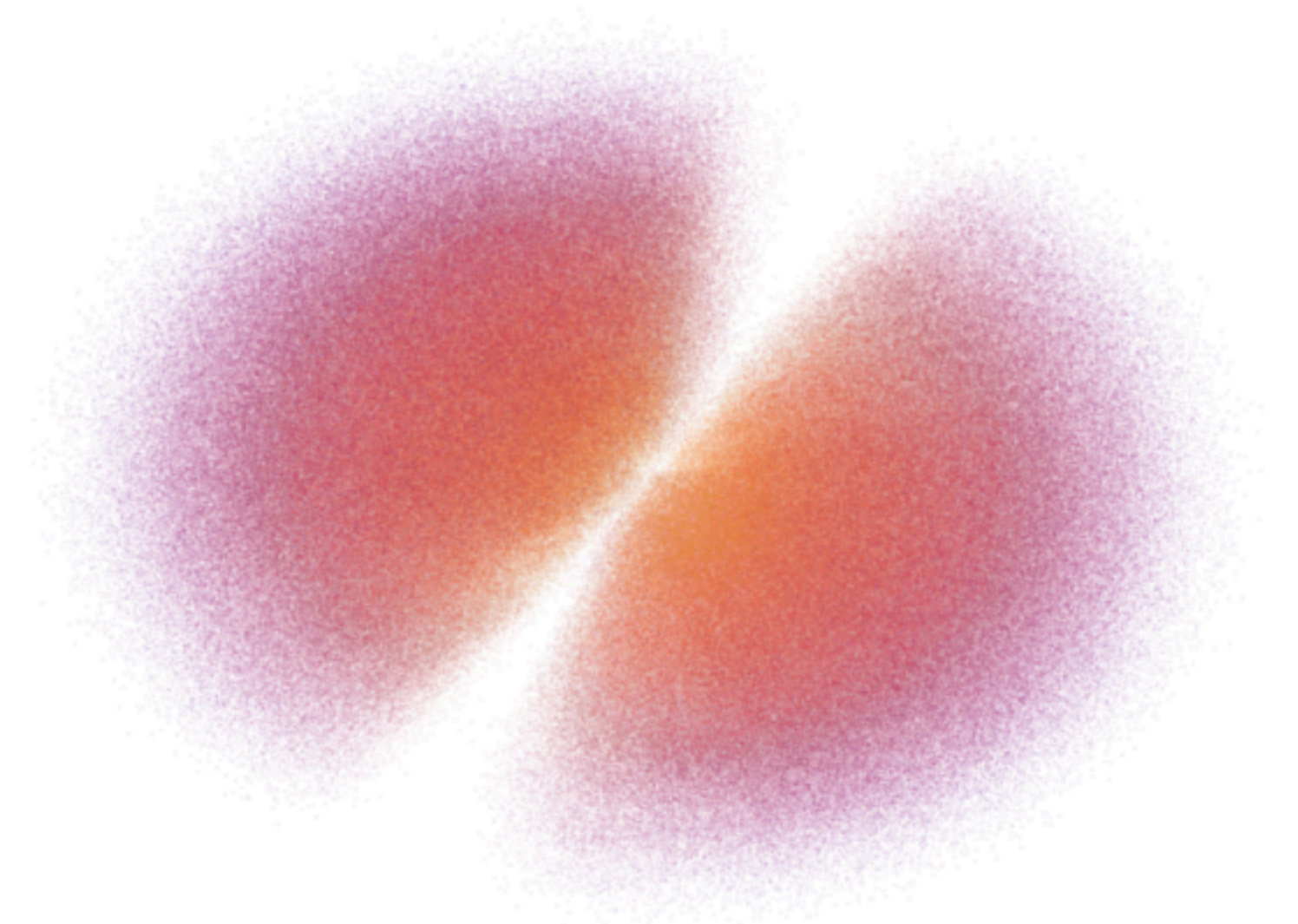
# Preliminary work: Quiaia analysis



**Storey-Fisher et al. (2023)**

# Preliminary work: Quiaia analysis

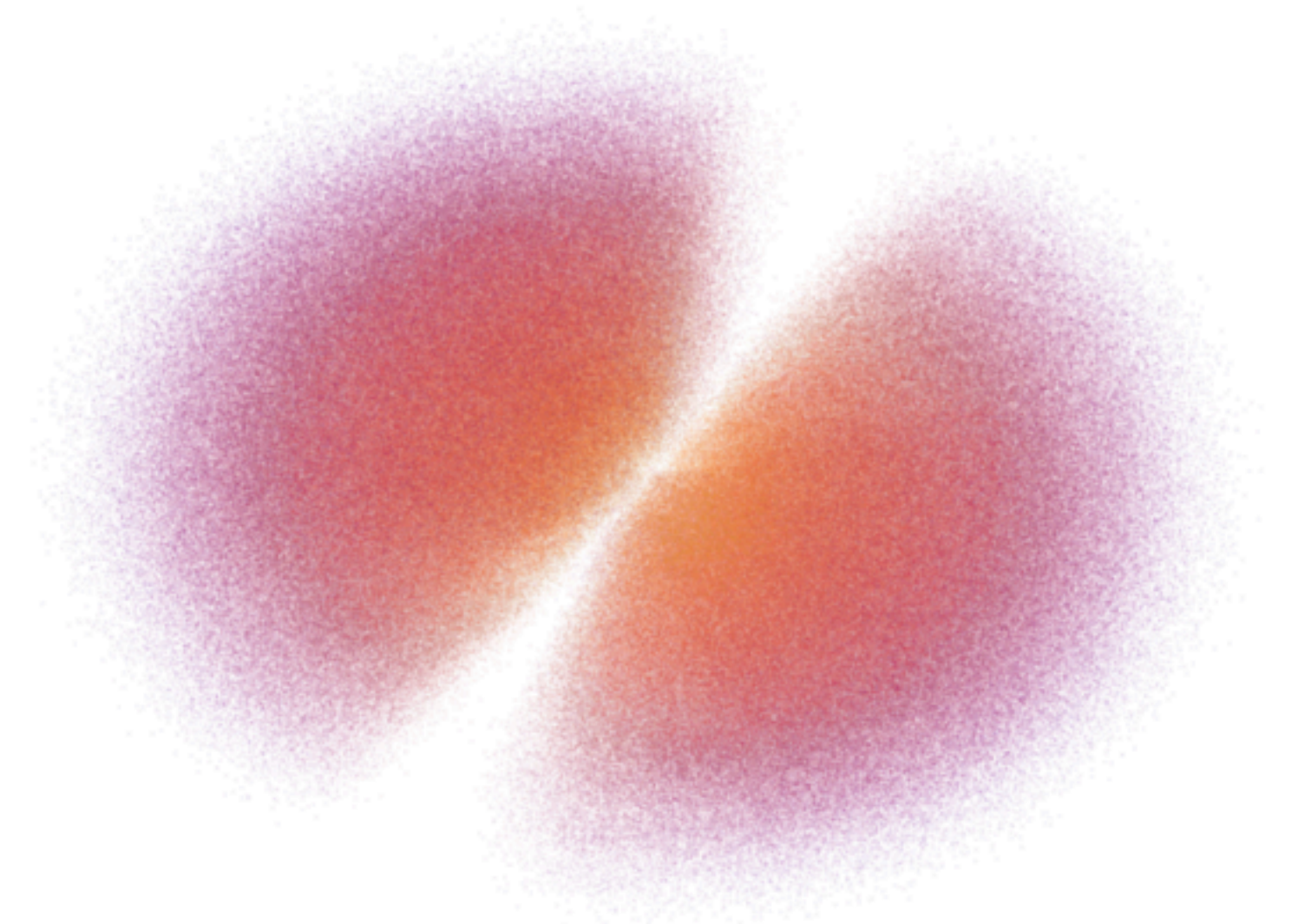
- Quasar compilation from *Gaia*  
(Storey-Fisher et al. (2023))



**Storey-Fisher et al. (2023)**

# Preliminary work: Quiaia analysis

- Quasar compilation from *Gaia* (Storey-Fisher et al. (2023))
- Full-sky, large volume ( $L=10$  Gpc/ $h$ )

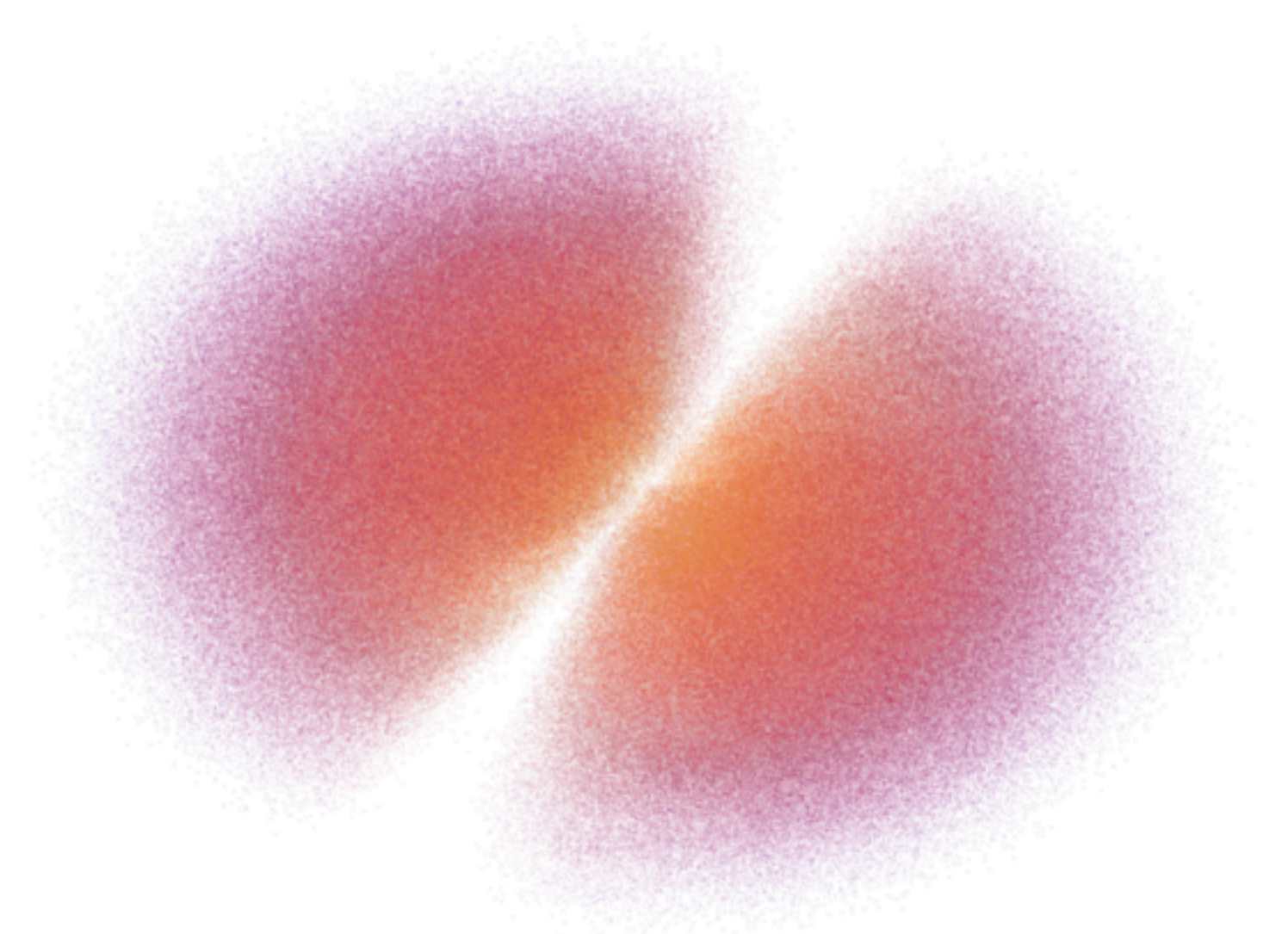


Storey-Fisher et al. (2023)



# Preliminary work: Quiaia analysis

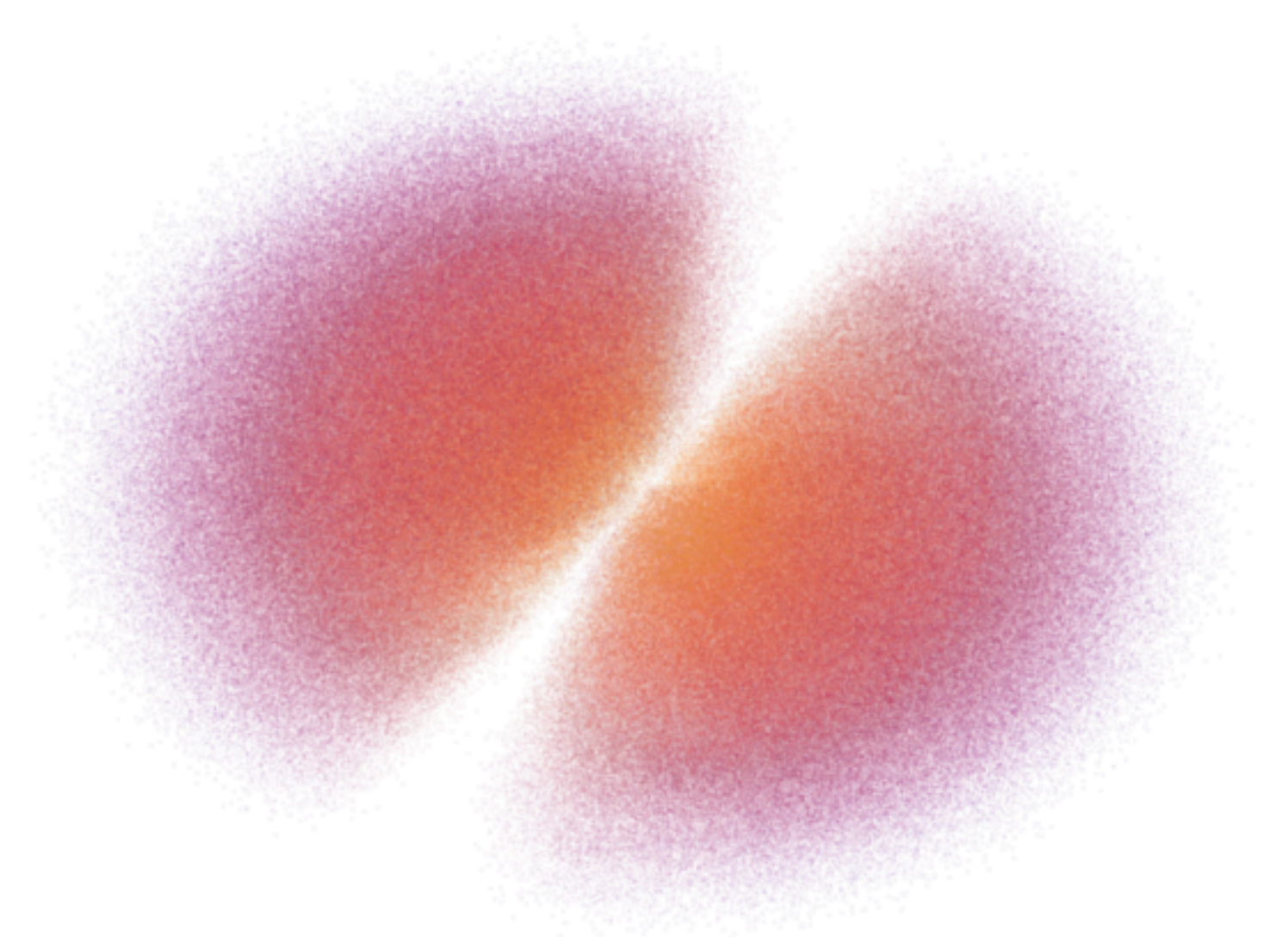
- Quasar compilation from *Gaia* (Storey-Fisher et al. (2023))
- Full-sky, large volume ( $L=10$  Gpc/ $h$ )
- Sparse data set ( $\sim 1.3$  million quasars in total)



Storey-Fisher et al. (2023)

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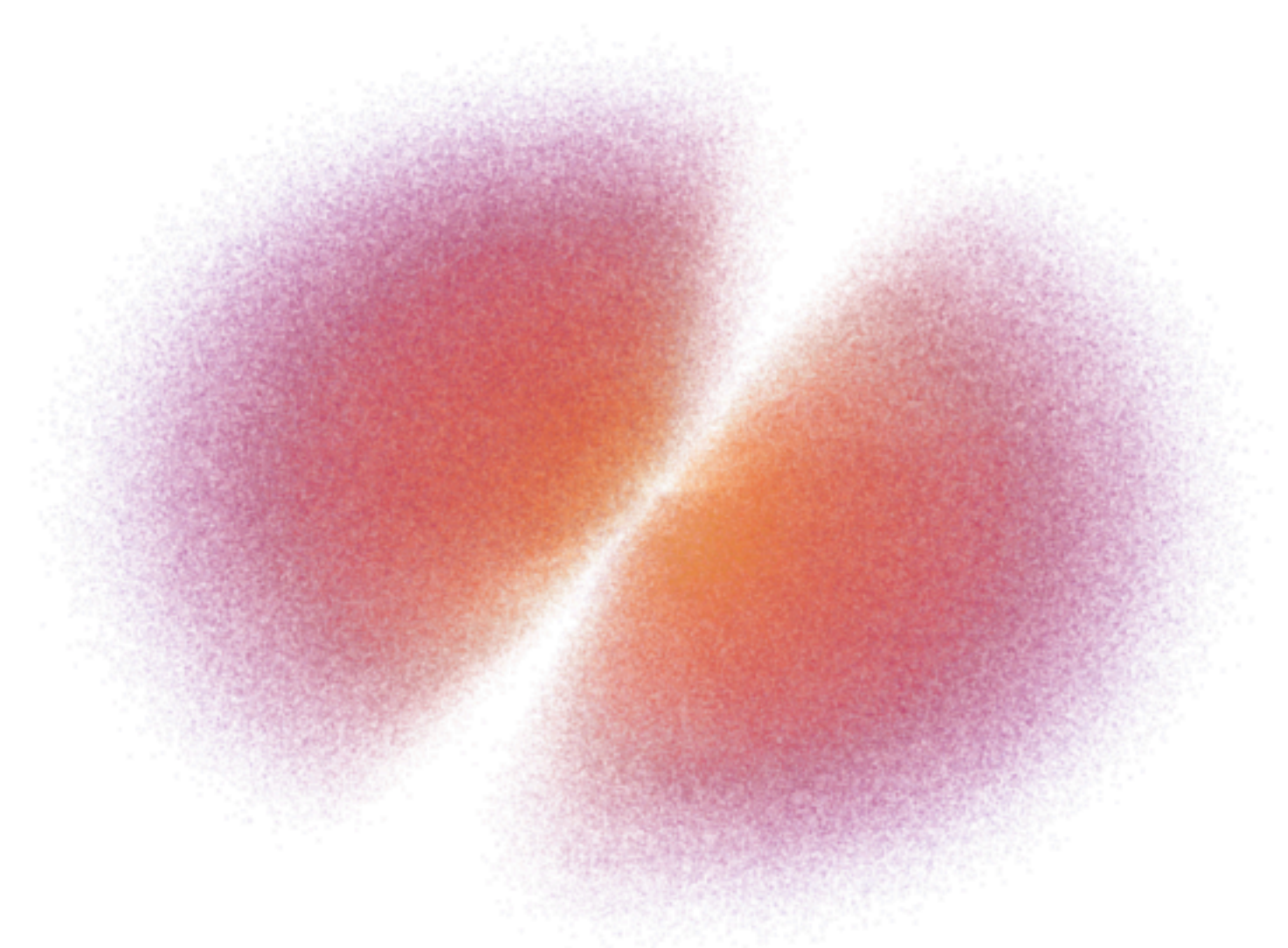
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Storey-Fisher et al. (2023)

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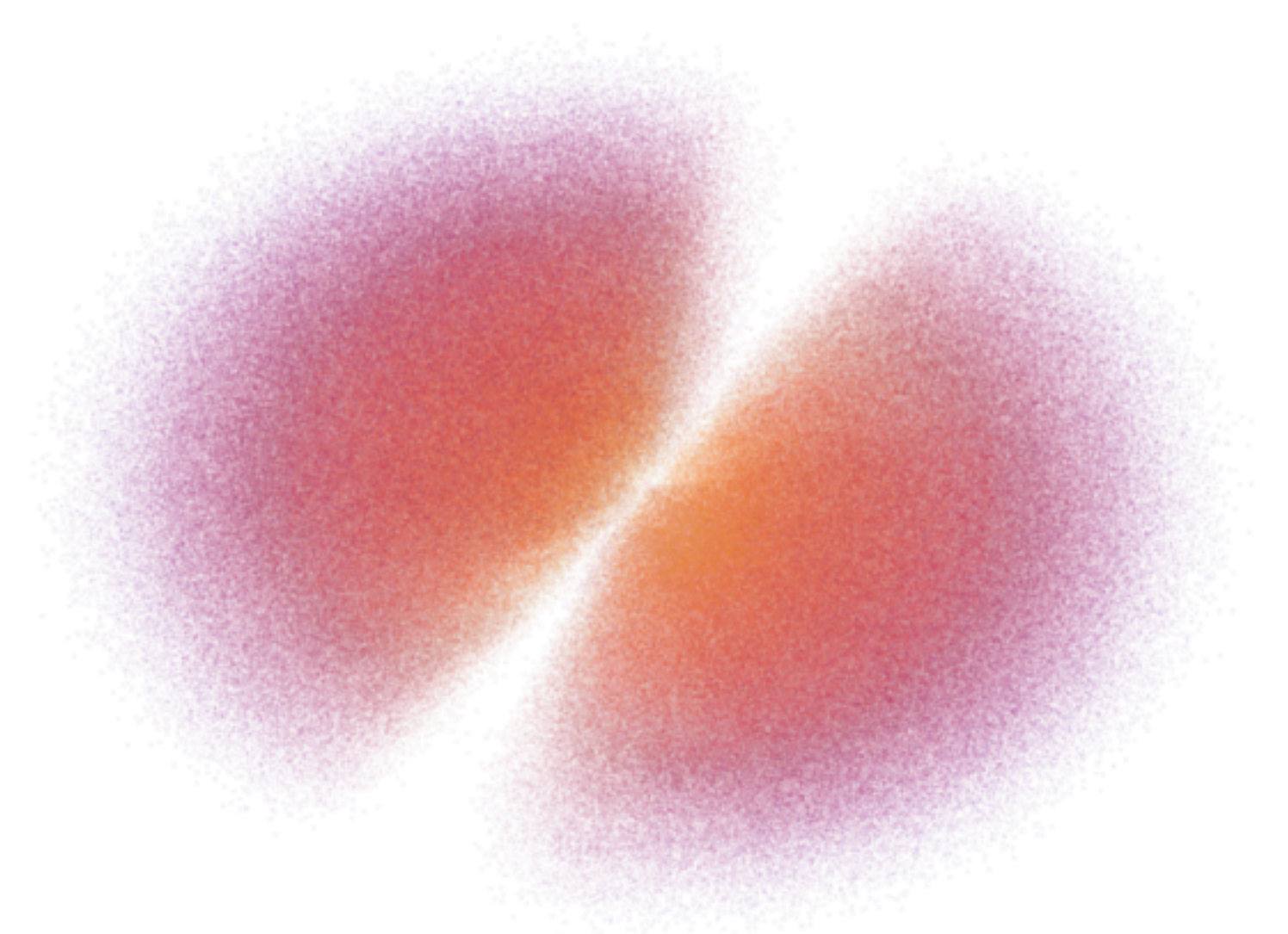
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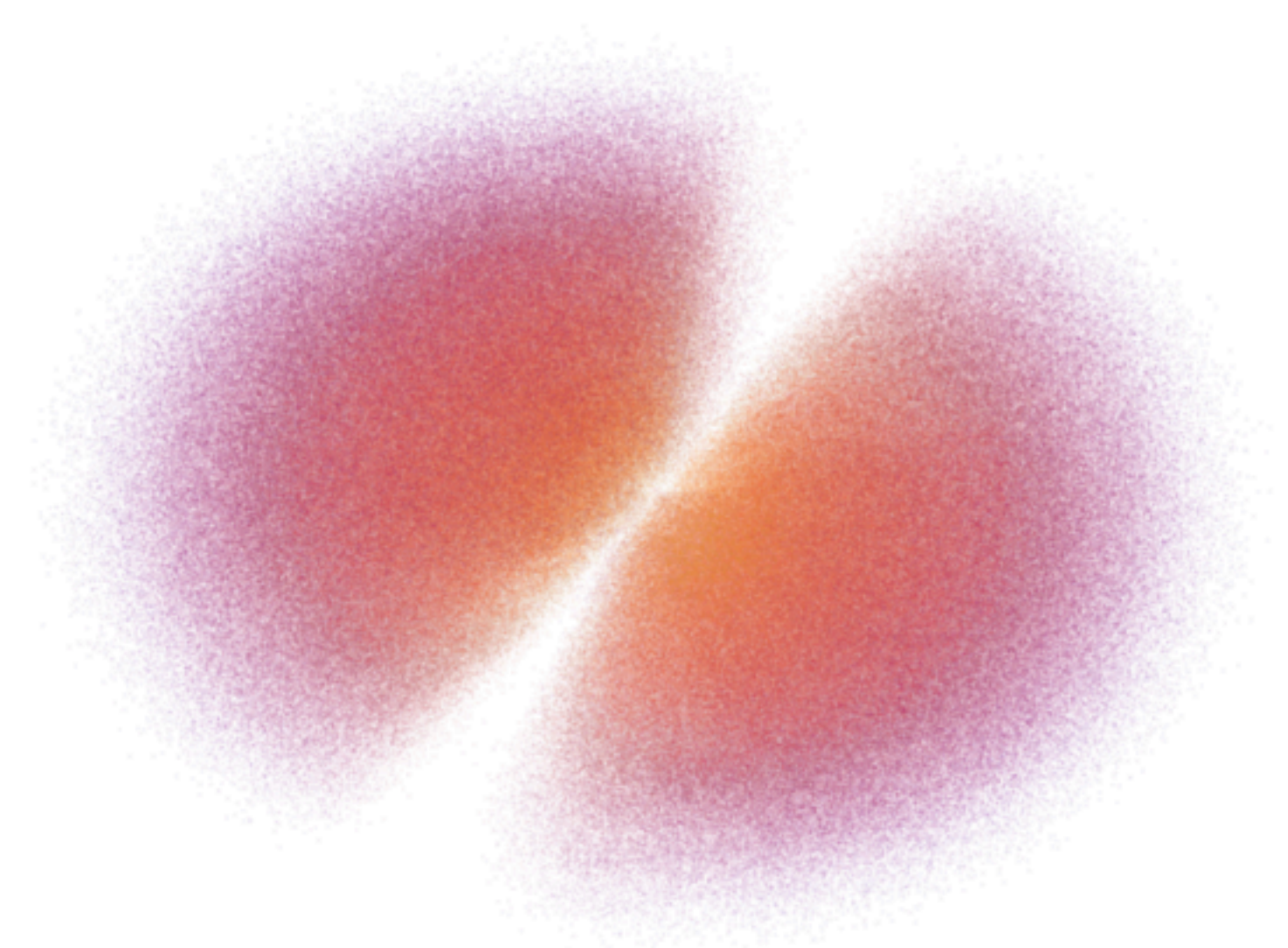
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  - **Large-scale** reconstruction



Storey-Fisher et al. (2023)

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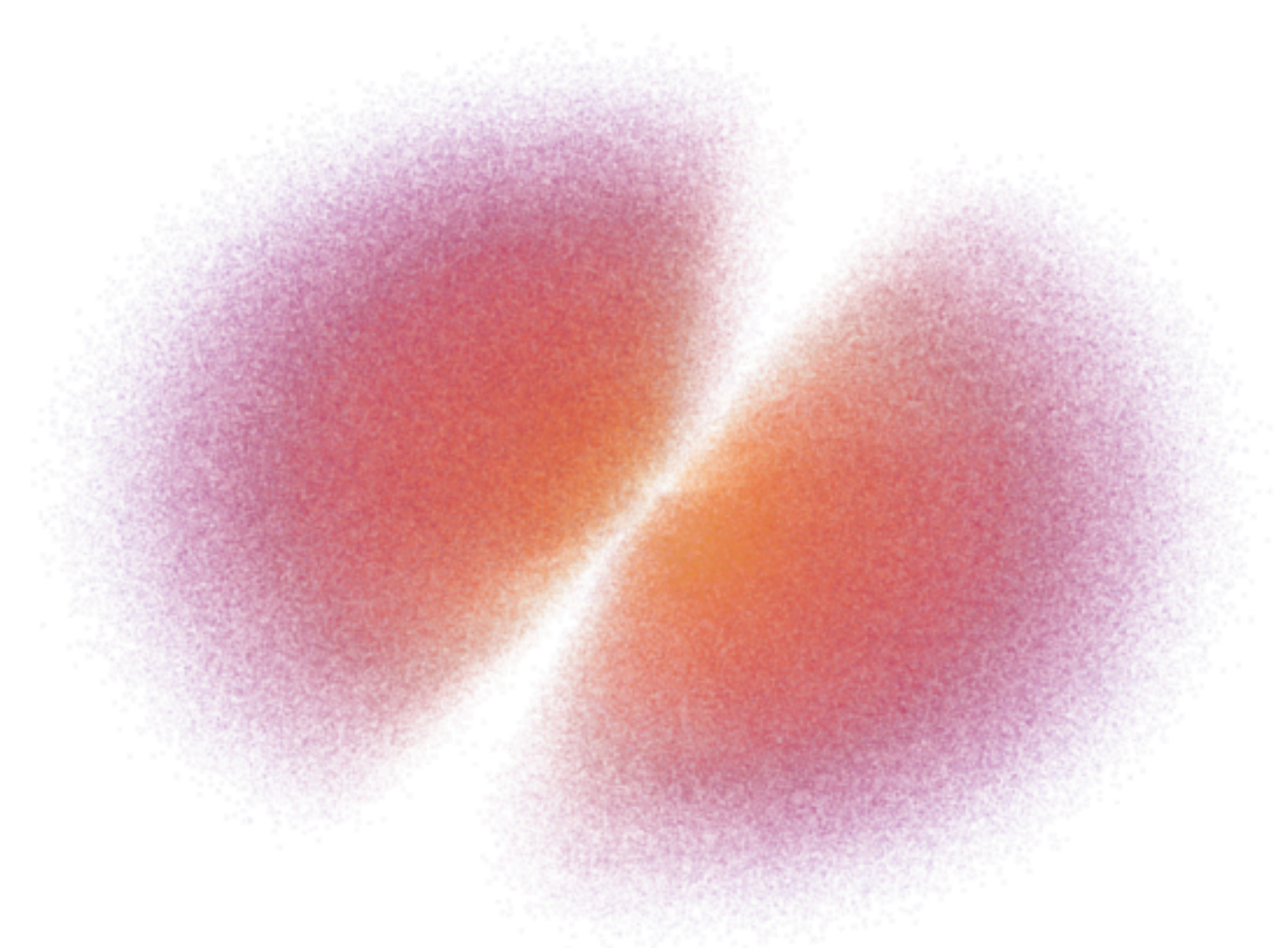
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- Goals:
  - **Large-scale** reconstruction
  - Infer **systematic contaminations**



Storey-Fisher et al. (2023)

# Preliminary work: Quiaia analysis

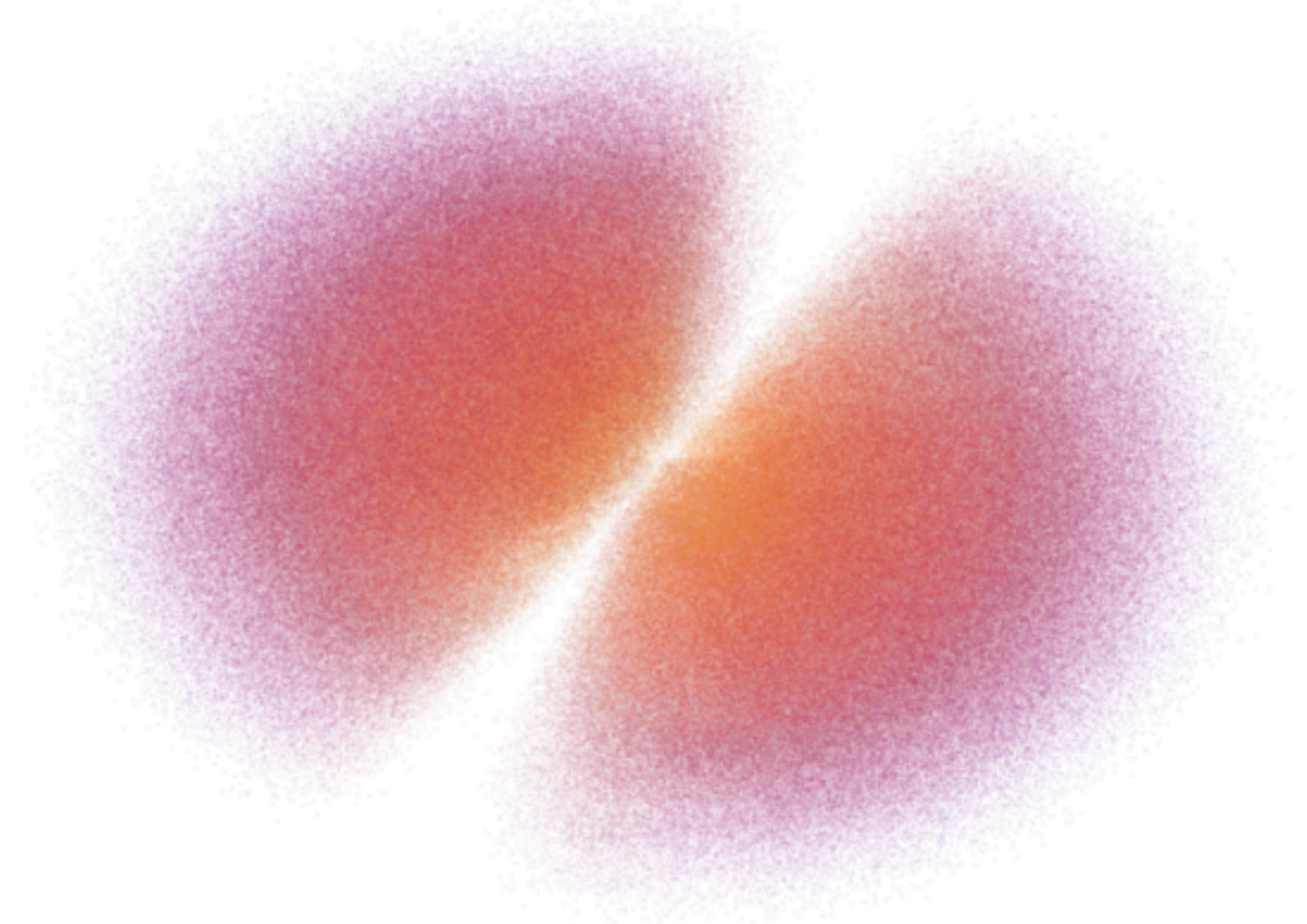
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  - Combine with other sources for **multi-tracer** analysis and **cross-correlations**



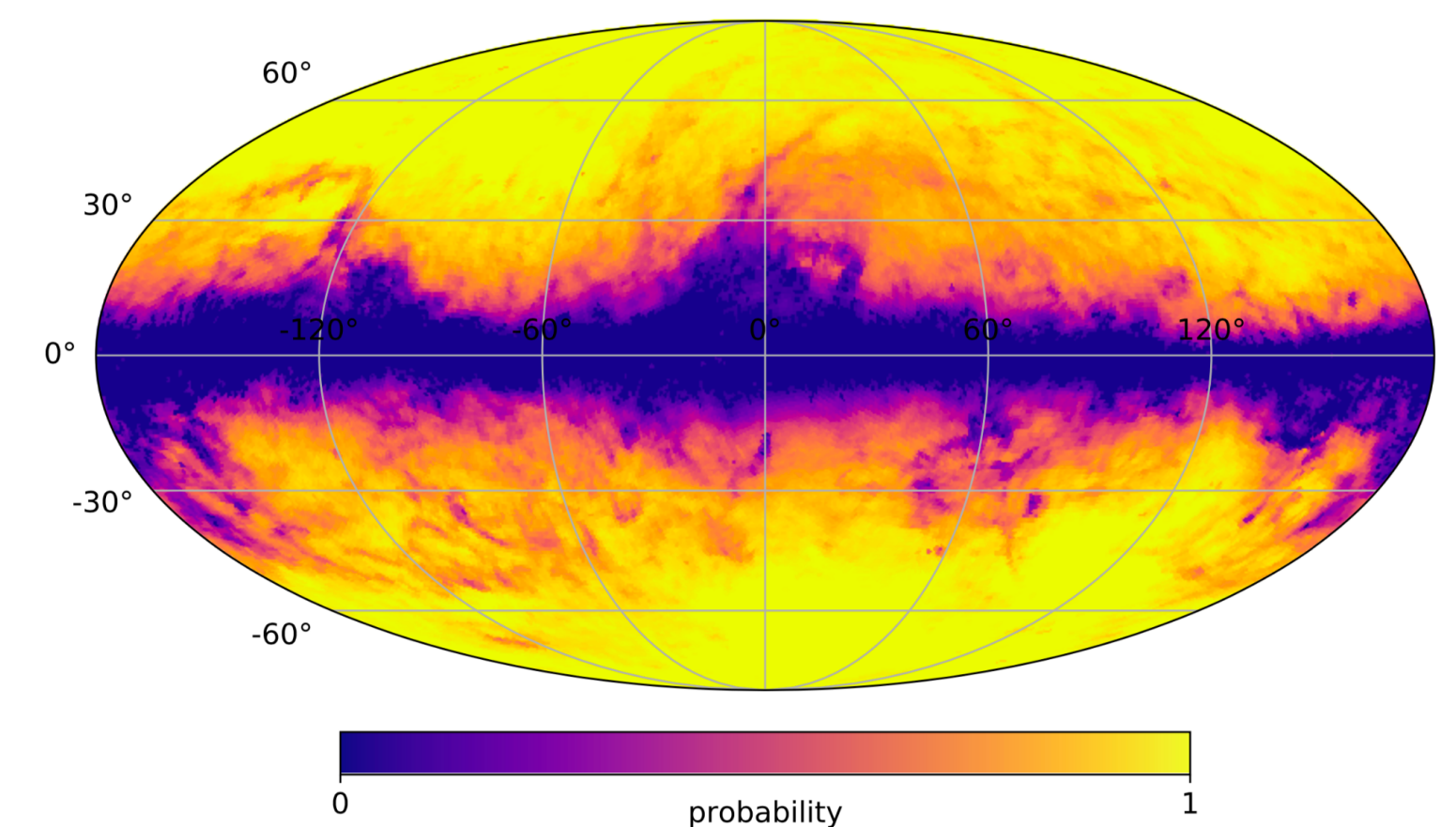
Storey-Fisher et al. (2023)

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Storey-Fisher et al. (2023)

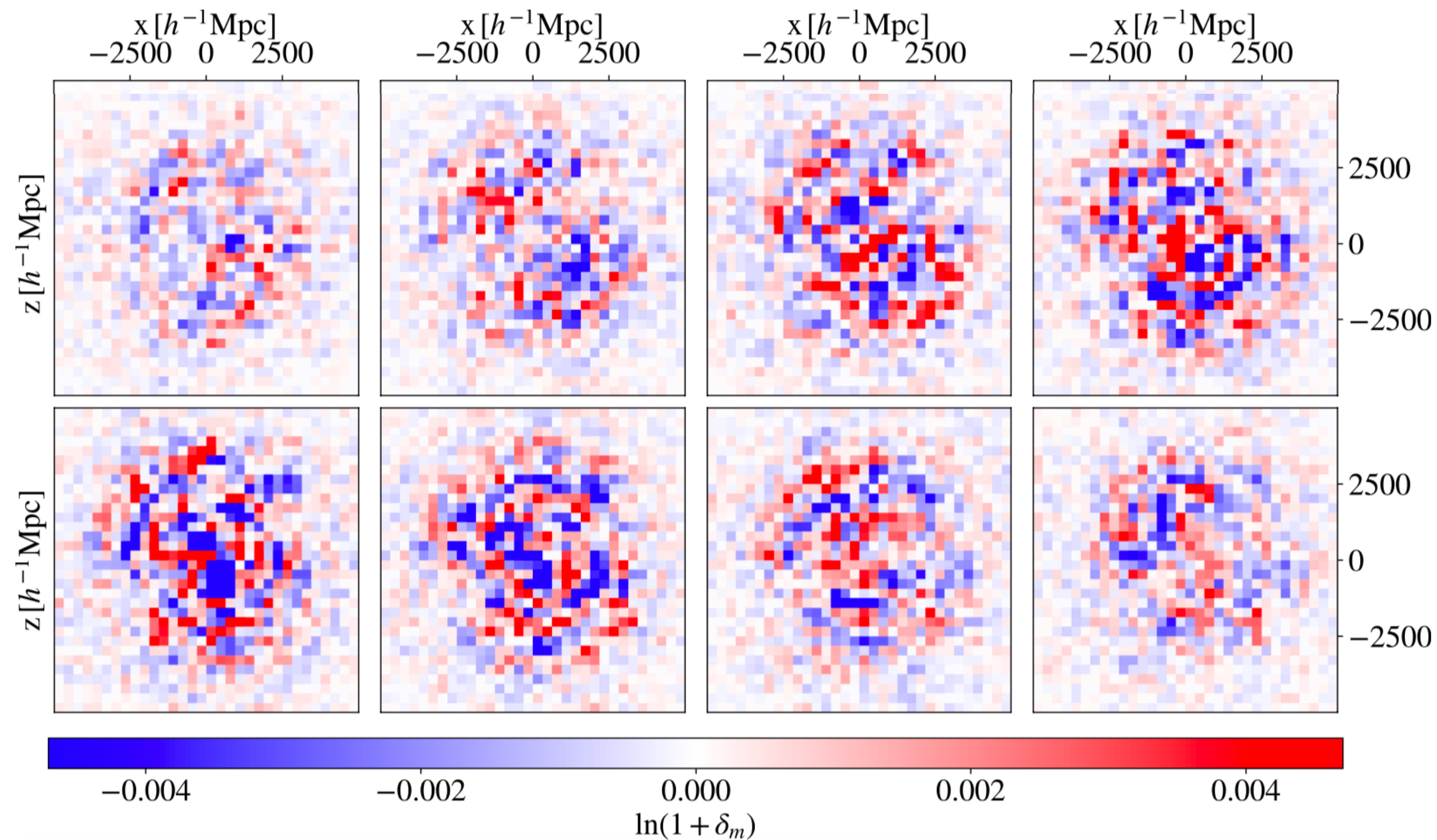


# Preliminary work: Quiaia analysis



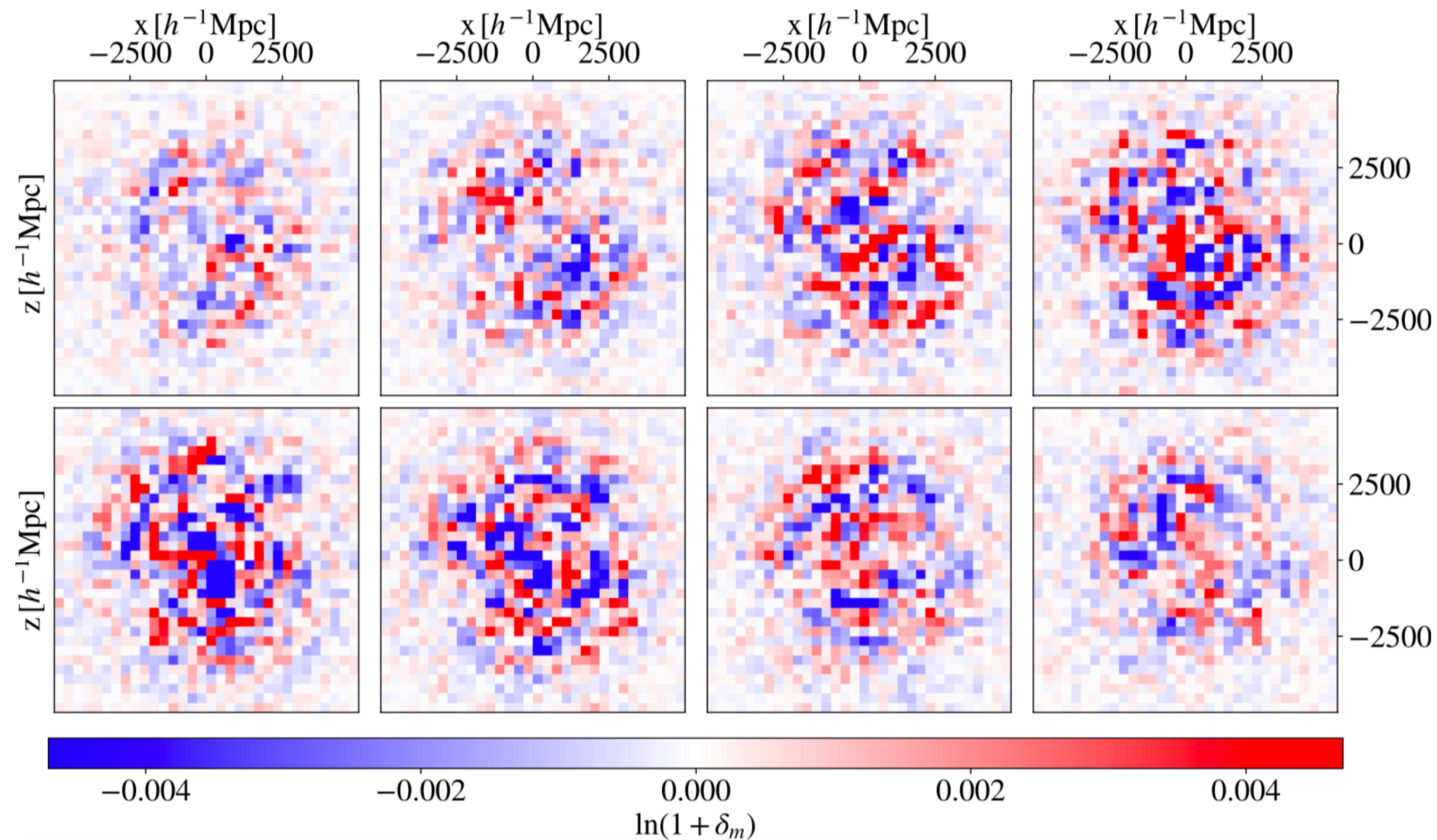
# Preliminary work: Quiaia analysis

**PRELIMINARY RESULTS:**  
**Slices of inferred density fields (over the chain)**

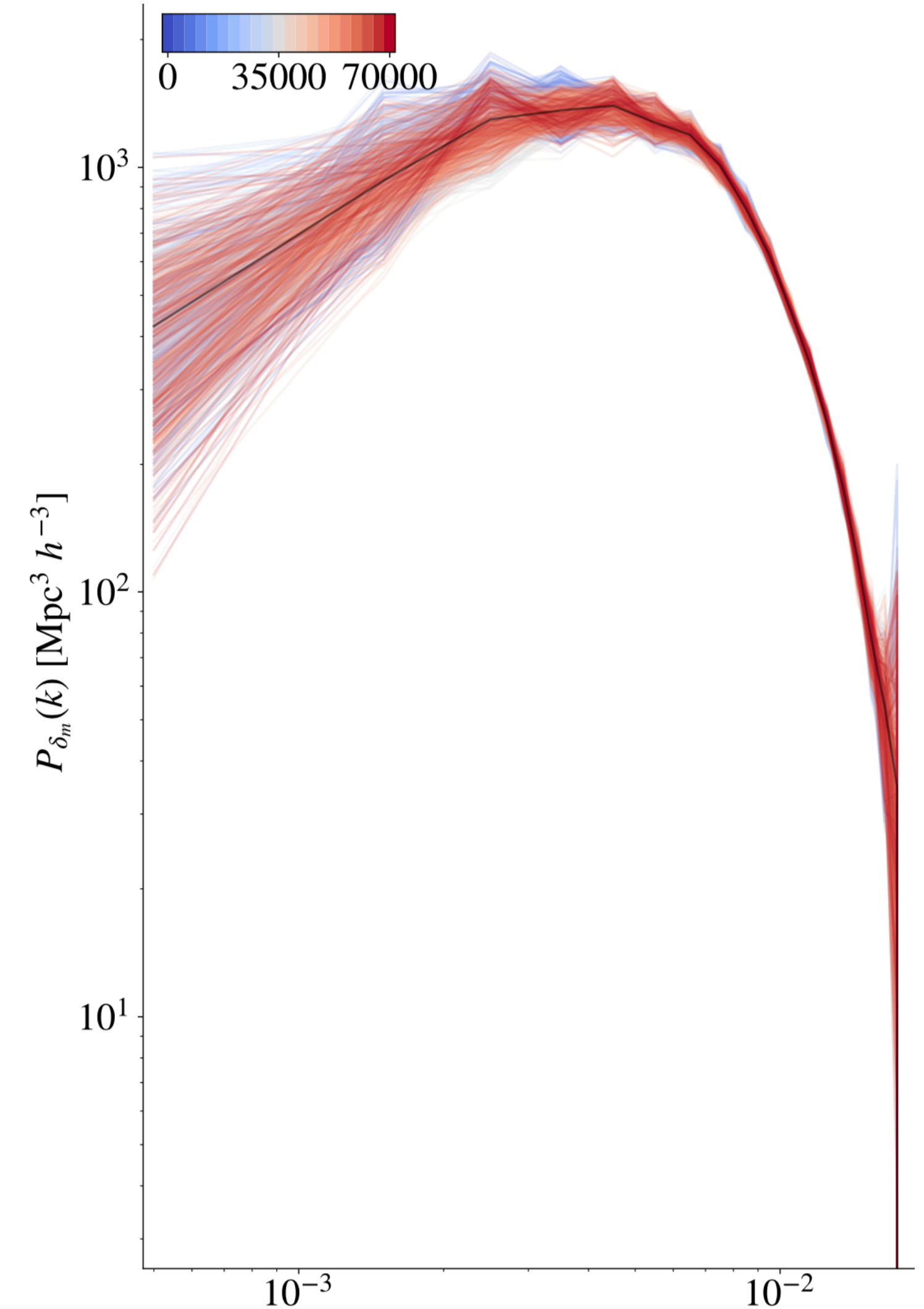


# Preliminary work: Quiaia analysis

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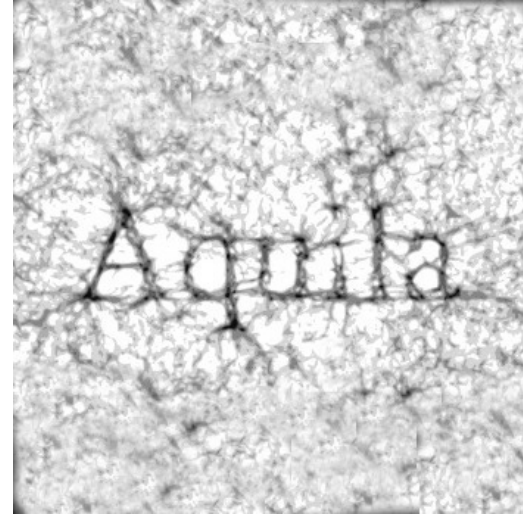


**PRELIMINARY RESULTS:**  
**Ensemble power spectra**

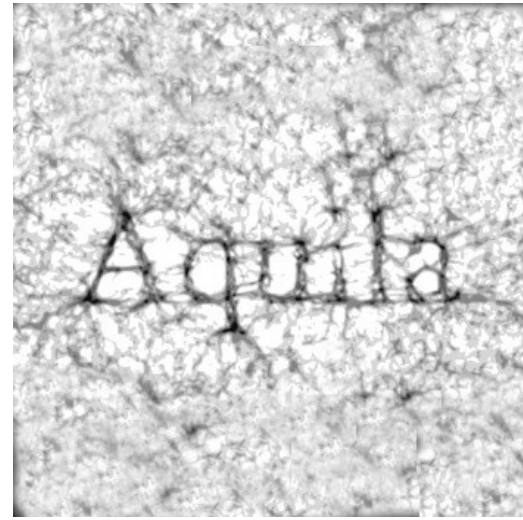




# Summary

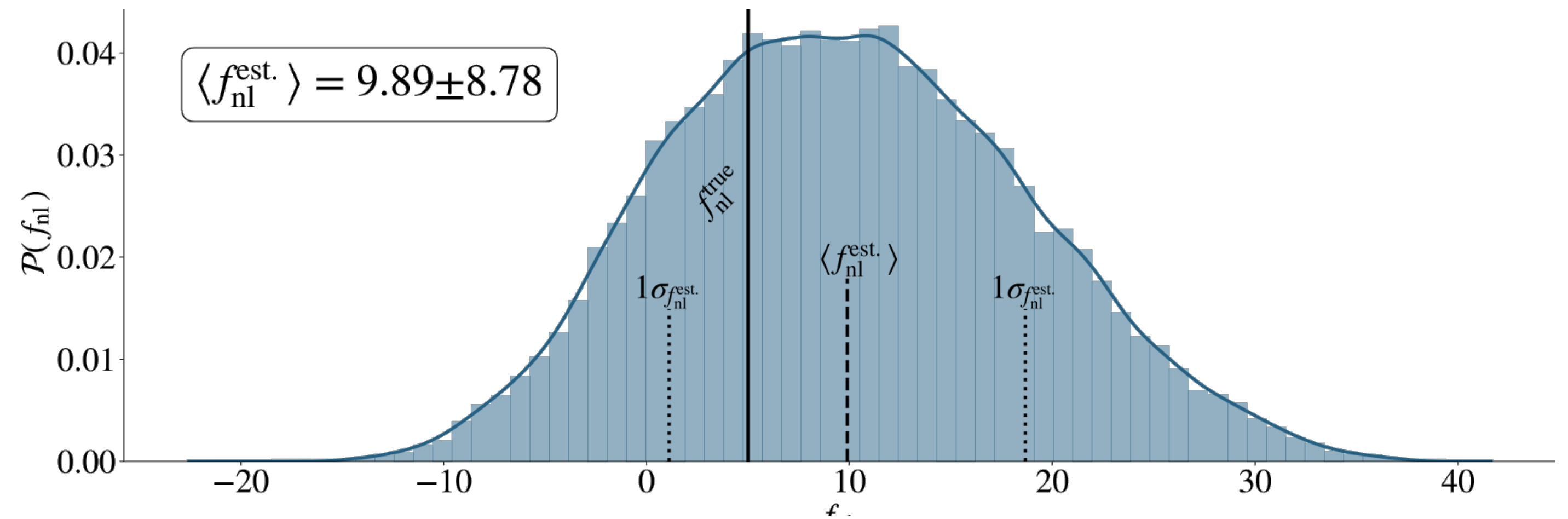


# Summary

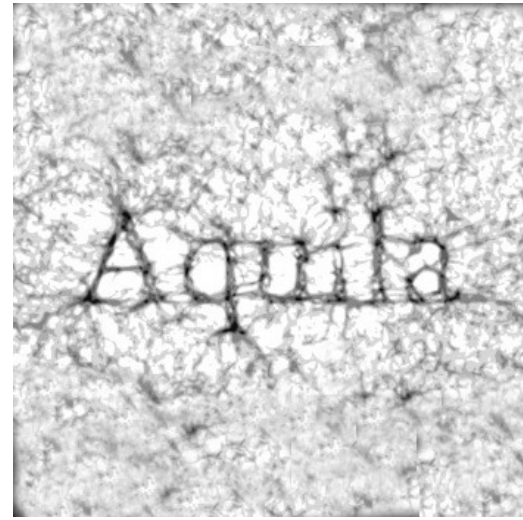


1. Developed a field-level inference which constrains  $\sigma_{f_{\text{nl}}} \approx 9$  (68%) on SDSS3-like data

Posterior distribution of  $f_{\text{nl}}$

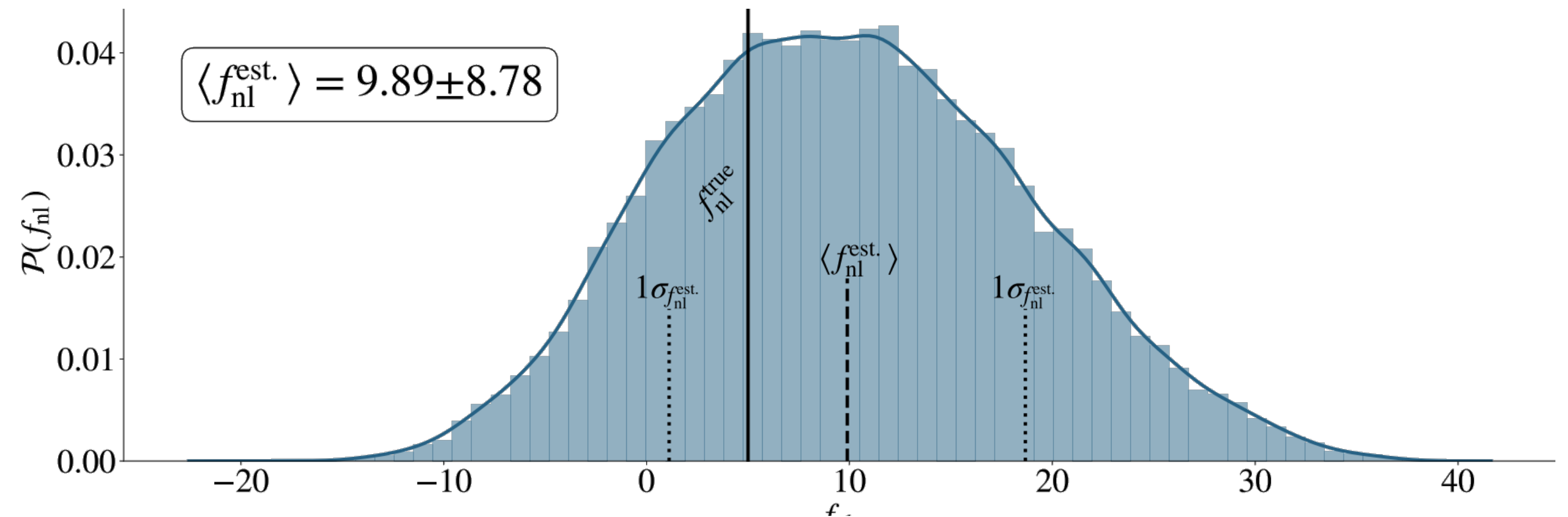


# Summary

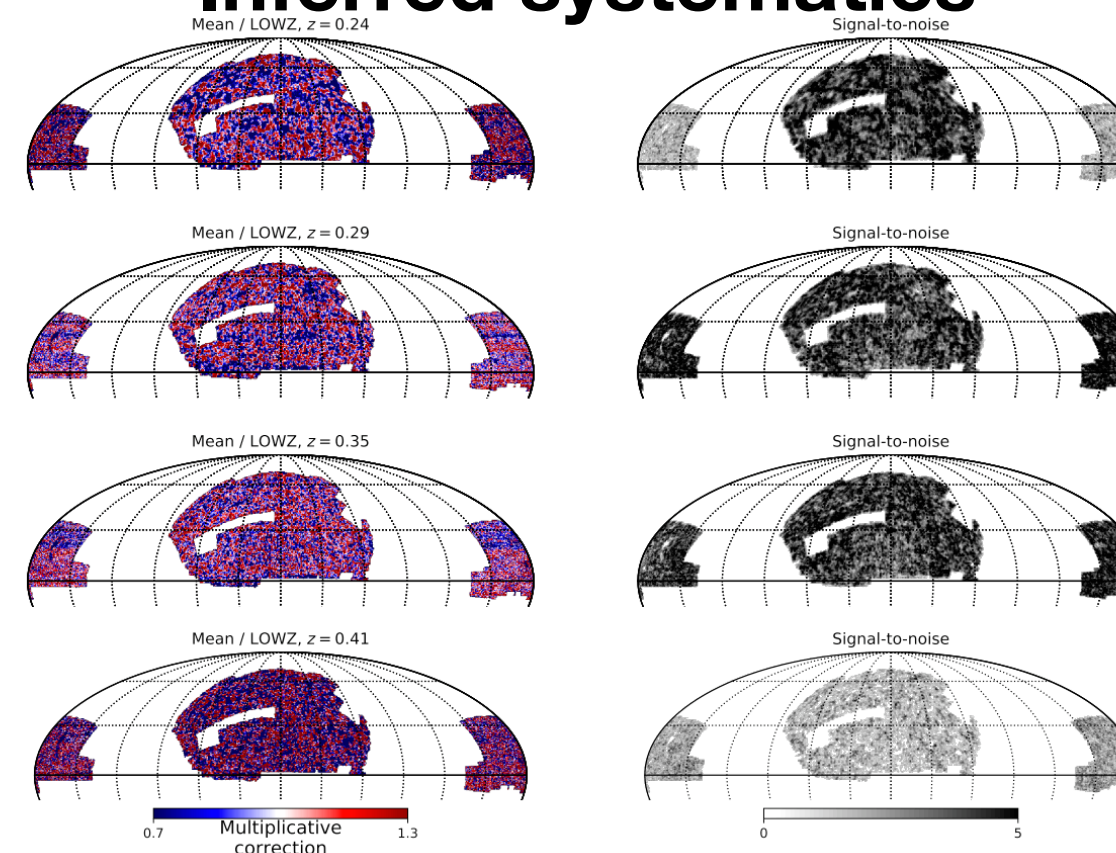


1. Developed a field-level inference which constrains  $\sigma_{f_{nl}} \approx 9$  (68%) on SDSS3-like data
2. Opportunity to include systematic effects into analysis

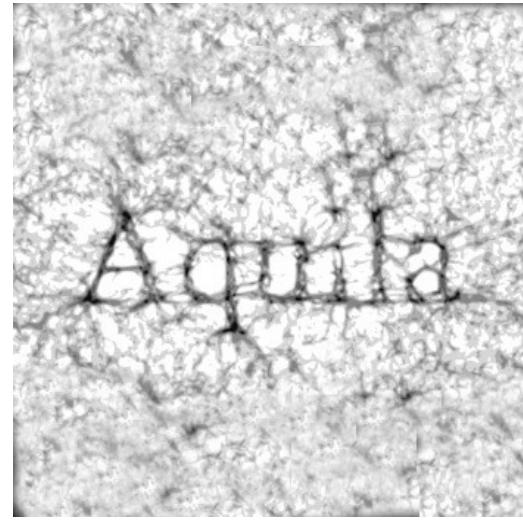
Posterior distribution of  $f_{nl}$



Inferred systematics

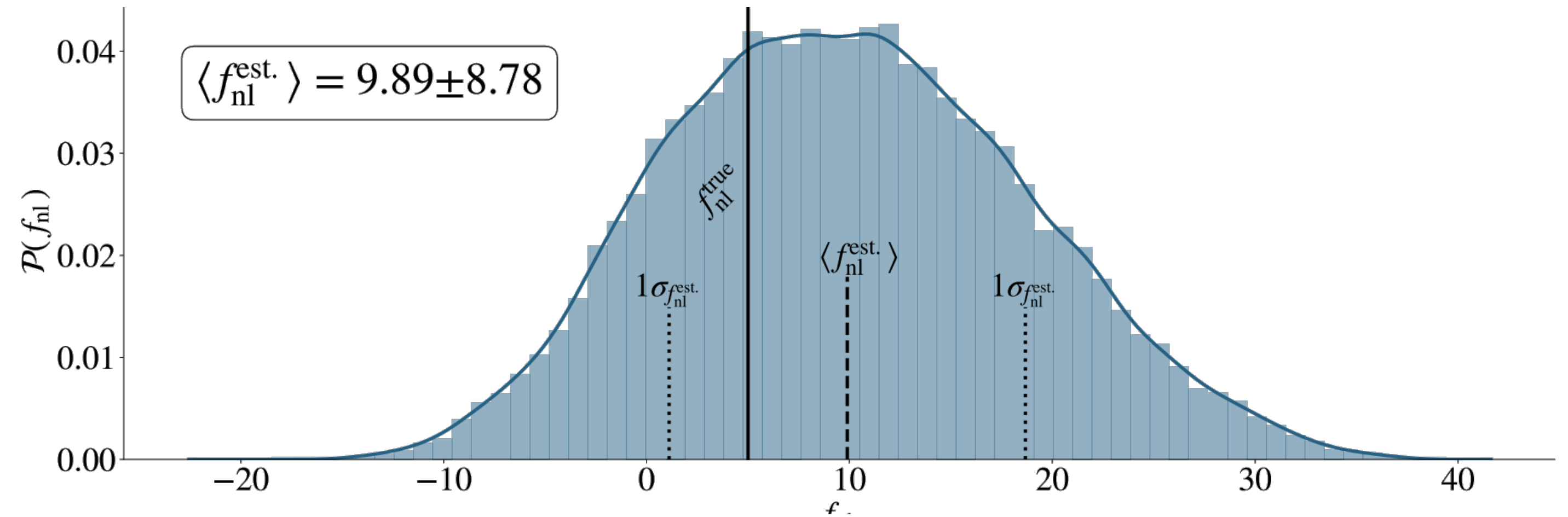


# Summary

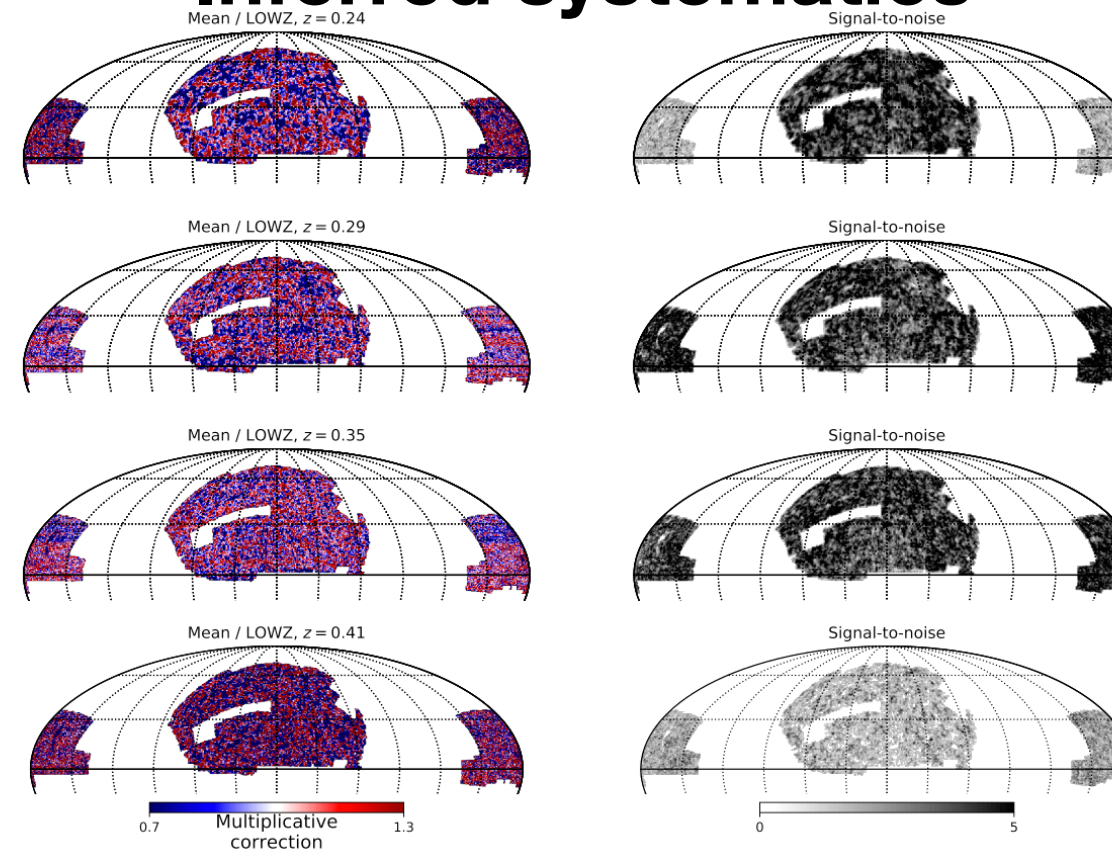


1. Developed a field-level inference which constrains  $\sigma_{f_{nl}} \approx 9$  (68%) on SDSS3-like data
2. Opportunity to include systematic effects into analysis
3. Additional data products

Posterior distribution of  $f_{nl}$



Inferred systematics



Inferred Density Field

