IMPERIAL

Field-level inferences of galaxy clustering

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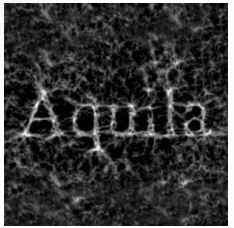
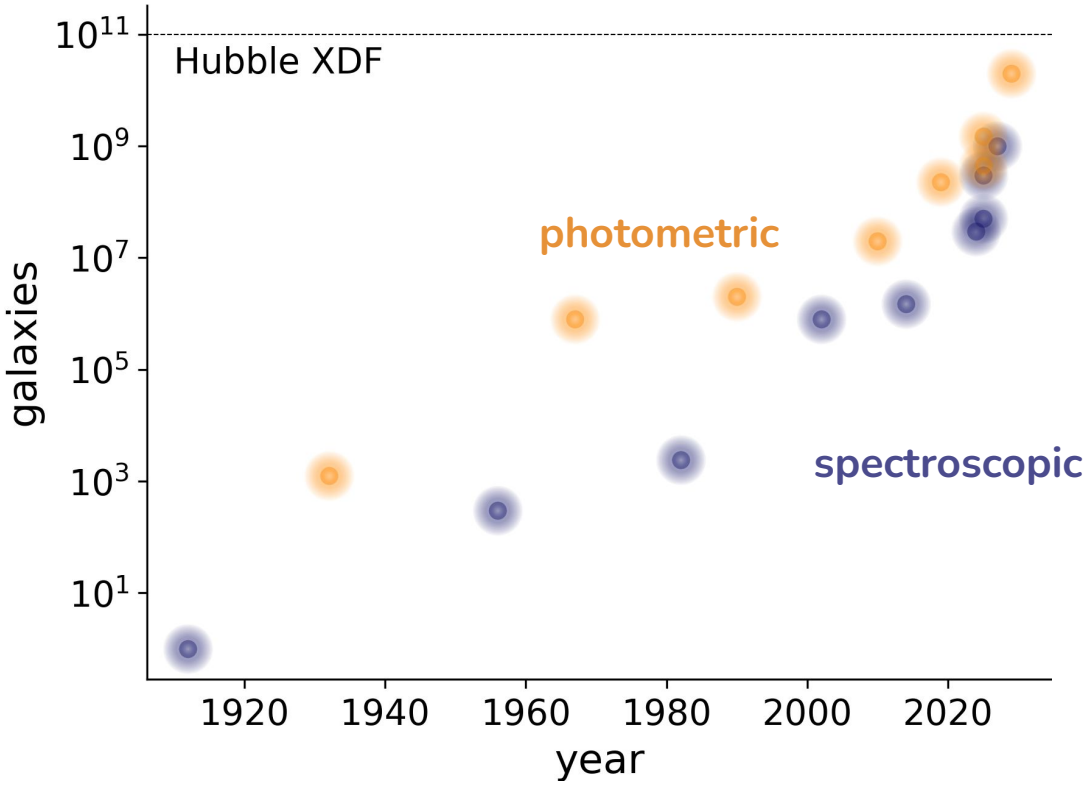
Imperial College London



Cosmo21 - May 22nd, 2024

Reaching an observational limit: how to optimally extract information?



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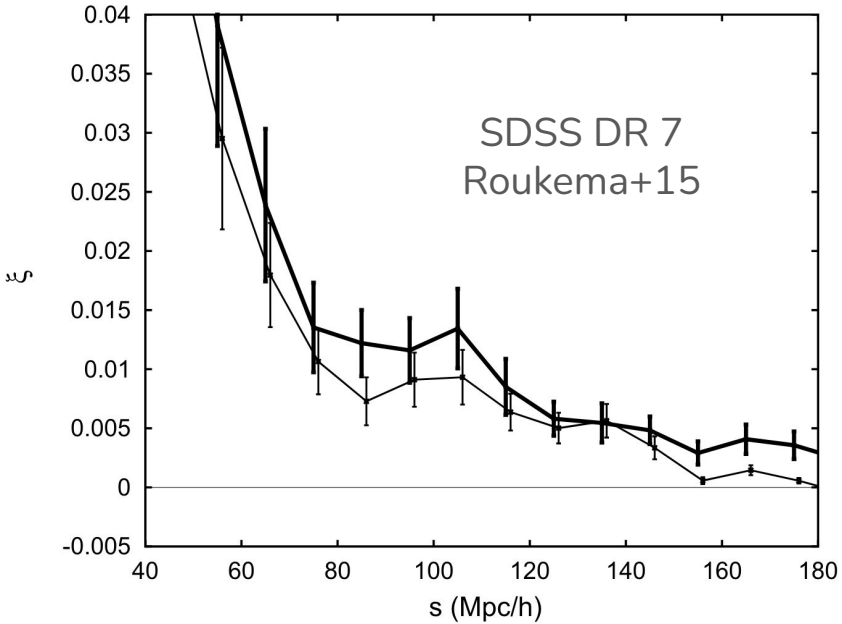
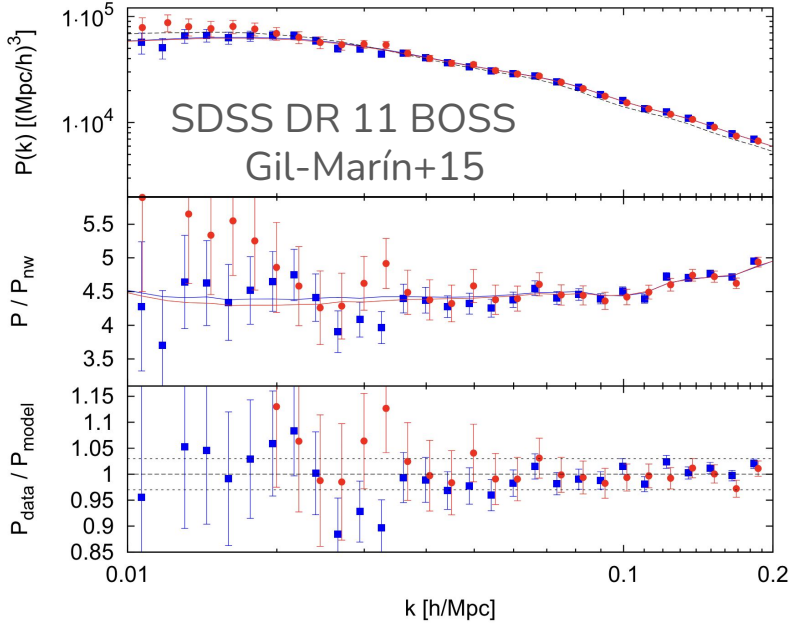
2-point statistics of galaxy clustering

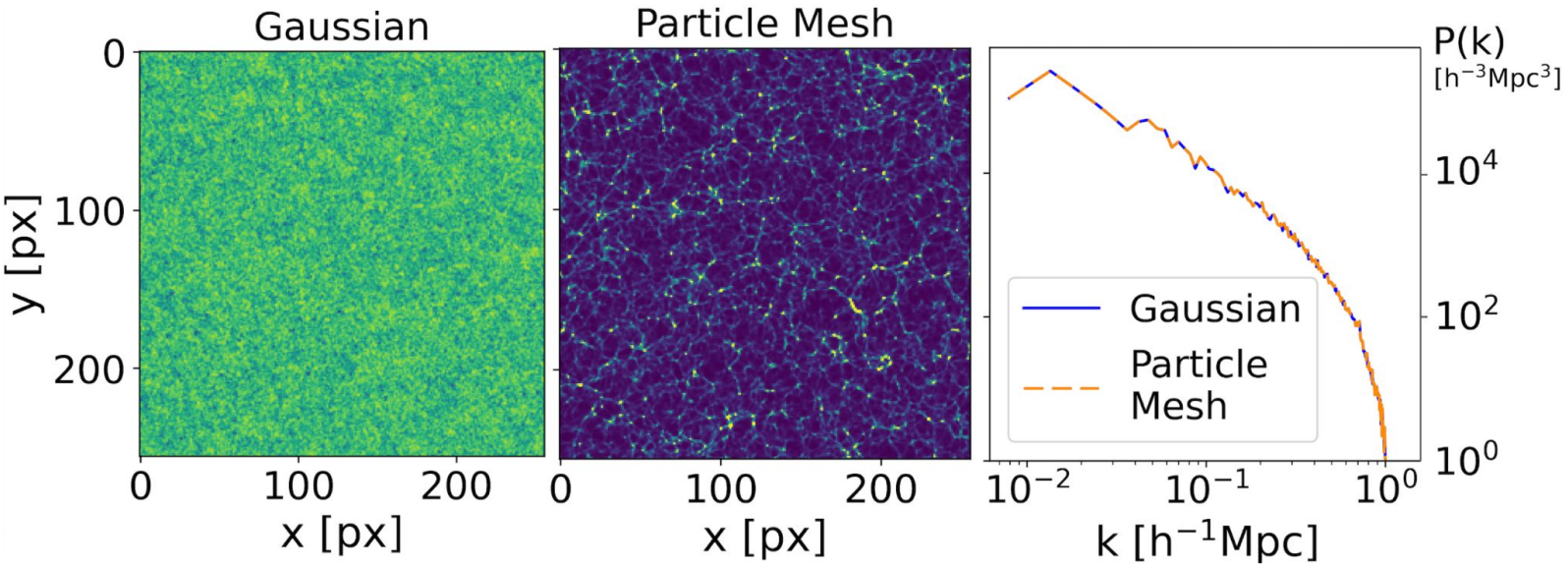


excess probability of observation



$P(k) \propto k^3$

Beyond 2-point statistics



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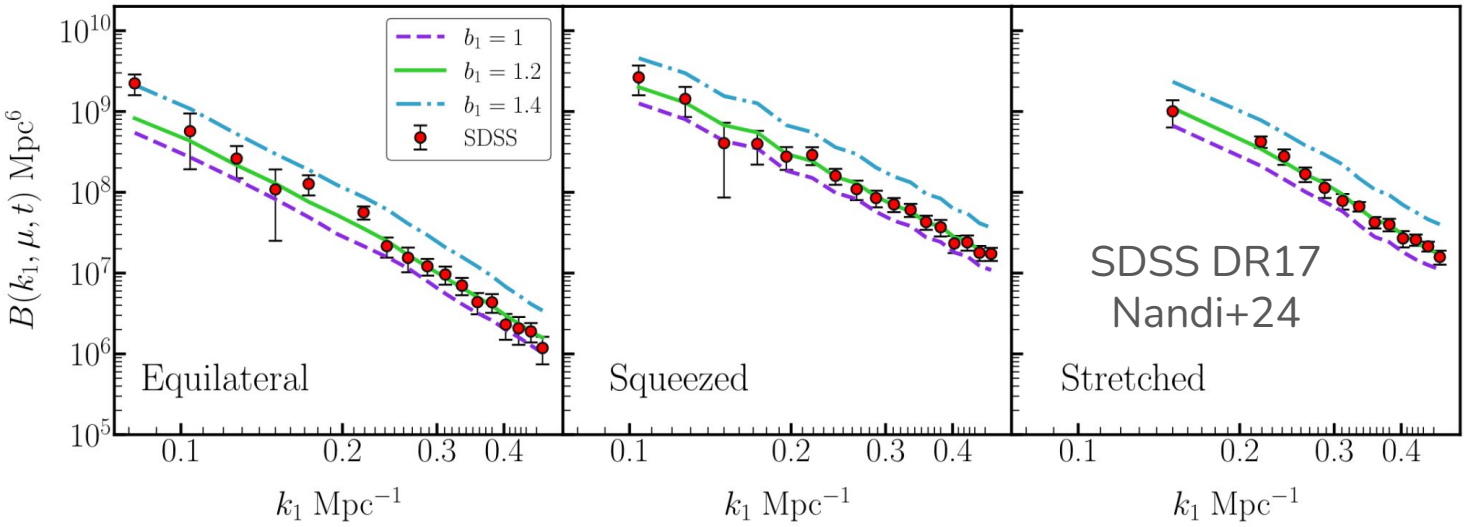
How can we go beyond?

Higher-order / non-Gaussian statistics



wavelet-based
peak statistics
Minkowski functionals
Betti numbers
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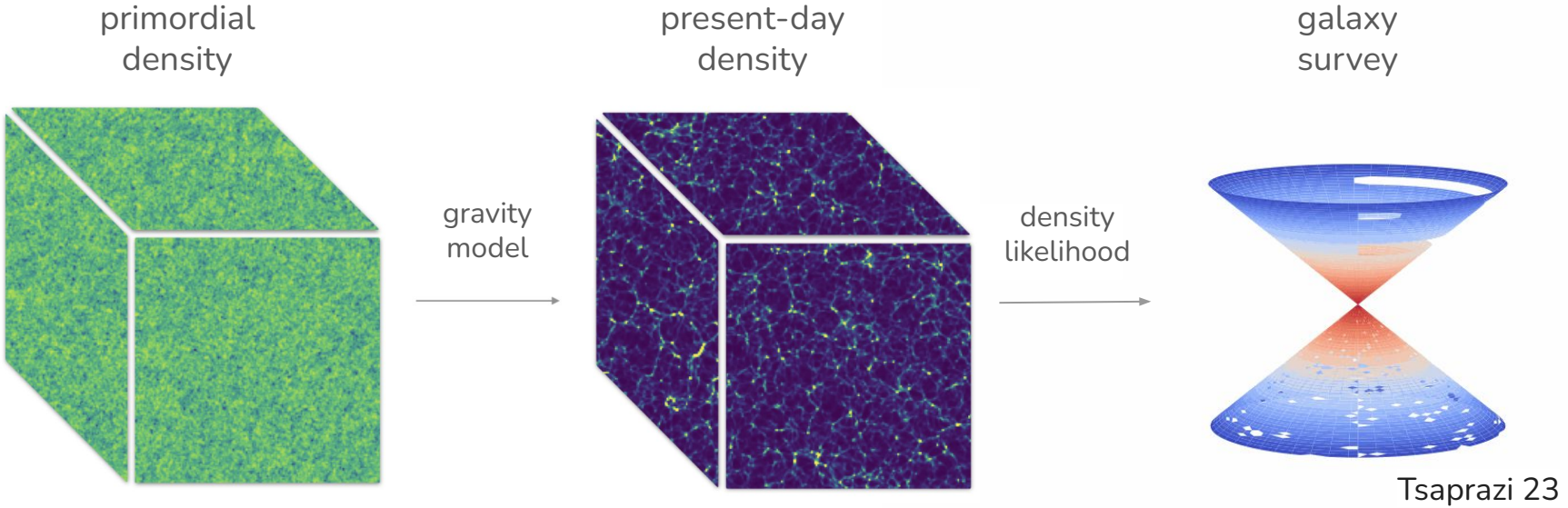
.

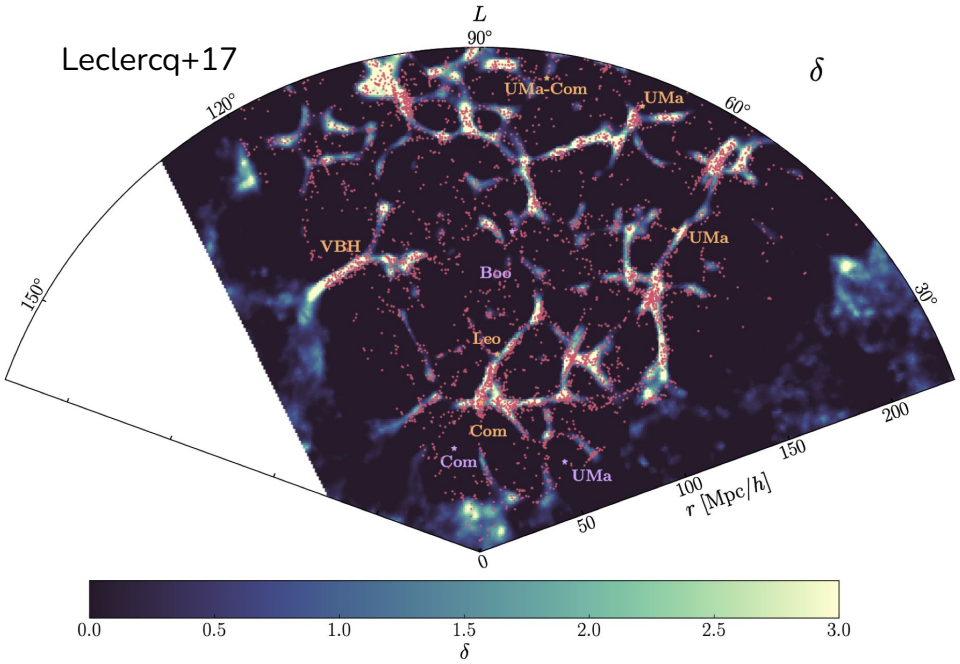
How can we extract information of the full field?

Extracting the full-field statistics with BORG

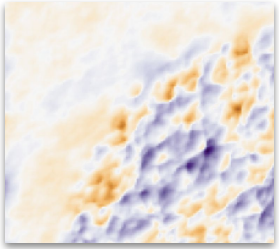


3D large-scale structure constrained with galaxy clustering accounting for survey geometry

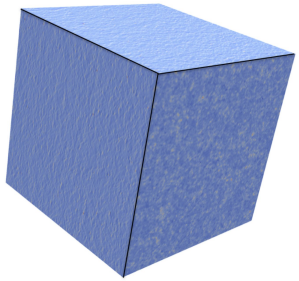
BORG has been successfully applied to real data



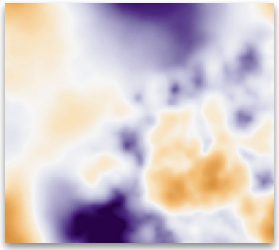
peculiar velocities



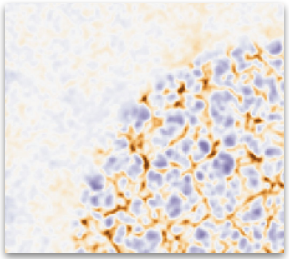
tidal shear



gravitational potential



divergence



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How can we prepare for next-generation data?
Full inference and / or cross-correlations

Field-level inference of galaxy intrinsic alignment

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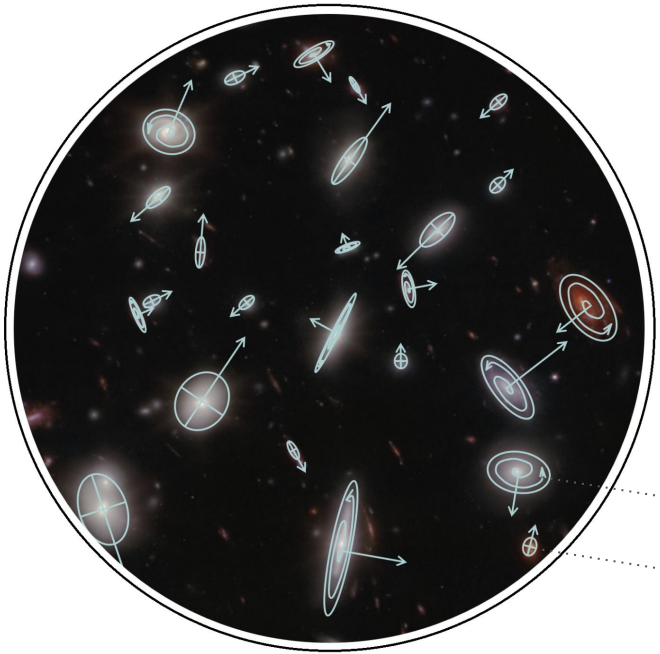
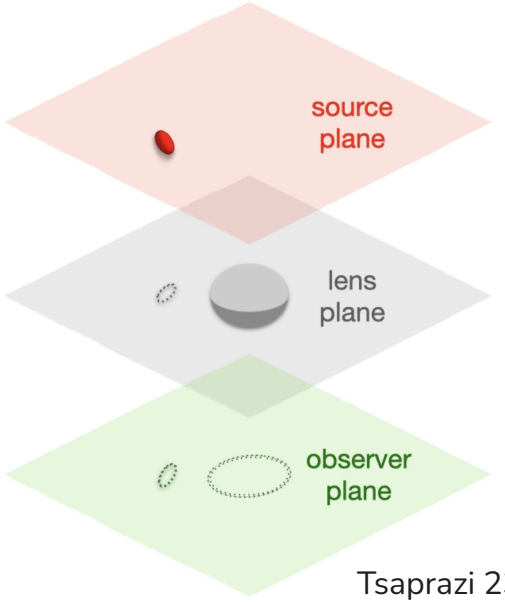


Lamman, **Tsaprazi**, Shi + 24

$$T_{ij} = \frac{\partial^2 \Phi}{\partial x_i \partial x_j}$$



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So far constrained at 2- / 3- point statistics

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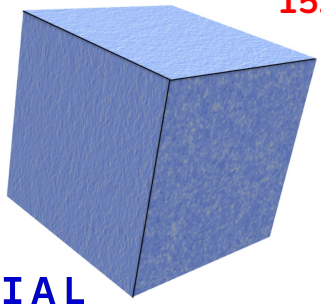
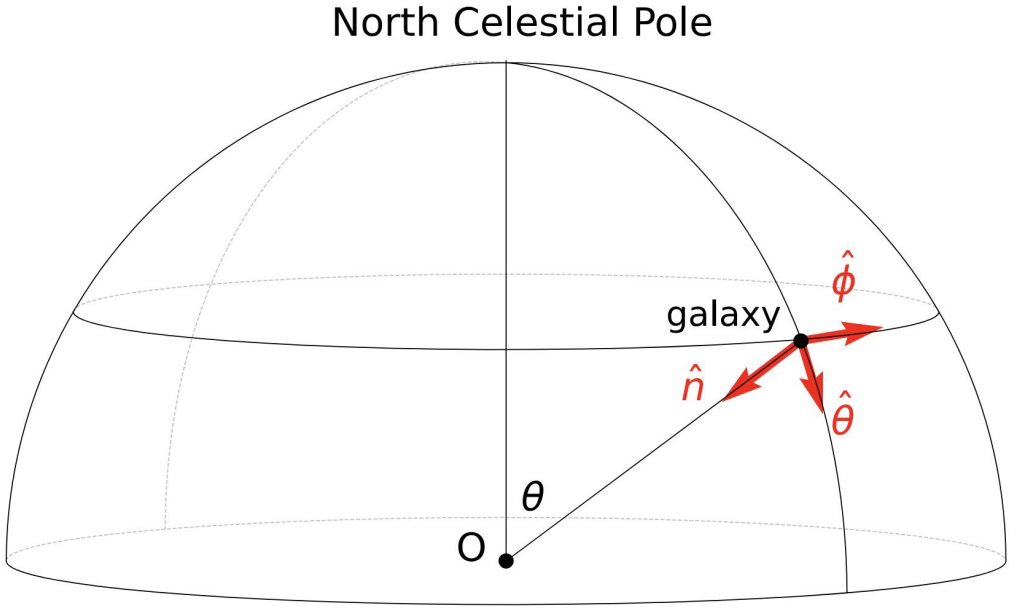
Field-level inference of galaxy intrinsic alignment

70,000 SDSS-III BOSS LRGs

3D tidal fields from SDSS-III BOSS

15.6 Mpc/h





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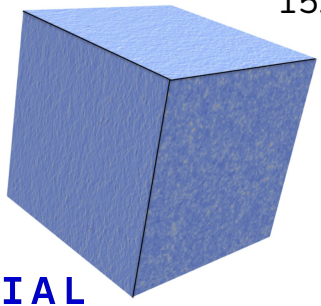
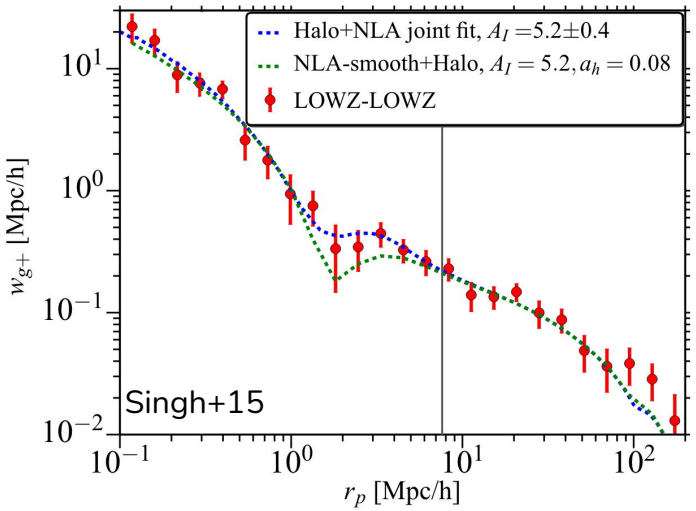
The non-linear alignment model

70,000 SDSS-III BOSS LRGs

3D tidal fields from SDSS-III BOSS
15.6 Mpc/h





$$e_1^{\rm I} \pm \iota\, e_2^{\rm I} = -\frac{C}{4\pi G}\, T_{\pm}$$

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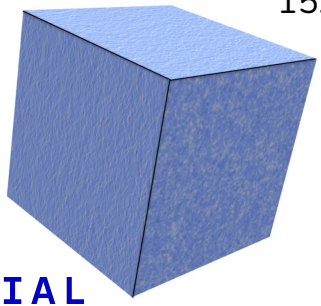
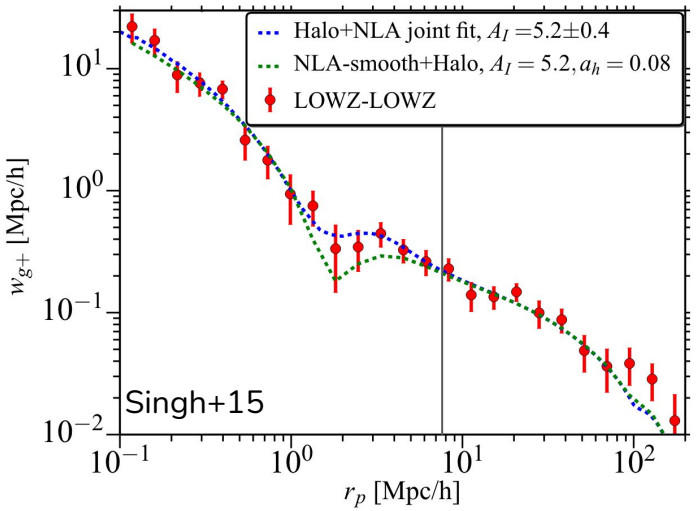
The non-linear alignment likelihood

70,000 SDSS-III BOSS LRGs

3D tidal fields from SDSS-III BOSS
15.6 Mpc/h





$$e_1^{\rm I} \pm \iota\, e_2^{\rm I} = -\frac{C}{4\pi G}\, T_{\pm}$$

$$P(e|C, T_s, \sigma^2) = \prod_{g=1}^{2N_g} \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left[-\frac{(e_g - C T_{g,s})^2}{2\sigma^2}\right]$$

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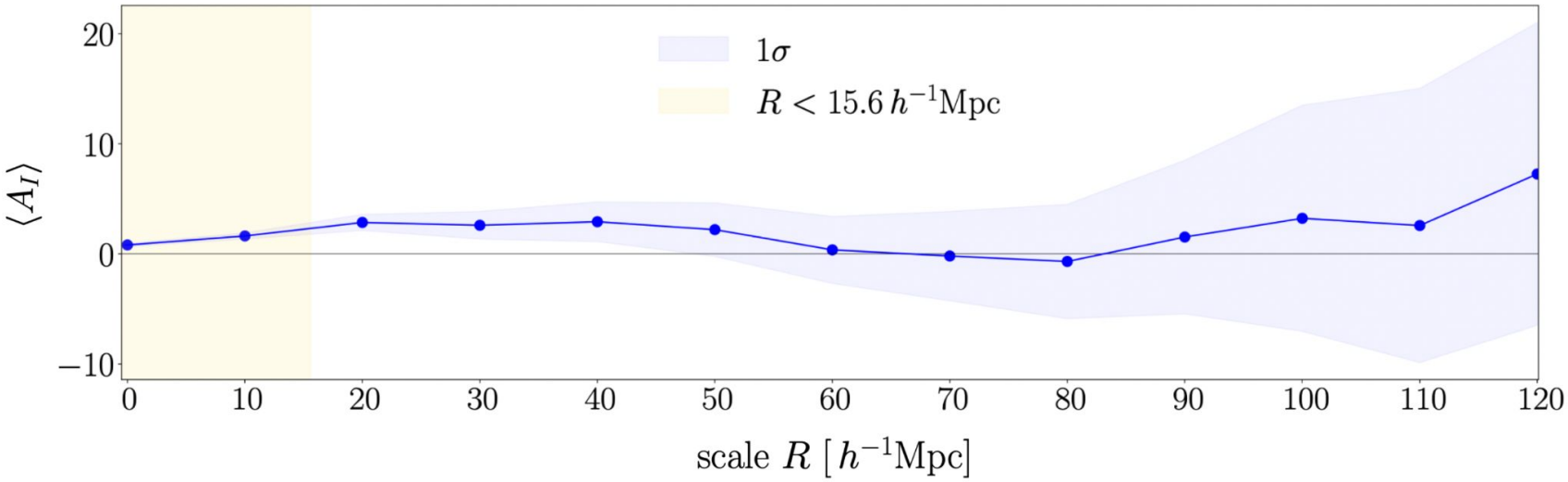
4σ detection at 20 Mpc/h



Constant with luminosity, color and redshift

2pt: 9σ at 6 Mpc/h, smaller scales — higher redshifts: need photometry

Field-level inference from spectroscopic and photometric redshifts

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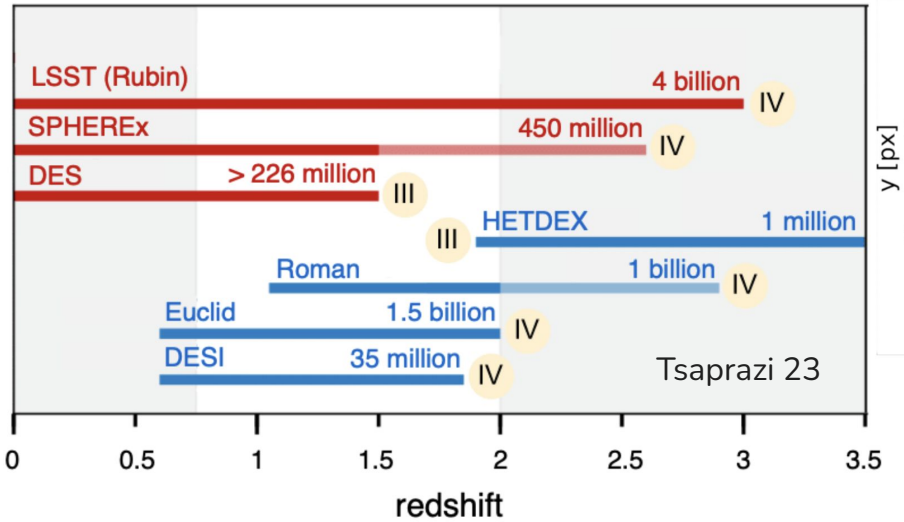

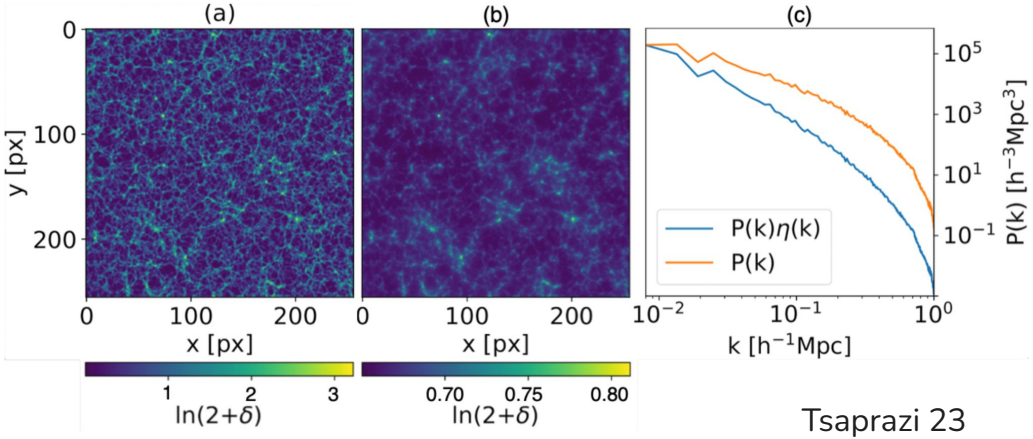

- Depth / magnitude vs accuracy
- Photo-z uncertainties can bias cosmological analyses

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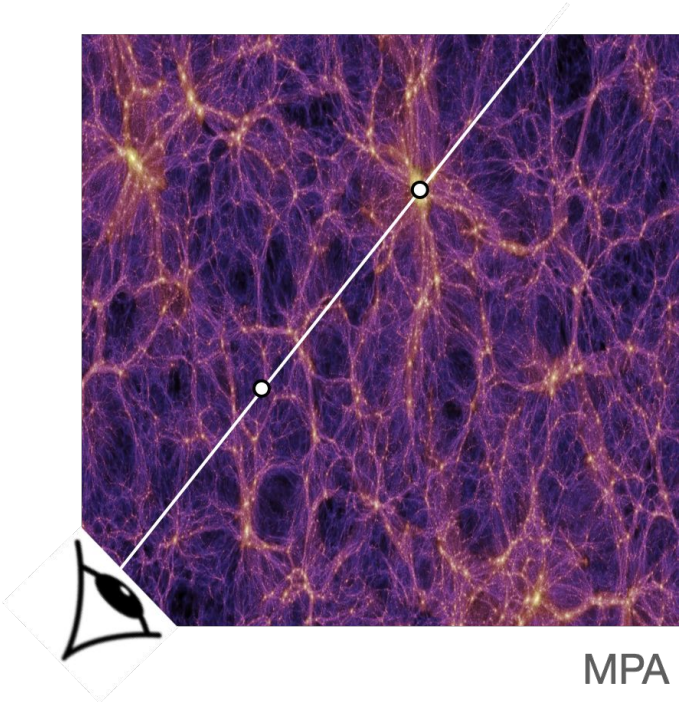
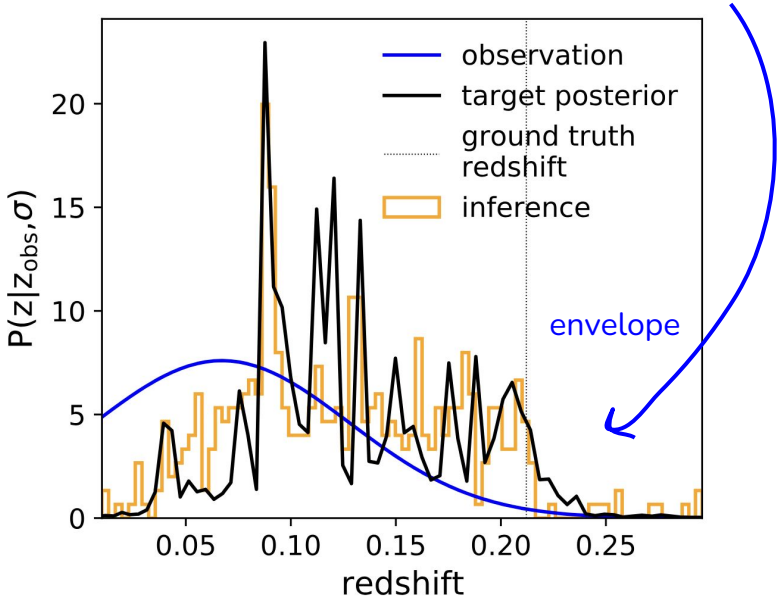
3D dark matter density can constrain galaxy locations

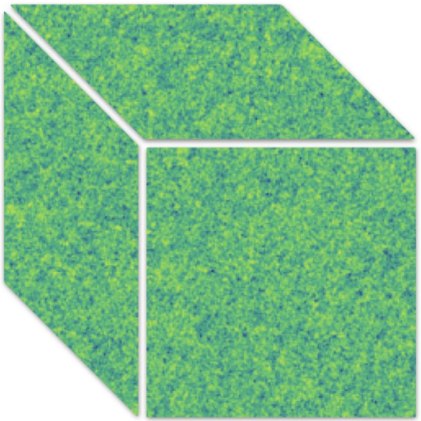


$$\mathcal{P}(z_i \mid z_{\mathrm{obs}\,i}, \delta) \propto \mathcal{P}(\delta \mid z_i)\mathcal{P}(z_i \mid z_{\mathrm{obs}\,i})$$



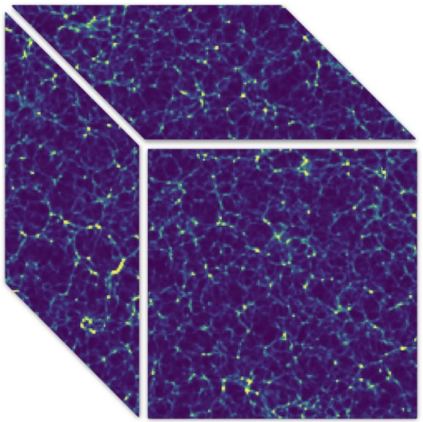
Constraining galaxy locations with clustering

primordial density



gravity model

present-day density



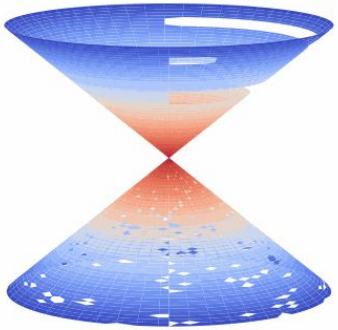
128^3 voxels

Gibbs sampling

redshift likelihood

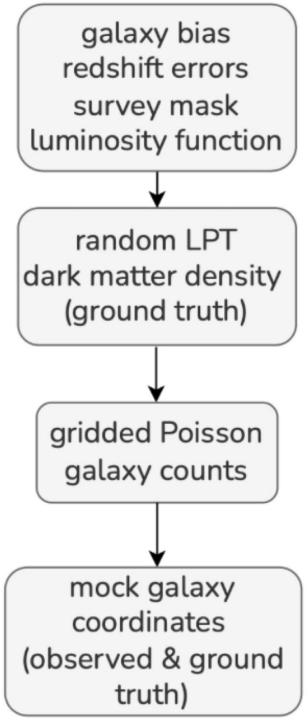
density likelihood

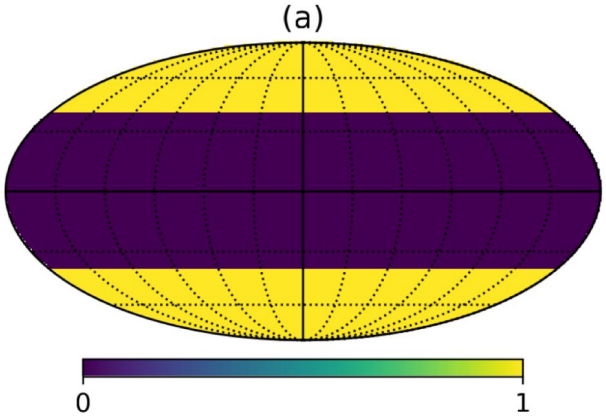
galaxy survey

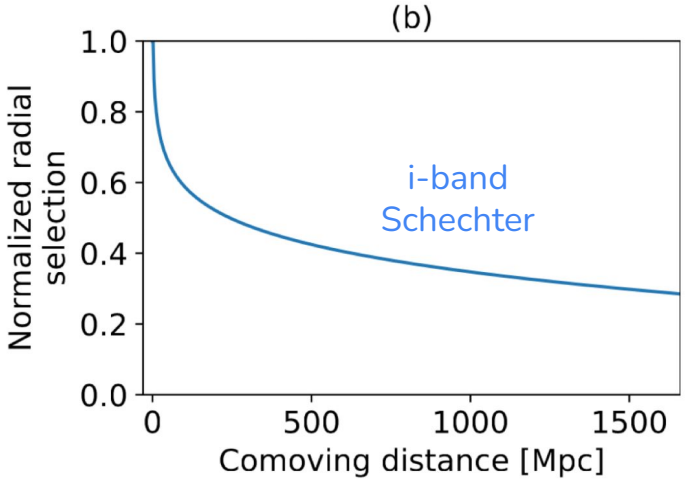


$\sim 10^7$ redshifts

Validation on self-consistent mock data







- Worst-case redshift uncertainties for upcoming surveys (300 Mpc)
- 2e7 photometric and 1% spectroscopic redshifts
- Power-law galaxy bias (linear), resolution 13 Mpc
- z = 0.7

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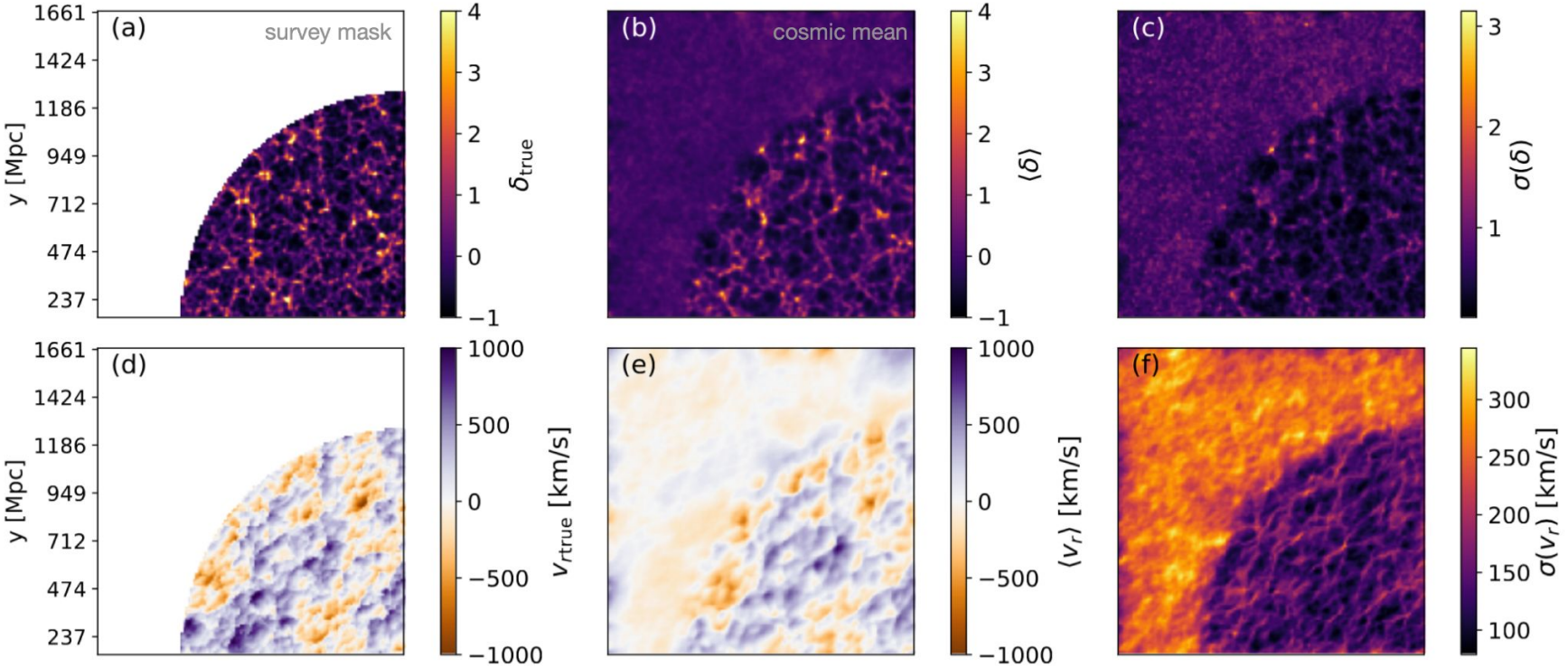
Constrained dark matter density and peculiar velocity



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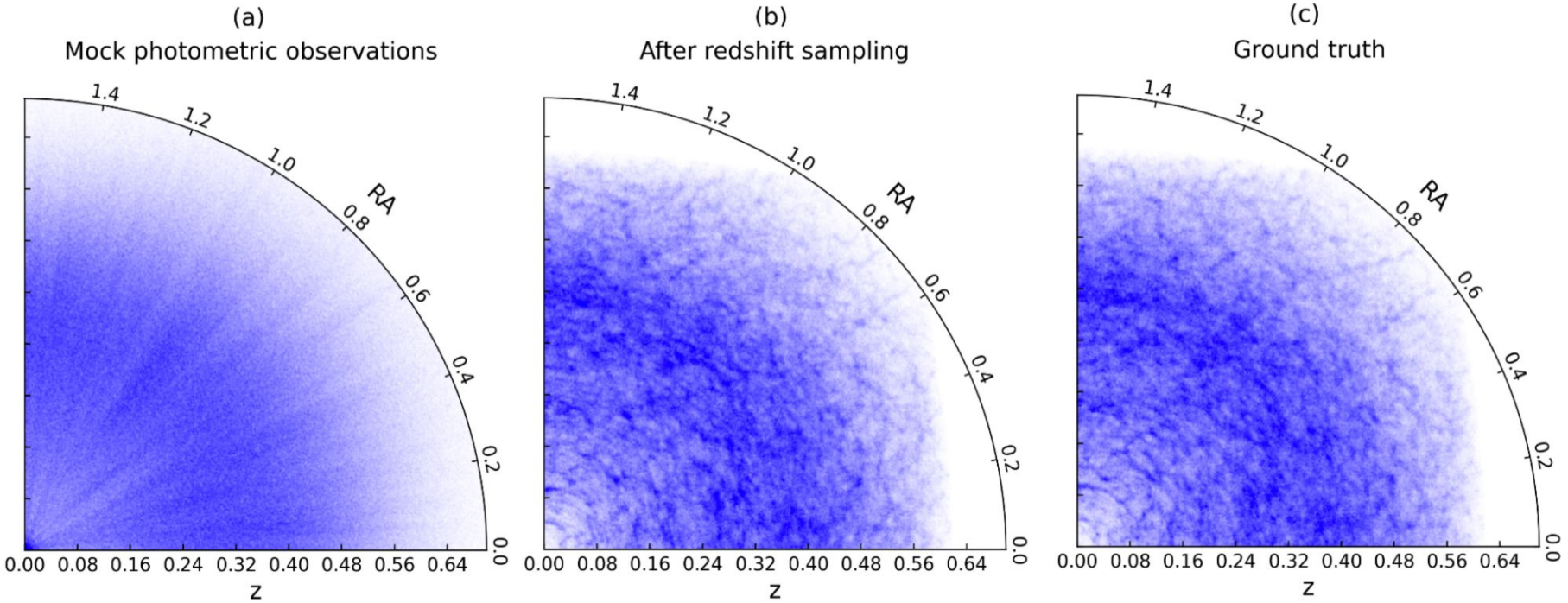
Filamentary structure thanks to the gravity model



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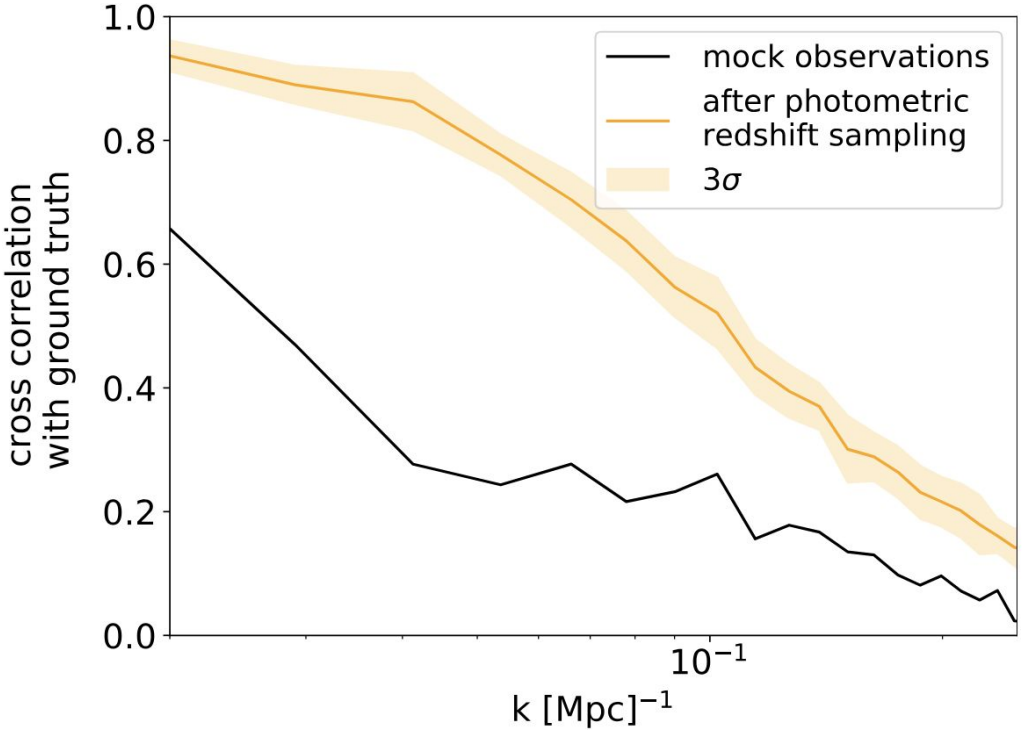
Increase in the galaxy count cross-correlation



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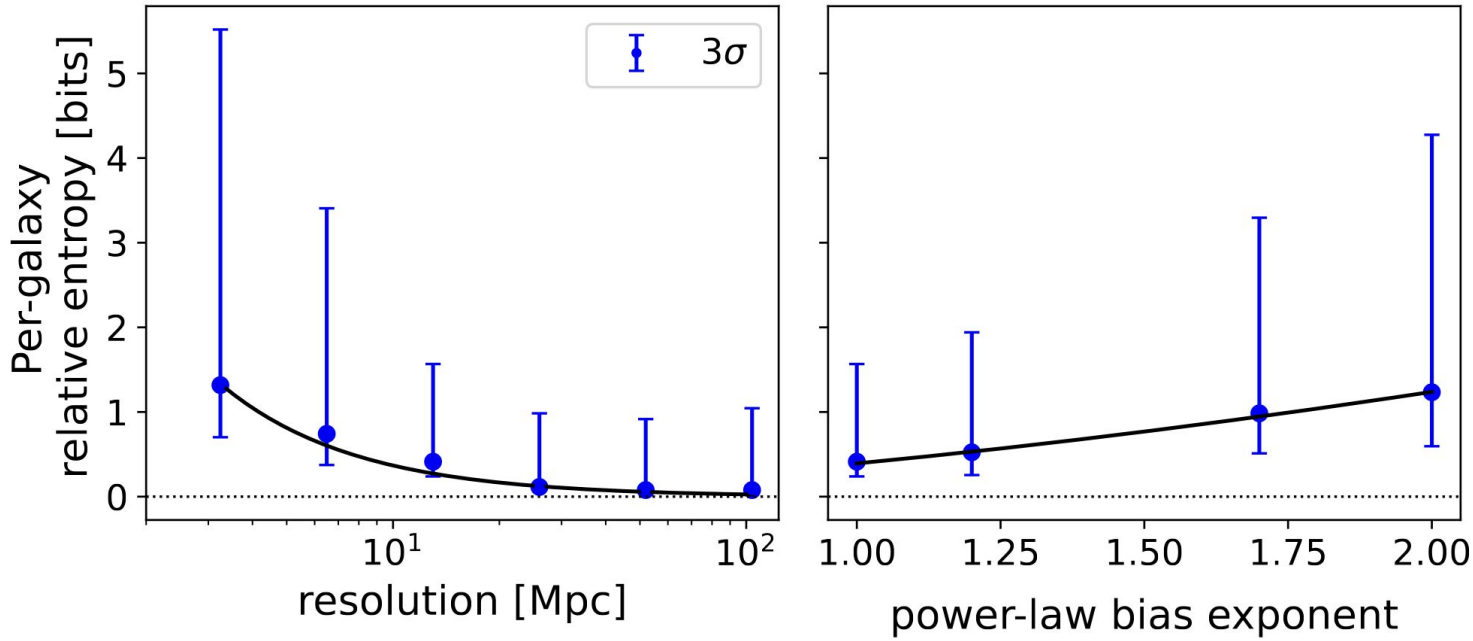
Information gain vs resolution / galaxy bias



Summary

- Existing 2-point estimators miss information
- Need all high-order statistics

- Galaxy intrinsic alignment
- Photometric galaxy clustering

Lamman+24

Outlook

- We're reaching the limit of observable galaxies
- Focus on
  - fully exploiting information in the data
  - self-consistently propagating uncertainties
  - demonstrating the power of high-order statistics