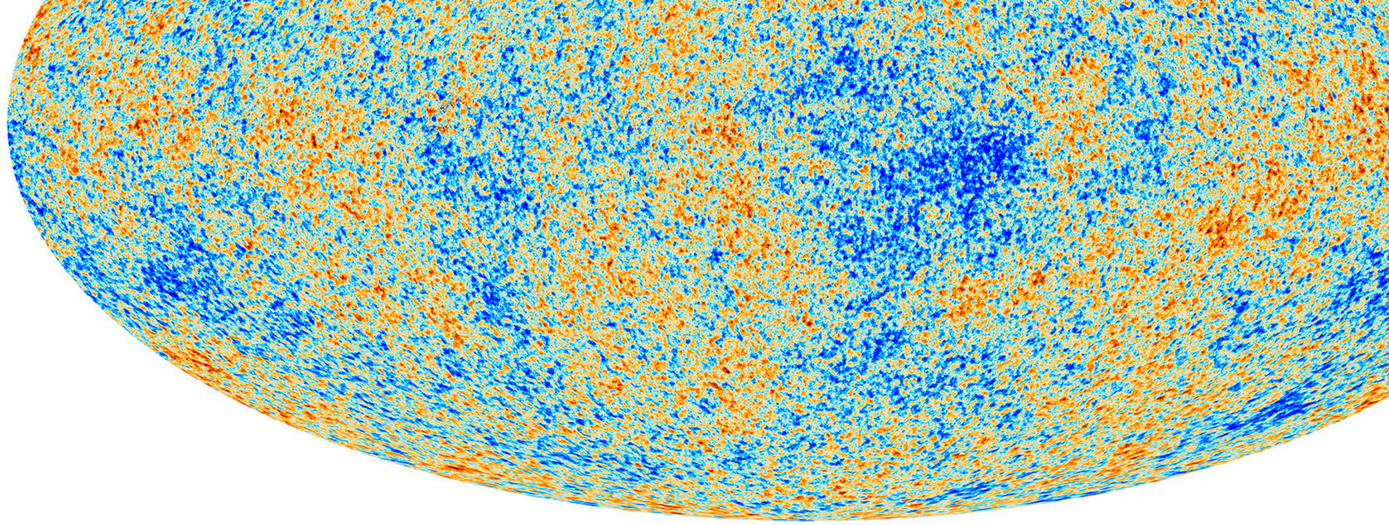

Forecasts on S_8 using tomographic cross-correlations with LSST

Impact of redshift bin mismatch

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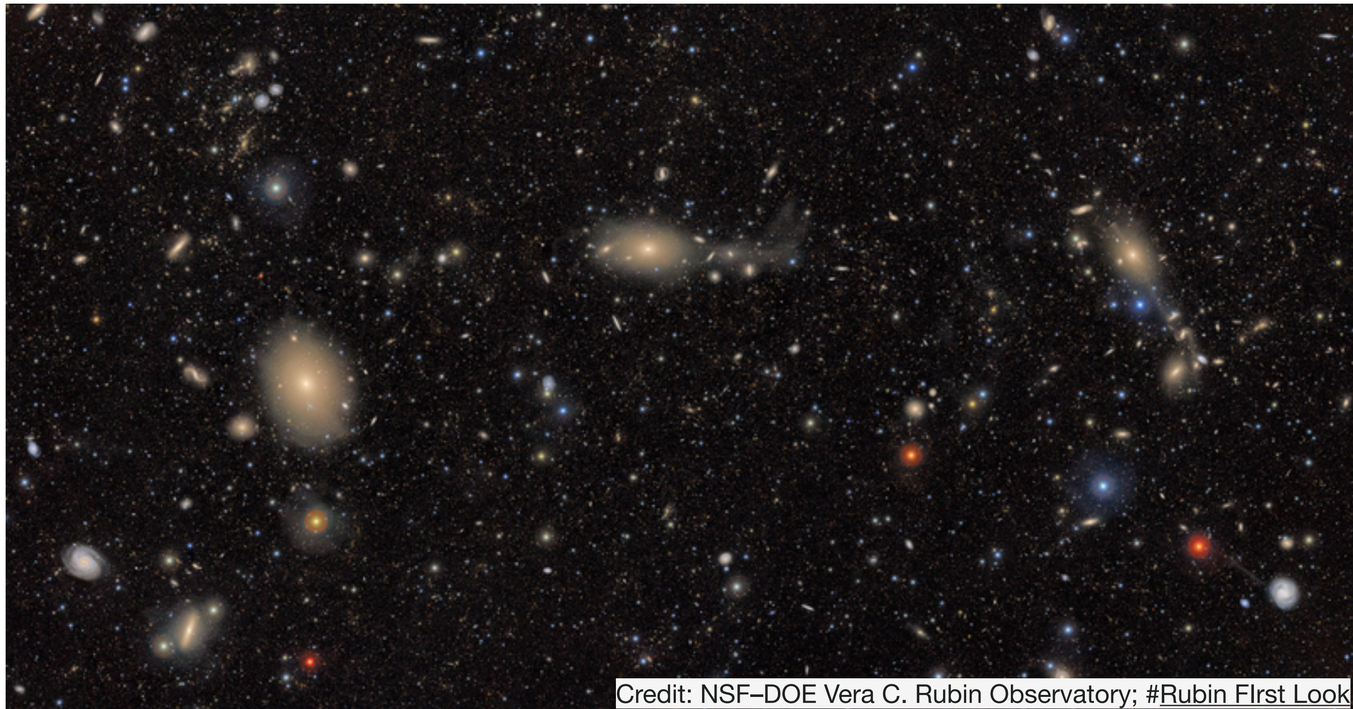
In collaboration with:
David Parkinson and Paweł Bielewicz

June 24, 2025
CosmoVerse@Istanbul, June 24-27, 2025

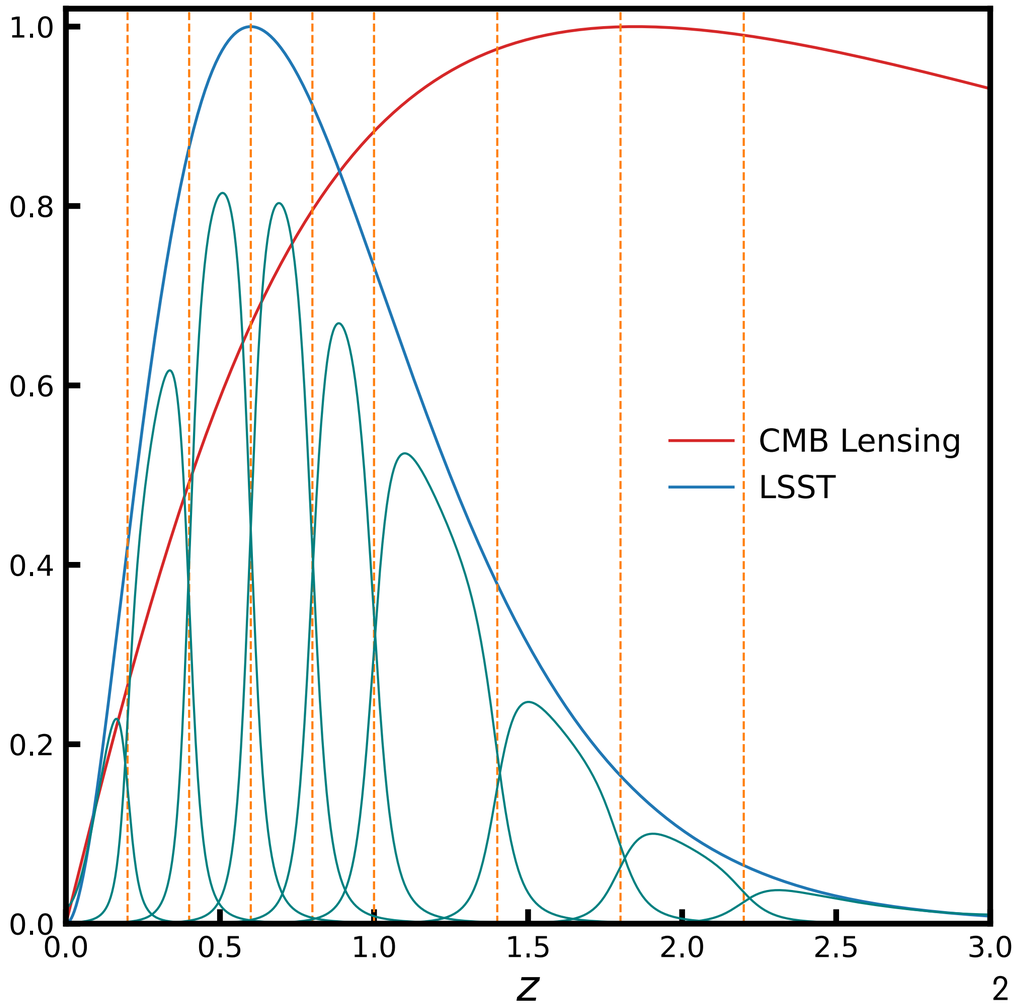

Credit: NSF–DOE Vera C. Rubin Observatory; #Rubin FIrst Look

Cross-correlation

- Tracers mapping the same large scale structure can be correlated if
    1. They overlap in redshift.
    2. They have same angular selection.

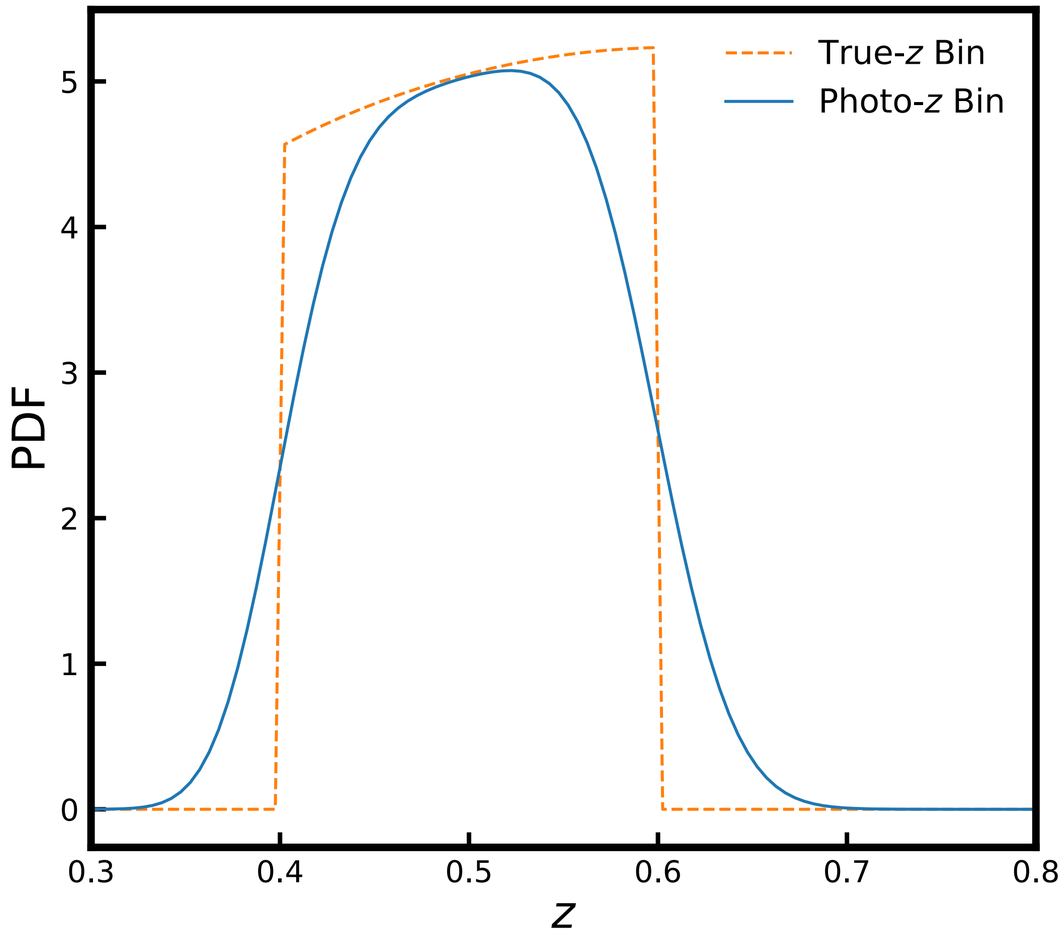
- E.g. CMB, galaxy surveys, quasars, HI intensity, etc.
- Cross-correlation with objects of known redshift
- Cross-correlation in redshift bins - *Tomography*
- Time evolution of cosmological parameters.
- Constrain cosmological models.

CSS and P. Bielewicz, 2024



Redshift bin mismatch

- Photometric redshifts (photo-z) have errors
- Causes leakage of objects across redshift bins.
- Can change inferences on cosmological parameters.



- Generally, SOMs and stretch/shift of the tomographic photo-z redshift distribution to account for photo-z errors.
- Condition the stretch and shift parameters on cross-correlation between redshift bins.

Redshift bin mismatch

CSS and P. Bielewicz, 2024; CSS et al 2024

- Stretch and shift parameters infer true $n(z)$.
- We have shown (in two papers) that just recovering the true $n(z)$ does not recover correct σ_8.

from photometric bins

(Zhang et al., 2010)

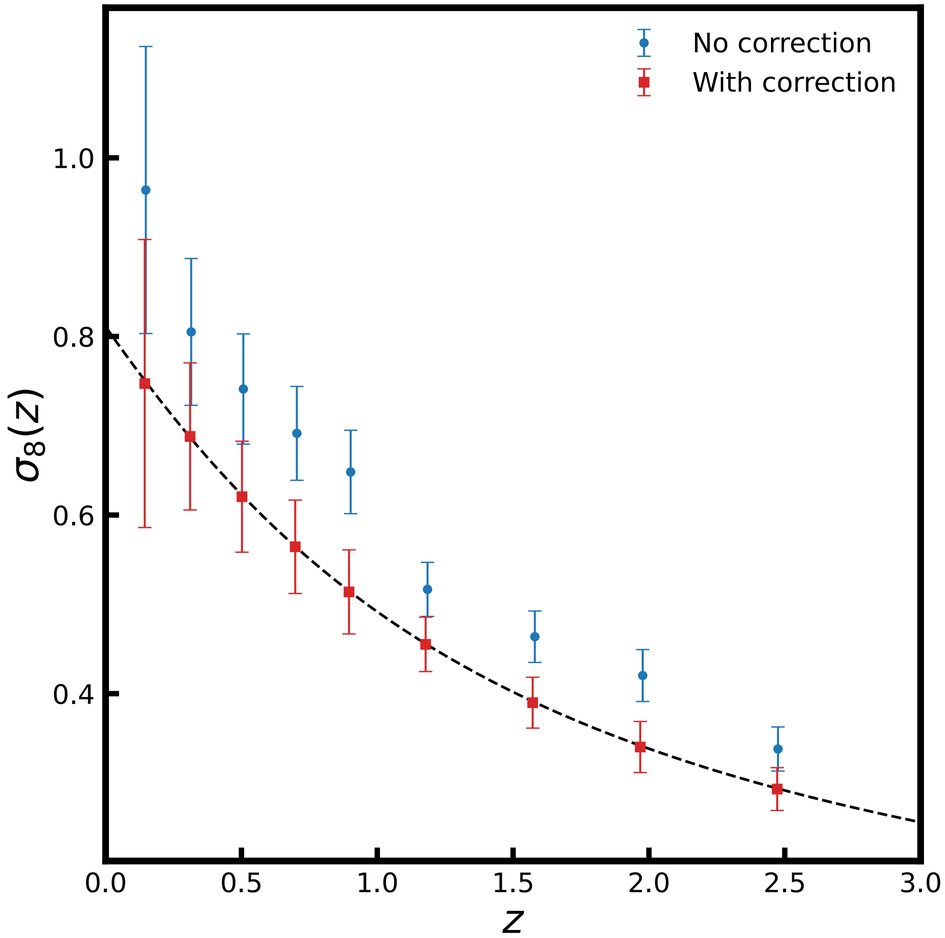
- $$C_{ij}^{gg,\mathrm{Ph}}(\ell) = \sum_k P_{ki} P_{kj} C_{kk}^{gg,\mathrm{Tr}}(\ell), \qquad C_i^{\kappa g,\mathrm{Ph}}(\ell) = \sum_k P_{ki} C_{kk}^{\kappa g,\mathrm{Tr}}(\ell)$$

from true bins (unknown)

Scattering matrix: (unknown) $P_{ij} \equiv \dfrac{N_{i\to j}}{N_j^{\mathrm{Ph}}}$

Scattering matrix formalism

- We compute scattering matrix from measured photo $n(z)$ and photo-z error distributions.
- Our method recovers unbiased σ_8 for LSST simulations (CSS and P. Bielewicz, 2024)



Assumptions

- Simple photo-z error distributions—Gaussian and modified Lorentzian.
- Photo-zs chosen randomly from a known posterior.
- Correlations induced using FLASK.
- Simulation inputs are redshift distributions and angular power spectra.

Possible shortcomings?

- Is our photo-z error distribution too idealistic to infer redshift bin mismatch?
- Is our method of getting photometric redshifts not adequate?
- Is FLASK inducing some artificial features?

Simulations with RAIL

LSST X Planck

Testing effects of photo-z error distribution

Simulation setup

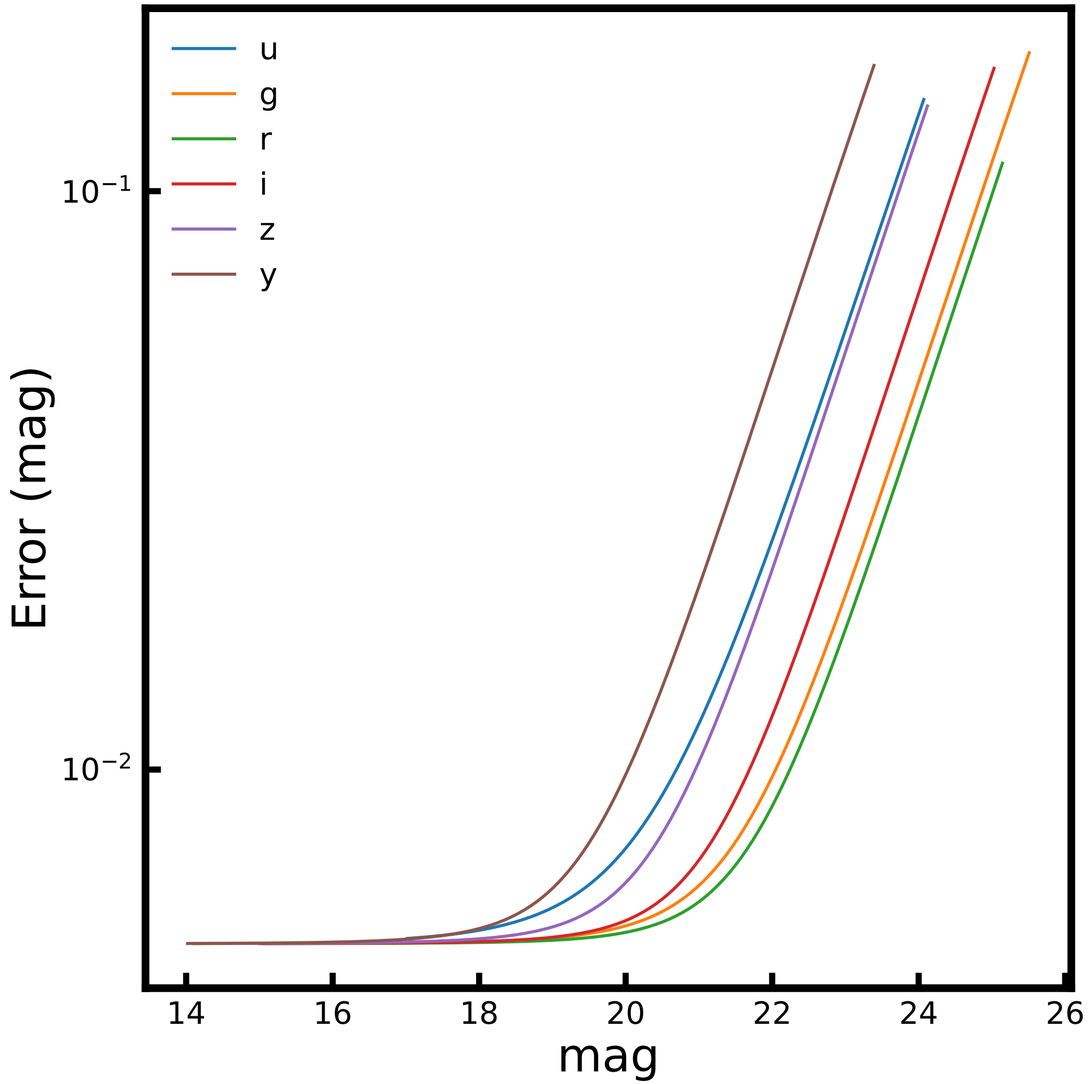
Simulation setup

- Redshift Assessment Infrastructure Layers (RAIL)
- Redshifts and six band mags from Buzzard simulations (DeRose et al. 2019)
- Add errors on photometric magnitudes consistent with LSST Y1

Simulation setup

- Redshift Assessment Infrastructure Layers (RAIL)
- Redshifts and six band mags from Buzzard simulations
- Add errors on photometric magnitudes consistent with Y1
- 5σ depths

$u : 24.07, g : 25.60, r : 25.81, i : 25.13, z : 24.13, y : 23.39$



Simulation setup

- Redshift Assessment Infrastructure Layers (RAIL)
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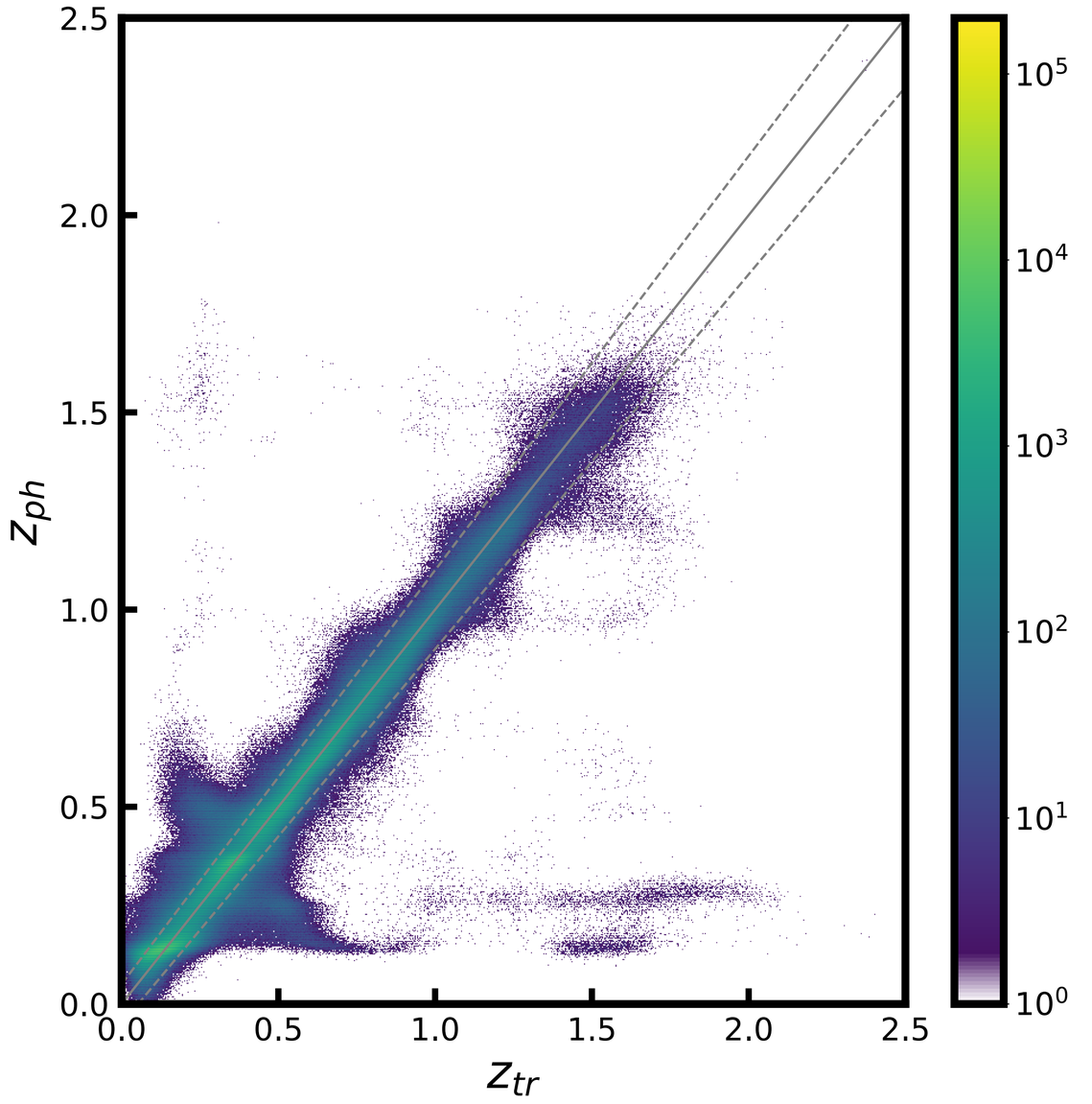
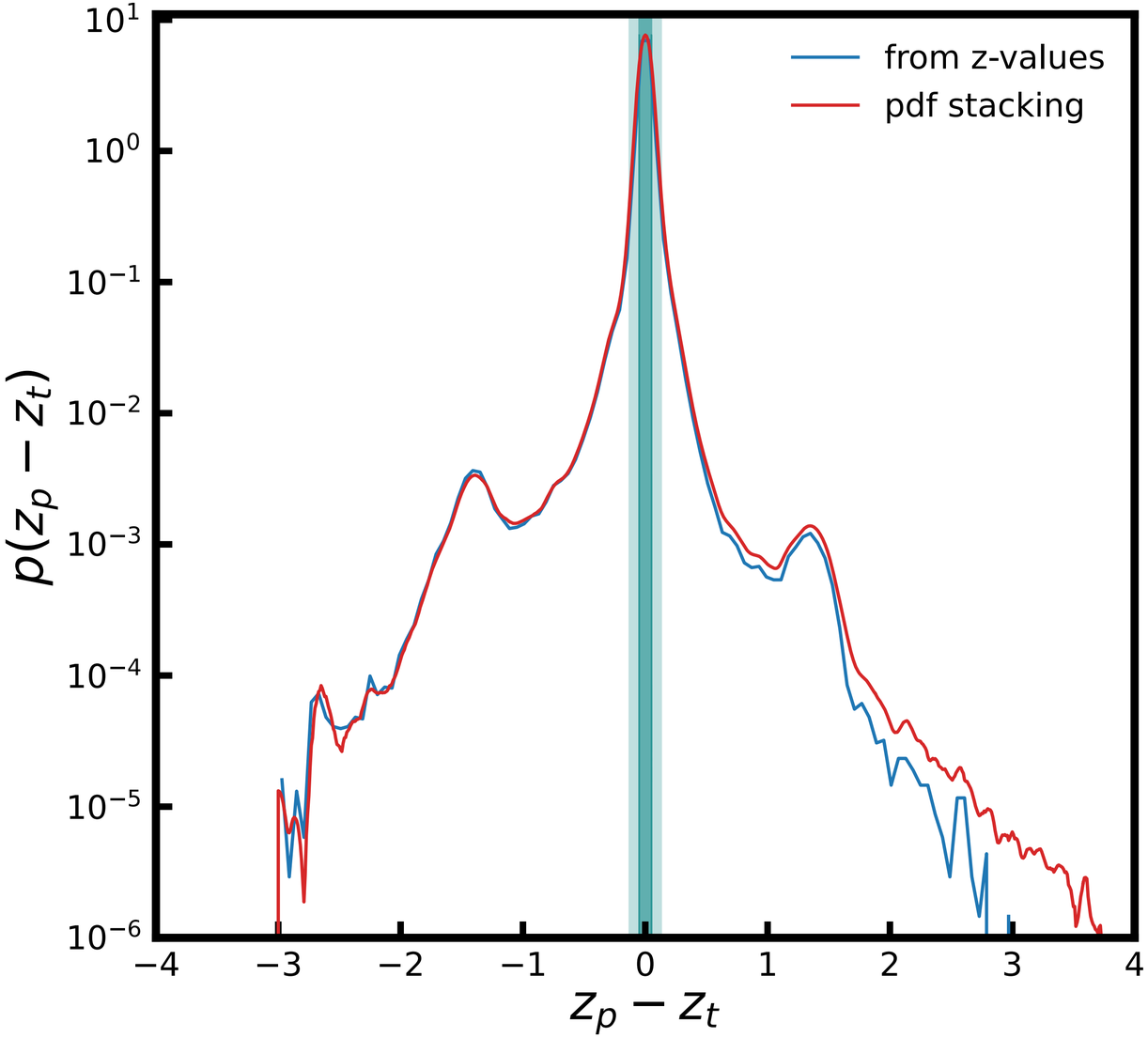
- Add errors on photometric magnitudes consistent with Y1
- 5σ depths

$$u : 24.07, g : 25.60, r : 25.81, i : 25.13, z : 24.13, y : 23.39$$

- Estimate photo-zs using FlexZBoost

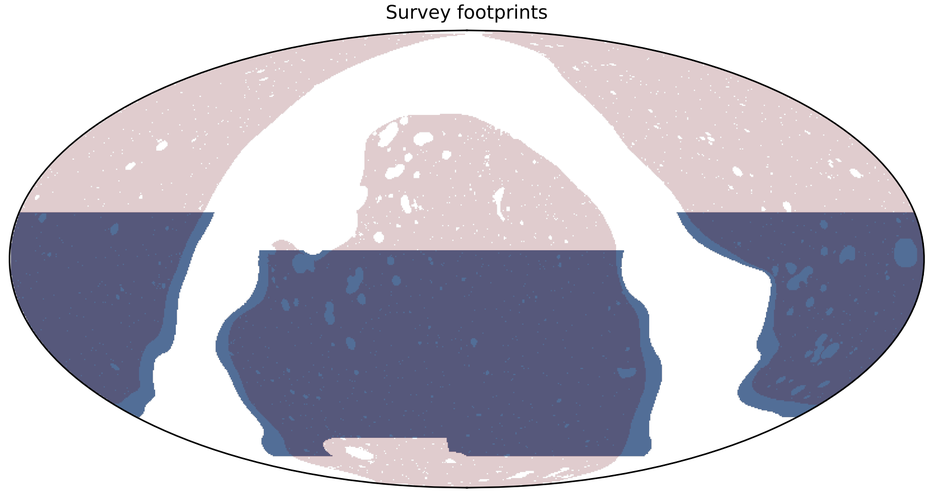


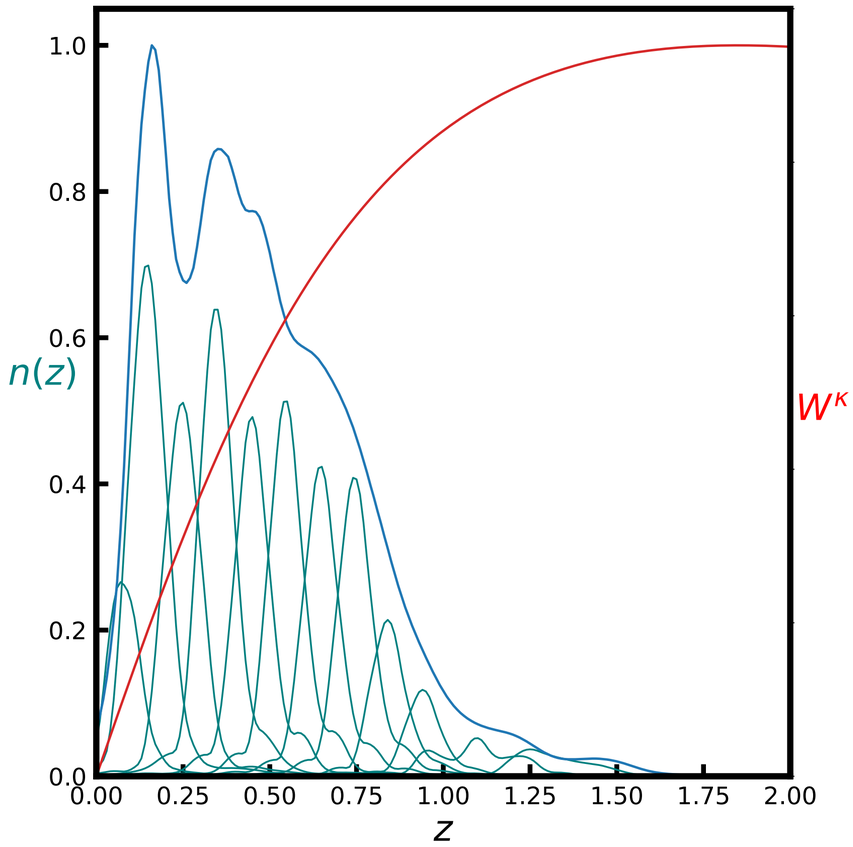
Redshift error distribution



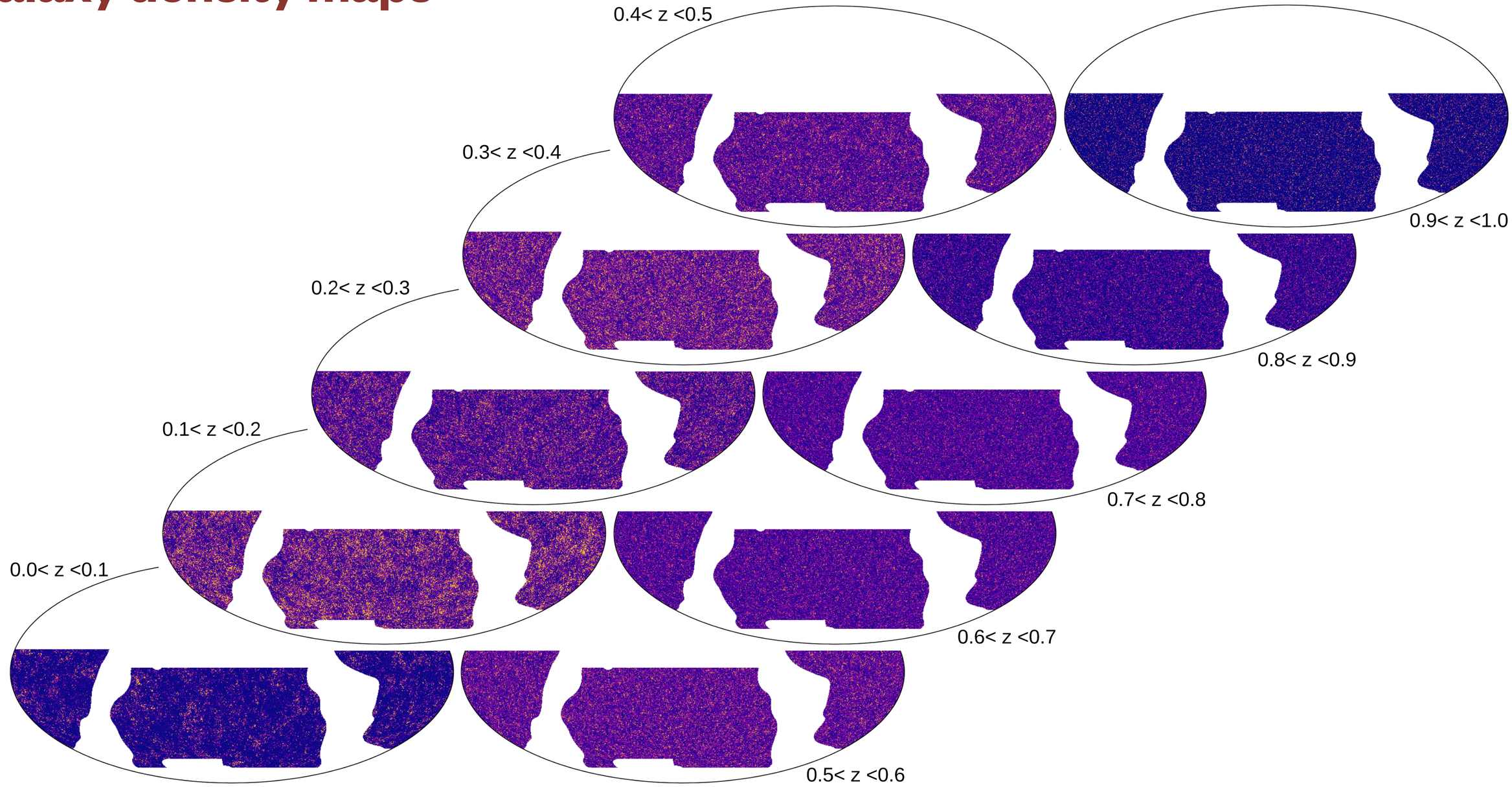
Simulation setup

- Redshift Assessment Infrastructure Layers (RAIL)
- Redshifts and six band mags from Buzzard simulations
- Add errors on photometric magnitudes consistent with Y1
- 5σ depths $u : 24.07, g : 25.60, r : 25.81, i : 25.13, z : 24.13, y : 23.39$
- Estimate photo-zs using FlexZBoost
- Add fiducial correlations using GLASS (Tessore et al. 2023)
- Compute angular power spectra based on photo-zs
- Estimate S_8 and galaxy bias





Galaxy density maps



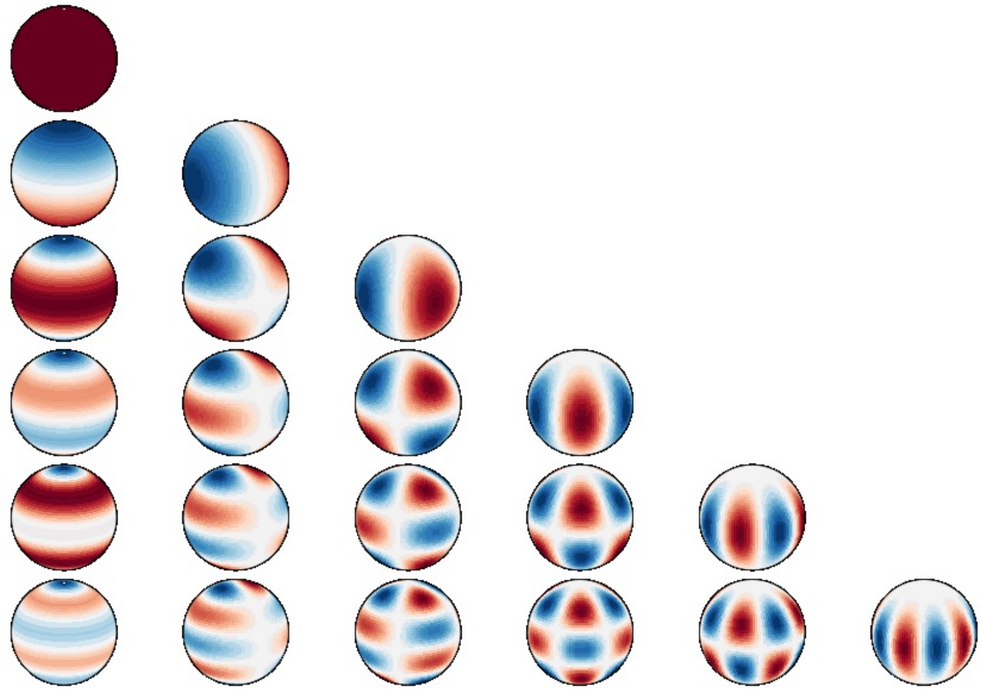
Angular Power Spectrum

Distribution of power as a function of angular scale

$$C_\ell^{XY} = \langle a_{\ell m}^X a_{\ell m}^{Y*} \rangle, \qquad \theta \propto \frac{1}{\ell}$$

Lensing Convergence: $\kappa(\hat{n}) = -\frac{1}{2}\nabla^2\phi(\hat{n})$

Galaxy over-density: $g(\hat{n}) = \frac{n_g(\hat{n}) - \overline{n_g}}{\overline{n_g}}$



Spherical Harmonics

Theoretical Power Spectrum

$$C_\ell^{XY} = \int_0^{\chi_*} d\chi \frac{W^X(\chi) W^Y(\chi)}{\chi^2} P\left(k = \frac{\ell + 1/2}{\chi}, z(\chi)\right)$$

Lensing Kernel: $W^\kappa(\chi) = \frac{3\Omega_{m,0}}{2c^2} H_0^2 (1+z)\chi \frac{\chi_* - \chi}{\chi_*}$

Galaxy Kernel: $W^g(\chi) = b(z)\frac{dN}{dz} + W^{RSD}(\chi)$

Following true redshifts from sims

$P(k, z) \equiv$ Matter power spectrum

$\chi \equiv$ comoving distance

$\chi_* \equiv$ comoving distance to last scattering

$z \equiv$ redshift

$\Omega_{m,0} \equiv$ present matter density parameter

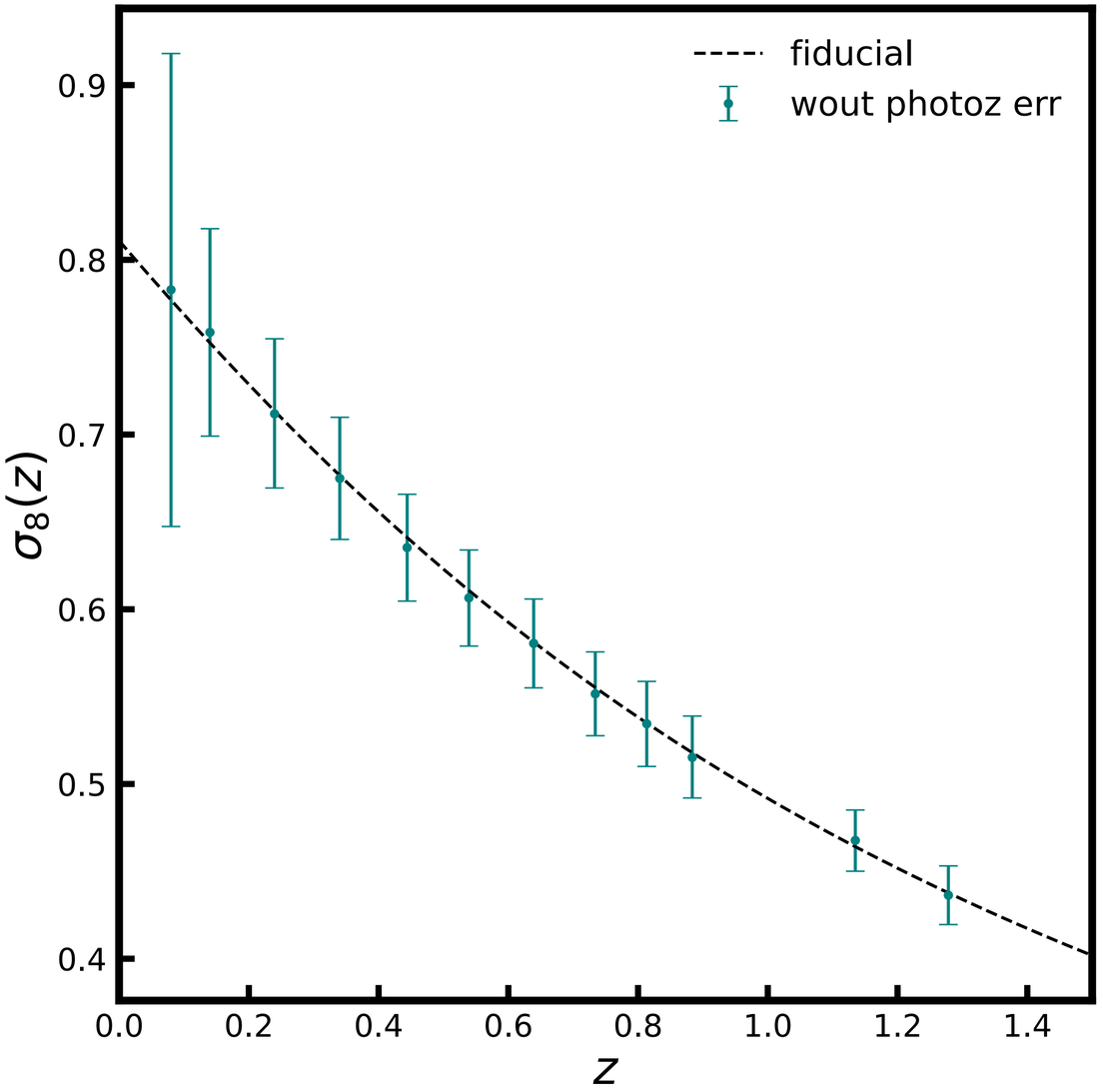
$H_0 \equiv$ Hubble constant

$c \equiv$ speed of light

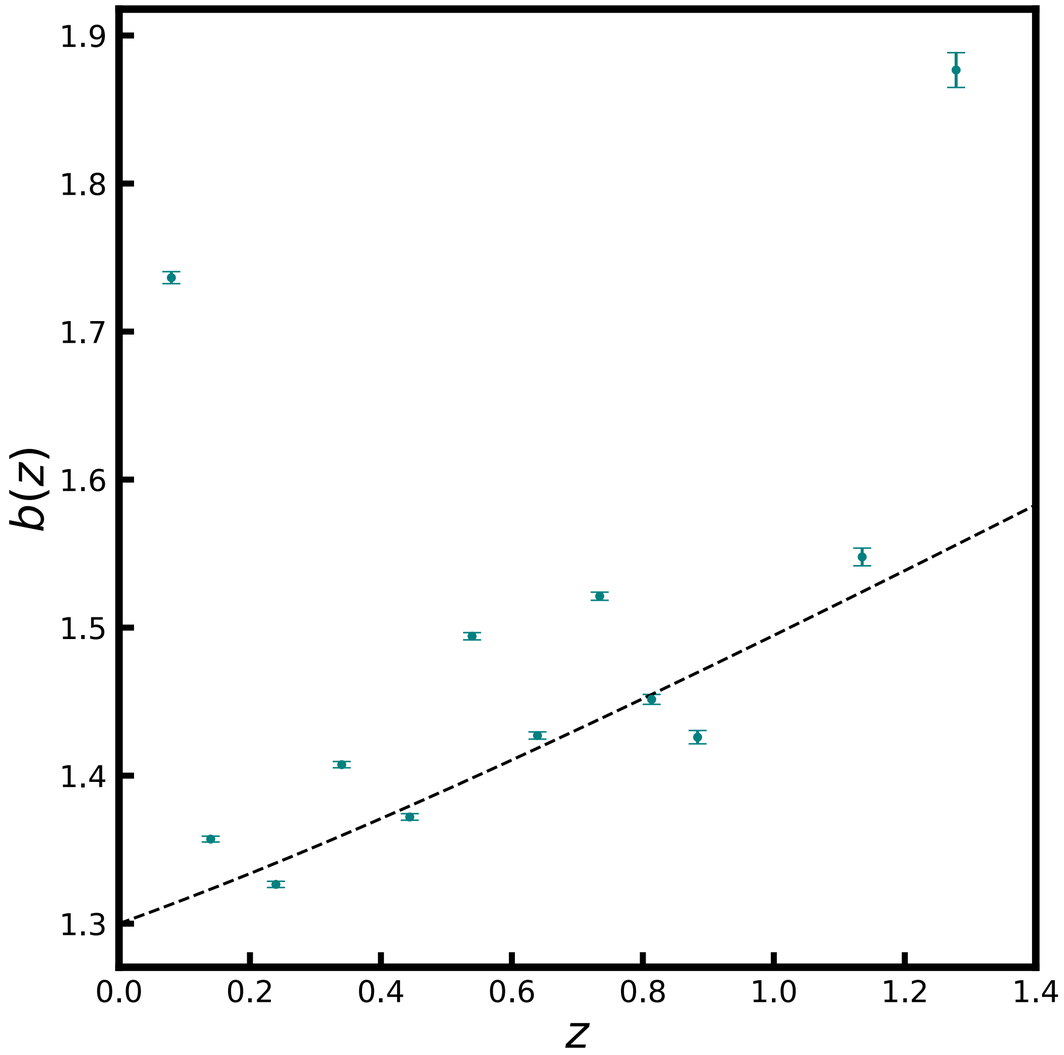
$\frac{dN}{dz} \equiv$ redshift distribution of galaxies

$b(z) \equiv$ galaxy bias

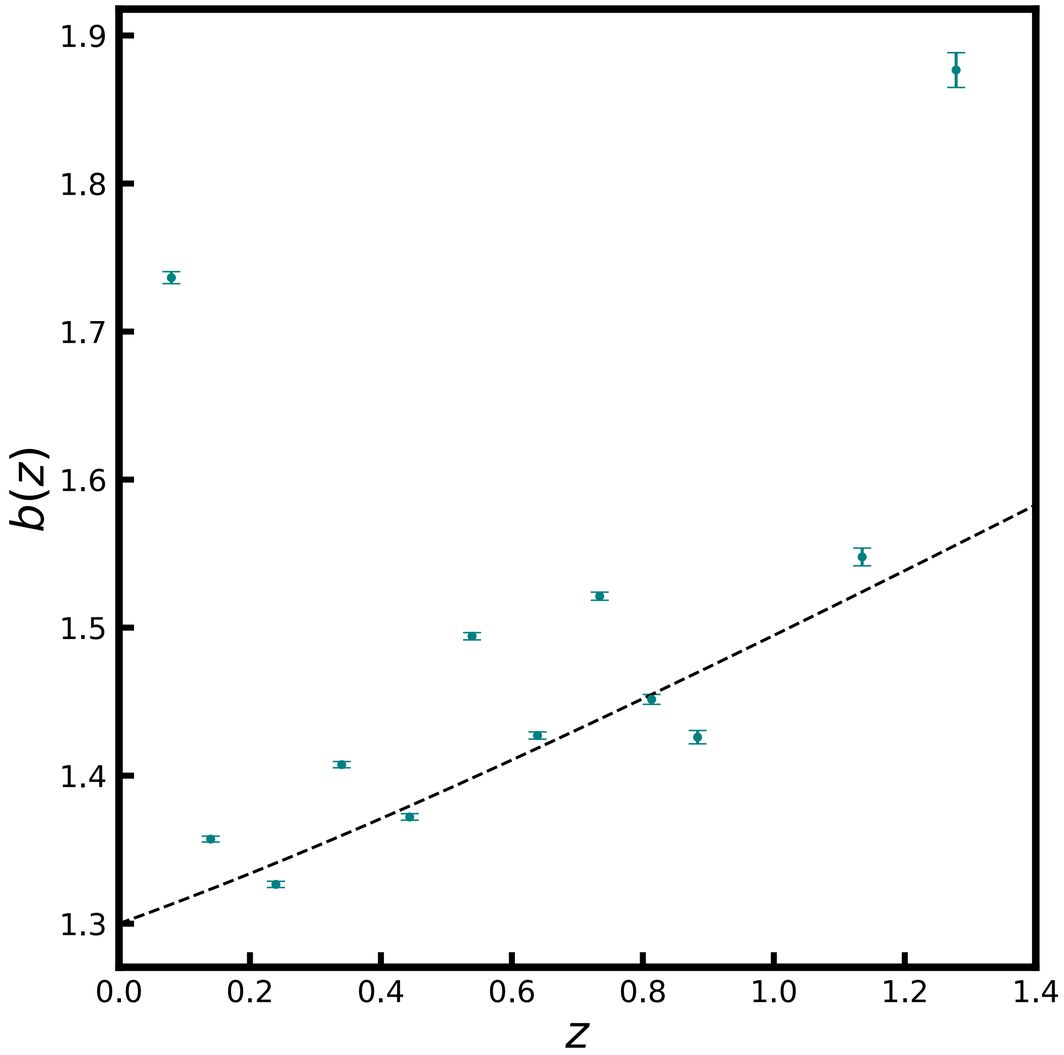
Validate pipeline—no photo-z errors

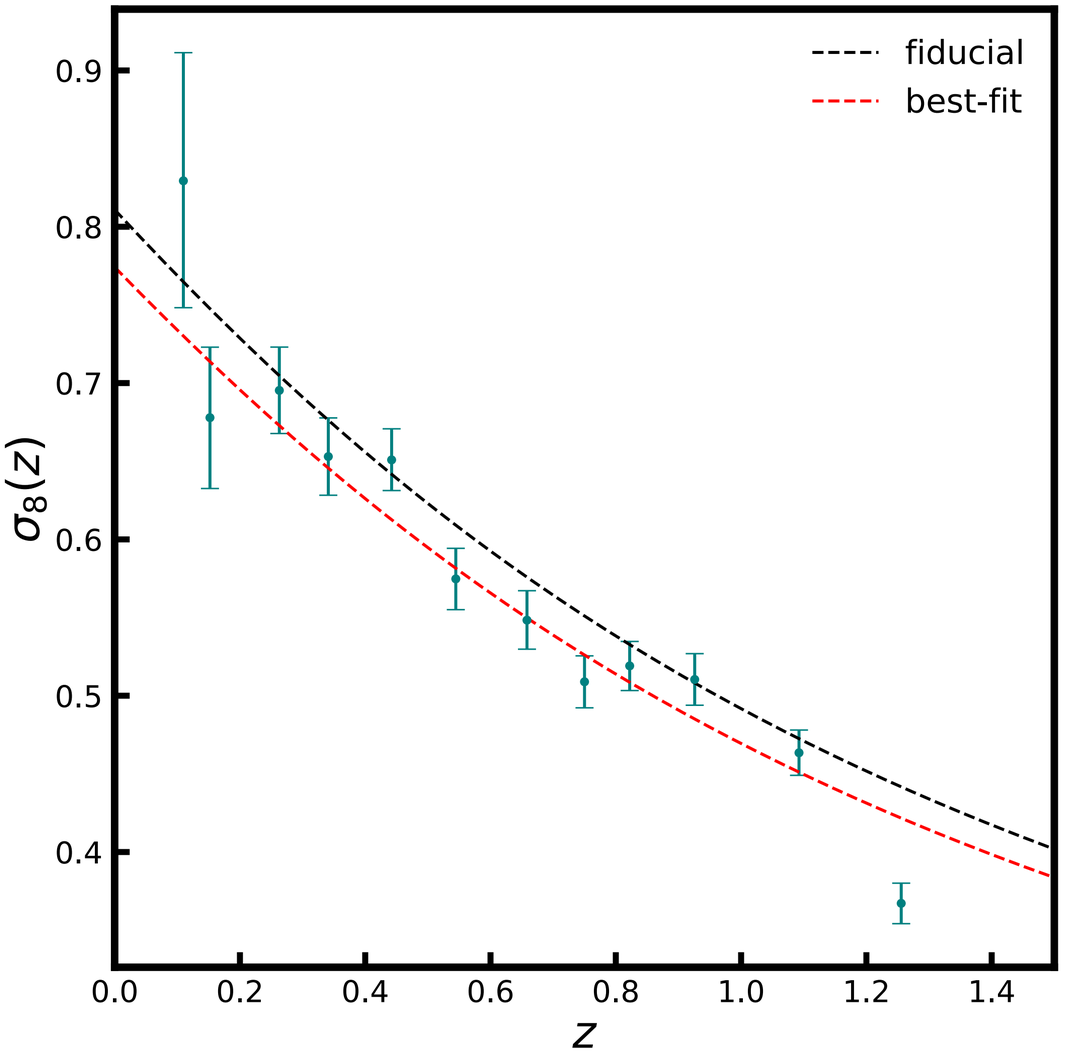


Galaxy bias



Galaxy bias and σ_8

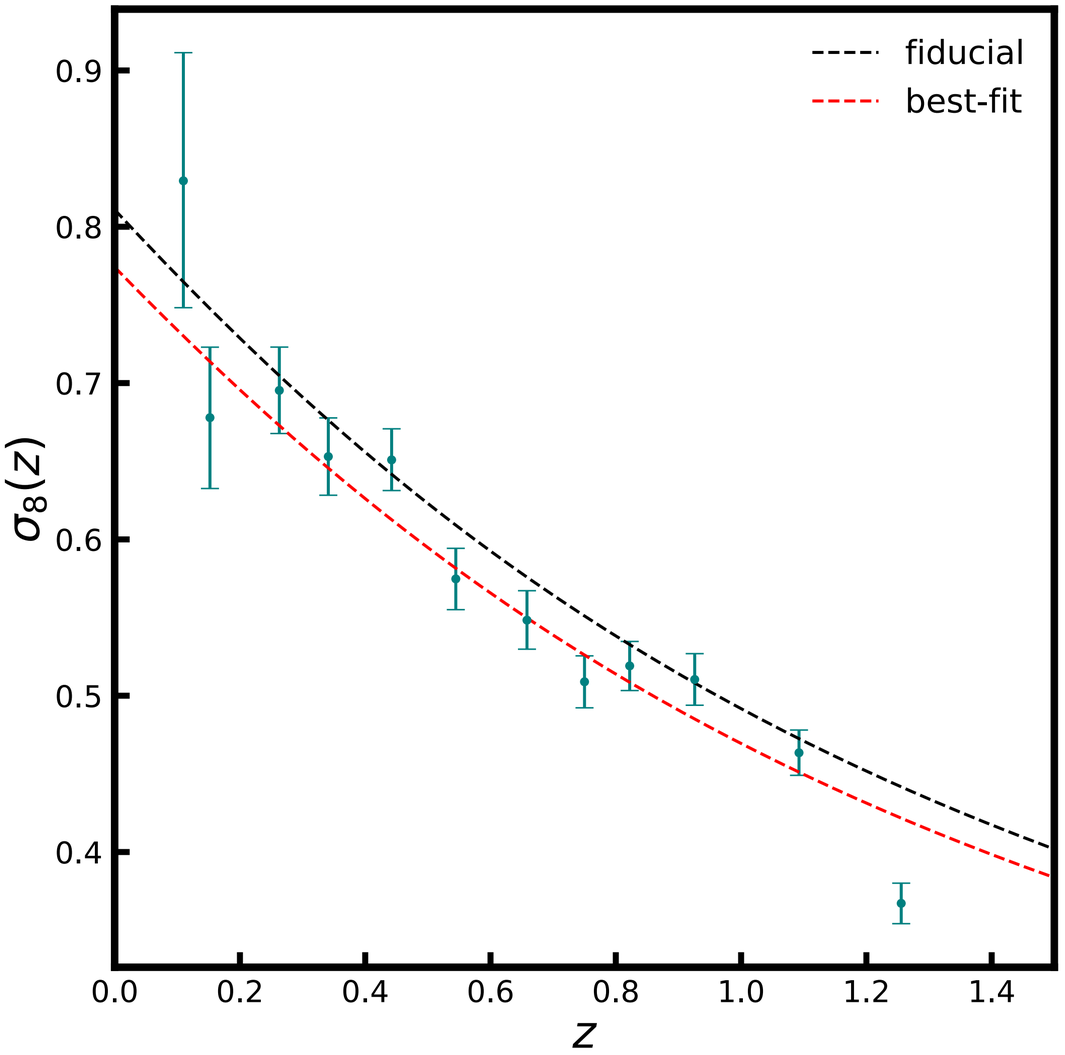




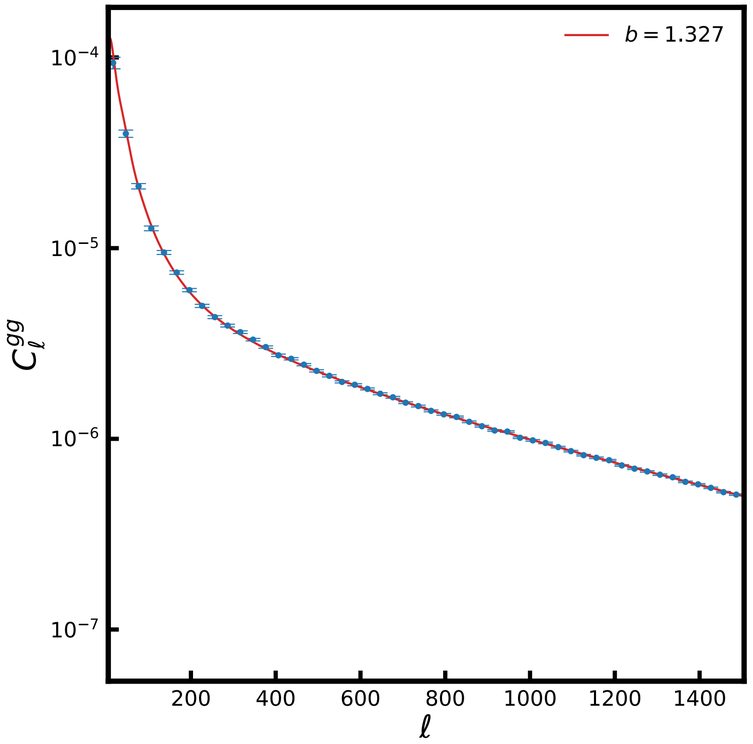
S_8 (tension)

$S_8 = 0.832 \pm 0.013$ (fiducial)

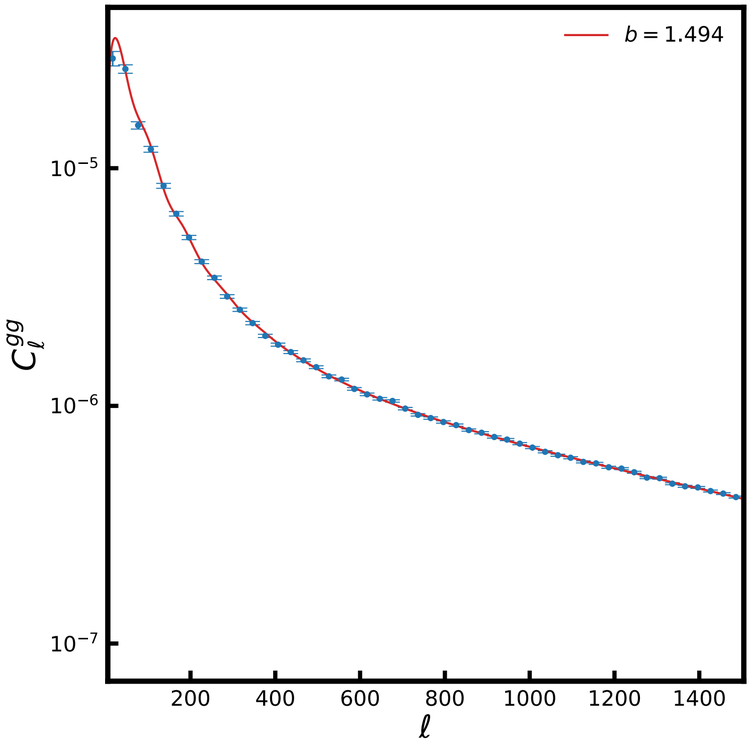
$S_8 = 0.792 \pm 0.013$



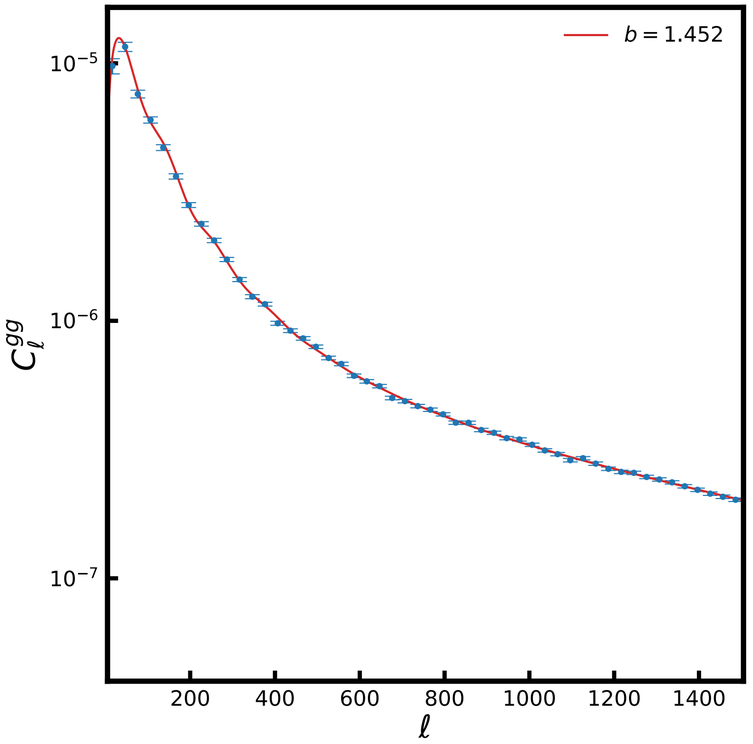
Galaxy auto power spectra



$0.2 \leq z < 0.3$

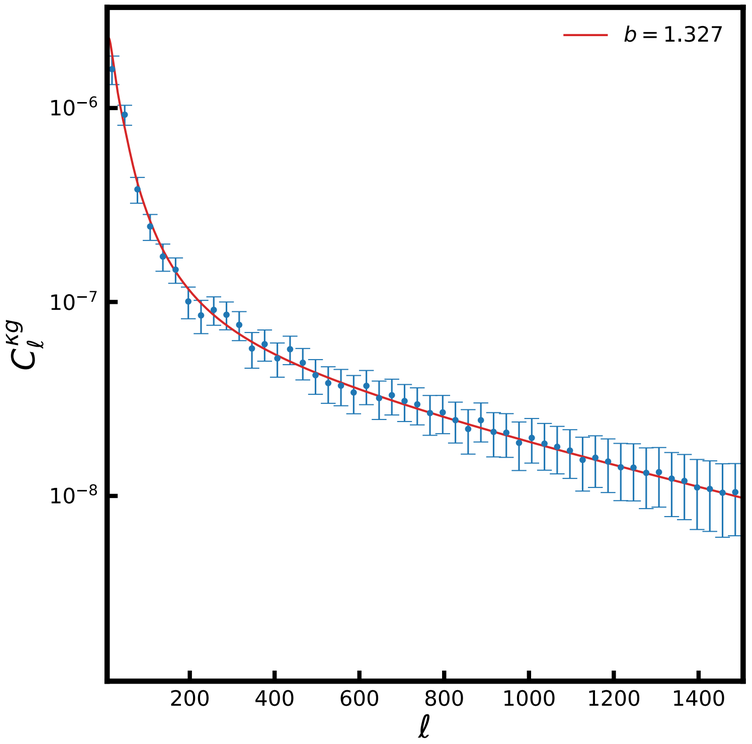


$0.5 \leq z < 0.6$

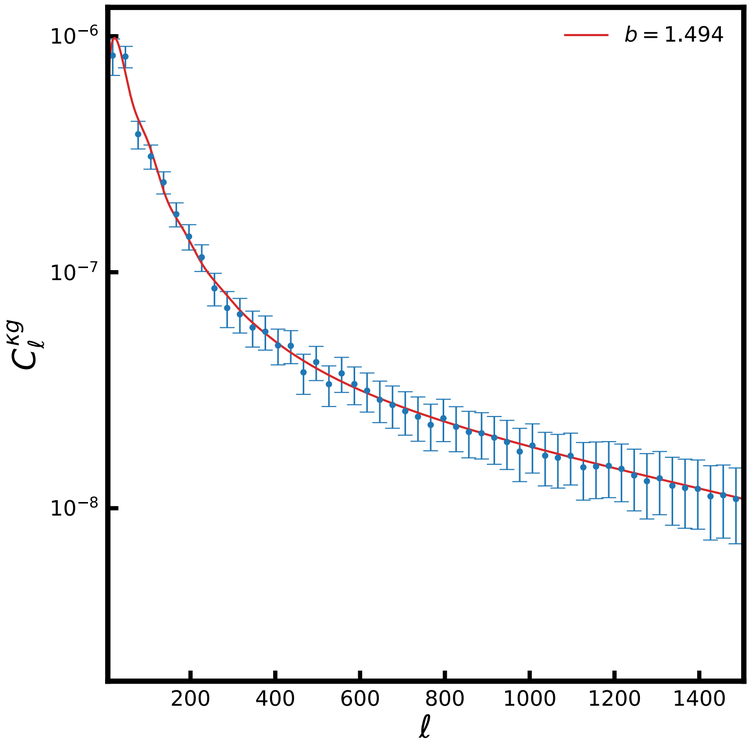


$0.8 \leq z < 0.9$

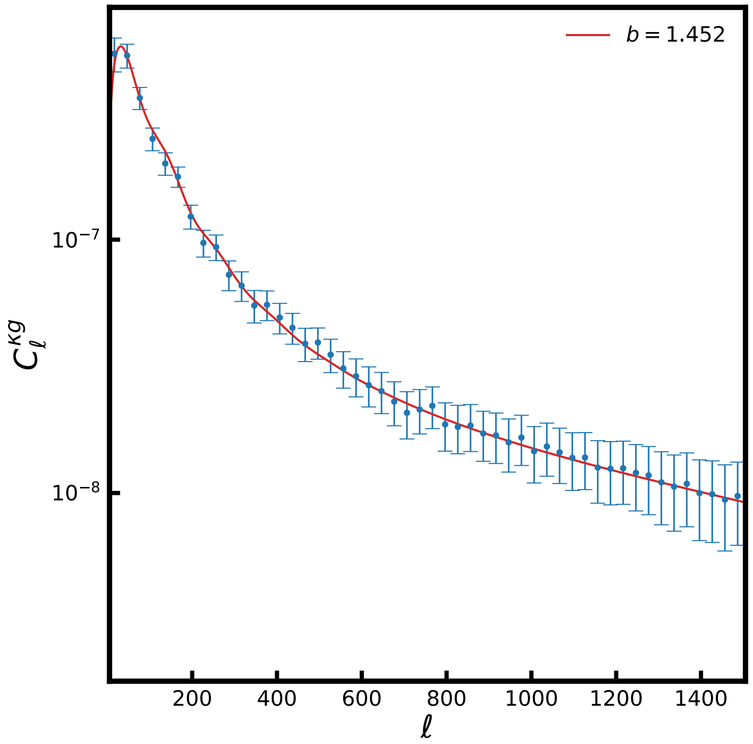
Cross power spectra



$0.2 \leq z < 0.3$



$0.5 \leq z < 0.6$



$0.8 \leq z < 0.9$

Redshift bin mismatch

CSS and P. Bielewicz, 2024; CSS et al 2024

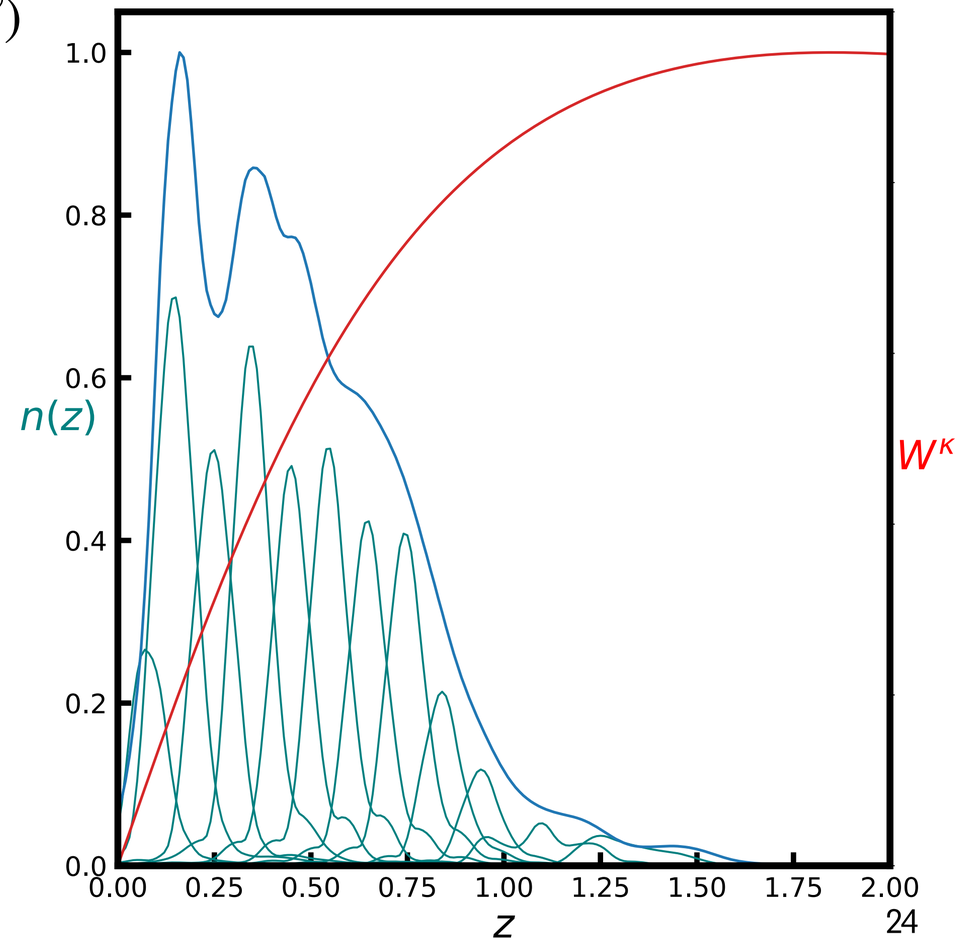
from photometric bins

(Zhang et al., 2010)

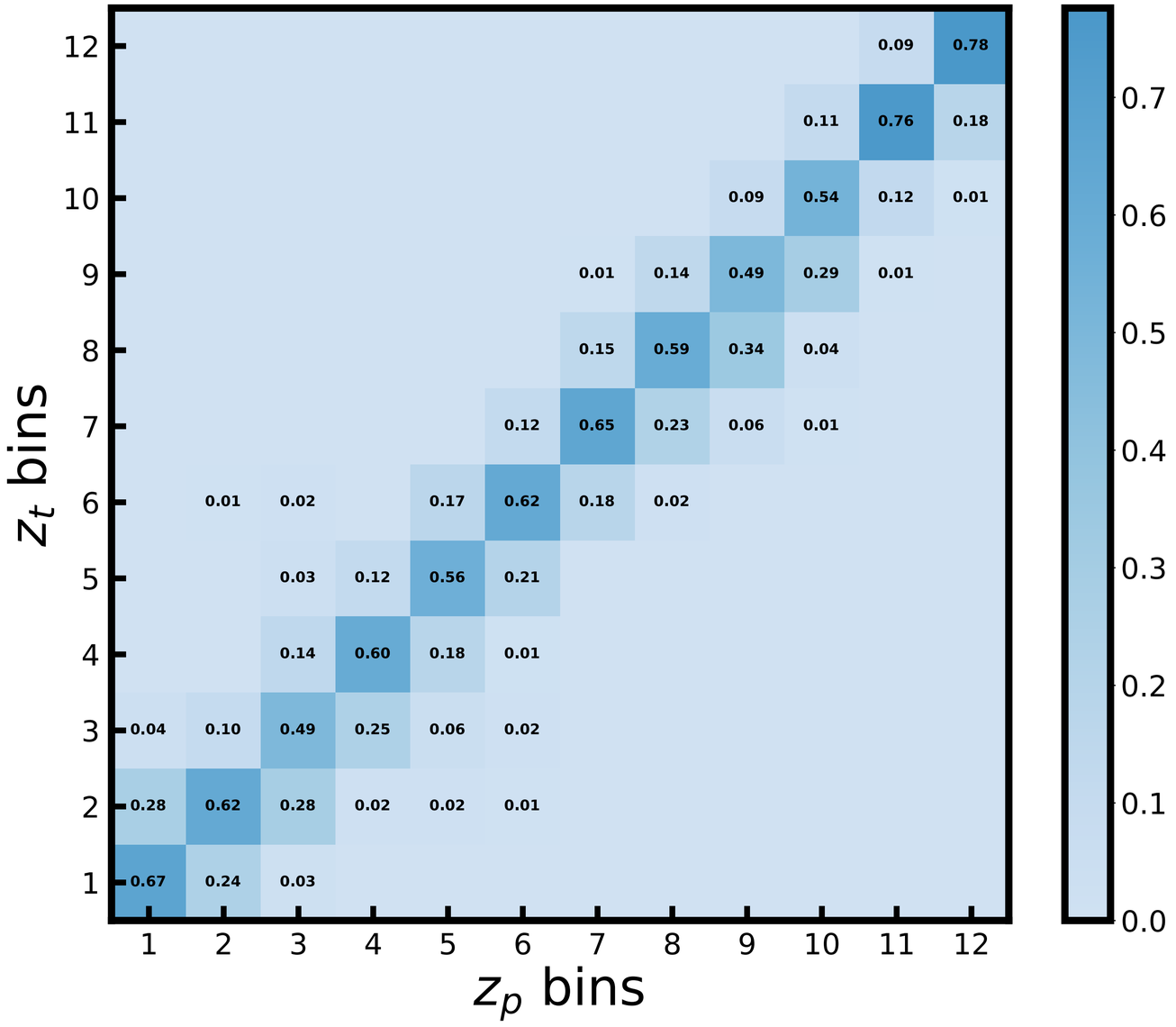
$$C_{ij}^{gg,\mathrm{Ph}}(\ell) = \sum_k P_{ki} P_{kj} C_{kk}^{gg,\mathrm{Tr}}(\ell), \qquad C_i^{\kappa g,\mathrm{Ph}}(\ell) = \sum_k P_{ki} C_{kk}^{\kappa g,\mathrm{Tr}}(\ell)$$

from true bins (unknown)

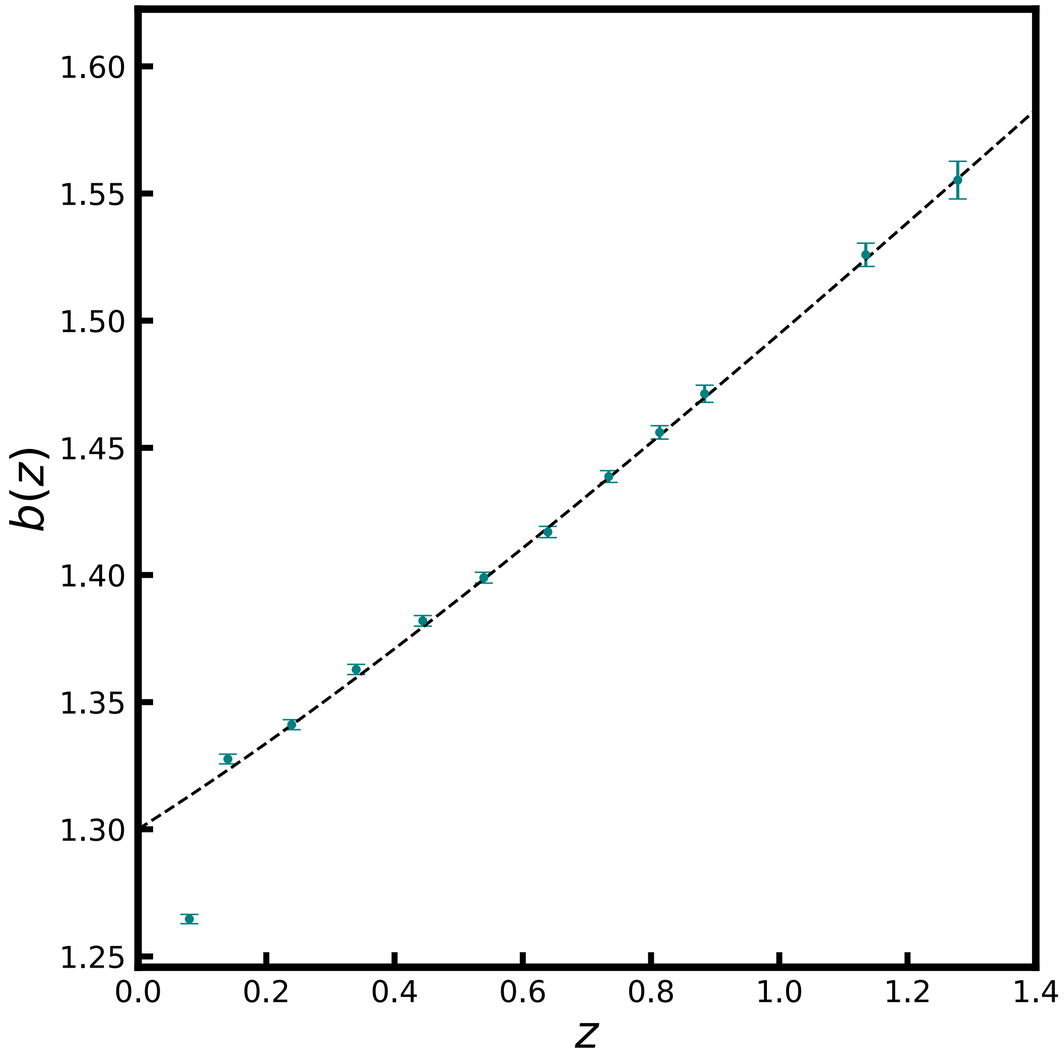
Scattering matrix: (unknown) $P_{ij} \equiv \dfrac{N_{i\to j}}{N_j^{\mathrm{Ph}}}$

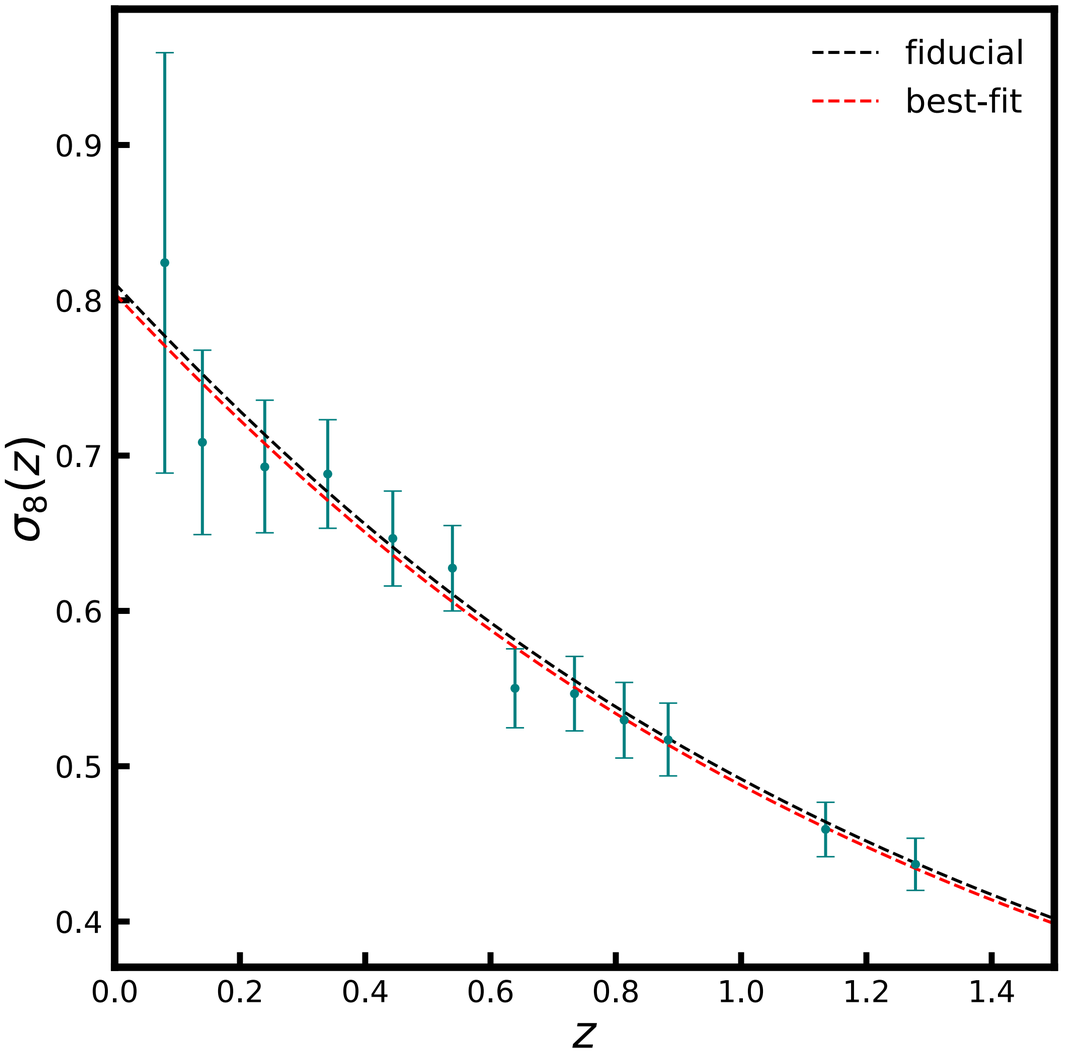


Scattering matrix



Corrected galaxy bias and σ_8



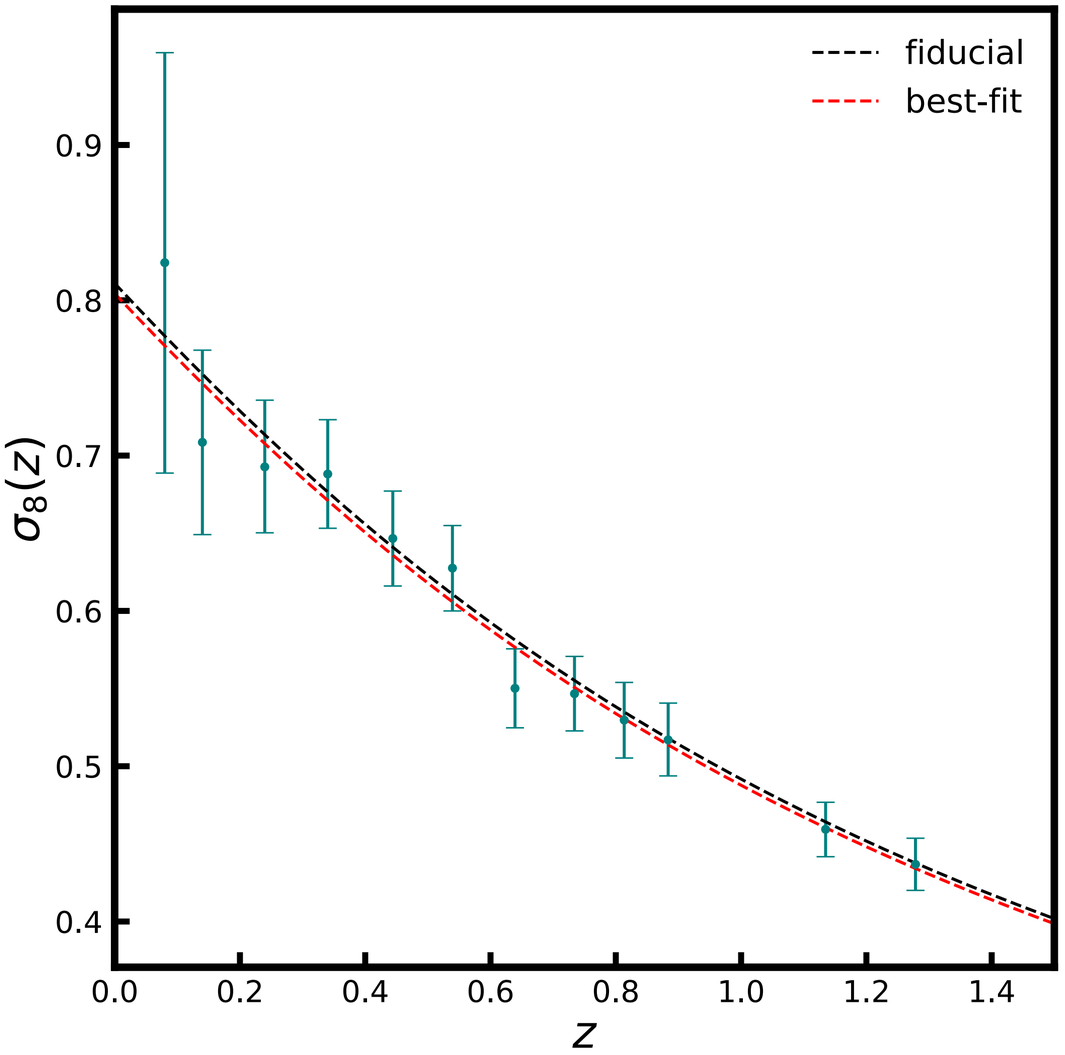


S_8

$S_8 = 0.832 \pm 0.013$ (fiducial)

$S_8 = 0.792 \pm 0.013$ (conventional)

$S_8 = 0.823 \pm 0.016$ (scattering matrix)

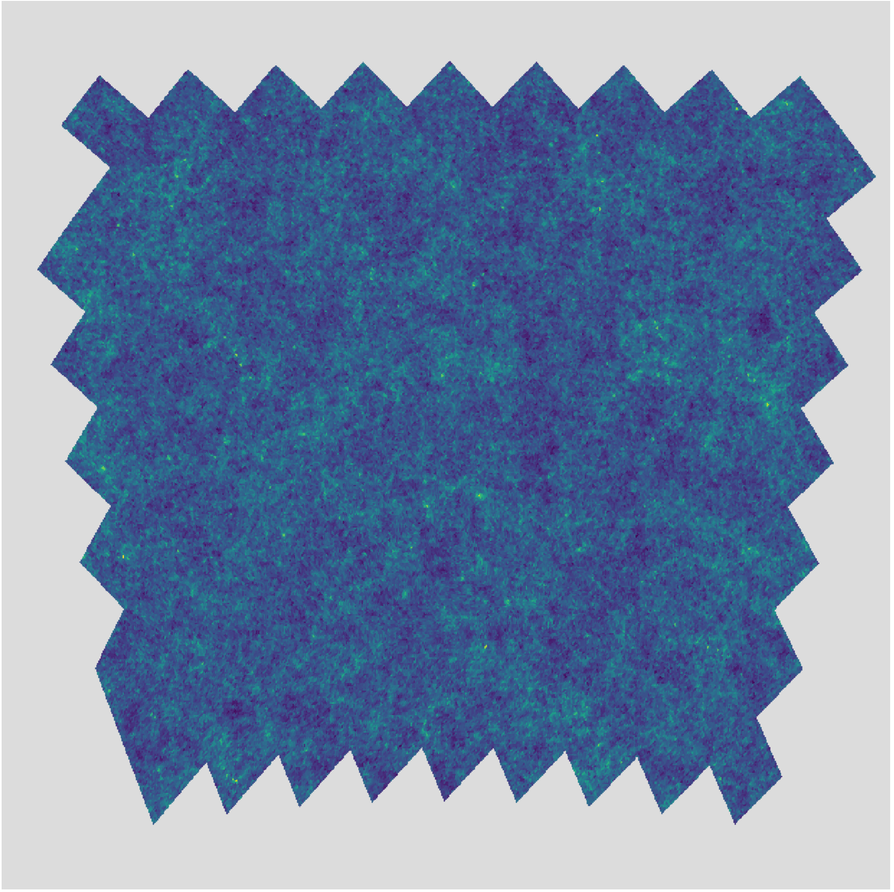


LSST cosmoDC2

Is FLASK/GLASS generating non-physical signatures?

cosmoDC2

- Based on Outer Rim simulations (300 times more volume than Millennium simulations.
- WMAP5 cosmology: $\sigma_8 = 0.8$
- Objects up-to redshift $z = 3$ and depth of $r = 28$.
- 300 sq. deg., all LSST filters $ugrizy$, redshift, position and ellipticities.
- Errors on magnitudes assuming 10 years of magnitude.
- Photo-z catalogue with BPZ and FlexZBoost for objects with $i < 26.5$.



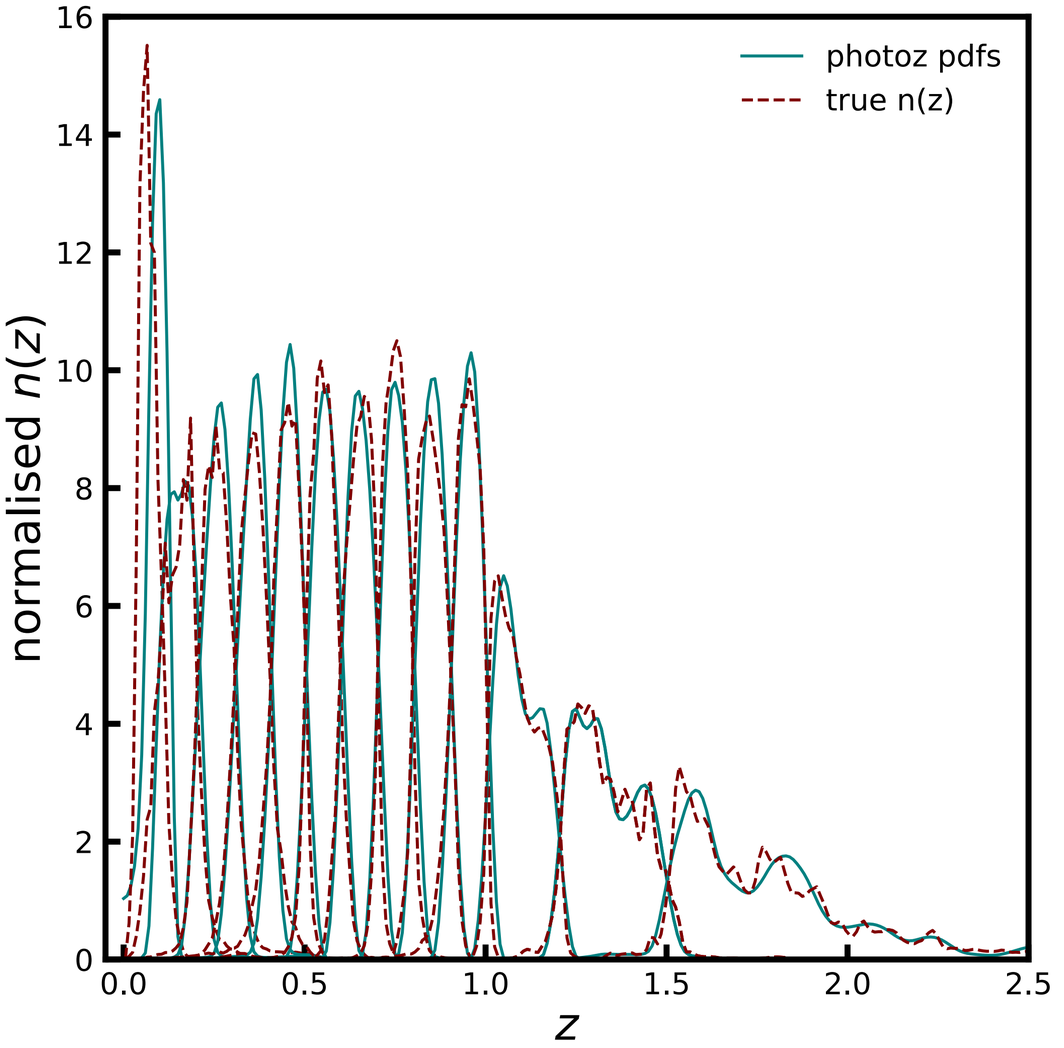
cosmoDC2

- Galaxies divided into 13 redshift bins.

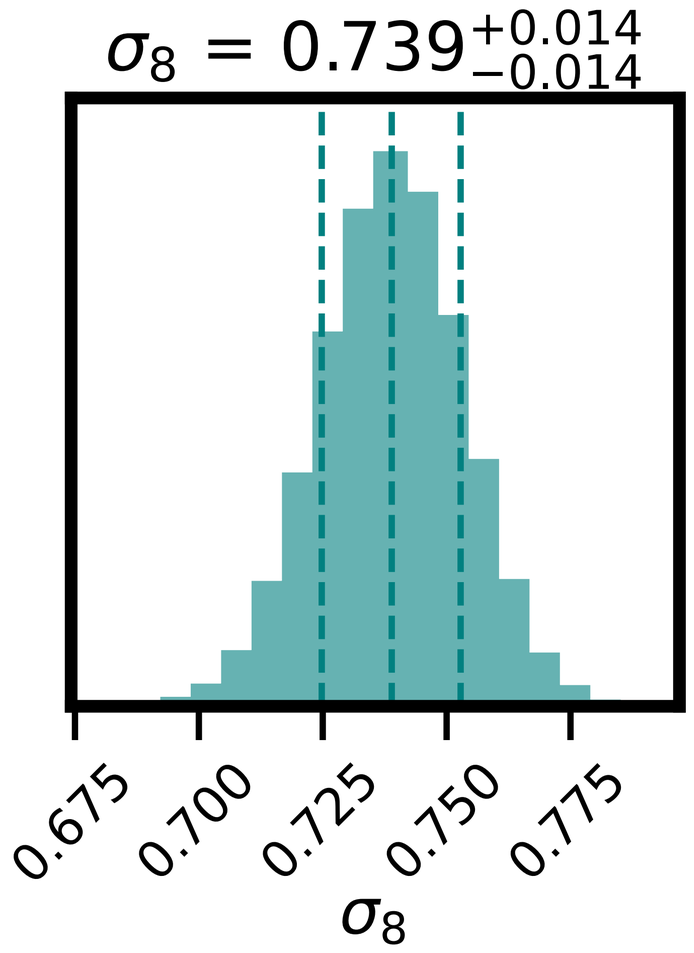
- Only objects with $i < 24$.

Analysis setup

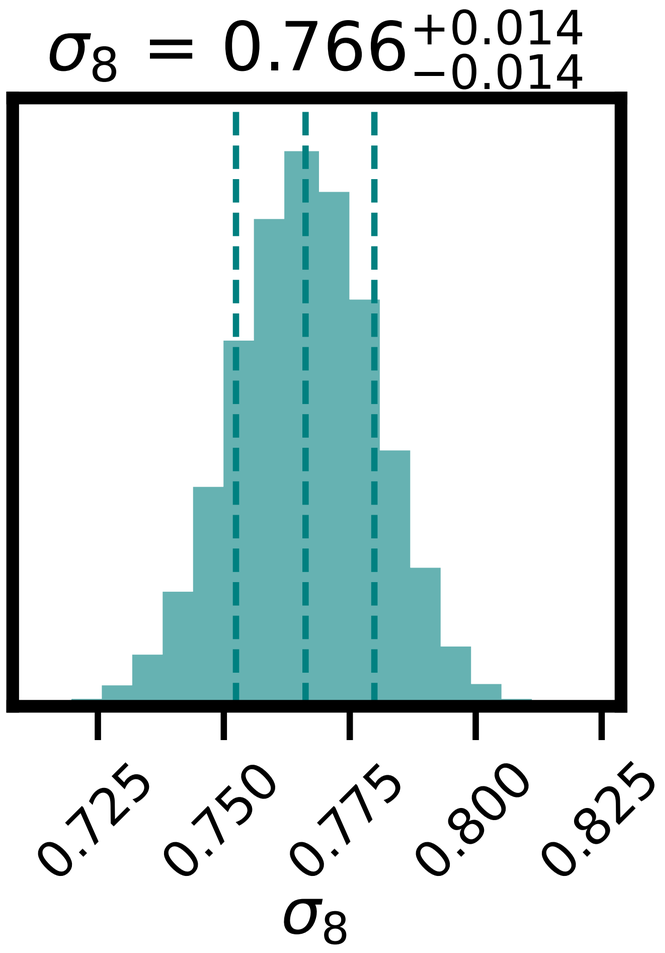
- Galaxies divided into 13 redshift bins.
- Only objects with $i < 24$.
- No magnification.
- Only galaxy clustering data.
- Theory model with $k < 0.3\,\mathrm{Mpc}^{-1}$
- Redshift distributions from
    1. Stacking photo-z posteriors
    2. Following truth catalogues



σ_8



Stacking photo-z PDFs



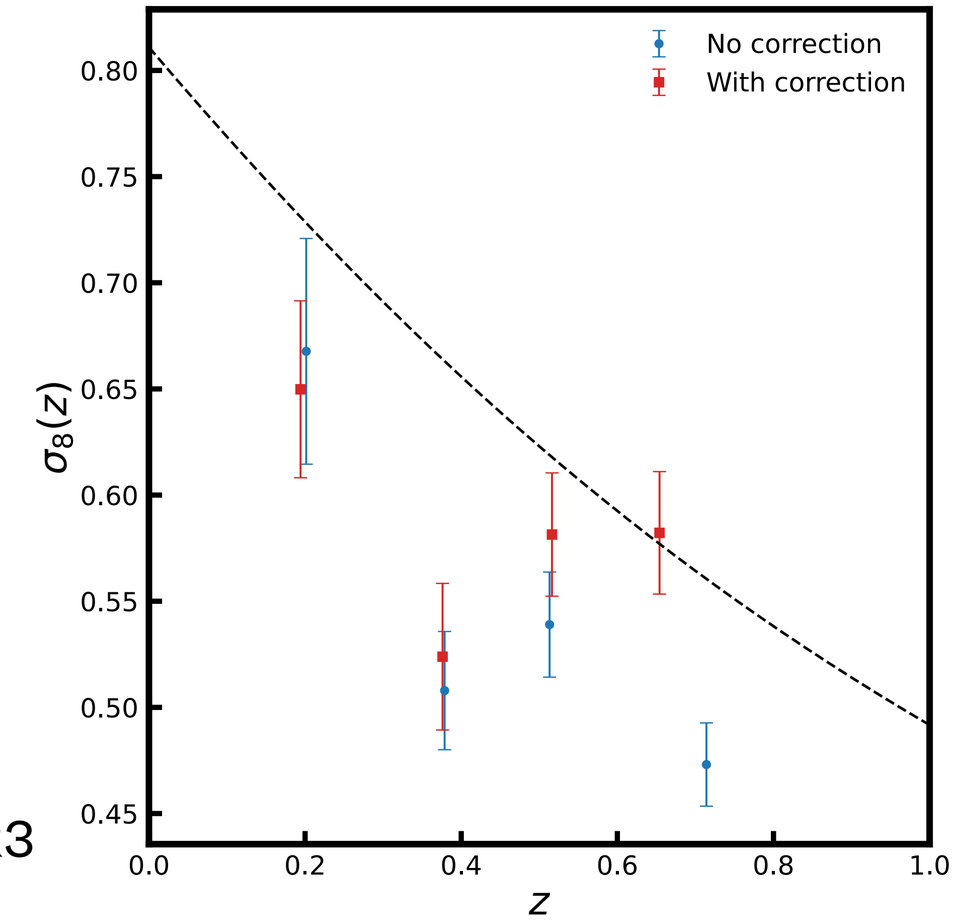
Truth catalogue

Looking forward

- Update scattering matrix formalism to include magnification bias and shear measurements.

- Analyse more real data to study the impact of bin mismatch on S_8.

CSS et al. 2024



DESI-LIS X Planck PR3

Summary

- Tomographic cross-correlation between CMB lensing map and galaxy surveys useful for tracing time evolution of the large-scale structure.
- Redshift bin mismatch can lead to apparent S_8-tension.
- LSST Y1 simulations predict $\sim 3\sigma$ tension on S_8 parameter due to bin mismatch
- Our scattering matrix formalism can be used to correct for bin mismatch.
- A potential solution to the S_8-tension in cosmology (?)

Credit: NSF–DOE Vera C. Rubin Observatory; #Rubin FIrst Look

THANK YOU