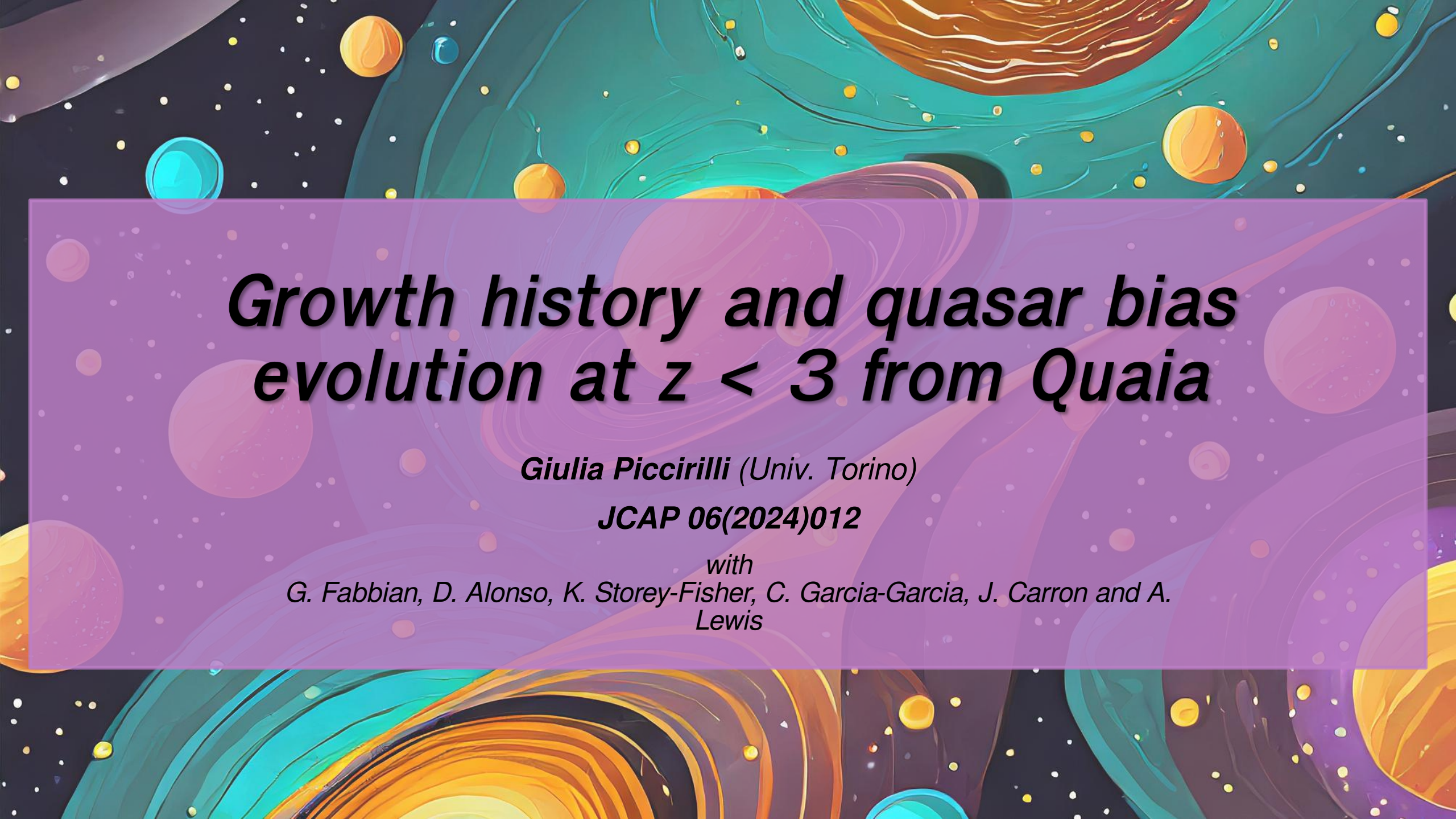

Growth history and quasar bias evolution at $z < 3$ from Quaia

Giulia Piccirilli *(Univ. Torino)*

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with
G. Fabbian, D. Alonso, K. Storey-Fisher, C. Garcia-Garcia, J. Carron and A. Lewis

Overview

We use the clustering of Quaia quasars and their cross-correlation with CMB lensing maps to achieve three main goals

1. Measurement of σ_8 as function of z at high redshift (z~3)
2. Study of the bias of quasars
3. Investigate the presence of possible systematics in CMB lensing reconstructions

Cross-correlation framework

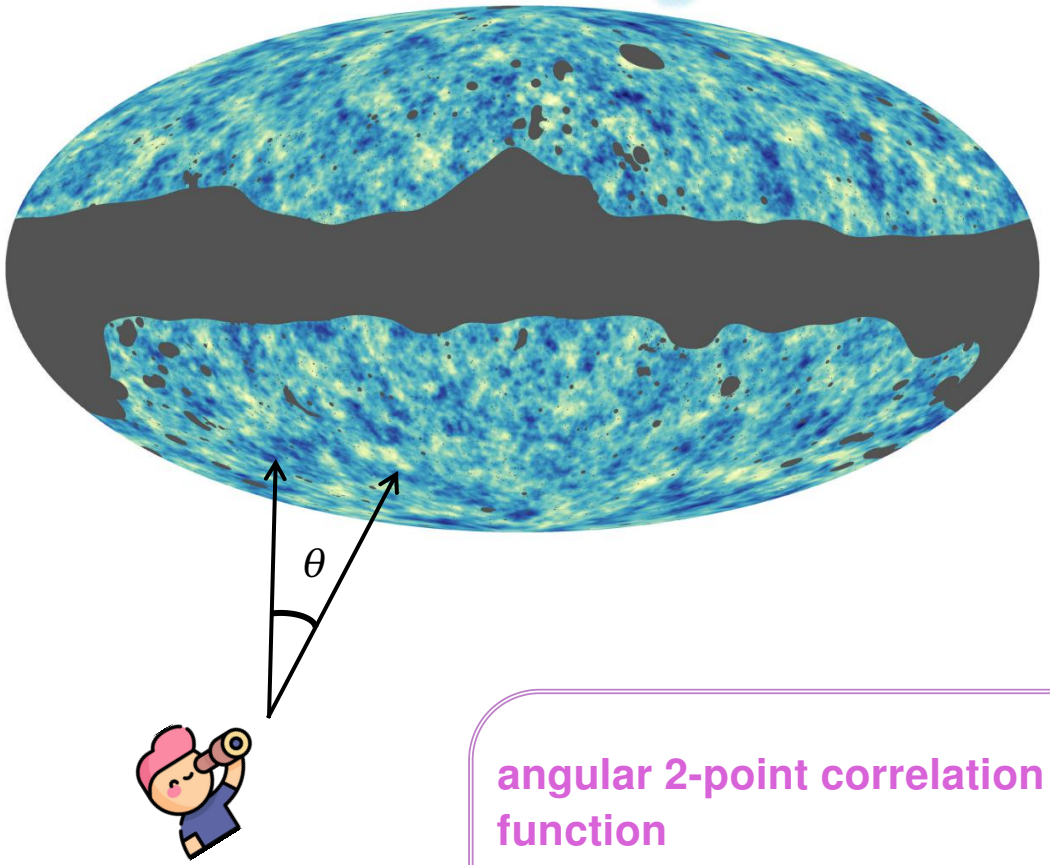
Why are we interested in cross-correlation analysis ?

*This is an invaluable tool for **probing the Universe** and **maximizing** the extraction of **information** from diverse datasets:*

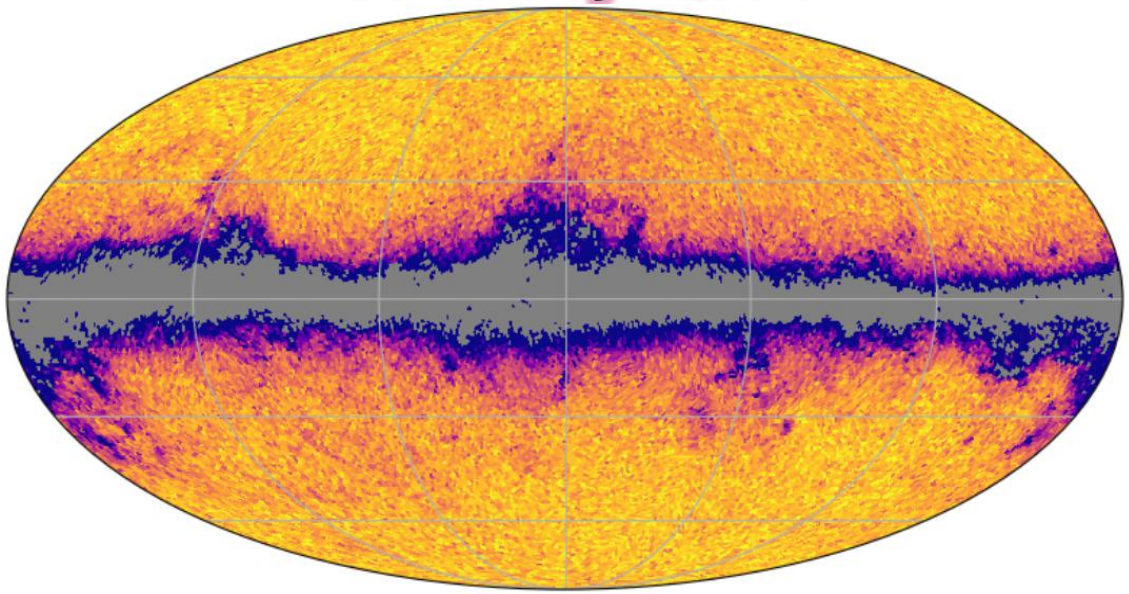
1. *enhanced control over systematic effects compared to auto-correlation analyses*
2. *constraining cosmological and nuisance parameters*
3. *revealing signals otherwise hidden by the noise level (e.g. Integrated Sachs Wolfe, ISW effect)*

Cross-correlation: statistical tools

CMB lensing



LSS survey: Quaia



angular 2-point correlation function

$$C(\theta) = \sum_{\ell=0}^{\infty} \left(\frac{2\ell + 1}{4\pi} \right) C_\ell P_\ell(\cos\theta)$$

angular power spectrum

$$C_\ell = \frac{1}{2\ell + 1} \sum_{m=-\ell}^{\ell} \langle |a_{\ell m}|^2 \rangle$$

Cross-correlation: statistical tools

Auto *angular power spectrum of quasars*

$$C_\ell^{gg} = \frac{2}{\pi}\int_0^\infty dz\,[W^g(z)]^2 \int_0^\infty dk\; k^2 P(k,z)\, j^2_\ell[k\,\chi(z)]$$

Cross *angular power spectrum*

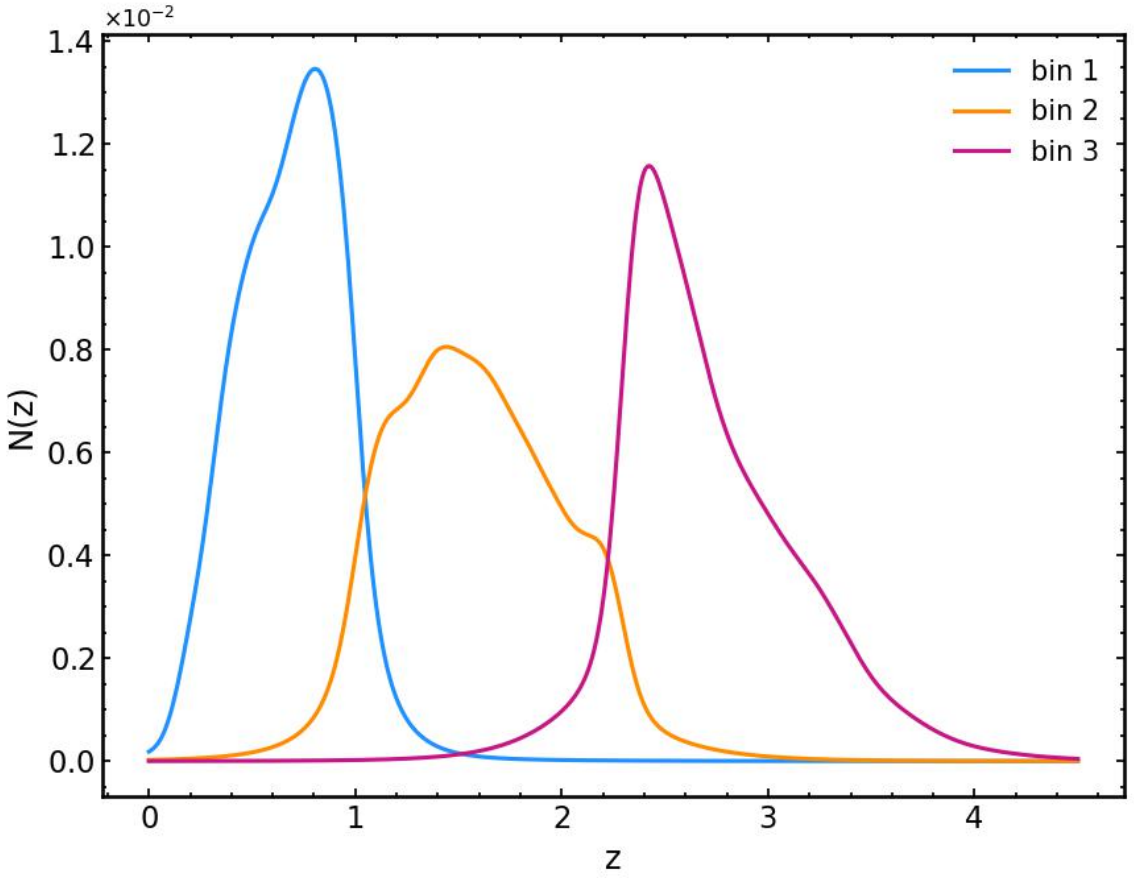
$$C_\ell^{\kappa g} = \frac{2}{\pi}\int_0^\infty dz\; W^g(z) \int_0^\infty dz' W^\kappa(z') \; x \int_0^\infty dk\; k^2 P(k,z,z') j_\ell[k\,\chi(z)] j_\ell[k\,\chi(z')]$$

g window function: $W^g(z) = \frac{b(z)N(z)}{\int dz'\, N(z')}$

κ window function: $W^\kappa(z) \propto \frac{(1+z)\chi(z)}{H(z)} \frac{\chi^* - \chi(z)}{\chi^*}$

Datasets: the Quaia catalogue

Gaia-unWise quasar catalog is an all sky survey with median redshift z = 1.67 and with 1,295,502 sources brighter than the limiting magnitude G=20.5 *(K. Storey-Fisher +, 2023)*



The measured bias in the redshift bins is well described by (*P. Laurent +, 2017*)

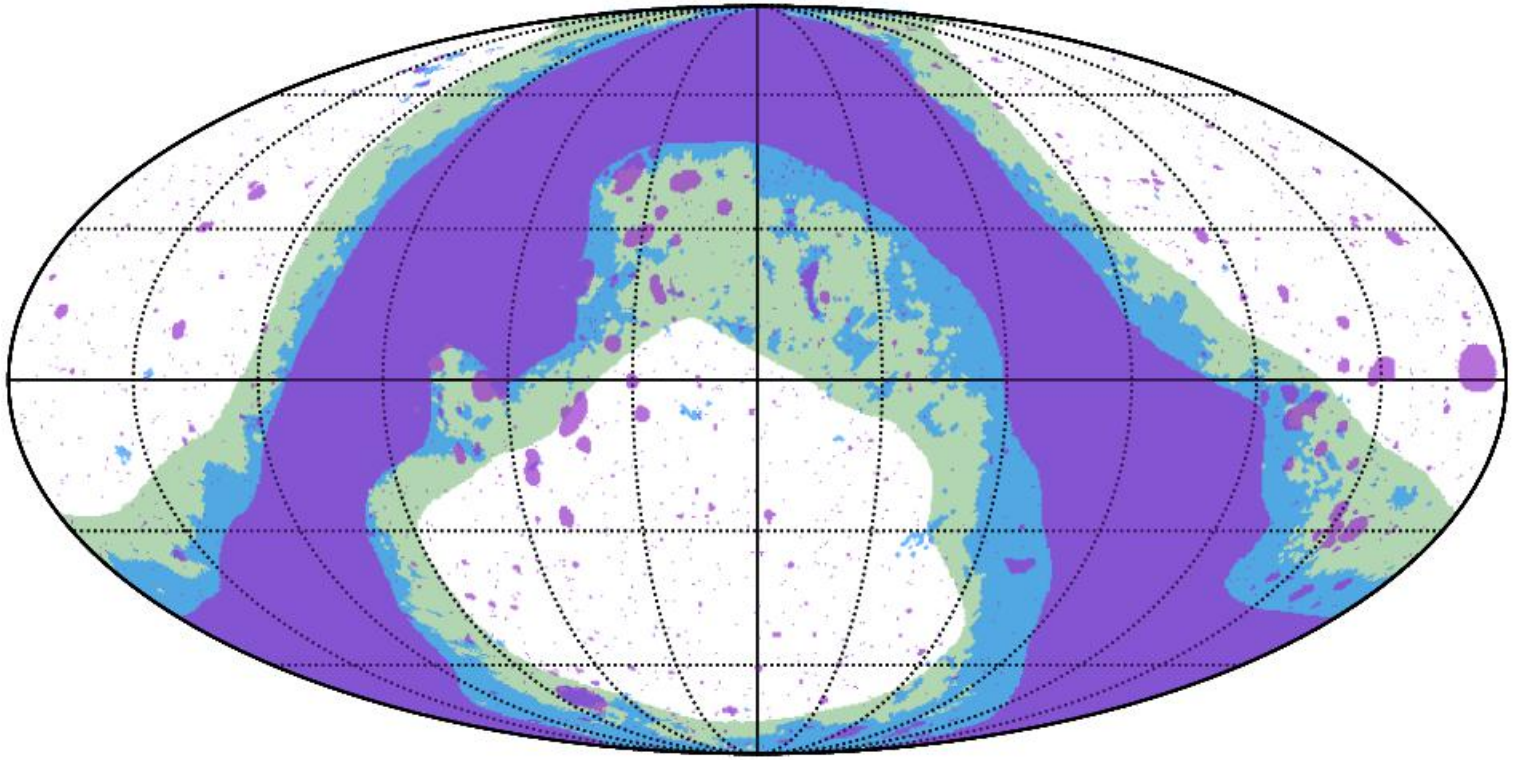
$$b^i(z) = b_g^i[0.278\,(1+z)^2 + \text{const}]$$

Datasets: CMB lensing maps

All maps are based on the latest Planck data release (PR4) but are obtained using different combinations of temperature and polarization data

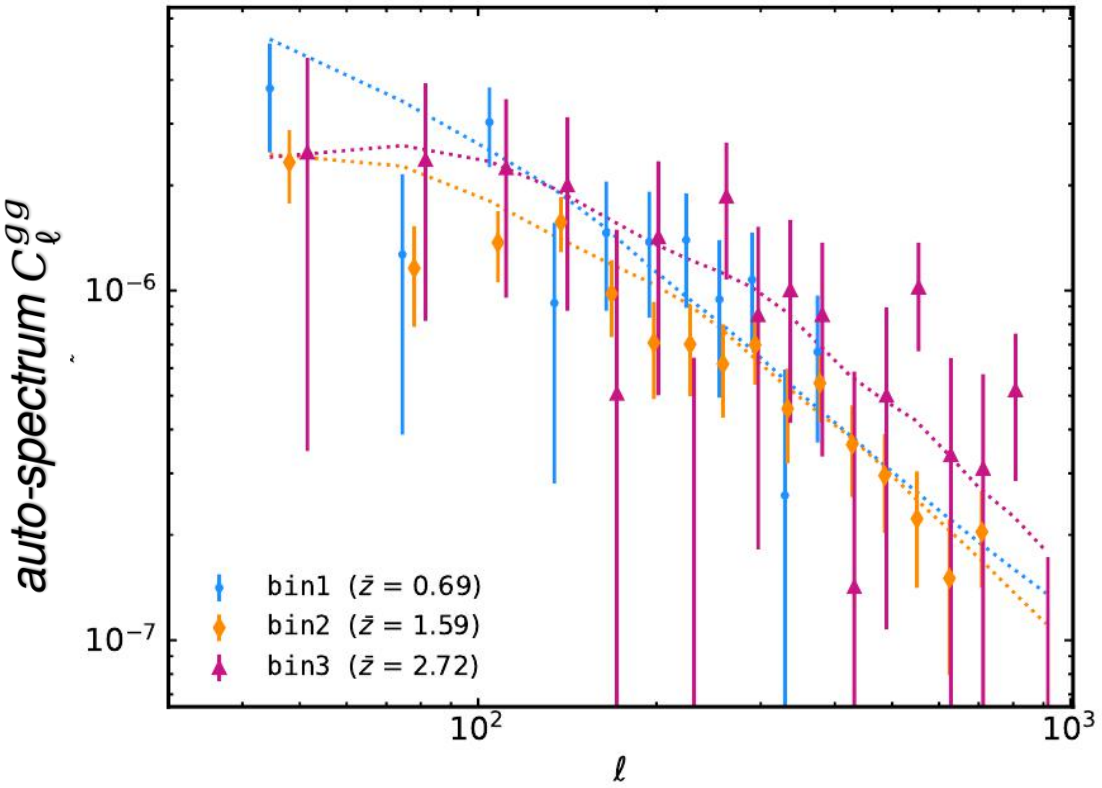
Baseline

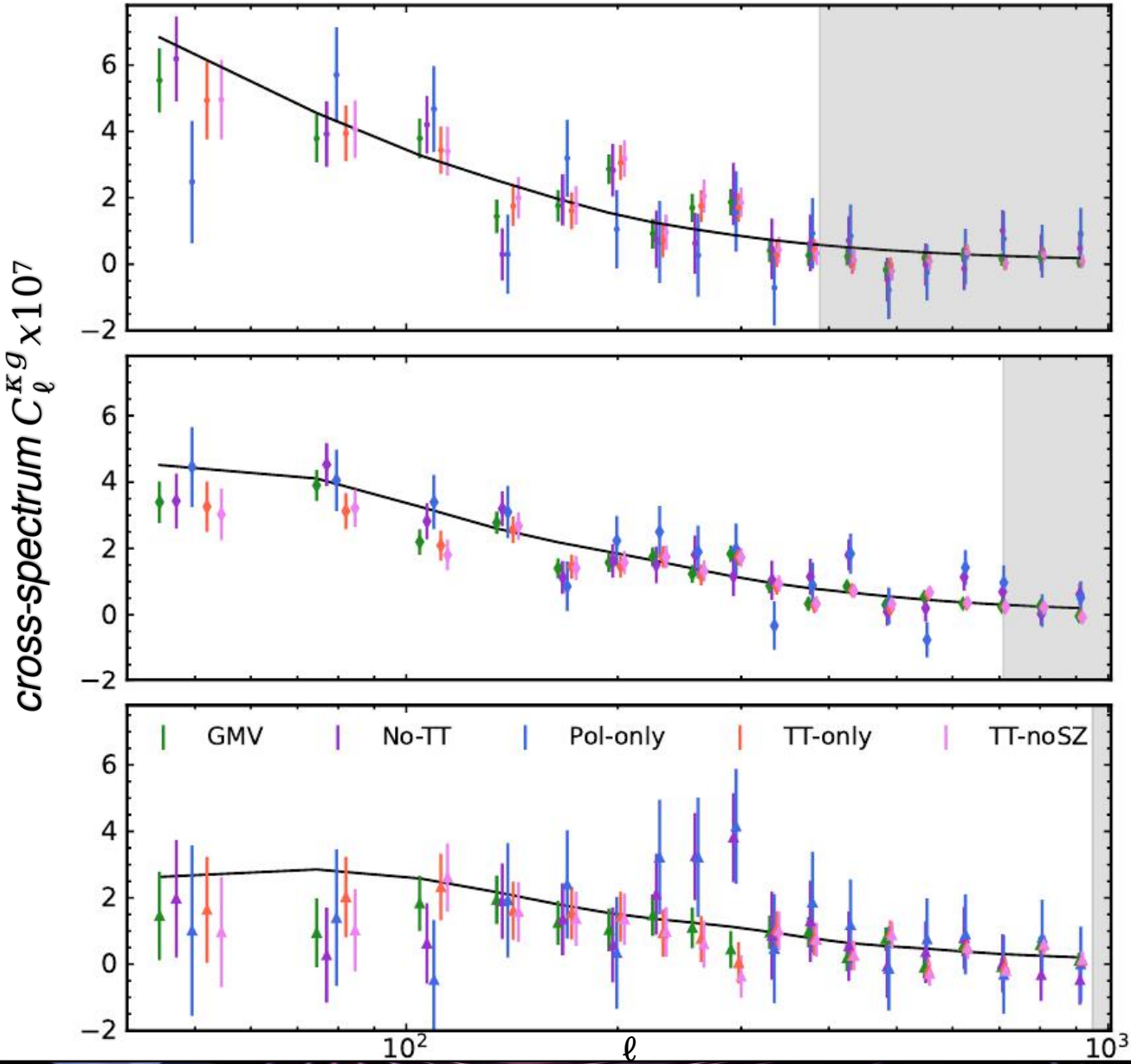
1. Generalized Minimum-Variance (“GMV”)
2. No-temperature (“No-TT”)
3. Polarisation-only (“Pol-only”)
4. Temperature alone (“TT-only”)
5. SZ-deprojected (“TT-noSZ”)



CMB lensing Quaia Planck Galactic Mask

Measured power spectra





Detection significance

$$S/N \equiv \sqrt{\chi_{null}{}^2 - \chi^{bf}}$$

	C_ℓ^{gg}	$C_\ell^{\kappa g,\,No-TT}$	$C_\ell^{\kappa g,\,GMV}$	$C_\ell^{\kappa g,\,Pol-only}$	$C_\ell^{\kappa g,\,TT-only}$	$C_\ell^{\kappa g,\,no-SZ}$
bin1	7.5	8.7	13.5	5.4	11.1	11.4
bin2	14.7	13.5	20.0	10.0	15.5	15.1
bin3	5.9	5.1	5.7	2.9	5.0	3.8
All	17.3	16.2	24.7	11.6	19.8	19.4

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baseline CMB lensing maps

Likelihood analysis

Gaussian Likelihood using $C_\ell^{\kappa g} + C_\ell^{gg}$ as dataset to constrain simultaneusly $\boldsymbol{\sigma_8}$ and the QSO bias (`Core Cosmology Library + Cobaya`)

Explored cosmological models:

1. `CosmoFix:` cosmological parameters fixed to Planck2020 best-fit values. Free parameters $\{b_g^i\}$
2. `CosmoMarg:` $\{\Omega_{\rm M}, \sigma_8, {\rm h}, b_g^i\}$
3. `CosmoGrowth:` $\{\Omega_{\rm M}, \ {\rm h}, \ \boldsymbol{\Delta_{\rm i}}, b_g^i\}$

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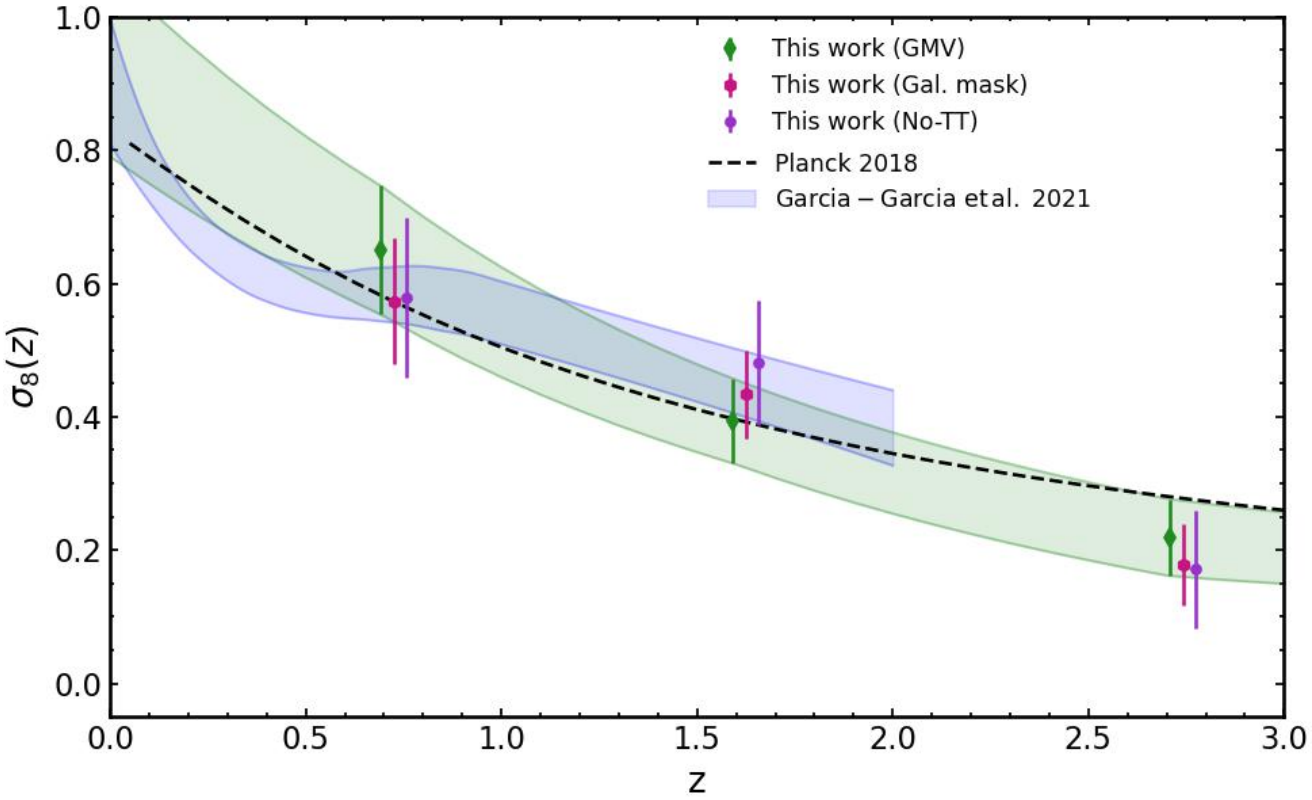
$$P_{lin}(k, z) = \boldsymbol{D(z)}^2 P_{lin}(k, z = 0)$$

$$\sigma 8 = \sigma_{8,\rm fid}\, \mathbf{D(z)^{fid}}(1 + \boldsymbol{\Delta_i})$$

Results 1: Measurements of σ_8



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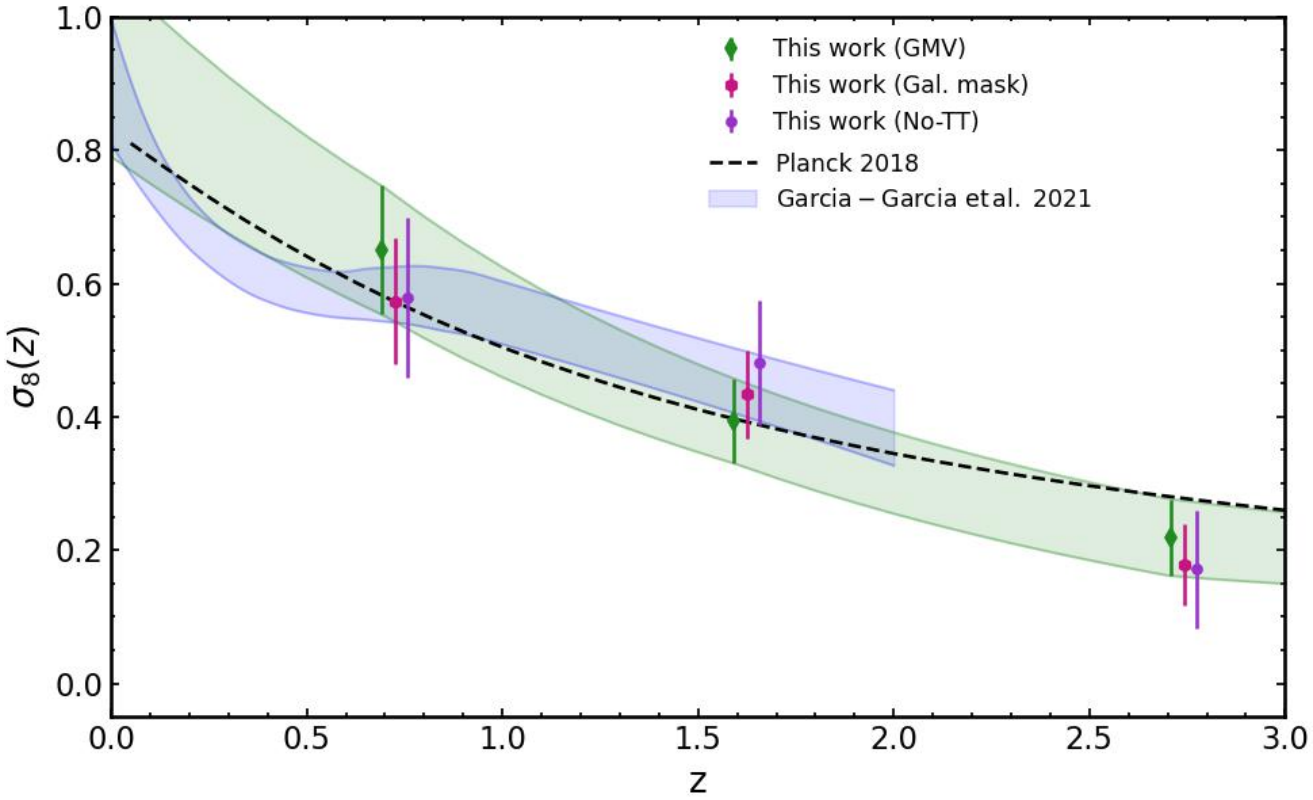
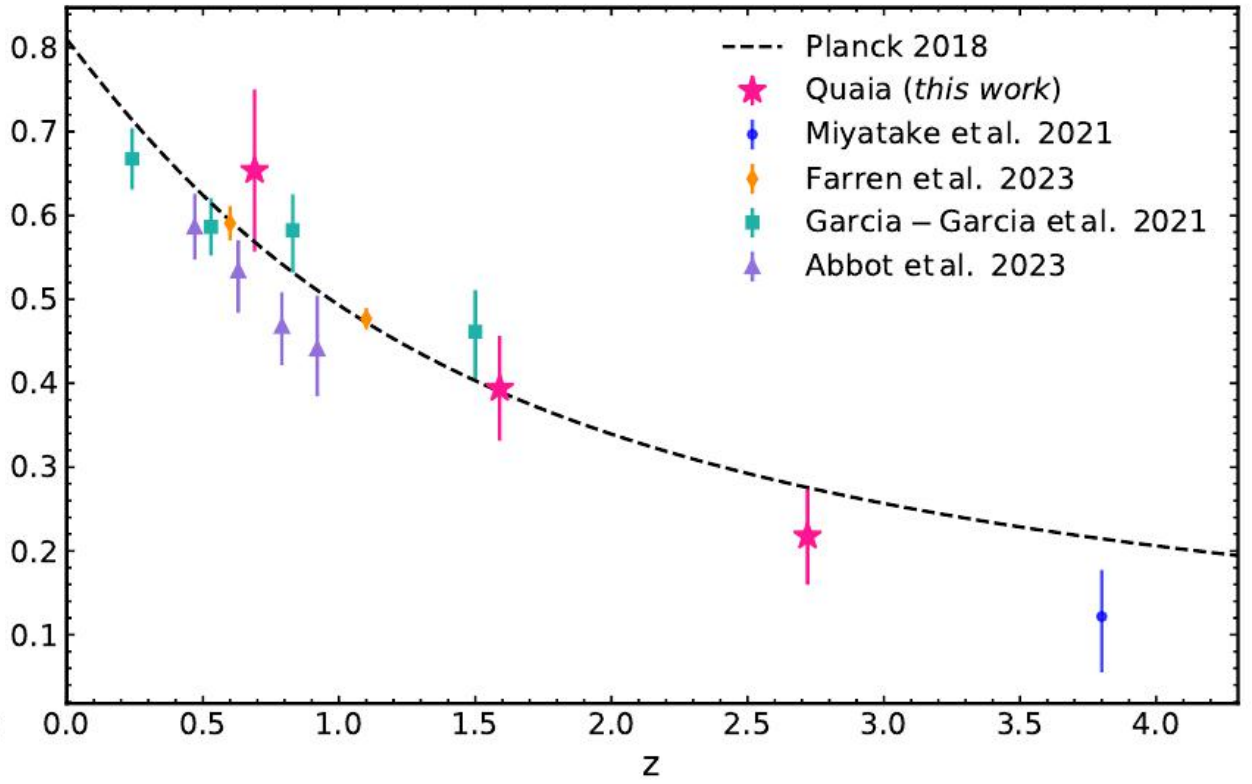
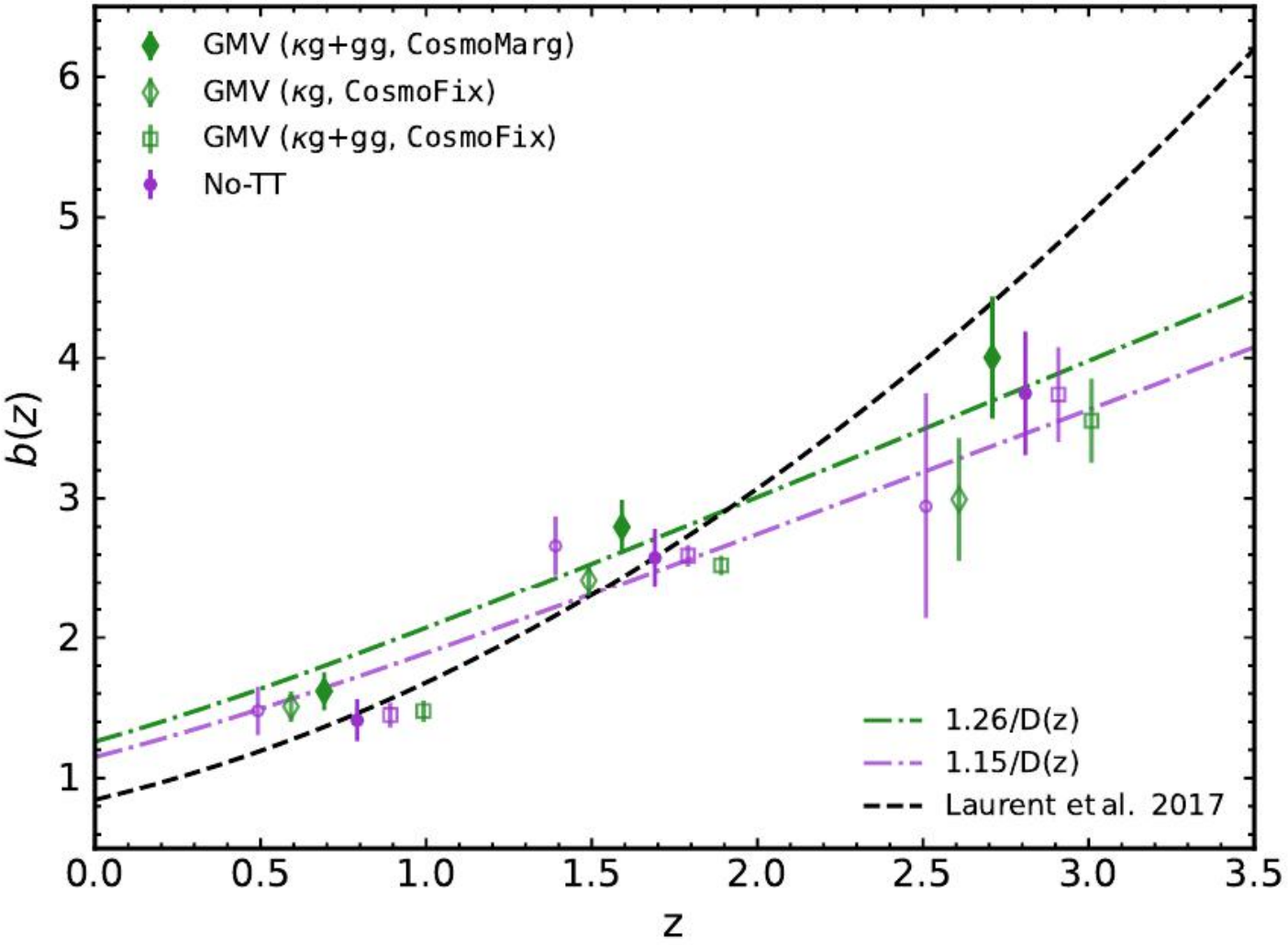




Our results are in agreement (within ~ 1σ) with ΛCDM prediction using Planck2020 best-fit parameters

One of the highest measurement in redshift of $\sigma_8(z)$!

Results 2: Quasar bias



General good agreement with *Laurent+, 2017*

Milder evolution at higher redshifts more compatible with: $b(z) = b_0/D_{fid}(z)$

Results are not strongly driven by contamination from extragalactic foregrounds in the CMB lensing map.

Results 3: study of contaminations in CMB maps

D. Alonso +, 2023 reported a potentially significant difference in the amplitude of the Quaia-CMB lensing cross-correlation using different κ maps at high redshifts

Isolating the range of redshifts is interesting to establish its potential extragalactic origin

Set up:

1. We divide the total redshift distribution of the Quaia sources into six redshift bins (z_{edges} = *[0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 5]*)
2. `CosmoFix` cosmological model
3. More CMB lensing maps: TE-only ("`TE-only`"), Minimum-variance source hardened ("`MVh`"), Temperature-only, source-hardened map ("`TTh`")

Results 3: study of contaminations in CMB maps

$$b_g = \frac{t^T Cov^{-1} d}{t^T Cov^{-1} t} \qquad \sigma(b_g) = \frac{1}{\sqrt{t^T Cov^{-1} t}}$$

Results 3: study of contaminations in CMB maps

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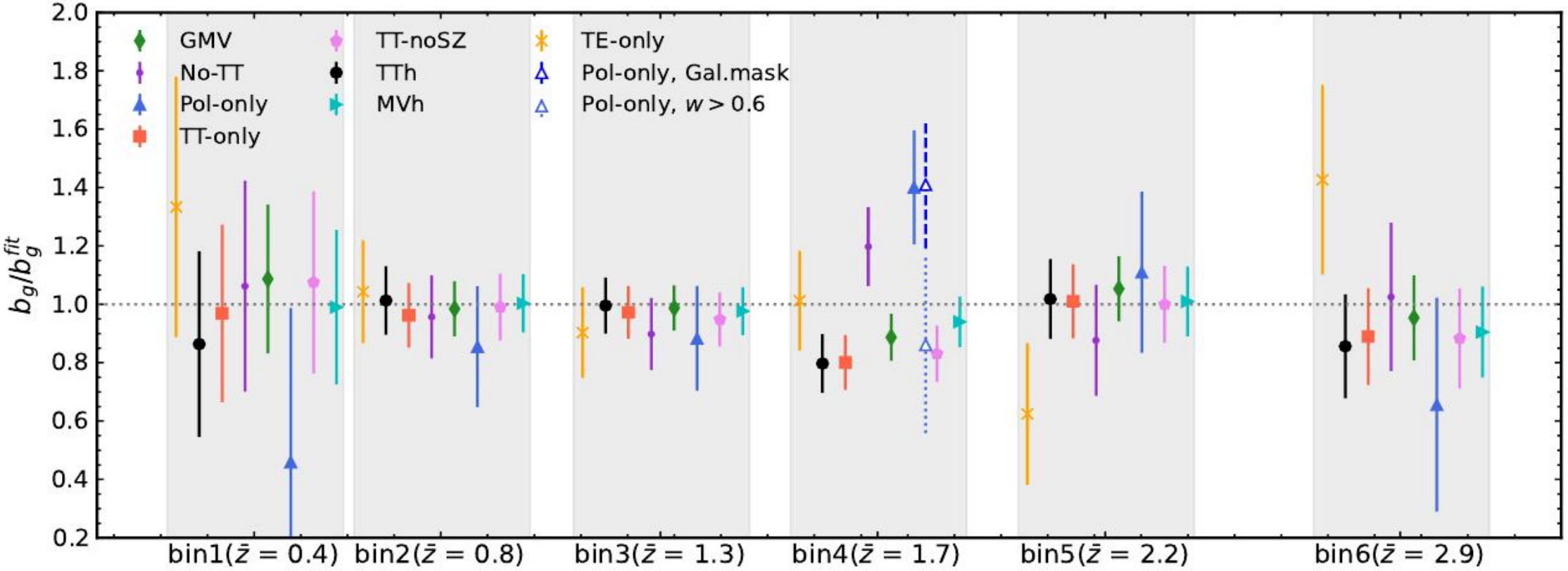

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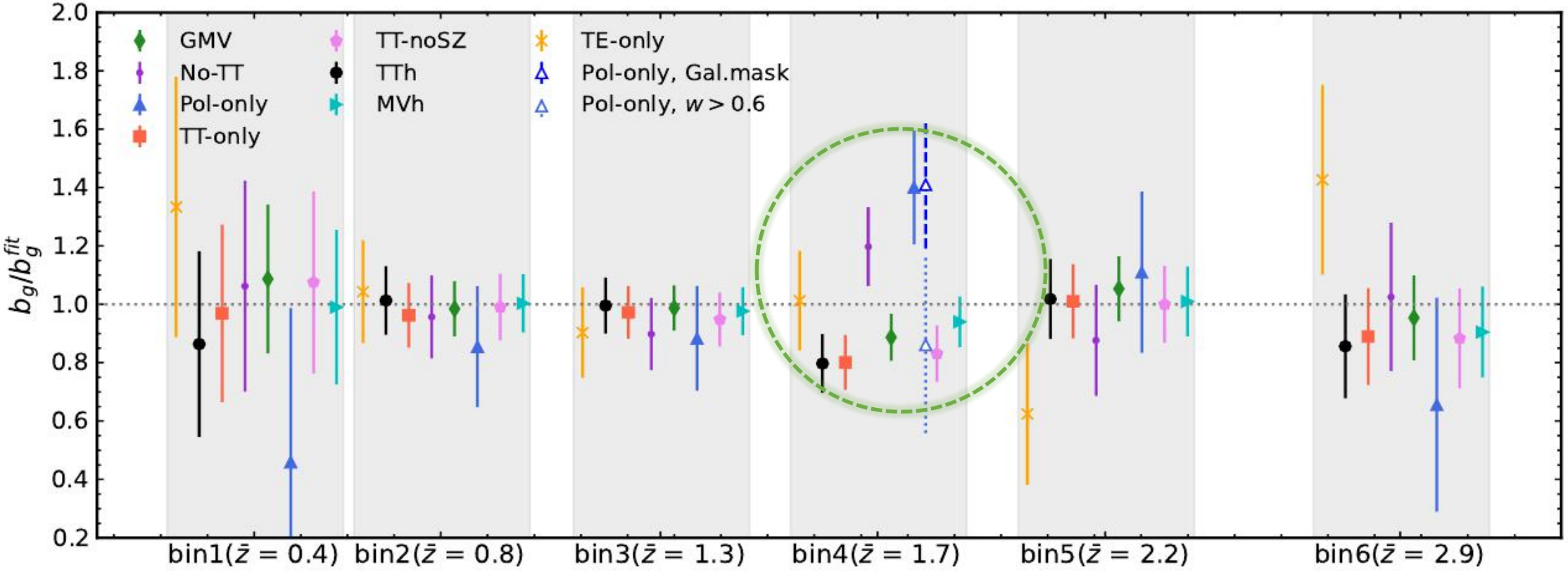


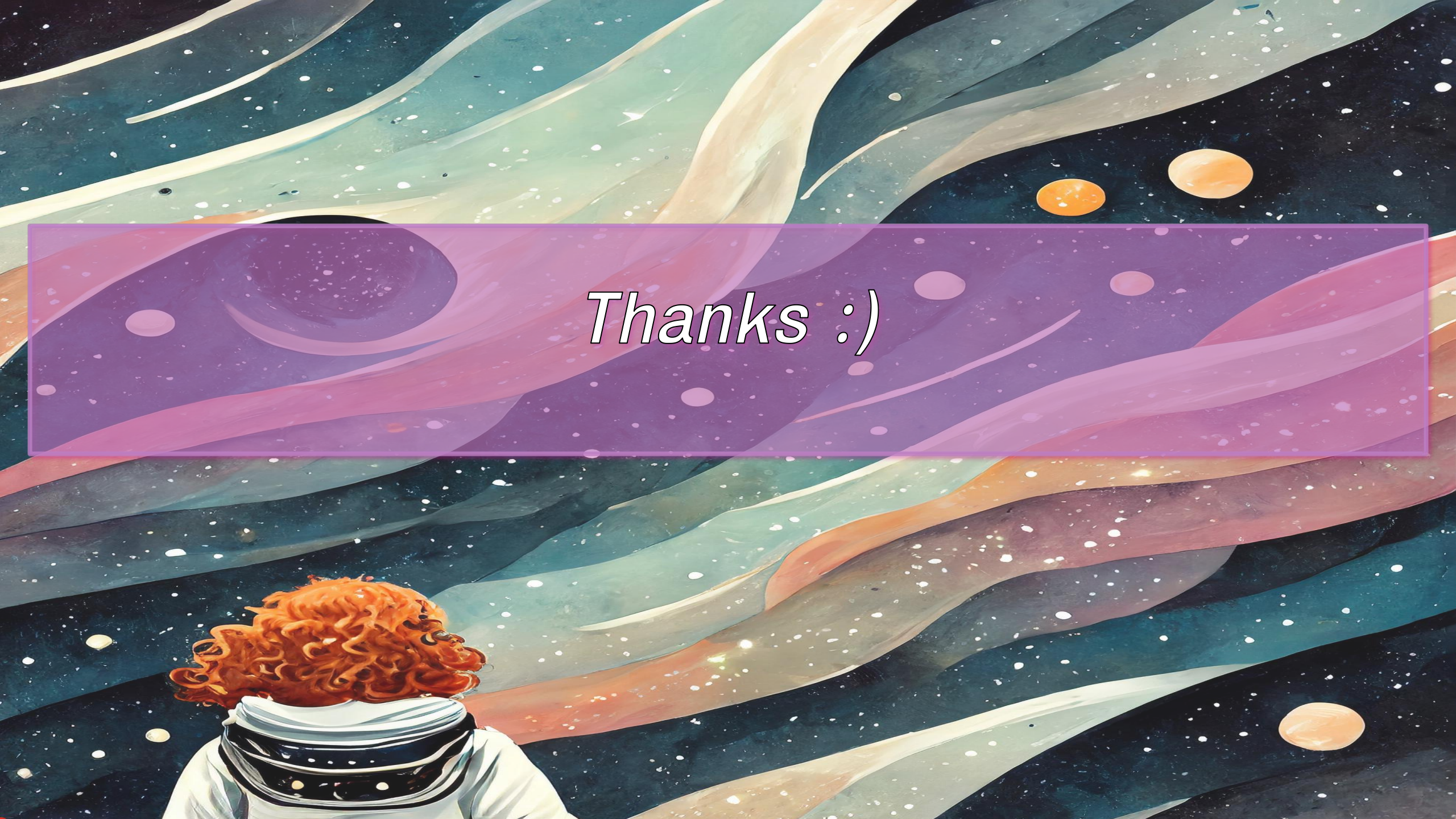
Conclusions

① One of the highest-redshift constraints on σ8 in the literature ($\sigma_8(z = 2.7) = 0.22 \pm 0.06$)

② The b(z) is overall comparable to that of eBOSS with a milder evolution at high redshifts. We find a dependency on the choice of cosmological model but our results are largely compatible between different analysis choices.

③ We investigated the presence of foreground contamination in the Planck lensing maps, finding a localized effect at $z \sim 1.7$ which can be explained by the extragalactic contamination from a clustered component. Nevertheless, we verified that our constraints on $\sigma_8(z)$ are not significantly affected by this potential systematic.

NEXT STEP: Use new CMB experiments (ACT, SO, and CMB Stage-4) that will probe significantly smaller angular scales with higher sensitivity, and over a wide range of frequencies, making it possible to improve the robustness of these constraints to both Galactic and extragalactic systematics.


Thanks :)

Results 3: Statistical significance

Lensing maps

1

We retrieved the κ maps using 480 independent realizations of simulated lensing reconstructions (PR4)

Correlated Gaussian realizations

2

We generated a correlated Gaussian realization of the QSOs overdensity map. We assumed the theoretical auto and cross-correlation, the same cosmology as in PR4 simulations, and the fiducial b(z) and N(z).

We added a shot noise component modeled usingcrandom realizations from the Quaia catalogue

bg estimates

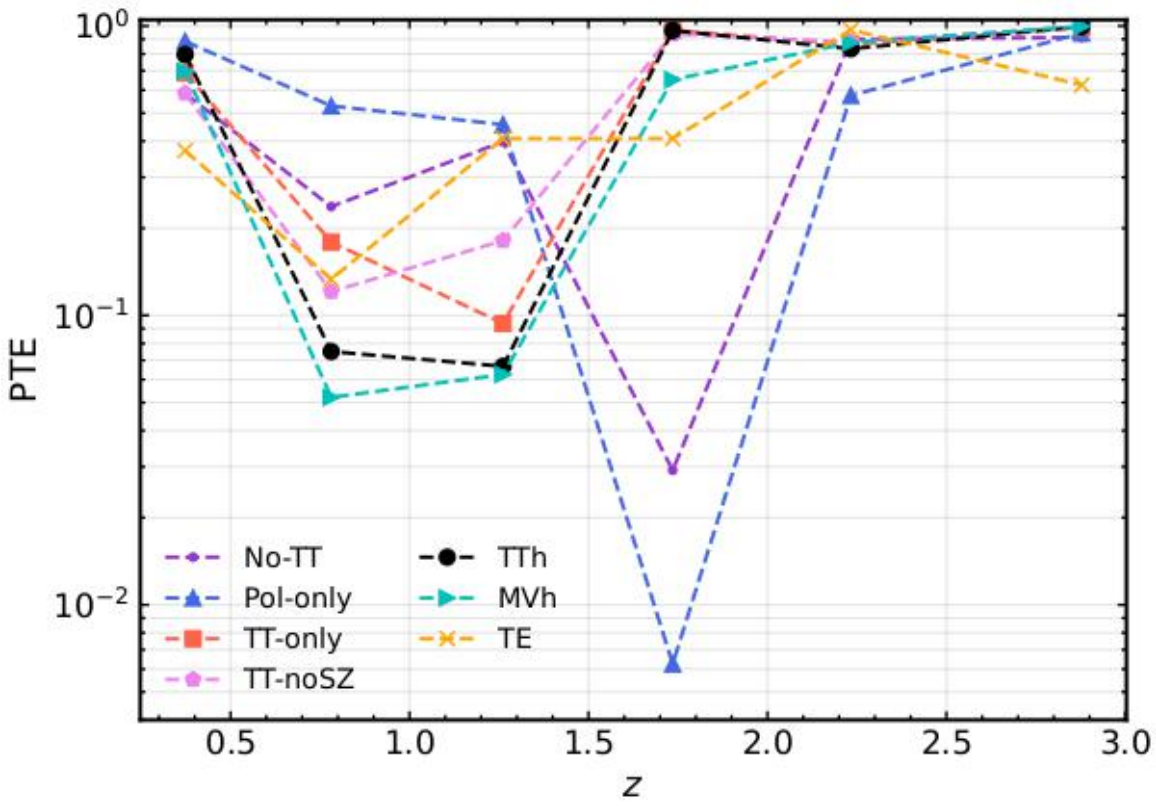
3

We computed the cross-spectrum for each realization and reconstruction method, and estimated the value of bg

PTE

4

We quantify the level of disagreement between different CMB lensing maps by calculating the fraction of simulated realizations for which a difference in the value of bg with respect to the one found for the corresponding GMV map is larger than the value measured in the data.



Quaia: old vs new catalogue