

Constraining structure growth and primordial non-Gaussianity with Euclid AGNs $\times$ CMB lensing

Matteo Peronaci, Giulia Piccirilli, Marina Migliaccio, Giulio Fabbian

“Exploring New Frontiers in Cosmology”

Galileo Galilei Institute, Firenze

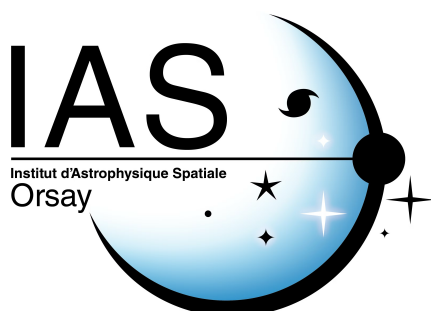
July 23, 2026



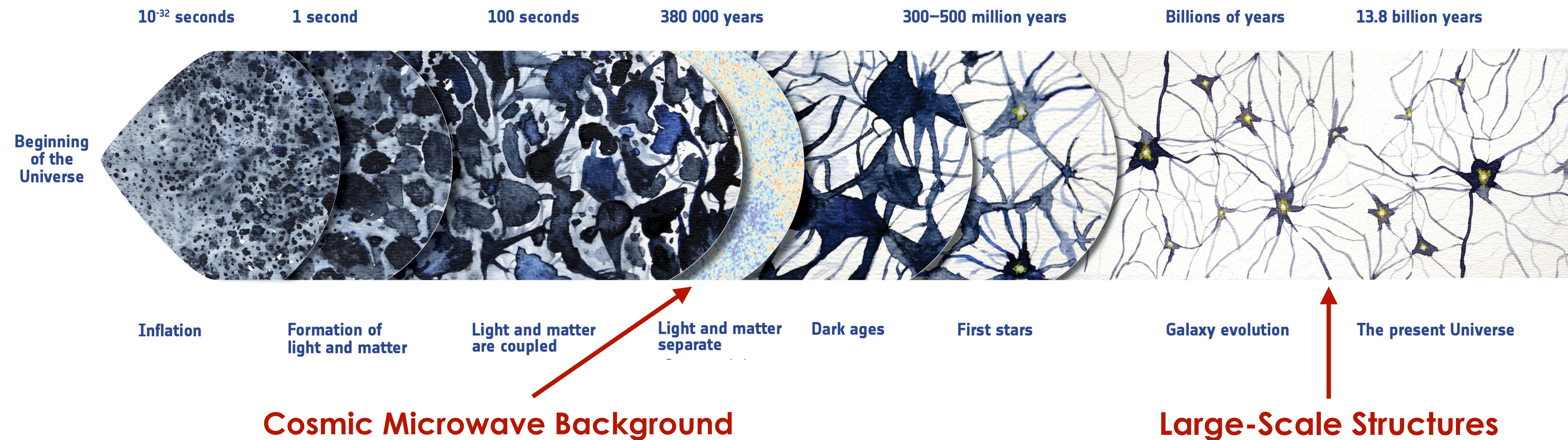
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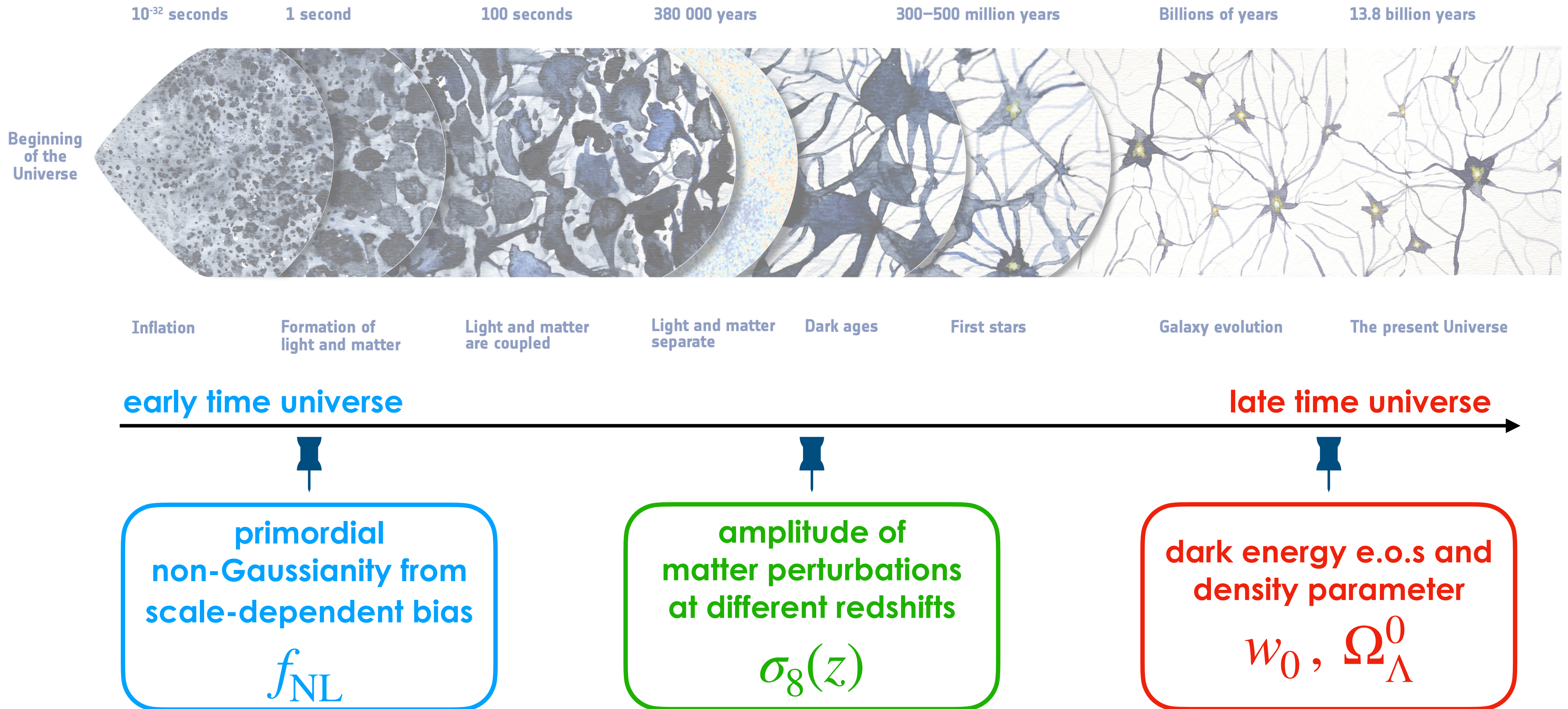
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Cosmic history and scientific targets

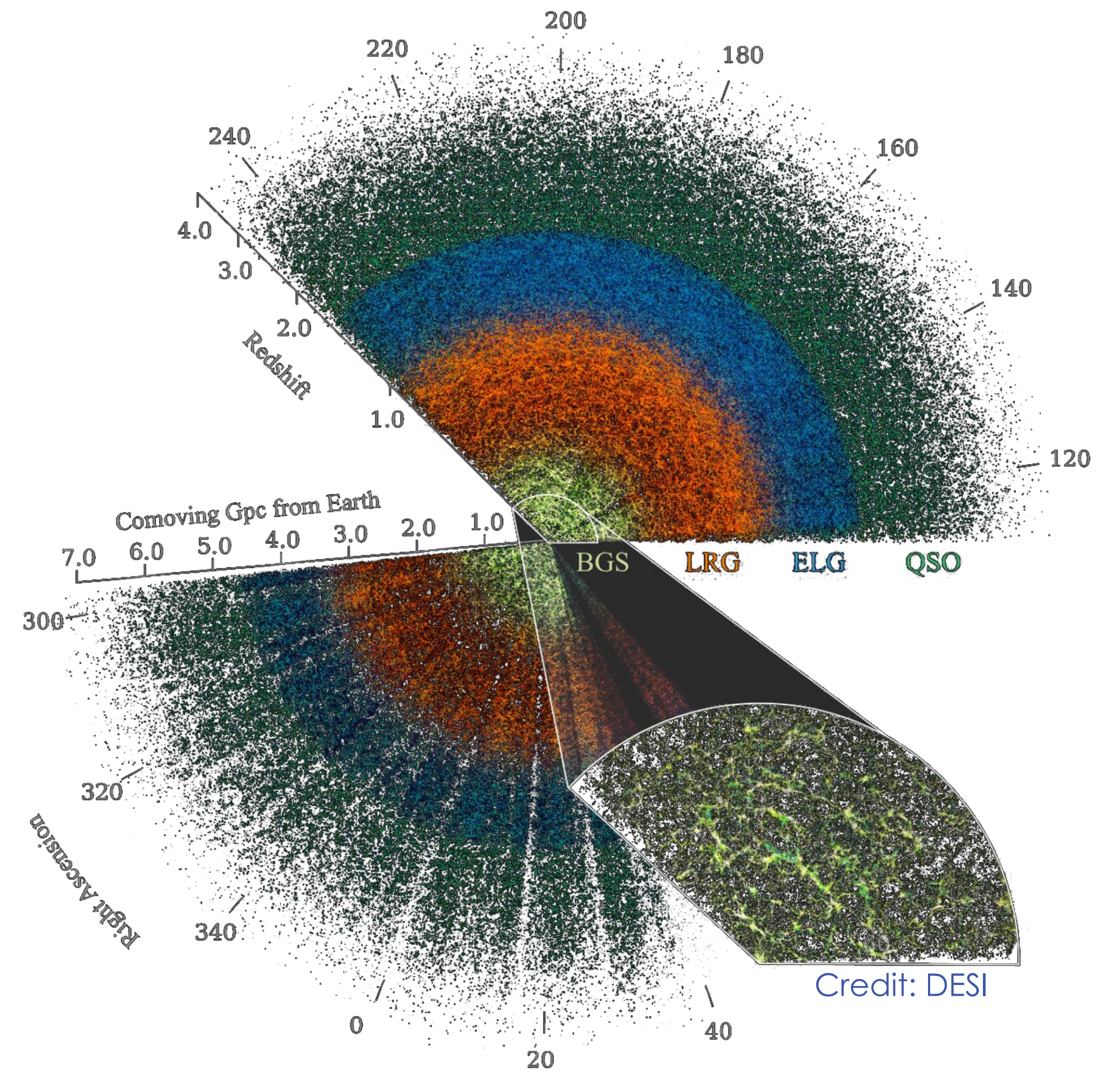


Cosmic history and scientific targets



Observables – LSS tracer

Active Galactic Nuclei !



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Active Galactic Nuclei !

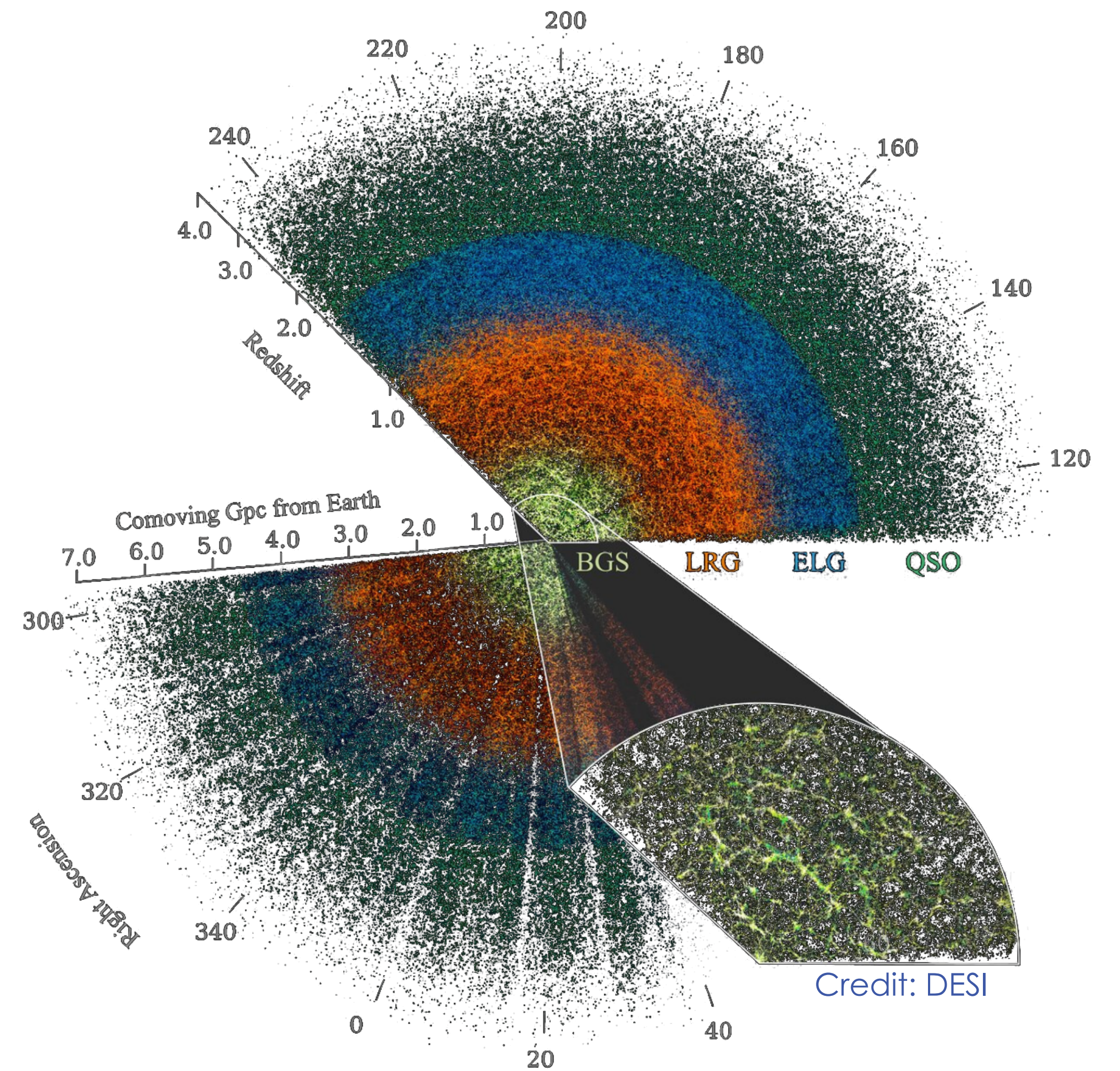
Why AGNs?

Trace the same dark matter potential wells
that host galaxy formation

Brighter, more massive, less affected by dust

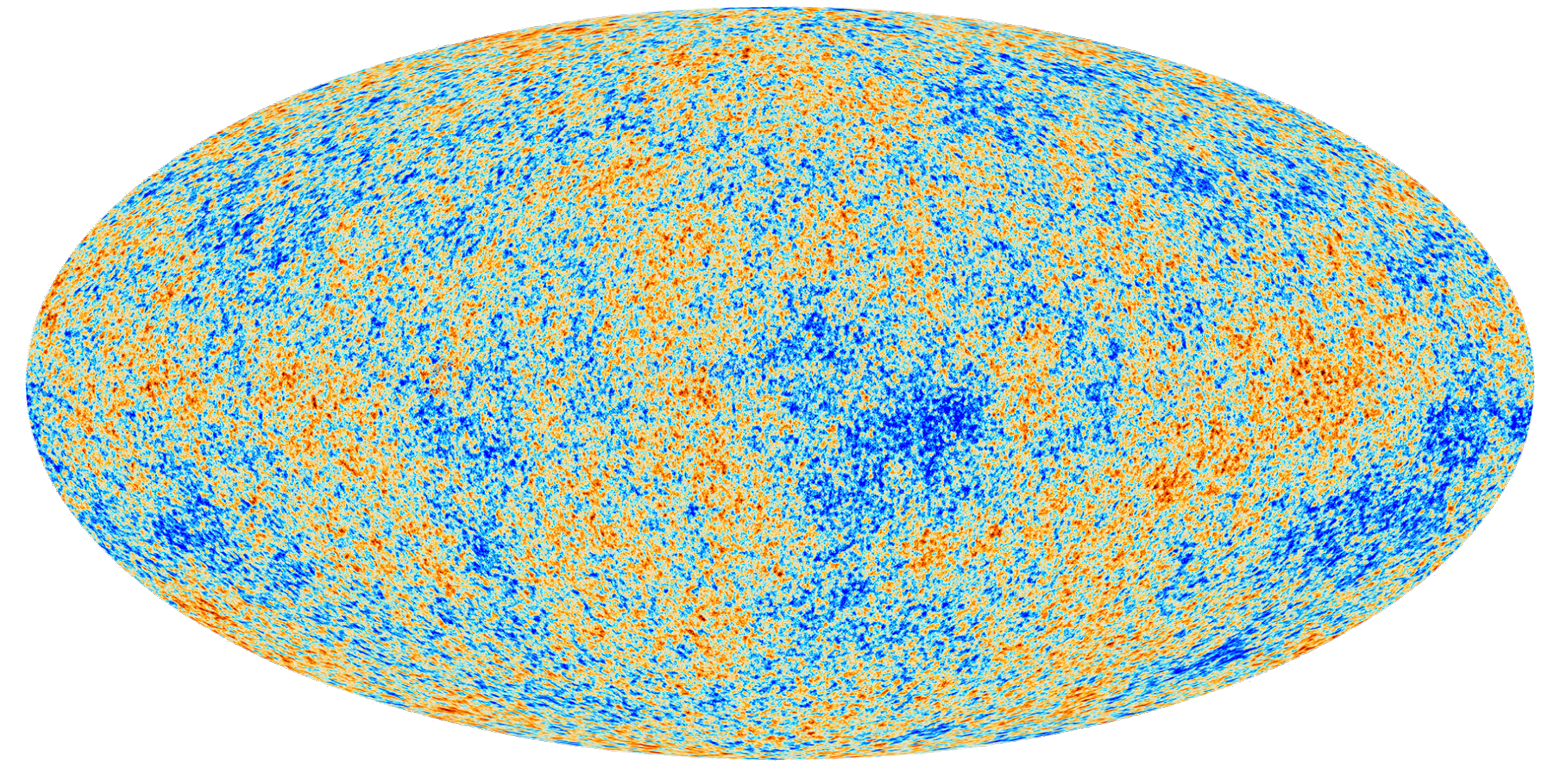
→ can be observed up to $z \gtrsim 5$

Highly biased sources



Observables – CMB temperature anisotropies

Primordial perturbations at $z \approx 1100$

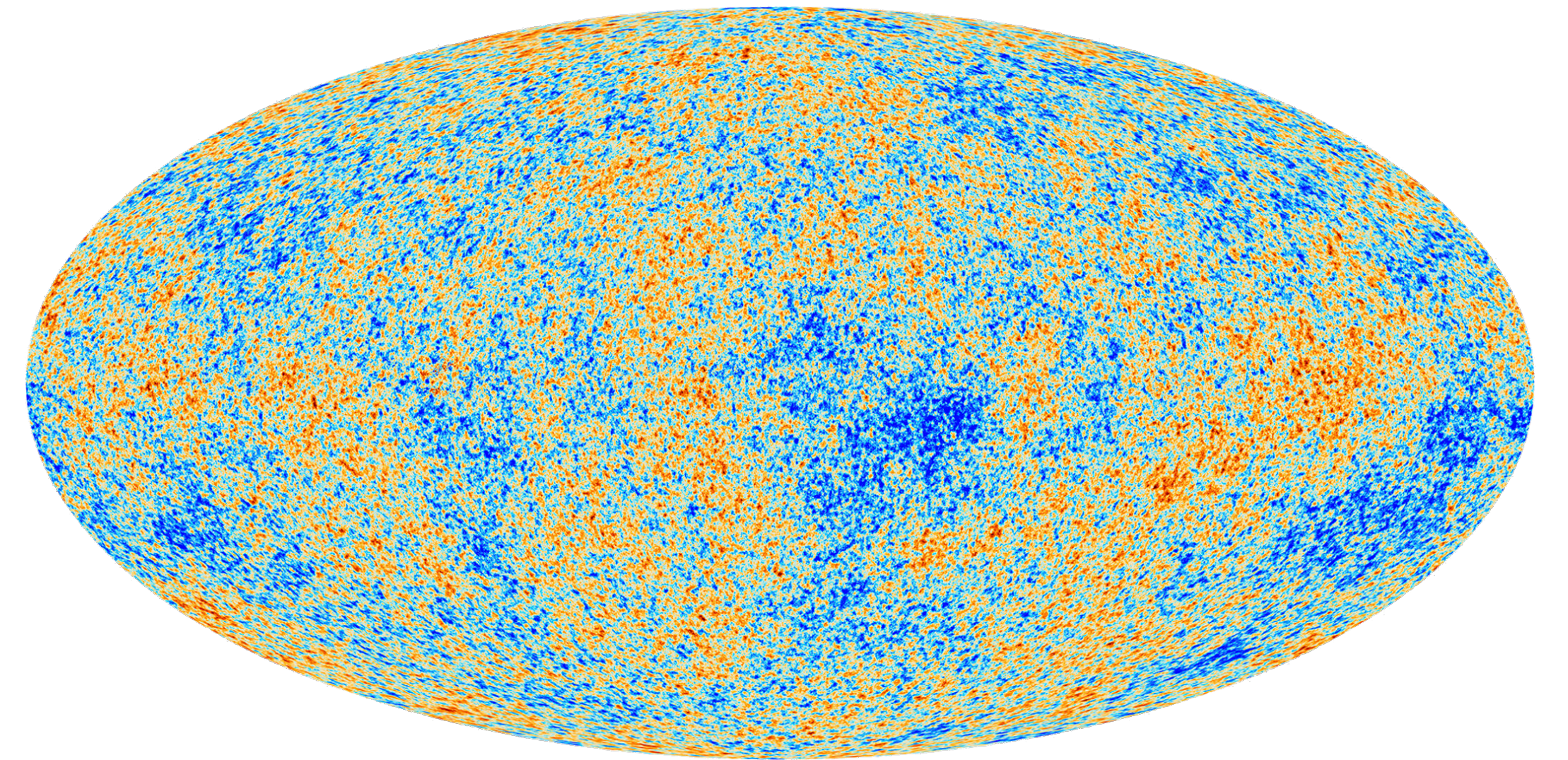


Observables – CMB temperature anisotropies

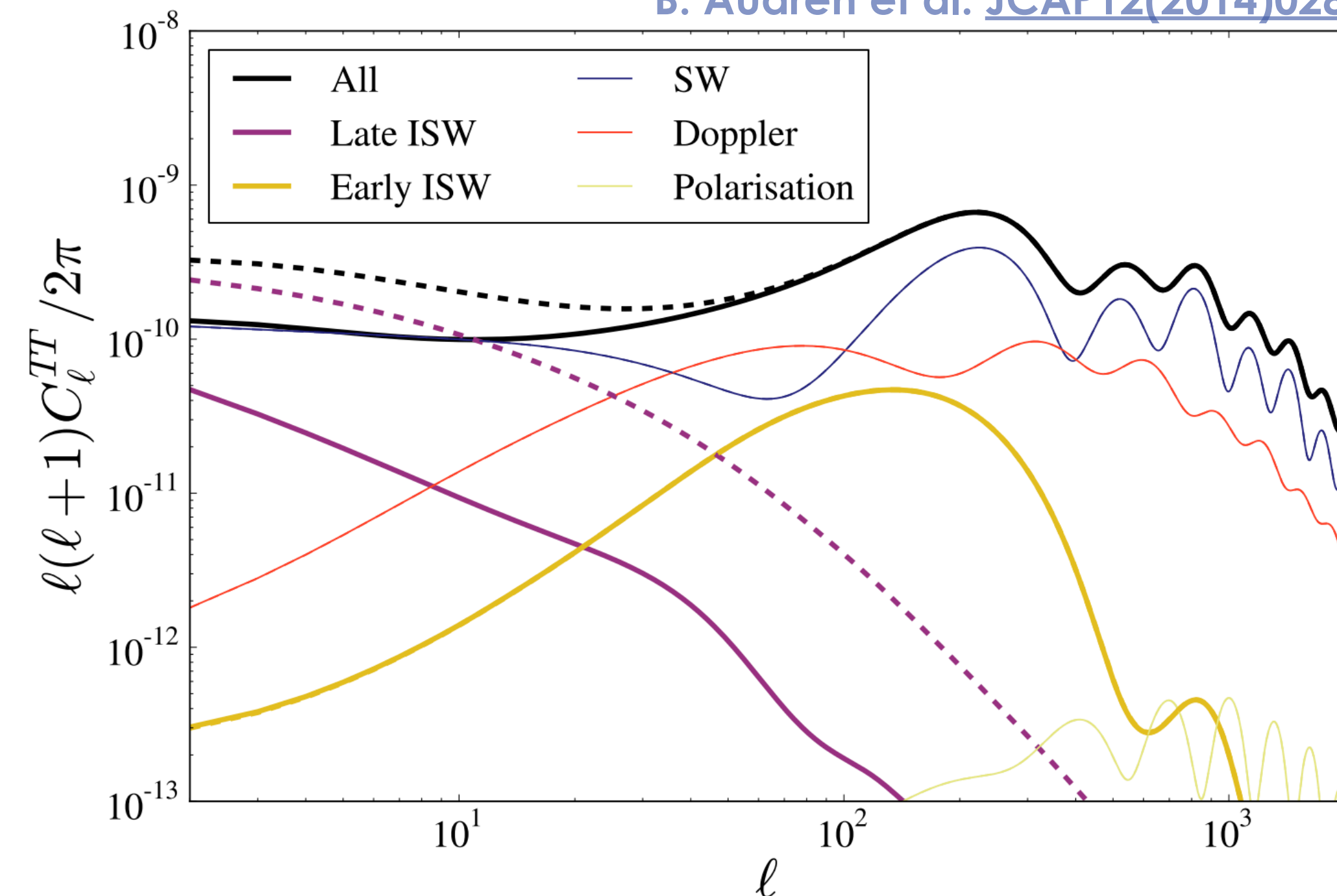
Primordial perturbations at $z \approx 1100$

Secondary anisotropies imprinted along the way

→ **late-time Integrated Sachs-Wolfe** effect



B. Audren et al. [JCAP12\(2014\)028](#)

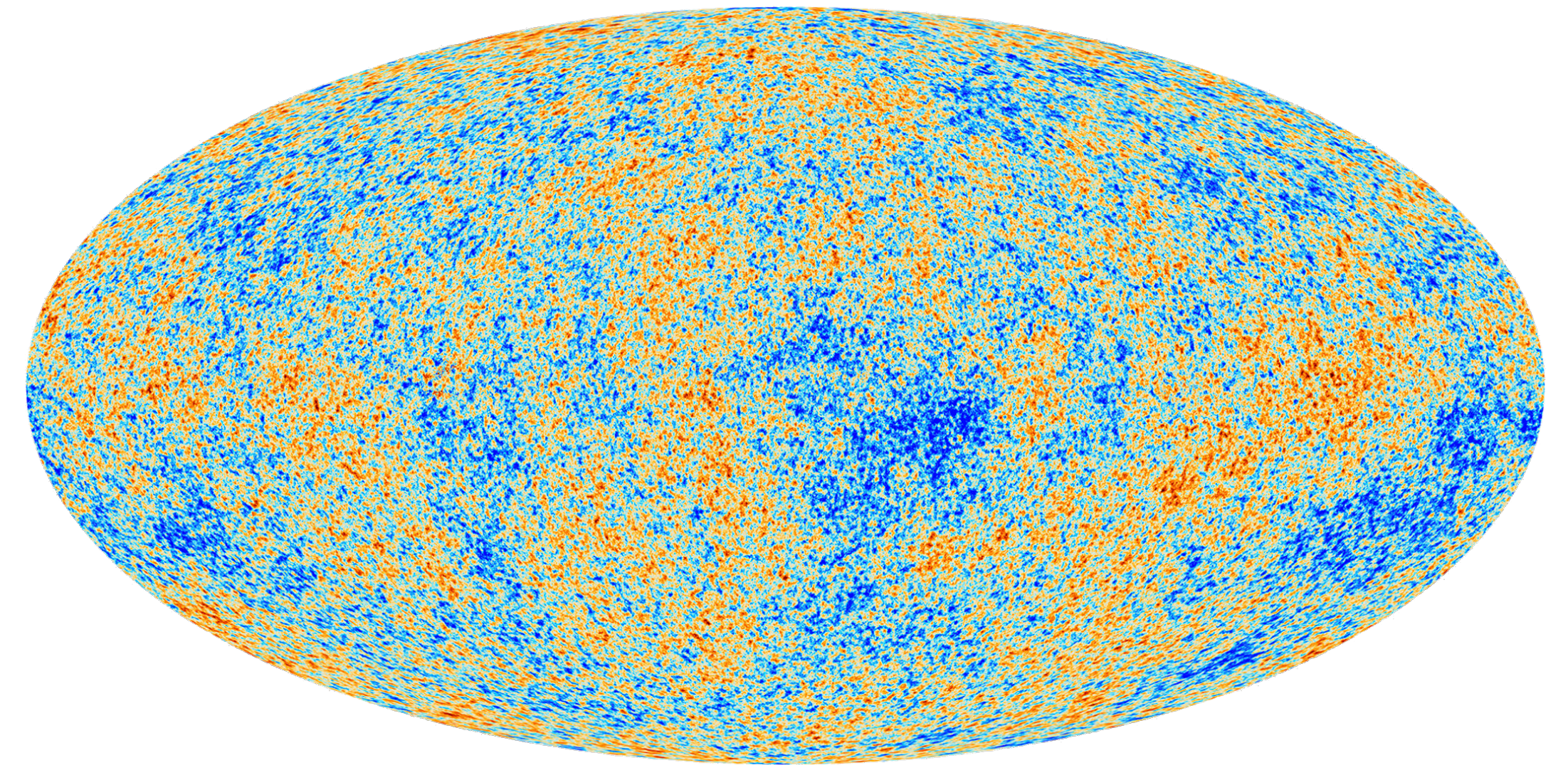


Observables – CMB temperature anisotropies

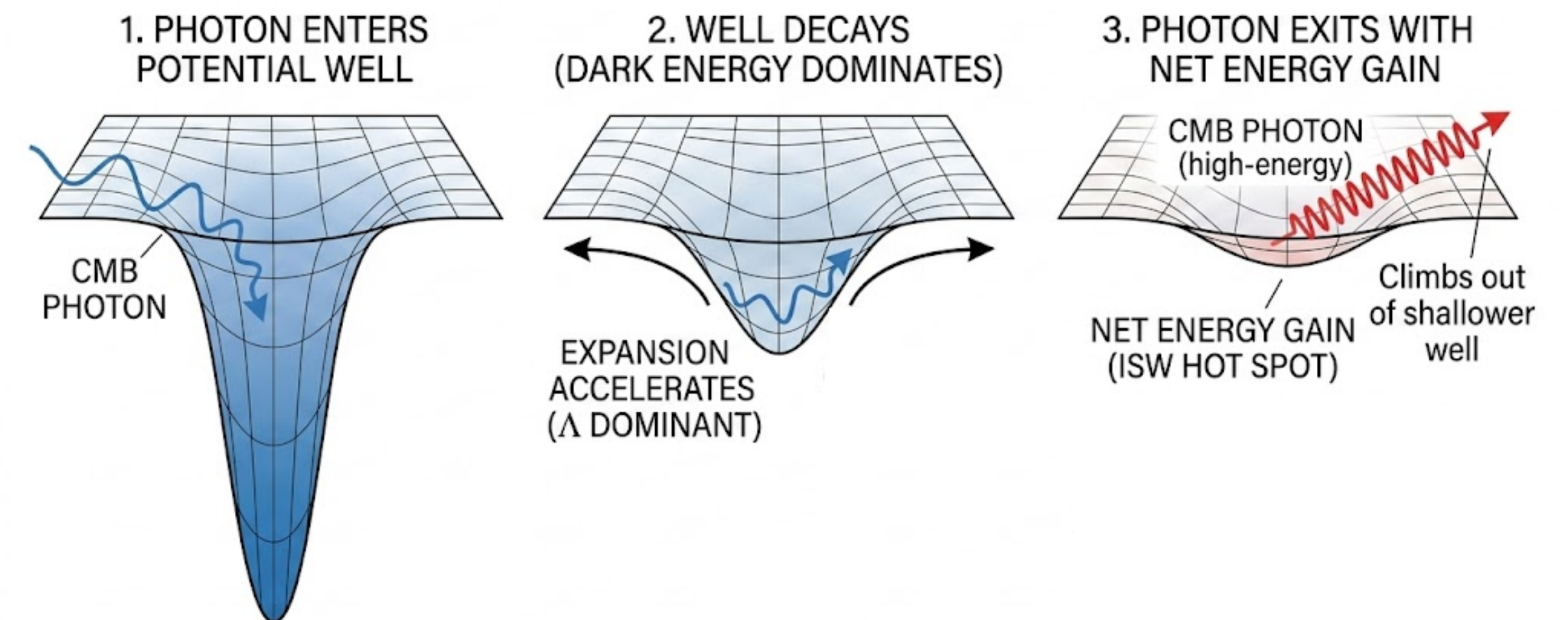
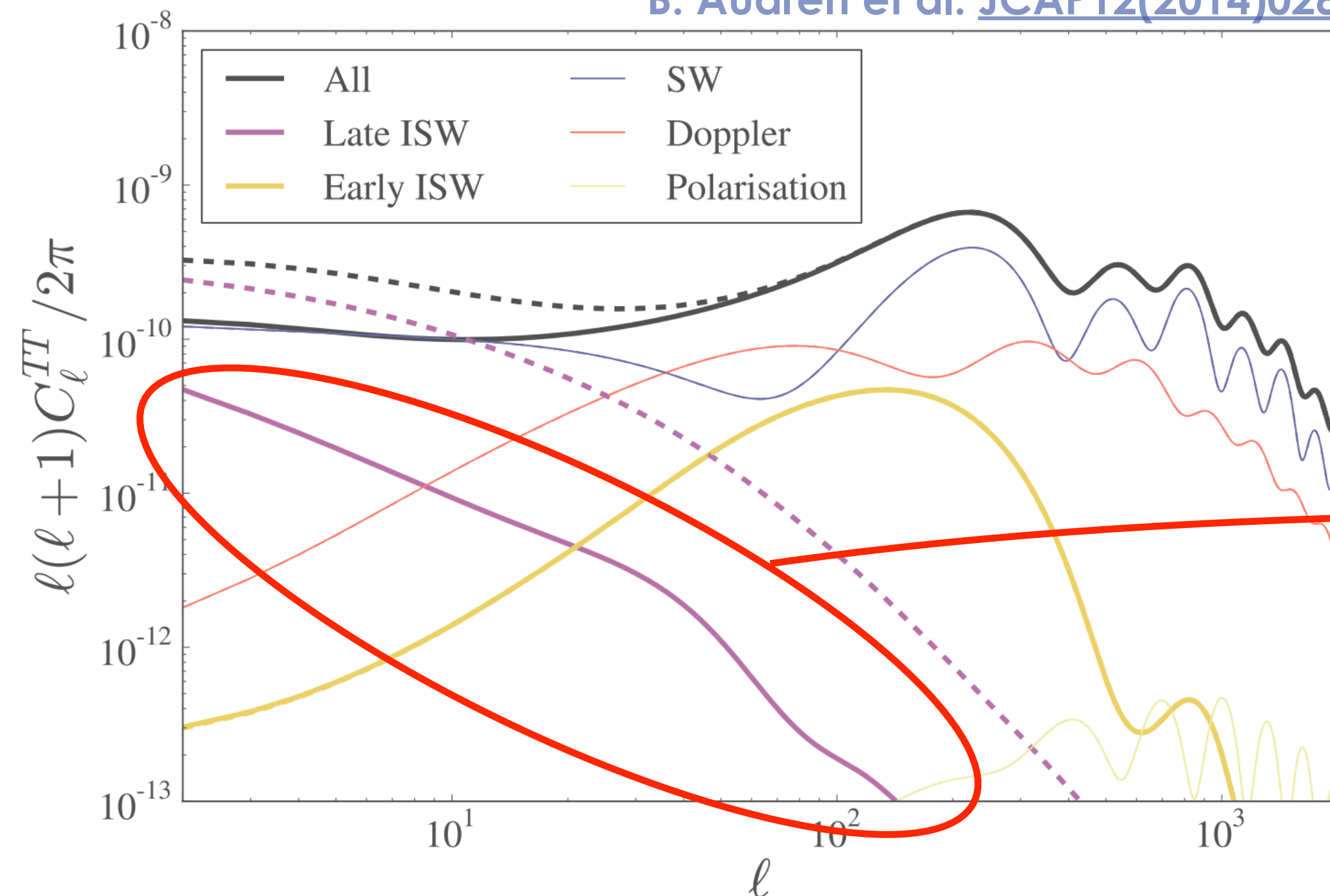
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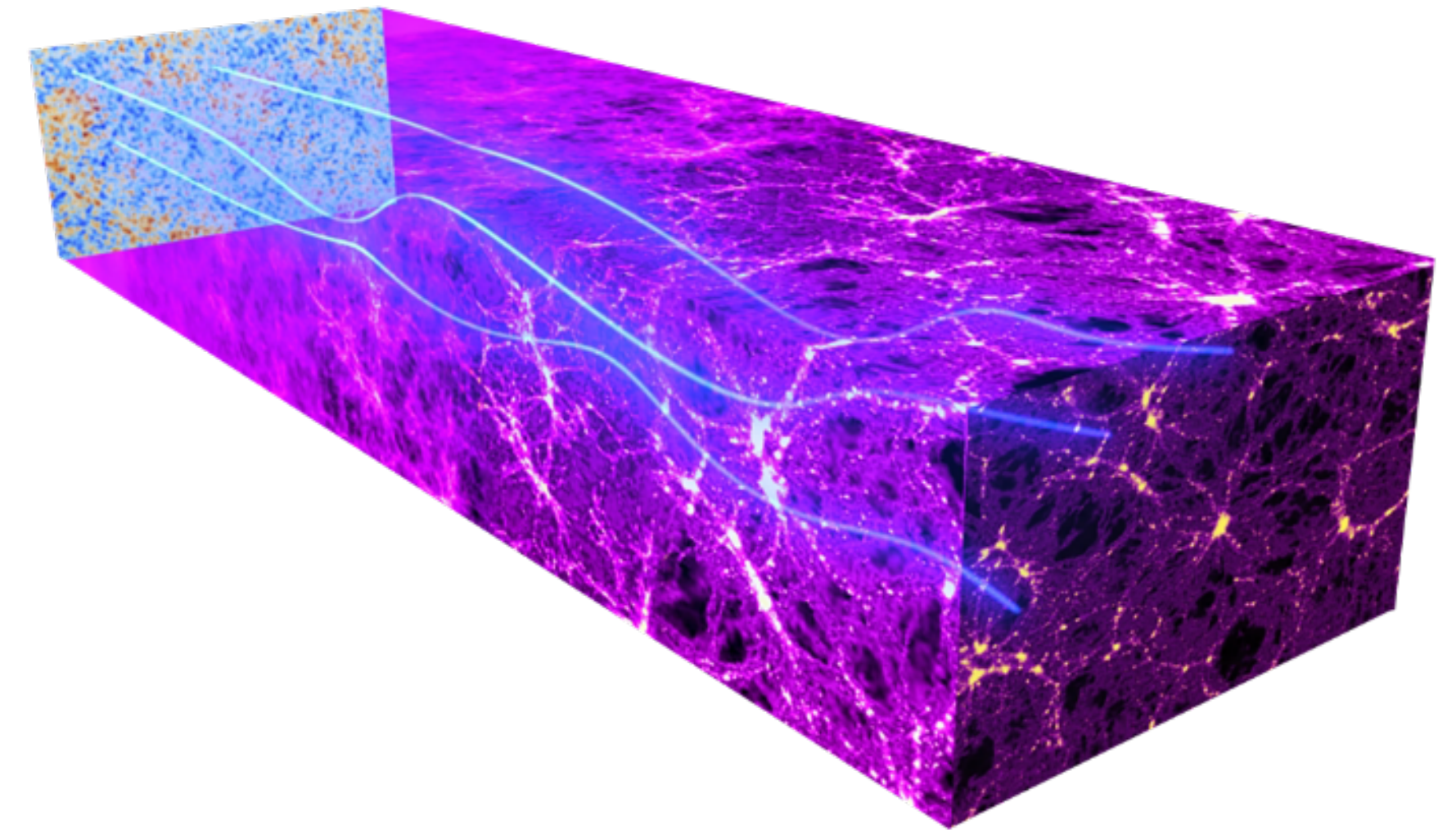
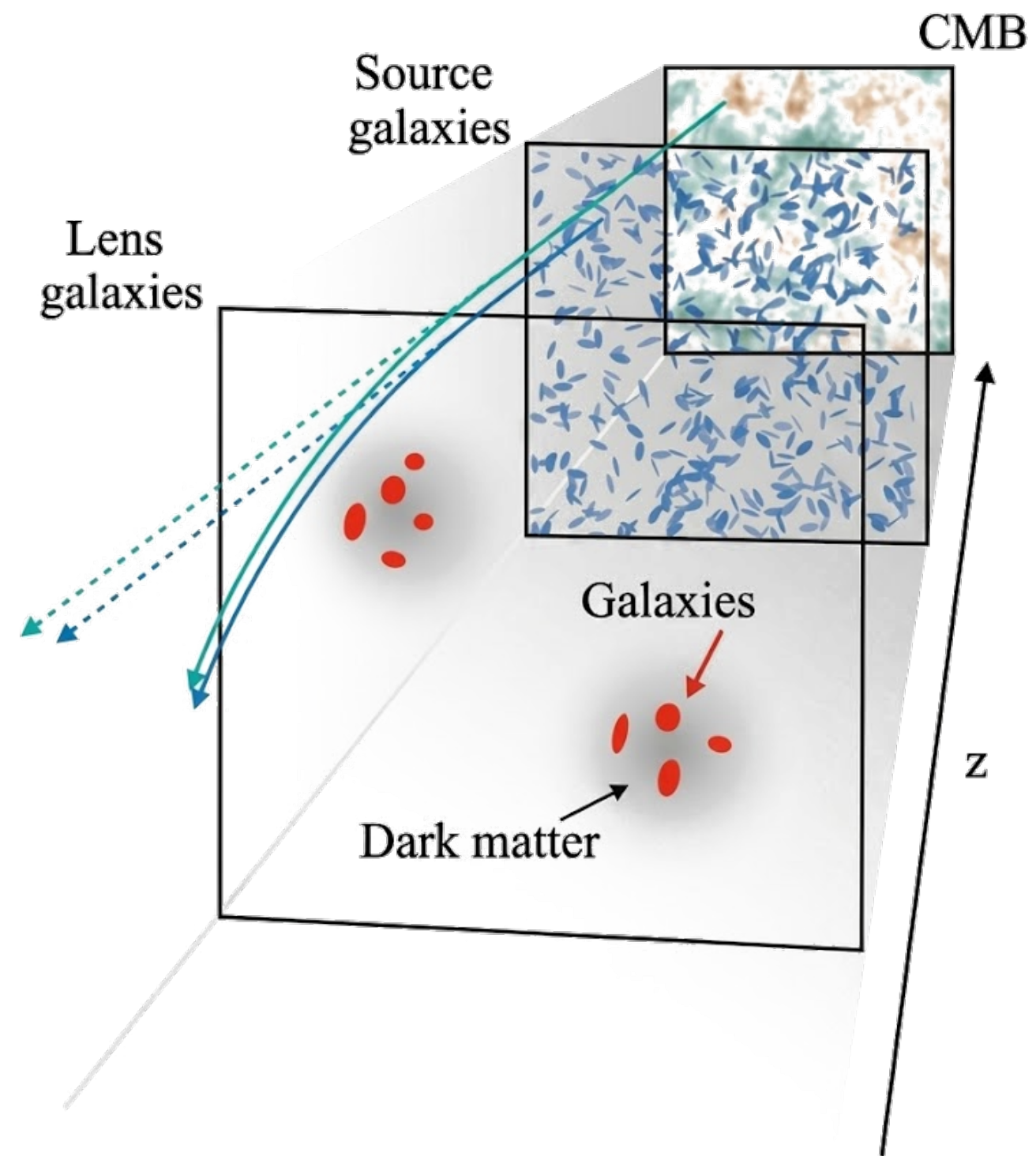


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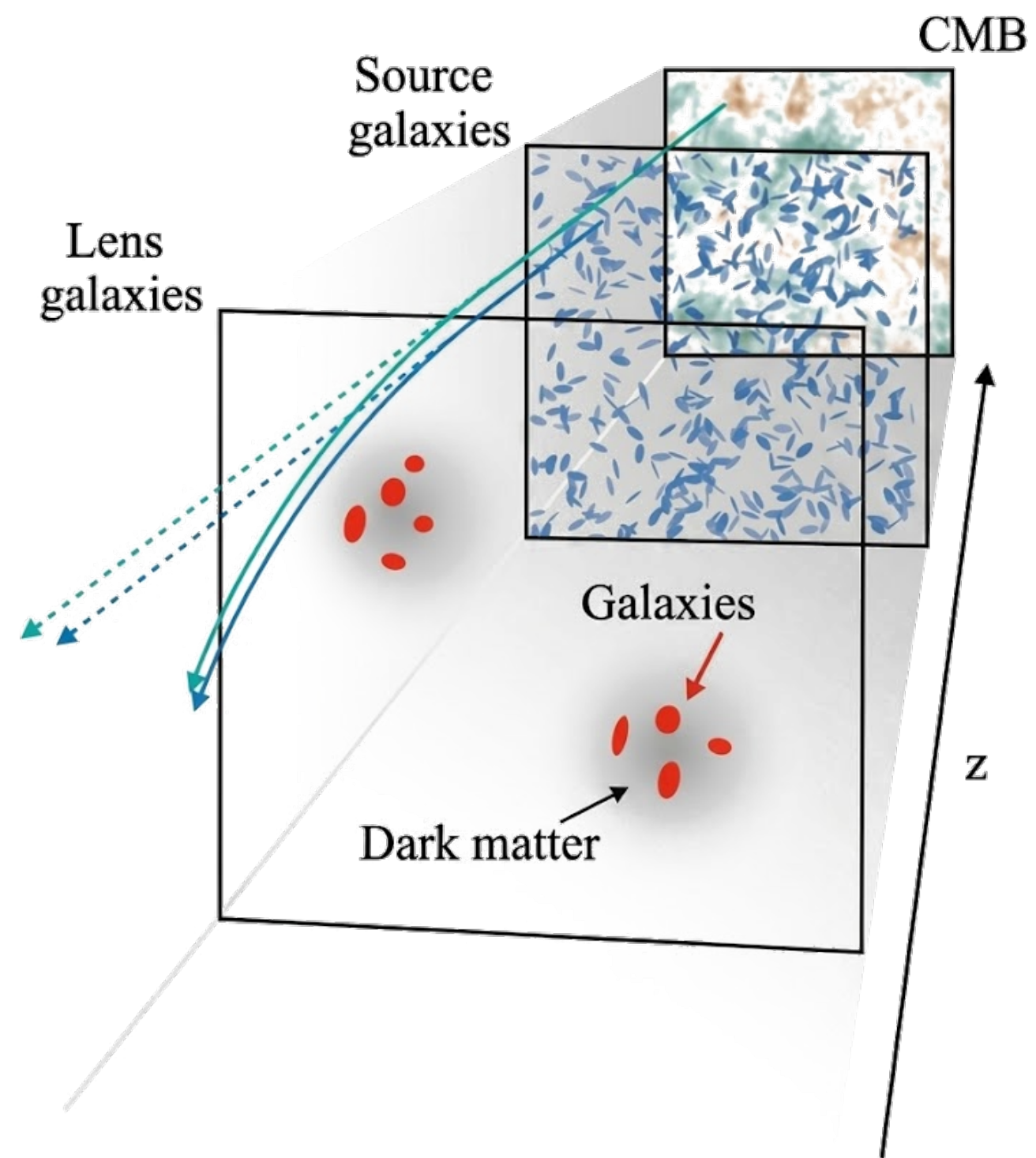
Observables – CMB lensing

LSS deflects the CMB photons along the whole line of sight

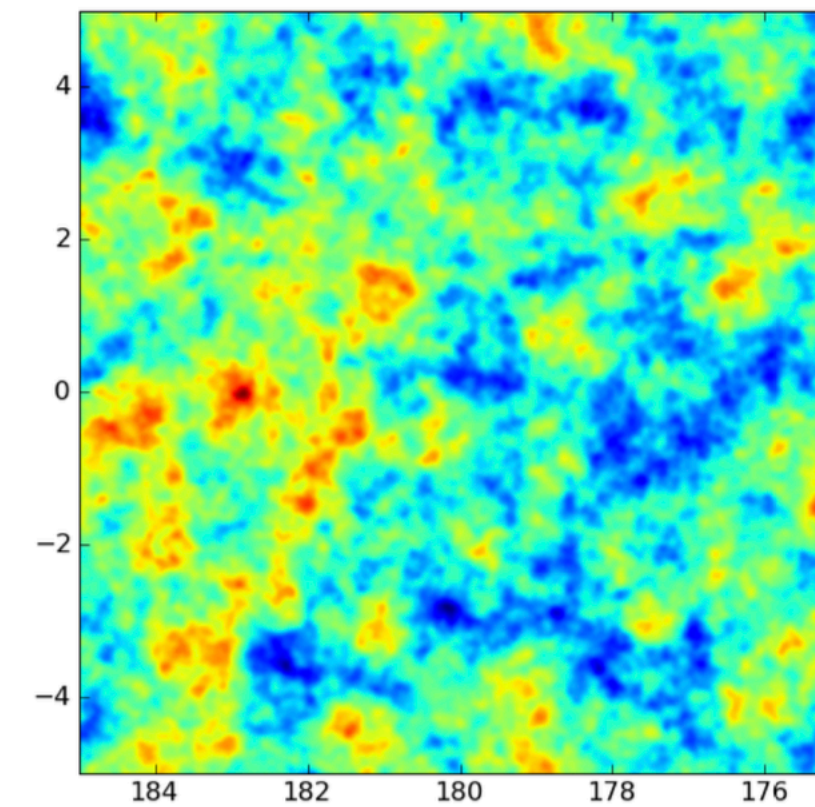
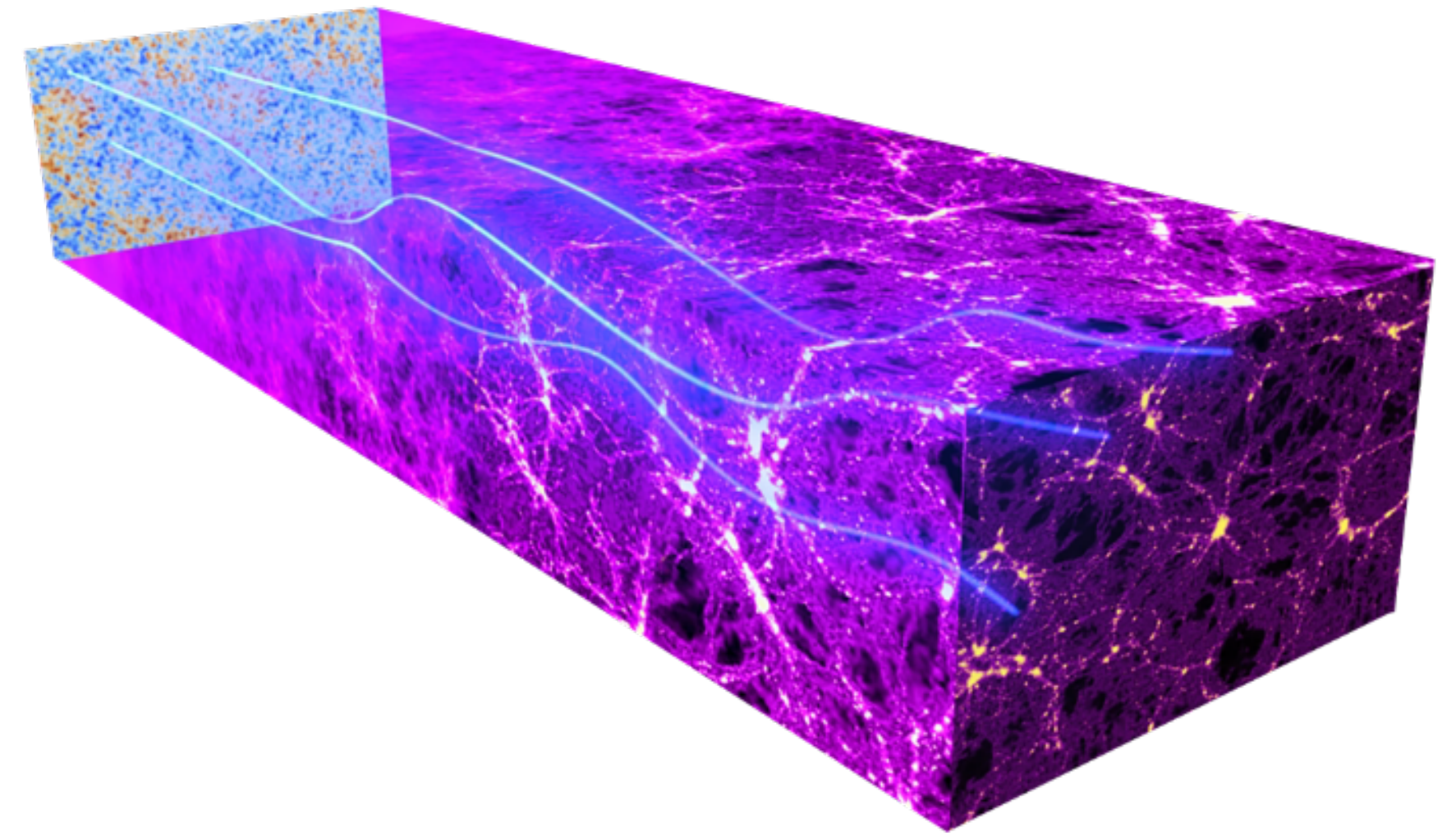


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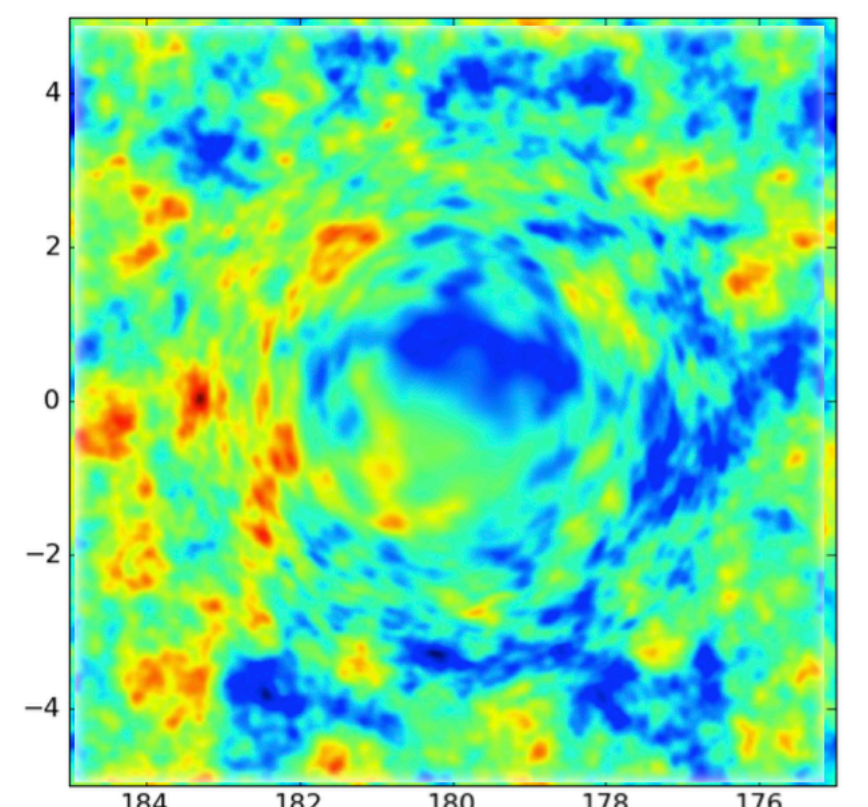
LSS deflects the CMB photons along
the whole line of sight



With a resulting
**deflection of photon
geodesics**

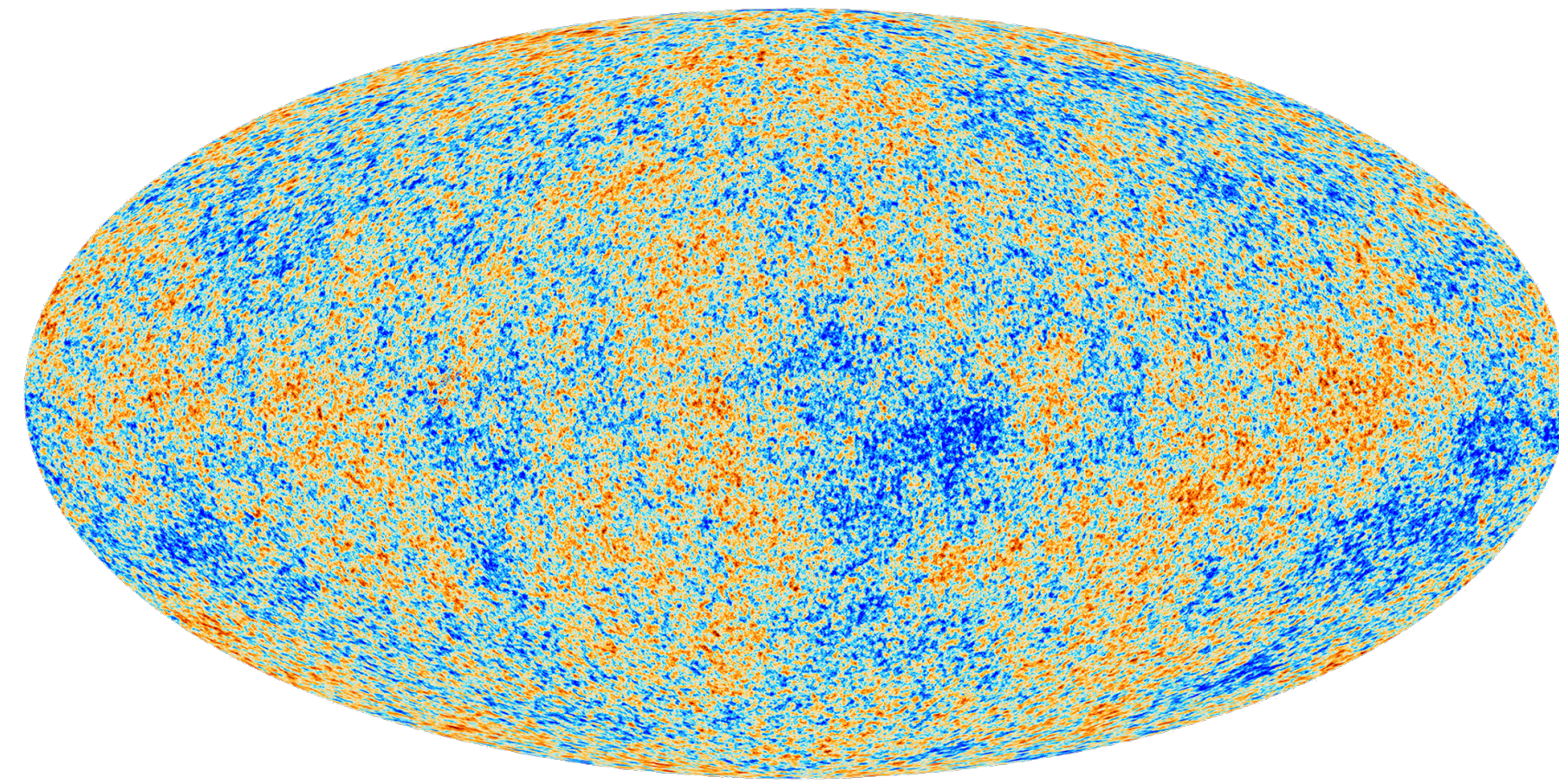


unlensed

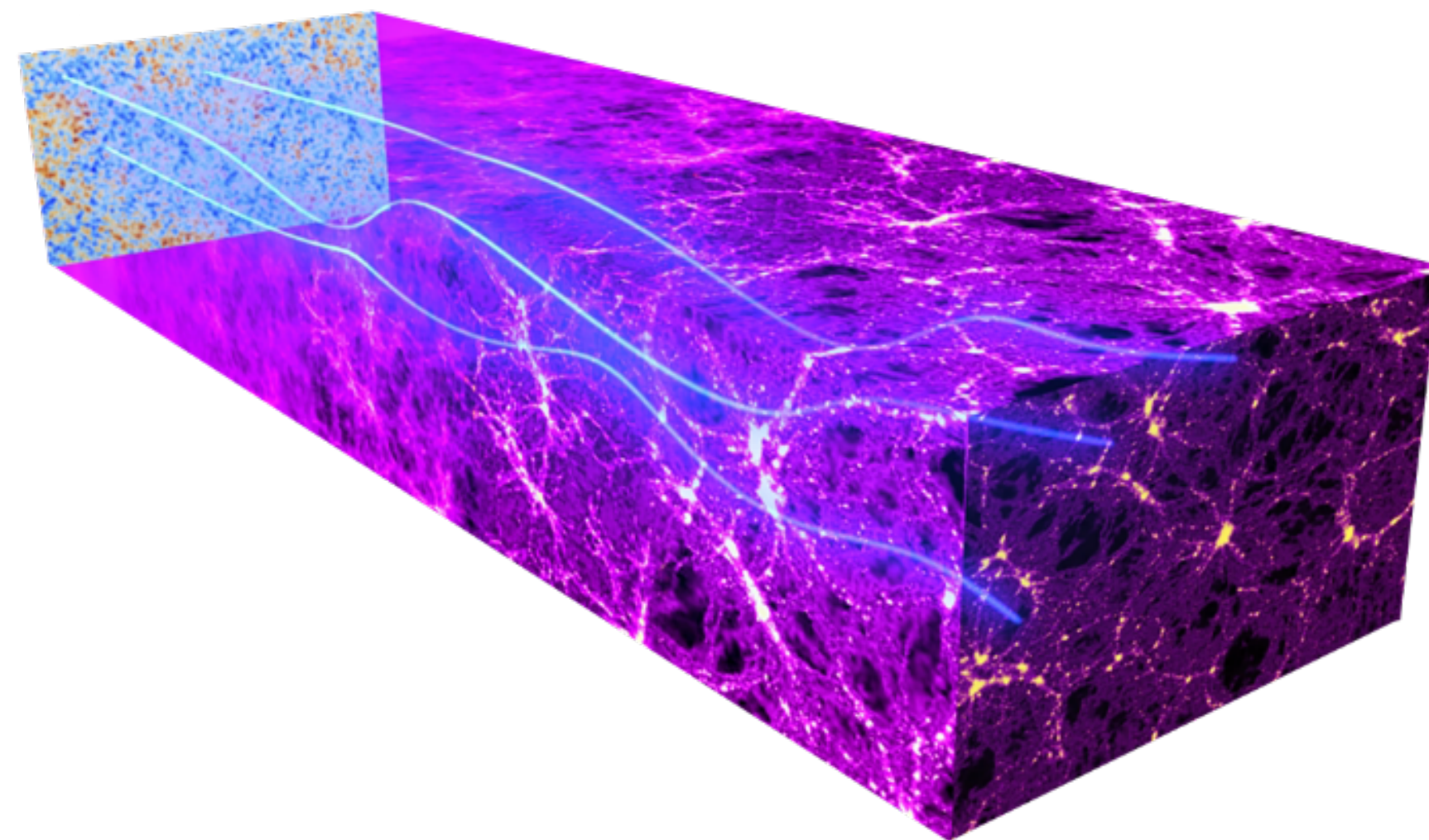


lensed

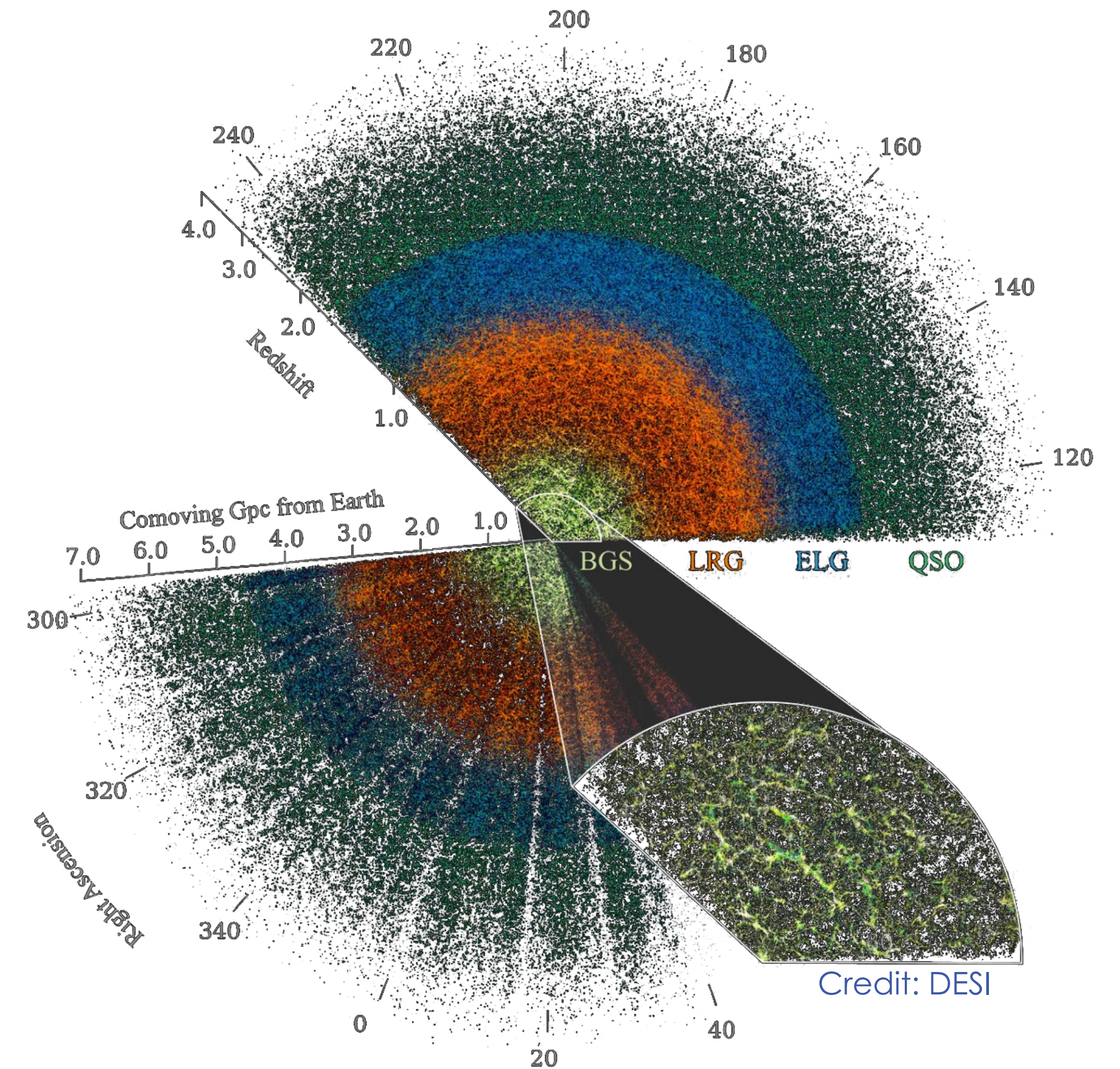
Cross-correlations



CMB temperature anisotropies



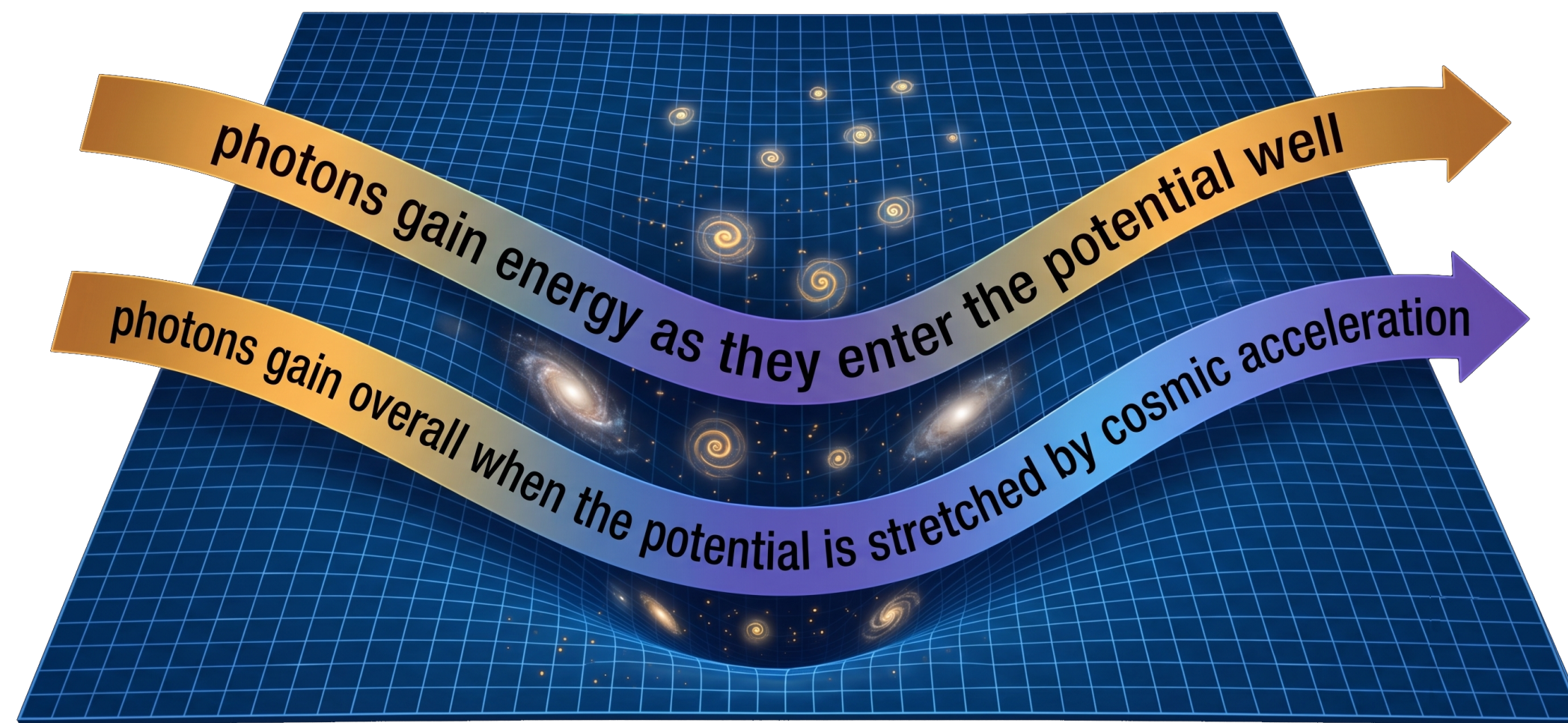
CMB lensing



High z large-scale structure tracers
AGNs

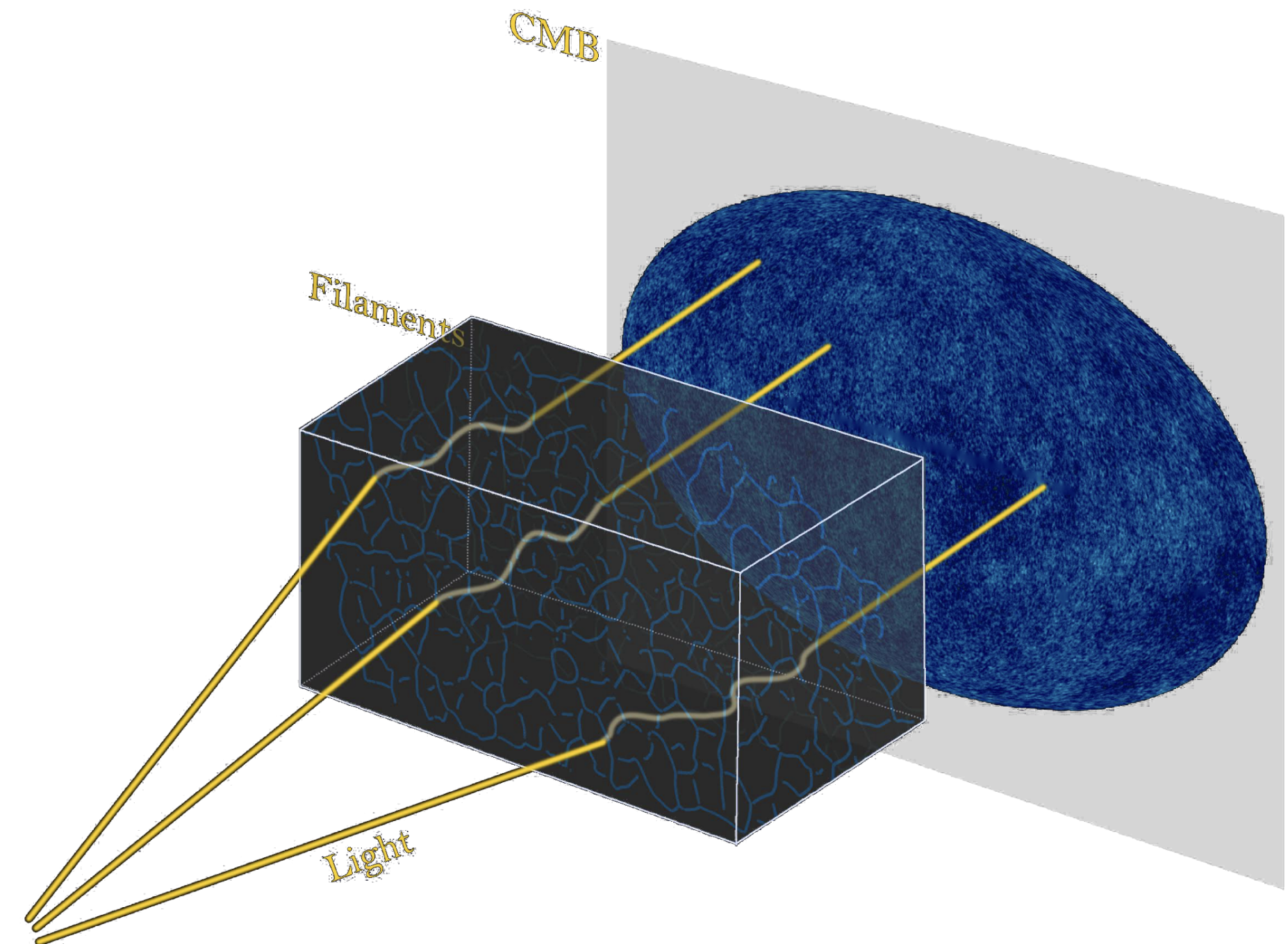
Cross-correlations

$$C_{\ell}^{X \times Y} = \frac{2}{\pi} \int_0^{\infty} dz \int_0^{\infty} dz' \int_0^{\infty} dk k^2 P_{\delta\delta}(k, z, z') W^X(k, z) W^Y(k, z') j_{\ell}[k\chi(z)] j_{\ell}[k\chi(z')]$$



Late-time Integrated Sachs-Wolfe

$$C_{\ell}^{T \times GC}$$



CMB lensing $\times$ AGN Clustering

$$C_{\ell}^{k \times GC}$$

Why cross-correlations?

Less affected by systematics

$$b_g^{NG}(k, z) \propto \frac{f_{NL}}{k^2}$$

f_{NL} is strong at low ℓ s, where systematics dominate

Break degeneracies!

$$C_\ell^{GC \times GC} \propto b^2 \sigma_8^2, \quad C_\ell^{\kappa \times GC} \propto b \sigma_8^2$$

Test specific physical effects!

$$C_\ell^{T \times GC} \simeq C_\ell^{ISW \times GC}$$

The Euclid mission: mapping the dark universe



**Launched in 2023, currently collecting data
from the second Lagrange point (L2)**

The Euclid mission: mapping the dark universe

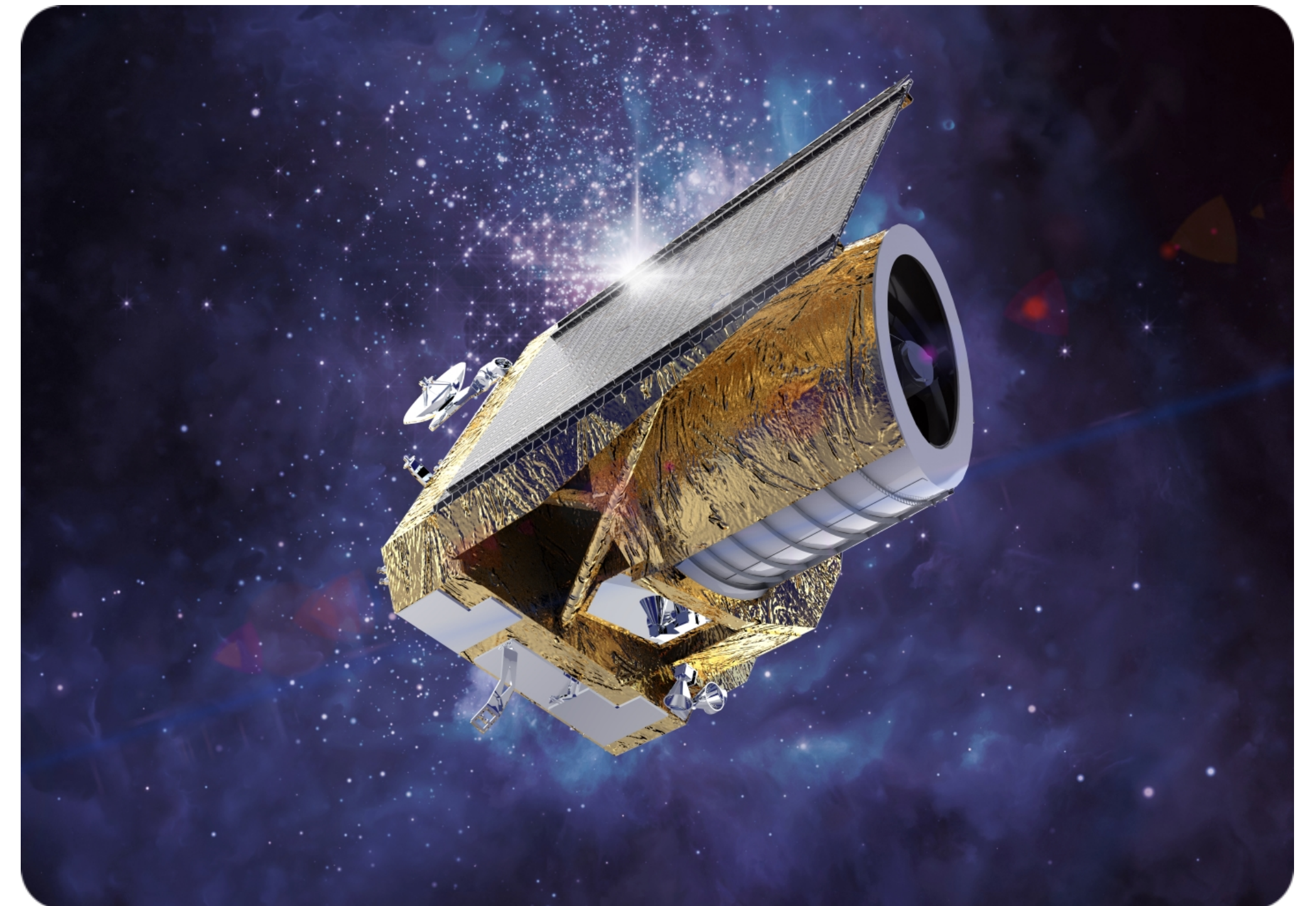


Launched in 2023, currently collecting data from the second Lagrange point (L2)

Main objective: investigate the expansion of the universe and the nature of dark energy and dark matter

Primary probes: galaxy clustering and weak gravitational lensing

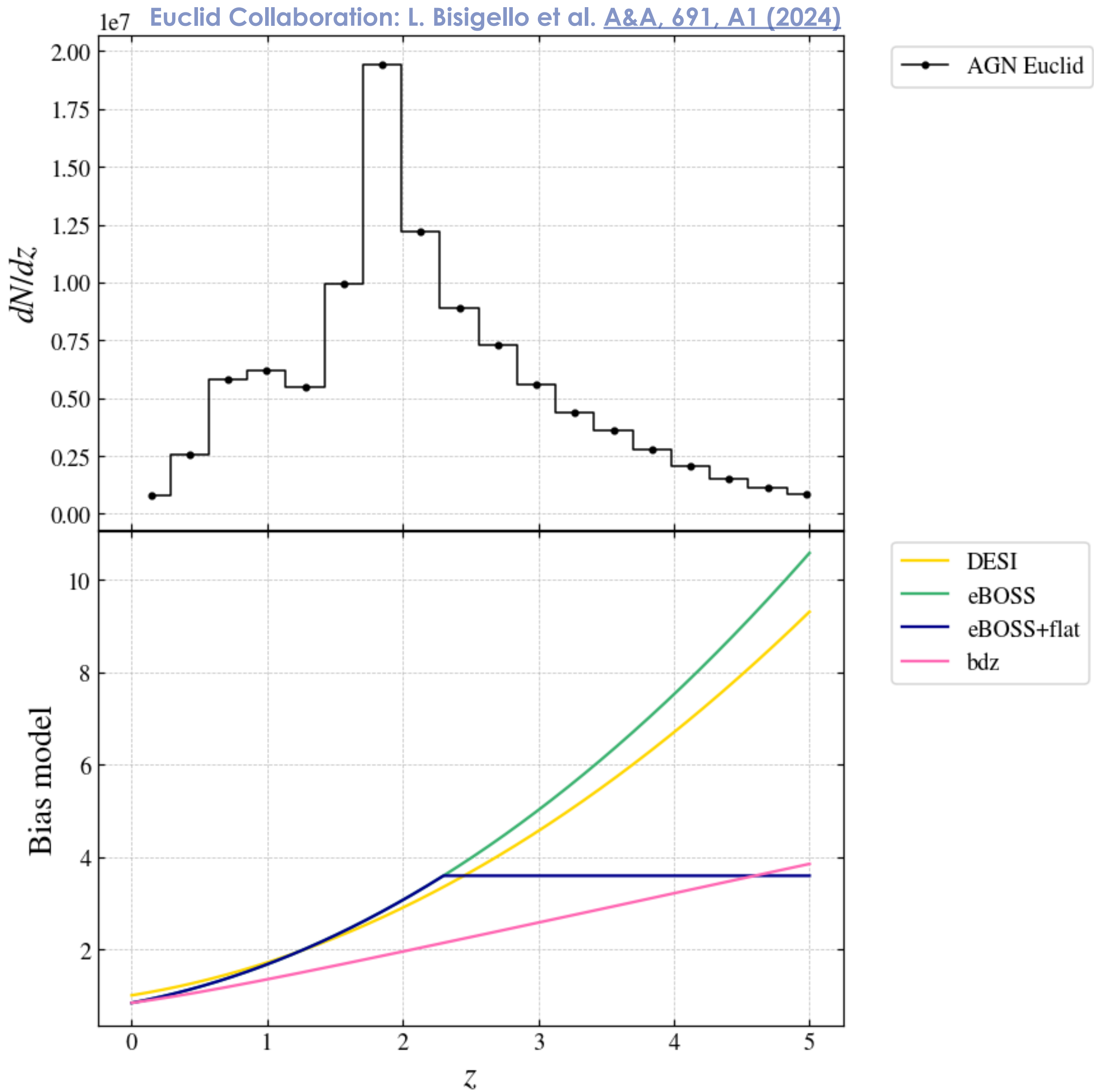
Additional observables: AGNs, high- z galaxies, supernovae, galaxy clusters, exoplanets, local observables...



Euclid AGNs sample (forecast)

$N_{\text{sources}} \sim 28 \cdot 10^6$

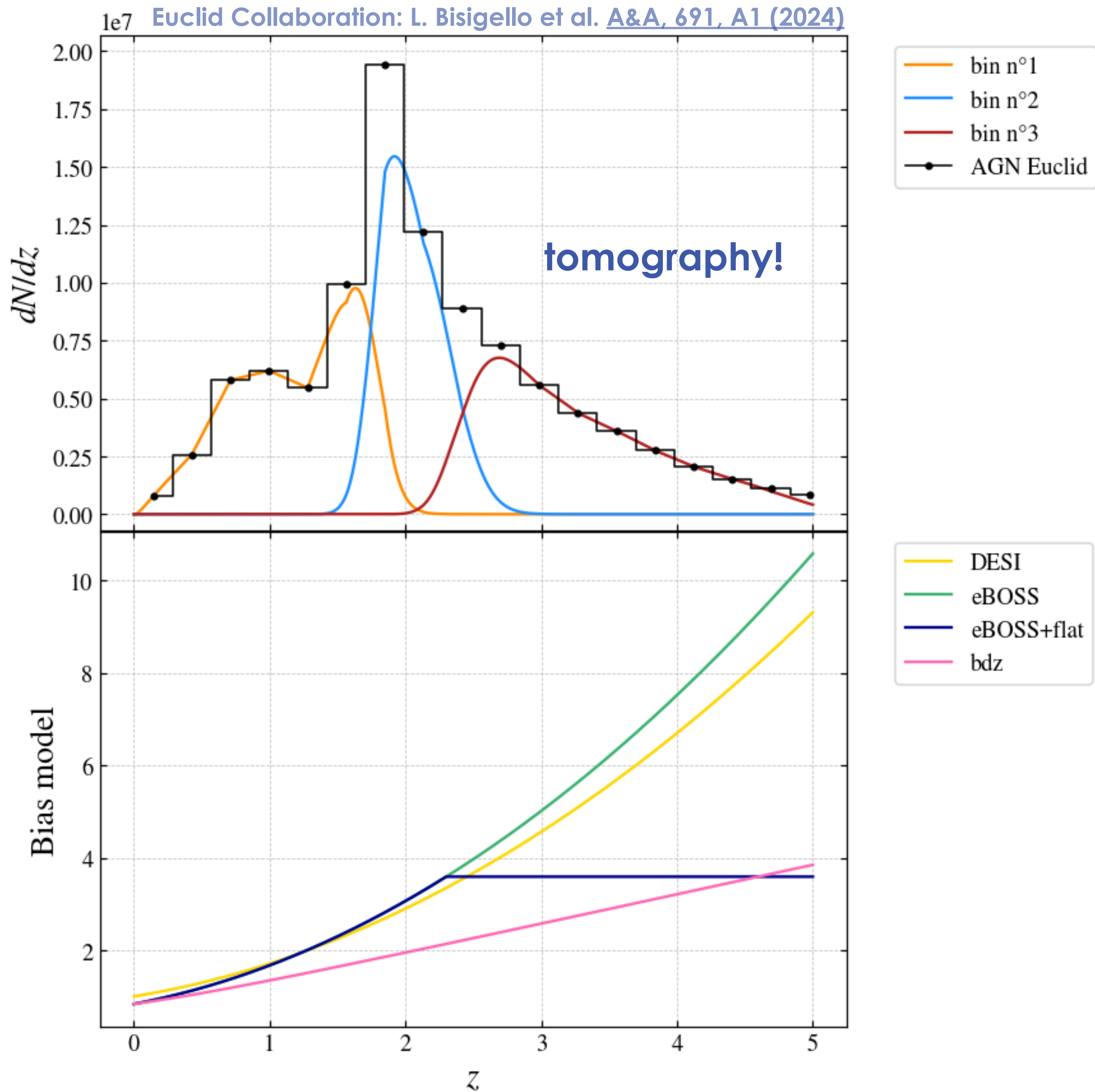
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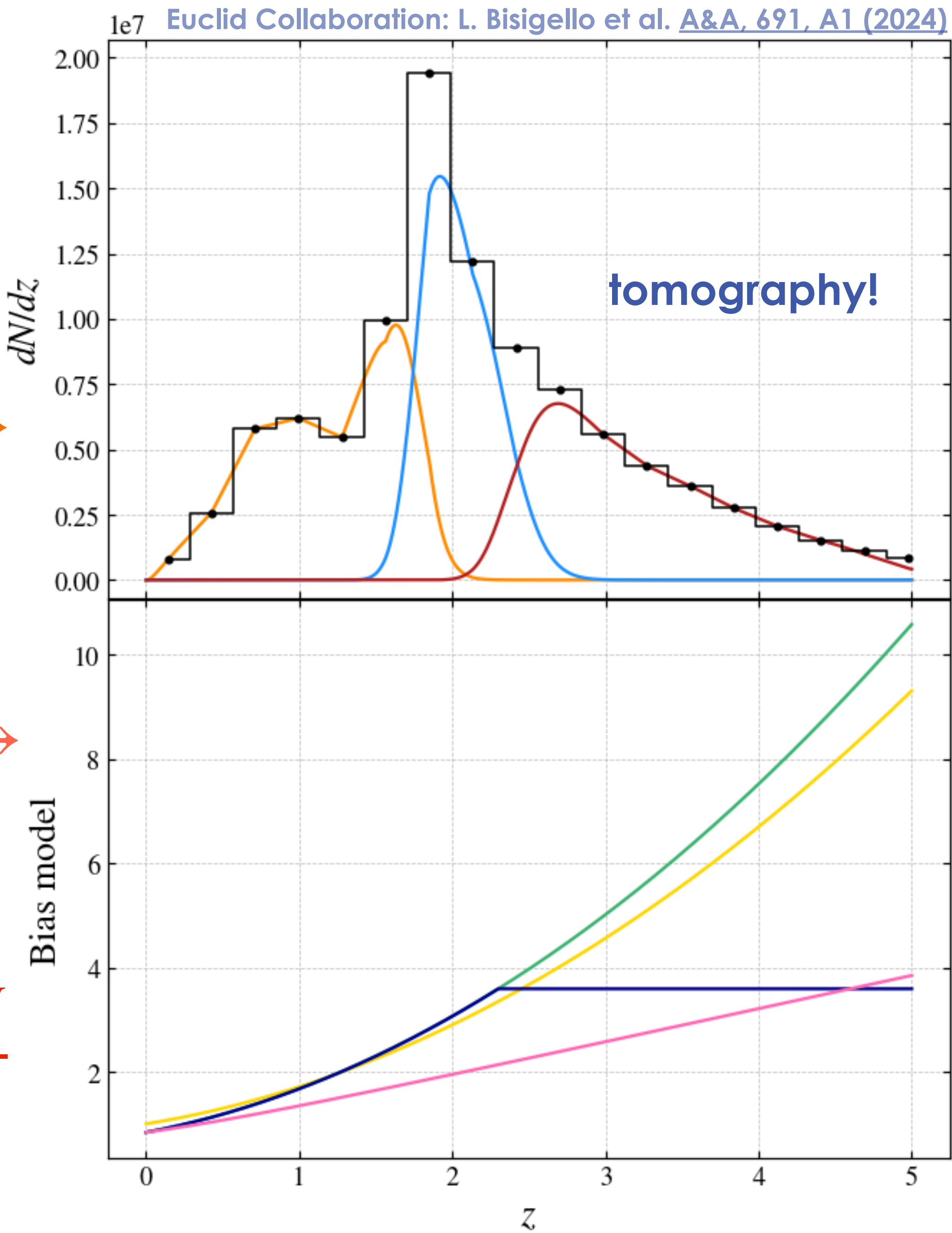
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$$W^{\text{GC}}(z) = b(z) \frac{dN}{dz}$$

$$\frac{dN}{dz} \longrightarrow$$

$$b_*(z) \longrightarrow$$

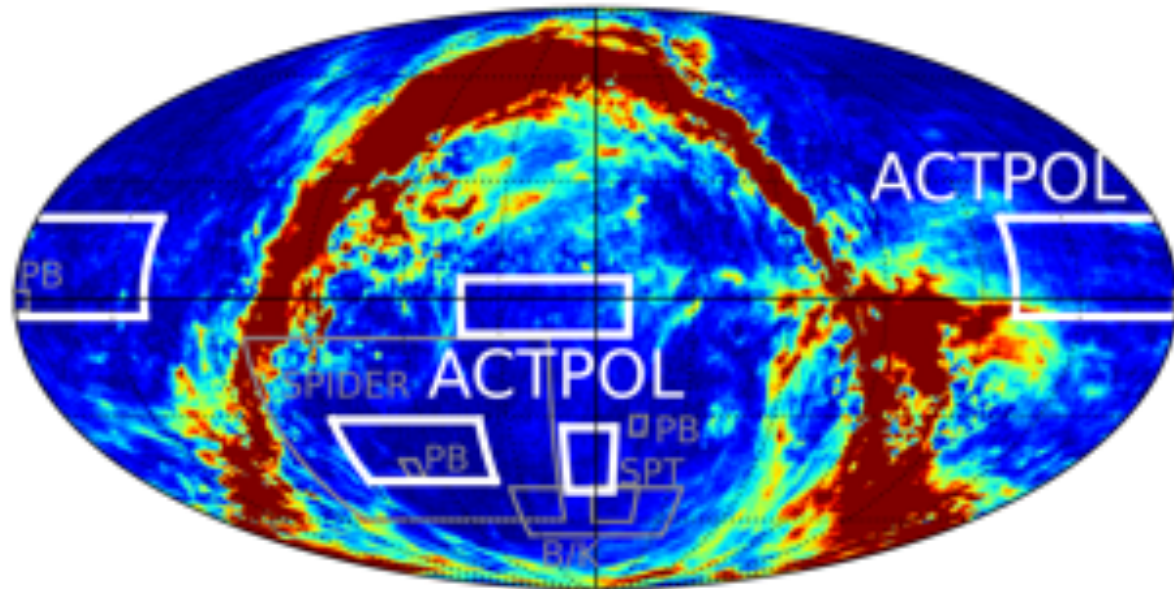


CMB surveys



Planck

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



Atacama
Cosmology
Telescope



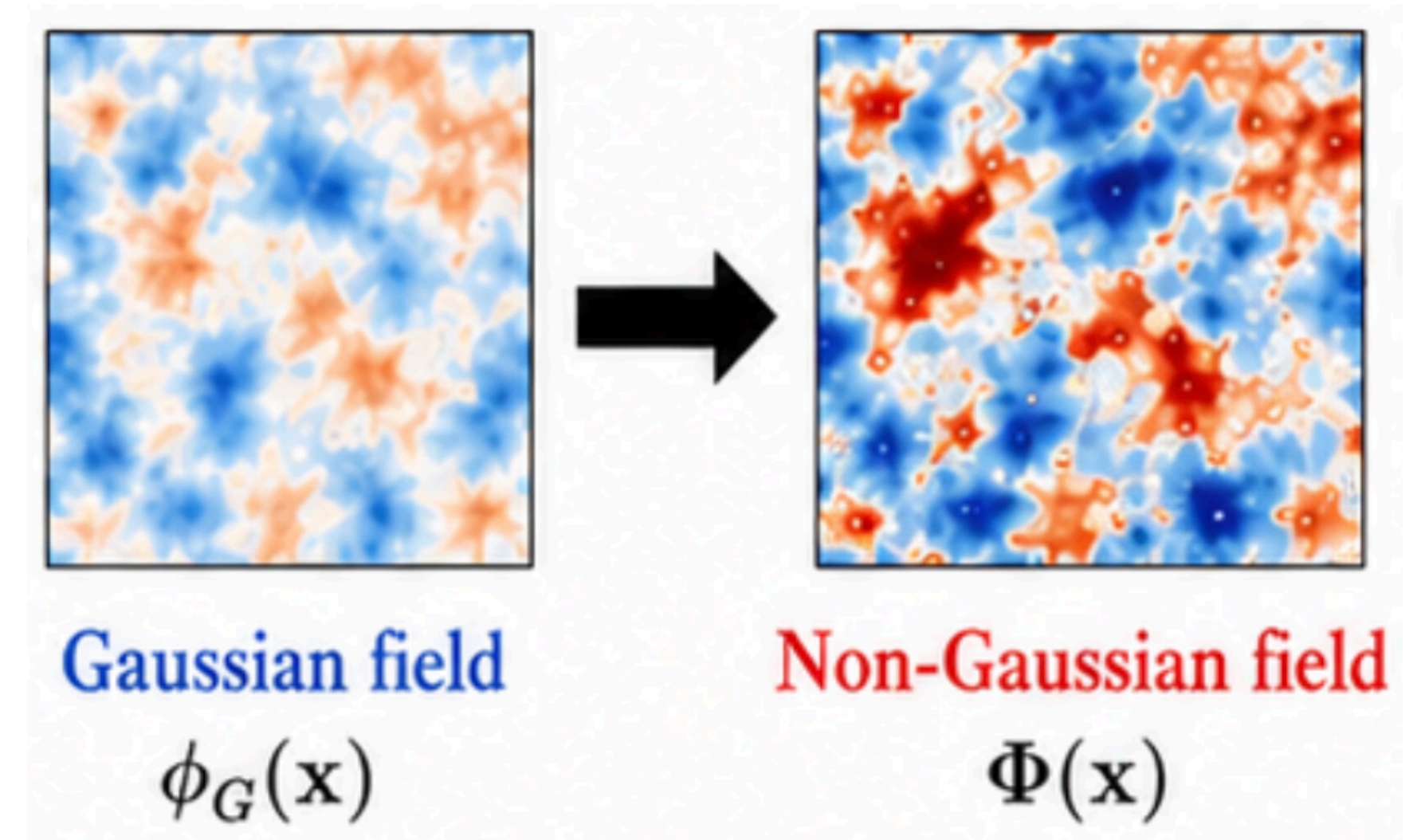
Simon's
Observatory
(forecast)

$$W^{\text{ISW}}(k, z) = - \frac{3\Omega_{m,0}H_0^2}{c^3k^2} H(z) \frac{d}{dz} [D(z)(1+z)]$$

Primordial non-Gaussianity (PNG) f_{NL}

$$\Phi_{\text{NG}}(x) = \phi_G(x) + f_{\text{NL}} \left(\phi_G^2(x) - \langle \phi_G^2 \rangle \right)$$

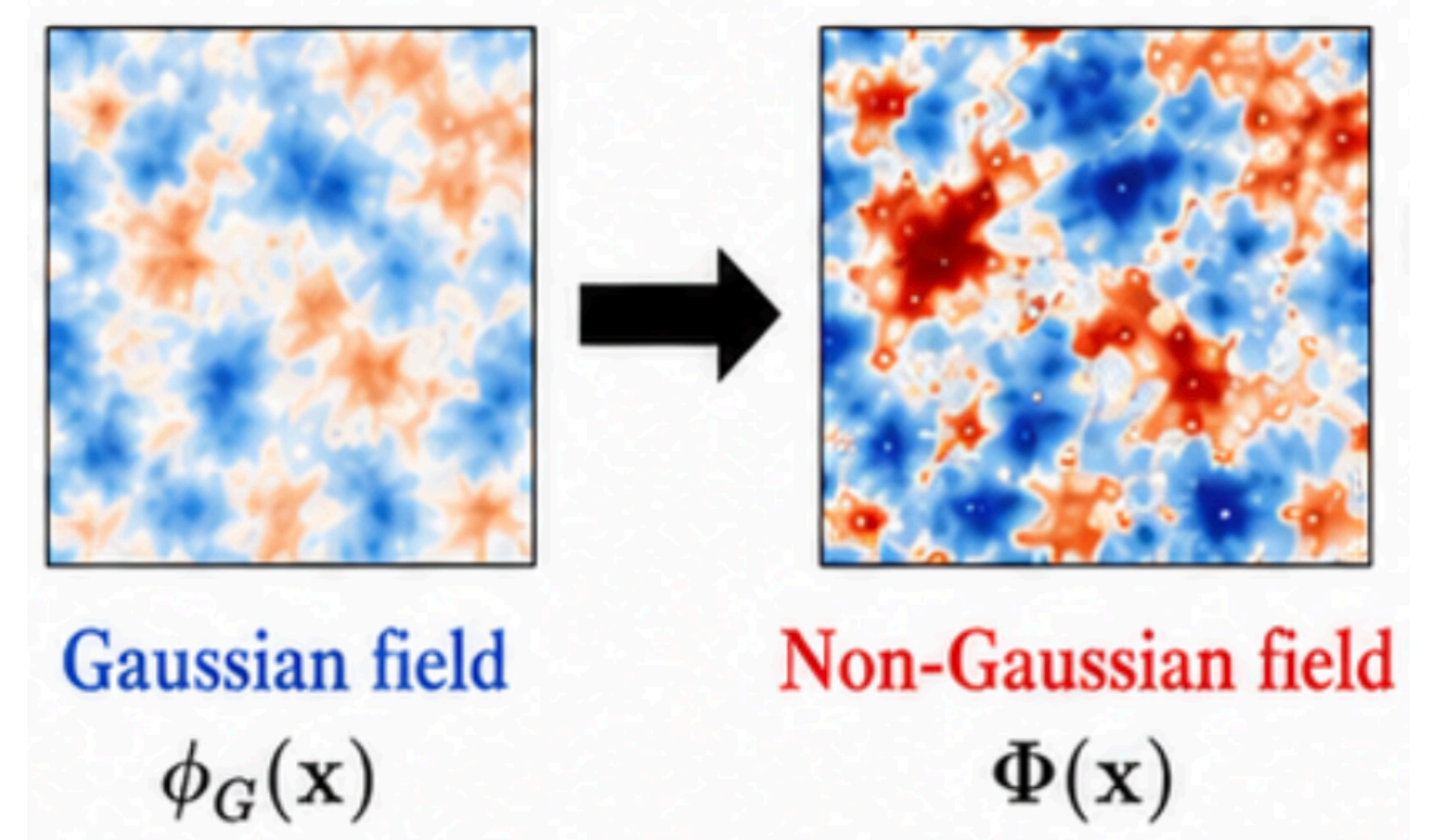
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$$b_g^{\text{NG}}(k, z) = b_g(z) \left[1 + \underbrace{f_{\text{NL}}}_{\text{circled}} \cdot 3 \frac{b_g(z) - p_\phi}{b_g(z)} \underbrace{k^2}_{\text{circled}} T(k) D(z) \frac{\Omega_{m,0} \delta_c}{c^2} \frac{H_0^2}{c^2} \right]$$

Local PNG induces a scale-dependent bias correction which is strongest on the larger scales

S. Matarrese and L. Verde [2008 ApJ 677 L77](#)

$$\Delta b_{f_{\text{NL}}} \propto \frac{f_{\text{NL}}}{k^2}$$

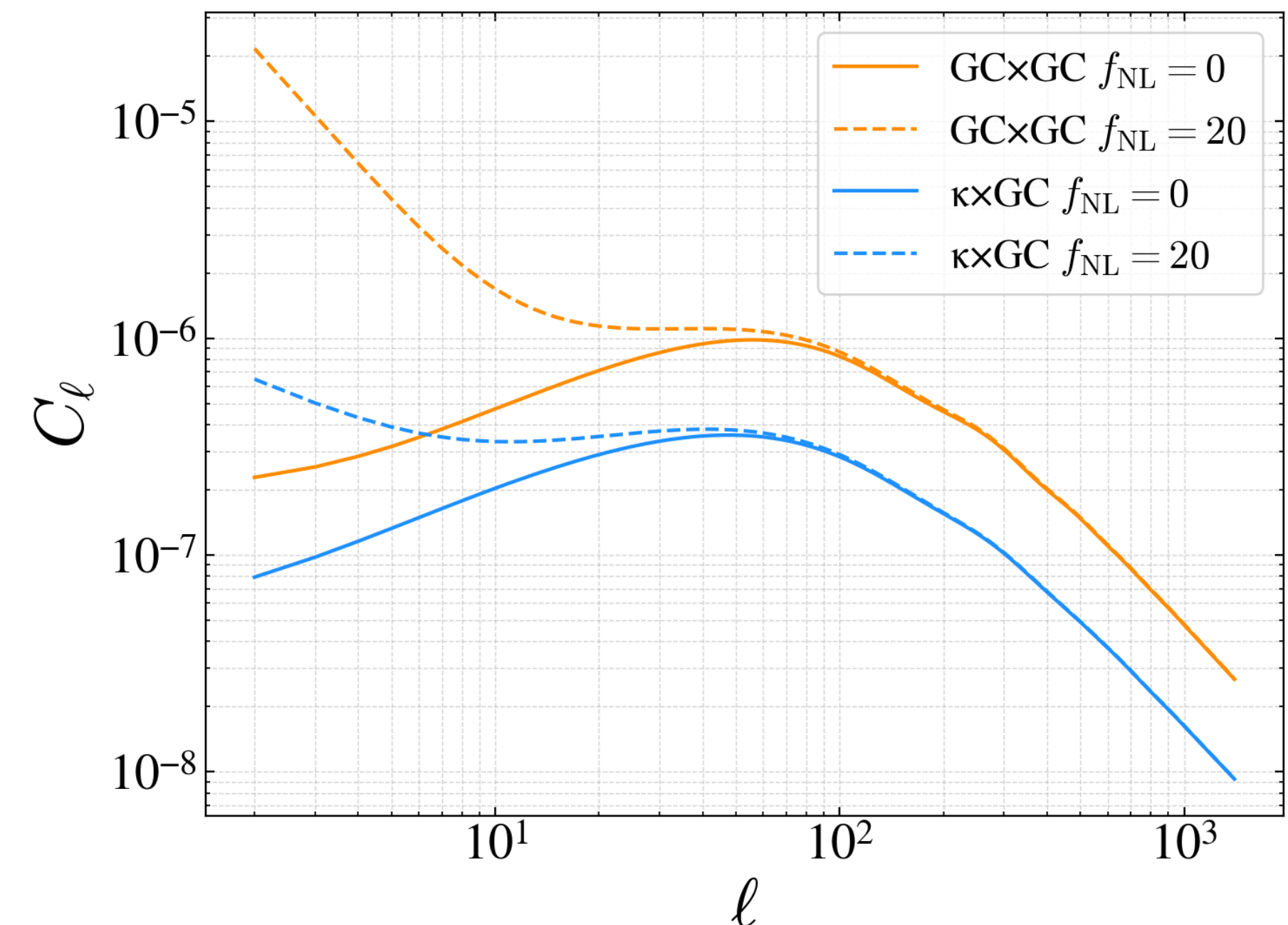
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Amplitude of matter perturbations $\sigma_8(z)$

$$\sigma_8^2(z) = \int_0^\infty dk \frac{k^2 P_{\text{lin}}(k, z)}{2\pi^2} \left| W_8(k) \right|^2$$

We model the evolution of matter perturbations at different redshift ranges

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C. Embil-Villagra et al. [JCAP12\(2025\)033](#)

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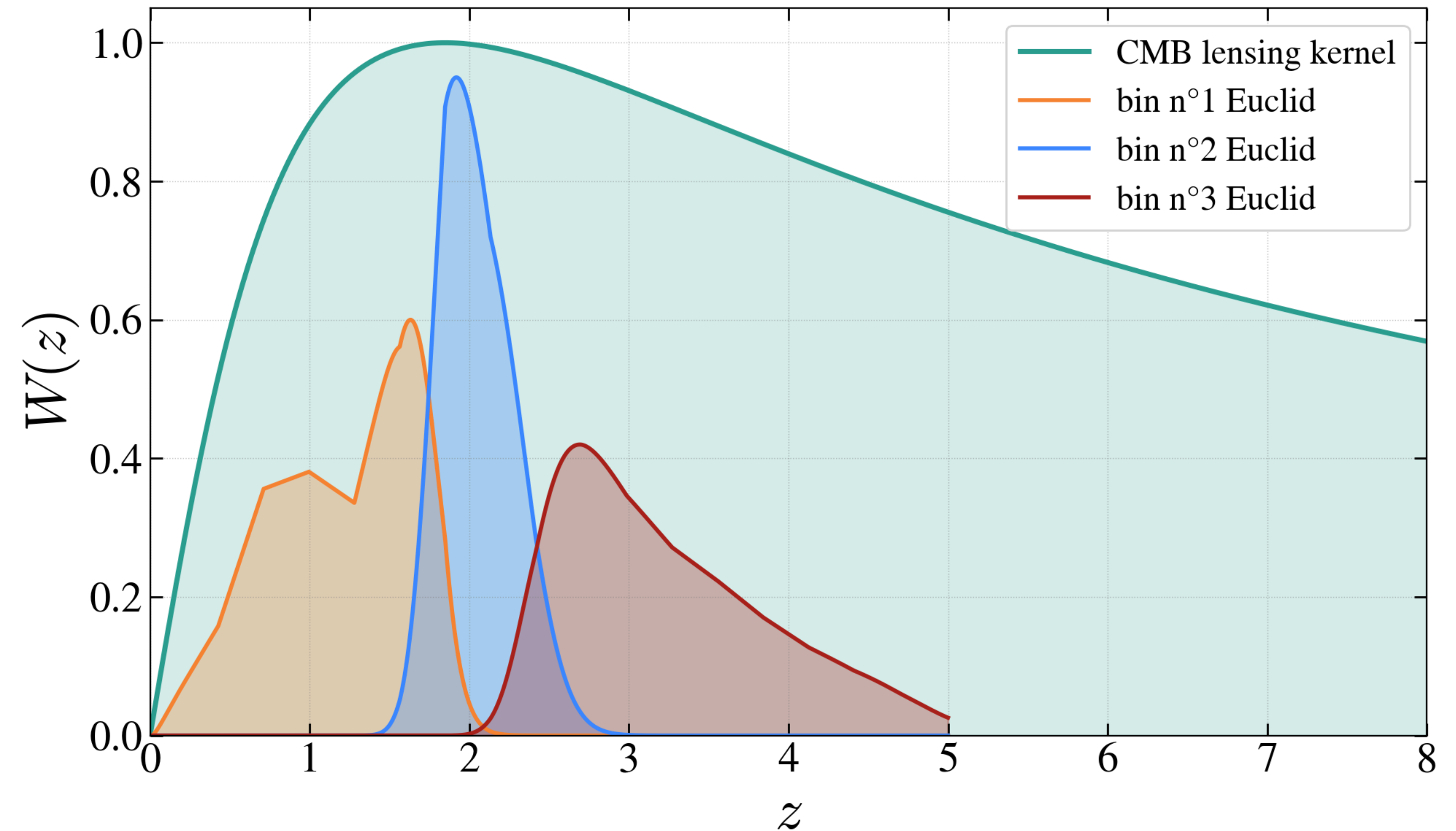
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$$P_{\text{lin}}^{\text{new}}(k, z) = A(z) P_{\text{lin}}(k, z)$$

$$A(z) = \begin{cases} A_1 & 0 \leq z < z_1 \text{ } (\kappa \times \text{GC}) \\ A_2 & z_1 \leq z < z_2 \text{ } (\kappa \times \text{GC}) \\ A_3 & z_2 \leq z < z_3 \text{ } (\kappa \times \text{GC}) \\ A_4 & z_3 \leq z \text{ } (\kappa \times \kappa) \end{cases}$$

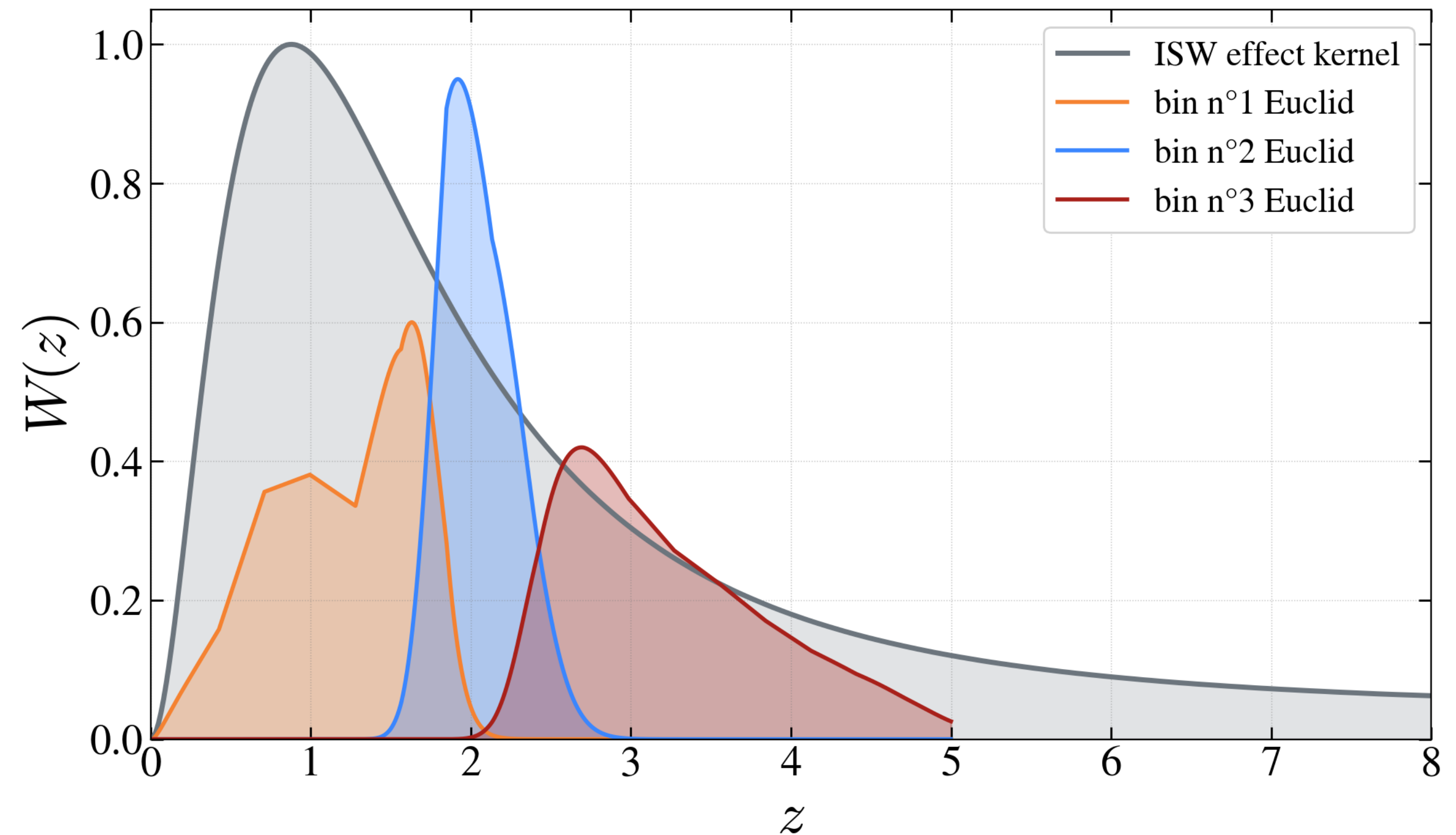


Dark energy e.o.s w_0 and density parameter Ω_Λ^0

For late-time ISW, the kernel peaks at lower redshifts than AGN's kernel



Consequently we have a low S/N , and expect non-tight constraints



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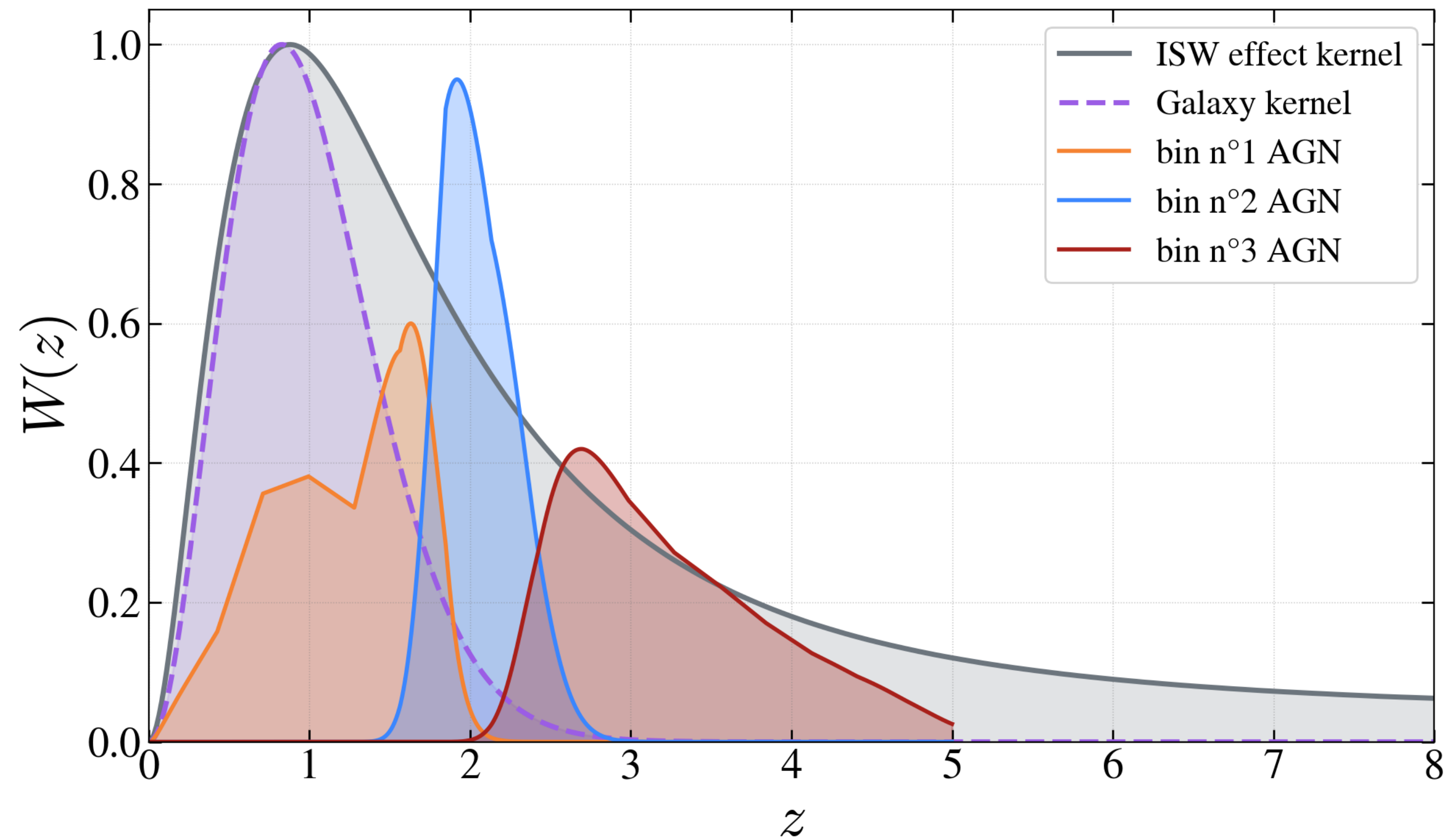
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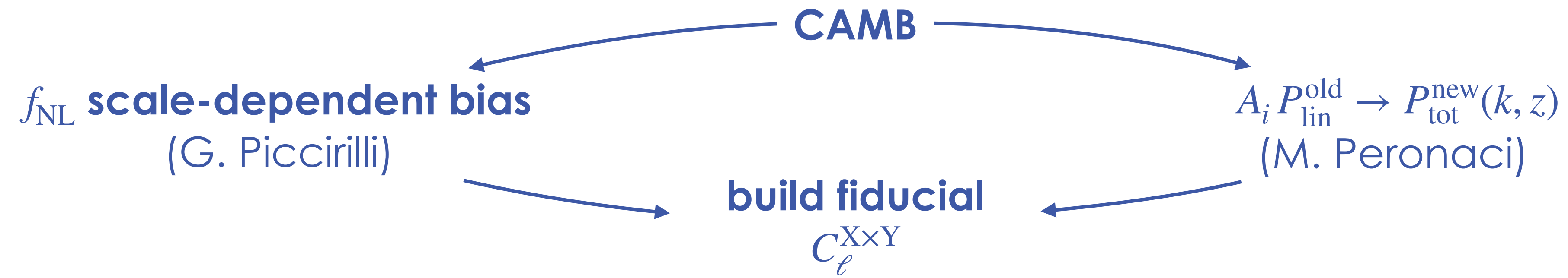
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BUT

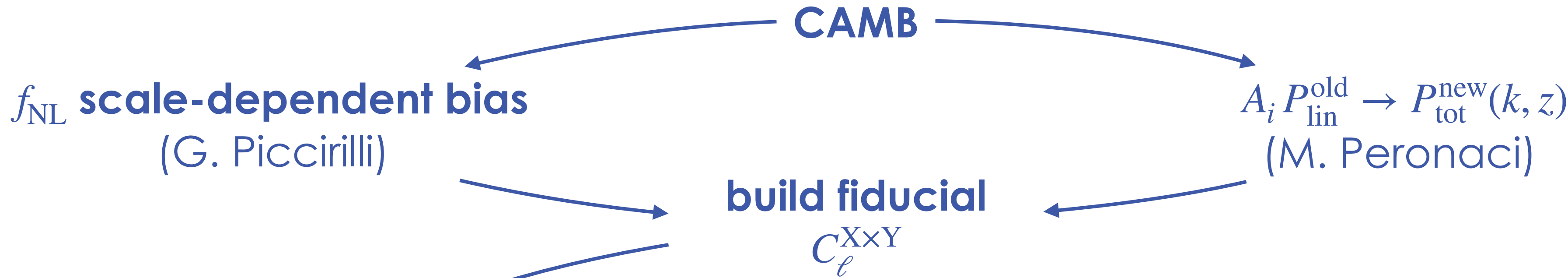
It still is a complementary measurement to galaxies at high redshifts



Methodology



Methodology

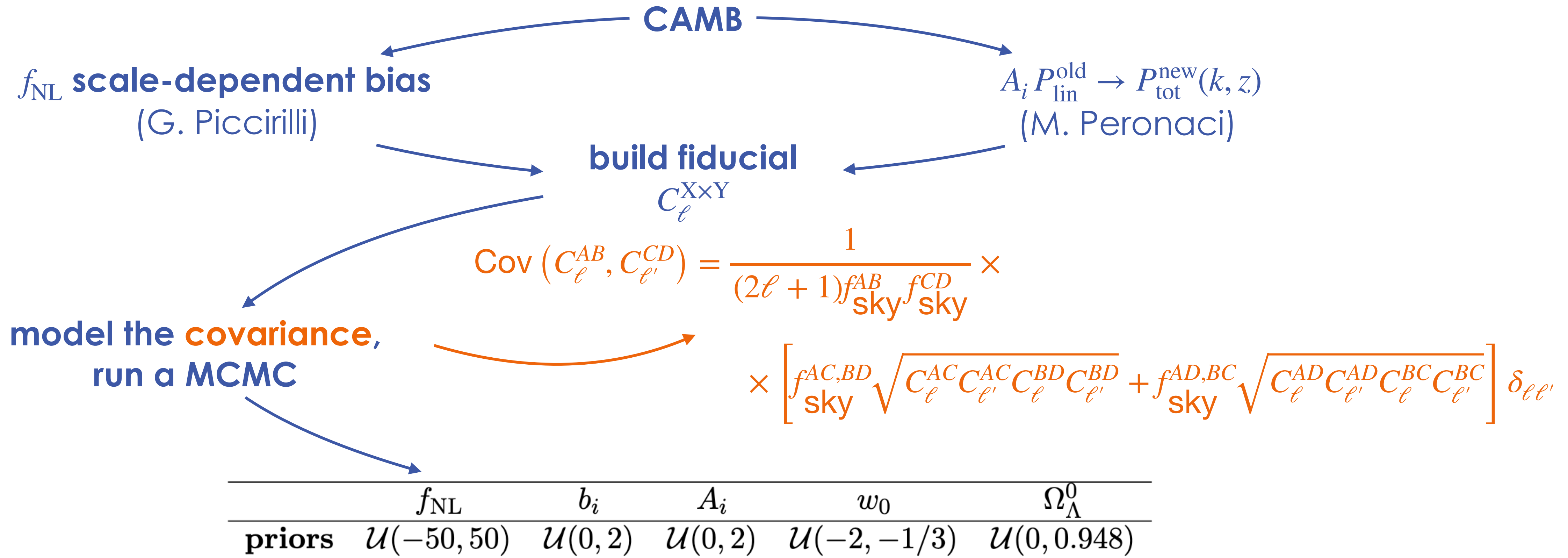


$$\text{Cov} \left(C_{\ell}^{AB}, C_{\ell'}^{CD} \right) = \frac{1}{(2\ell + 1) f_{\text{sky}}^{AB} f_{\text{sky}}^{CD}} \times$$

$$\times \left[f_{\text{sky}}^{AC,BD} \sqrt{C_{\ell}^{AC} C_{\ell'}^{AC} C_{\ell}^{BD} C_{\ell'}^{BD}} + f_{\text{sky}}^{AD,BC} \sqrt{C_{\ell}^{AD} C_{\ell'}^{AD} C_{\ell}^{BC} C_{\ell'}^{BC}} \right] \delta_{\ell\ell'}$$

	f_{NL}	b_i	A_i	w_0	Ω_{Λ}^0
priors	$\mathcal{U}(-50, 50)$	$\mathcal{U}(0, 2)$	$\mathcal{U}(0, 2)$	$\mathcal{U}(-2, -1/3)$	$\mathcal{U}(0, 0.948)$

Methodology

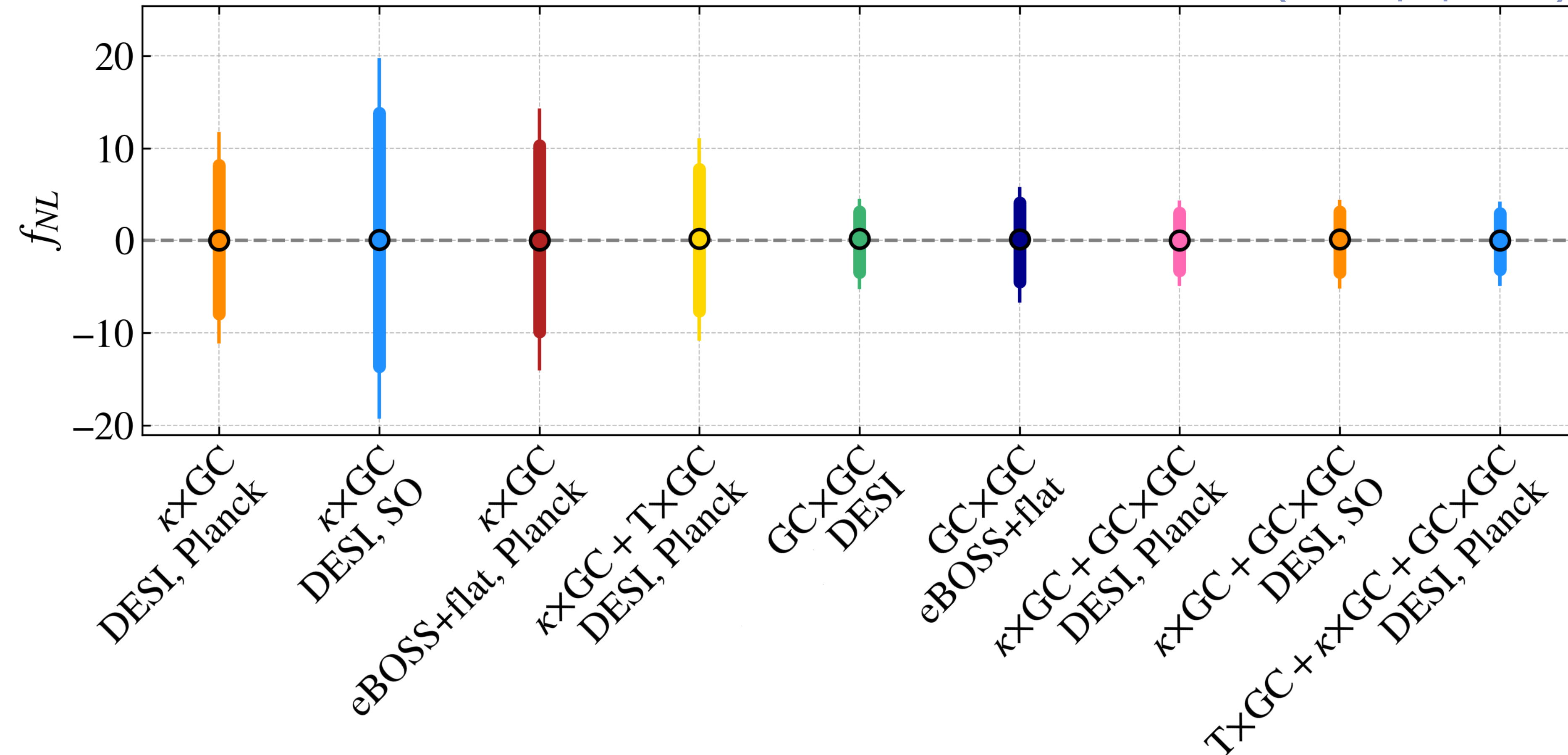


since these are forecasts, we are only interested in the constraining power of the quantities:

$$\sigma_{f_{\text{NL}}}, \sigma_{b_i}, \sigma_{A_i}, \sigma_{w_0}, \sigma_{\Omega_{\Lambda}^0}$$

Results – Primordial non-Gaussianity f_{NL}

M. Peronaci et al. (2026, in preparation)

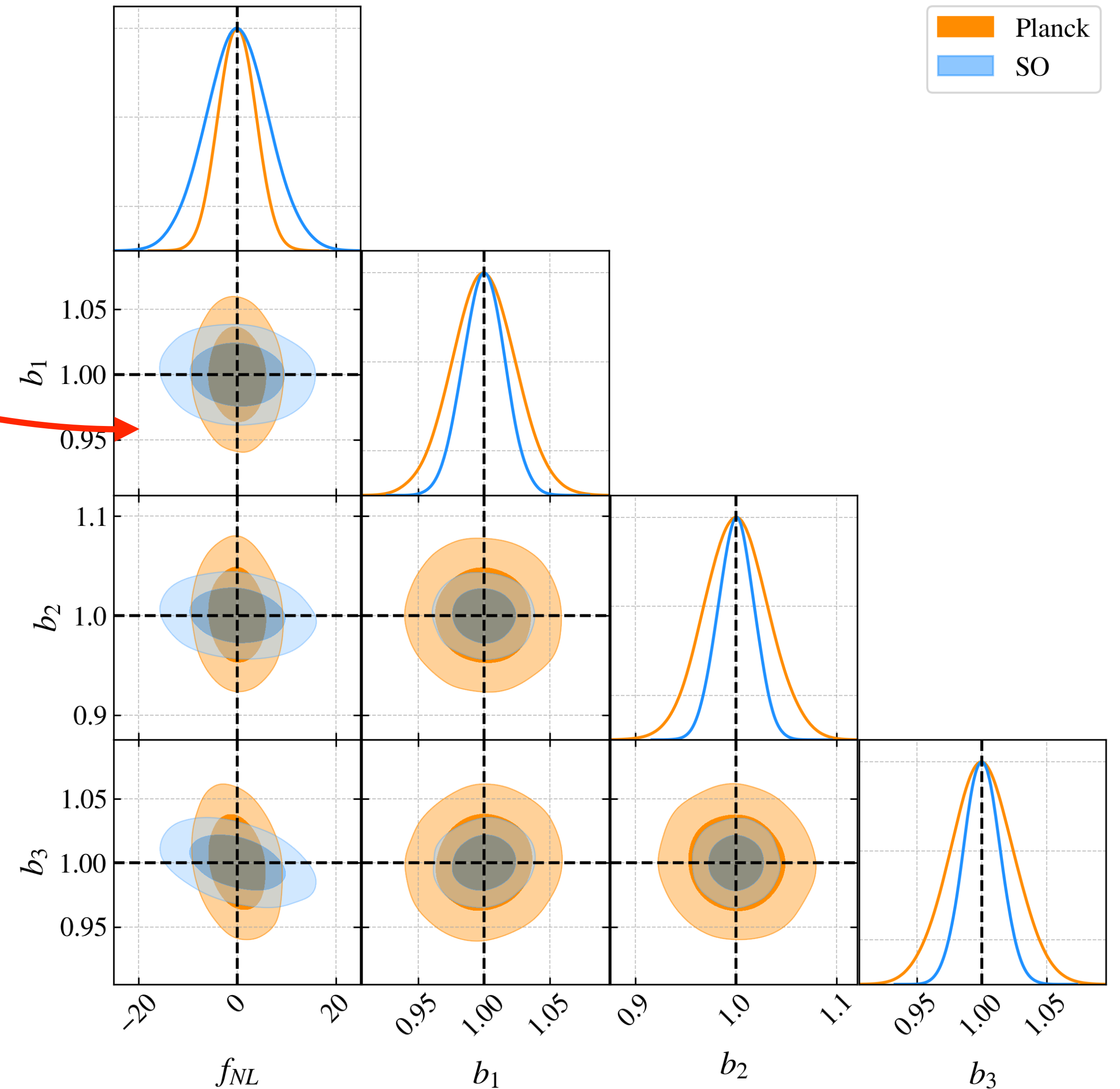


with Euclid DR3
we expect
 $\sigma_{f_{\text{NL}}, \text{best}} \approx 2.5$ vs
 $\sigma_{f_{\text{NL}}} \approx 17$ from
comparable
analyses

N.B. “DESI”, “eBOSS+flat” are the AGN bias models assumed
N.B. “Planck”, “SO” are the lensing noise curves

Results – Primordial non-Gaussianity f_{NL}

When considering **just the cross-correlation $\kappa \times \text{GC}$** with Planck and SO, there is a “rotation” in the correlation due to the **CMB κ survey**



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Results – Primordial non-Gaussianity f_{NL}

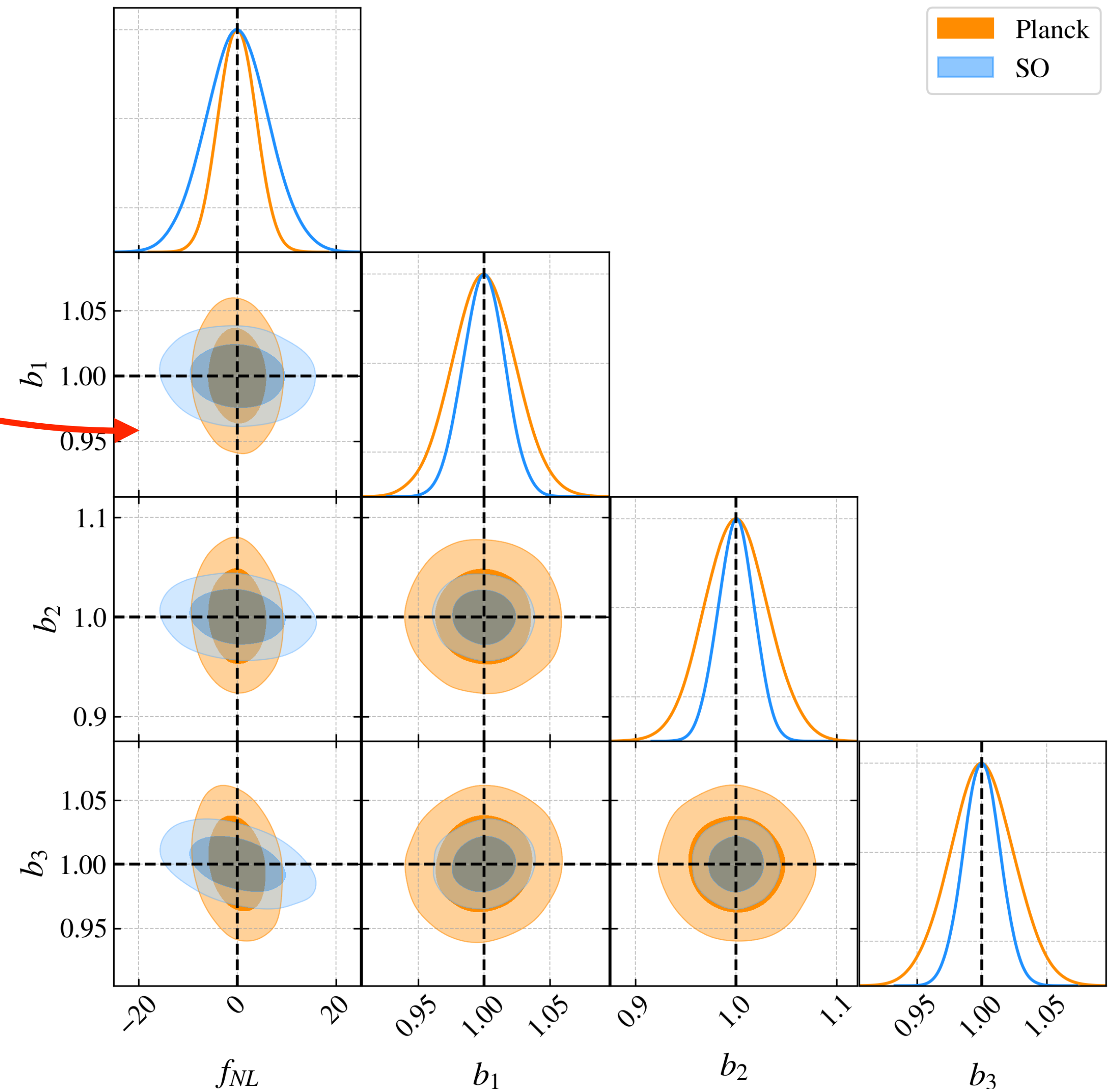
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Planck has higher lensing noise
 $\Rightarrow$ less constraining power on the bias

SO has limited multipole ranges
 $\Rightarrow$ less constraining power on the f_{NL}

$$\ell_{\kappa \times \text{GC}}^{\text{Planck}} \in [4, 400], \ell_{\kappa \times \text{GC}}^{\text{SO}} \in [30, 3000]$$

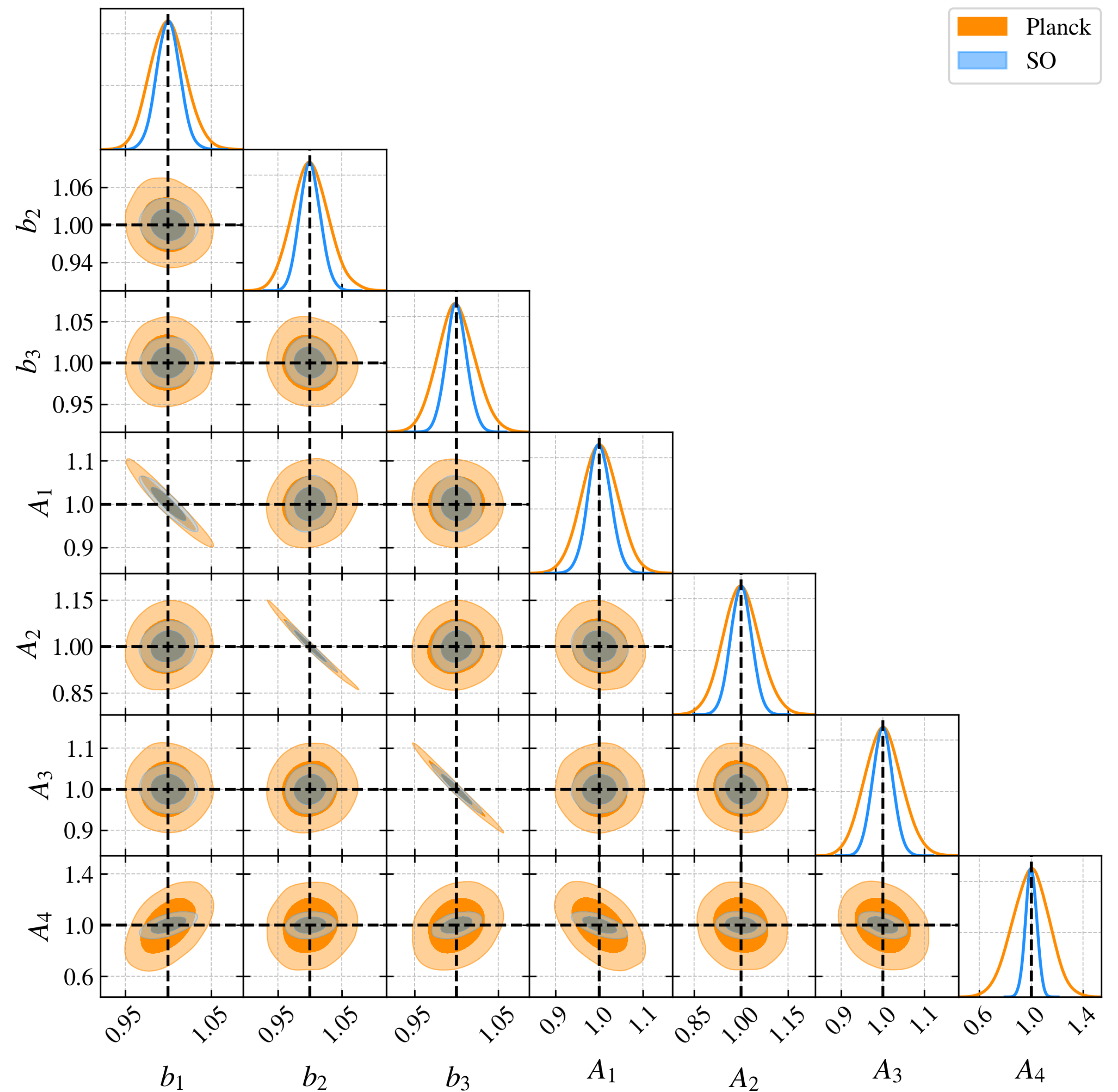
M. Peronaci et al. (2026, in preparation)



Results – Amplitude of matter perturbations $\sigma_8(z)$

The combination of $\kappa\times\kappa + \kappa\times\text{GC} + \text{GC}\times\text{GC}$ helps us fixing A_i for each redshift interval

M. Peronaci et al. (2026, in preparation)



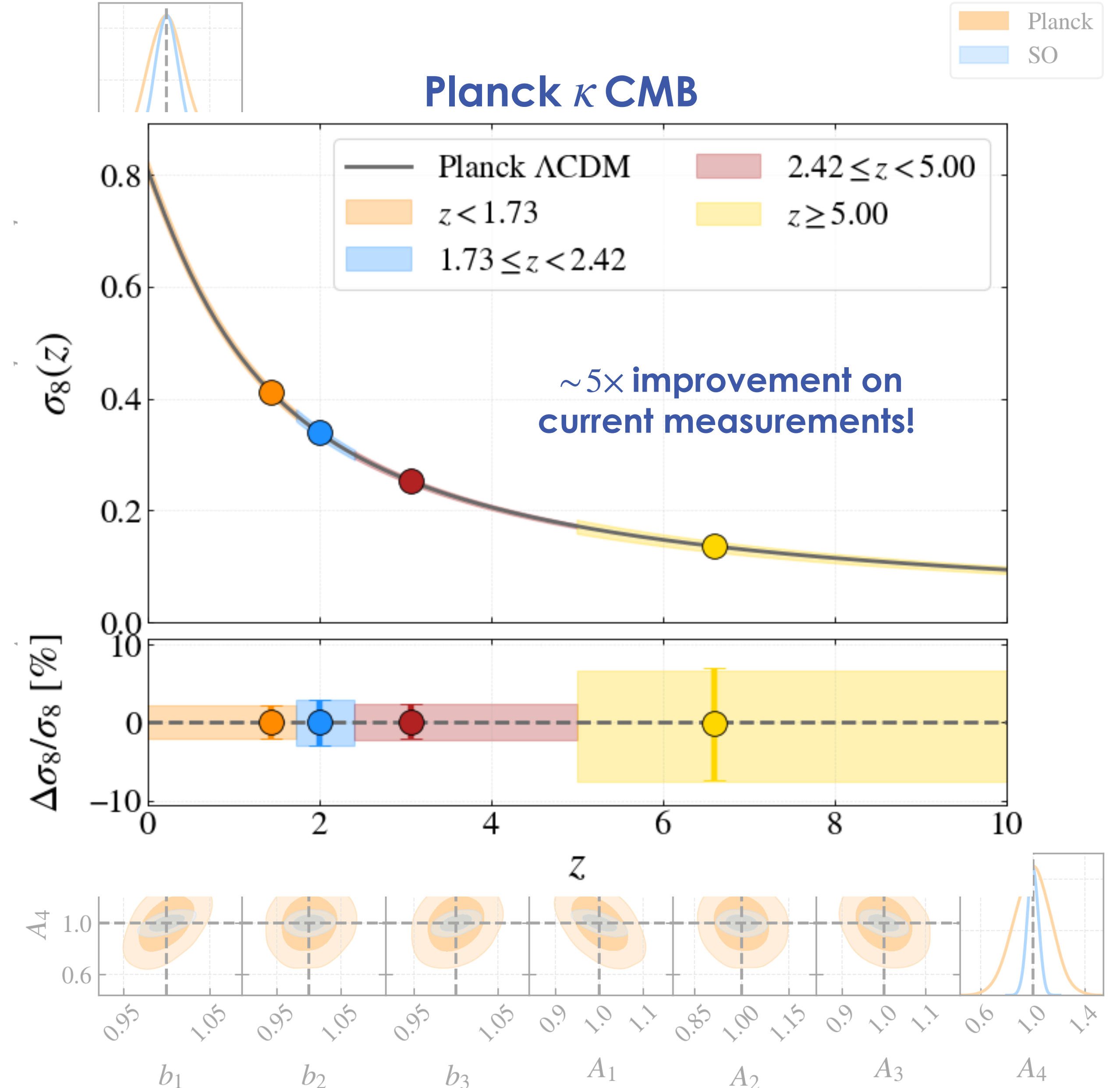
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Once we have A_i we obtain unique measurements of structure growth at high redshifts

$$\tilde{\sigma}_8(z_i) = \sigma_8(z_i) \sqrt{A_i}$$

M. Peronaci et al. (2026, in preparation)

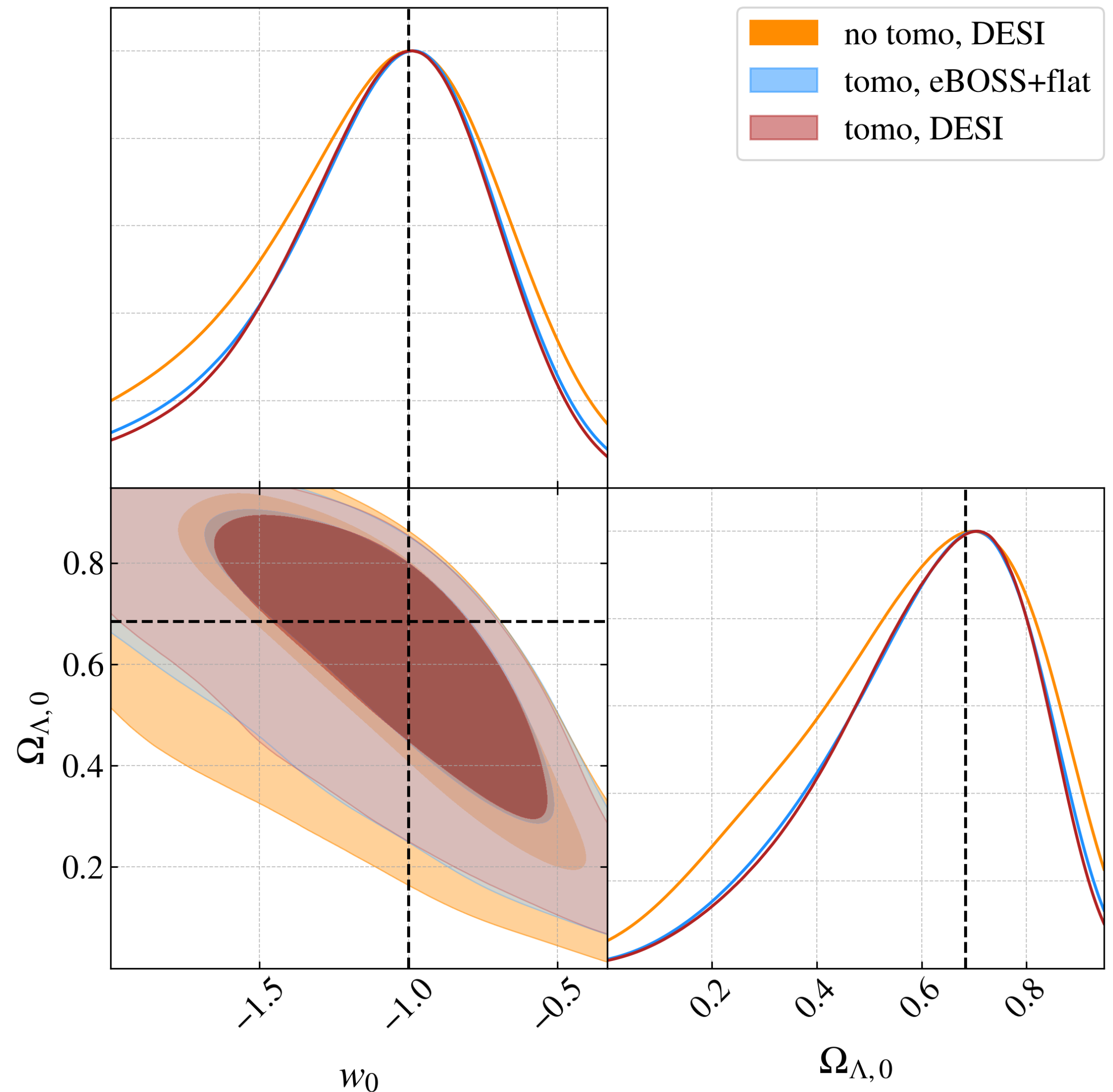


Results – Dark energy and density parameter w_0 , Ω_{Λ}^0

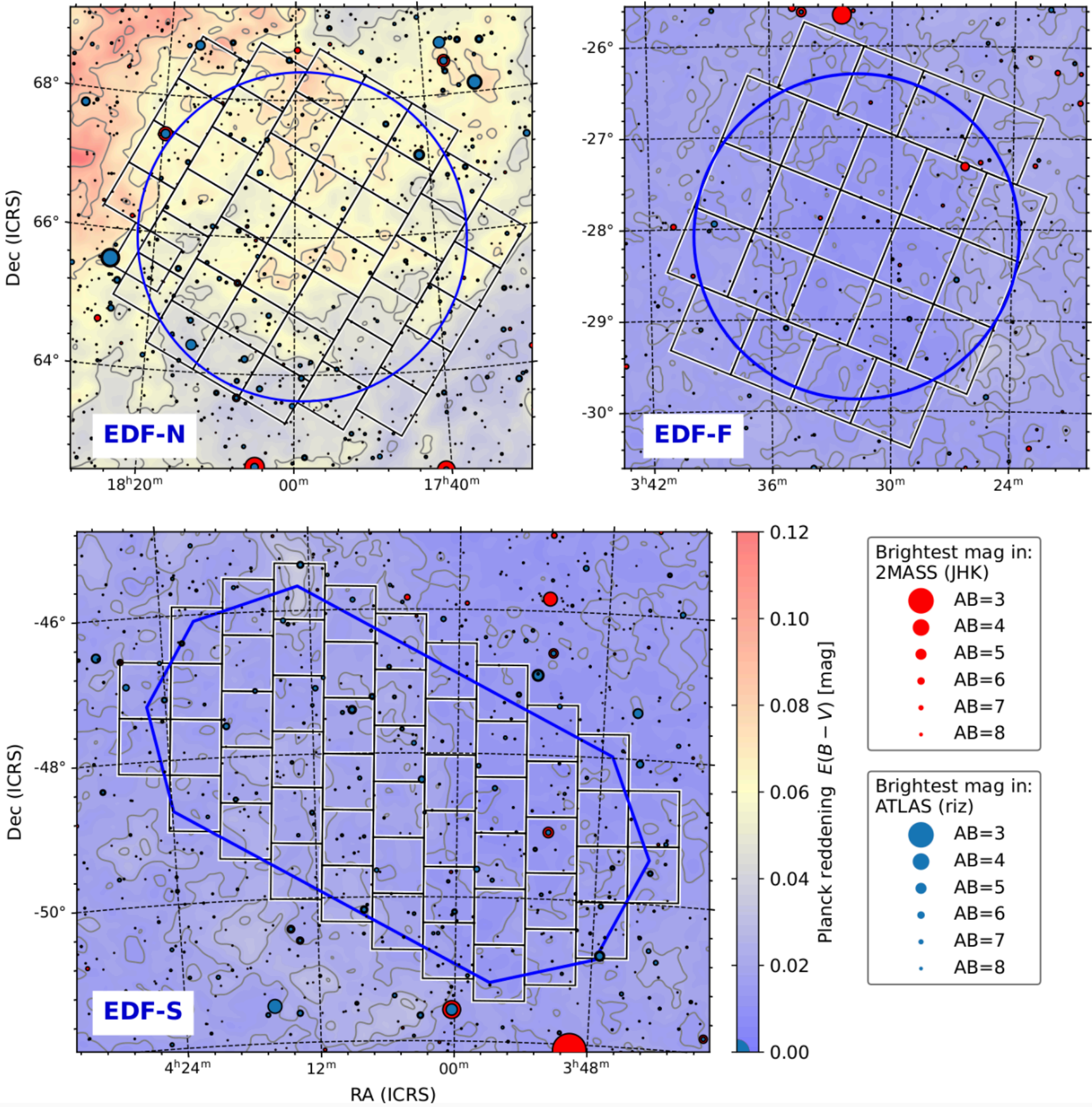
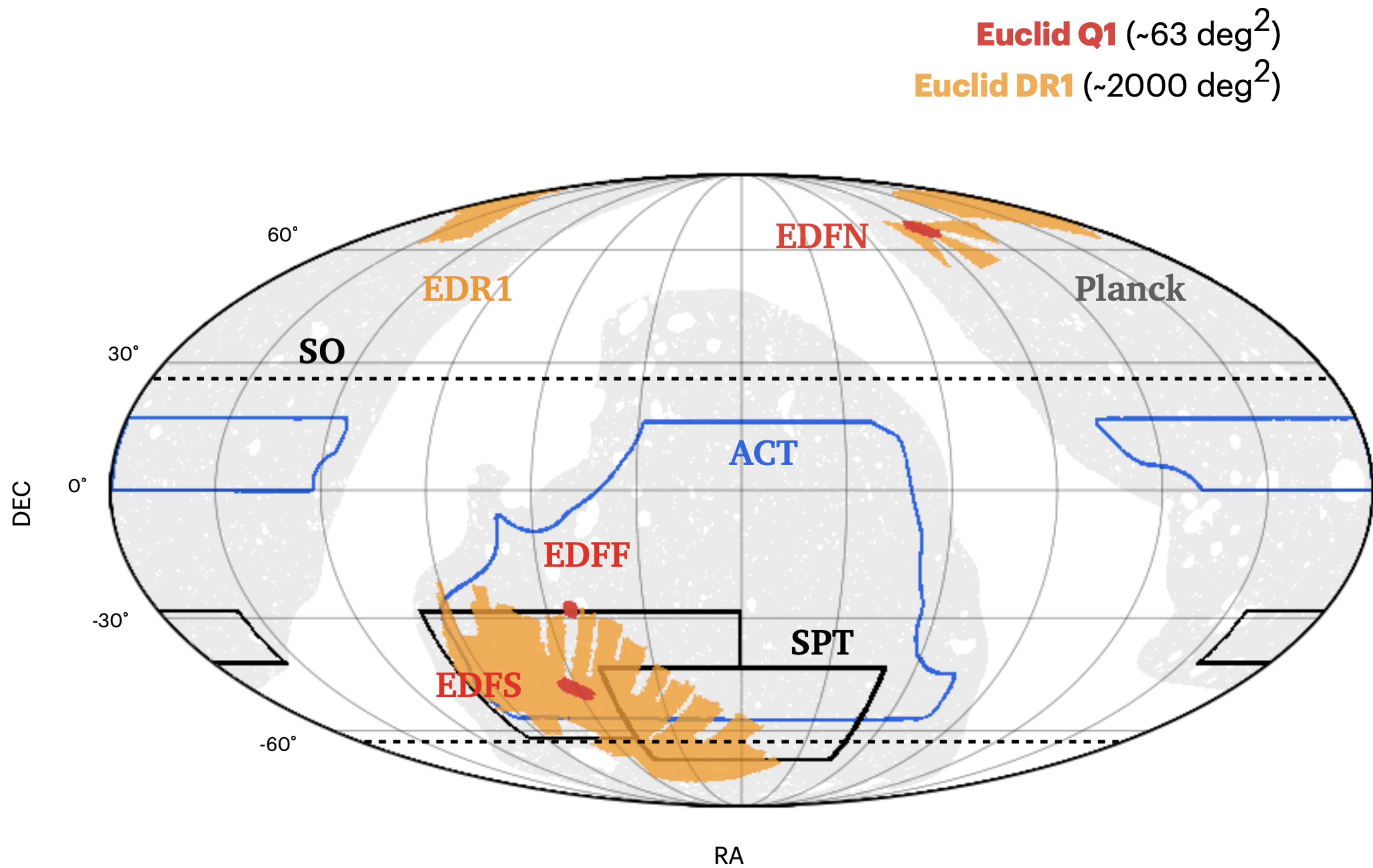
Assuming a Λ CDM model,
ISW with AGN is less constraining than with
galaxies because W^{ISW} better overlaps with
galaxy clustering...

...But it still works as a high redshift
complementary probe for ISW science!

M. Peronaci et al. (2026, in preparation)



From forecasts to Euclid data (Q1)



Data filtering and extraction of $N(z)$

Select required flags:

- ☒ good_flags
- ☐ medium_vis_mag_bin
- ☐ PRF_qso_candidate
- ☐ leH_gz_qso_candidate
- ☐ B24b_qso_candidate
- ☐ R90_agn_candidate
- ☐ bright_vis_mag_bin
- ☐ faint_vis_mag_bin
- ☒ JH_leY_qso_candidate
- ☐ B24a_qso_candidate
- ☐ C75_agn_candidate
- ☐ GDR3_qso_candidate

PDF Source:

- ☐ Most Probable (QSOV vs EXTNV)
- ☒ Use QSOV Only
- ☐ Use EXTNV Only
- ☐ Require source to have a Spec-z

z-assignment:

- ☐ Use spec-z when available
- ☒ Photo-z only

Thresholds:

- mumax (<):

-2.60
- prob_GAL (<=):

1.00
- prob_QSO (>=):

0.00
- z_min (>=):

0.30
- z_max (<=):

3.00

Photo- z estimation:
Euclid Collaboration: B. Laloux et al. [A&A. \(2026, accepted\)](#)

Multiwavelength data and AGN candidate color selection:
Euclid Collaboration: T. Matamoro-Zatarain et al. [A&A, 711, A1 \(2026\)](#)

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- ☐ R90_agn_candidate
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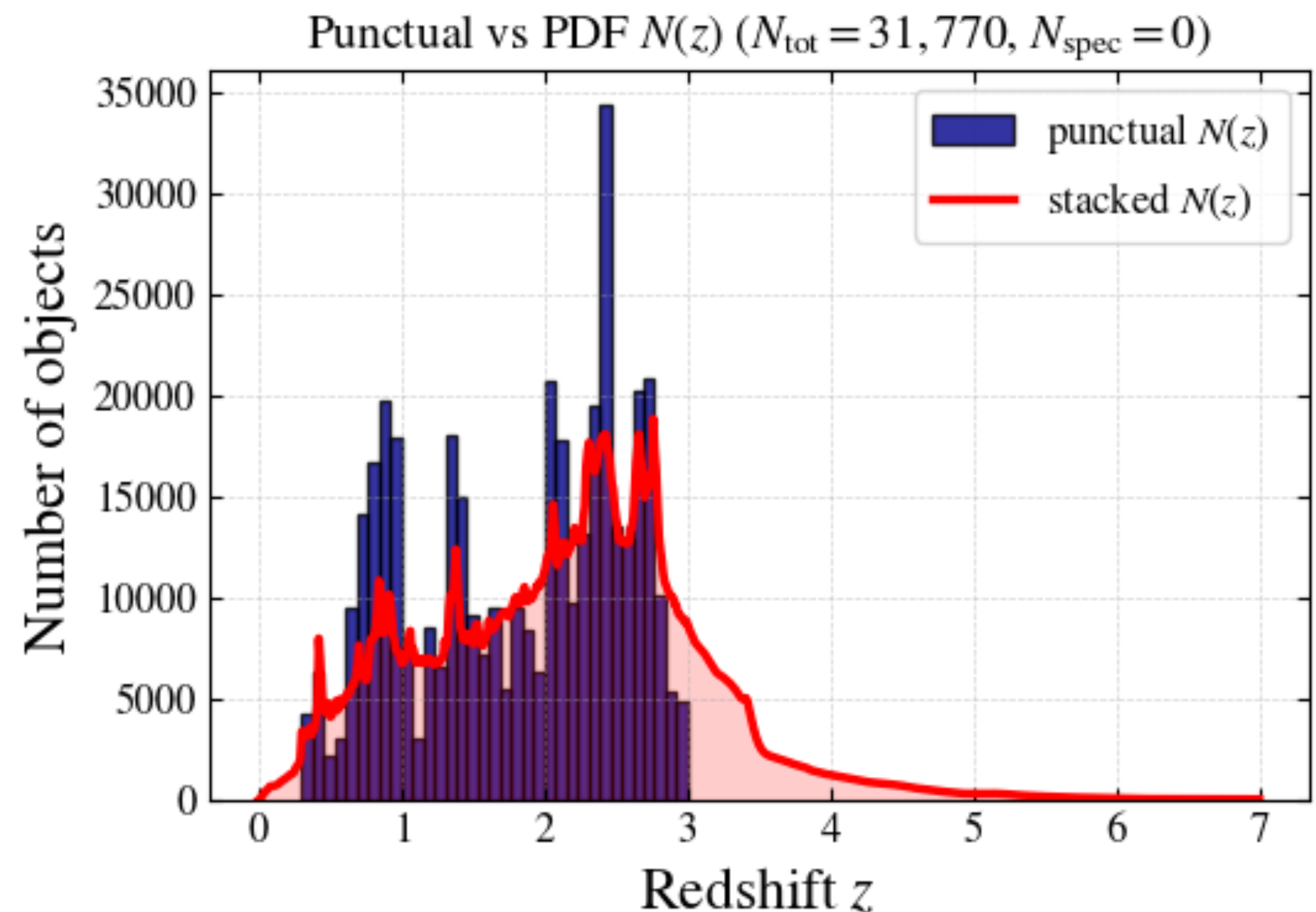
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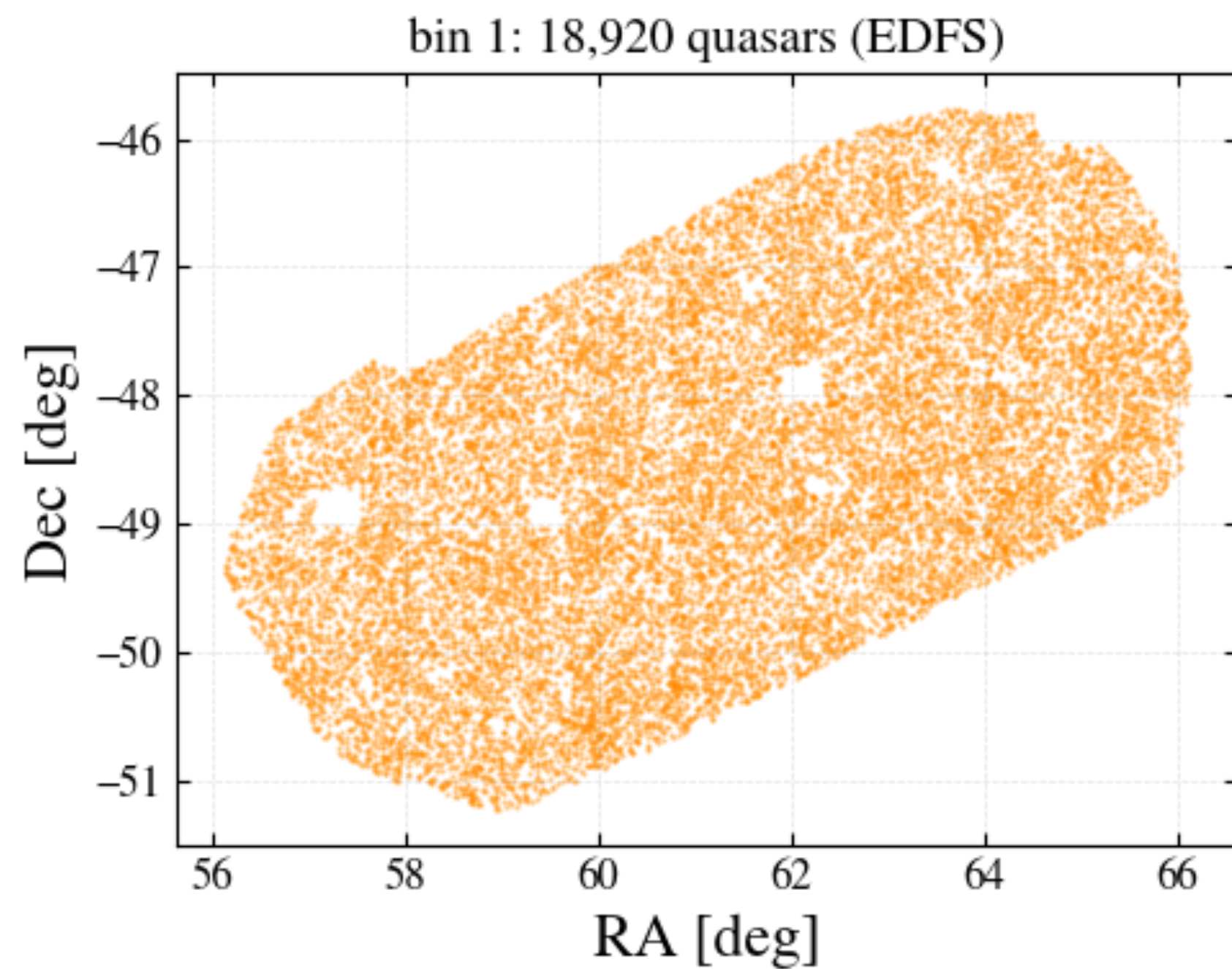
Multiwavelength data and AGN candidate color selection:
Euclid Collaboration: T. Matamoro-Zatarain et al. [A&A, 711, A1 \(2026\)](#)



Map making – AGNs

We use the filtered catalog to build an AGN overdensity map

Import extracted RA/Dec

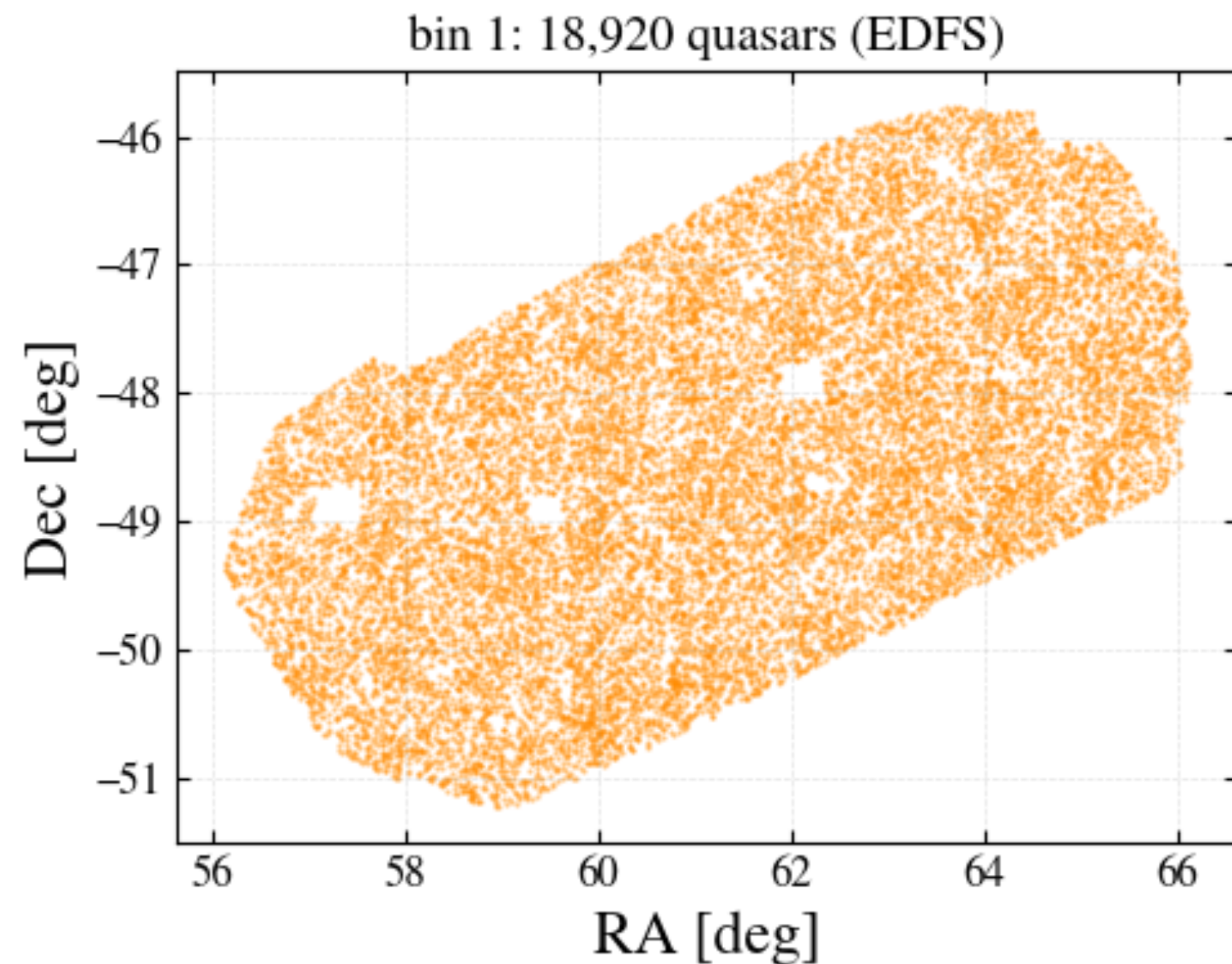


n_i : number of AGNs in pixel i

Map making – AGNs

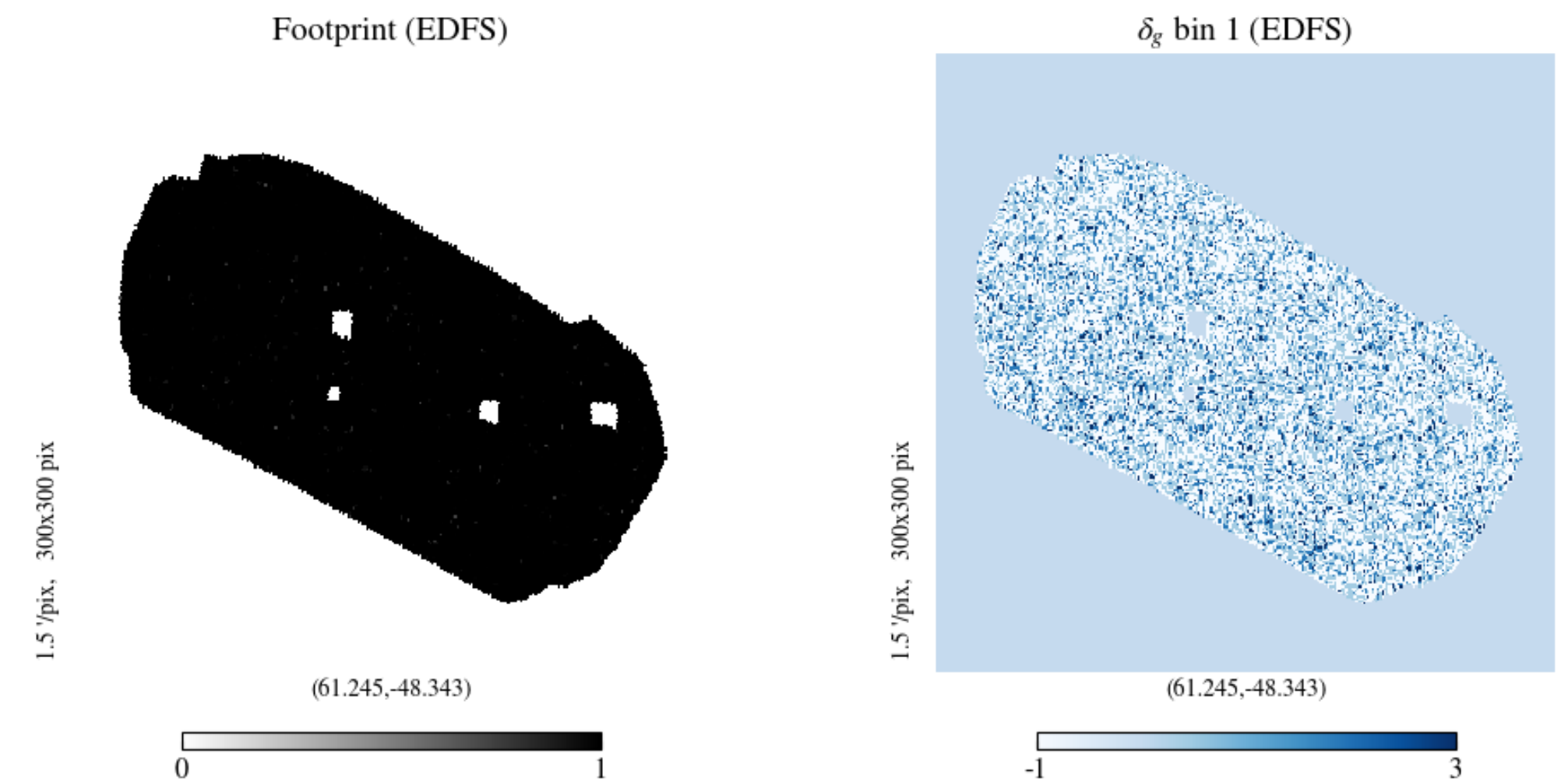
We use the filtered catalog to build an AGN overdensity map

Import extracted RA/Dec



n_i : number of AGNs in pixel i

Build the overdensity map δ_g

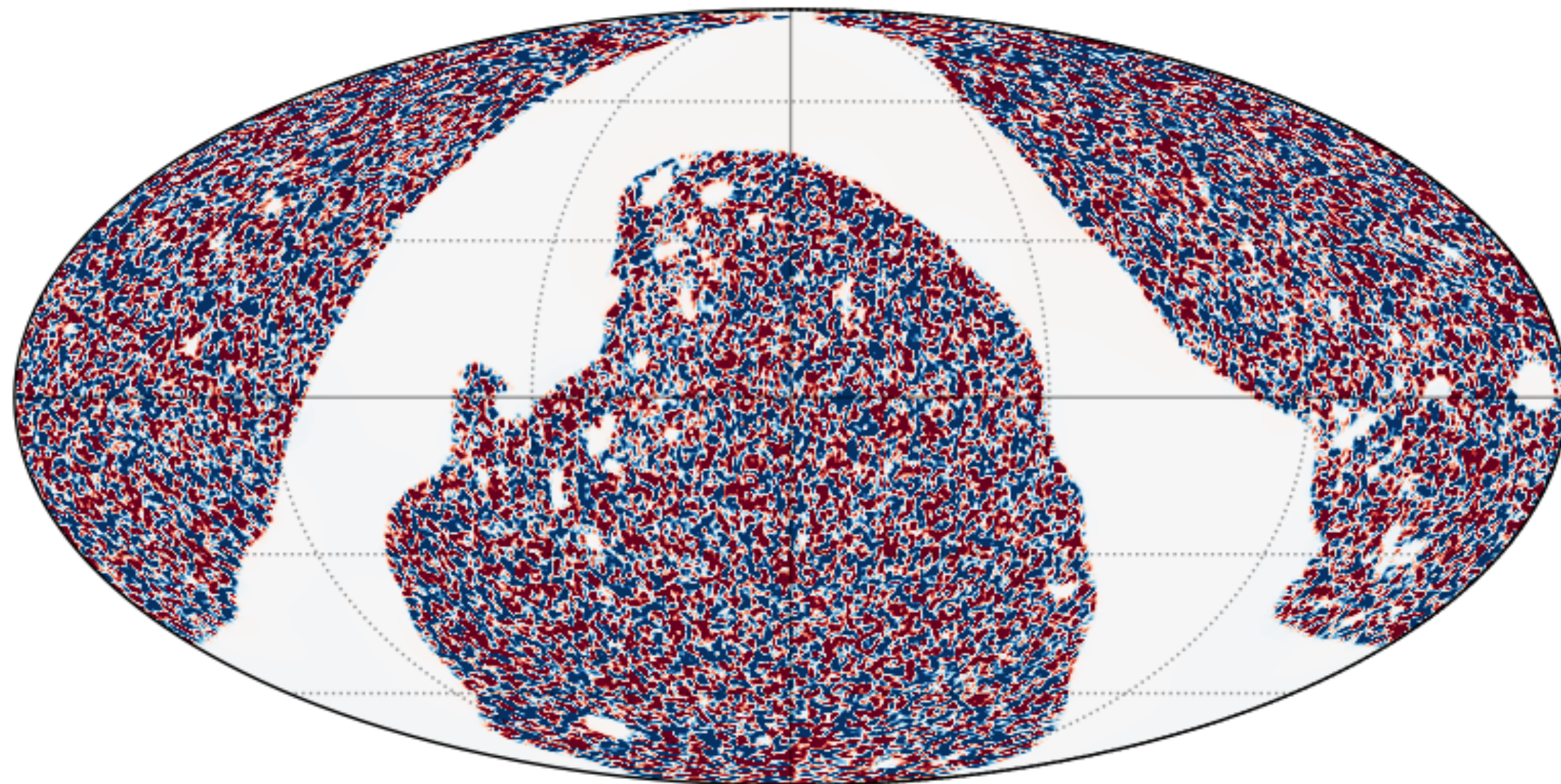


Map making – CMB lensing

We select the CMB lensing map based on the chosen field:
ACT for the South and Fornax fields, **Planck** for the North field

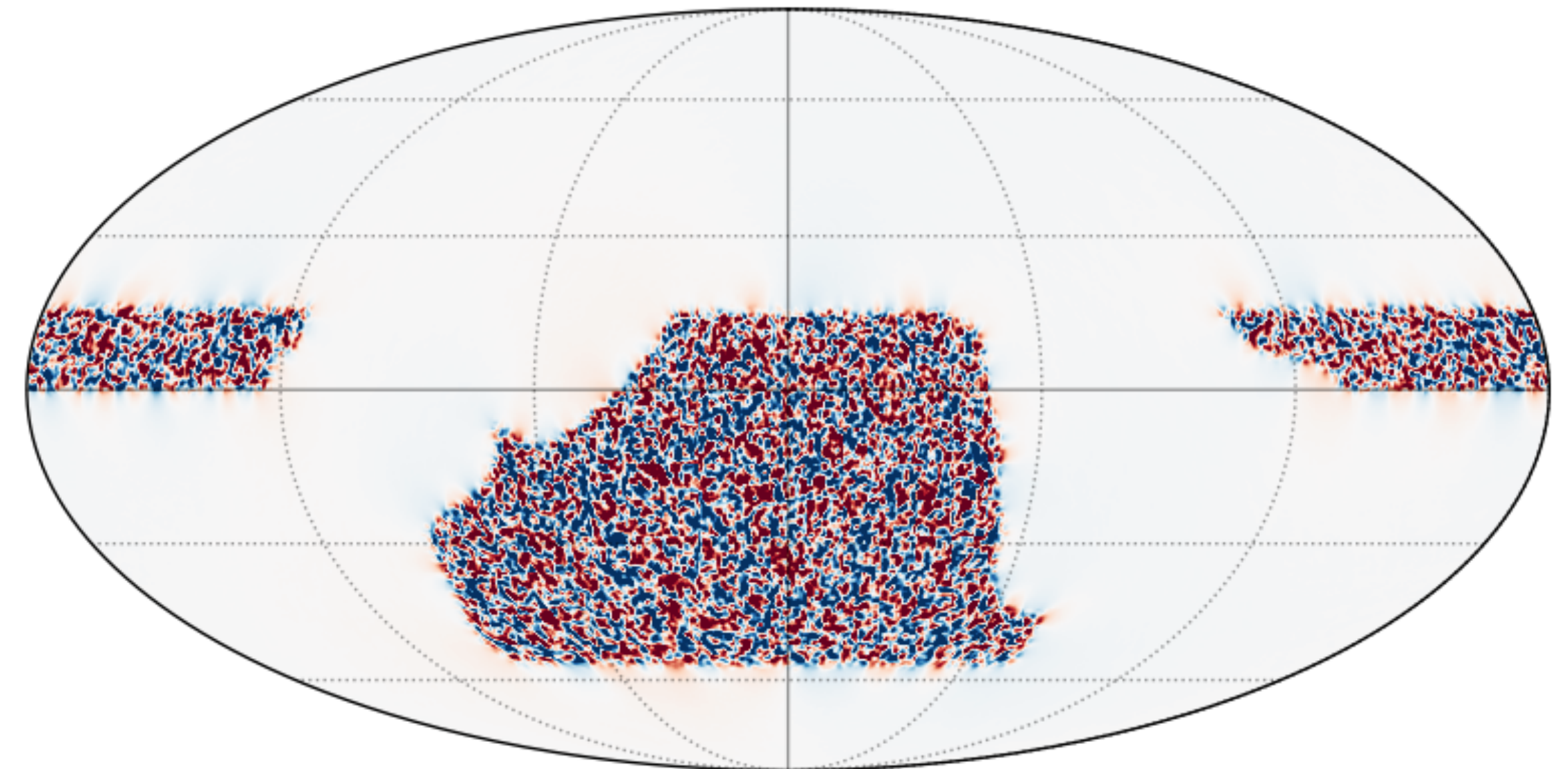
Planck

PLANCK κ map (smoothed 1°)



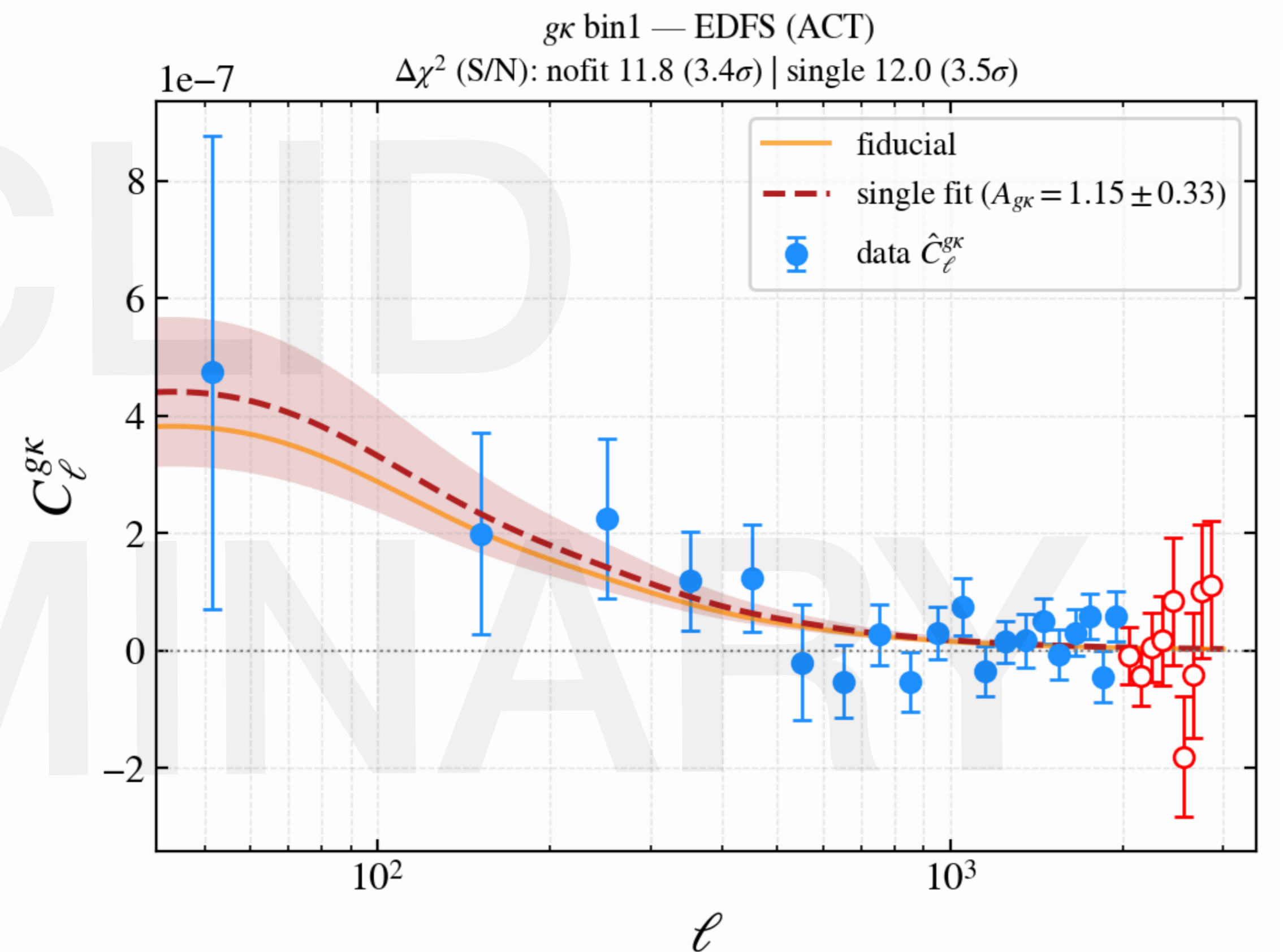
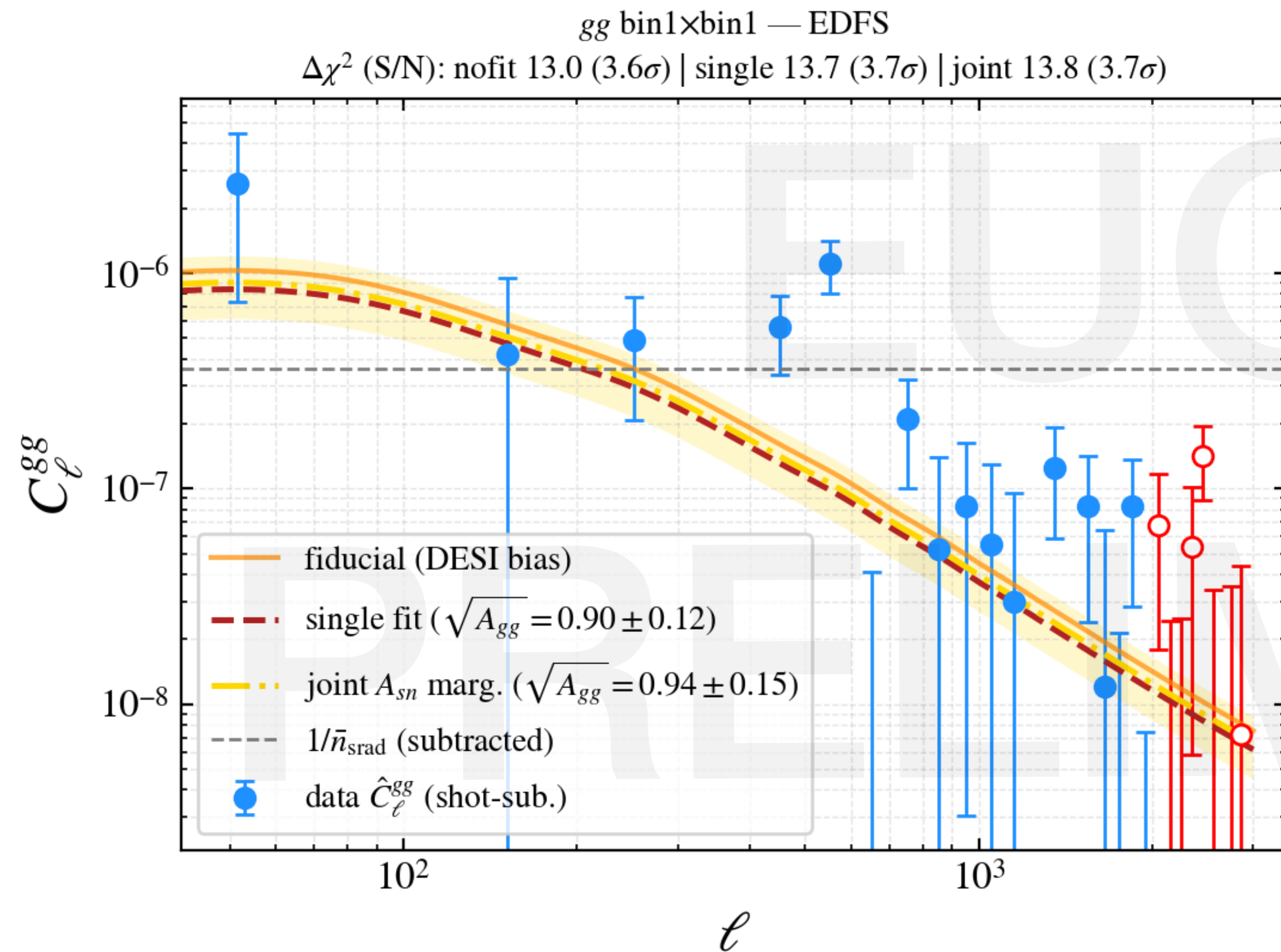
ACT

ACT κ map (smoothed 1°)



C_ℓ and Cov with NaMaster

We compute the bandpower-binned angular power spectra for $C_\ell^{\text{GC} \times \text{GC}}$ and $C_\ell^{k \times \text{GC}}$ with associated Gaussian covariance matrices for these fields



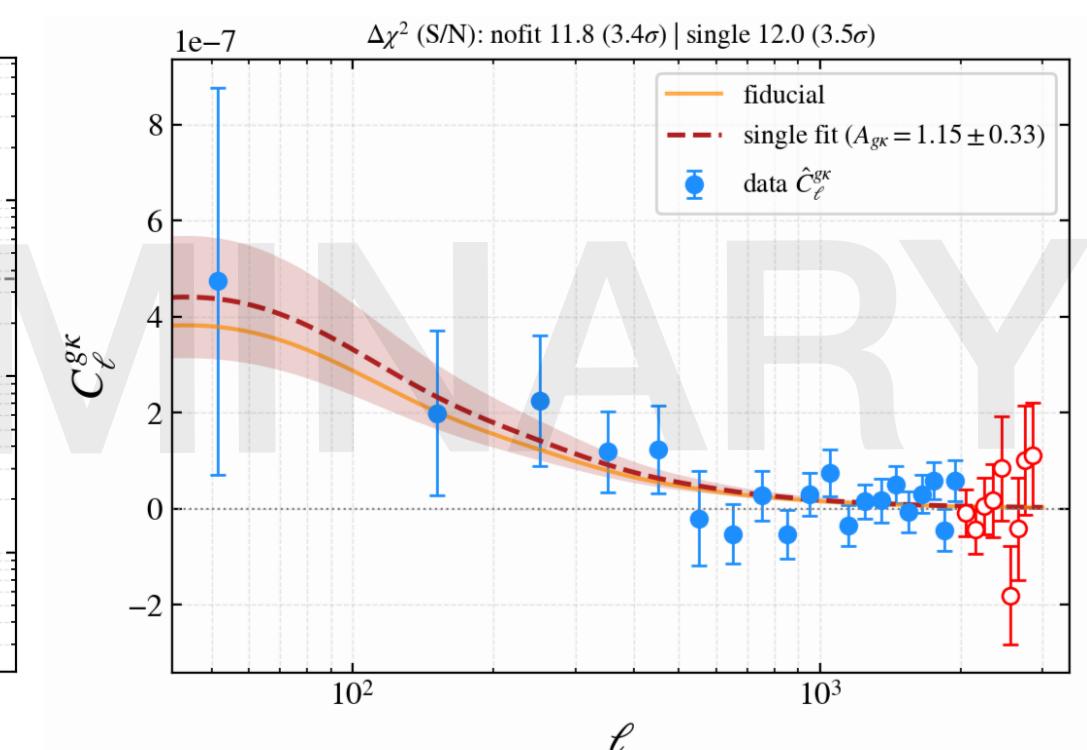
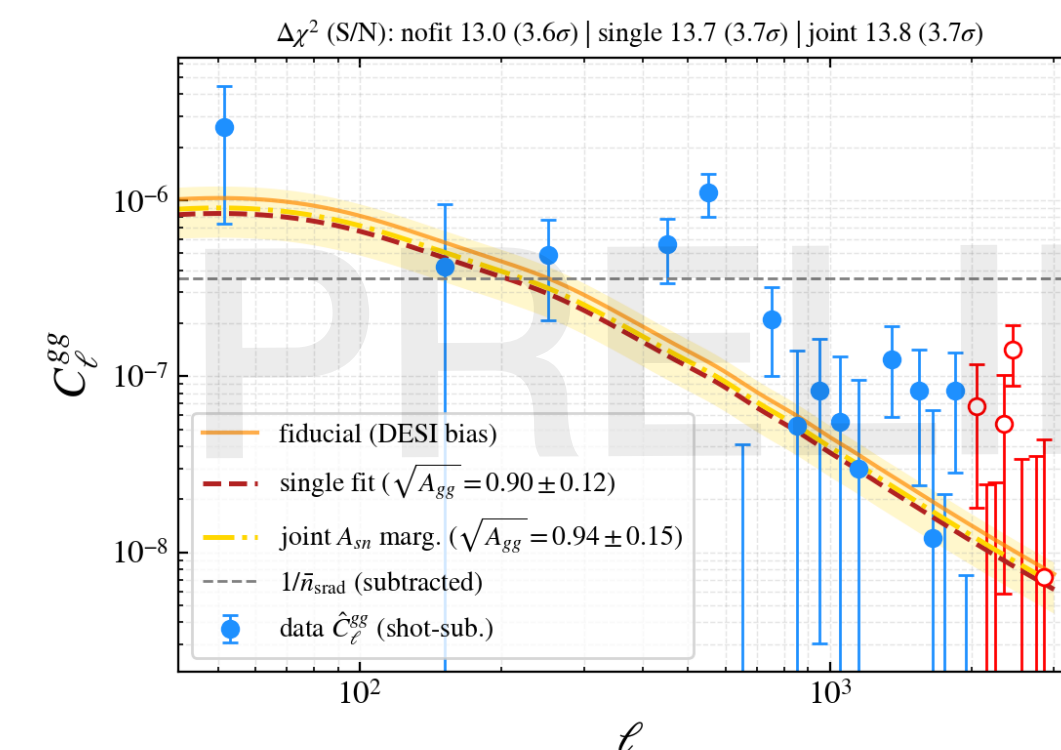
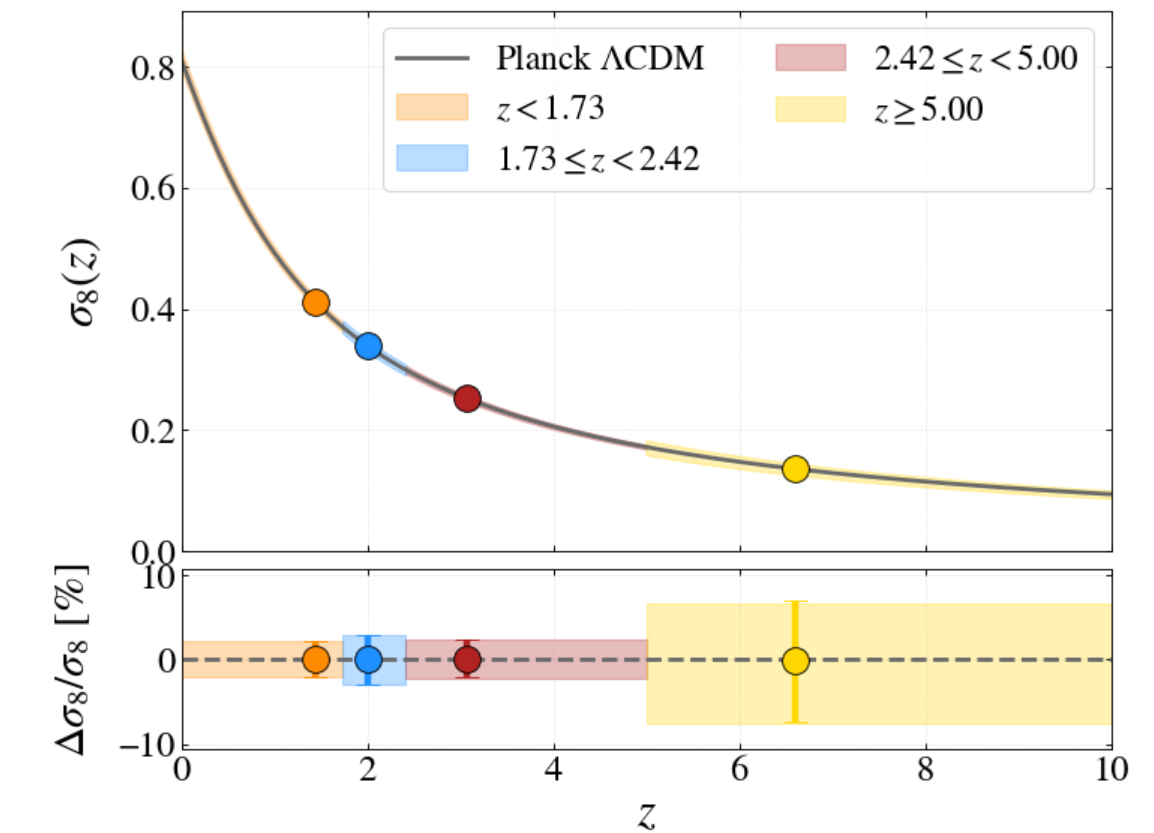
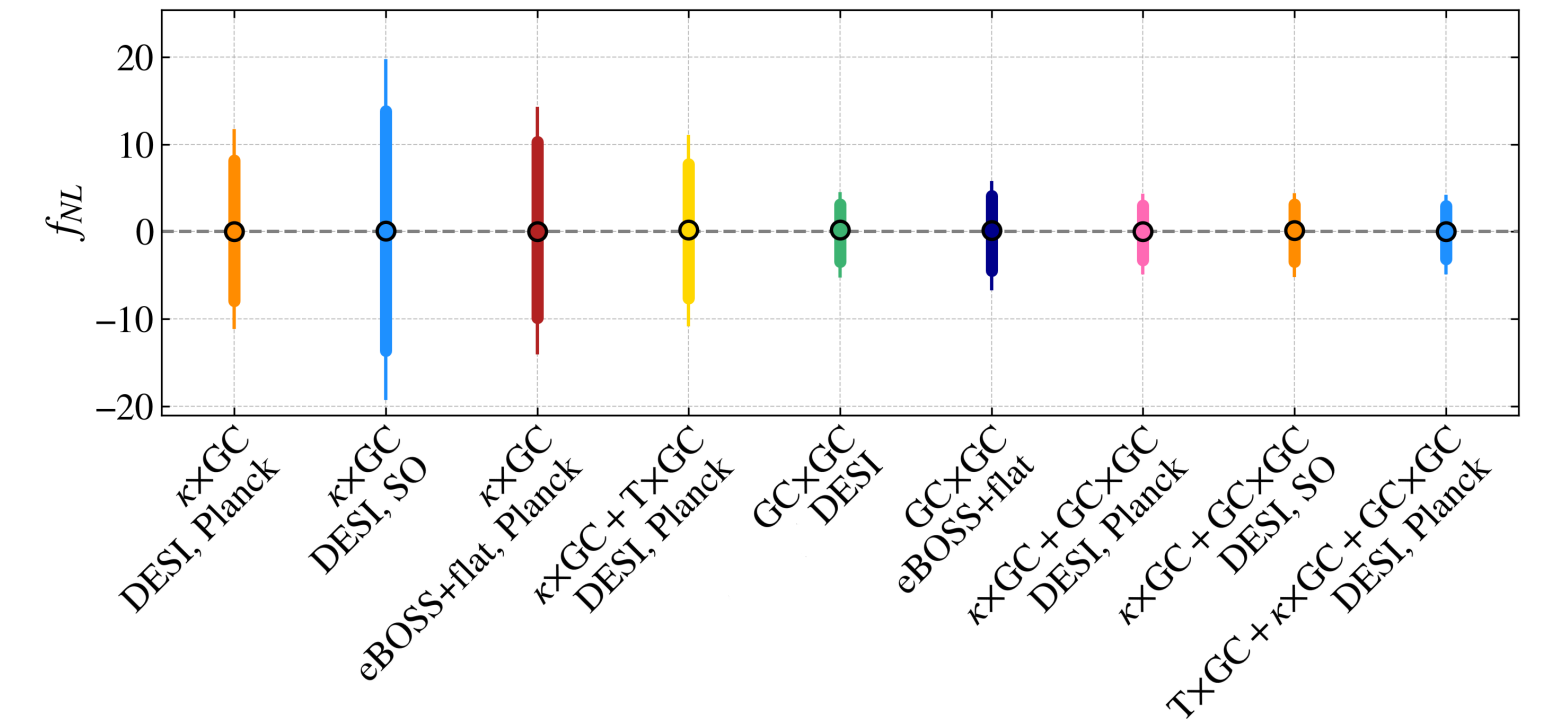
N.B. Red points are those excluded from the fit

Take-home messages and conclusions

- Euclid will observe millions of AGNs up to $z \sim 5$
- Combining AGN auto-correlation (GCxGC) and cross-correlation with CMB lensing ($\kappa \times \text{GC}$) we obtain tight measurements of PNG ($\sigma_{f_{\text{NL}}} \approx 2.5$)
- Extending the “2x2pt” to “3x2pt” with the CMB lensing auto-correlation ($\kappa \times \kappa$), we obtain tight measurements of the amplitude of matter perturbation $\sigma_8(z)$ up to $z \gtrsim 6$
- Cross-correlating AGNs with CMB temperature anisotropies (TxGC), we are not able to obtain tight measurements of ISW
- Developed a pipeline for Euclid Q1 AGNs and for soon-available Euclid DR1. First Q1 measurements look promising!

contact

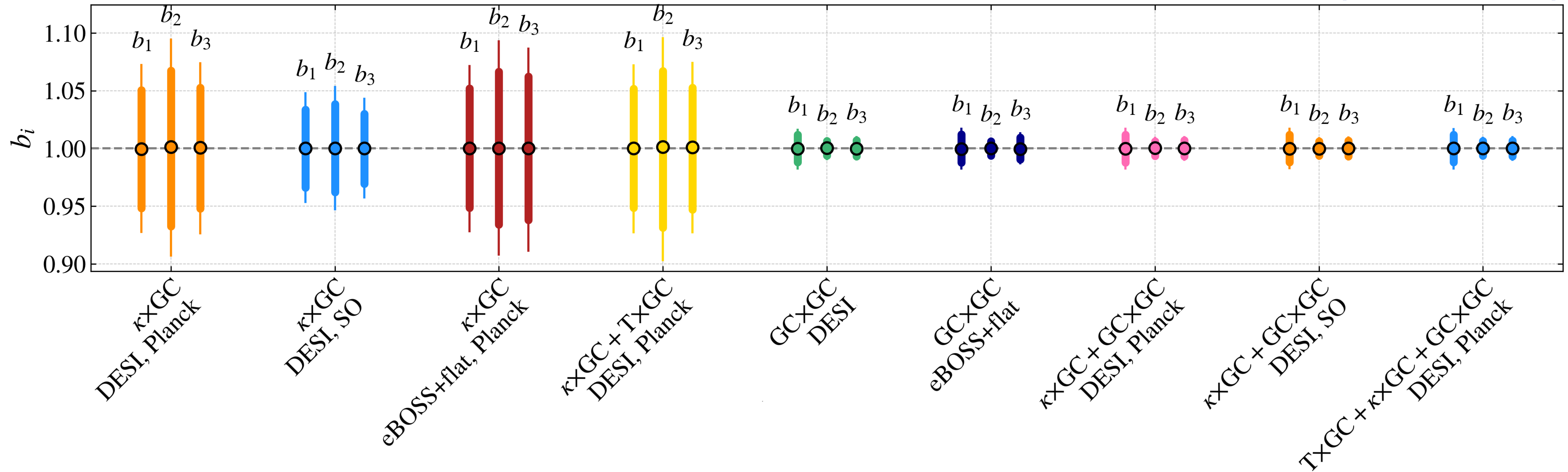
matteo.peronaci@uniroma1.it



Backup slides

Results – Primordial non-Gaussianity f_{NL}

M. Peronaci et al. (2026, in preparation)



We will be able to improve our knowledge on AGN bias and distinguish between different bias models

N.B. “DESI”, “eBOSS+flat” are the AGN bias models assumed
N.B. “Planck”, “SO” are the lensing noise curves

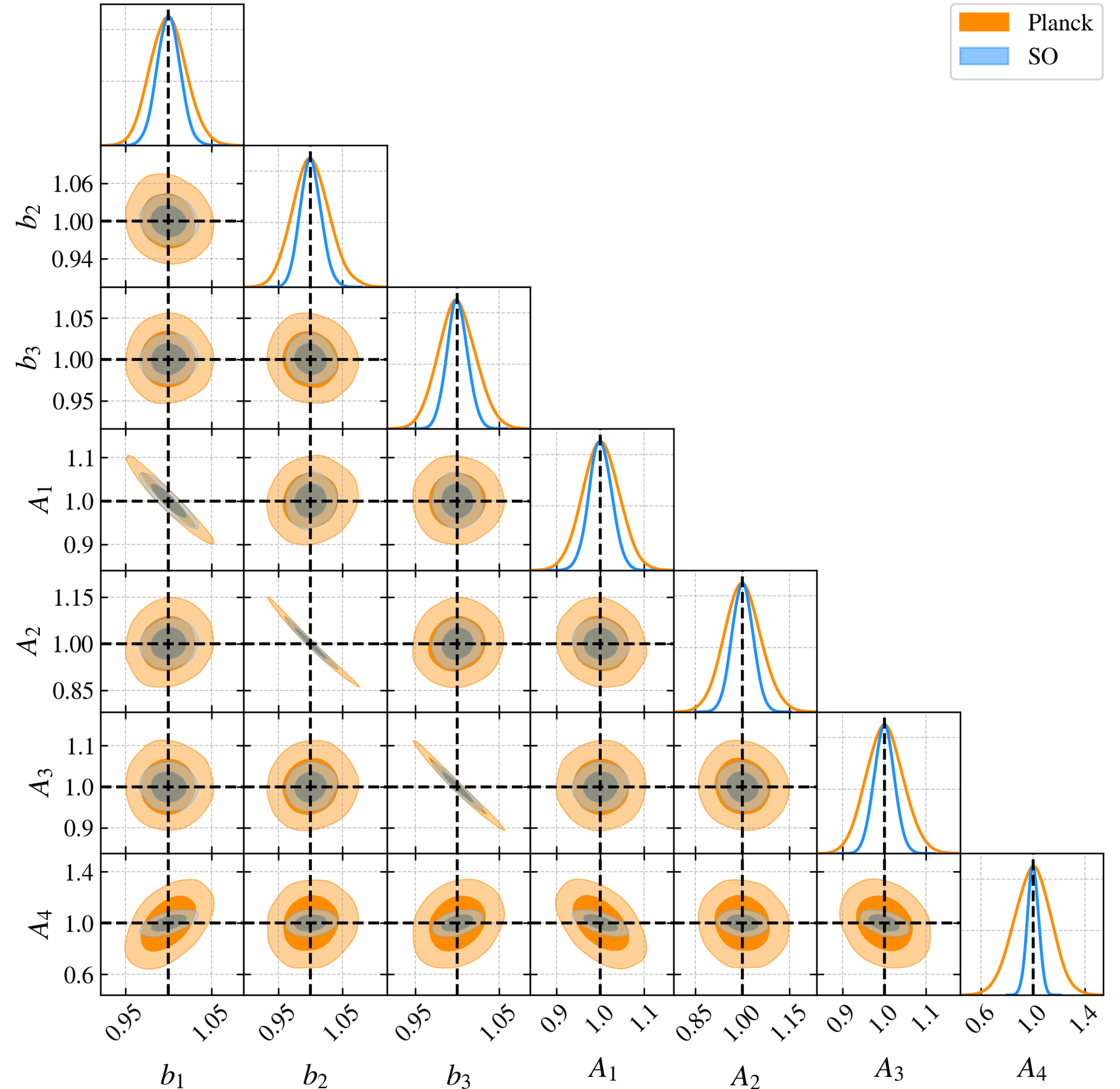
Results – Amplitude of matter perturbations $\sigma_8(z)$

The combination of $\kappa \times \kappa + \kappa \times \text{GC} + \text{GC} \times \text{GC}$ helps us fixing A_i for each redshift interval

Once we have A_i we obtain unique measurements of structure growth at high redshifts

$$\tilde{\sigma}_8(z_i) = \sigma_8(z_i) \sqrt{A_i}$$

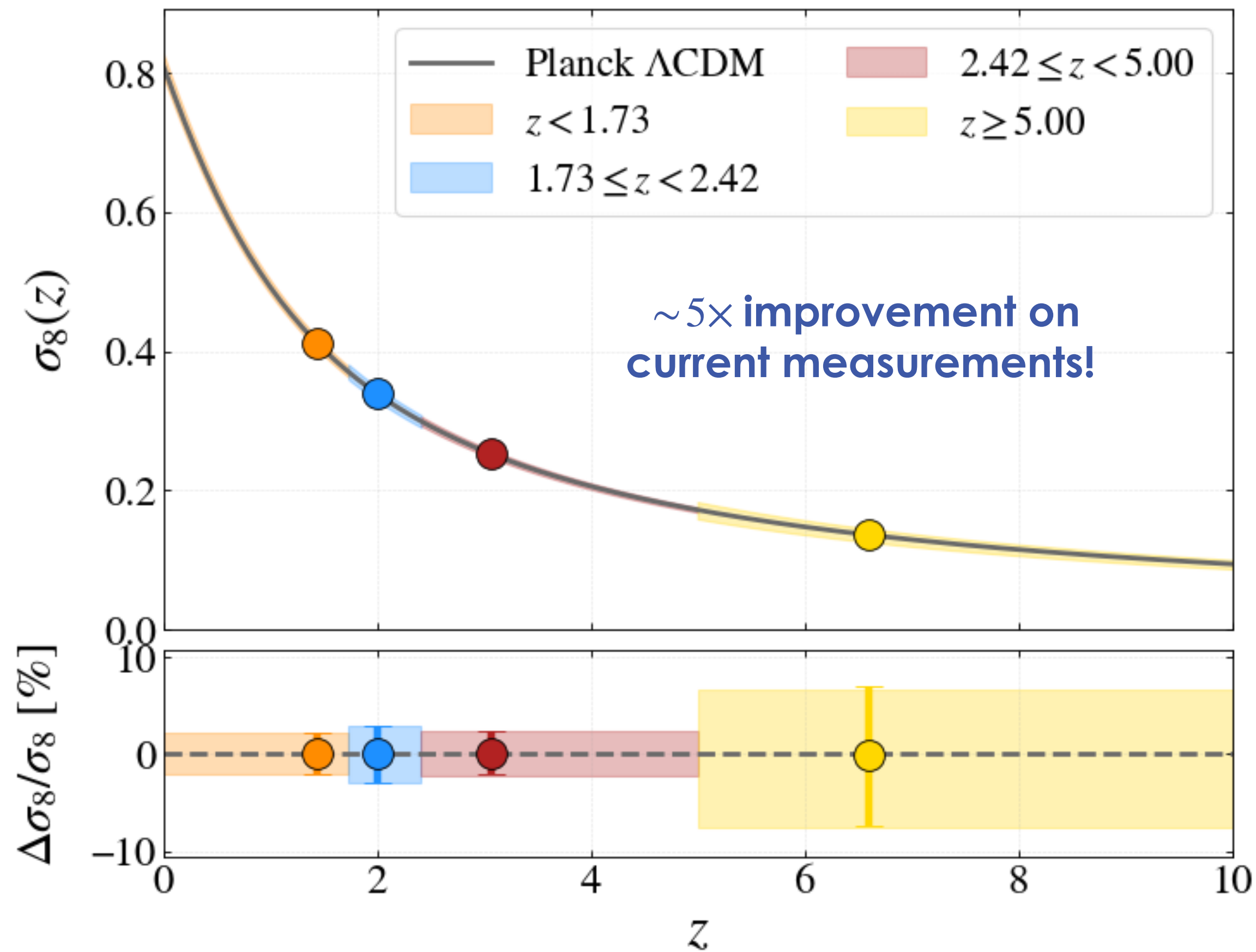
M. Peronaci et al. (2026, in preparation)



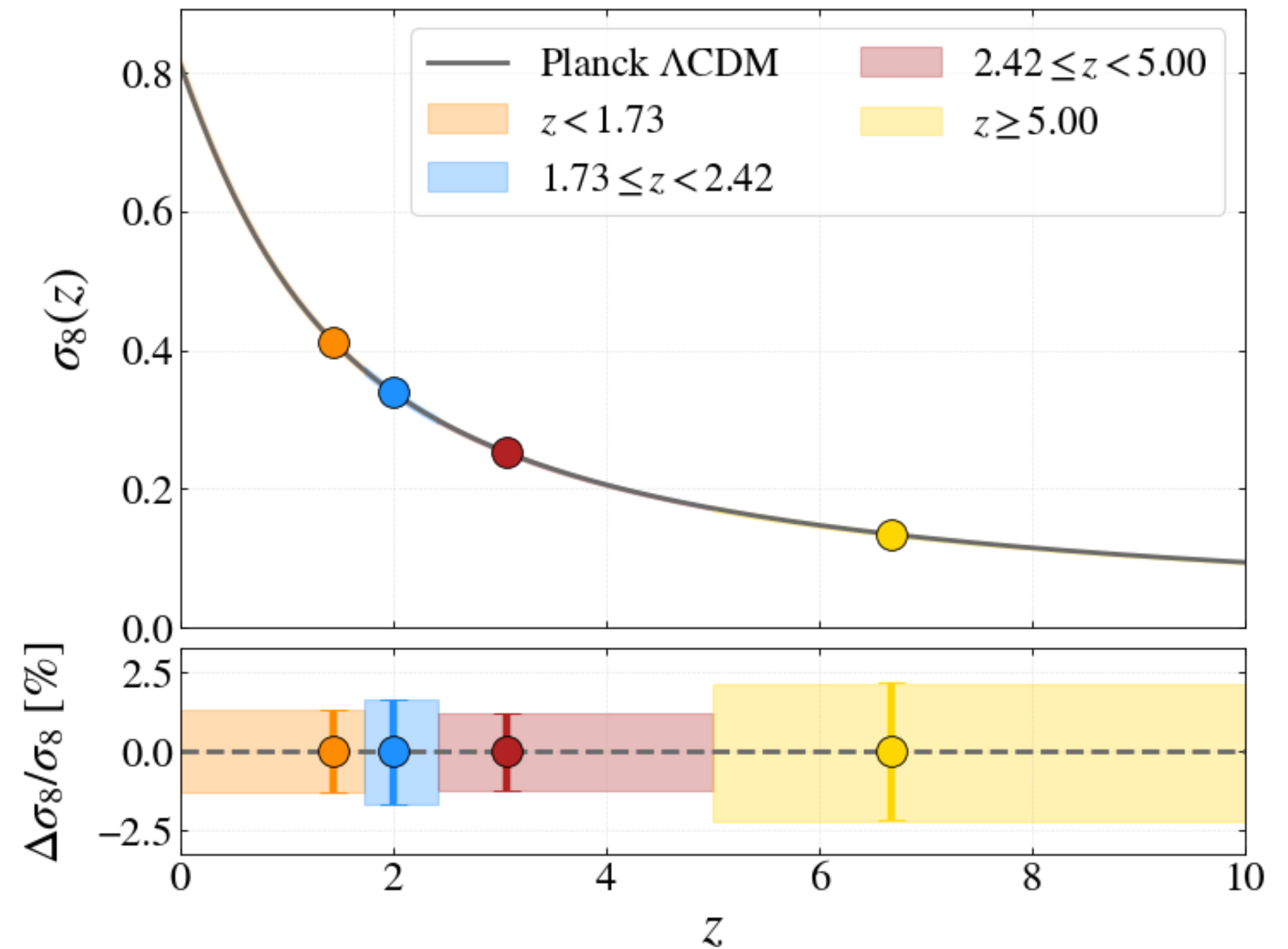
Results – Amplitude of matter perturbations $\sigma_8(z)$

The “3x2pt” combination reconstructs structure growth $\sigma_8(z)$ in four redshift intervals up to high z

Planck κ CMB



SO κ CMB



C_ℓ and Cov with NaMaster

From the AGN and CMB maps, it is possible to use Namaster to compute the pseudo- C_ℓ :

$$\tilde{C}_\ell(a_v, b_w) = \frac{1}{2\ell + 1} \sum_{m=-\ell}^{\ell} a_{v,\ell m} b_{w,\ell m}^\dagger$$

Where a_v, b_w are the masked AGN and CMB lensing fields.

Because of the mask, the pseudo- C_ℓ is biased. Its ensemble average is a linear combination of the true, underlying power spectra $C_{\ell'}$:

$$\langle \tilde{C}_\ell \rangle = \sum_{\ell'} M_{\ell\ell'} C_{\ell'}$$

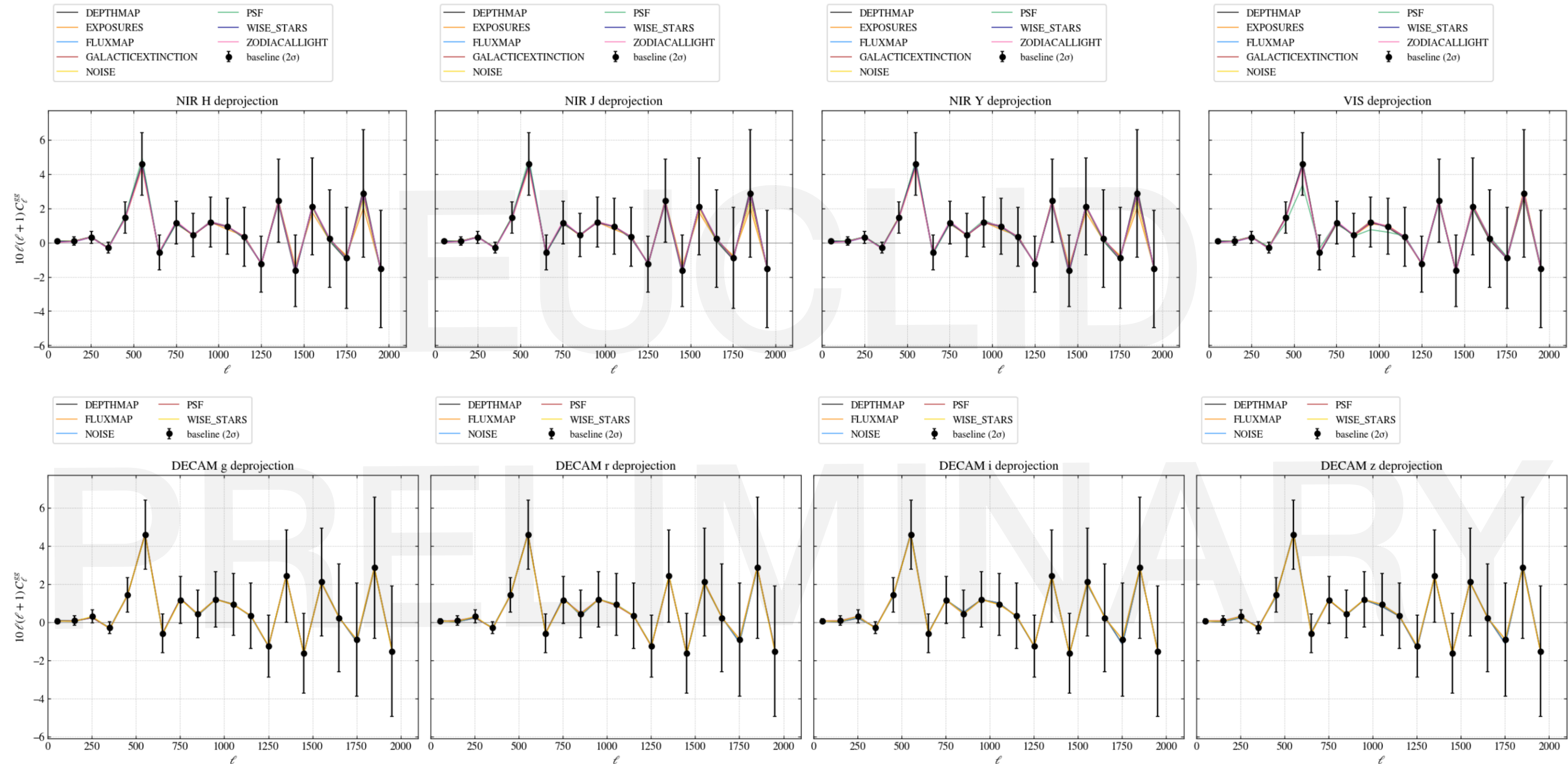
Where $M_{\ell\ell'}$ is the mode-coupling matrix. Namaster calculates it analytically based entirely on the geometry and power spectrum of the input masks.

Also, because the mask removes information, the full matrix cannot be inverted. To solve this, NaMaster groups the multiples into band powers with specific weights w_ℓ^q :

$$\tilde{B}_q = \sum_{\ell \in q} w_\ell^q \tilde{C}_\ell \implies B_q = \sum_{q'} \left(M_{qq'} \right)^{-1} \tilde{B}_{q'}$$

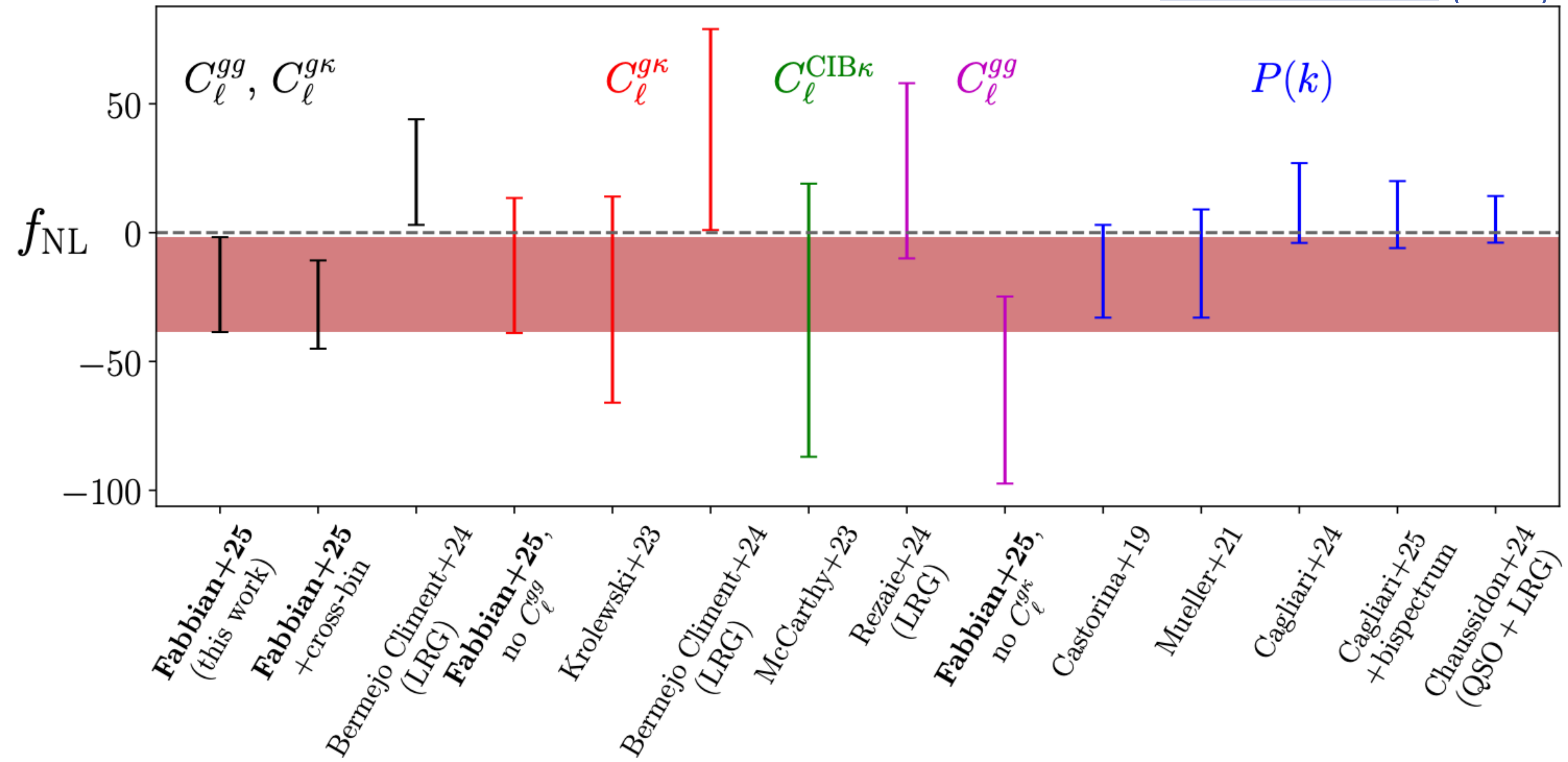
Systematics deprojection

We analyse many observation templates and deprojects them to test if the measured signals are driven by observational systematics like stellar crowding or dust



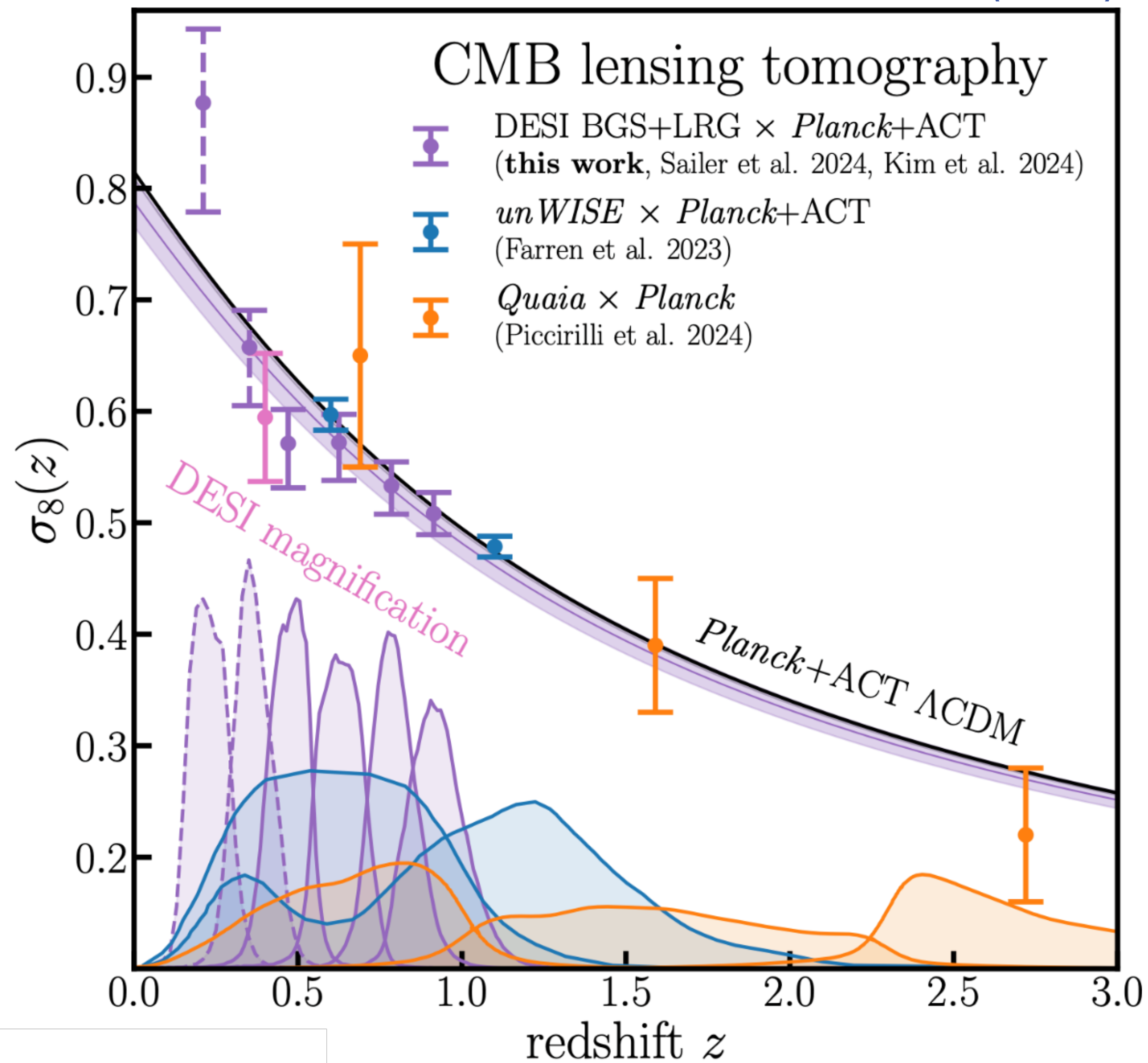
Current constraints on f_{NL} w/LSS

G. Fabbian et al. [arXiv:2504.20992](#) (2025)



Current constraints on $\sigma_8(z)$ w/CC

N. Sailer et al. [arXiv:2503.24385](https://arxiv.org/abs/2503.24385) (2025)



C. Villagra et al. [arXiv:2507.08798](https://arxiv.org/abs/2507.08798) (2025)

