Non-Gaussianity in CMB lensing

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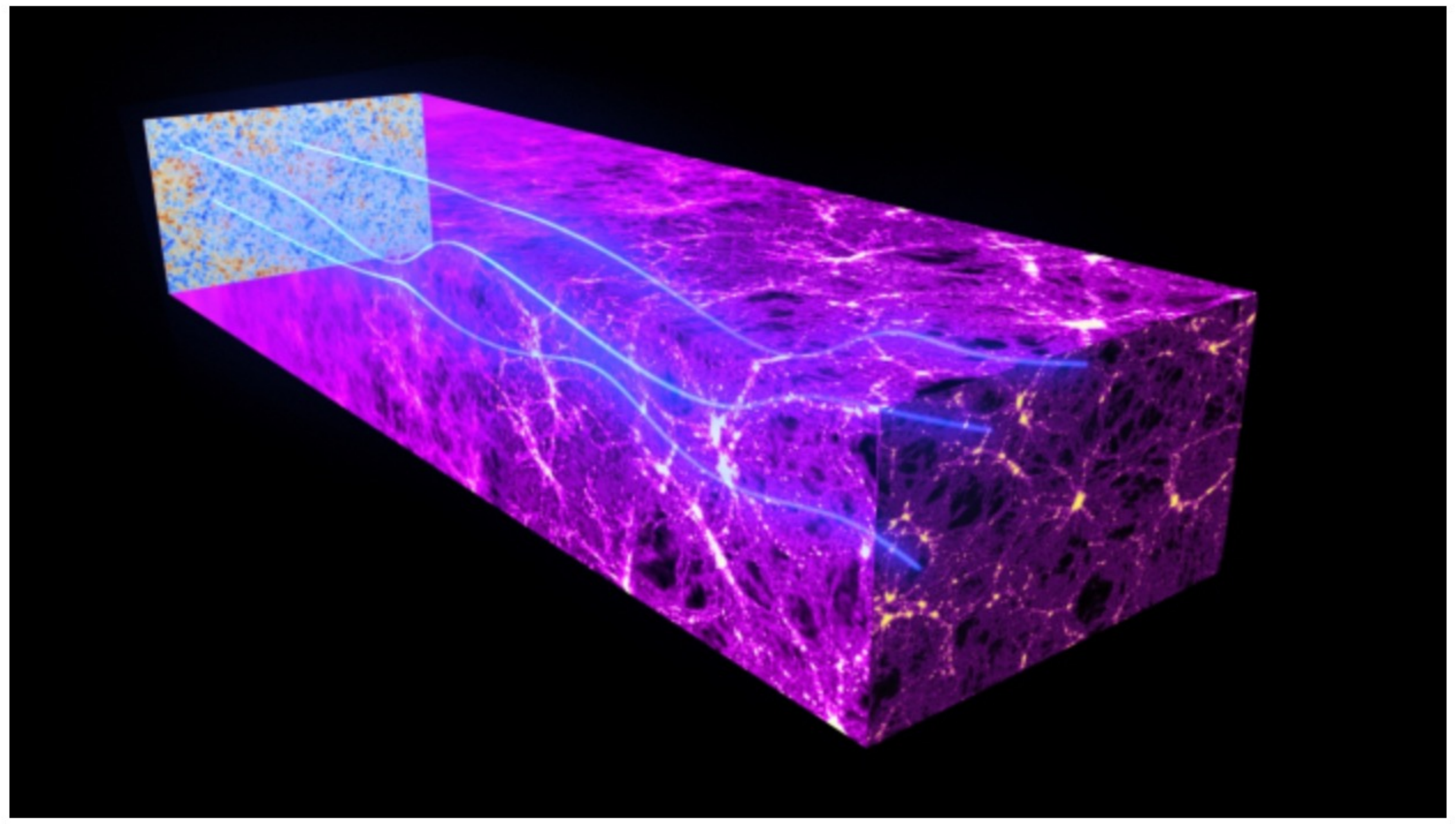
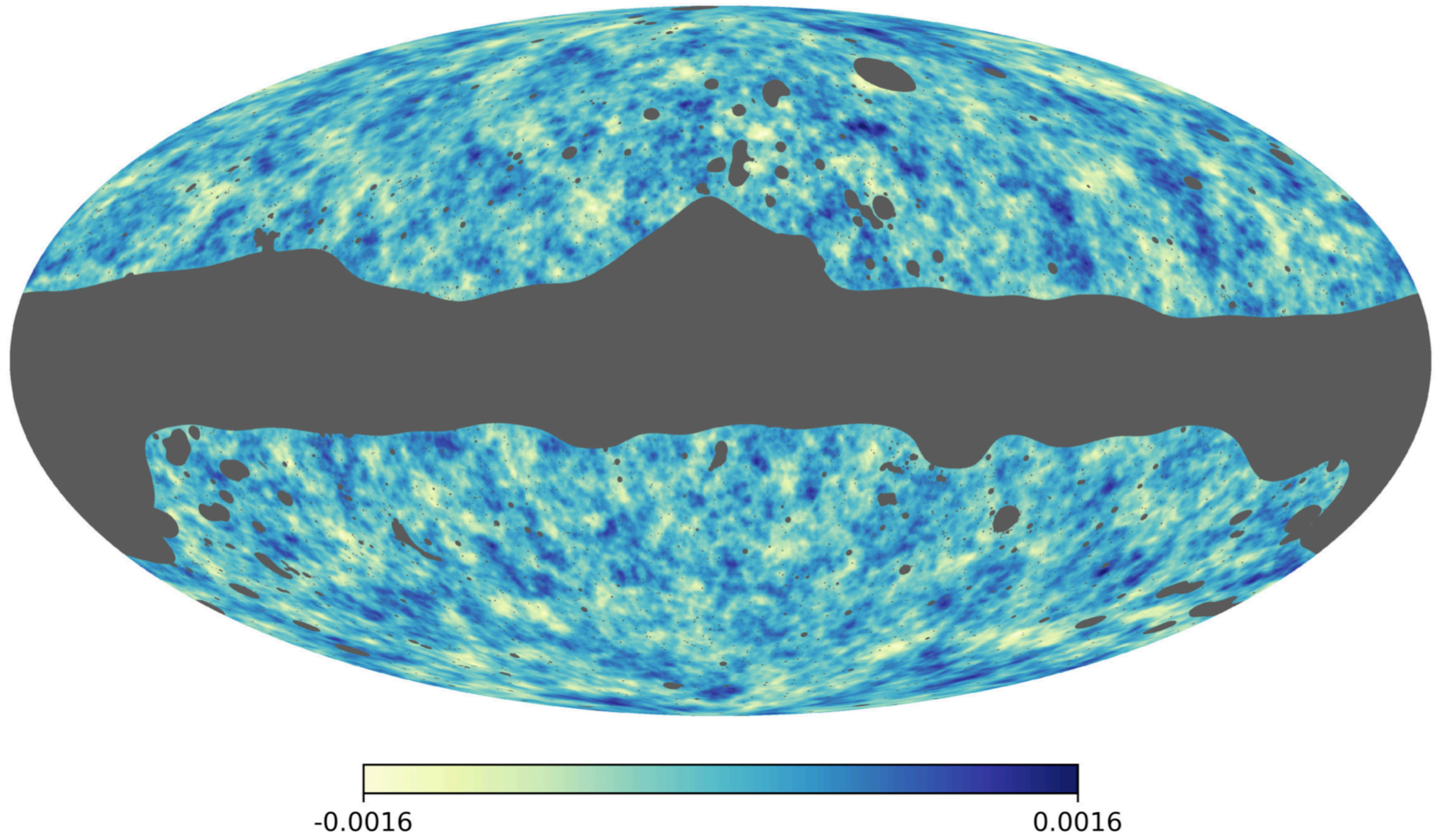
University of the New South Wales

In collaboration with **Jan Hamann**

CMB lensing



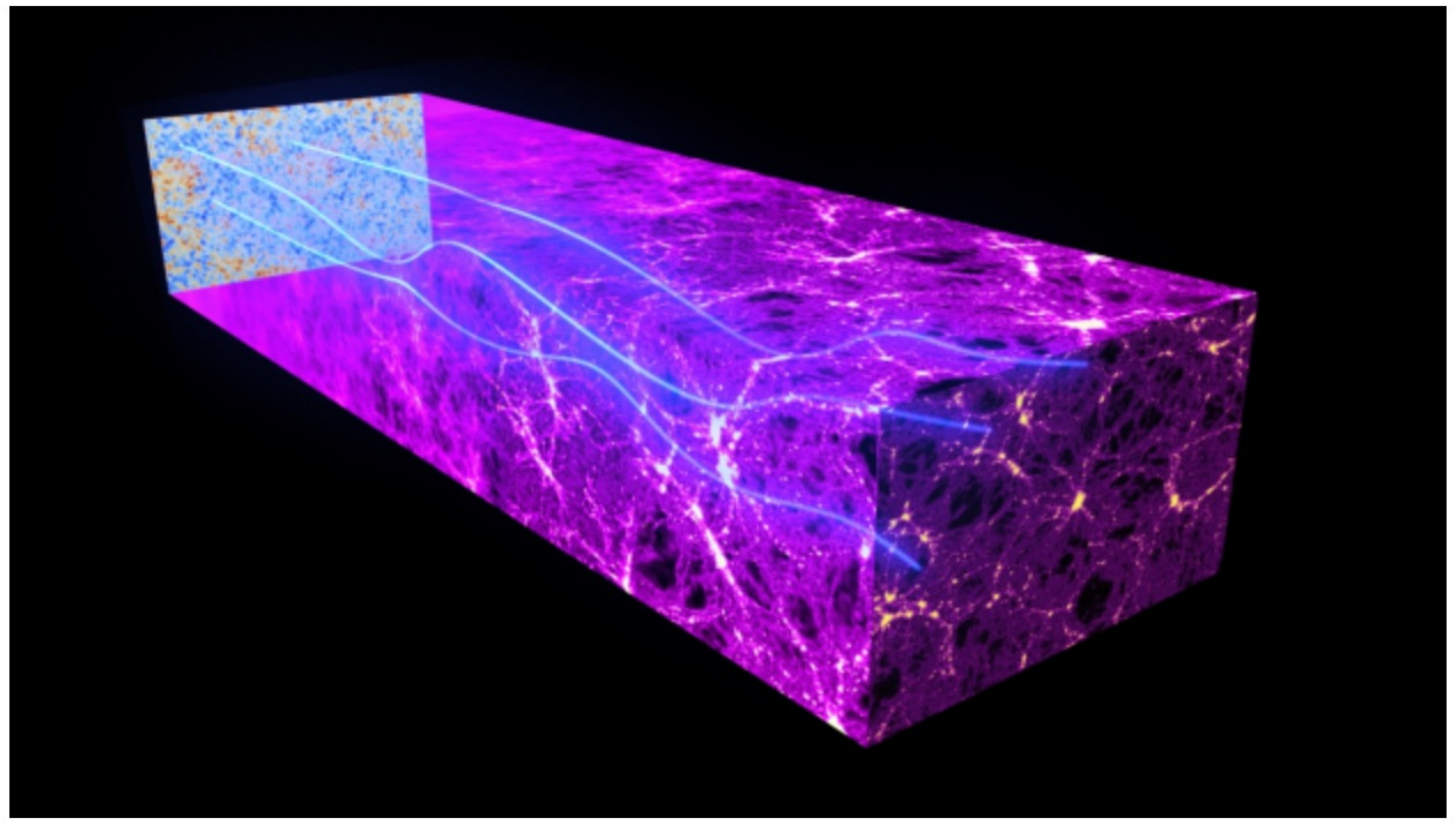
ESA and the Planck Collaboration



Planck Collaboration: *Planck* 2018 lensing

CMB lensing

CMB lensing is weakly non-Gaussian



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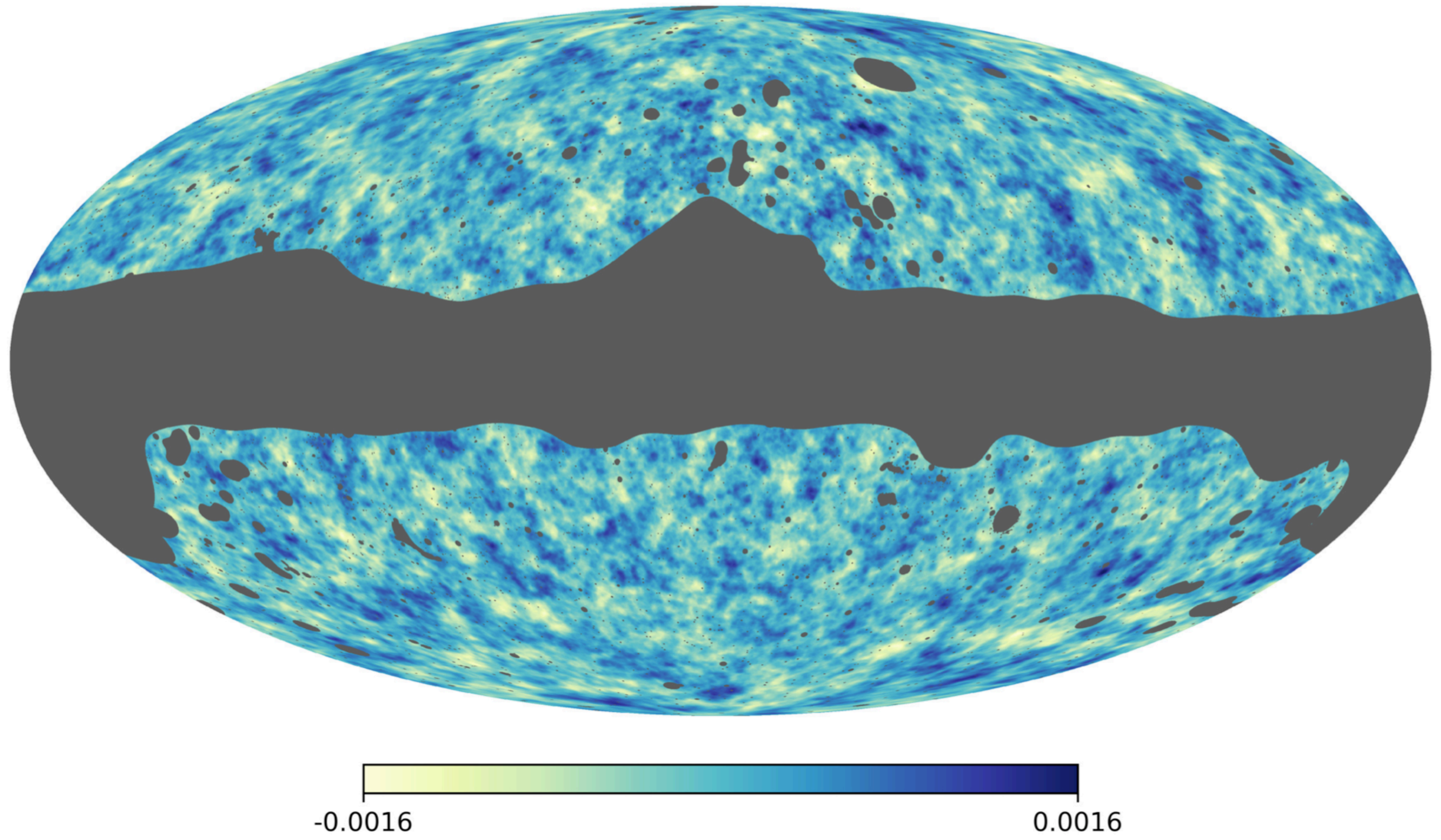

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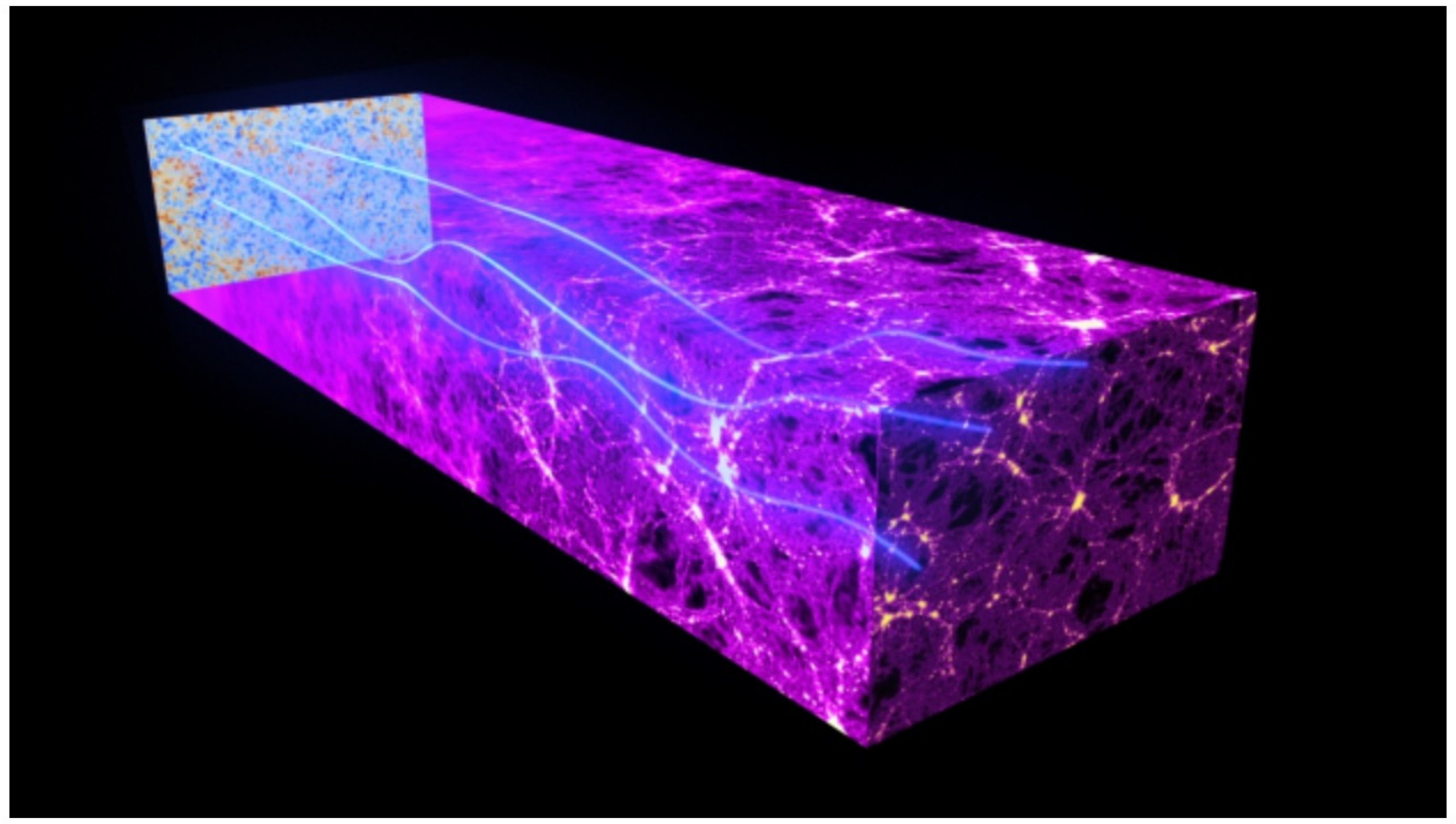

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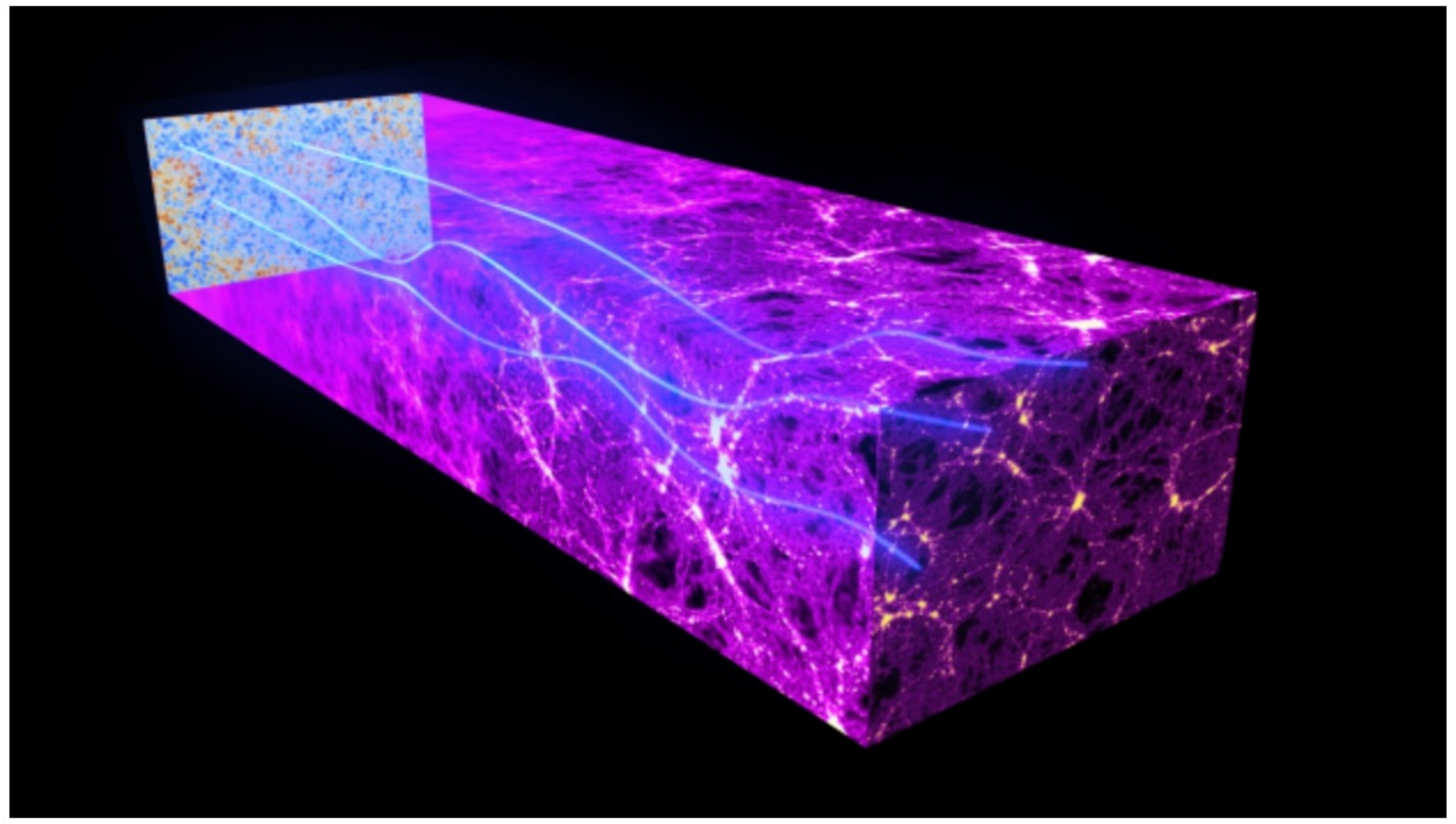
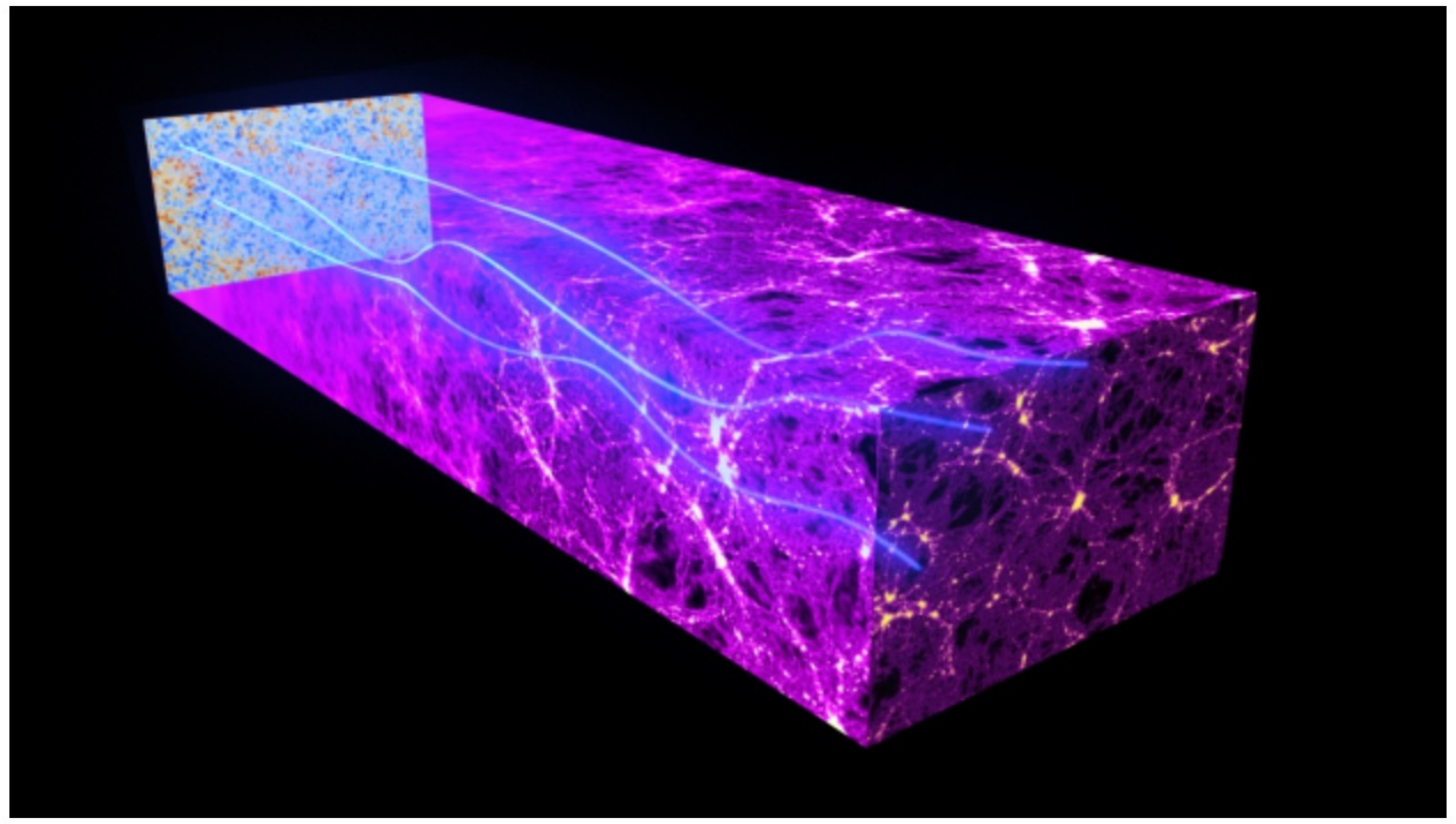


ESA and the Planck Collaboration

CMB lensing is weakly non-Gaussian

- Lensing is a non-linear process
- Large scale structure growth is non-linear in small scales (gravitational collapse)

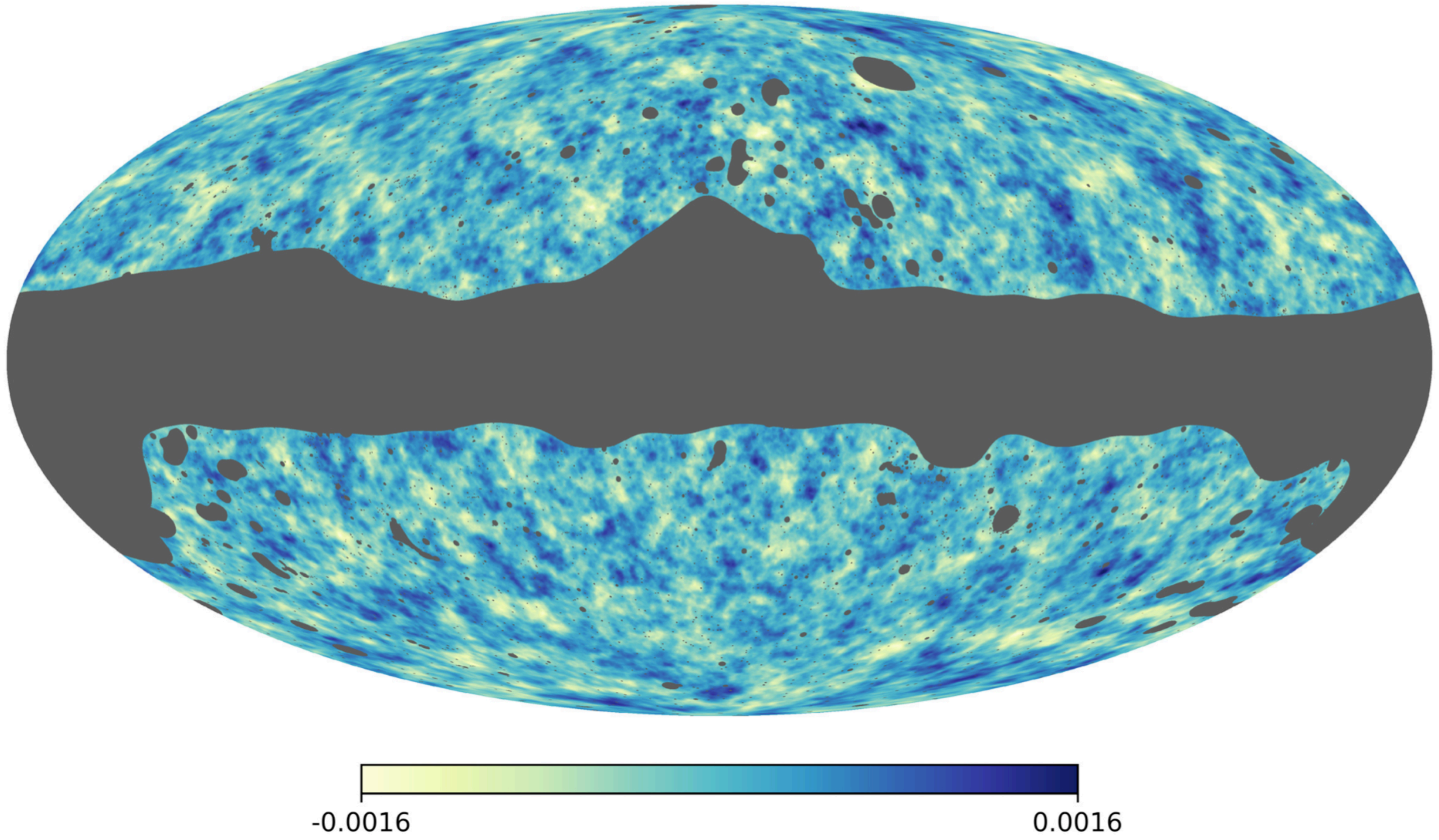
CMB lensing


ESA and the Planck Collaboration

CMB lensing is weakly non-Gaussian

- Lensing is a non-linear process
- Large scale structure growth is non-linear in small scales (gravitational collapse)
- Non-Gaussian introduced from systematics (reconstruction noise, masking, anisotropic beam, foregrounds….)

Planck CMB lensing reconstruction



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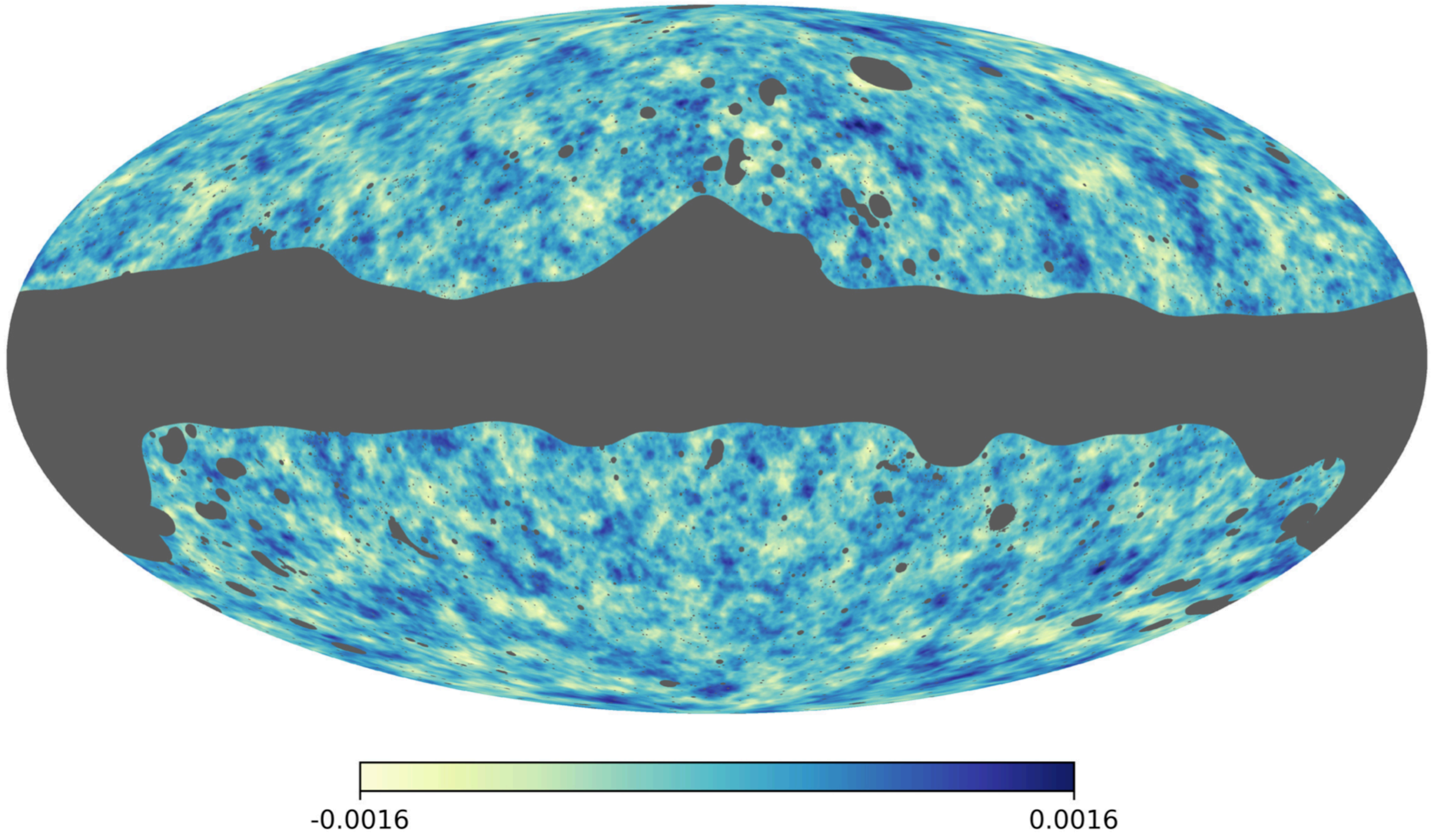

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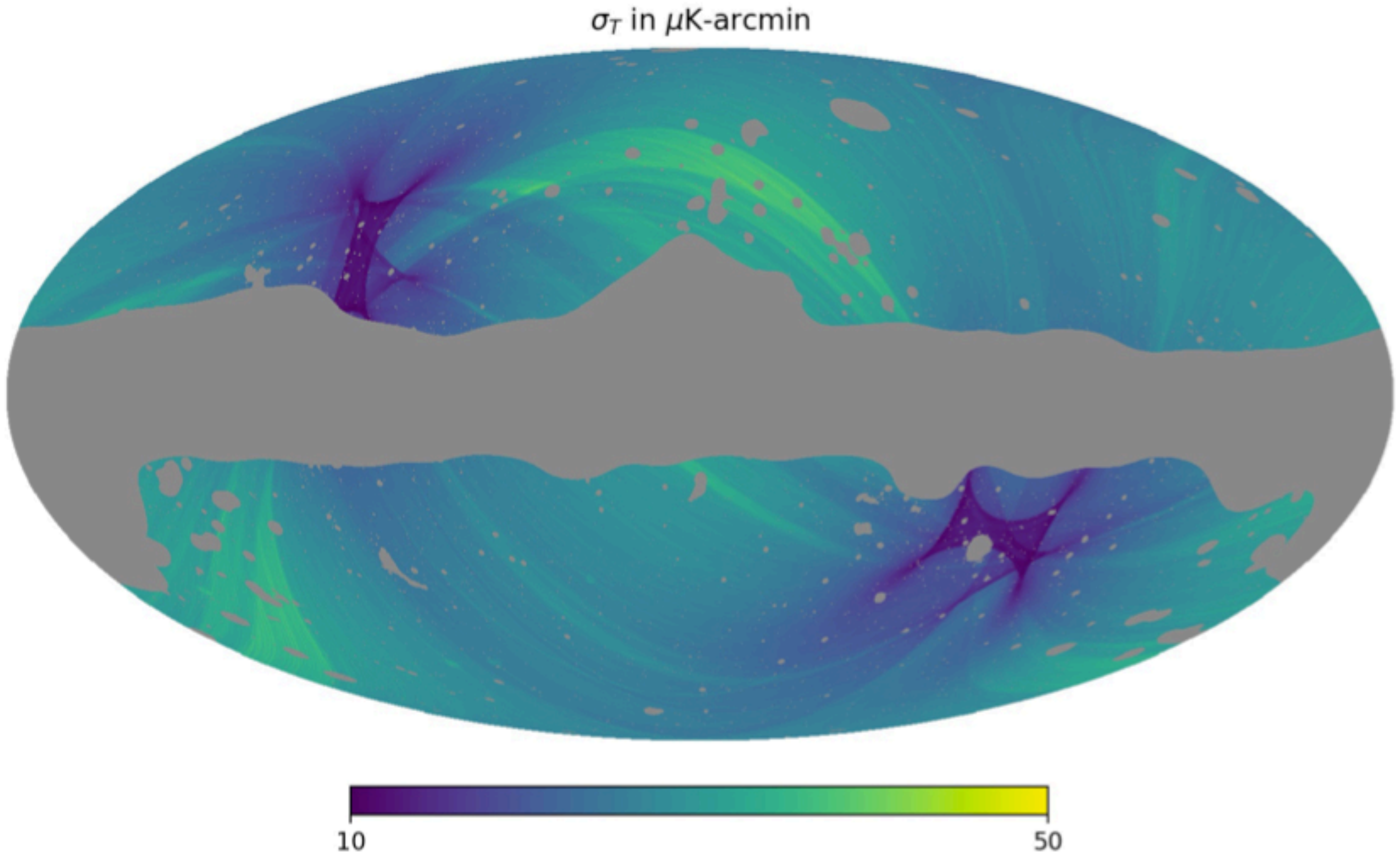

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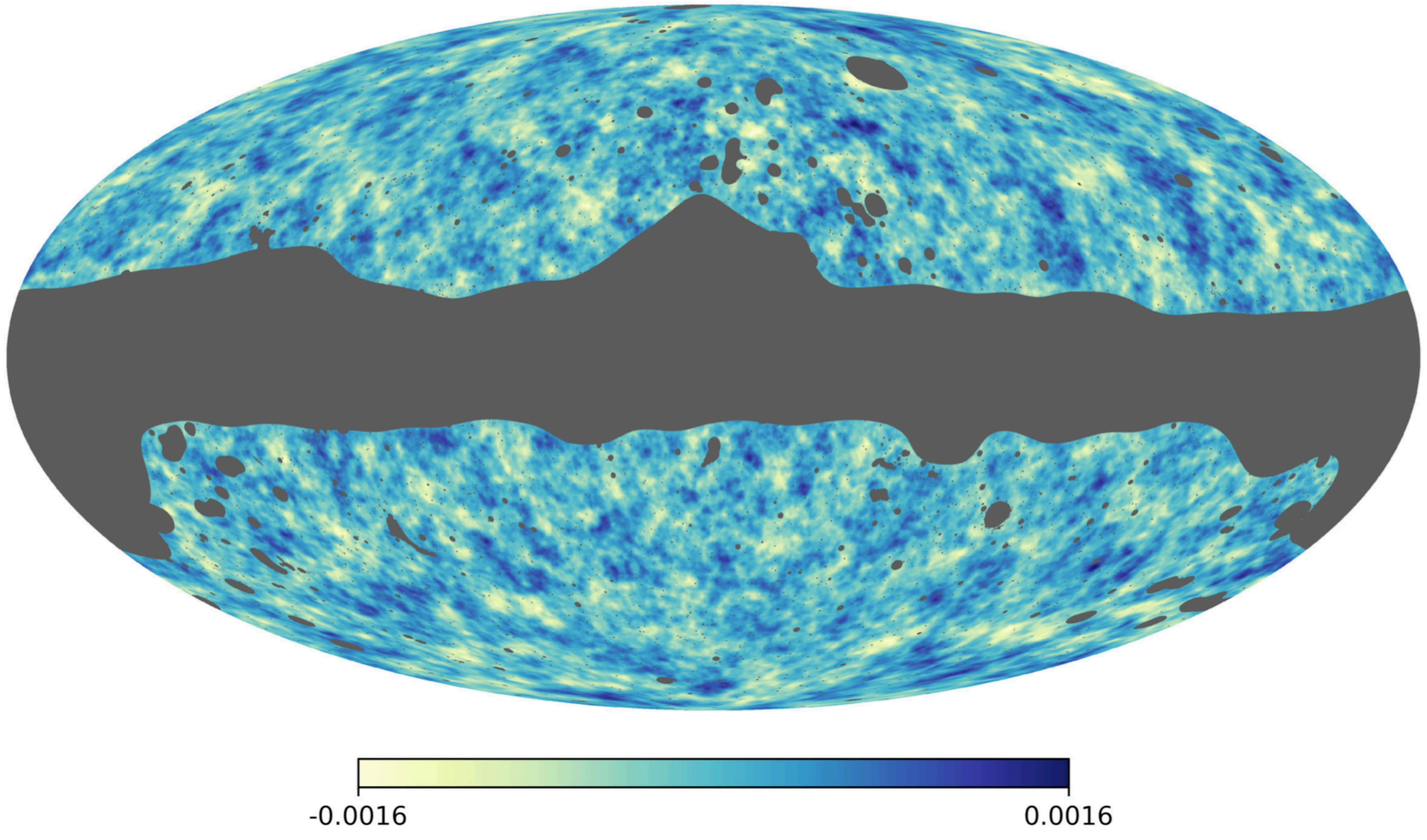

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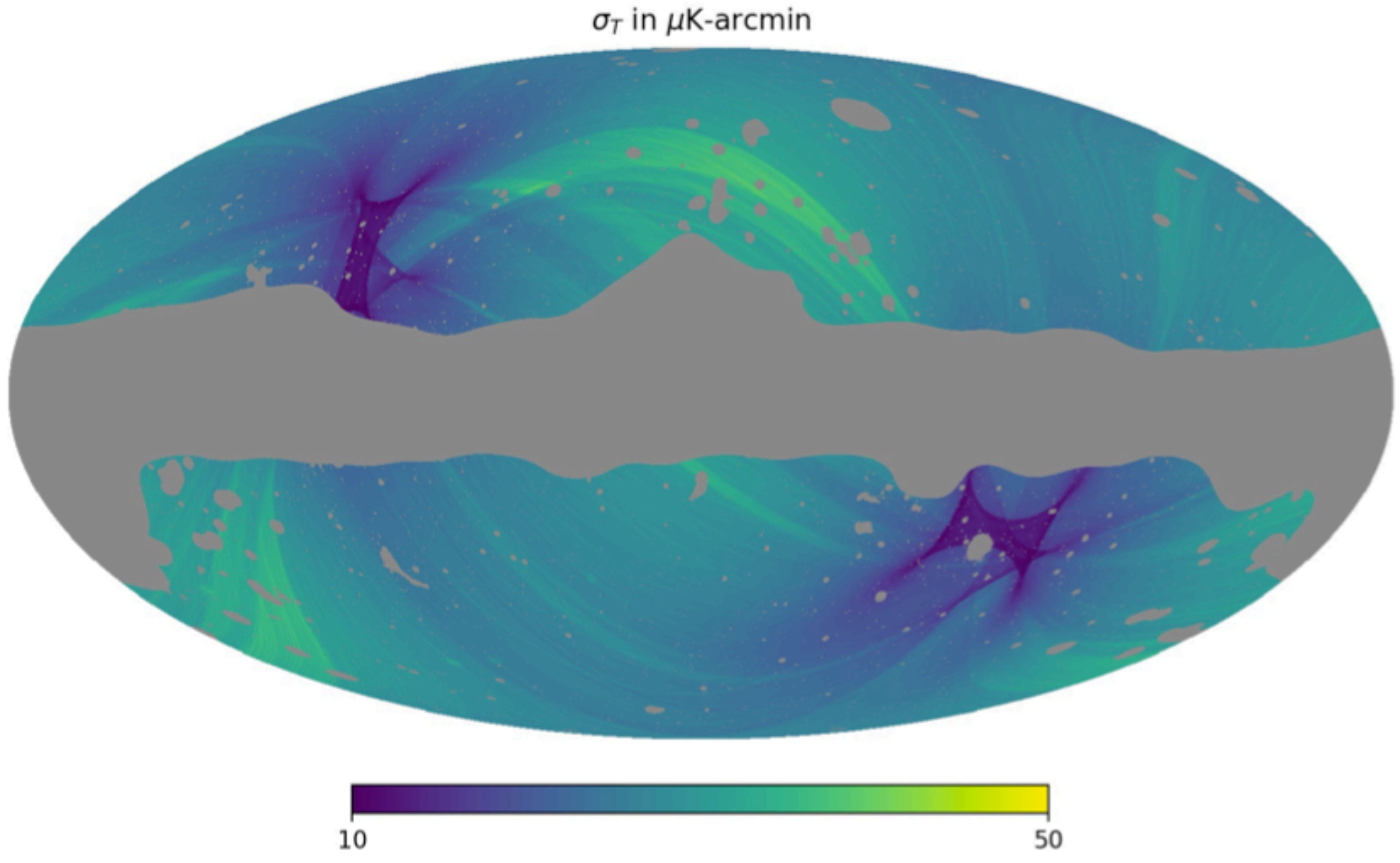
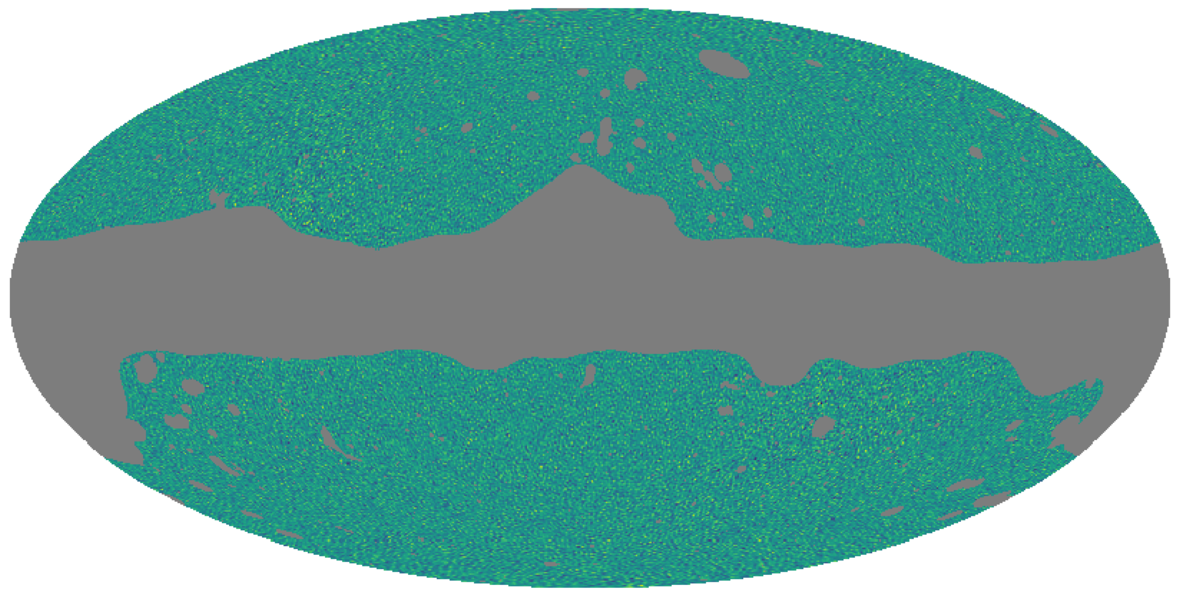


Planck Collaboration: *Planck* 2018 lensing

The non-Gaussianity in Planck lensing reconstruction is dominated by the noise

Analysis with morphological descriptors: Minkowski Functionals



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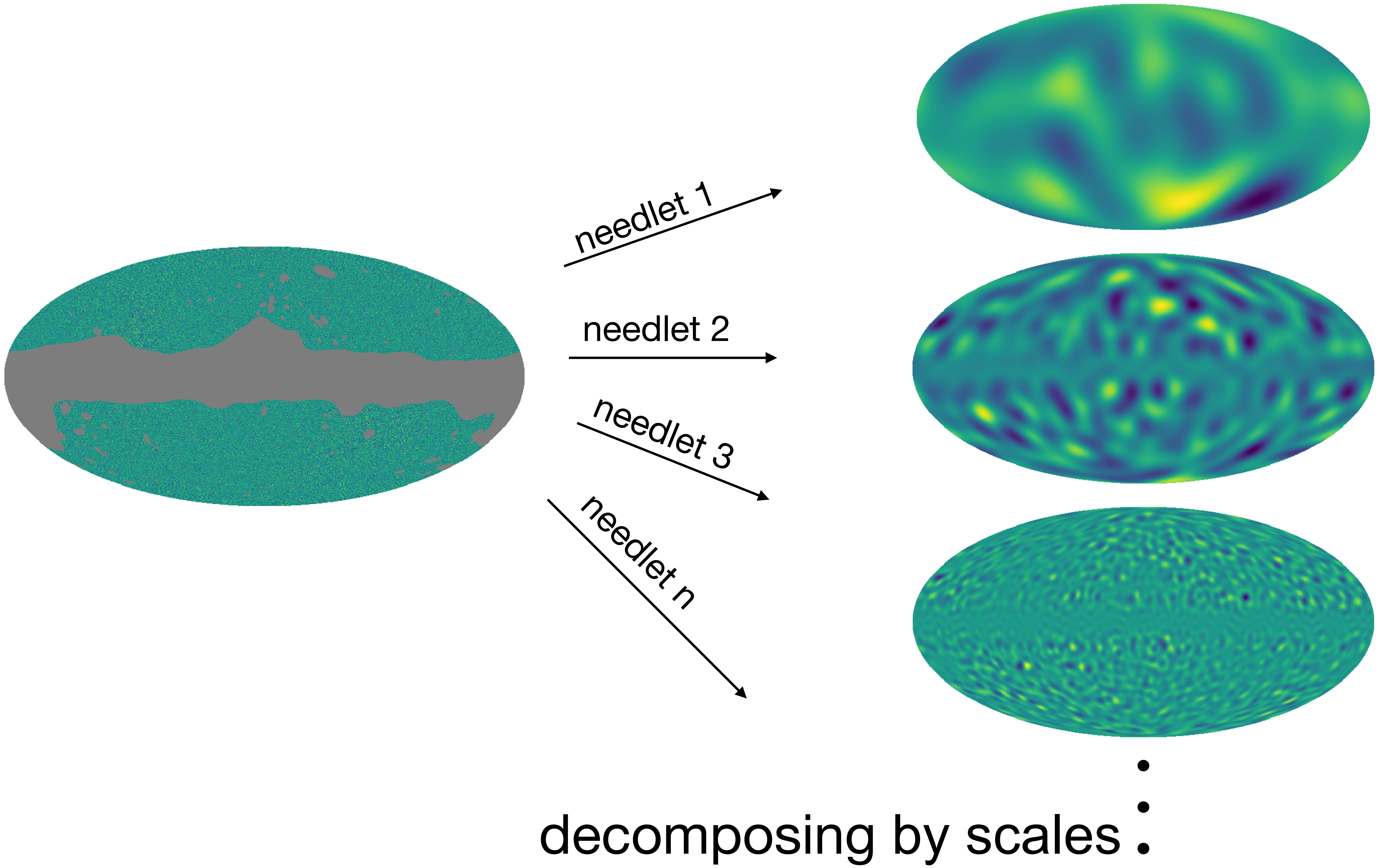
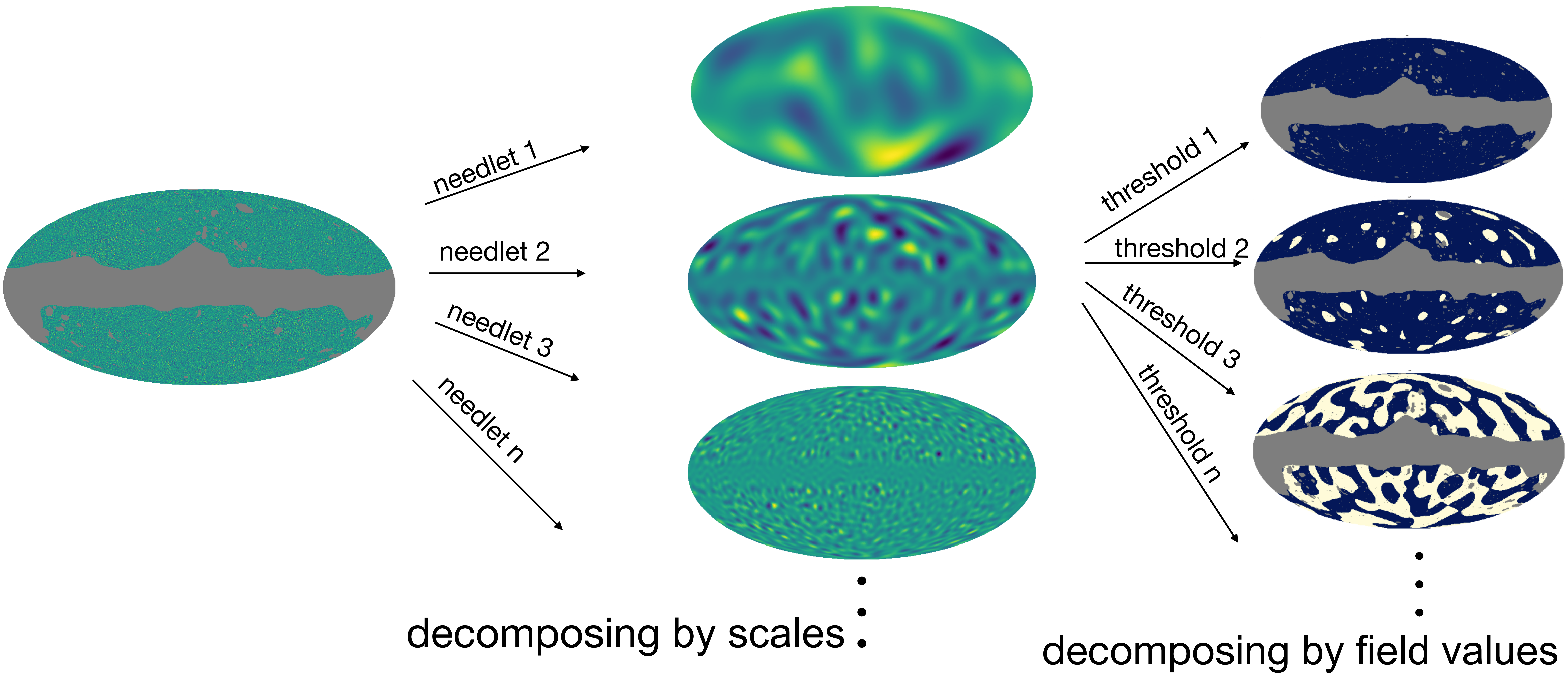


decomposing by scales

Analysis with morphological descriptors: Minkowski Functionals



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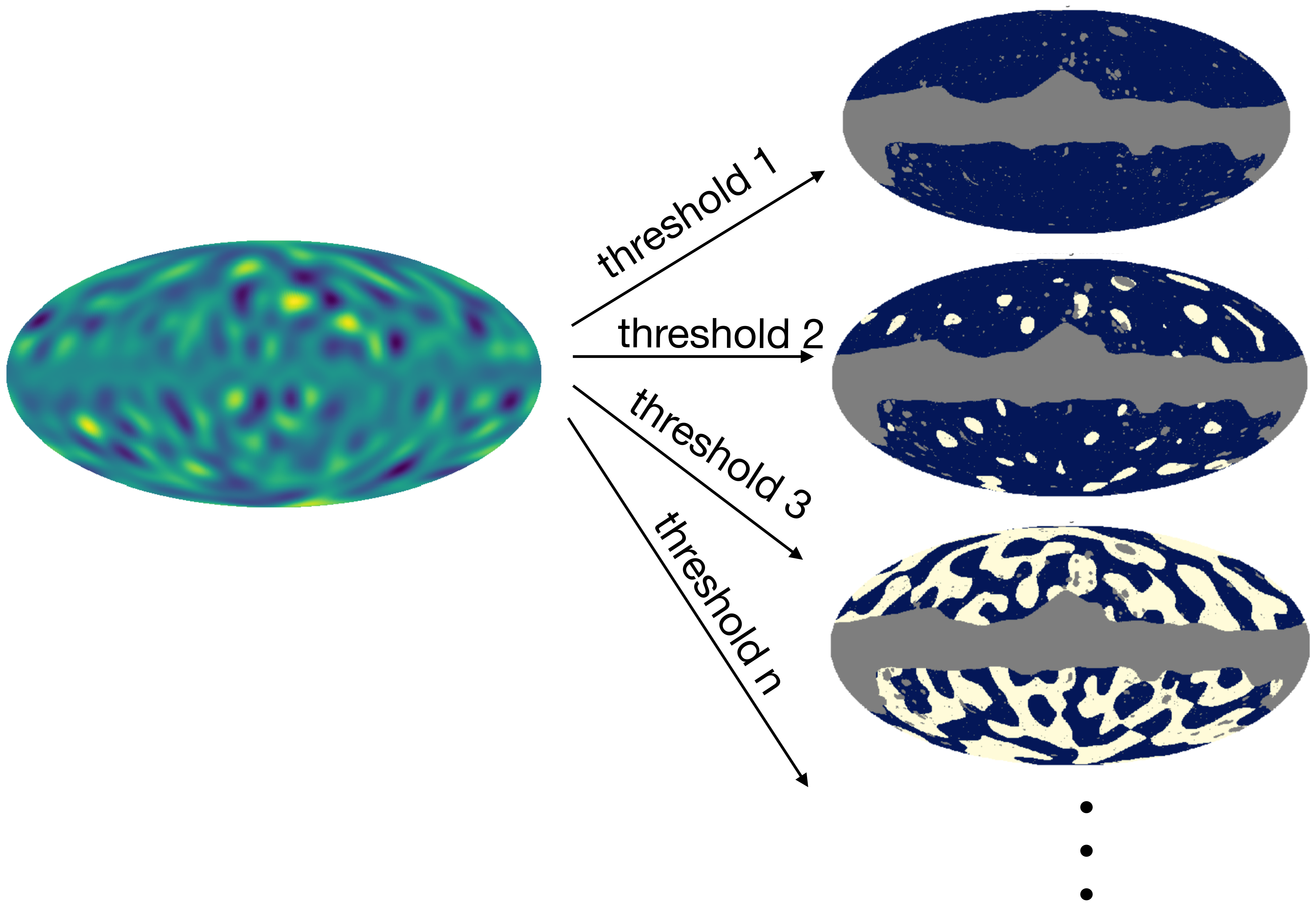
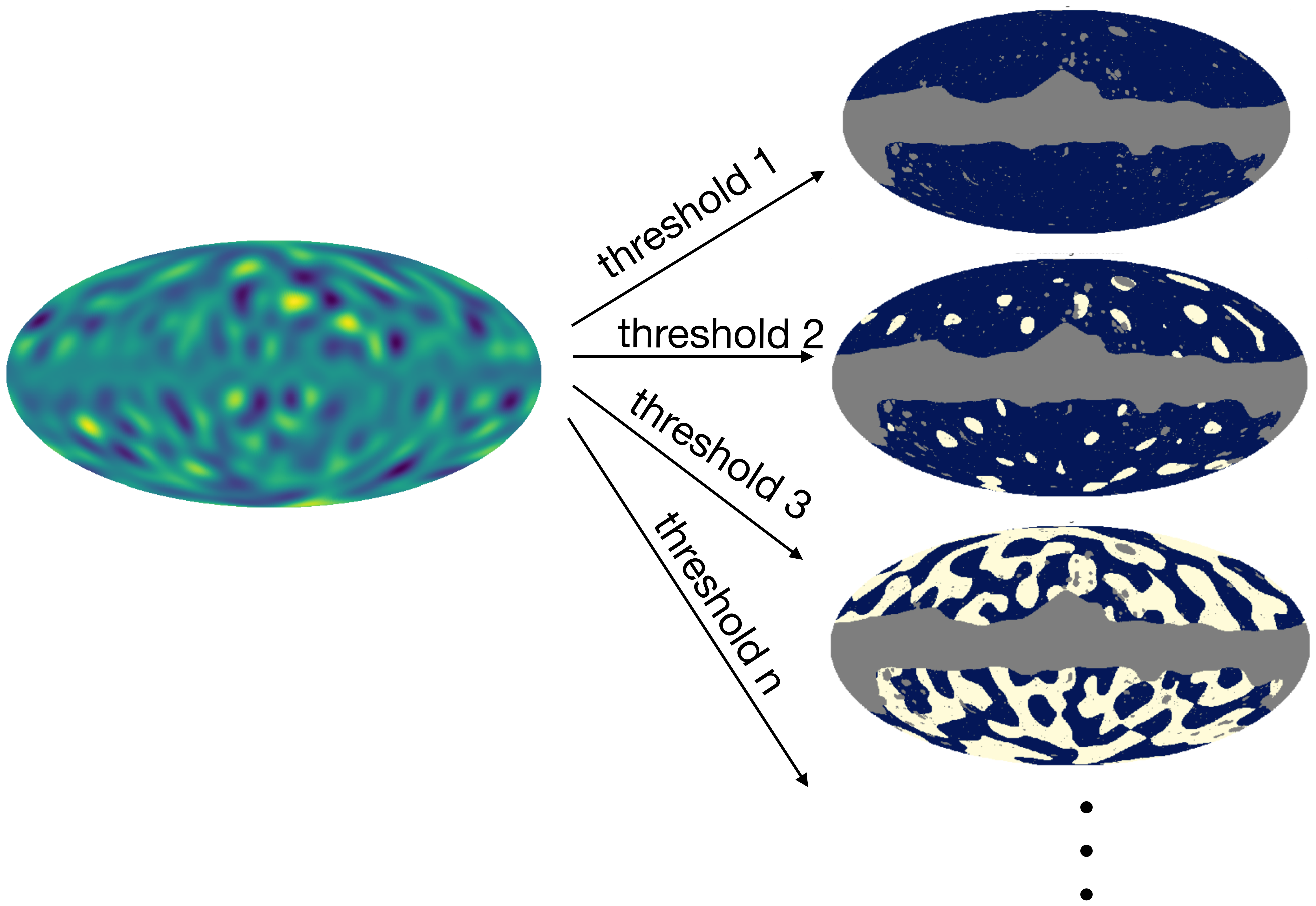


decomposing by field values

Analysis with morphological descriptors: Minkowski Functionals



decomposing by field values

d	1	2	3
V_0	length	area	volume
V_1	χ	circumference	surface area
V_2	–	χ	total mean curvature
V_3	–	–	χ

χ = # disconnected white – #black

Analysis with morphological descriptors: Minkowski Functionals

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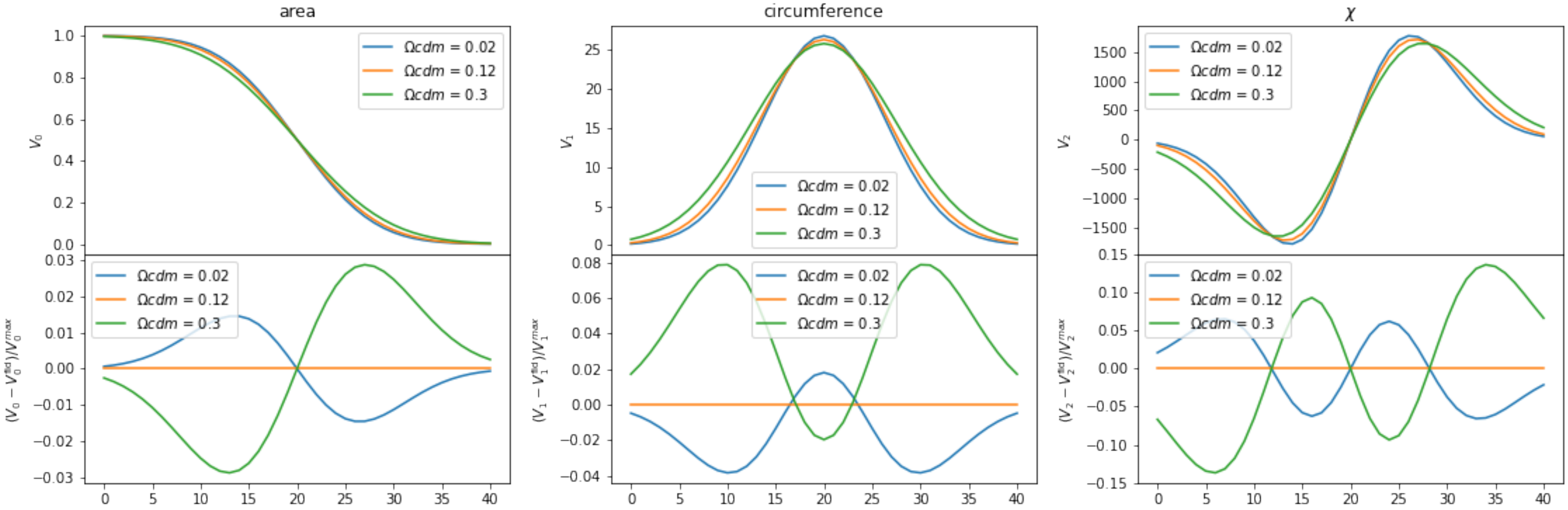

A_s , Ω_{cdm} & Σm_ν constrain with Planck CMB lensing

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Subtract non-Gaussian information with measurements from Planck like realisations (FFP10)

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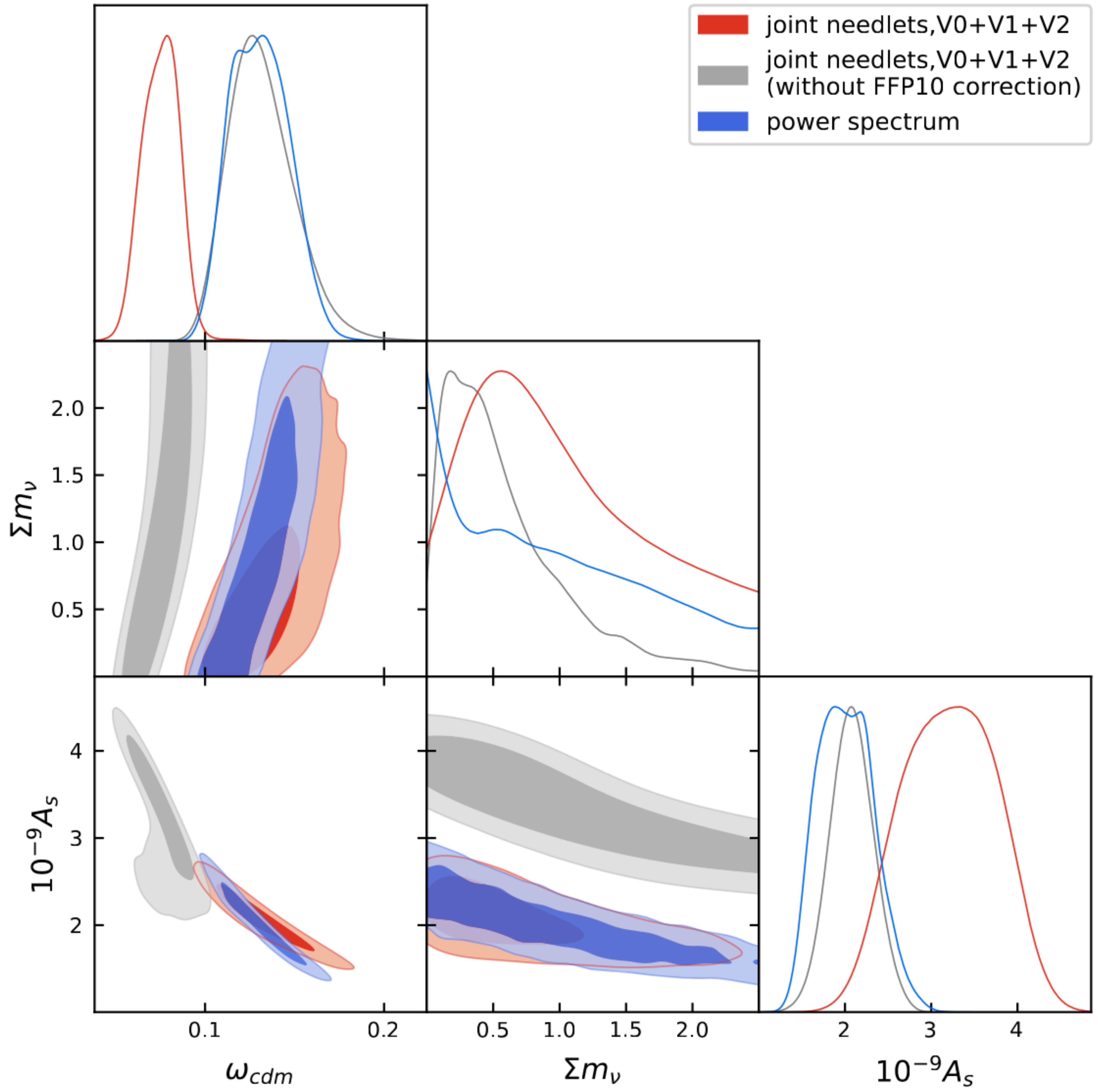

Subtract non-Gaussian information with measurements from Planck like realisations (FFP10)

Non-Gaussian from lensing itself

Source:

- Non-linear large scale structure growth
- Non-linear lensing process

Method:

- Simulating CMB lensing by ray-tracing through N-body simulation
- Measure the non-Gaussianity of simulated maps

Non-Gaussian from lensing itself

- The lensing convergence field $\kappa(\theta)$ in lowest order

$$\kappa(\boldsymbol{\theta}) = \frac{3H_0^2\Omega_{\rm m}}{2}\int_0^{z_{\rm s}} \frac{dz}{H(z)}\frac{r(z)\left(r_{\rm s} - r(z)\right)}{a(z)r_{\rm s}}\delta(r\boldsymbol{\theta}, r; z)$$

  - $r(z)$: comoving distance to the redshift z
  - $\delta(\boldsymbol{x}; z)$: matter density contrast at position $\boldsymbol{x}$ at z
  - z_s : Source redshift

Non-Gaussian from lensing itself

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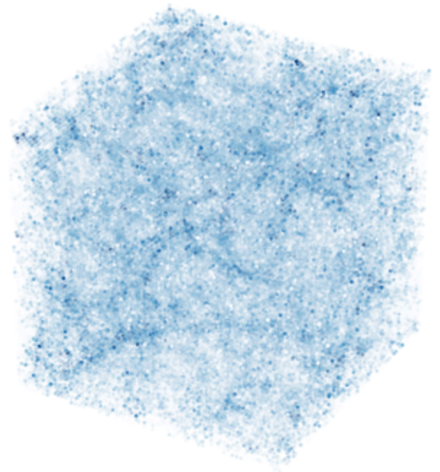
$$\kappa \approx \frac{3H_0^2\Omega_\mathrm{m}}{2} \sum_k \frac{D_k}{H_k} \frac{r_k\left(r_\mathrm{s} - r_k\right)}{a_k r_\mathrm{s}} \delta_k$$

Full sky CMB lensing

$$\kappa \approx \frac{3H_0^2\Omega_{\rm m}}{2}\sum_k \frac{D_k}{H_k}\frac{r_k\left(r_{\rm s}-r_k\right)}{a_k r_{\rm s}}\delta_k$$



A snapshot of N-body
at redshift z_k

(With periodic boundary)

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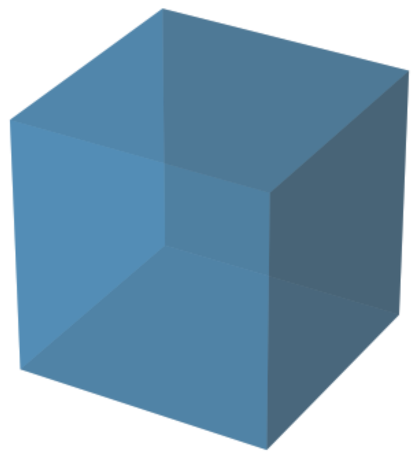

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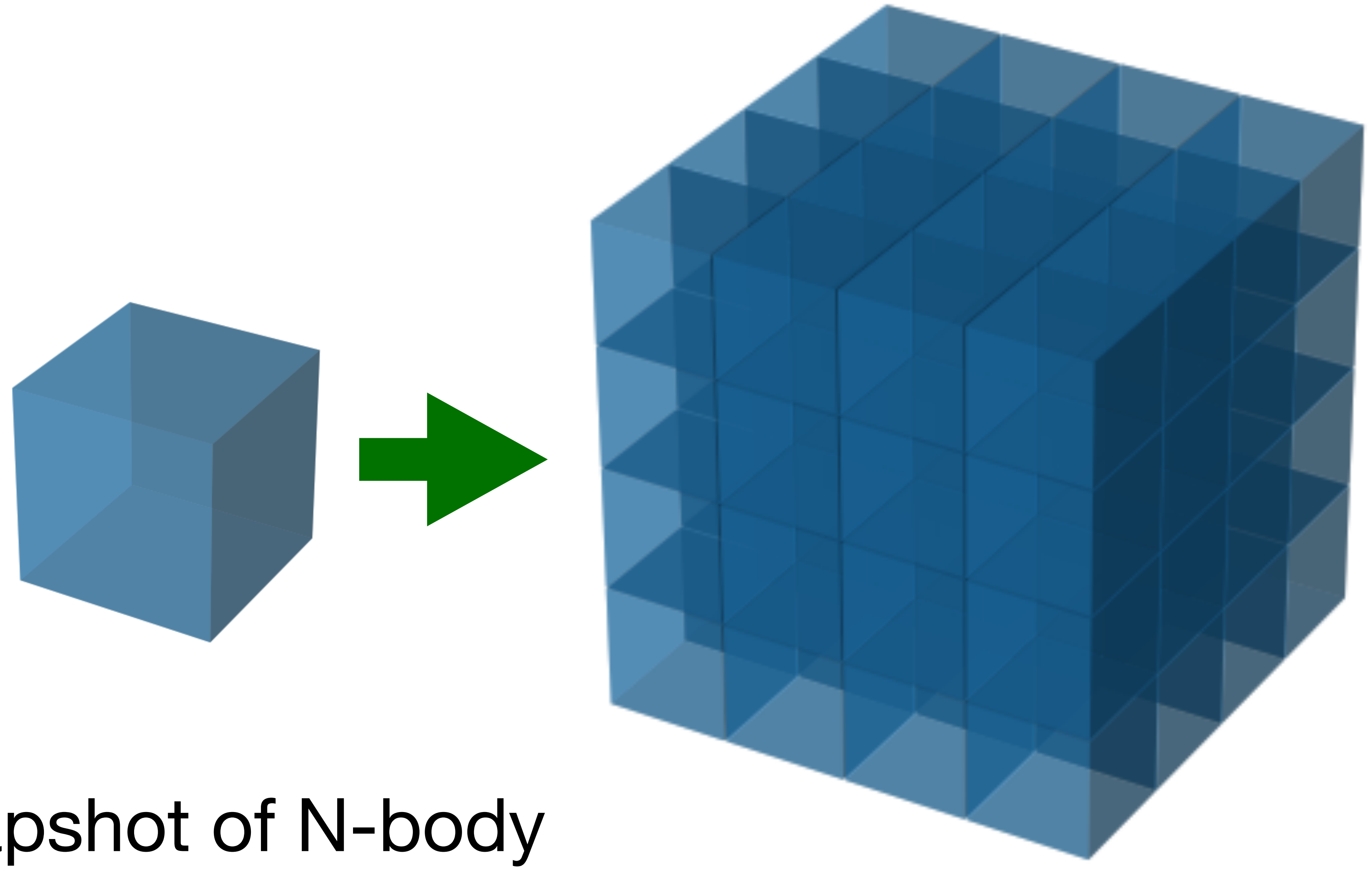

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Stacking

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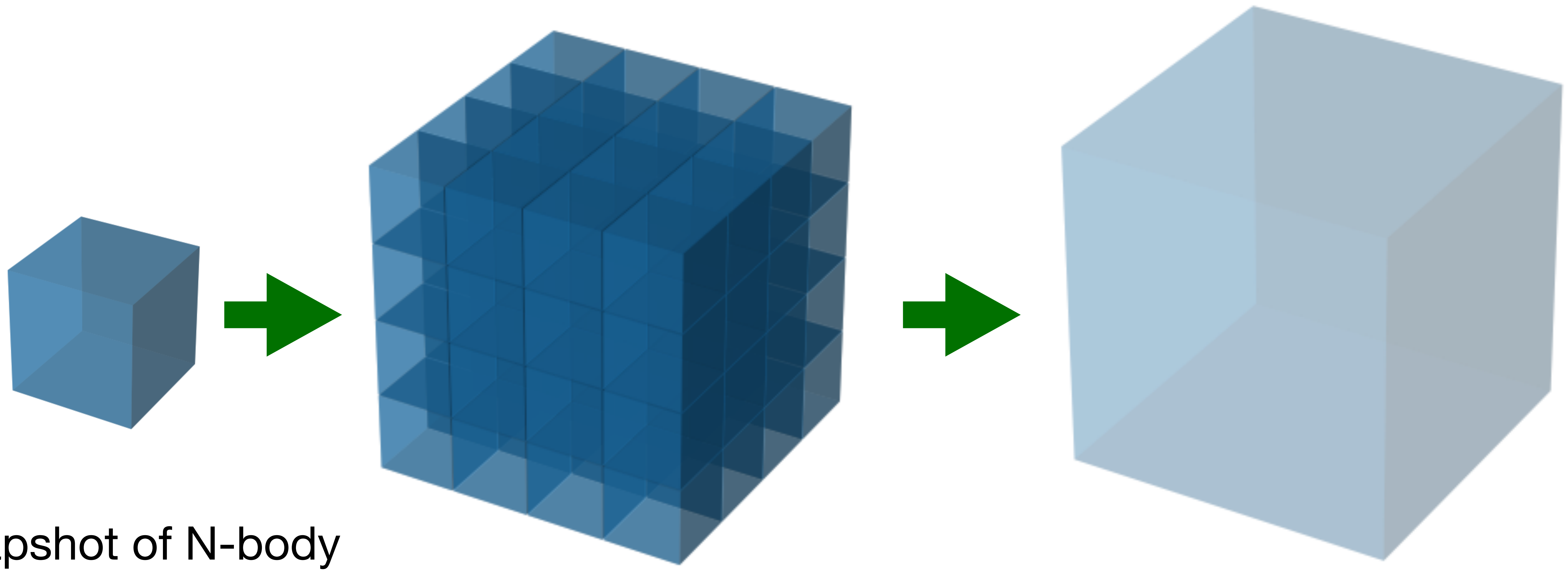

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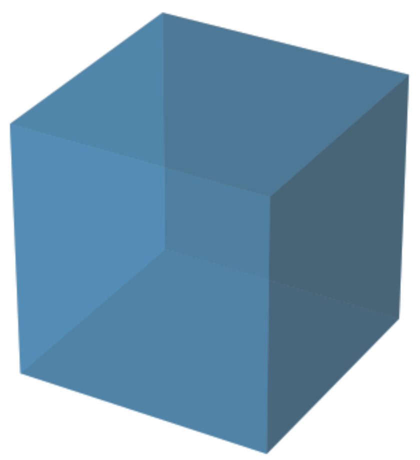

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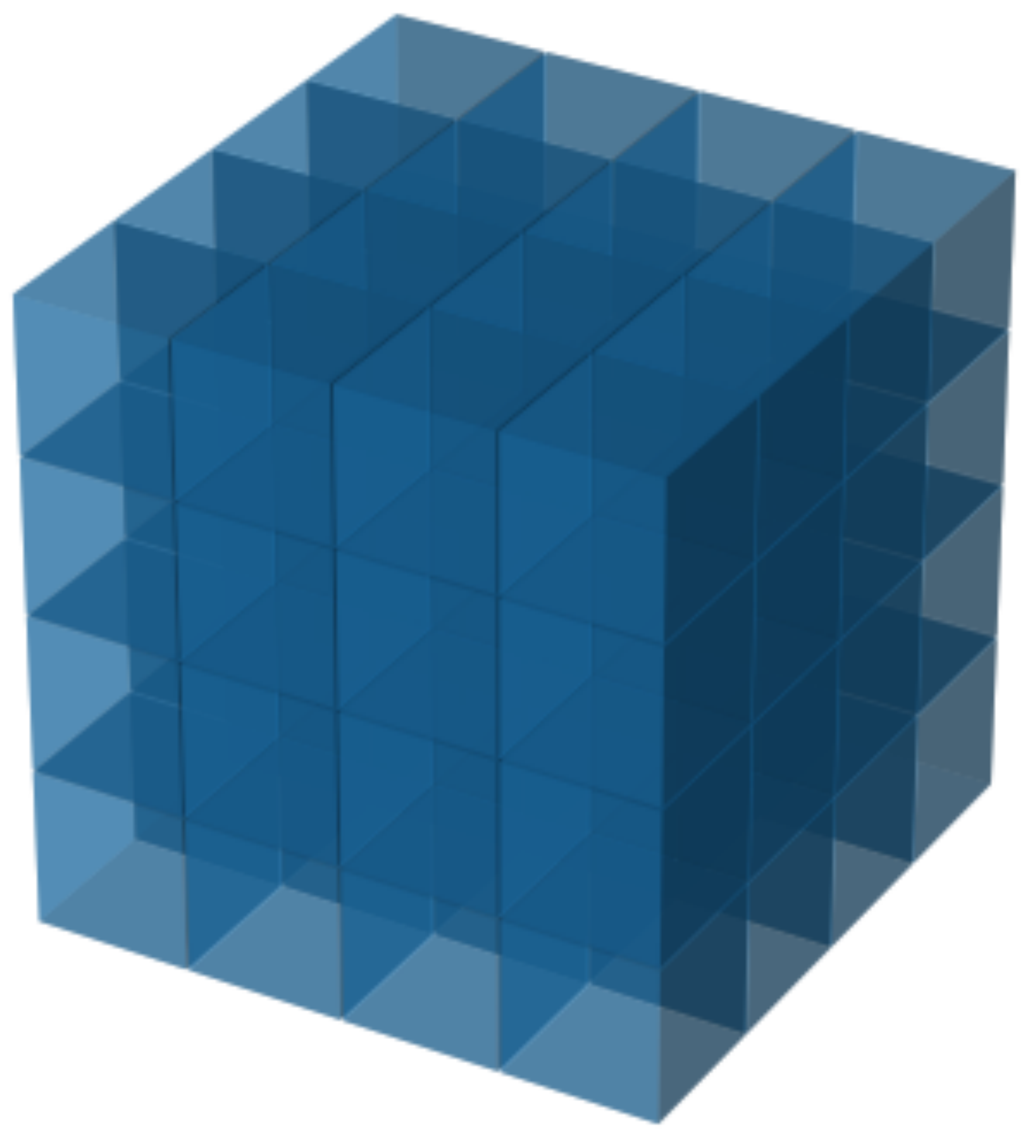

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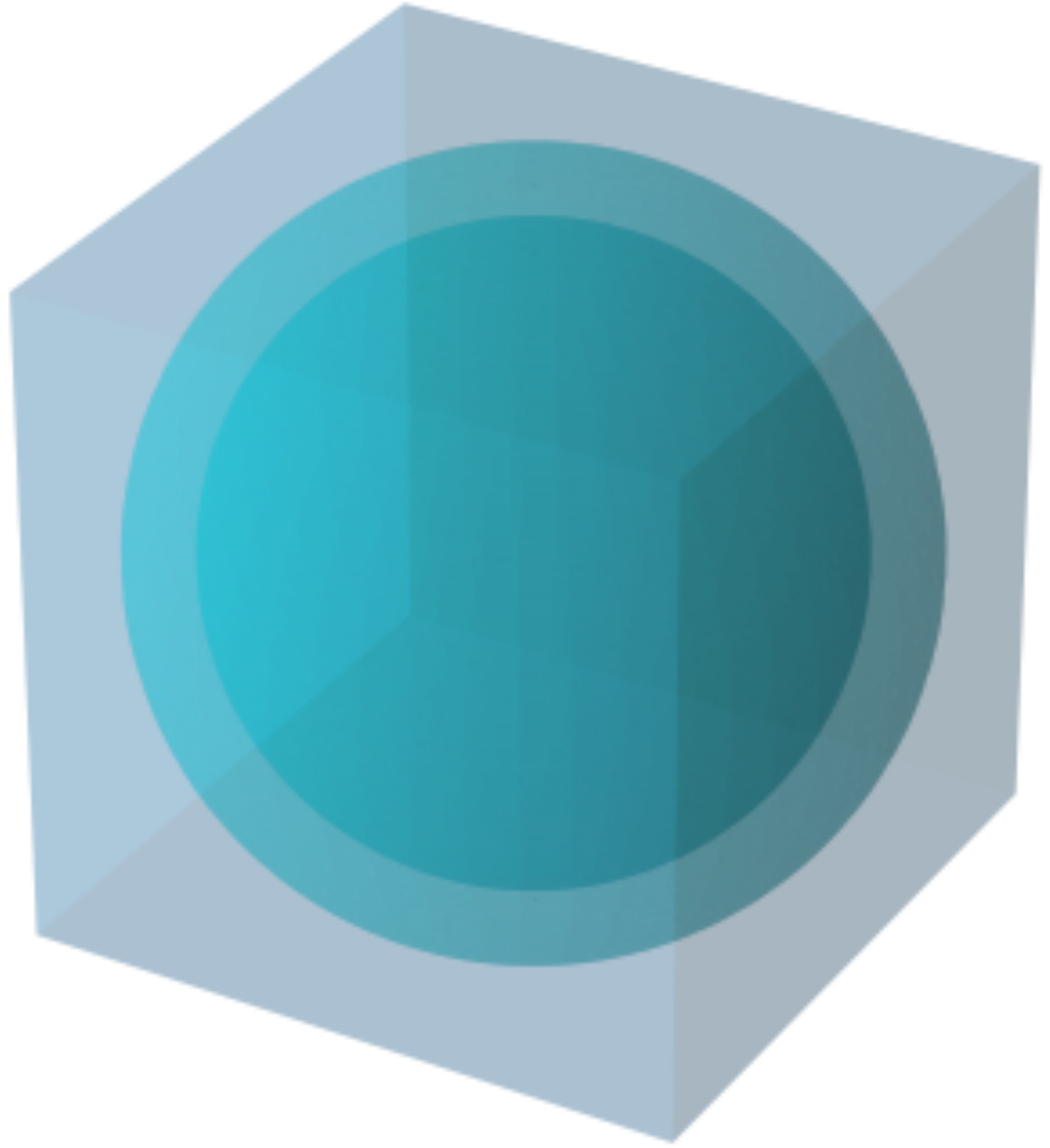

Cutting shell from big snapshot box

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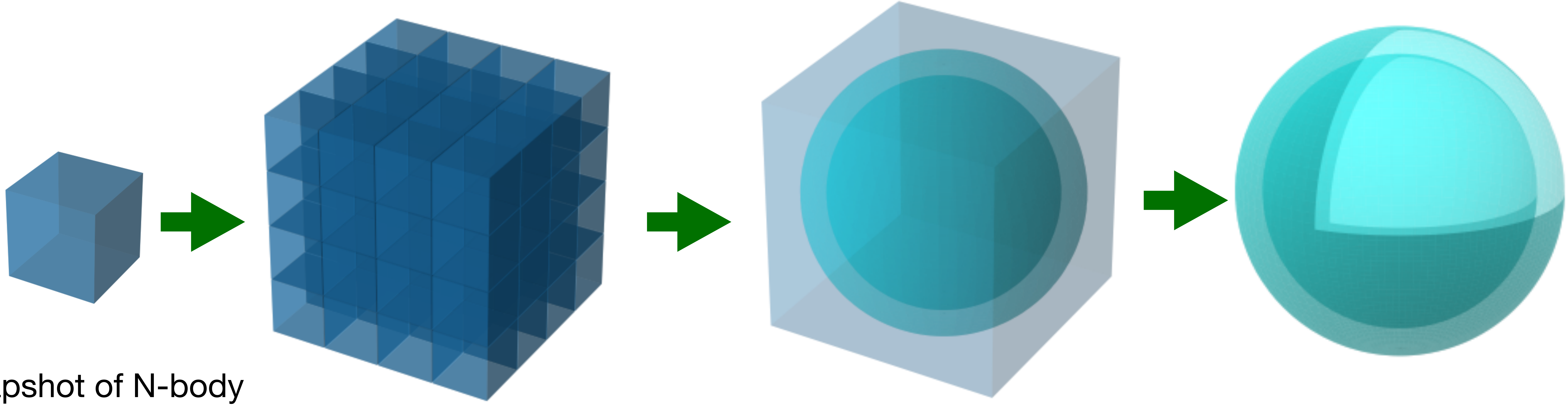

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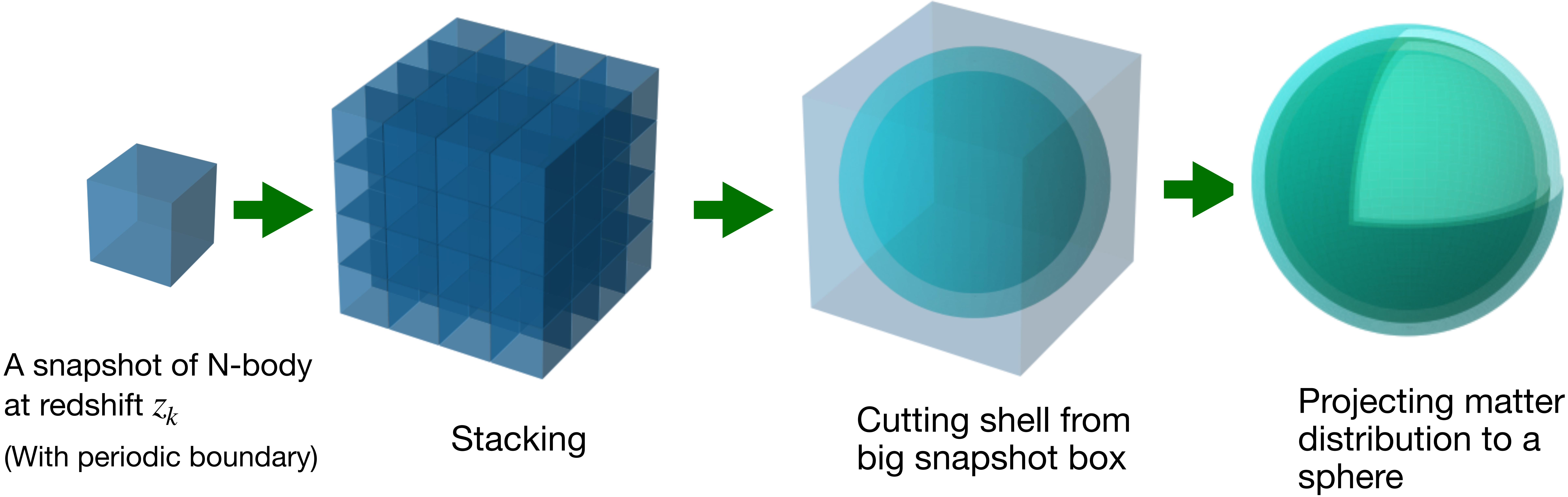

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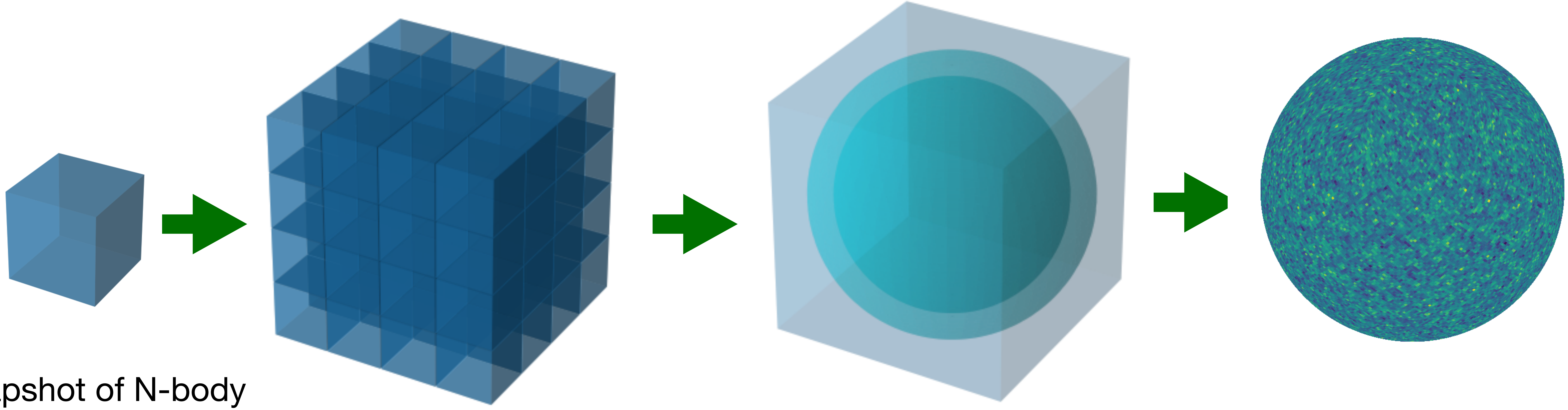

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Stacking

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Projecting matter distribution to a sphere

Full sky CMB lensing

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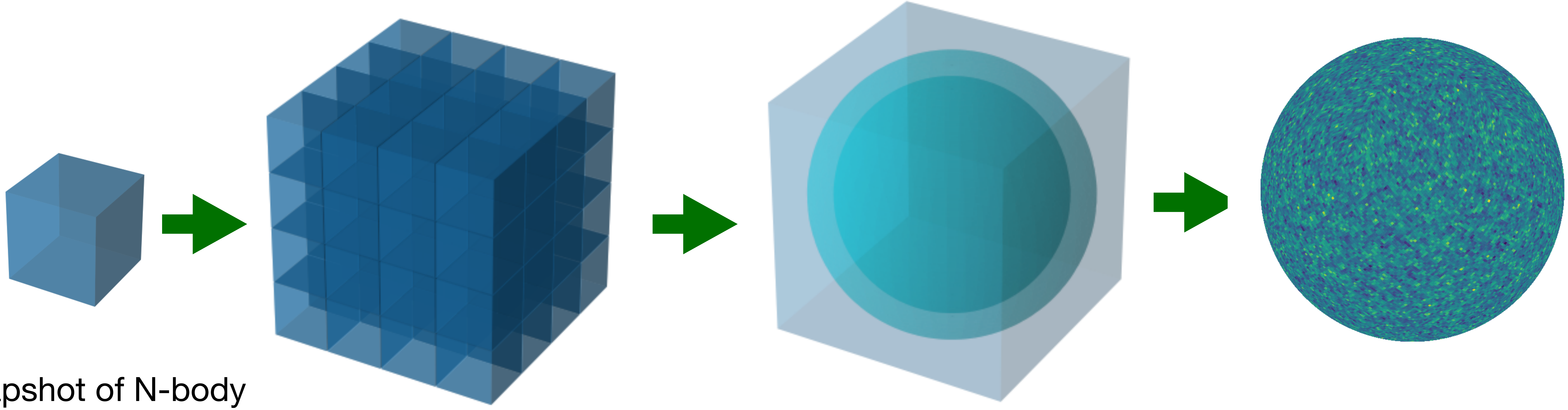
Replace large scale (l>40) with Gaussian realisations



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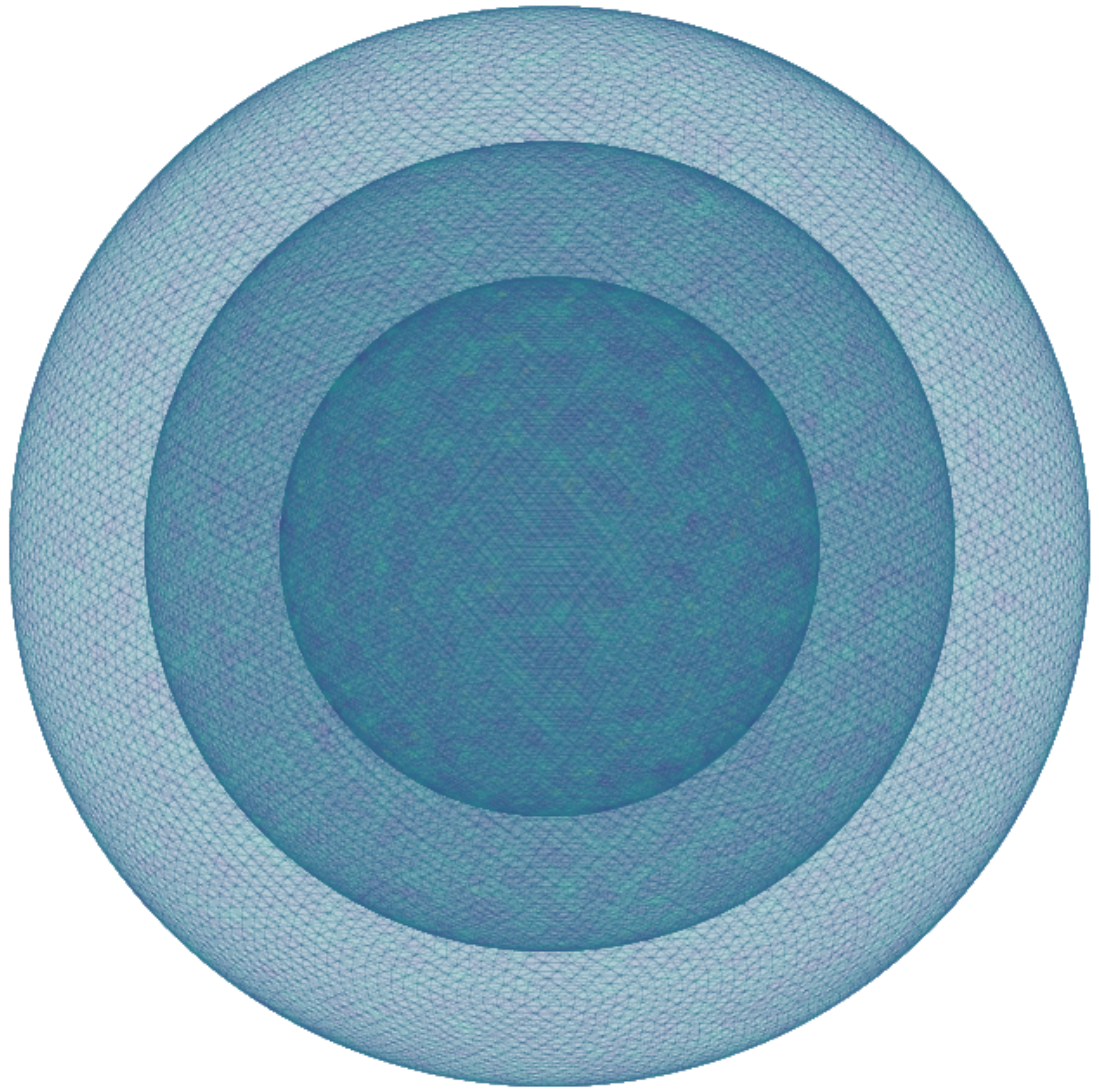

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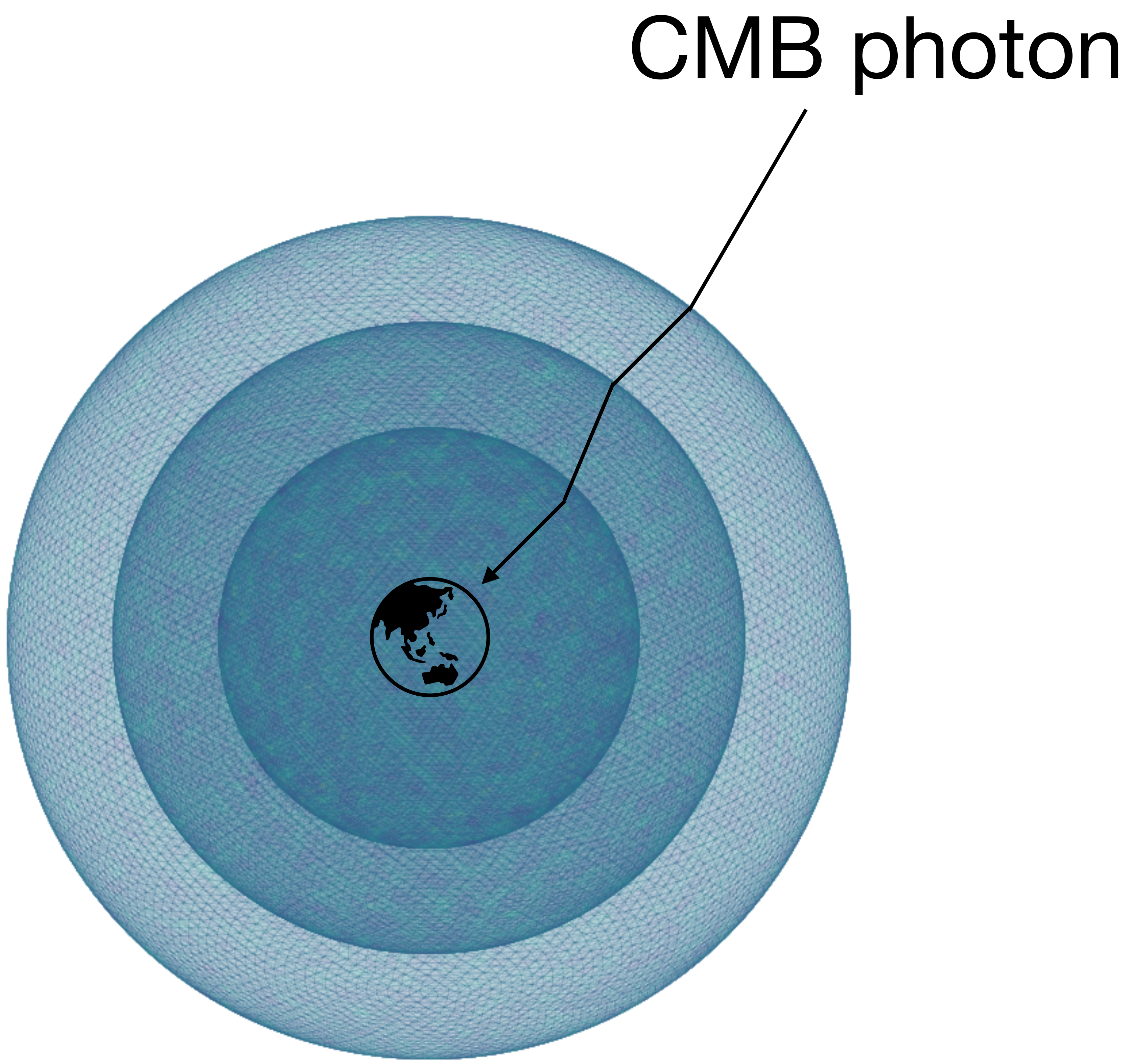

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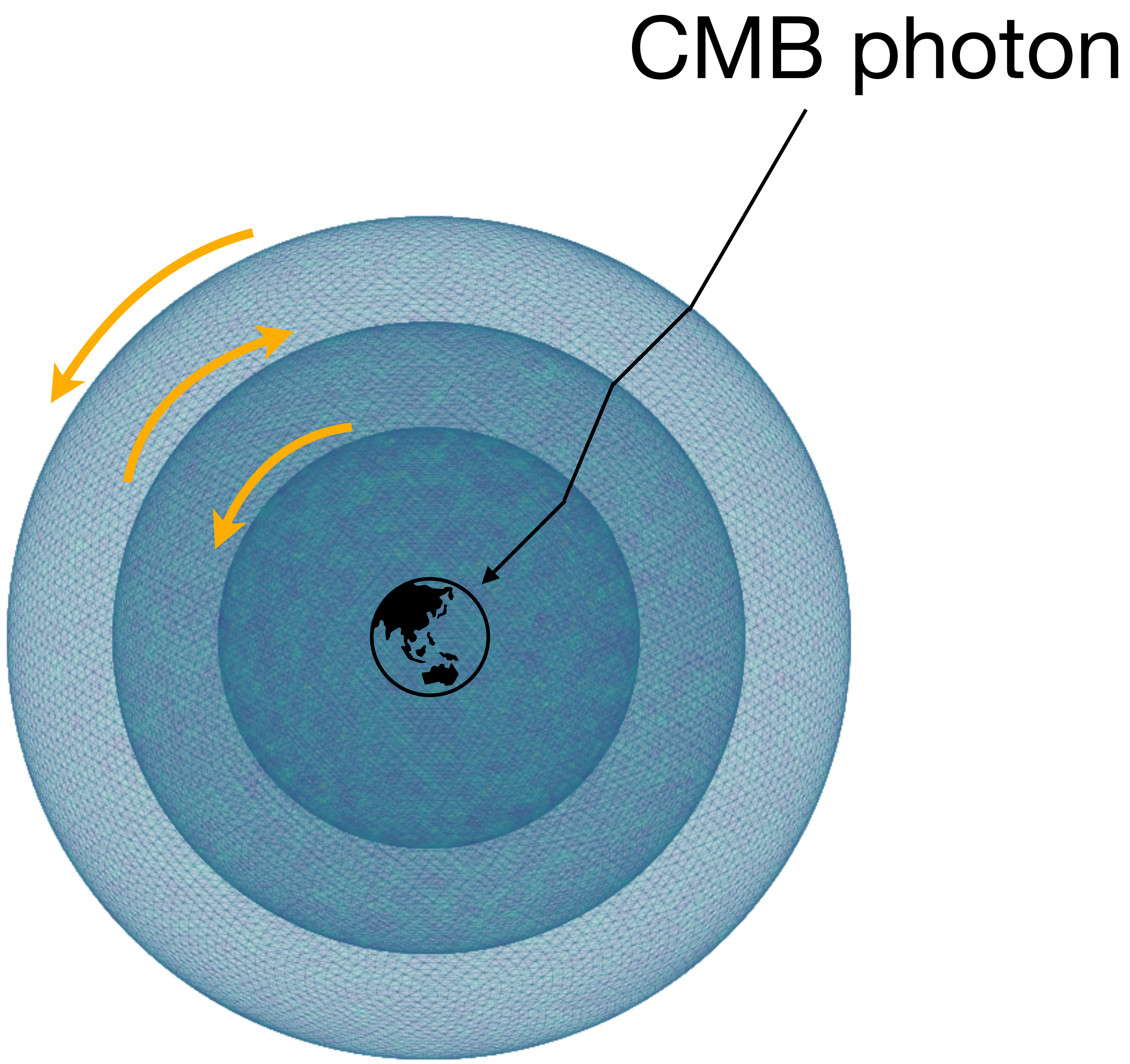

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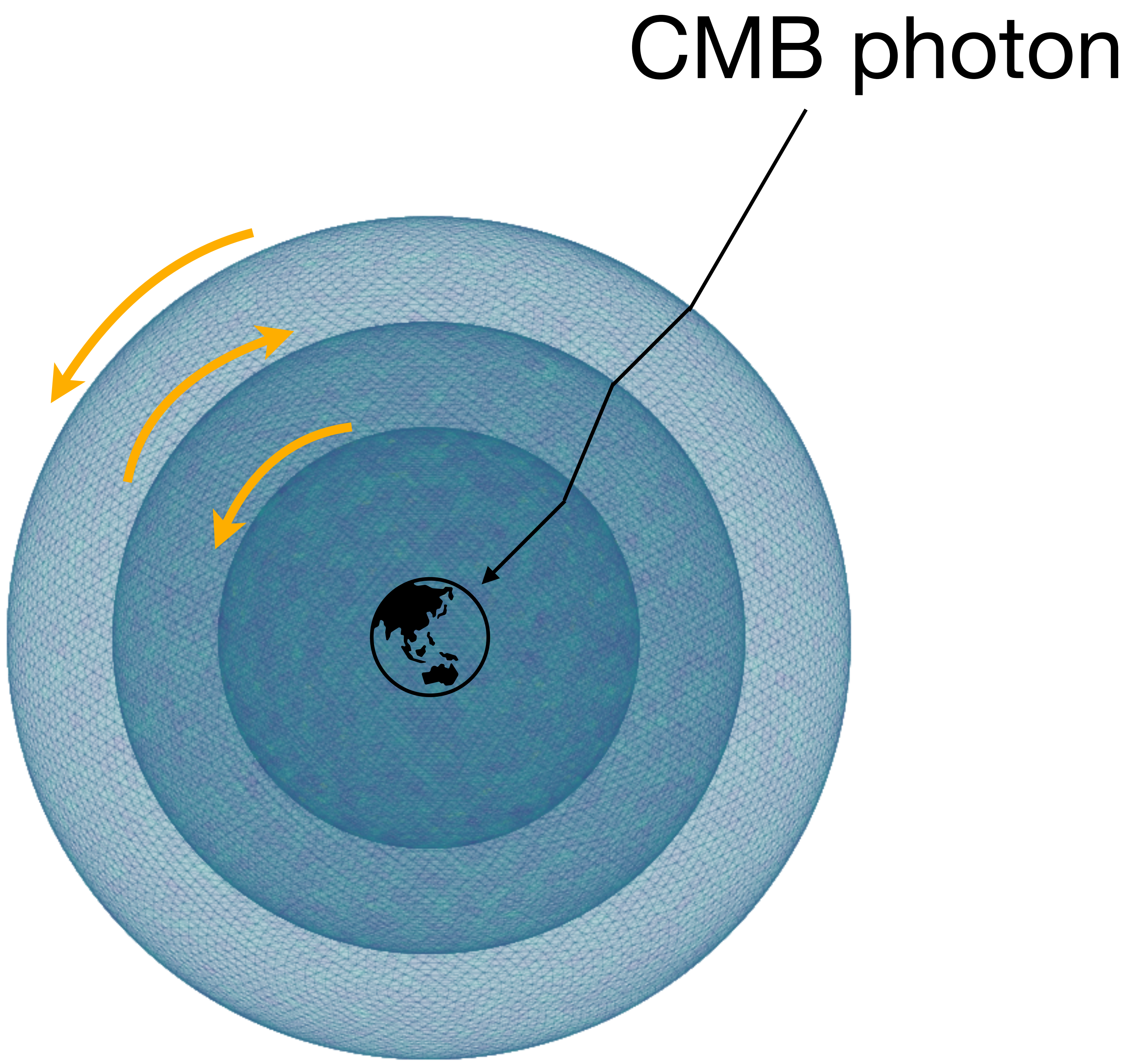

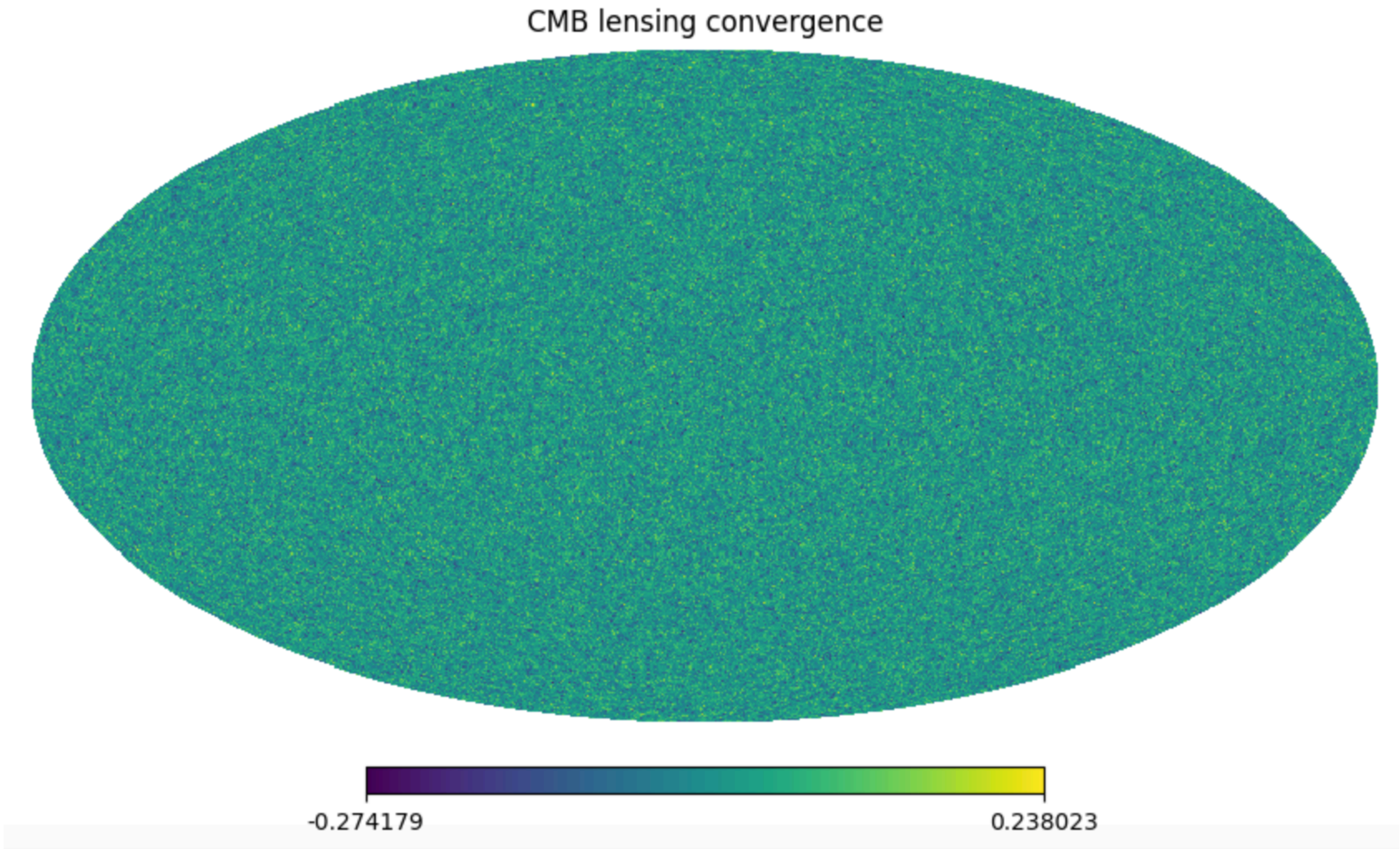

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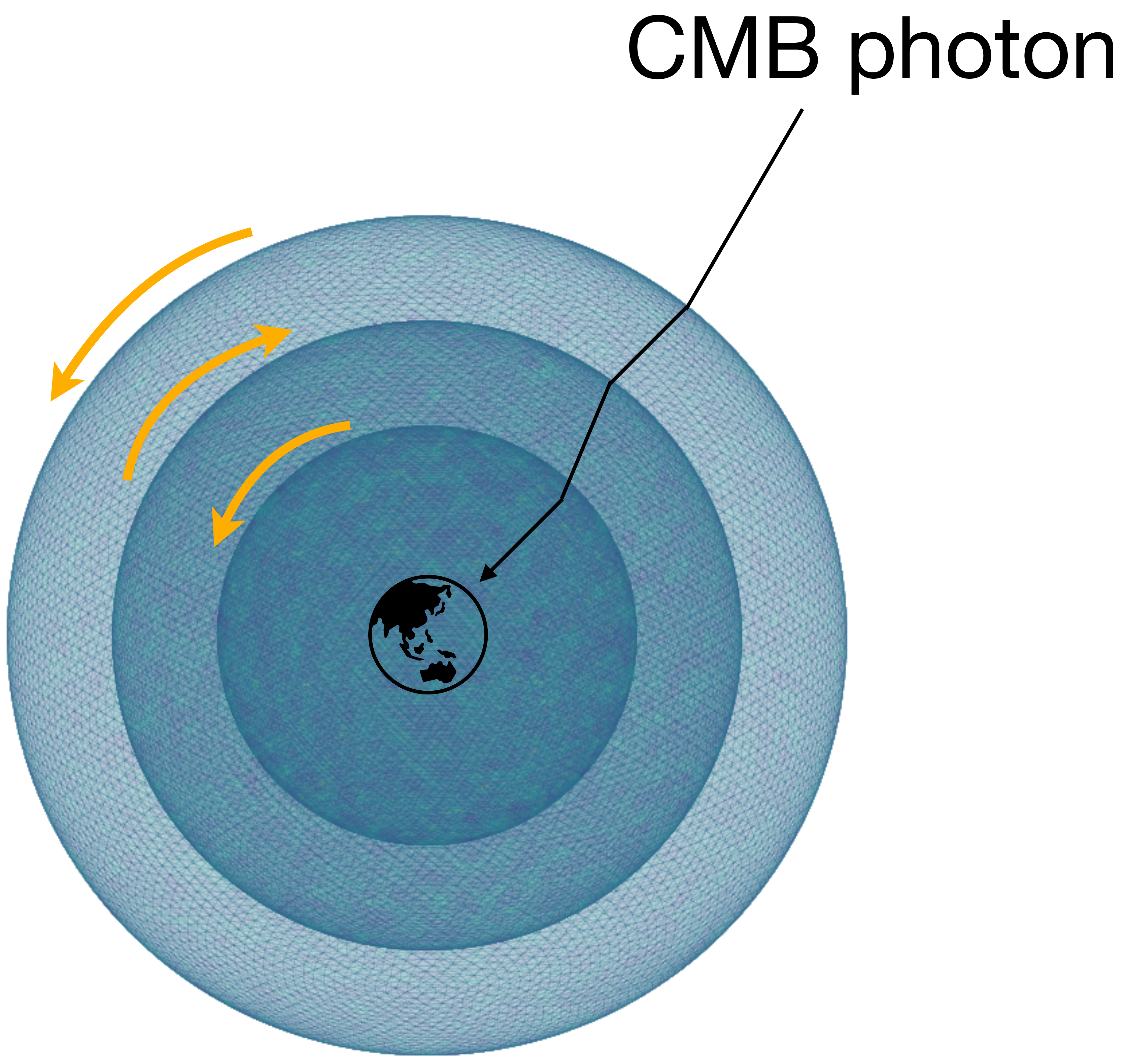
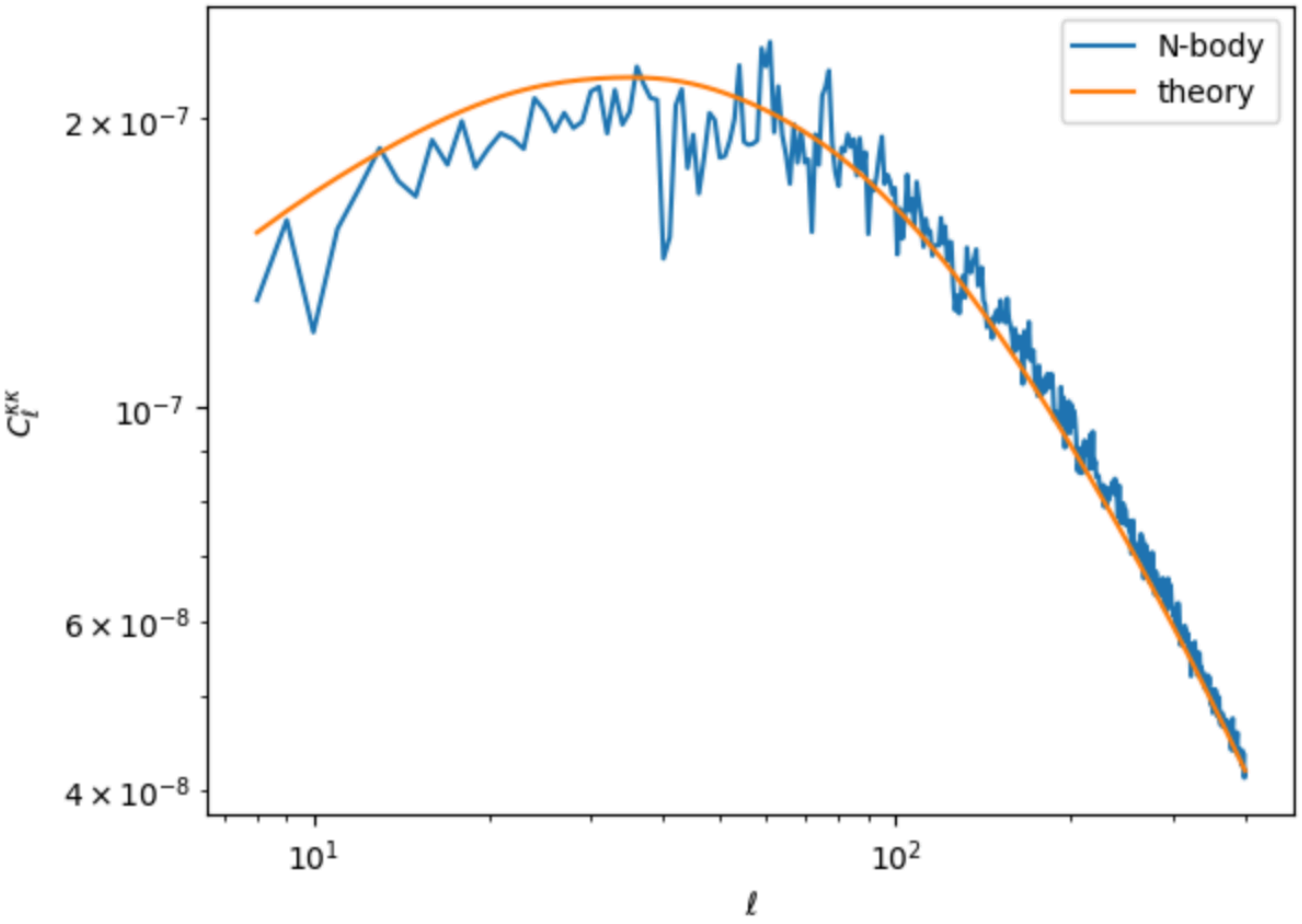




Non-Gaussian from full sky simulation

$$S^{(0)} = \frac{\langle f^3 \rangle_c}{\sigma_0^4}, \quad S^{(1)} = \frac{3}{2} \frac{\langle f |\nabla f|^2 \rangle_c}{\sigma_0^2 \sigma_1^2},$$

$$S^{(2)} = -3 \frac{\langle |\nabla f|^2 \Delta f \rangle_c}{\sigma_1^4},$$

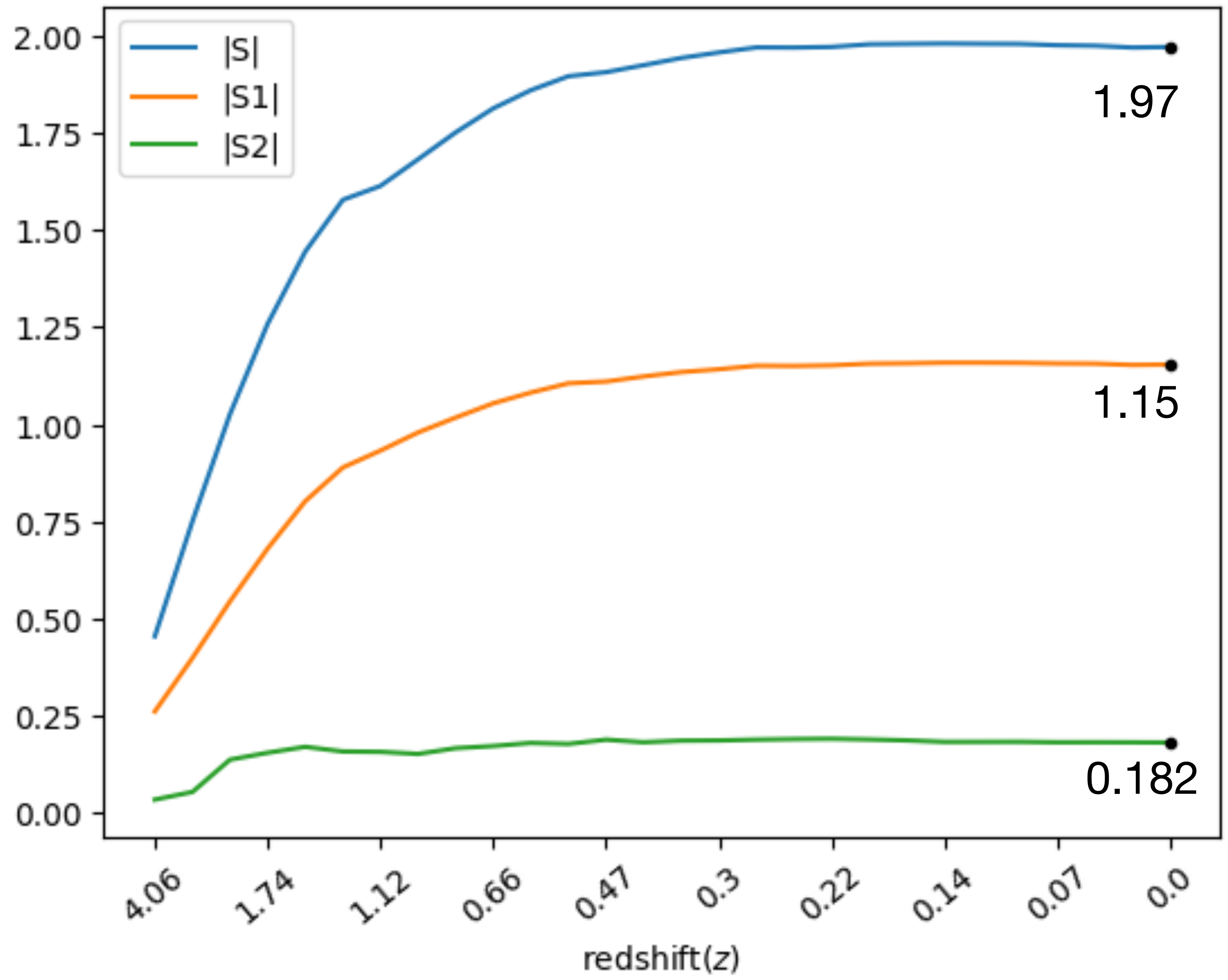
$$K^{(0)} = \frac{\langle f^4 \rangle_c}{\sigma_0^6}, \quad K^{(1)} = 2 \frac{\langle f^2 |\nabla f|^2 \rangle_c}{\sigma_0^4 \sigma_1^2},$$

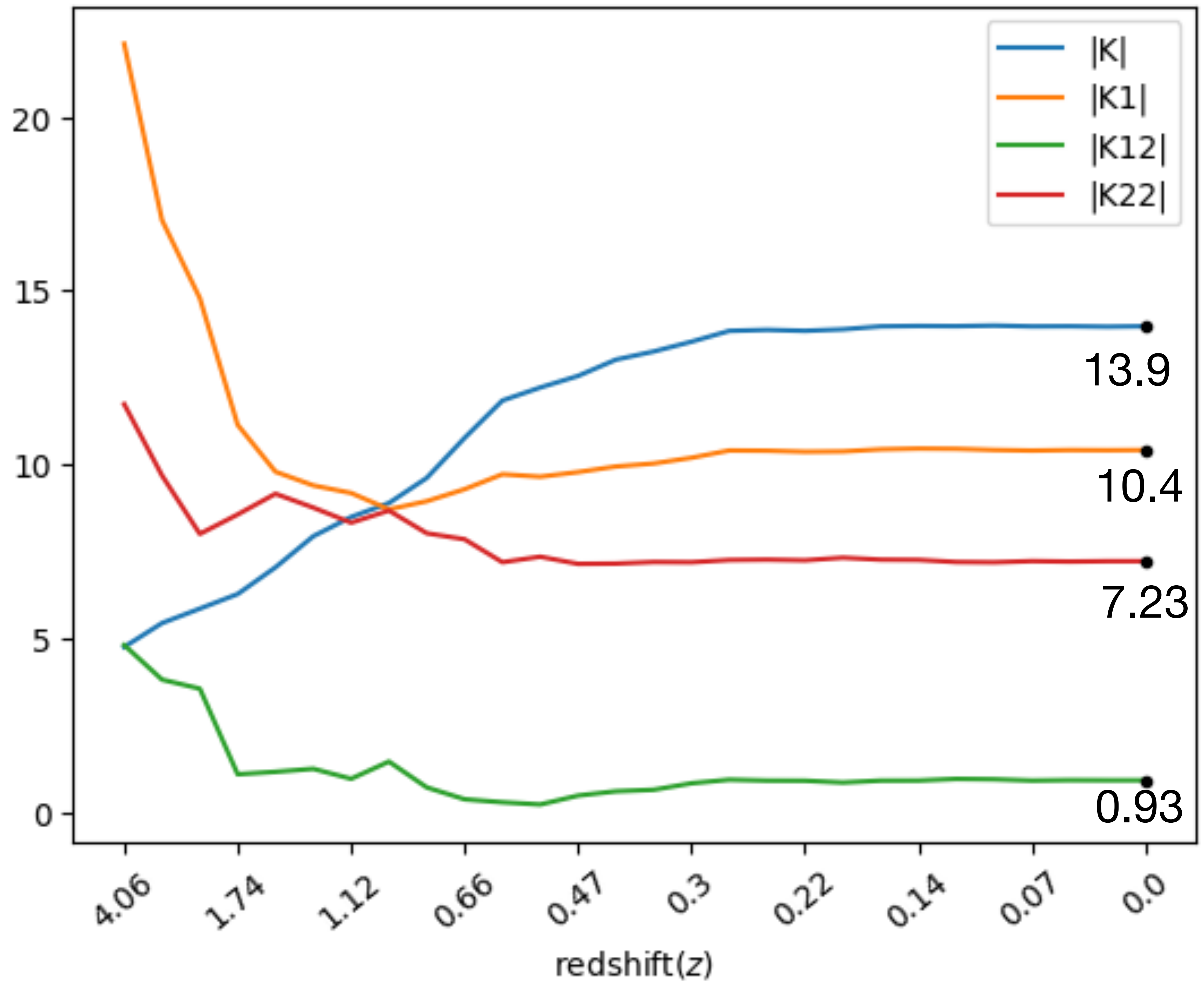
$$K_1^{(2)} = -\frac{4 \langle f |\nabla f|^2 \Delta f \rangle_c + \langle |\nabla f|^4 \rangle_c}{\sigma_0^2 \sigma_1^4},$$

$$K_2^{(2)} = -\frac{4 \langle f |\nabla f|^2 \Delta f \rangle_c + 2 \langle |\nabla f|^4 \rangle_c}{\sigma_0^2 \sigma_1^4},$$

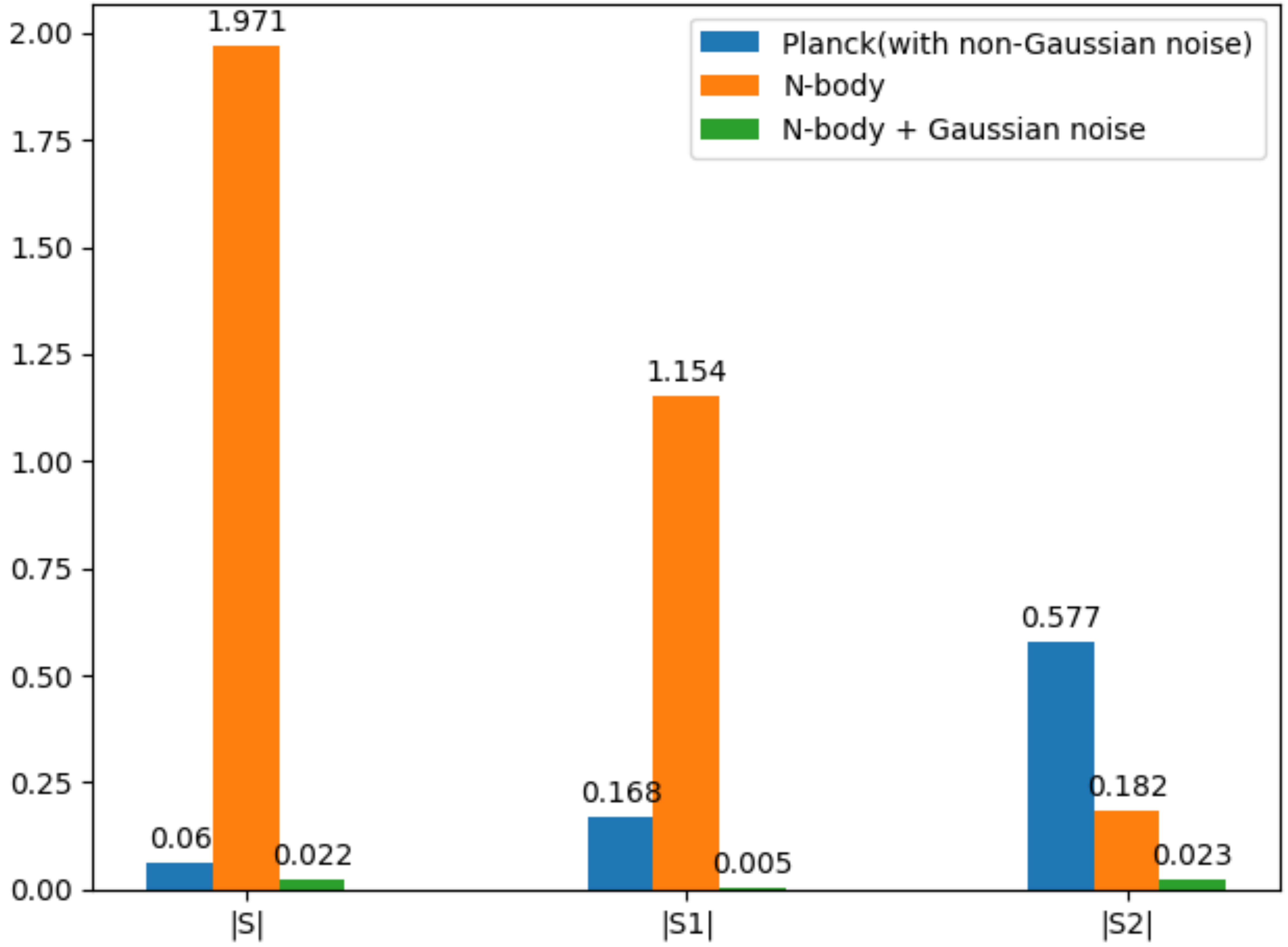
σ_0 and σ_1 are the standard deviation and first moment of the field

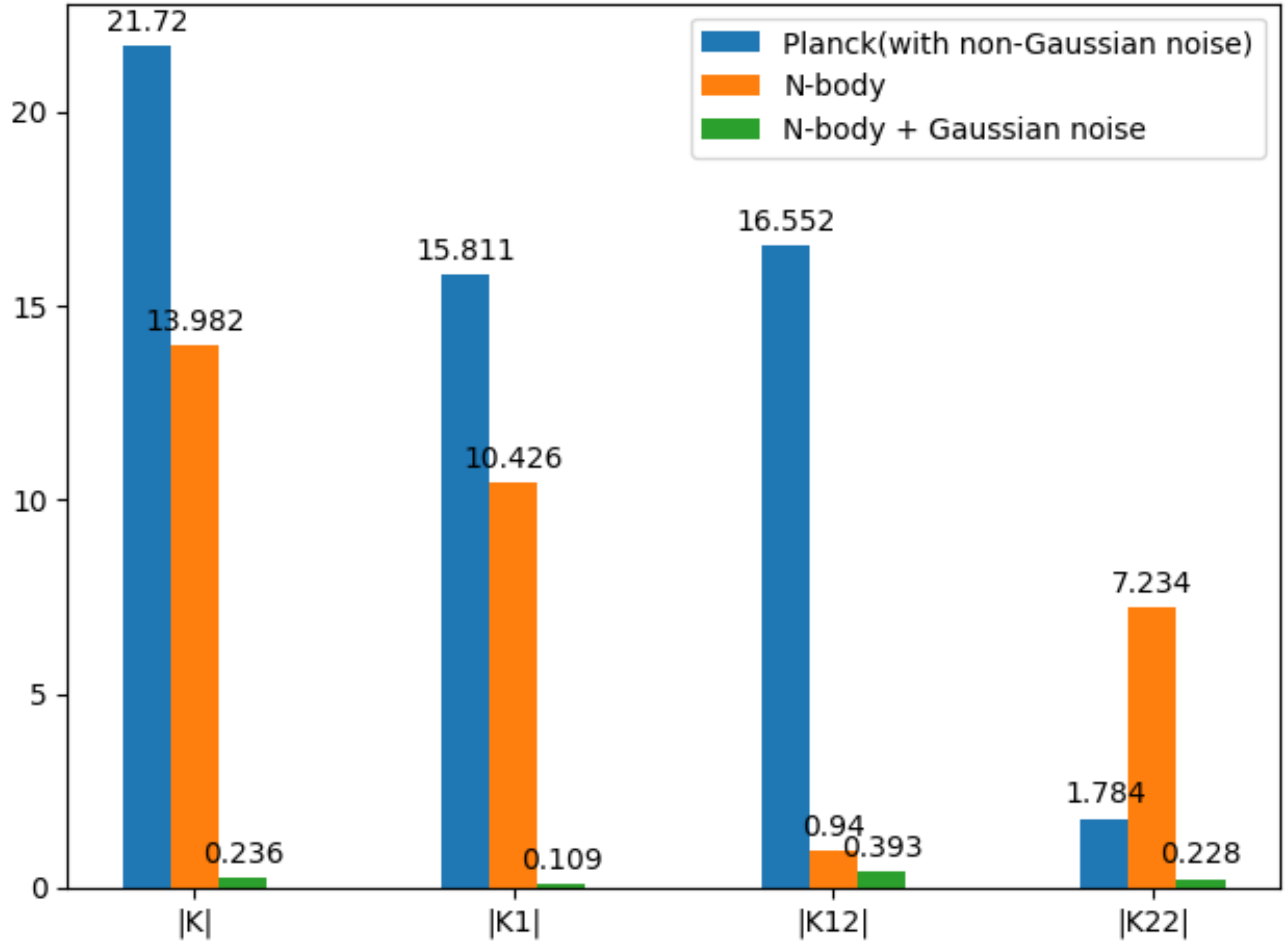
Non-Gaussian from full sky simulation





Compare with Planck CMB lensing reconstruction





Non-Gaussian information is dramatically dilute by the Gaussian reconstruction noise

Summary

- With decomposition of map, the Minkowski functionals have competitive constrain power compare to power spectrum result.
- For Planck CMB lensing reconstruction, the magnitude of non-Gaussian information in lensing signal is much smaller than the noise.
- The future higher resolution CMB observations like CMB-S4 could give higher signal to noise , which means non-Gaussianity in CMB lensing is still a promising probes for cosmology.