Systematics in delensing of CMB B modes and constraint on r

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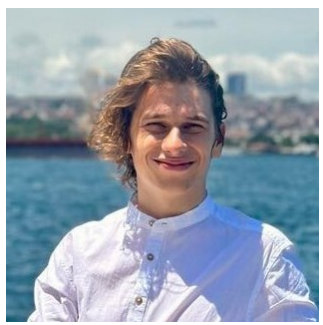
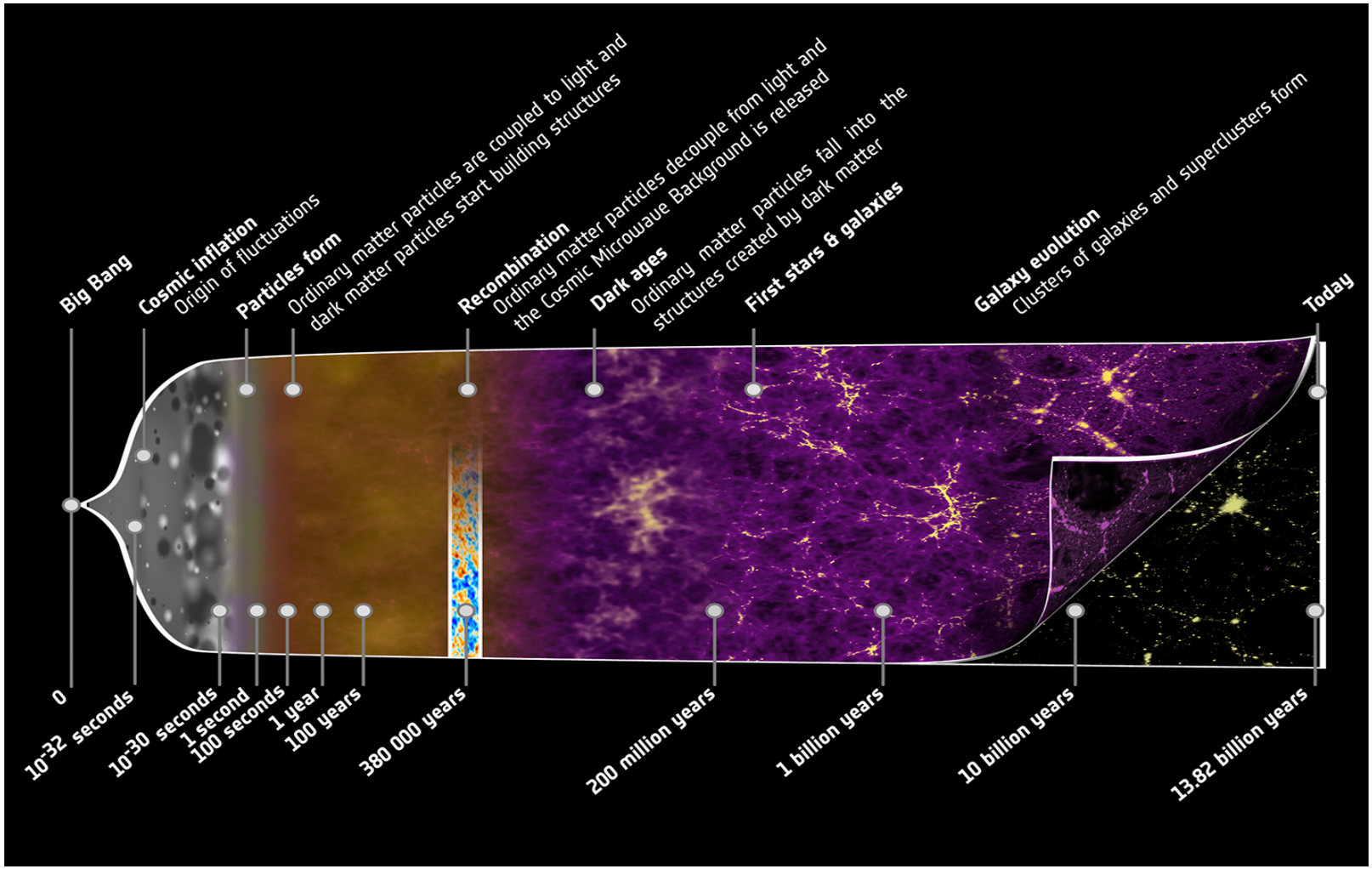


Paweł

Nicola

NARODOWE CENTRUM BADAŃ JĄDROWYCH ŚWIERK

Evolution of the Universe



Planck team(ESA)

CMB Polarisation : E and B modes

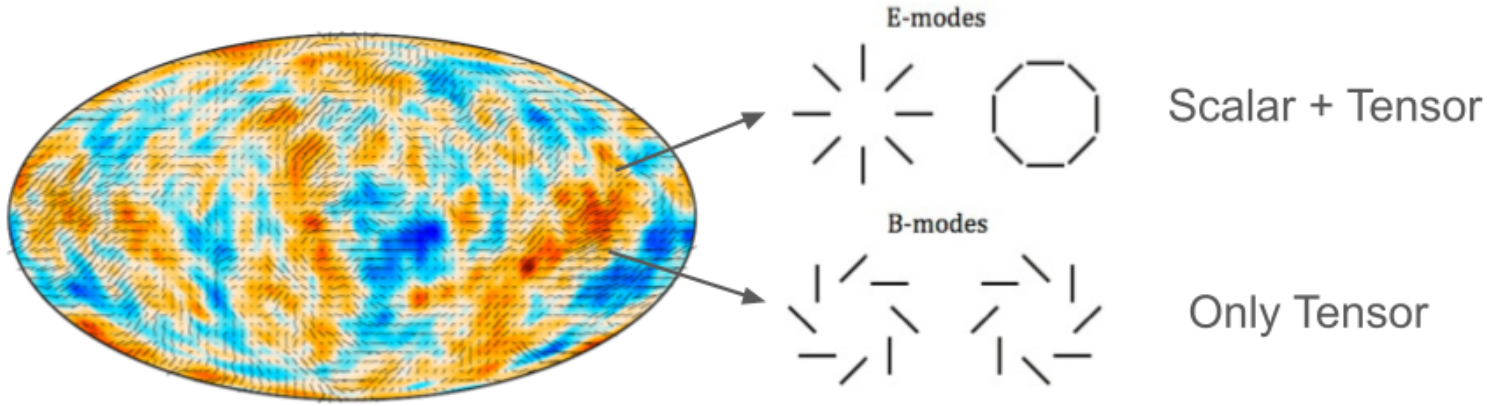


Figure: CMB polarisation

CMB Polarisation : E and B modes

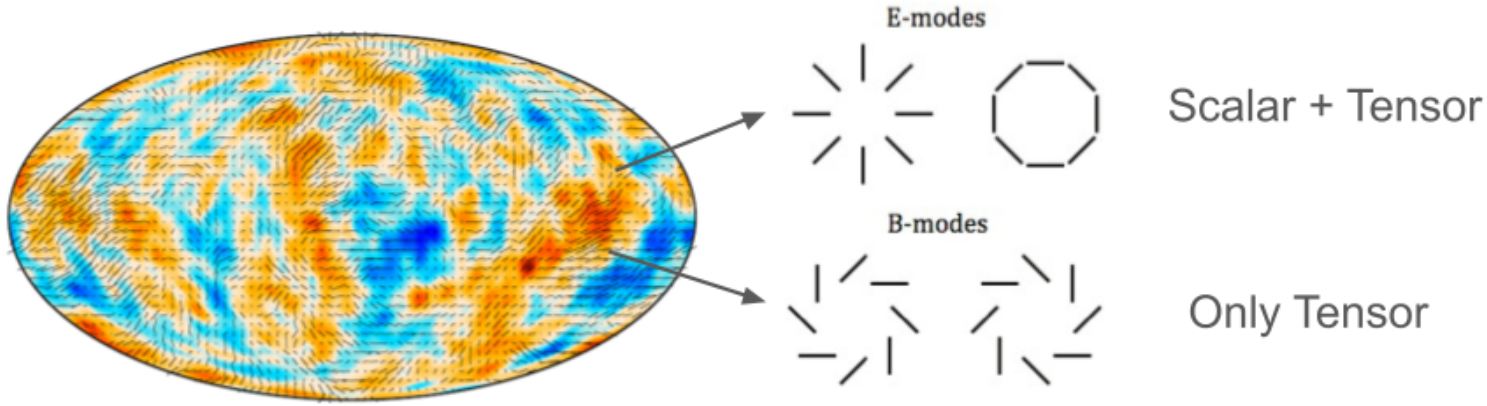


Figure: CMB polarisation

Inflationary gravity waves(**GW**) imprints Primordial B modes.

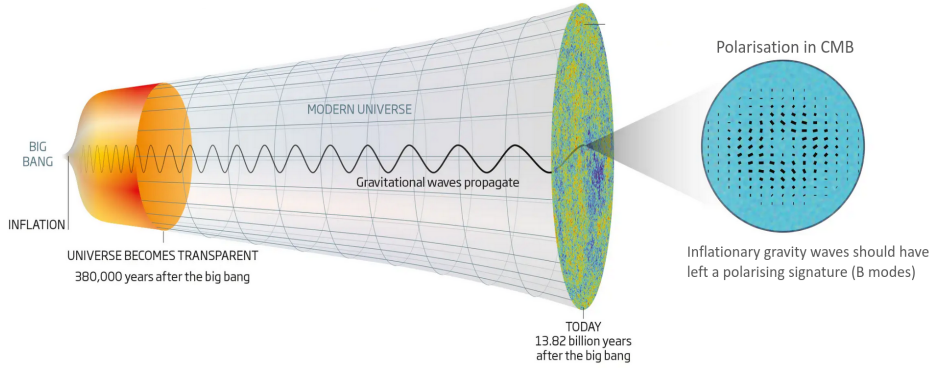


Figure: Primordial B mode pattern

Primordial tensor B-mode

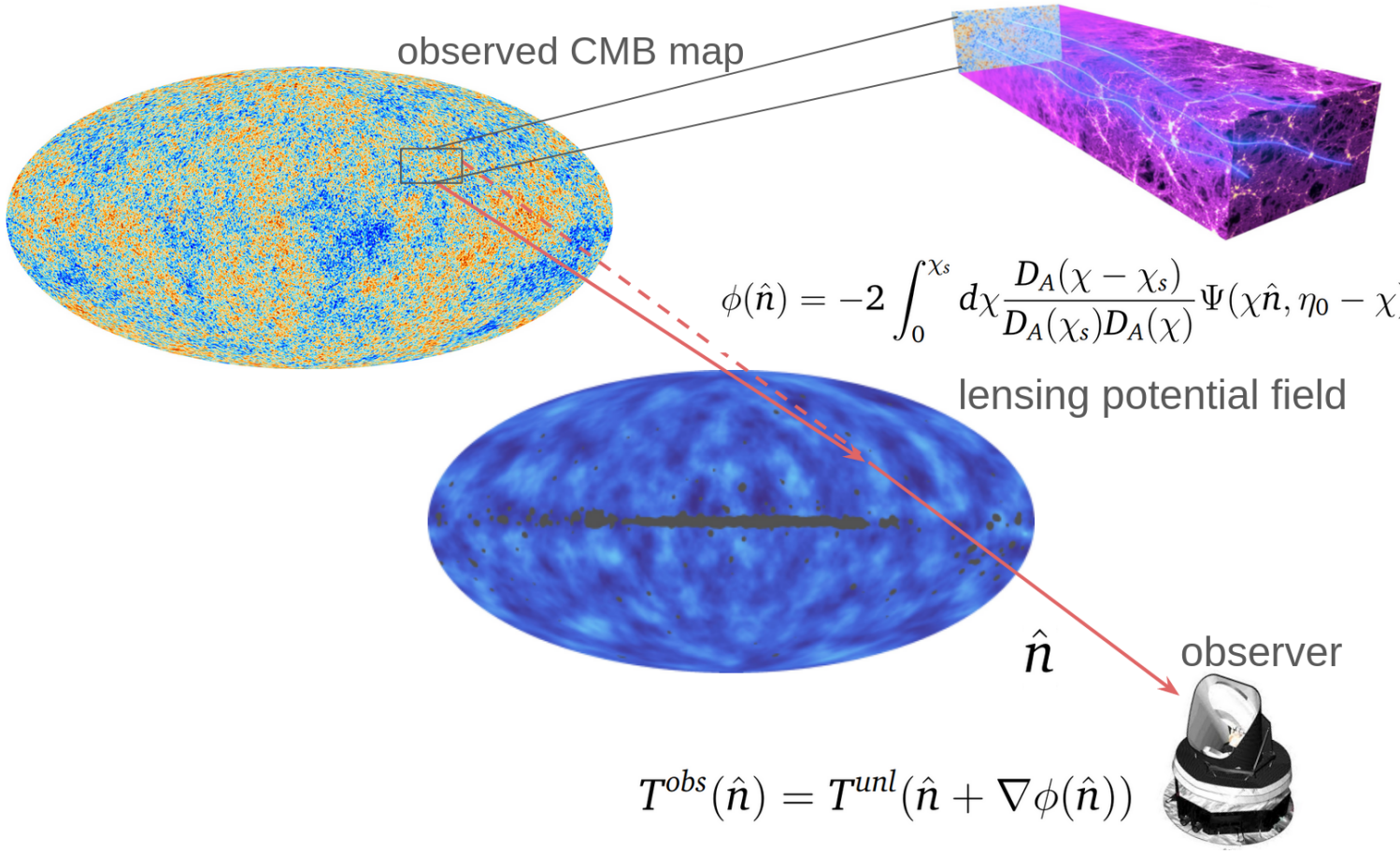
Ongoing and upcoming CMB experiments targets **Constraining the primordial gravity wave (PGW) amplitude** $\rightarrow$

Tensor-to-Scalar ratio

$$r = \frac{\text{amplitude of tensor fluctuations}}{\text{amplitude of scalar fluctuations}}$$

Next generation survey targets to achieve $r < 0.003$.

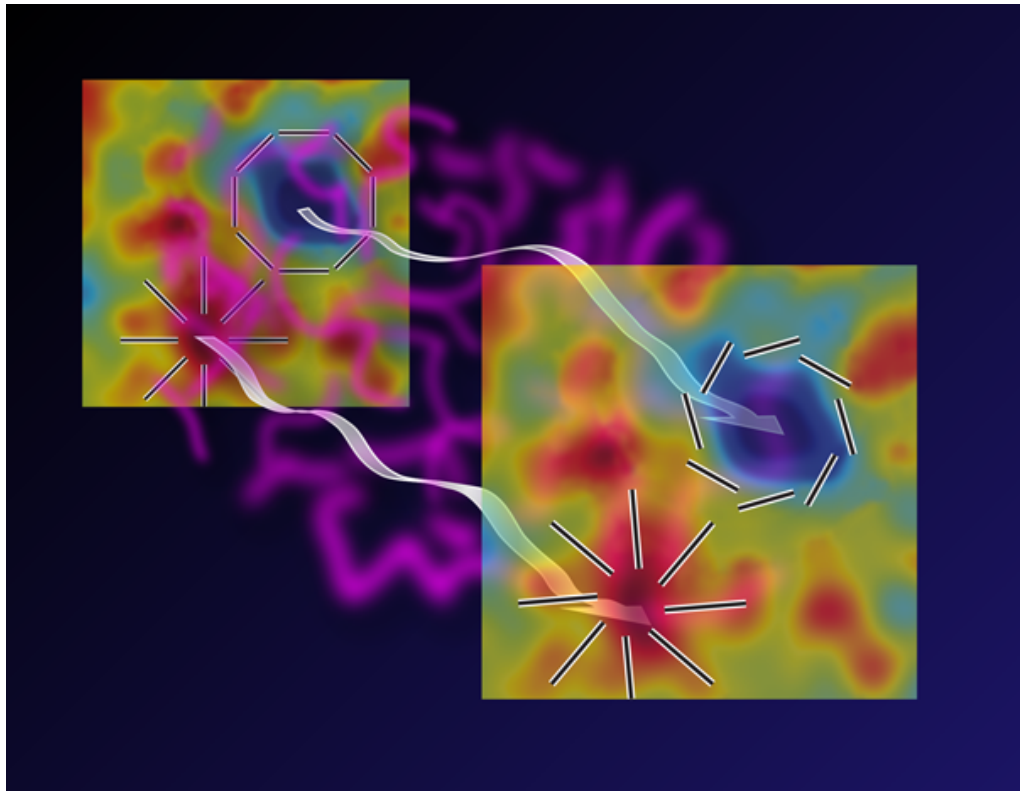
CMB weak lensing



Lensing field traces the integrated line-of-sight dark matter distribution and large-scale structures (LSS).

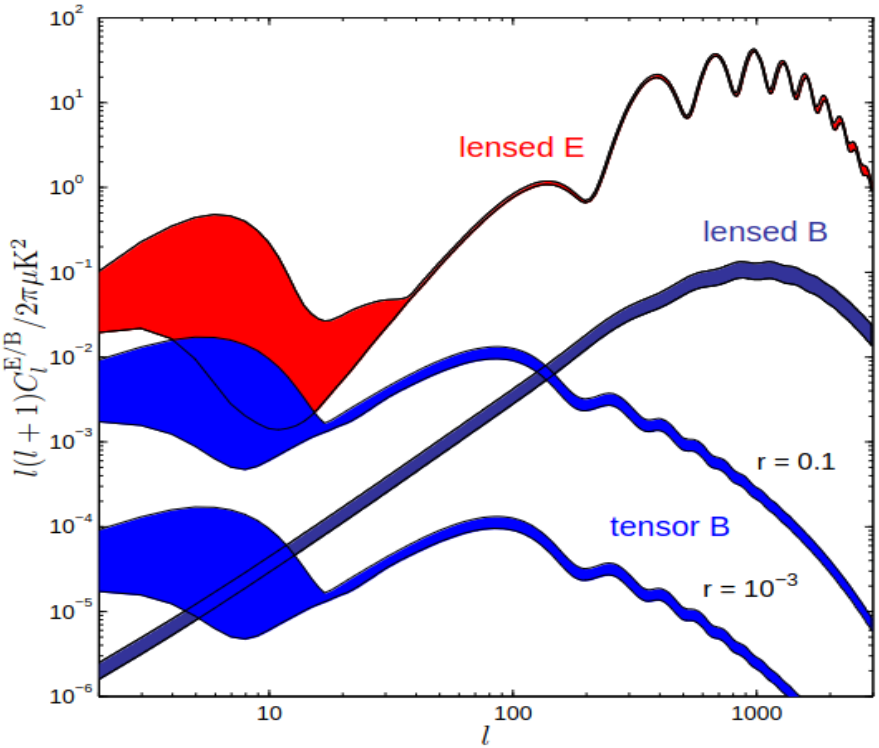
Lensing B modes

- Lensing twists primordial E modes
  $\Longrightarrow$ generates lensing B modes



APS / Alan Stonebrake

Lensing B-mode vs. Tensor B-mode



Lewis, Challinor (2006)

Lensing B modes dominates over tensor B modes ($r \sim 10^{-3}$).

Motivation

- Reconstruction of the lensing potential field.
- Subtract lensed B-mode template from observed signal.
- Improve constraints on tensor-to-scalar ratio (r).

Step-1 : Lensing reconstruction

Quadratic Estimator [Hu & Okamoto (2002)]

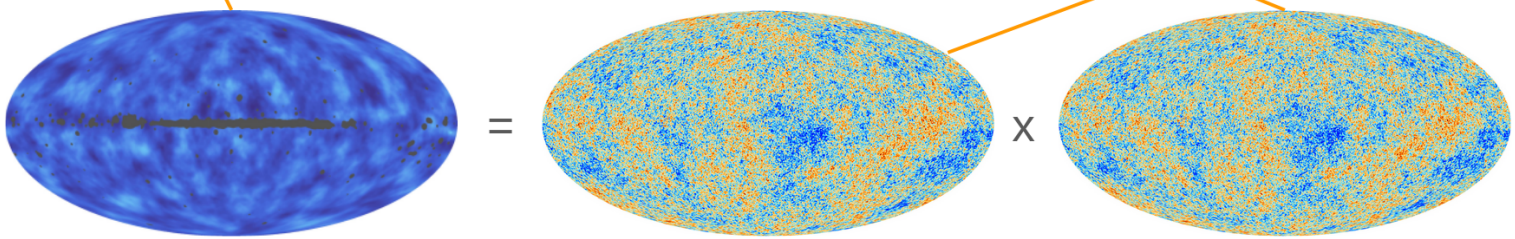
$$\hat{\phi}_{LM} = \frac{(-1)^M}{A_L^{XY}} \sum_{l_1 m_1, l_2 m_2} \begin{pmatrix} l_1 & l_2 & L \\ m_1 & m_2 & M \end{pmatrix} \left[\mathcal{W}_{l_1 l_2 L}^{XY}\right]^* \bar{X}_{l_1 m_1} \bar{Y}_{l_2 m_2}$$

Lensing estimate

Normalisation

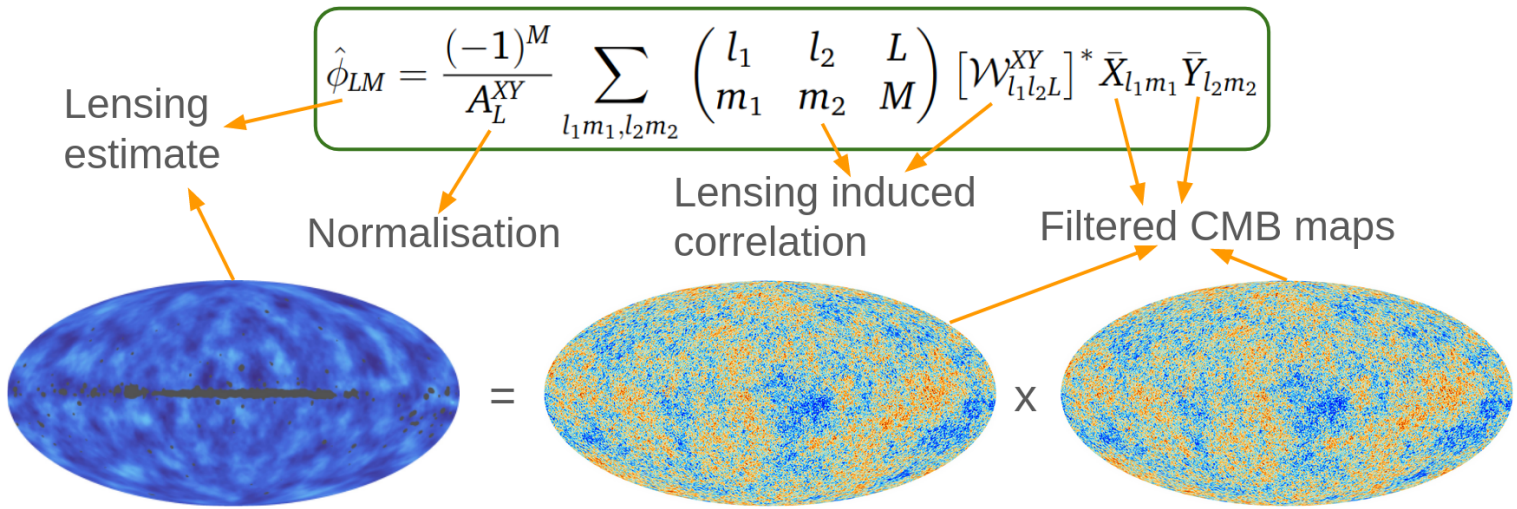
Lensing induced correlation

Filtered CMB maps

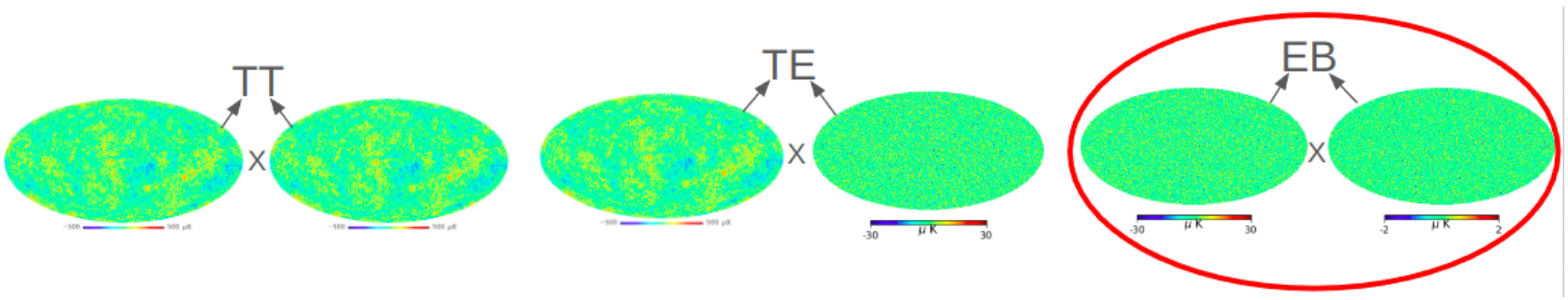


Step-1 : Lensing reconstruction

Quadratic Estimator [Hu & Okamoto (2002)]



Different pairs of CMB observations



Step-2 : Delensing of B-mode

Template-based delensing

Lensed B-mode template: $B^{template} = E^{obs} \circ \phi^{recon.}$

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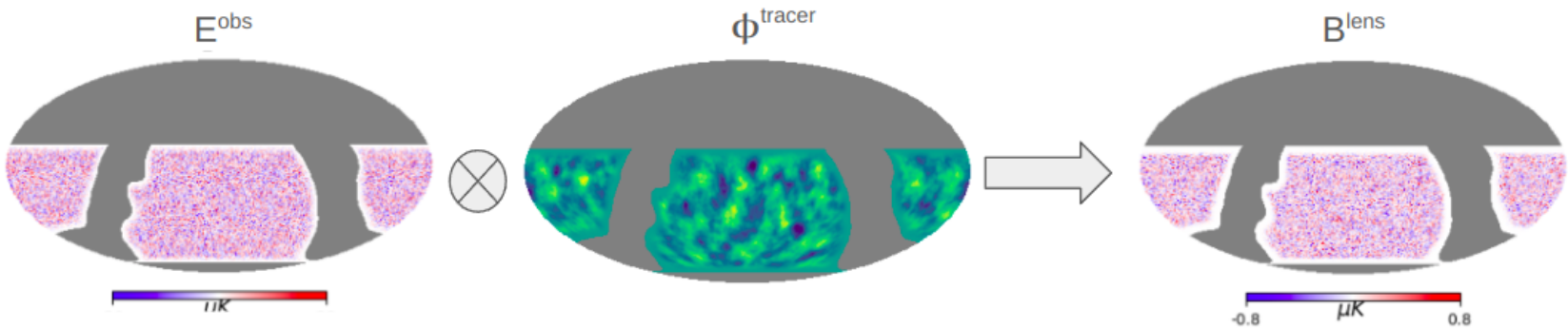

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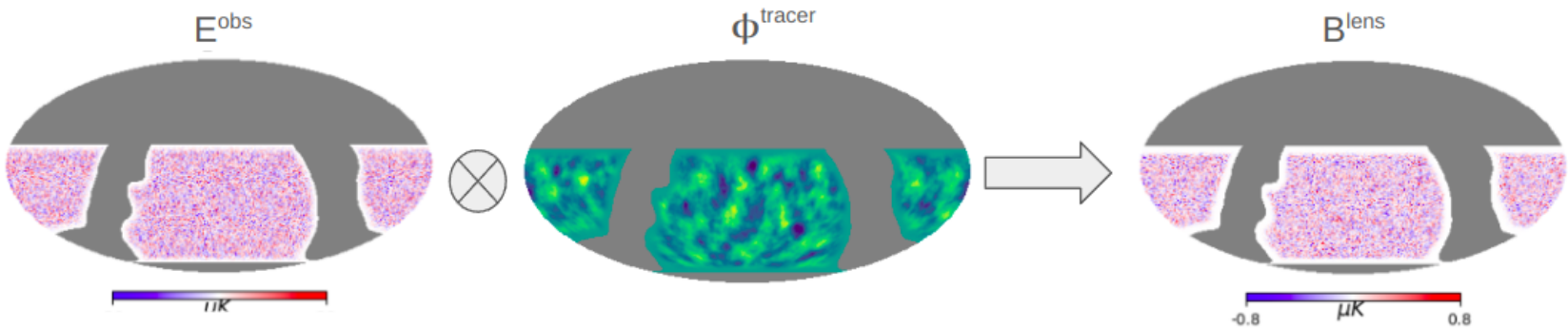
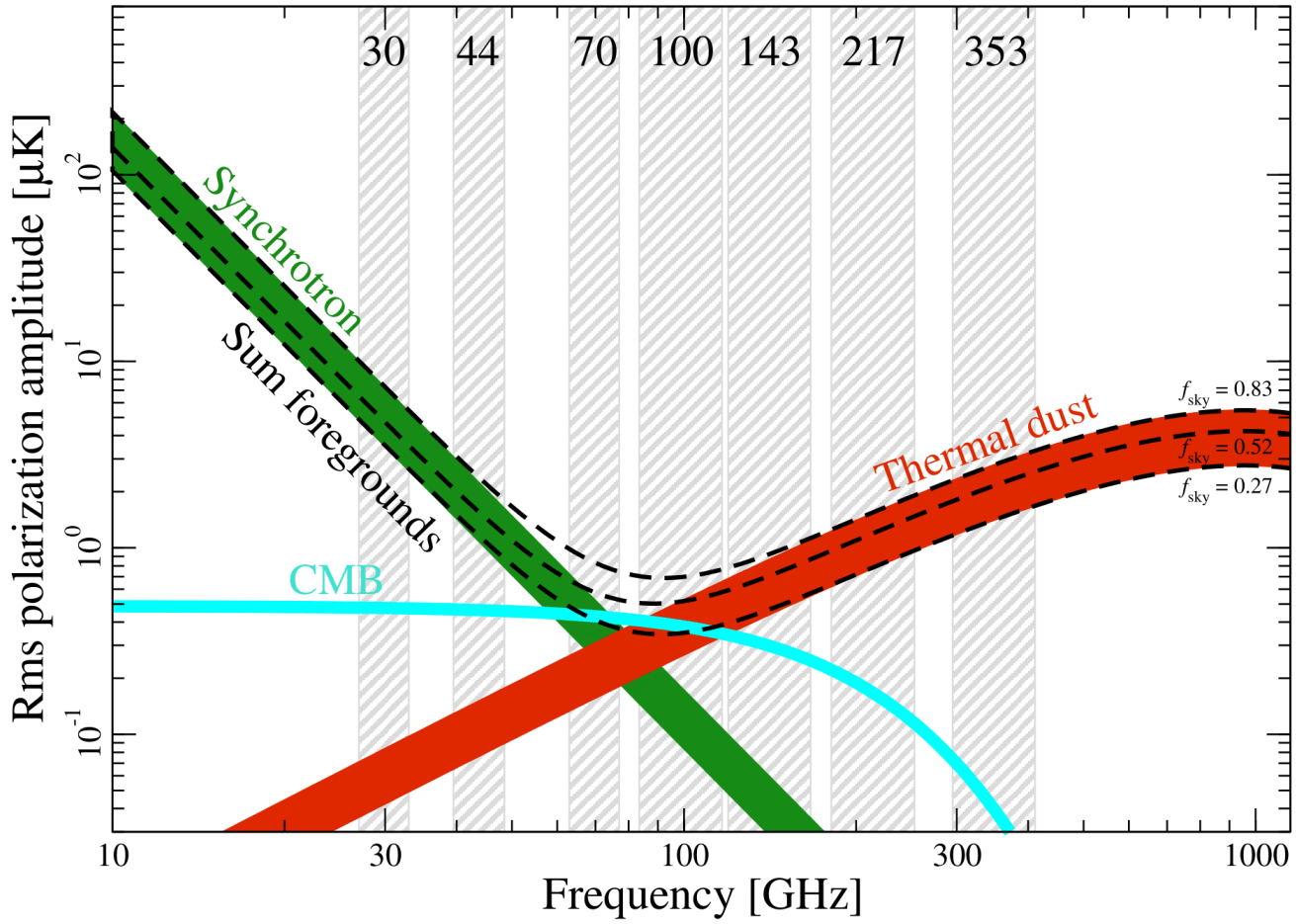


Delensing : $B^{del} = B^{obs} - B^{template}$

[Smith et al. (2012)]

Galactic foregrounds



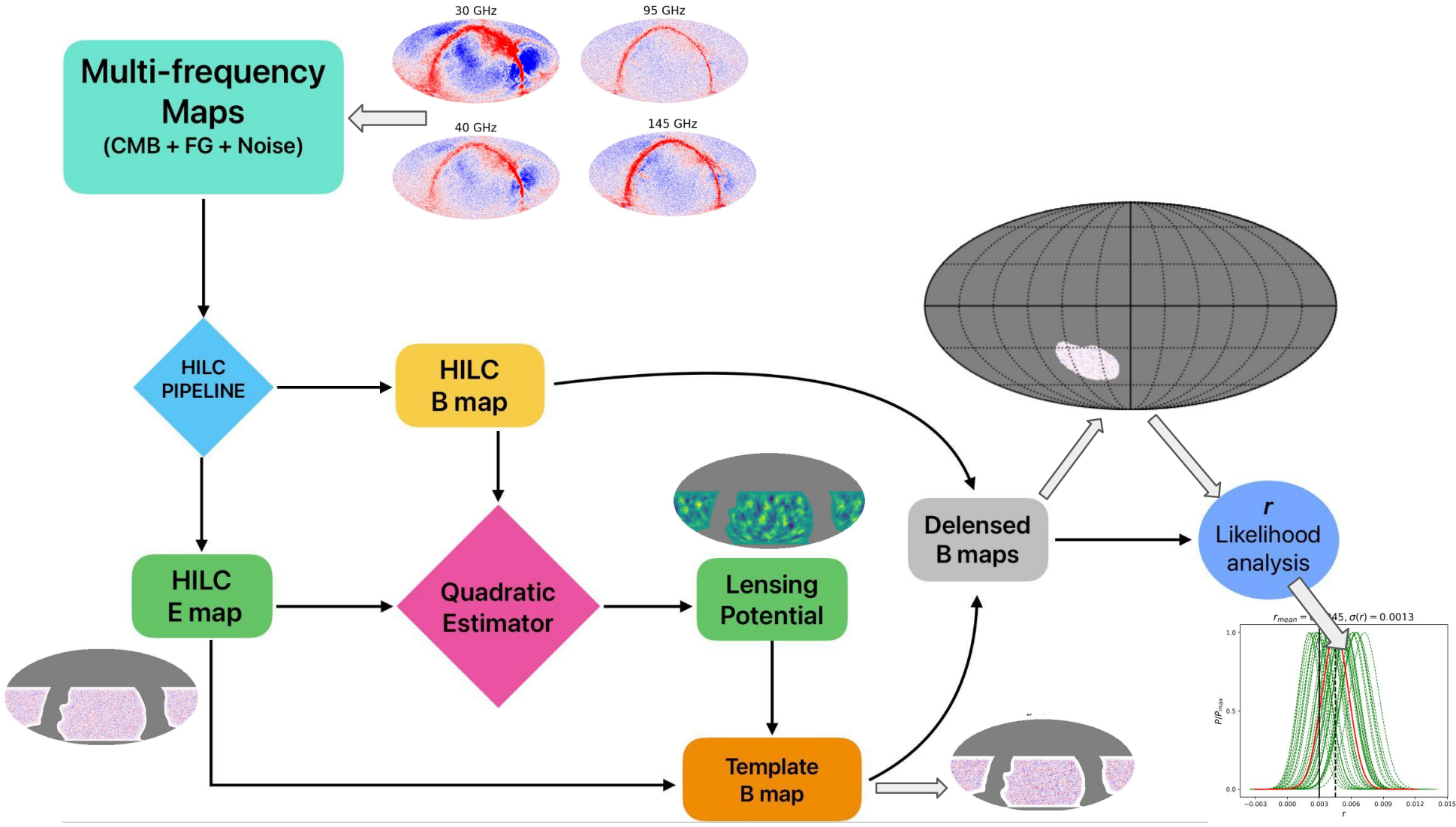
Planck 2018 results IV

What is the impact of Galactic foregrounds on the lensing reconstruction and on the delensed B modes?

... in the context of CMB-S4–like experiment.

Check out : arXiv:2511.11147 **(submitted to A & A)**

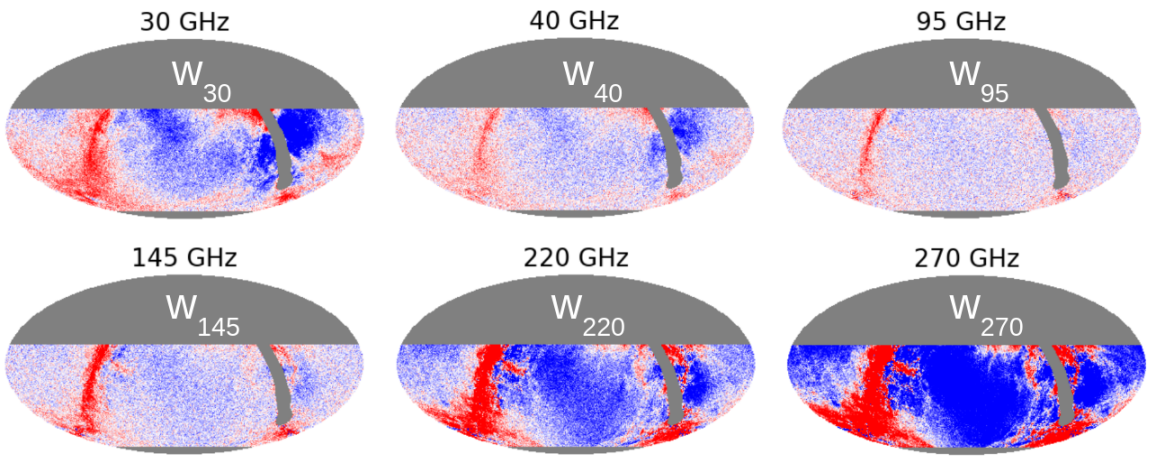
The workflow



Component Separation

Internal Linear Combination (ILC) of multi-frequency observations, D^i,

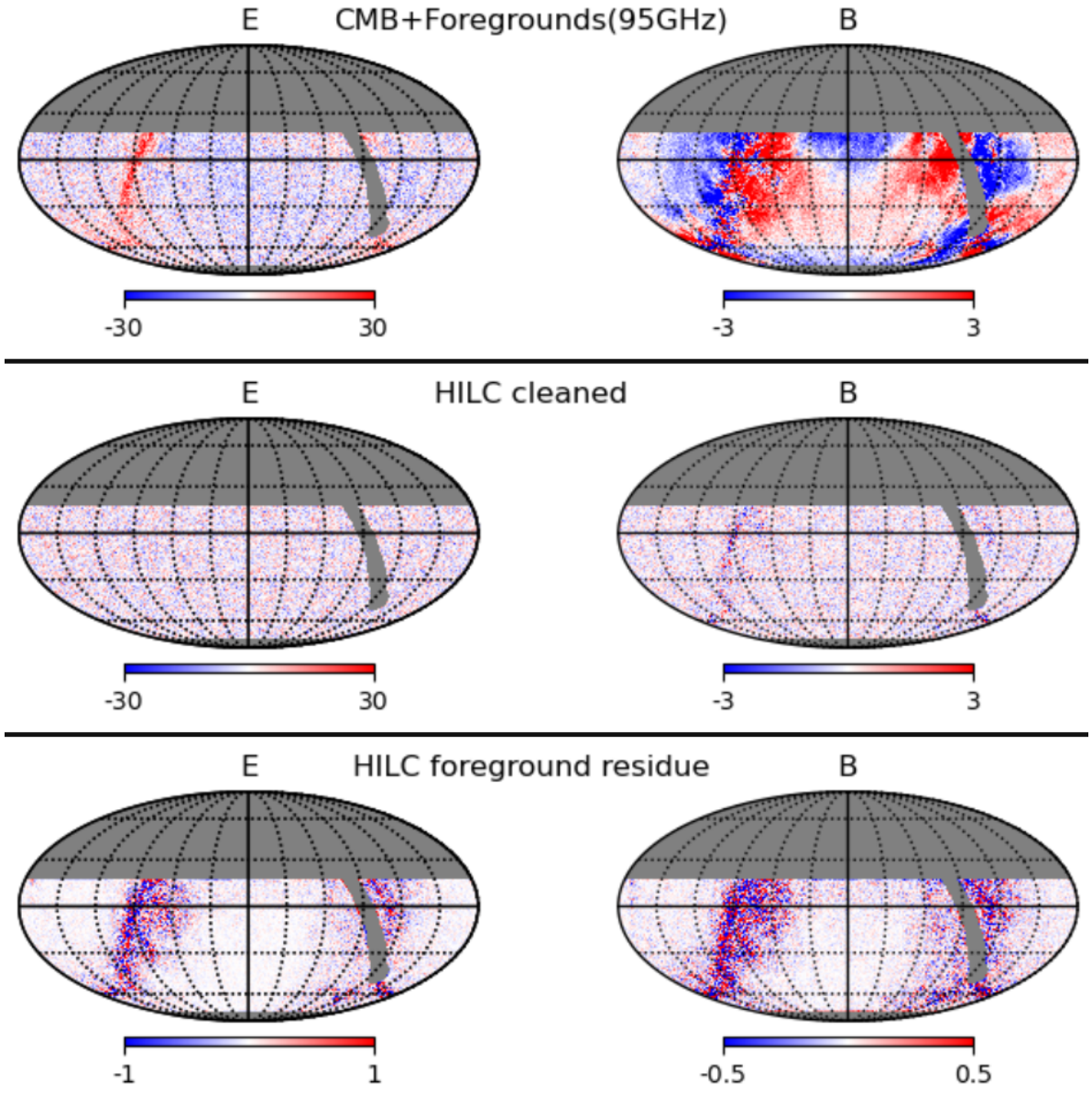
$$T^{CMB}(\hat{n}) = \sum_i w_i D^i(\hat{n}) \quad \text{for} \quad i \in \{1, \ldots, N_c\}$$



Minimize variance of T^{CMB} under the constraint $\sum_i w_i = 1$

We do it in Harmoinc (Fourier) space, so it is Harmonic ILC.

Harmonic ILC (HILC)



Biases in lensing reconstruction

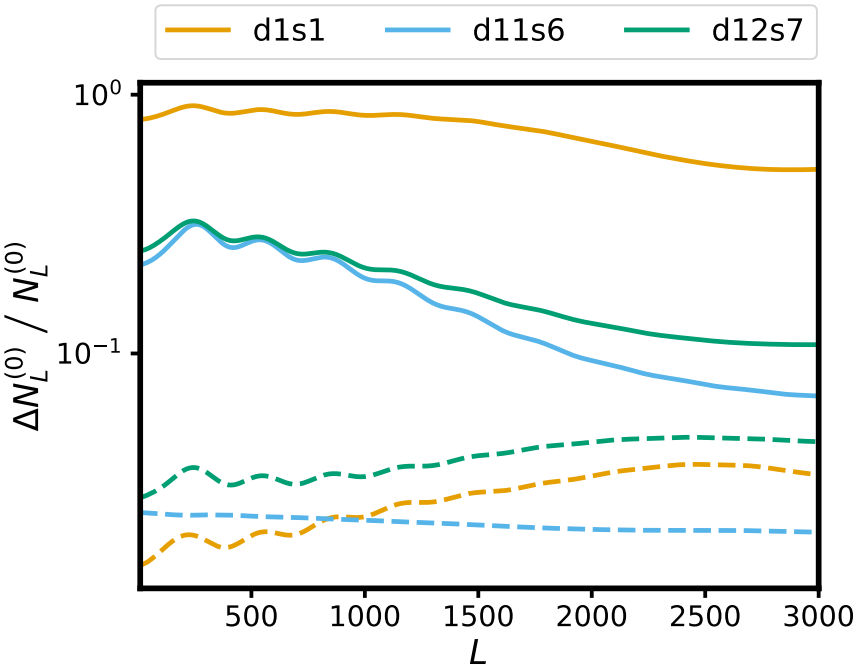
We did lensing reconstruction for two cases :

(I) **Medium Frequency :** averaged 95+145 GHz maps before component separation.

(II) **HILC products :** Harmonic ILC maps after component separation.

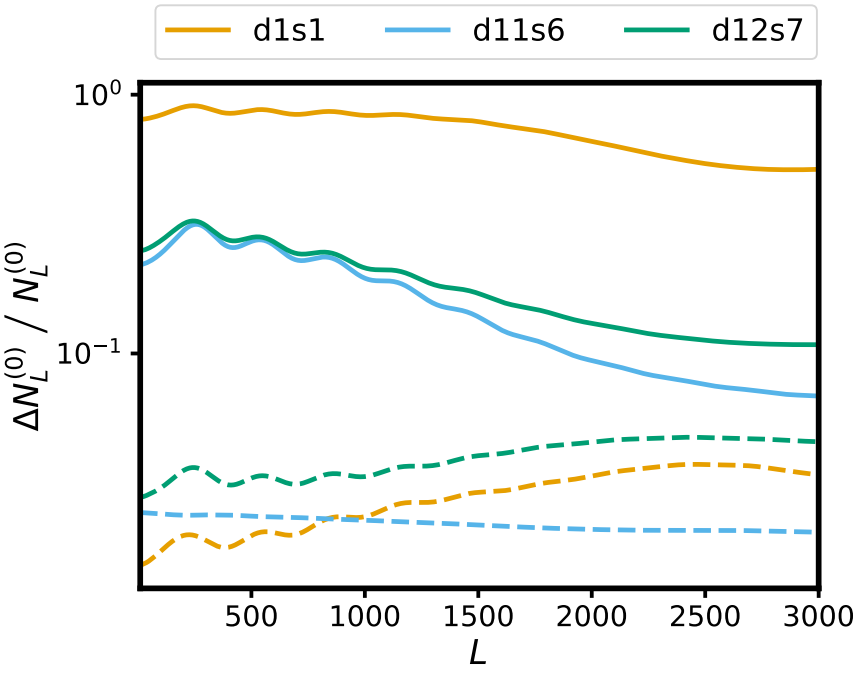
Both maps have same noise realisations.

Biases in lensing reconstruction



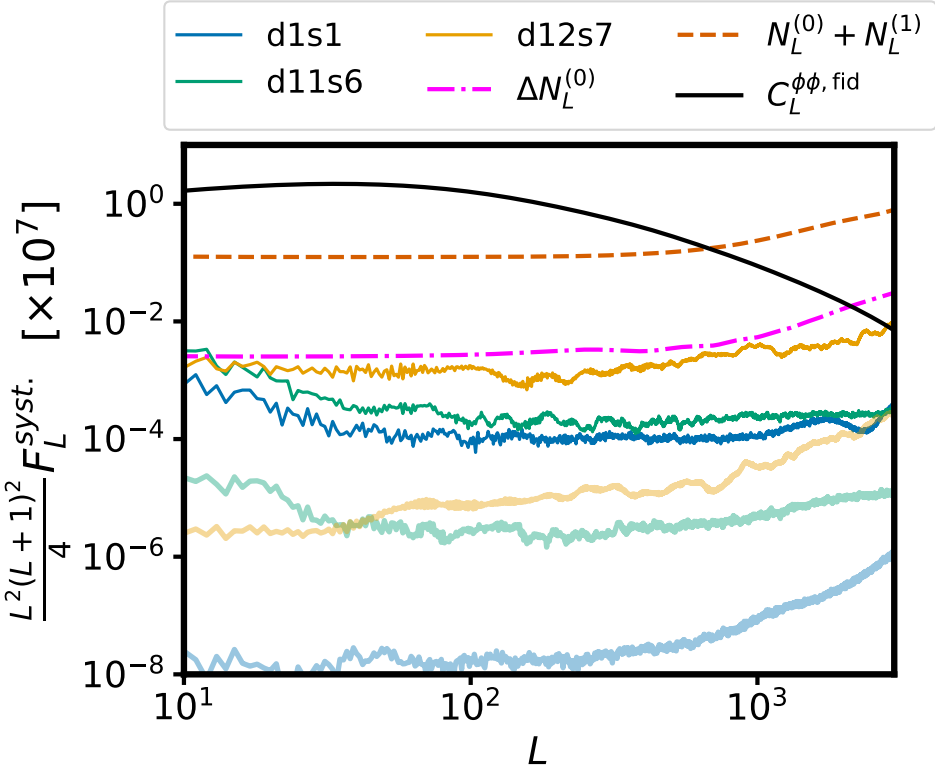
$\Delta N_L^{(0)}$ is the increase in reconstruction noise due to presence of foregrounds.

Biases in lensing reconstruction



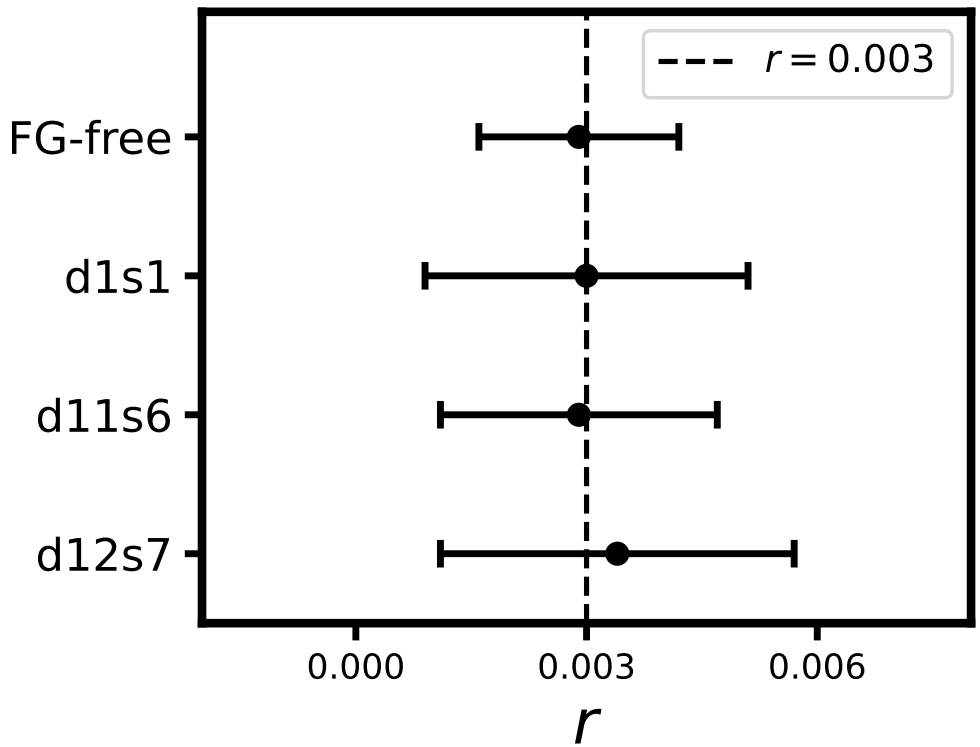
$\Delta N_L^{(0)}$ is the increase in reconstruction noise due to presence of foregrounds.

$F_L^{\text{syst.}}$ is the systematic bias in reconstructed lensing power spectra due to foregrounds.



Impact on r constraint

$$C_l^{BB,\,\mathrm{del}} = r\,C_l^{BB,\,\mathrm{tens}} + C_l^{BB,\,\mathrm{res}} + C_l^{BB,\,\mathrm{fgres}} + C_l^{BB,\,\mathrm{noise}}$$



Mean r and $\sigma(r)$.

Impact on r constraint

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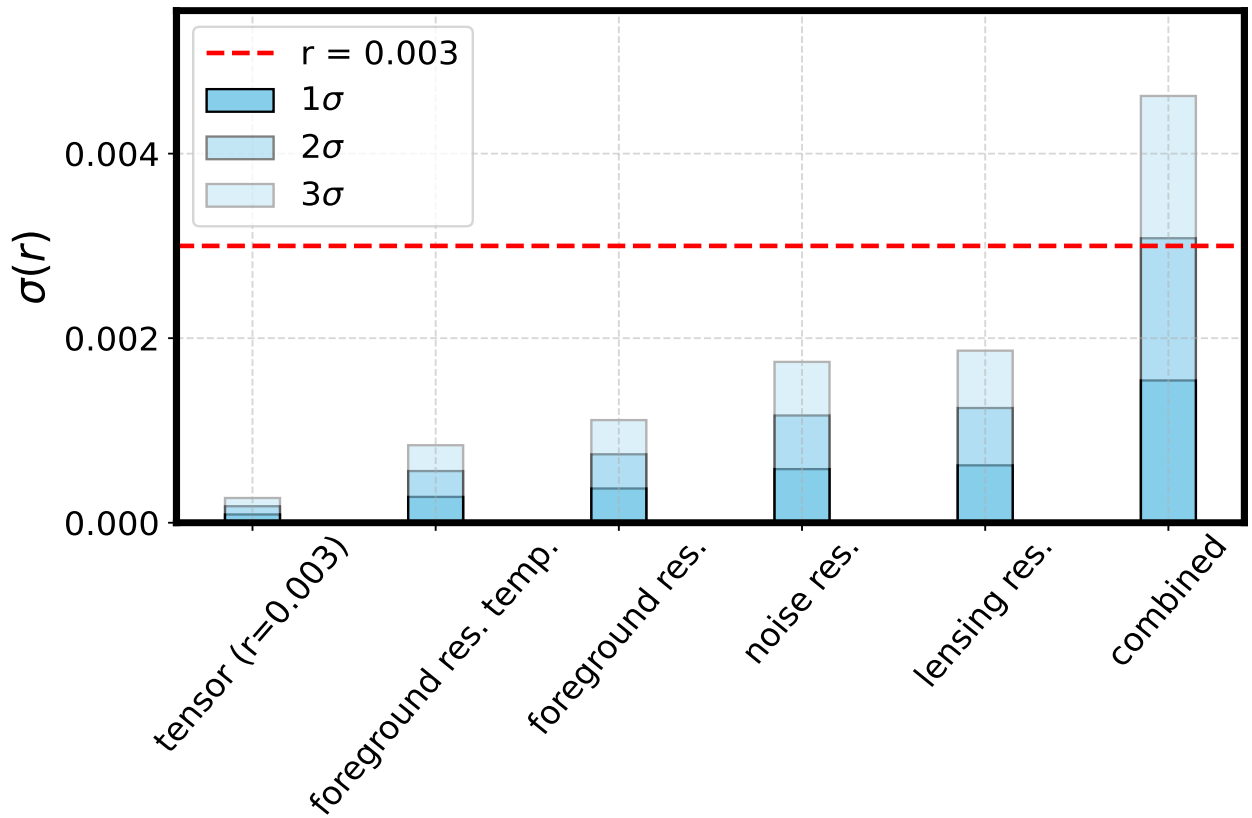
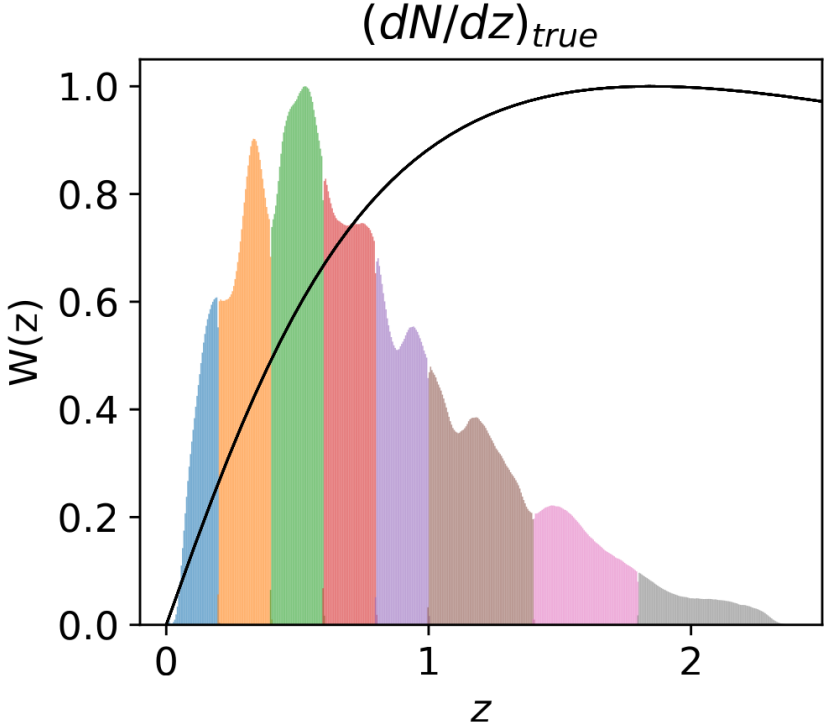


Contribution to $\sigma(r)$.

Delensing using LSS tracers

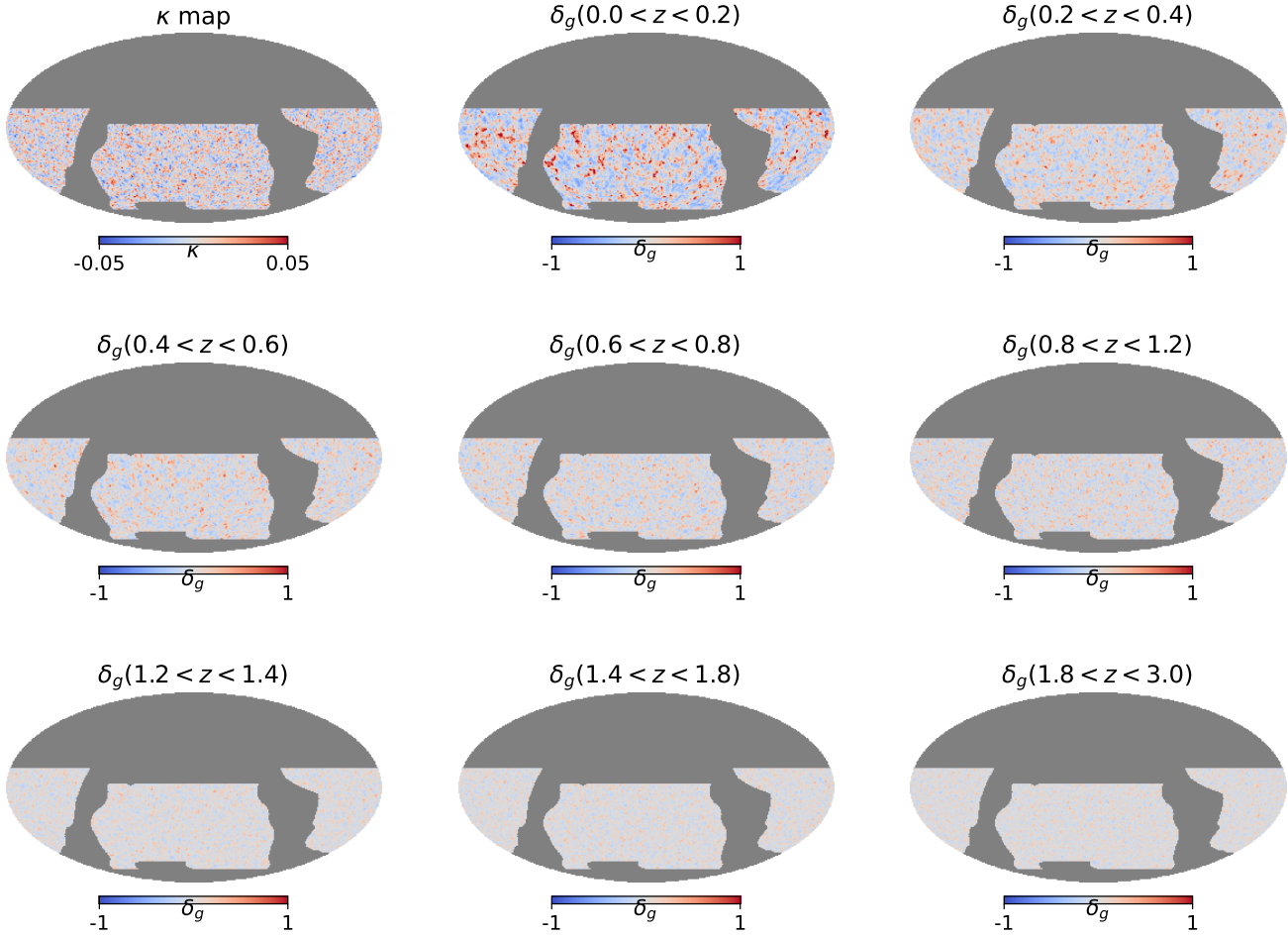
Question : How much does multi-tracer approach improve CMB delensing?

What about **CMB x LSST** ?



LSST Y10 redshift distribution from RAIL.
[RAIL Team et al. (2025)]

Correlated δ_g and κ



Correlated log-normal galaxy overdensity and CMB lensing convergence fields using `GLASS` code [Tessore et. al. (2023)].
Simulations created by **Chandra Shekhar Saraf (KASI)**

Delensing with CMB x LSST

Lensing template: $B^{template} = E^{obs} \circ \phi^{recon.} + \sum_i E^{obs} \circ (c_i \delta^i)$

with optimal weights, c_i, that are function of auto and cross power spectra. [Manzotti (2017)]

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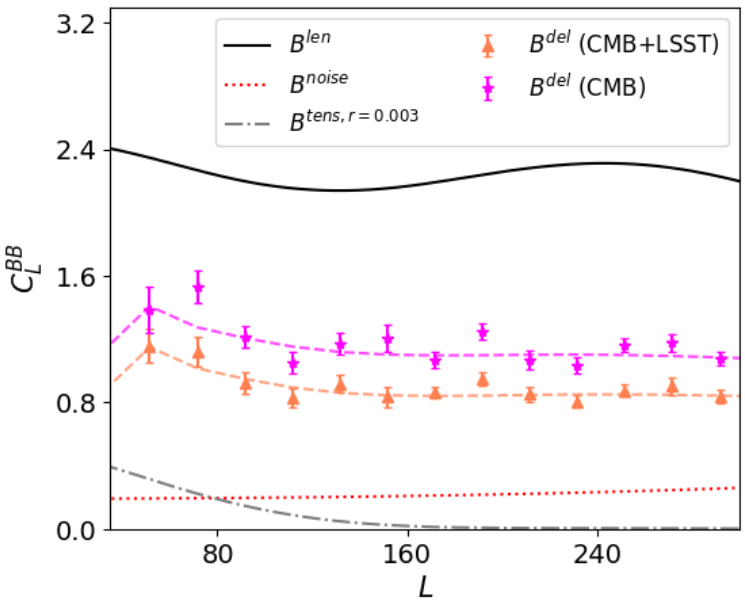

Delensed B modes

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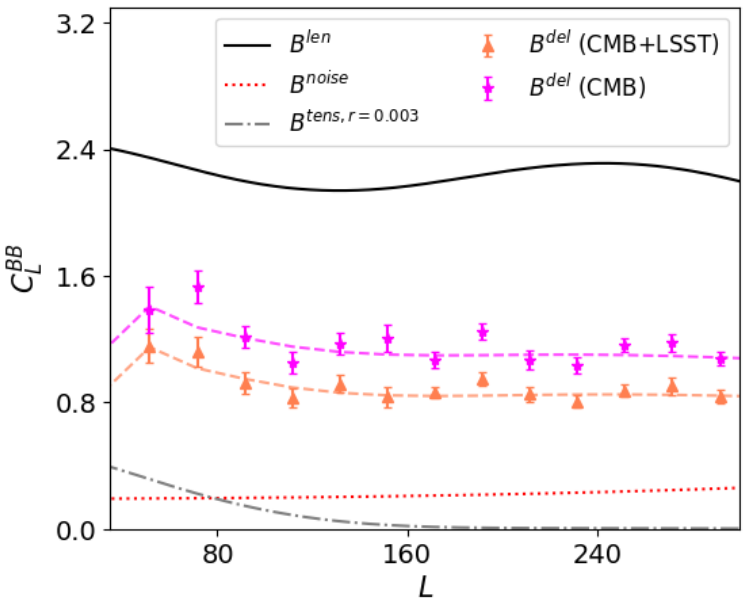
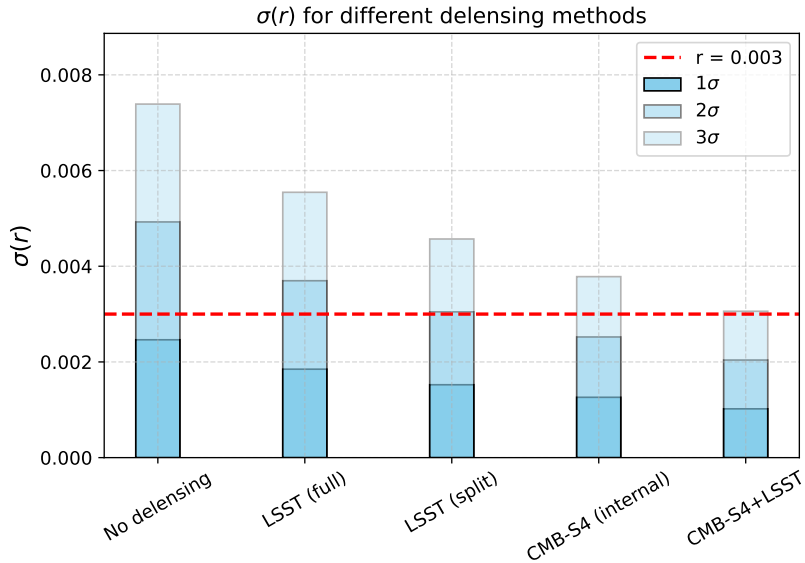


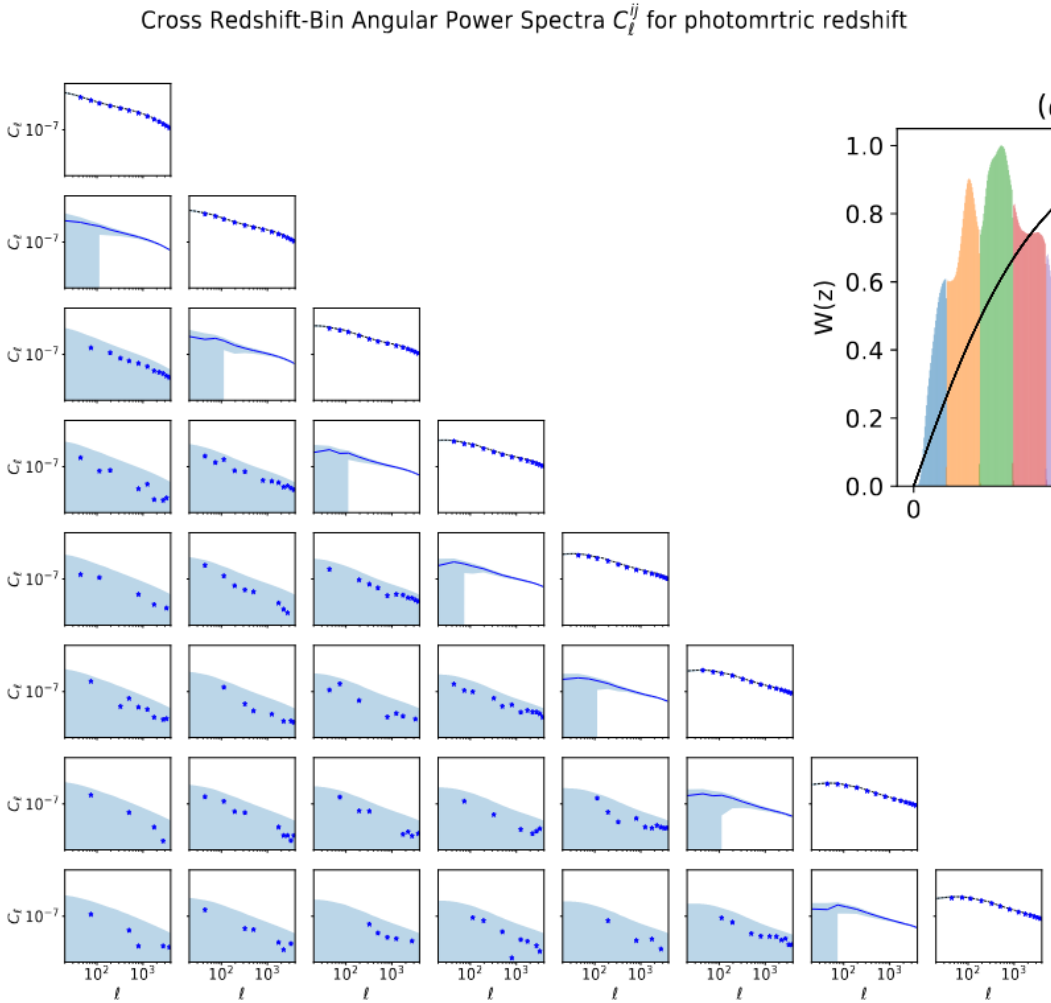
Delensed B modes

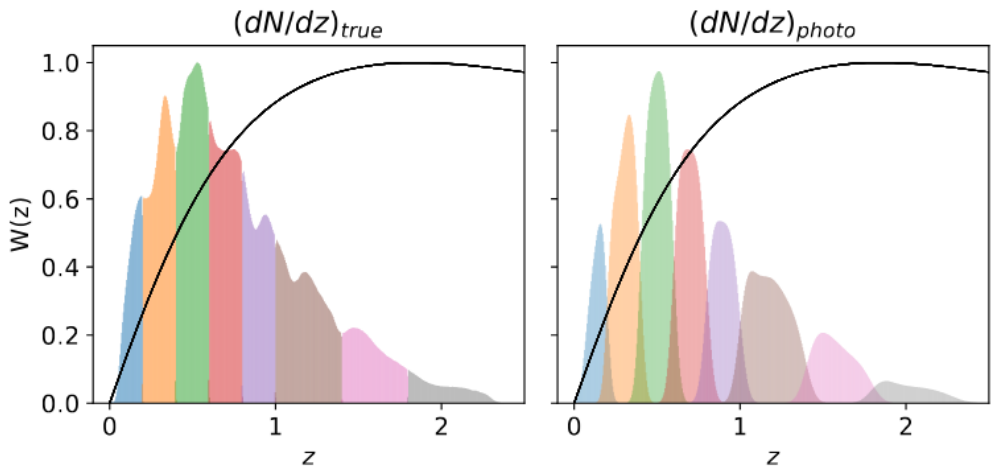


Constraints on r

Photometric redshift distribution

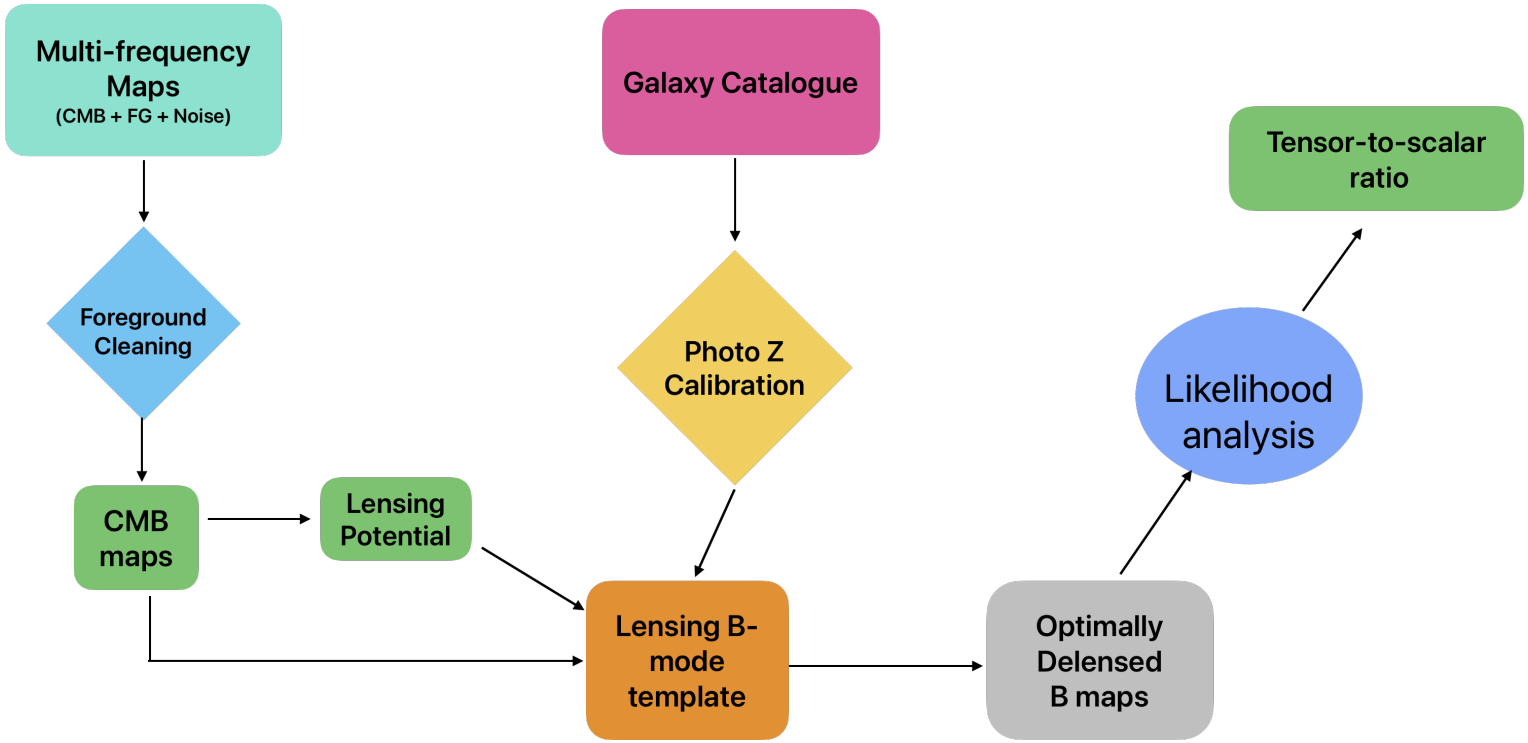
Photometric redshift error introduces correlation between redshift bins.





Optimal delensing pipeline

SO x LSST (in prep.)



Impact of photometric redshift bin mismatch error on tensor-to-scalar ratio contraints.

Take away

- Constraint on r is mostly **lensing residue limited** for the case of internal delensing using QE.
- Residual foreground in delensed B-mode maps contributes to **60%** increase in uncertainty of r.
- Improved delensing with tomographic cross-correlation between CMB and galaxy survey is possible.
- Photometric redshift errors may need extra care for upcoming **SO x LSST** delensing studies.

THANK YOU!