Improved full-sky reconstruction of the gravitational lensing potential through the combination of Planck and LiteBIRD CMB data

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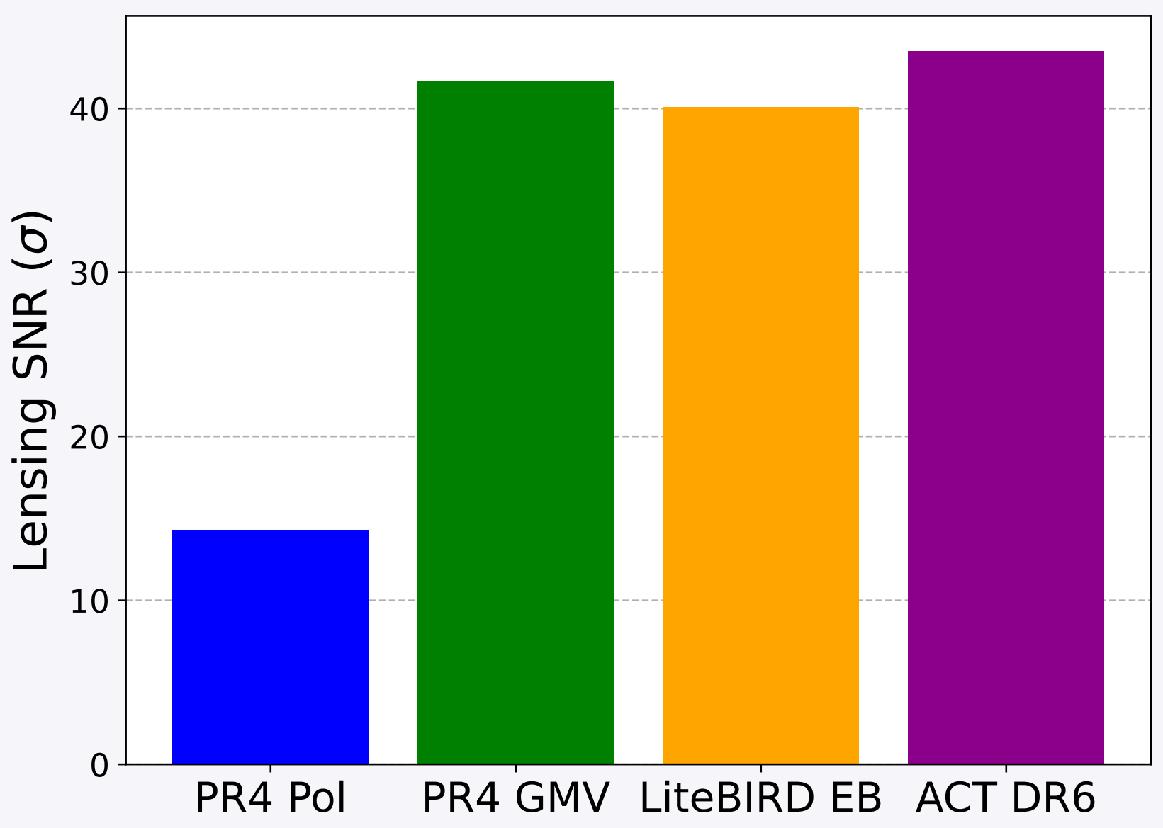
MOTIVATION

- The *Planck* team successfully measured a $\sim \mathbf{40\sigma}$ lensing map relying mostly on CMB temperature information using the Generalized Minimum Variance estimator, GMV [1, 2]. *Planck*'s polarization-only reconstruction leads to a $\sim \mathbf{15\sigma}$ detection, having a minor impact on the GMV.
- Despite its low angular resolution, LiteBIRD [3] will provide high-precision measurements of the CMB polarization that would allow the reconstruction of an independent lensing map of signal-to-noise comparable to *Planck*'s but with polarization information alone [4]. Exploiting the complementarity between both experiments, a combined analysis of LiteBIRD's large-scale polarization data and *Planck*'s high-resolution temperature anisotropies will provide the **best lensing full-sky measurement to date**.



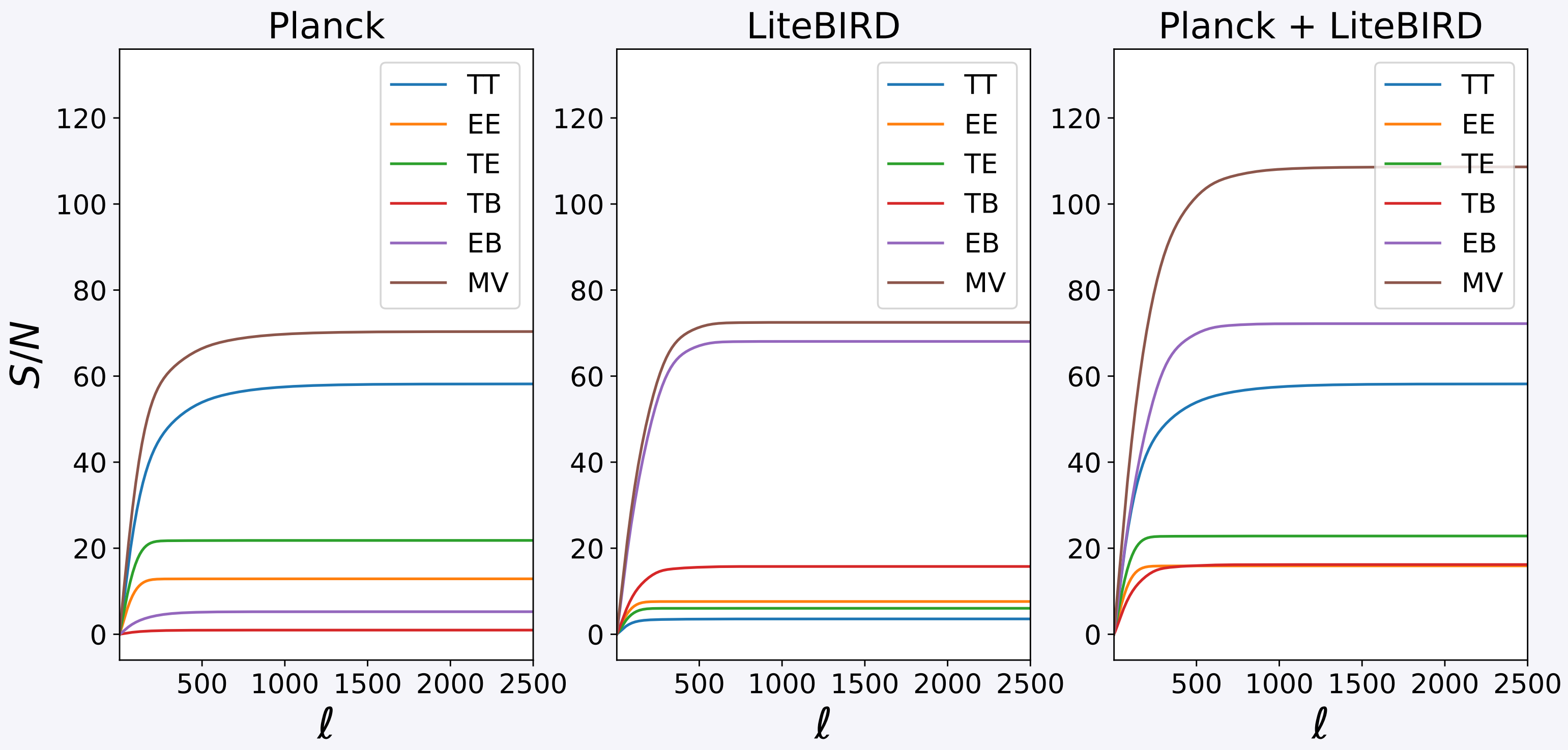
PRELIMINARY RESULTS

- From the theoretical (and idealized) power spectra of *Planck*, LiteBIRD, and the combination of both of them, we have computed the signal-to-noise ratio (S/N) of the lensing reconstruction,

$$S/N = \left(\sum_\ell \frac{s_\ell^2}{\sigma_\ell^2}\right)^{1/2} = \left(\sum_\ell \frac{\left(C_\ell^{\phi\phi}\right)^2}{\left(C_\ell^{\phi\phi} + N_\ell^{(0)}\right)^2} f_{sky}(\ell + 0.5)\right)^{1/2},$$

where $C_\ell^{\phi\phi}$ is the lensing power spectrum, $N_\ell^{(0)}$ is the zero-order lensing reconstruction noise bias and $f_{sky} = \mathbf{0.67}$.

$\sim$ **50% improvement** ($\sim$ **60**$\boldsymbol{\sigma}$ detection)



METHODOLOGY

We will follow the same methodology as in [4], but with some modifications to make it computationally cheaper.

(1) SIMULATION

1. Generate correlated unlensed CMB and lensing potential maps using a Cholesky decomposition.
2. Lens the maps using `lenspyx`[a].
3. Add foregrounds with `pysm3`[b].
4. Convolve with the beam and add the white noise of each frequency channel.
5. Using the HILC implemented in `fgbuster`[c], perform component separation on the observed maps.
6. Combine the CMB spherical harmonic coefficients from *Planck* and LiteBIRD.

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[a] `https://github.com/carronj/lenspyx`
[b] `https://github.com/galsci/pysm`
[c] `https://github.com/fgbuster/fgbuster`

(2) FILTERING

In [4], they perform a Wiener filtering in pixel-space, which allows to mask a portion of the sky,

$$\bar{\mathbf{s}} = S^{-1}\left[S^{-1} + \mathcal{Y}^T N^{-1} \mathcal{Y}\right]^{-1} \mathcal{Y}^T N^{-1} \mathbf{d}.$$

In this work, we plan to perform an **harmonic based filtering** which is much cheaper, as done by ACT collaboration [5],

$$\bar{s}_{\ell m} = \frac{d_{\ell m}}{C_\ell^{\mathrm{CMB}} + \langle N_\ell \rangle},$$

where $d_{\ell m}$ are the simulated maps, $\bar{s}_{\ell m}$ the filtered maps and $\langle N_\ell \rangle$ is the mean noise taken over 400 simulations.

(3) RECONSTRUCTION

Using the quadratic estimators introduced by Hu & Okamoto [6], we calculate the reconstructed lensing angular power spectra,

$$C_L^{\hat{\phi}\hat{\phi}} = A_L^{MC} C_L^{\phi\phi} - RDN_L^{(0)} - N_L^{(1)},$$

applying a Monte Carlo correction to the estimator's normalization A_L^{MC}, and subtracting the realization-dependent zero-order and first-order biases, $RDN_L^{(0)}$ and $N_L^{(1)}$ respectively.
We estimate the **significance of the lensing effect detection** from the reconstructed spectra of **400 simulations**.

COMBINATION OF PLANCK AND LITEBIRD DATA

- **Inverse-variance weighting**: minimizing the noise of the combination through a linear combination of the individual maps,

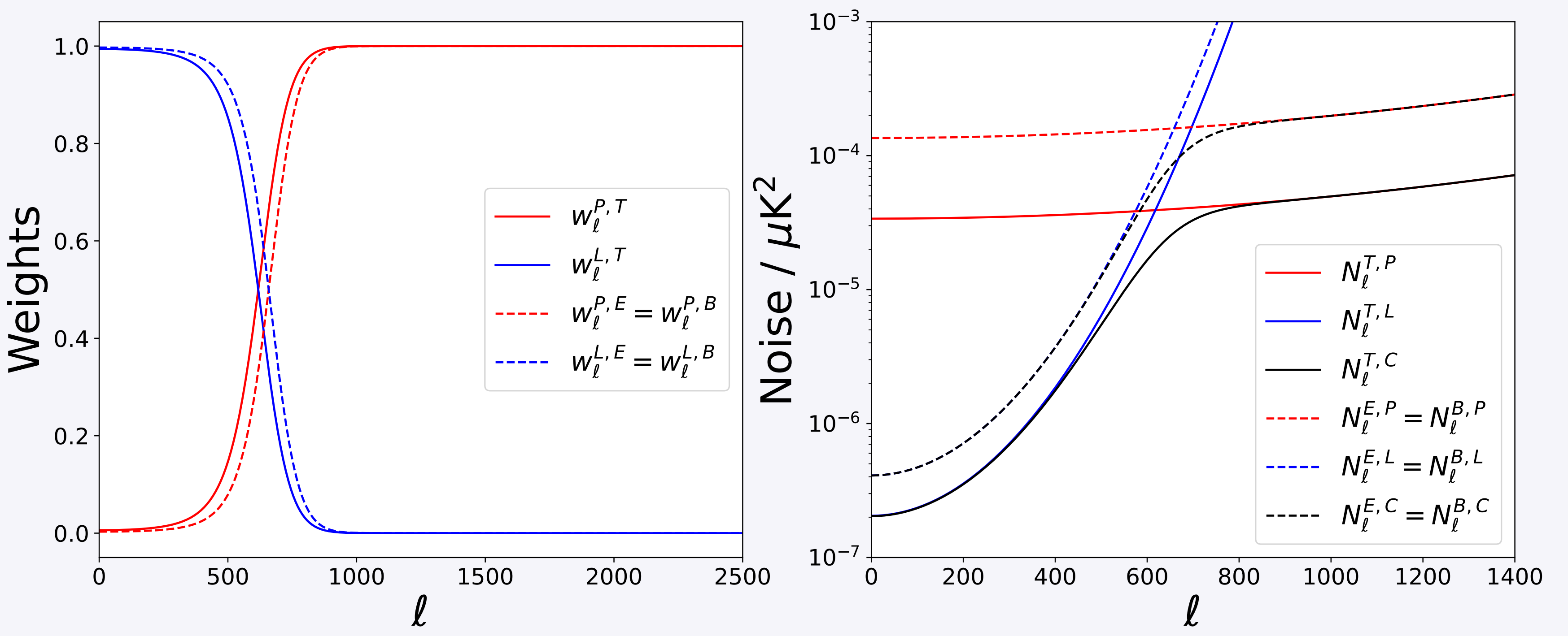
$$t_{\ell m}^C = w_\ell^{P,T} t_{\ell m}^P + w_\ell^{L,T} t_{\ell m}^L,$$
$$e_{\ell m}^C = w_\ell^{P,E} e_{\ell m}^P + w_\ell^{L,E} e_{\ell m}^L,$$
$$b_{\ell m}^C = w_\ell^{P,B} b_{\ell m}^P + w_\ell^{L,B} b_{\ell m}^L,$$

where for $X \in \{T, E, B\}$ and $S_\ell^X = N_\ell^{X,P} + N_\ell^{X,L}$, the weights are

$$w_\ell^{P,X} = N_\ell^{X,L}/S_\ell^X, \; w_\ell^{L,X} = N_\ell^{X,P}/S_\ell^X.$$

The deconvolved noise power spectra of the combination is

$$N_\ell^{X,C} = (w_\ell^{P,X})^2 N_\ell^{X,P} + (w_\ell^{L,X})^2 N_\ell^{X,L}.$$



STATUS AND FUTURE WORK

- Currently at the final stages of the lensing pipeline validation.
- Explore the optimal combination of *Planck* and LiteBIRD TT, TE, TB, EE, and EB quadratic estimators.
- Explore the use of different masks for *Planck* and LiteBIRD.
- Quantify how the improved ϕ helps to constrain primordial non-Gaussanity through galaxy-lensing cross-correlations [4] or to LiteBIRD's internal delensing [7], among other uses.

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