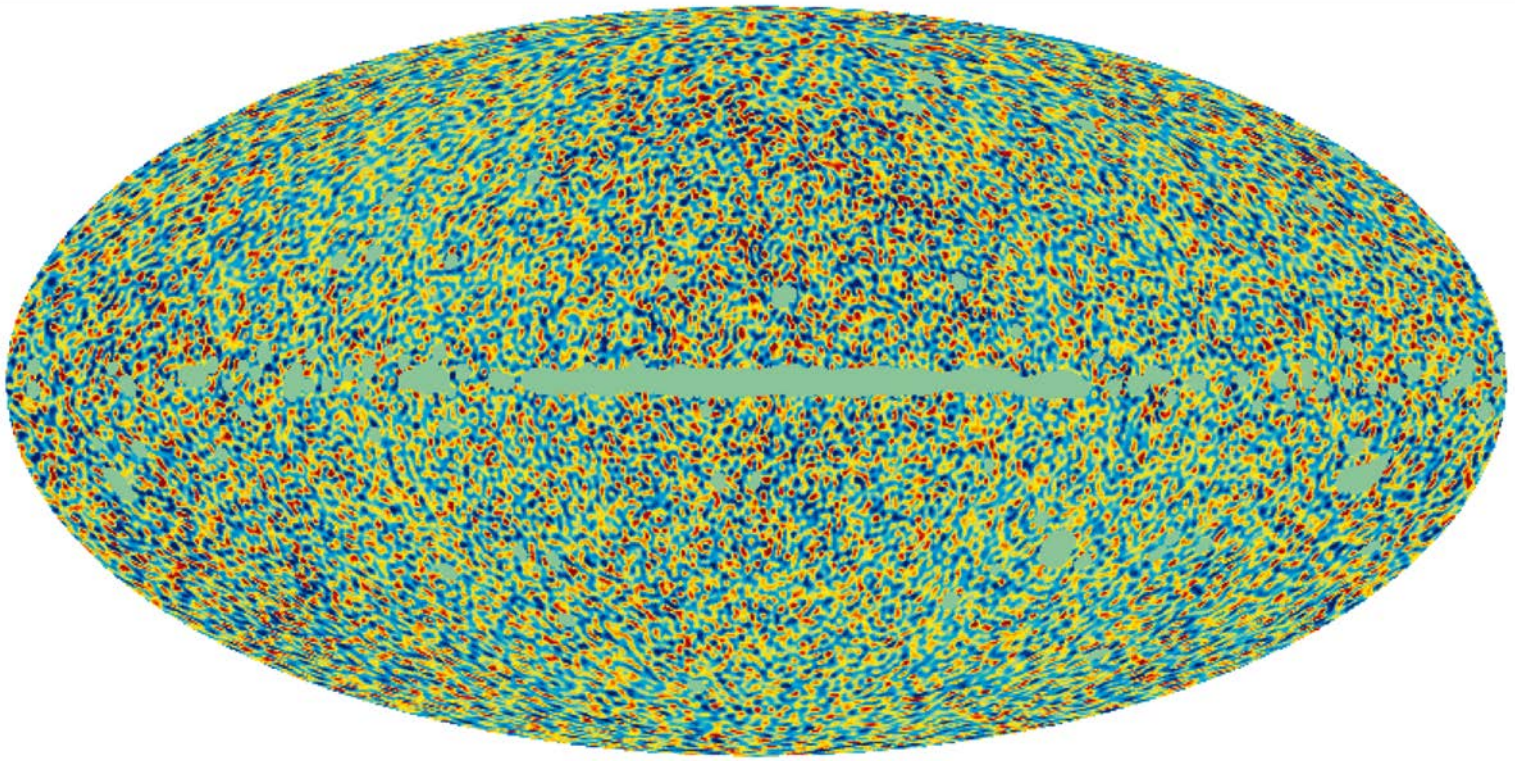
PLANCK 2014

THE MICROWAVE SKY IN TEMPERATURE AND POLARIZATION



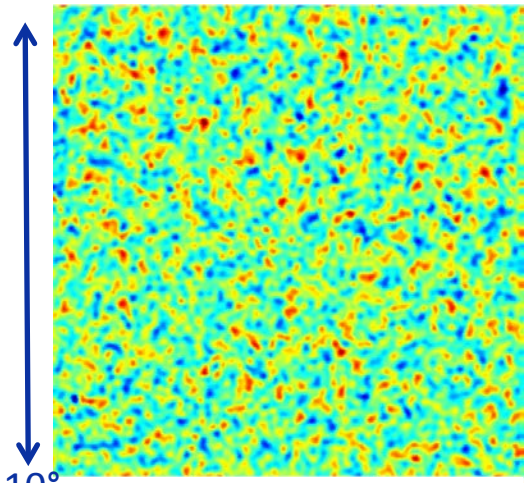
The lensing-induced B-mode from PLANCK

Laurence Perotto, LPSC/CNRS on behalf of the Planck Collaboration

The lensing-induced B-mode

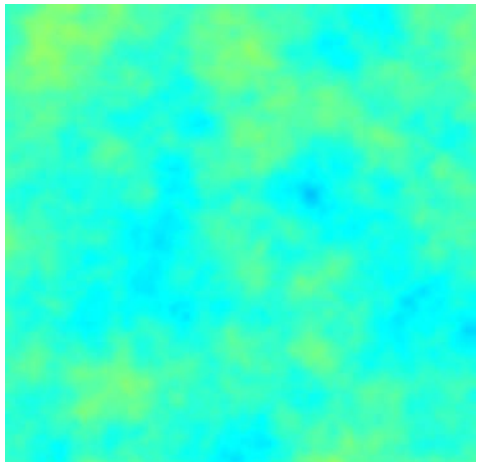
Secondary B-mode of polarization (B-lensing) is due to the remapping of the polarisation by the lensing effect, inducing primordial E-mode leakage.

• it encloses the matter distribution information integrated back to the LSS
• it constitutes a contaminant for the primordial B-mode from inflation, which dominates for angular scales > few degrees.



unlensed E

A B-lensing template map covering the angular scales from few degrees to sub-degrees is usefull to desantangle primordial-to-secondary contribution.



unlensed B for r=0.2 (x10)

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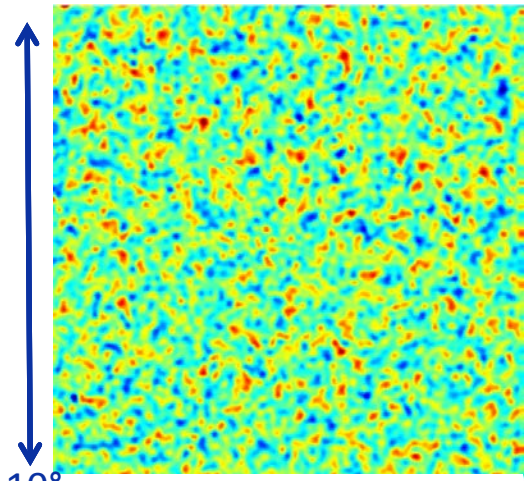
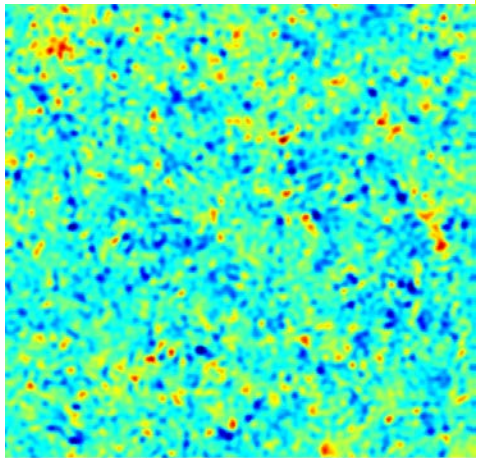


lensed E



lensed B for r=0.2 (x10)

Outlines

I. Lensing-induced B-mode map synthesis: methodology

II. Lensing-induced B-mode map with Planck

III. Characterising the lensing-induced B-mode power spectrum on simulations

IV. $C_\ell^{B_{\rm lens}}$ measurements and robustness tests.

B-lensing maps synthesis: formalism

- B-lensing polarisation maps:

Starting from the first-order B-lensing polarisation

$$\left(Q^{\rm lens} \pm iU^{\rm lens}\right) = \nabla\left(Q^{\rm primo} \pm iU^{\rm primo}\right) \cdot \nabla\phi$$

we build a B-lensing map estimator:

$$\left(\hat{Q}^{\rm lens} \pm i\hat{U}^{\rm lens}\right) = \mathcal{B}^{-1}\nabla\left(\tilde{Q}^{E} \pm i\tilde{U}^{E}\right) \cdot \nabla\tilde{\phi}$$

Filtered version of pure E-mode Q, U maps

filtered lensing potential map

- filters are optimised to minimise the map variance
- $\mathcal{B}^{-1}$, the analytical filtering transfer function ensures the estimator is unbiased

- B-lensing spherical harmonics:

$$\hat{B}^{\rm lens}_{\ell m} = \mathcal{B}^{-1} \sum_{LM} \sum_{\ell' m'} \tilde{\phi}_{LM} \tilde{E}_{\ell' m'} \mathcal{W}^{mMm'}_{\ell L \ell'}$$

weight function
(geometrical terms)

The B-lensing synthesis methods

We developped 2 independent methods :

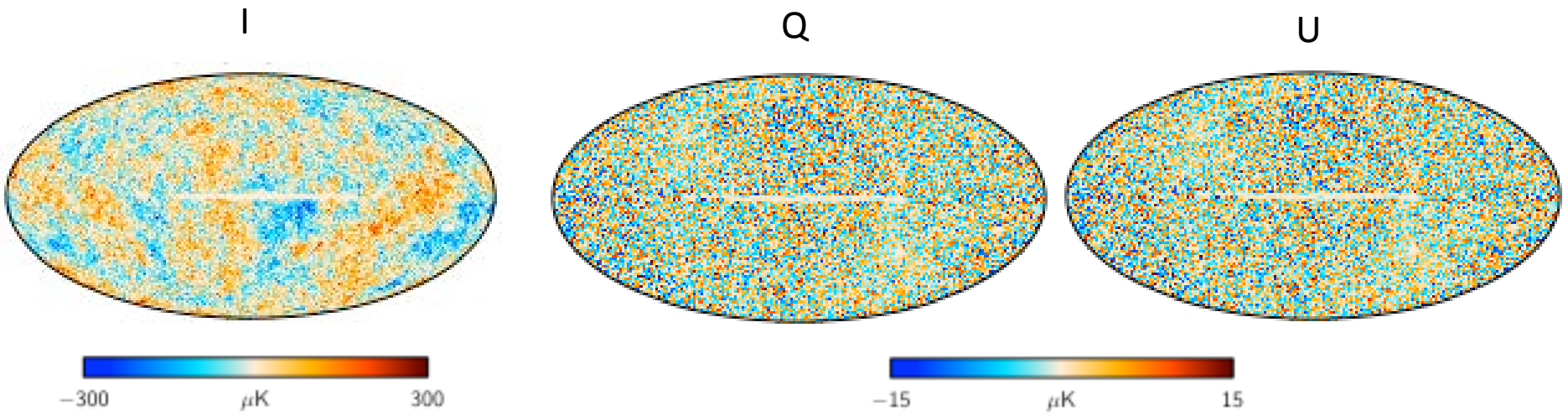
- main difference in the sky cuts treatment
- different implementions / same mathematics

- The official method:
  - direct implementation of $\hat{B}^{\rm lens}_{\ell m}$: labeled 'harmonics' for spherical-harmonics space-based method
  - mask treatment: minimum-variance filtering of T and P
  - based on the baseline lensing extraction of Planck 2014 lensing (*see Lewis's talk*)

- The alternative method
  - direct implementation of $\hat{Q}^{\rm lens}$, $\hat{U}^{\rm lens}$: labeled 'real-space' for real-space based method
  - mask treatment: inpainting of T, apodisation of P
  - based on the Planck 2013 lensing METIS extraction method applied to 2014 data

Data Sets

Foreground cleaned I, Q, U maps using SMICA (*see Rocha's talk*)



Mask:

- lensing-targeted
- includes:
  - compact objects from Planck's catalogs and foreground maps
  - diffuse emission (galactic plane, nearby galaxies and CO)
- $f_{\rm sky} \simeq 70\%$

The B-lensing power spectrum

When cross-correlated to the observed polarisation maps, the B-lensing polarisation maps provide a B-lensing power spectrum measurement :

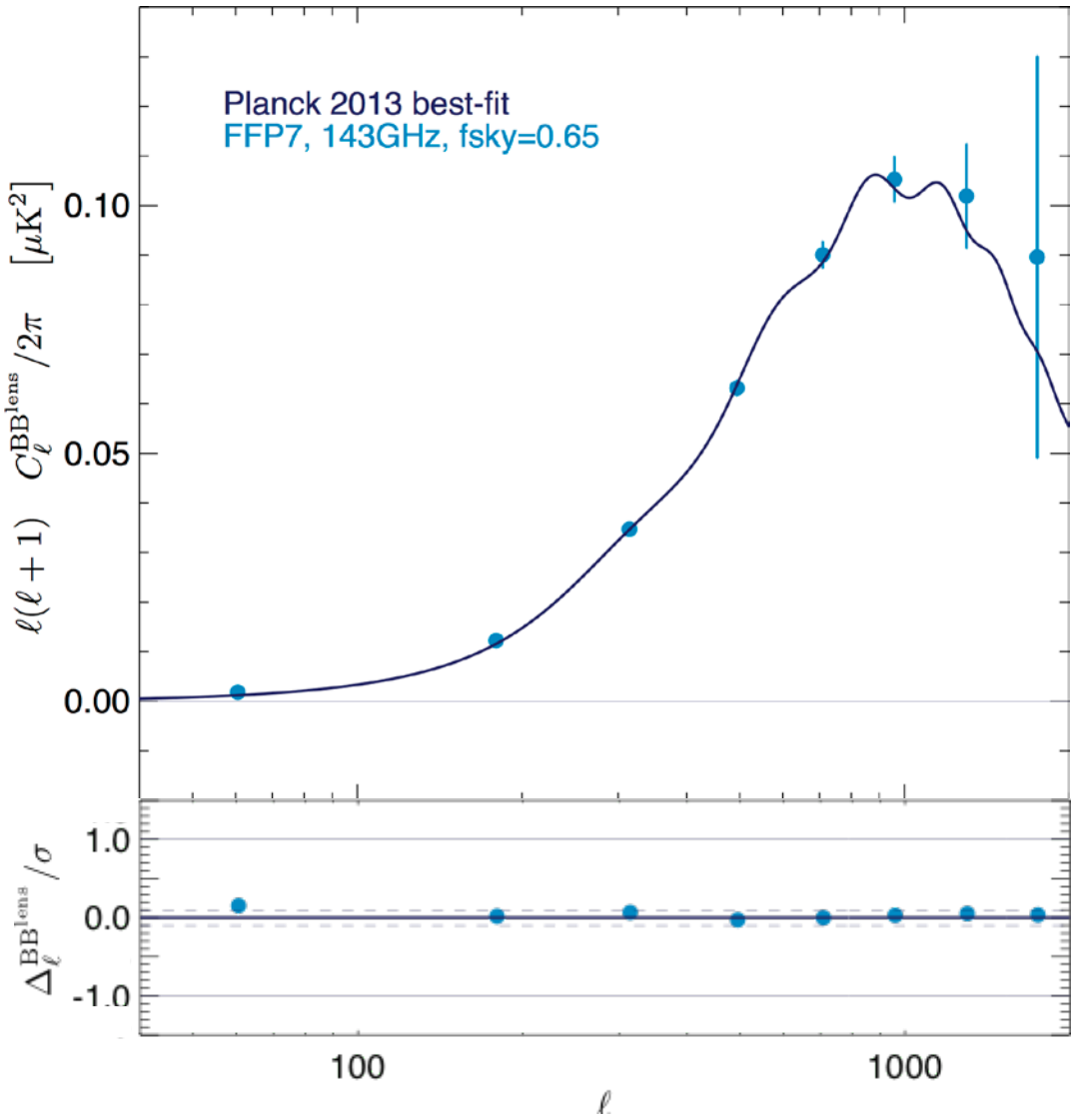
$$\hat{C}_\ell^{B_{\rm lens}} = \frac{f_{\rm sky}^{-1}}{2\ell+1} \sum_m B^*_{\ell m} \hat{B}^{\rm lens}_{\ell m}$$

We characterise the $C_\ell^{B_{\rm lens}}$ measurement (bias, uncertainties) using Monte-Carlo simulations.

Monte-Carlo Validation

The simulation set:

- 100 cmb + noise TQU @ 143GHz
- lensing potential estimates from T maps
- $B^{fiducial}$ x $B^{lensing}$



→ By construction (cross-correlation), no need to correct for any noise term

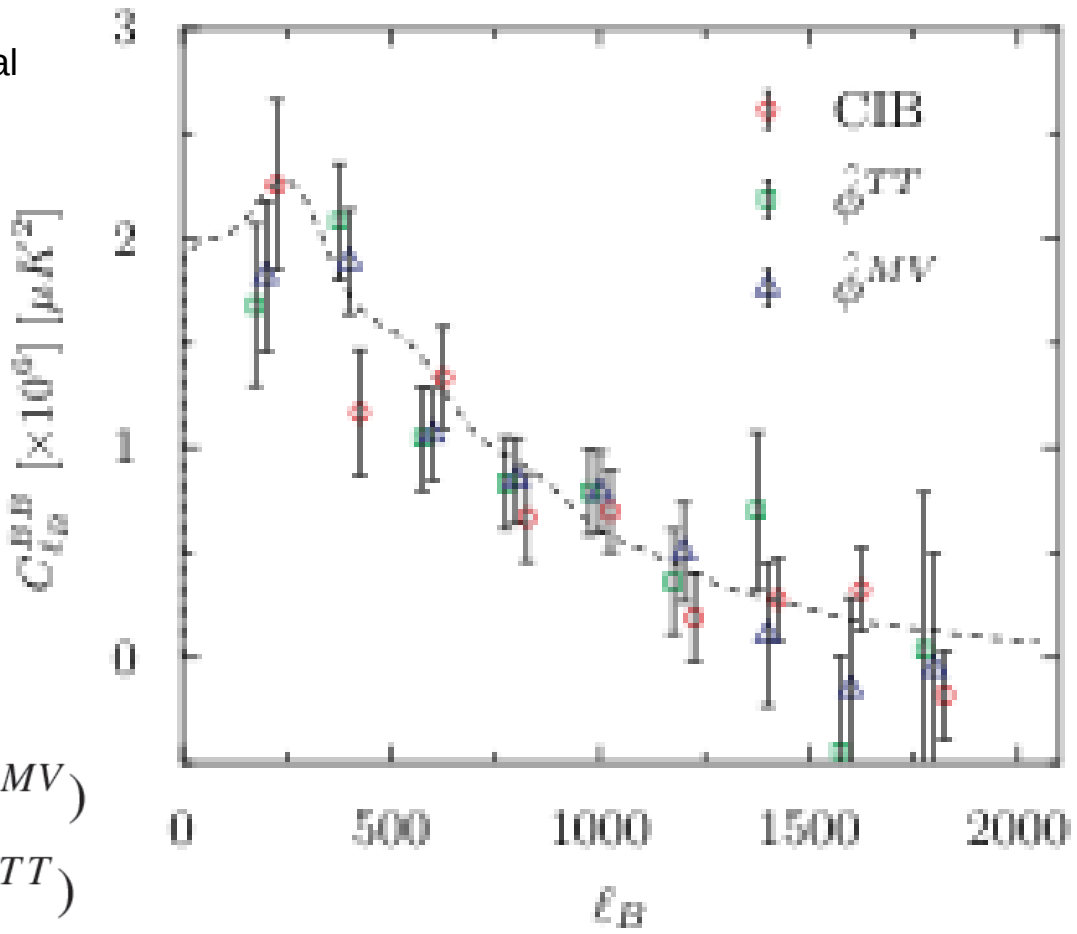
→ Negligible residual bias

B-lensing power spectrum measurements

PRELIMINARY

Results using the official method based on different mass tracers:

- Temperature-based lensing potential
- Temperature+Polarisation lensing
- CIB measured in the 545GHz map



$$\hat{A}^B_{8\to 2048} = 0.93 \pm 0.08 \quad (\phi^{MV})$$
$$\hat{A}^B_{8\to 2048} = 0.95 \pm 0.09 \quad (\phi^{TT})$$
$$\hat{A}^B_{8\to 2048} = 0.93 \pm 0.10 \quad (\mathrm{CIB})$$

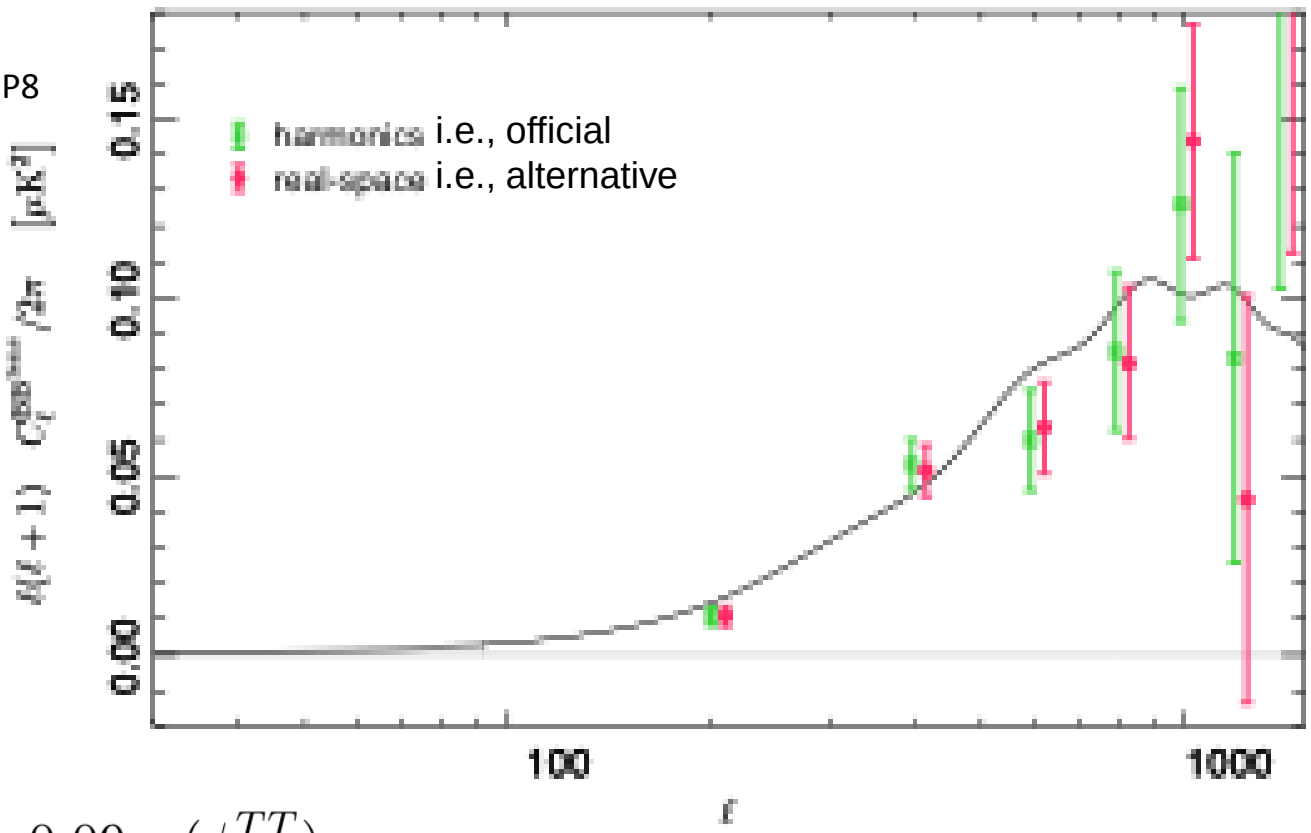
→ $\gtrsim 10\sigma$ detection of the B-lensing

Consistency with alternative method

PRELIMINARY

We use the same setup:

- SMICA T and P maps
- TT-only lensing extraction
- lensing bias estimate using FFP8
- $f_{\rm sky} \simeq 70\%$



$$\hat{A}_B^{\rm official} = 0.95 \pm 0.09 \quad (\phi^{TT})$$

$$\hat{A}_B^{\rm alternative} = 0.97 \pm 0.08$$

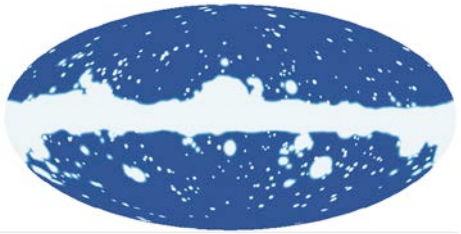
→ consistent results using 2 independent methods

Foreground residuals robustness tests : I/II

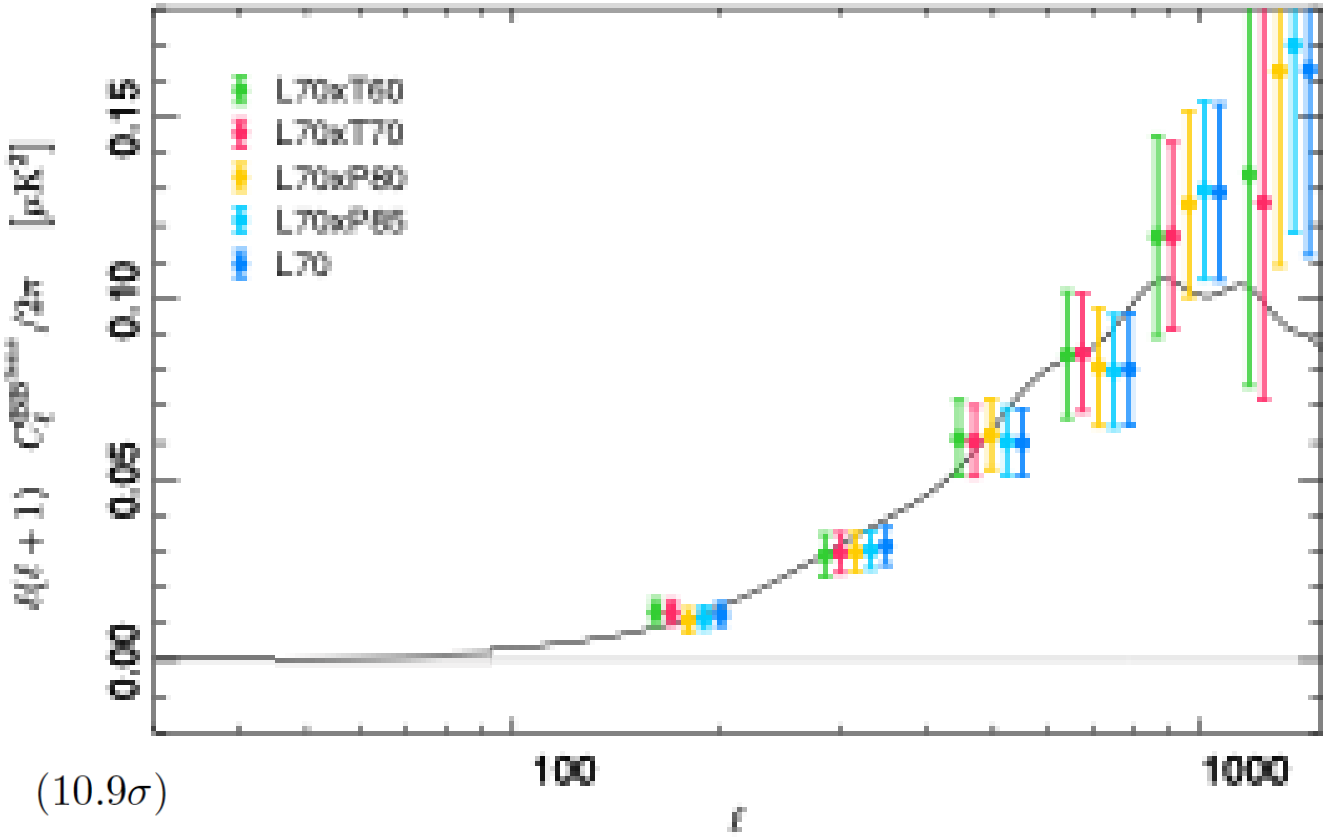
PRELIMINARY

We test against foreground contamination using the $f_{\rm sky} \simeq 80\%$ mask and a series of more conservative masks of various morphologies

The 'L70' mask



- $f_{\rm sky} \simeq 80\%$ mask
- apodisation



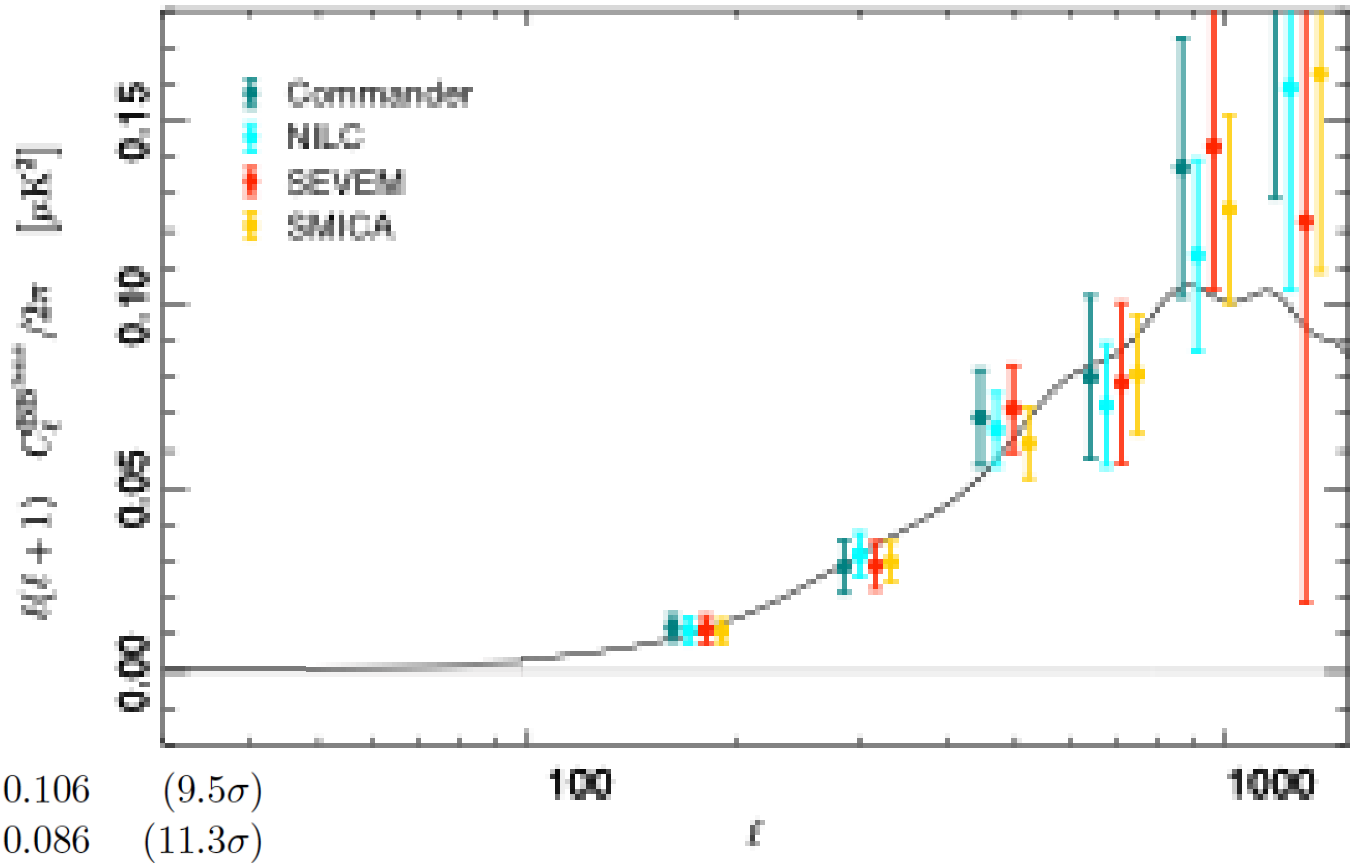
$$A_B^{\rm L70T60} = 0.971 \pm 0.089 \quad (10.9\sigma)$$
$$A_B^{\rm L70T70} = 0.970 \pm 0.082 \quad (11.8\sigma)$$
$$A_B^{\rm L70P80} = 0.970 \pm 0.082 \quad (11.8\sigma)$$
$$A_B^{\rm L70P85} = 0.980 \pm 0.079 \quad (12.5\sigma)$$
$$A_B^{\rm L70} = 0.990 \pm 0.079 \quad (12.7\sigma)$$

→ good consistency: indication of the robustness against foregrounds

Foreground residuals robustness tests: II/II

PRELIMINARY

Using foreground-cleaned T, Q, U from different component separation methods [Ref: Planck 2014: compsep] with a common $f_{\rm sky} \simeq 70\%$ mask (L70P80)



$$A_B^{\rm Commander} = 1.007 \pm 0.106 \quad (9.5\sigma)$$
$$A_B^{\rm NILC} = 0.974 \pm 0.086 \quad (11.3\sigma)$$
$$A_B^{\rm SEVEM} = 1.000 \pm 0.103 \quad (9.7\sigma)$$
$$A_B^{\rm SMICA} = 0.970 \pm 0.082 \quad (11.8\sigma)$$

→ consistent results based on independant component separations

→ the B-lensing extimate is immune to foreground residuals

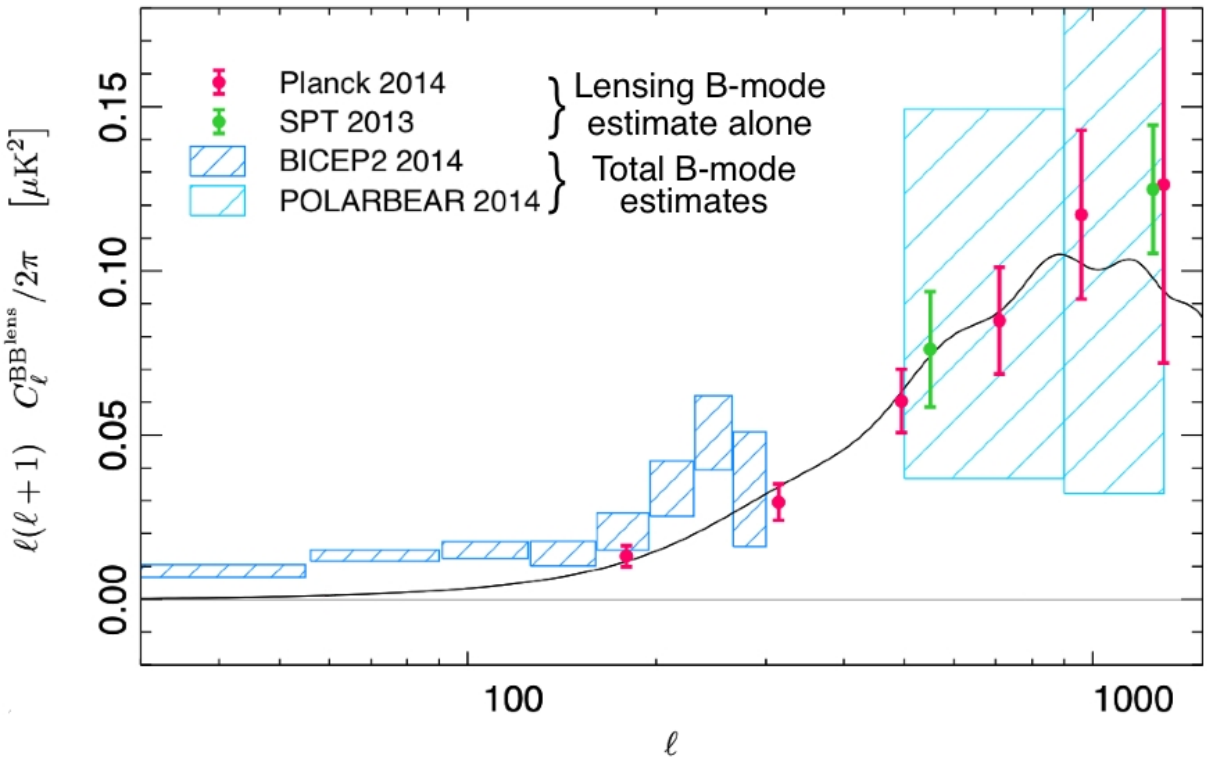
Comparison to external measurements

PRELIMINARY

- direct B-mode measurements (i. e. auto-Cl of the observed B-mode)

POLARBEAR 2014
[Ref P.A.R. Ade et al. 2014 (arXiv:1403.2369)]

BICEP2 2014
[Ref P.A.R. Ade et al. 2014 (arXiv:1403.3985)]



- Cross-correlation measurements

SPT 2013
[Ref D. Hanson et al. 2013 (arXiv:1307.5830)]
SPTpol@150GHz + Herschel CIB

see also POLARBEAR 2014
[Ref P.A.R. Ade et al. 2014b (arXiv:1312.6646)]

→ secondary-to-primordial desentanglement capacities

→ the most accurate B-lensing measurment to date up to $\ell \lesssim 1000$

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada.

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.