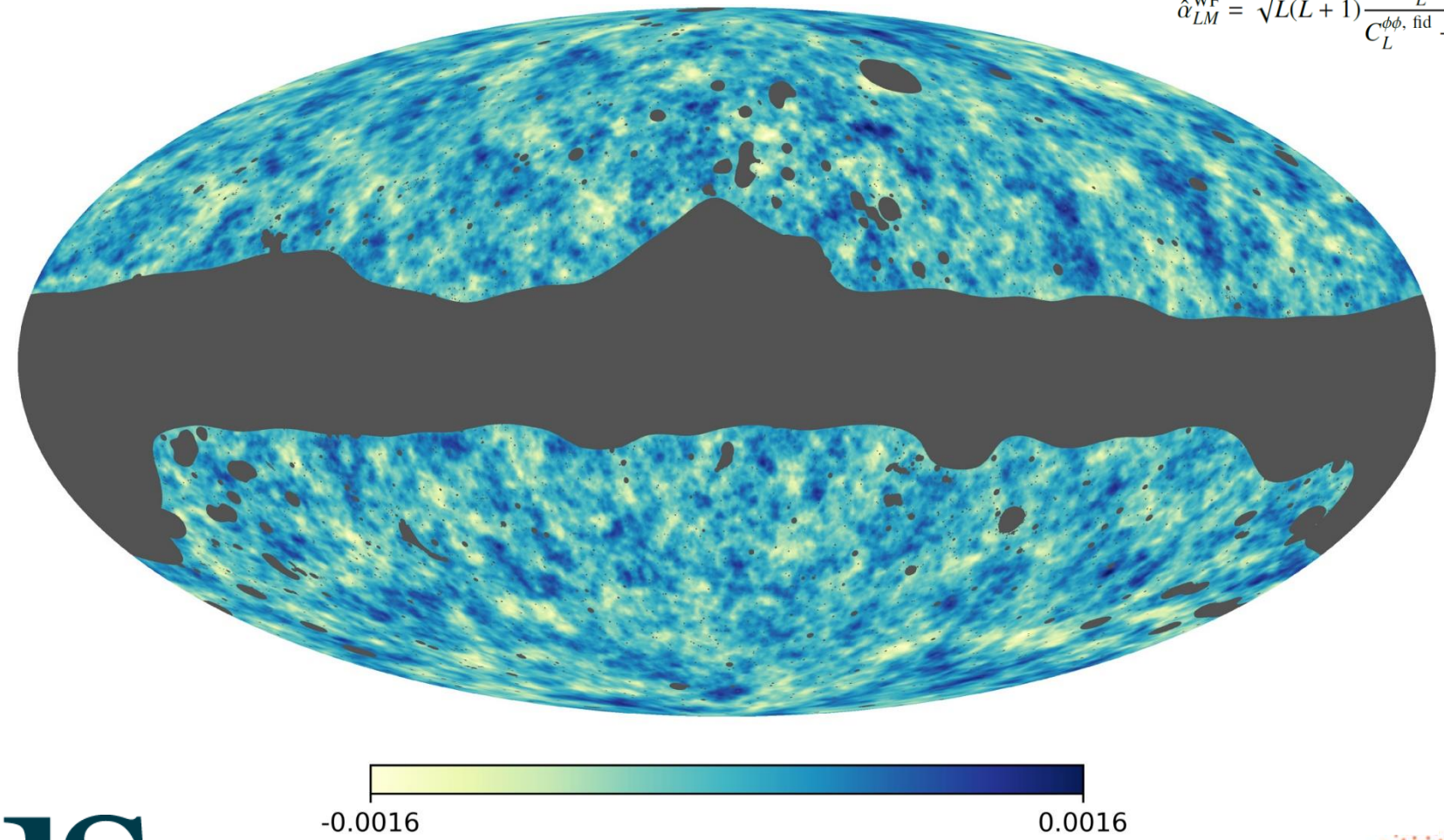
Planck Lensing 2018

arXiv:1807.06210 (+1807.06209)

$$\hat{\alpha}^{\rm WF}_{LM} = \sqrt{L(L+1)}\frac{C_L^{\phi\phi,\,\rm fid}}{C_L^{\phi\phi,\,\rm fid}+N_L^{\phi\phi}}\hat{\phi}^{\rm MV}_{LM}$$



Antony Lewis

http://cosmologist.info/

on behalf of the Planck Collaboration.

UNIVERSITY OF SUSSEX

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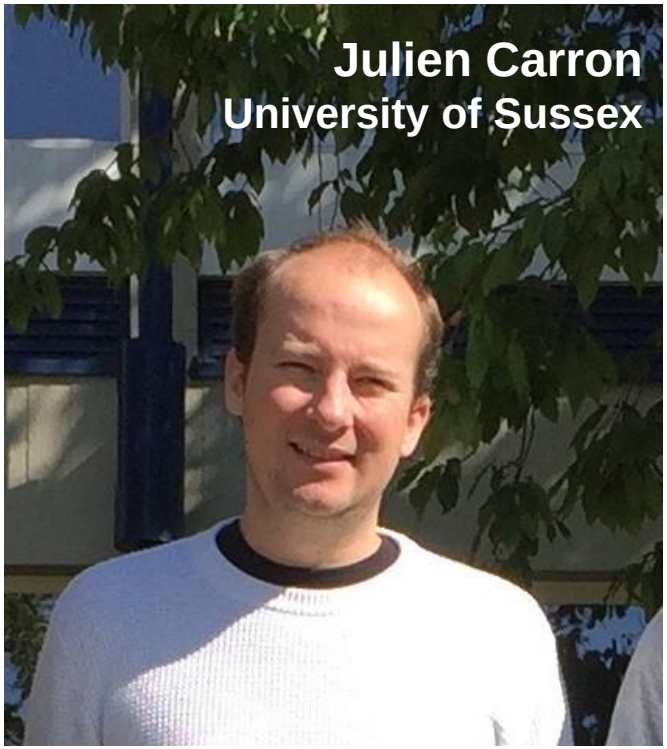
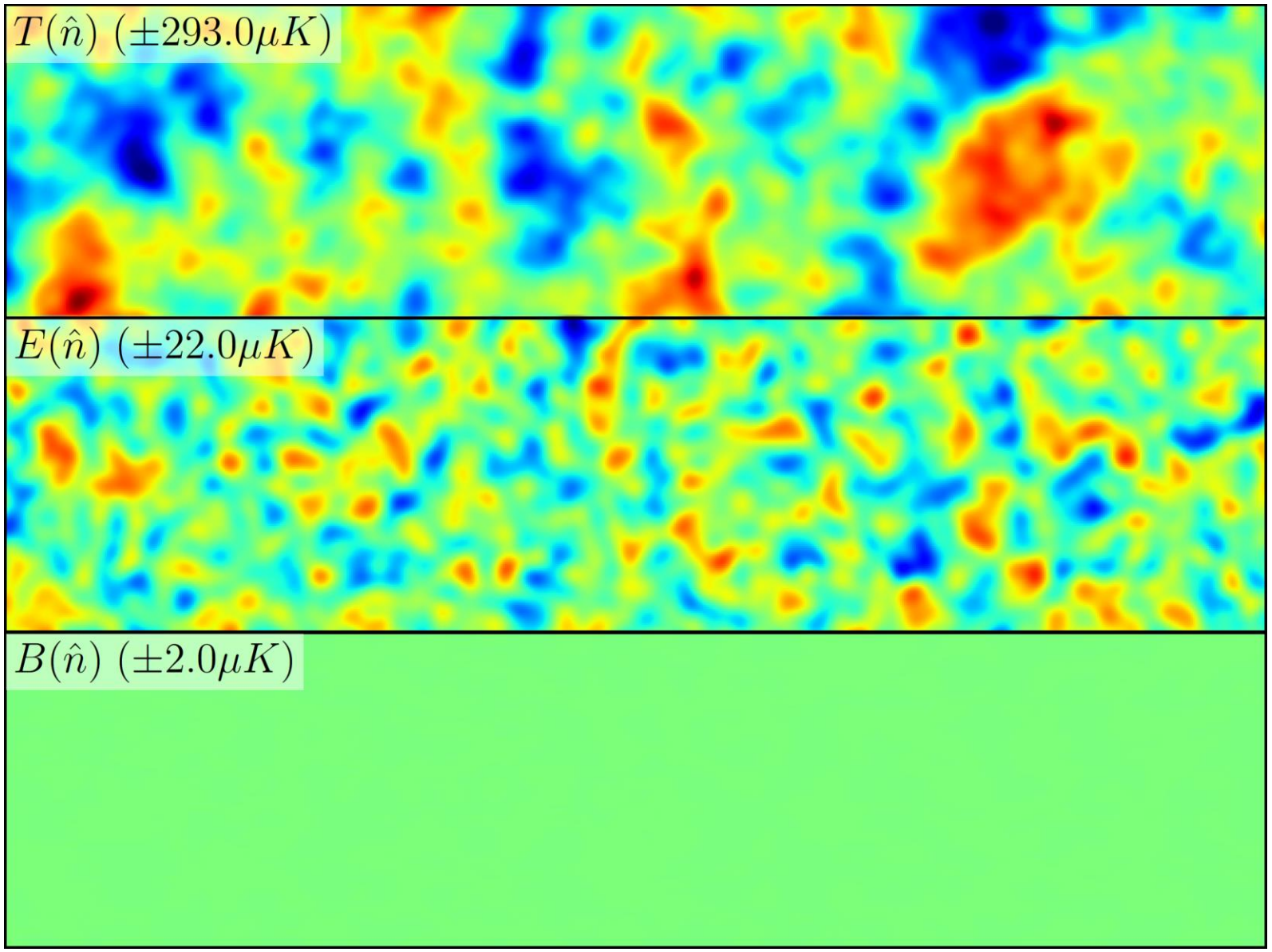
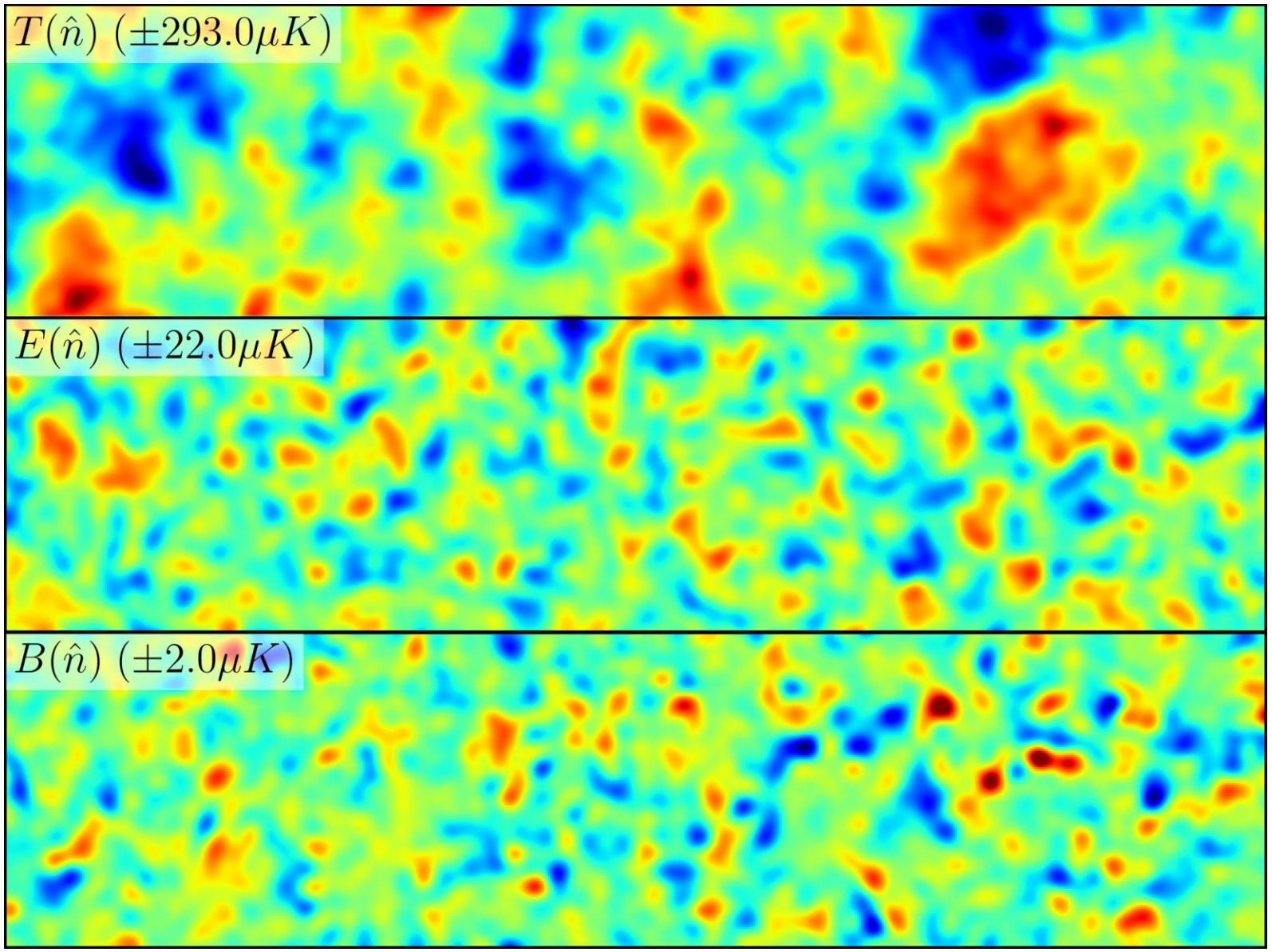
The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada.

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.



+ thanks to Anthony Challinor for a few slides


$T(\hat{n})$ $(\pm 293.0 \mu K)$
$E(\hat{n})$ $(\pm 22.0 \mu K)$
$B(\hat{n})$ $(\pm 2.0 \mu K)$


$T(\hat{n})$ $(\pm 293.0 \mu K)$
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Lensing Reconstruction – Quadratic Estimators

- Fixed lenses introduce statistically-anisotropic correlations:

$$\Delta\langle X_{l_1 m_1} Y_{l_2 m_2}\rangle_{\rm CMB} = \sum_{LM} (-1)^M \begin{pmatrix} l_1 & l_2 & L \\ m_1 & m_2 & -M \end{pmatrix} \mathcal{W}^{XY}_{l_1 l_2 L} \phi_{LM}$$

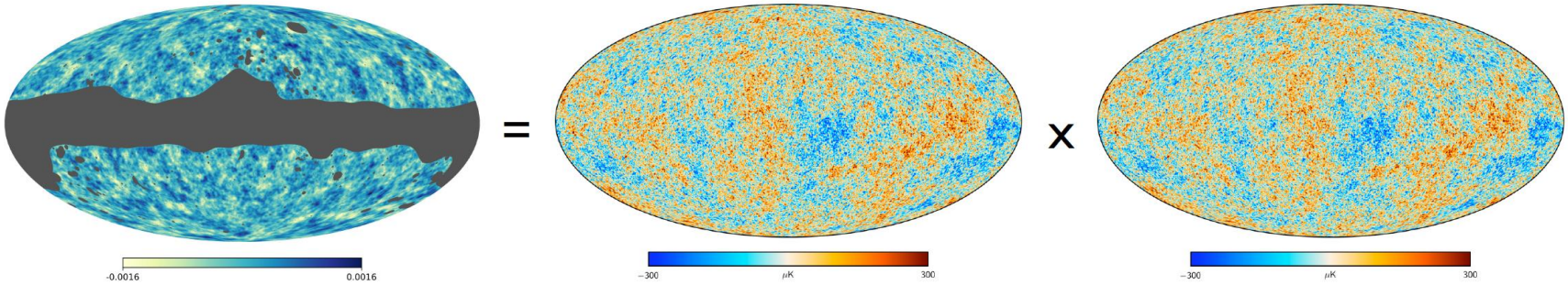
- Noisy lensing estimates from quadratic CMB combinations:

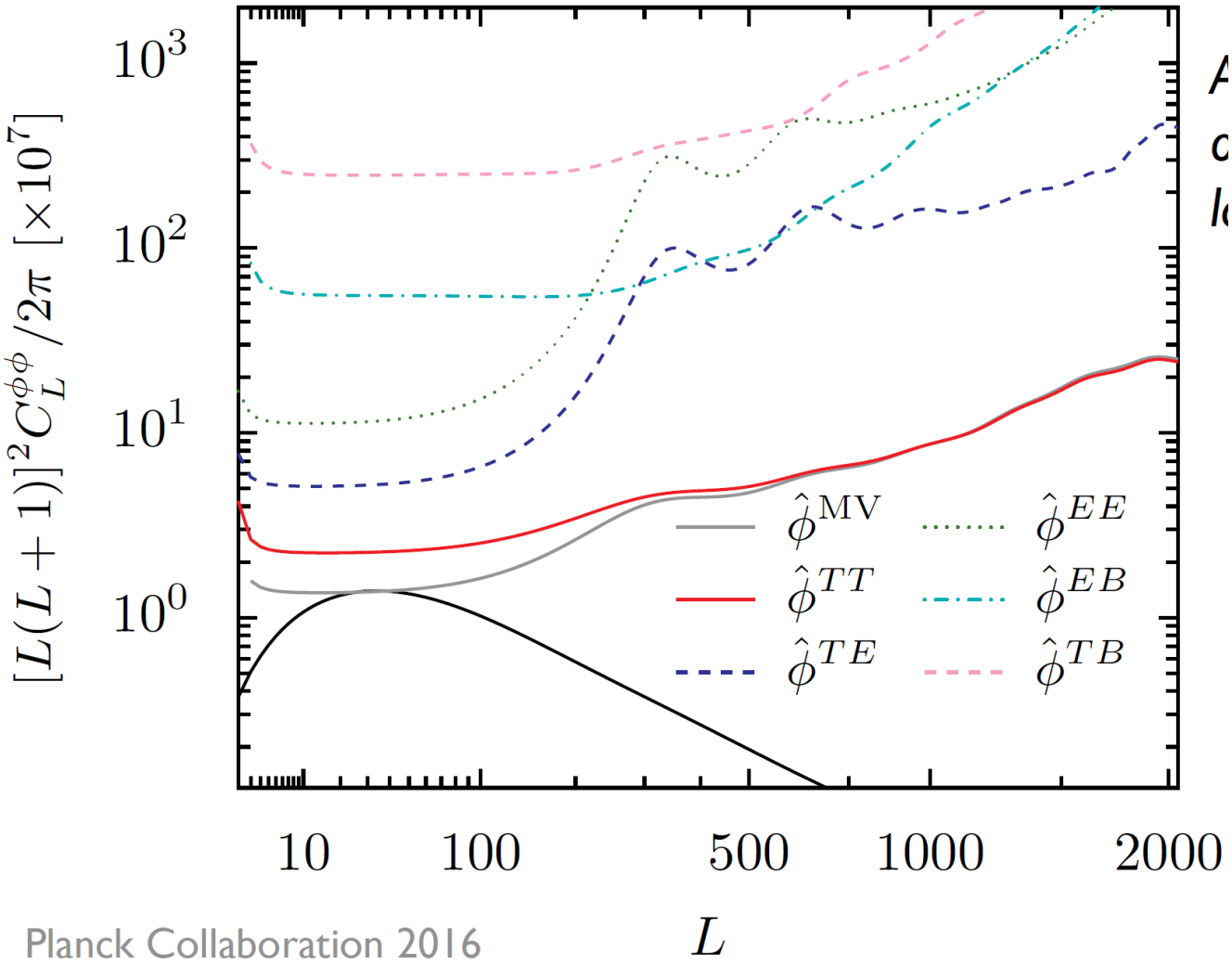
$$\hat{\phi}_{LM} = \frac{(-1)^M}{2} \frac{1}{\mathcal{R}^{XY}_L} \sum_{l_1 m_1, l_2 m_2} \begin{pmatrix} l_1 & l_2 & L \\ m_1 & m_2 & -M \end{pmatrix} \left[\mathcal{W}^{XY}_{l_1 l_2 L}\right]^* \bar{X}_{l_1 m_1} \bar{Y}_{l_2 m_2}$$

Normalisation

Known lensing-induced correlations

Inverse-variance-weighted CMB fields





Planck Collaboration 2016

Changes since 2015

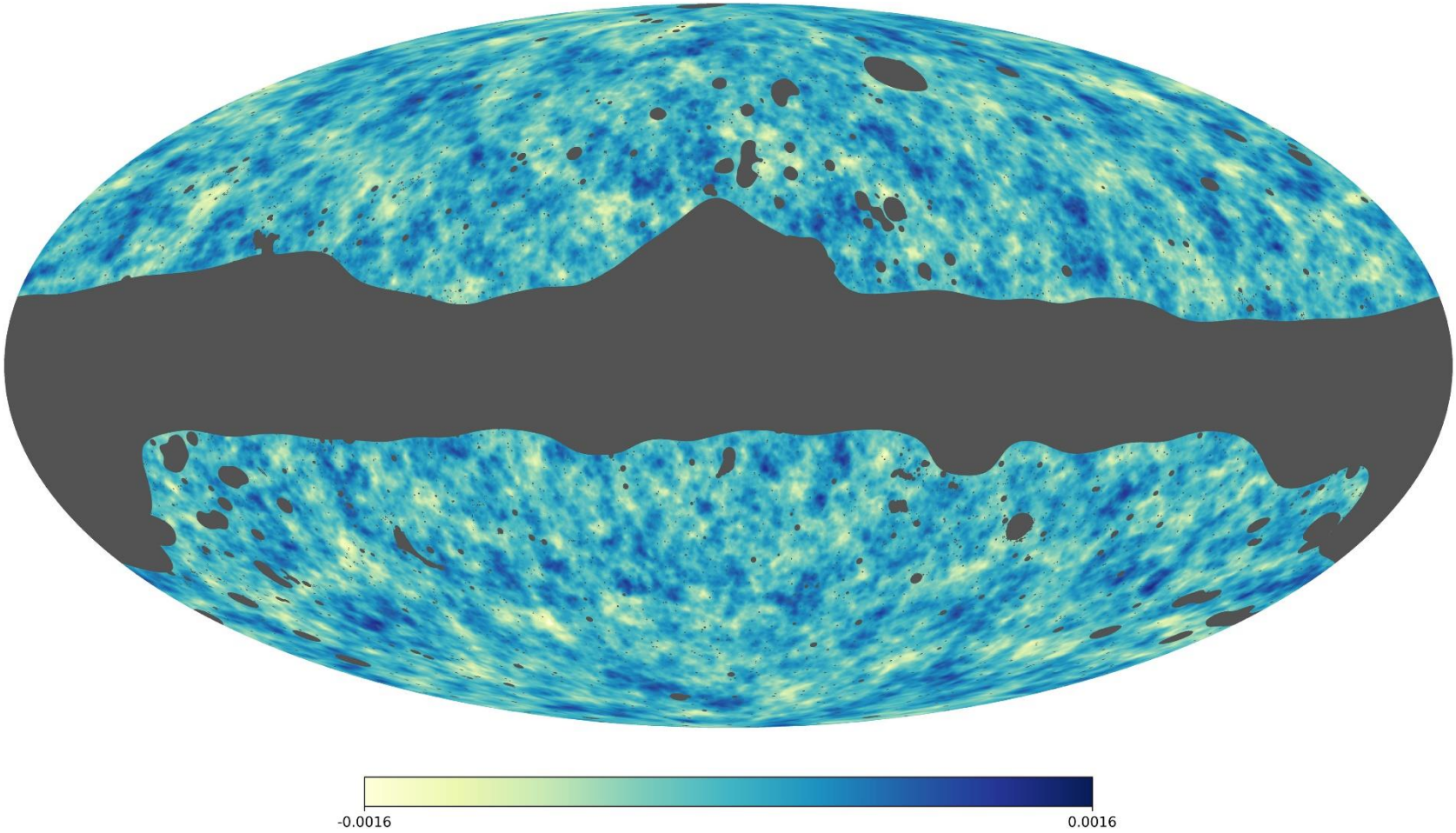
- Maps largely unchanged at high-ℓ
  - *but* component-separation (SMICA) frequency weights changed
- Better masks: lower point-source contamination
- Extensive data consistency tests + correlated foreground simulations to assess foreground biases
- Likelihood extended to $L_{\rm min} = 8$ (was $L_{\rm min} = 40$)
- Lensing-only likelihood is CMB marginalized (independent of cosmology fit to CMB spectra)
- Results to higher $L_{\rm max}$
- Multiplicative MC correction (good for optimal filtering)
- Monte Carlo errors included in covariance

New Results

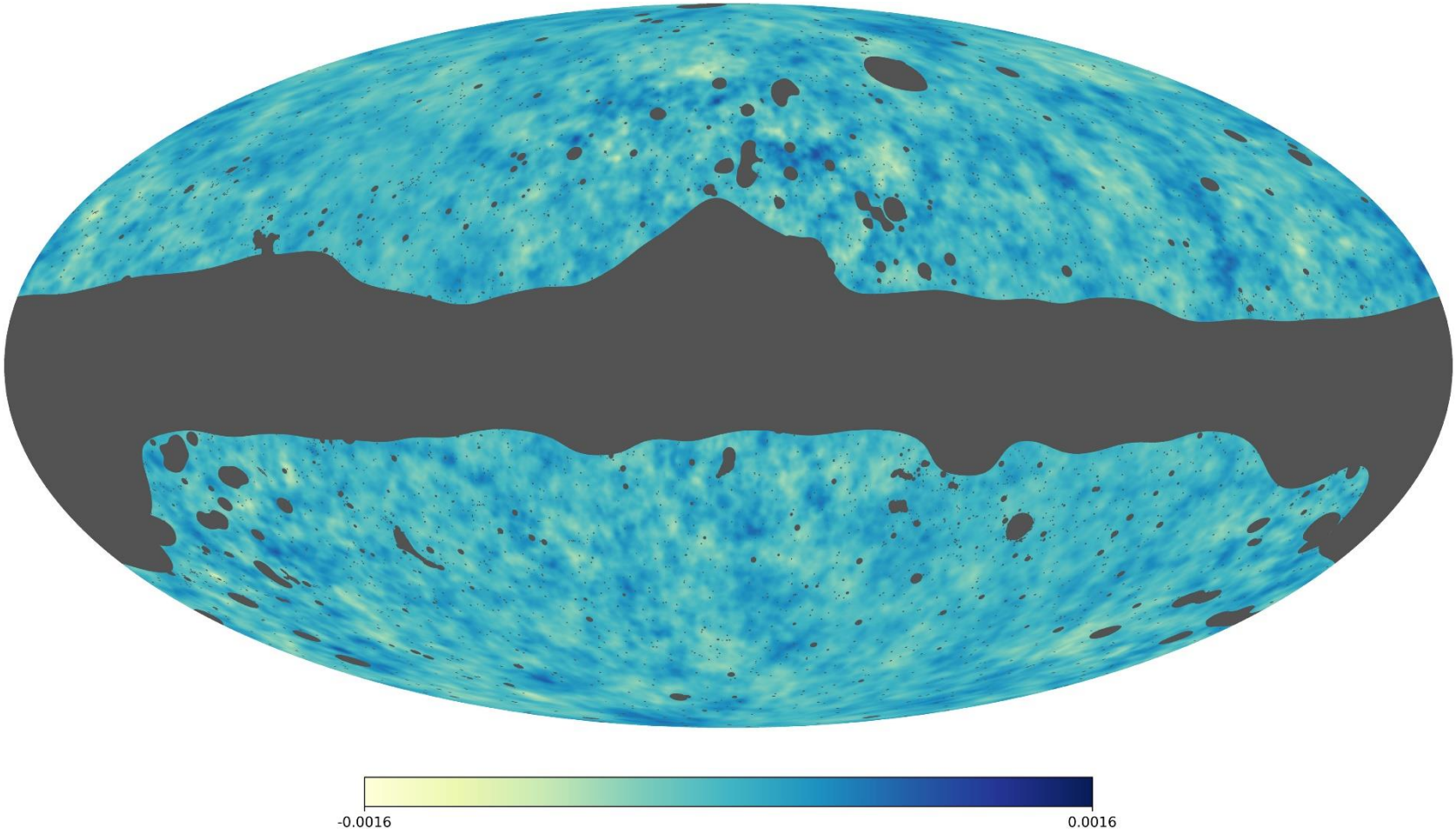
- New optimally-filtered polarization reconstruction
- Combined reconstruction+CIB lensing map
- Template BB delensing
- TT,TE,EE peak sharpening

} Using MV, TT+TE+EE and with CIB

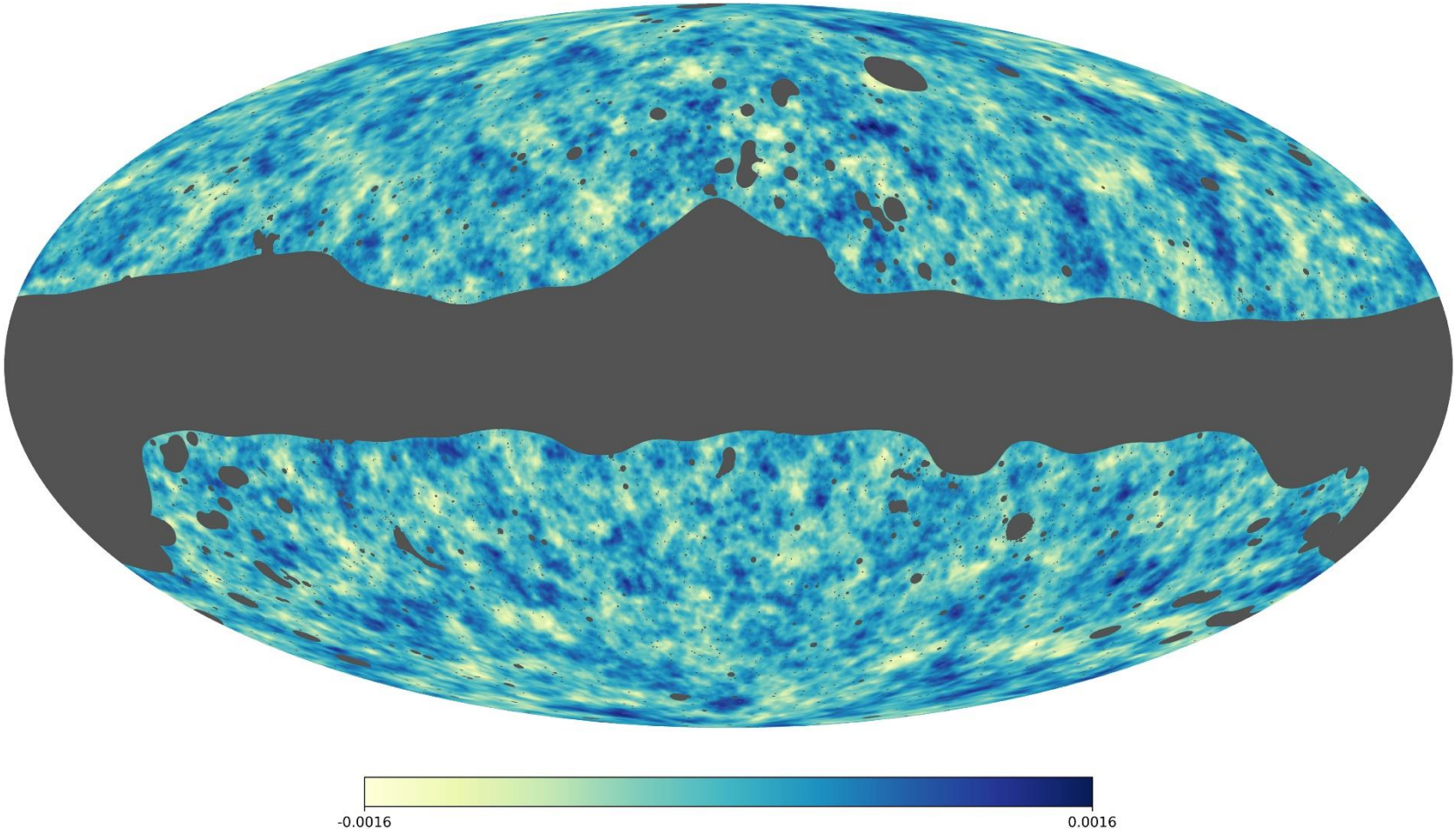
TT

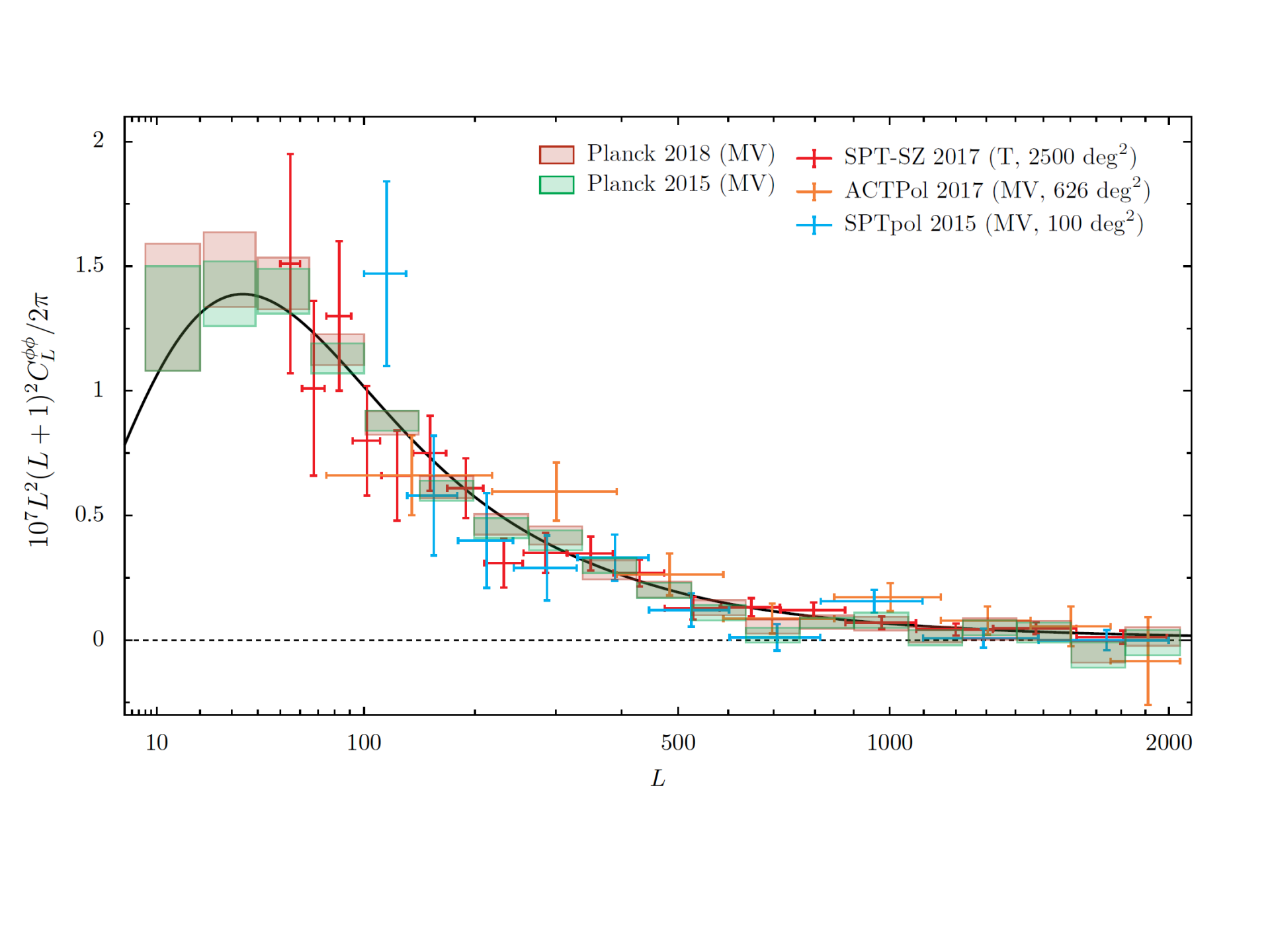


Polarization

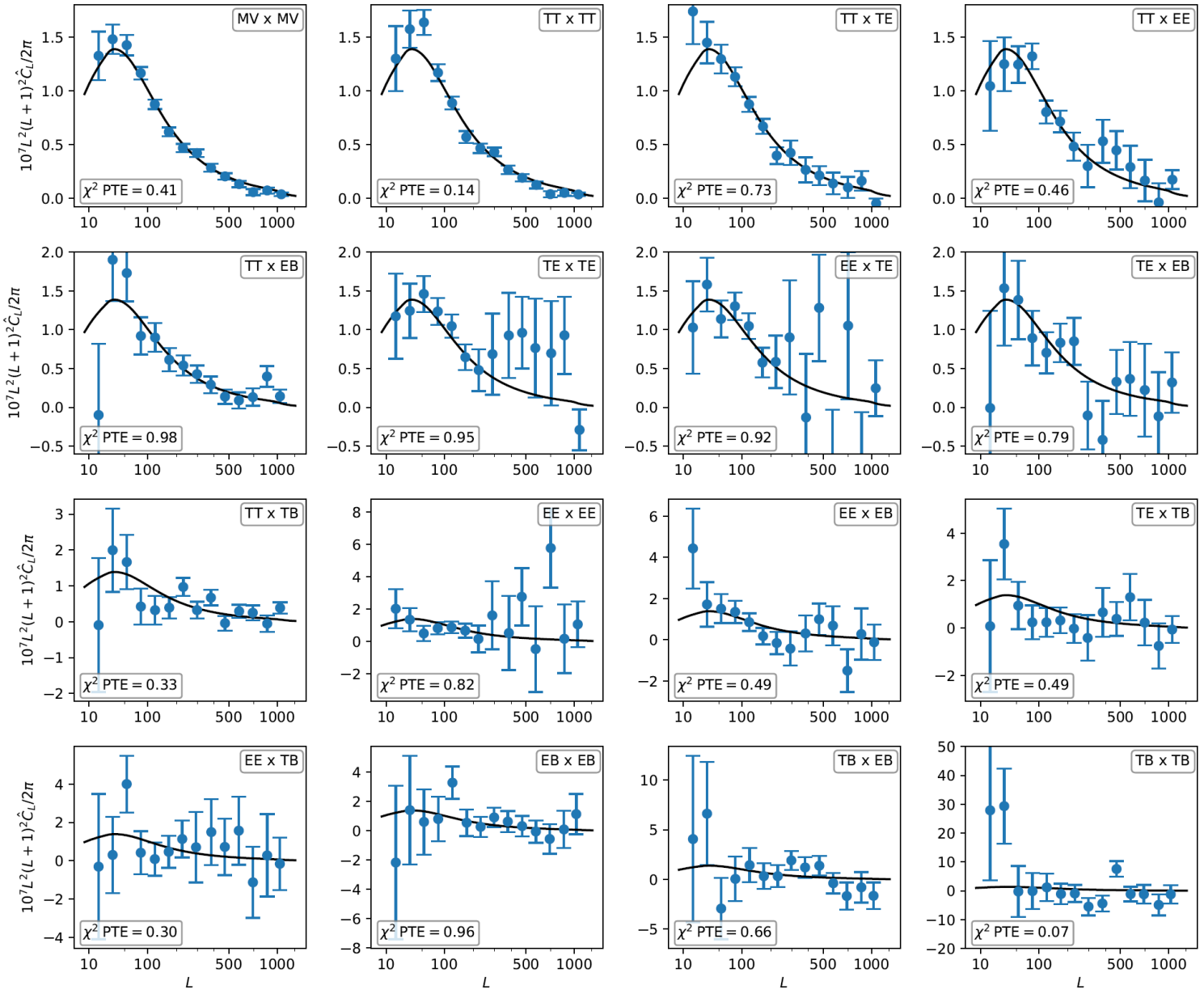


MV



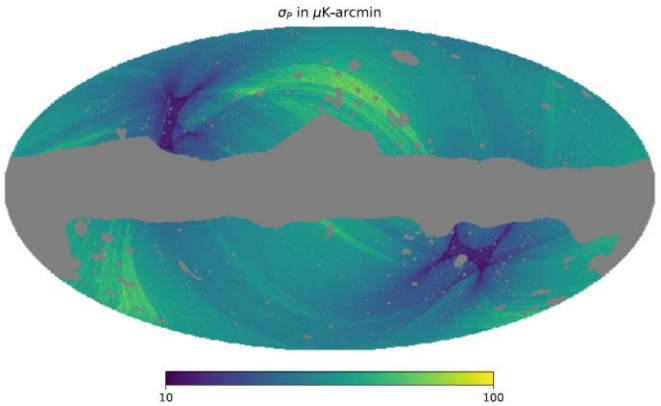

Planck 2018 (MV)
Planck 2015 (MV)
SPT-SZ 2017 (T, 2500 deg^2)
ACTPol 2017 (MV, 626 deg^2)
SPTpol 2015 (MV, 100 deg^2)
$10^7 L^2(L+1)^2 C_L^{\phi\phi}/2\pi$
L
2
1.5
1
0.5
0
10
100
500
1000
2000

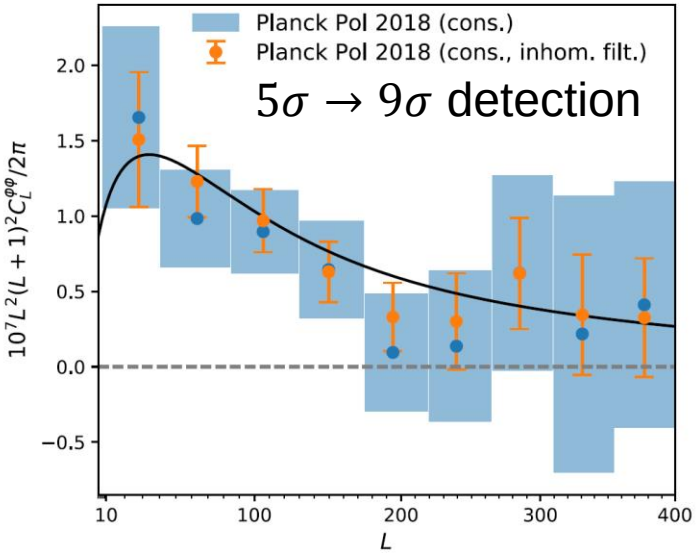
Individual estimators



New optimal polarization analysis

- Greatly improved pol. reconstruction. up to 2 x tighter error bars.
- Maps are filtered using inhomogeneous noise variance maps.
- Filtering performed with conjugate gradient search with multigrid preconditioner



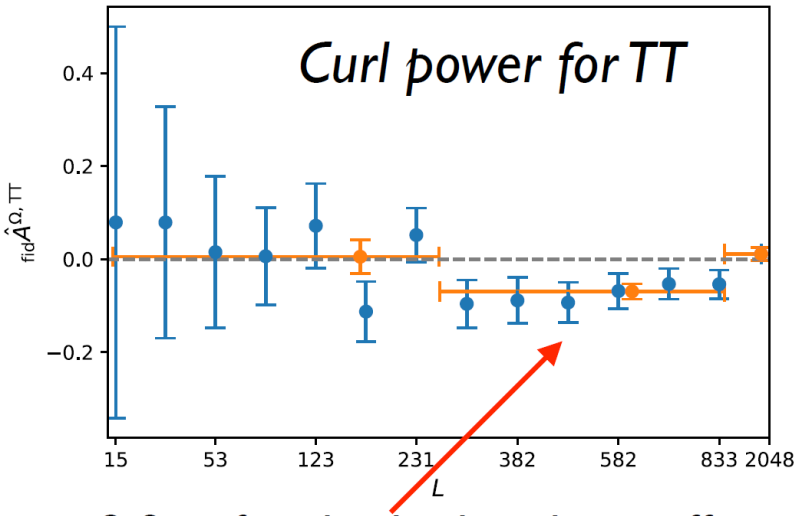


Note: Lensing response (normalization) now varies over sky.
Good approximation: noise varies slowly, independent patch approximation

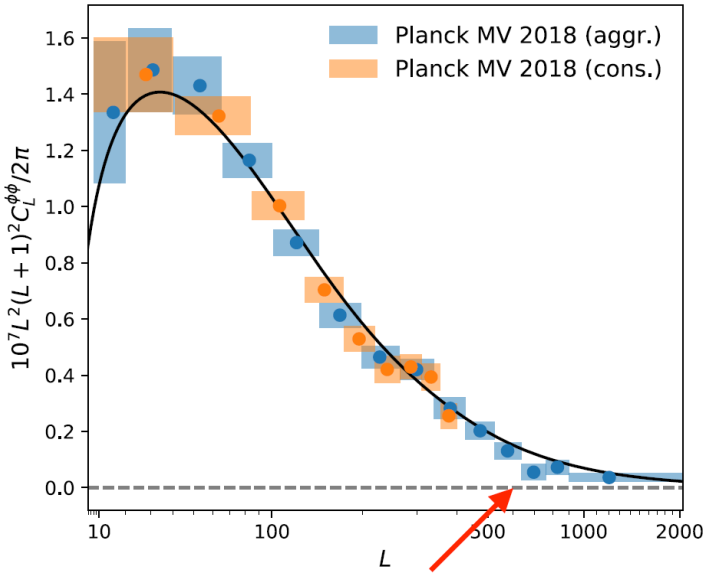
.

e.g. $$\frac{\left\langle \hat{C}_L^{\phi\phi} \right\rangle}{C_L^{\phi\phi,\mathrm{fid}}} \simeq \int \frac{d\hat{\boldsymbol{n}}}{4\pi} \left(\frac{\mathcal{R}_L(\hat{\boldsymbol{n}})}{\mathcal{R}_L^{\mathrm{fid}}} \right)^2 \qquad N_L^{(1)} \simeq \int \frac{d\hat{\boldsymbol{n}}}{4\pi} \left(\frac{\mathcal{R}_L(\hat{\boldsymbol{n}})}{\mathcal{R}_L^{\mathrm{fid}}} \right)^2 N_L^{(1)}(\hat{\boldsymbol{n}})$$

Null tests and features



- 2.9σ after look-elsewhere effects
- Specific to *TT* estimator
- Some sensitivity to sky region
  - *Closer to zero at ecliptic poles but not statistically significant*

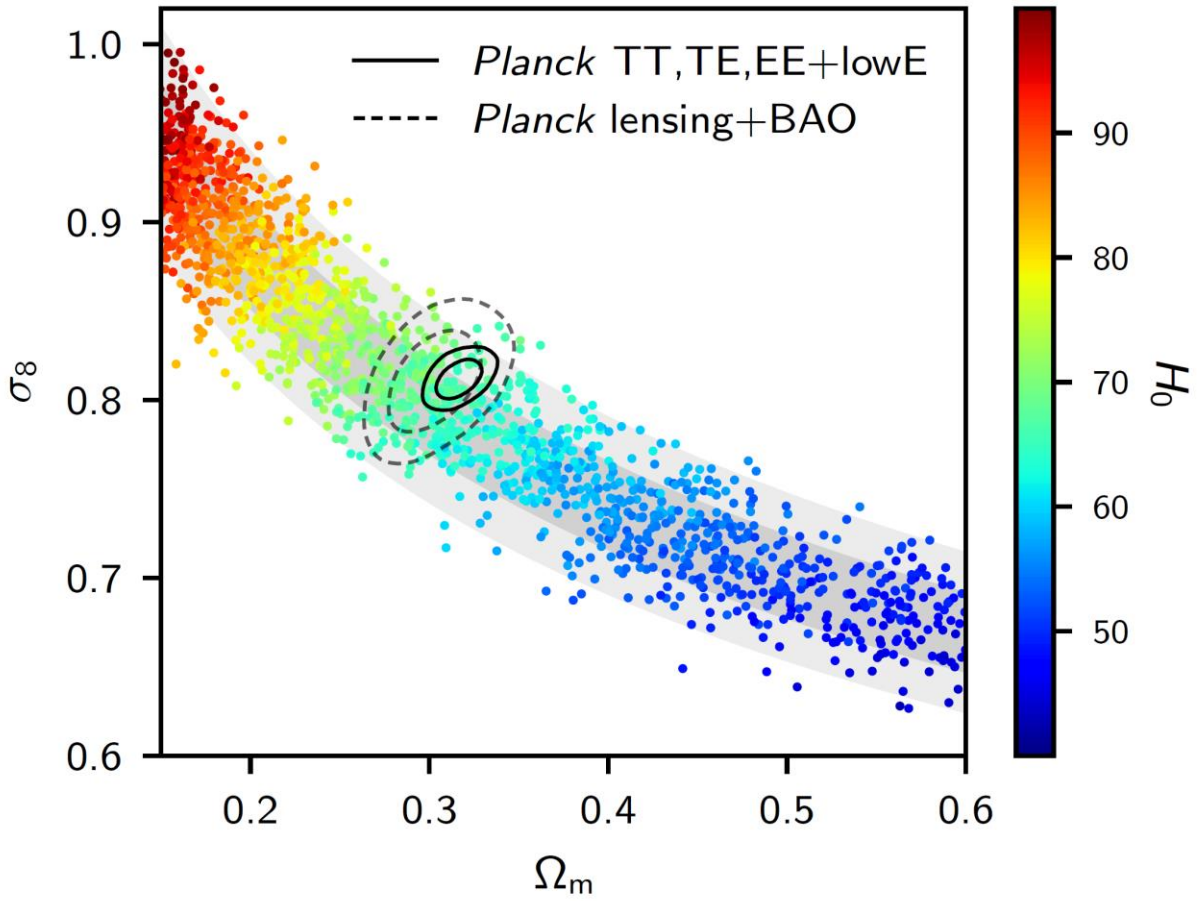


- Only anomalous at 5% in *TT*
- Not seen in cross-correlation
- Lower in HM1 than HM2 (but difference ok statistically)

"Conservative" reconstruction L=8–400 robust to many tests

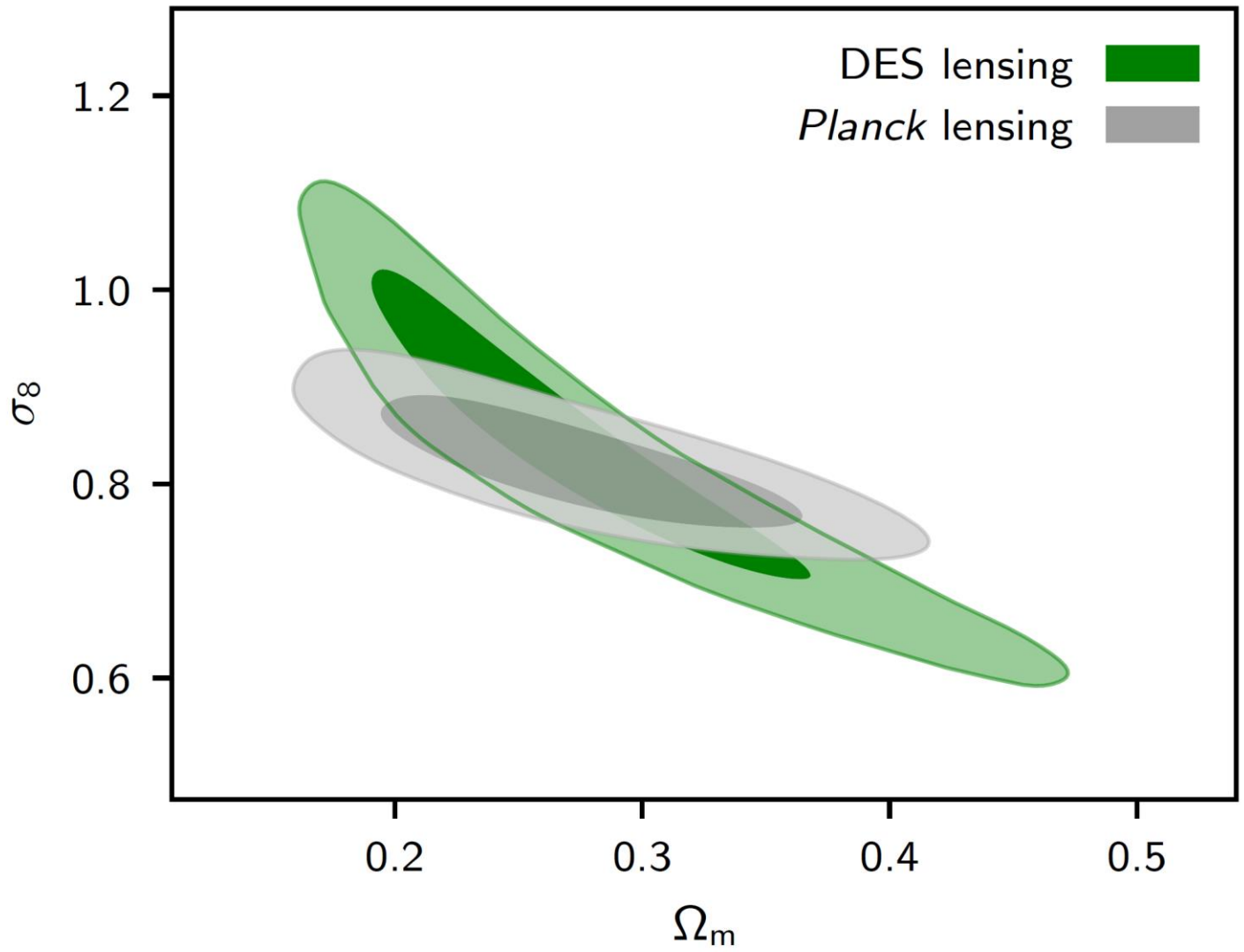
Lensing LCDM parameters

CMB lensing best measures $\sim \sigma_8 \Omega_m^{0.25} = 0.589 \pm 0.020$.

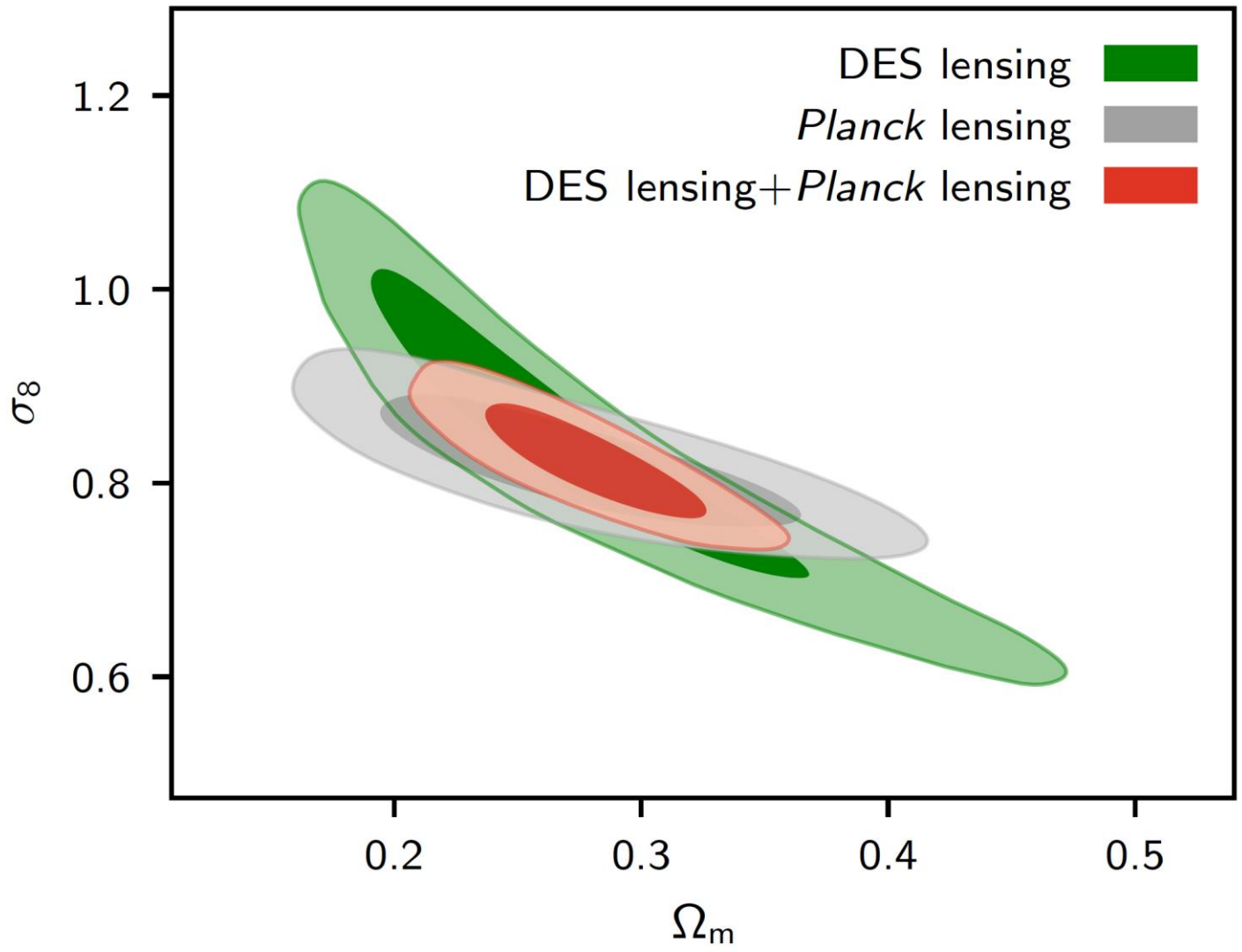


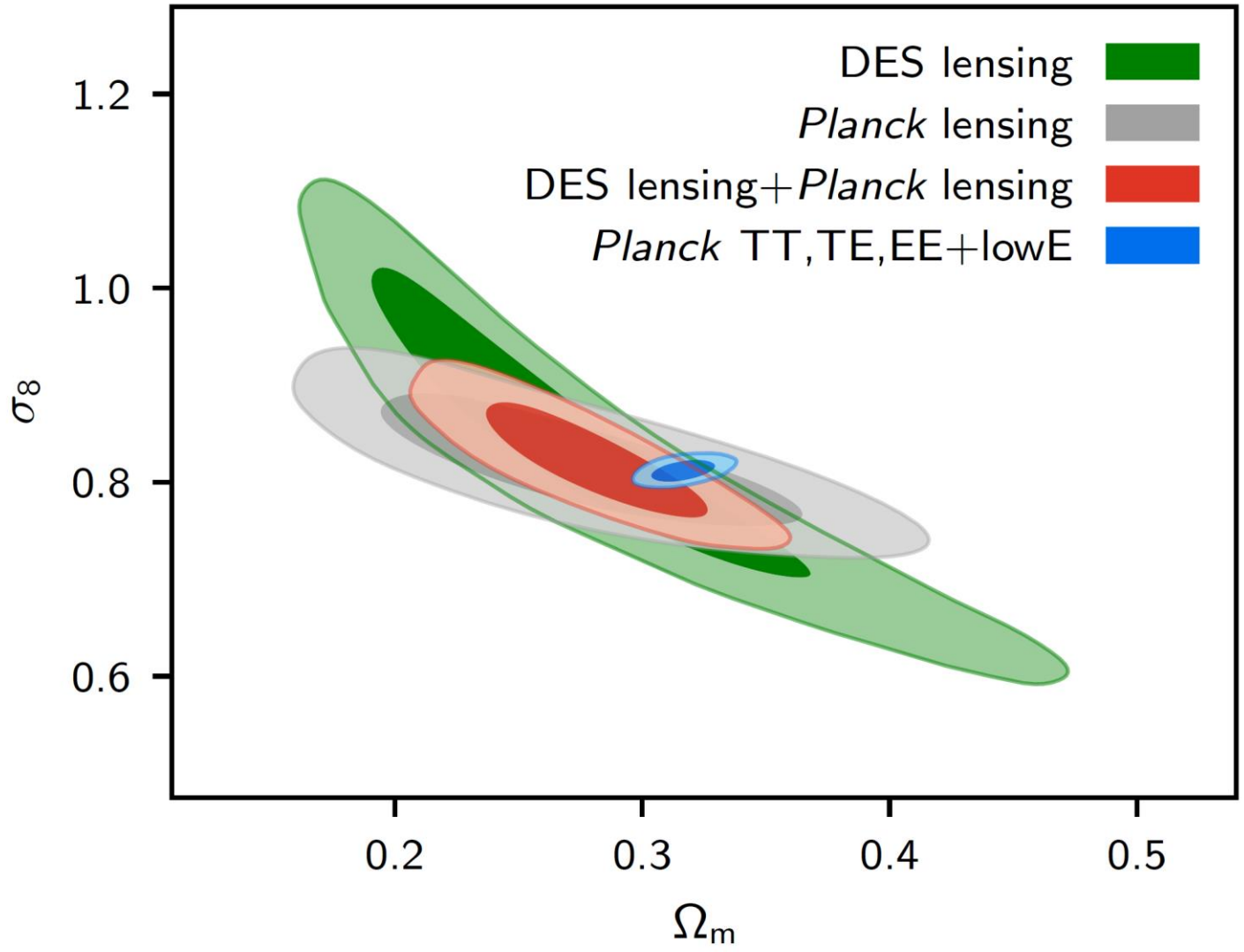
"Lensing-only" priors:
$\Omega_b h^2 = 0.0222 \pm 0.0005$,
$n_s = 0.96 \pm 0.02$
$0.4 < h < 1$

$$\left.\begin{aligned} H_0 &= 67.9^{+1.2}_{-1.3}\ \mathrm{km\ s^{-1}Mpc^{-1}}, \\ \sigma_8 &= 0.811 \pm 0.019, \\ \Omega_m &= 0.303^{+0.016}_{-0.018}, \end{aligned}\right\} \ 68\,\%, \text{ lensing+BAO}$$

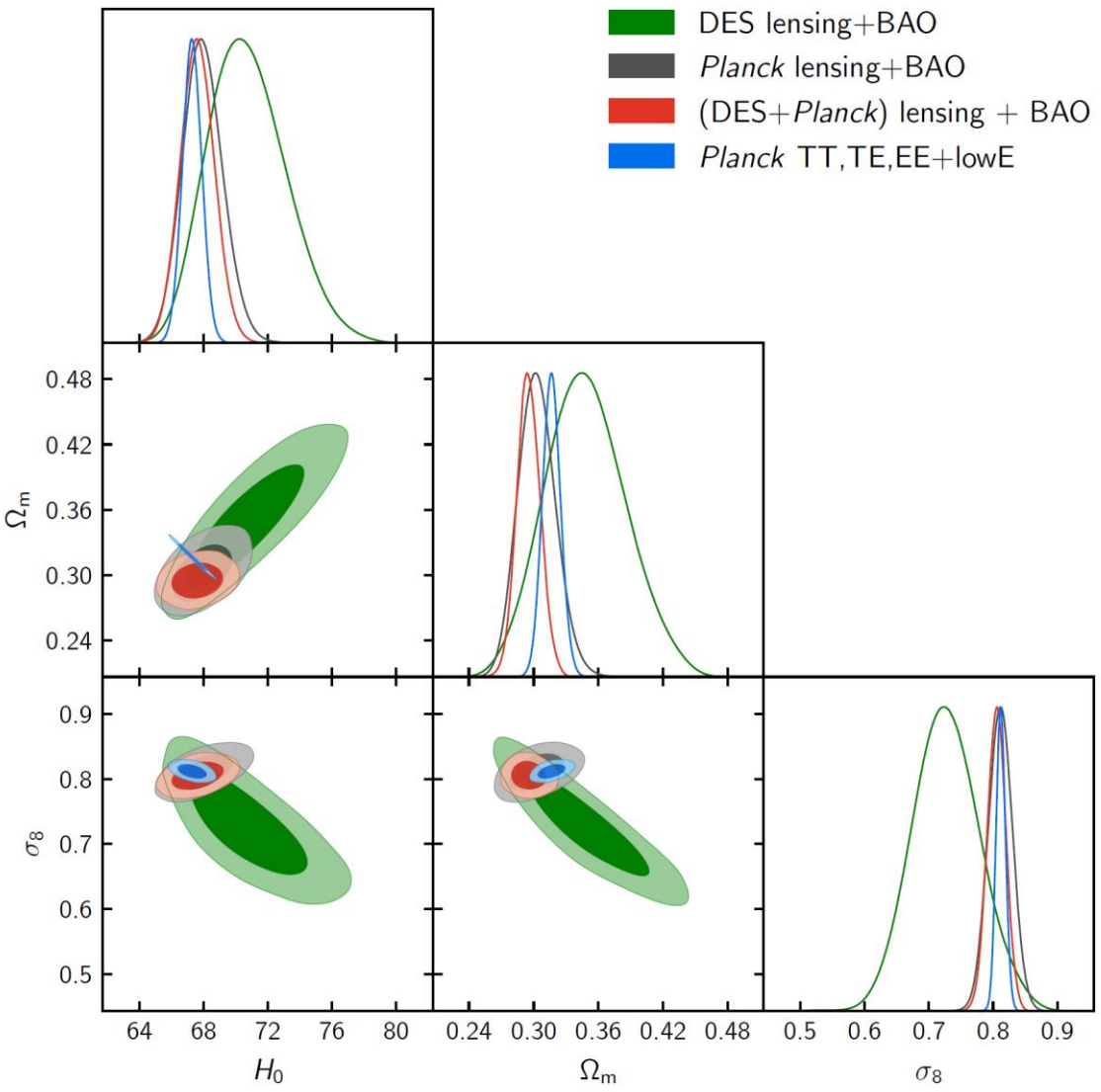


DES lensing from Troxel et al. (DES Collaboration 2017, 10 nuisance parameters marginalized)


DES lensing
Planck lensing
DES lensing+*Planck* lensing
1.2
1.0
0.8
0.6
σ_8
0.2
0.3
0.4
0.5
Ω_m


DES lensing
Planck lensing
DES lensing+*Planck* lensing
Planck TT,TE,EE+lowE
1.2
1.0
0.8
0.6
σ_8
0.2
0.3
0.4
0.5
Ω_m

Lensing + BAO + ($\Omega_b h^2 = 0.0222 \pm 0.0005$)

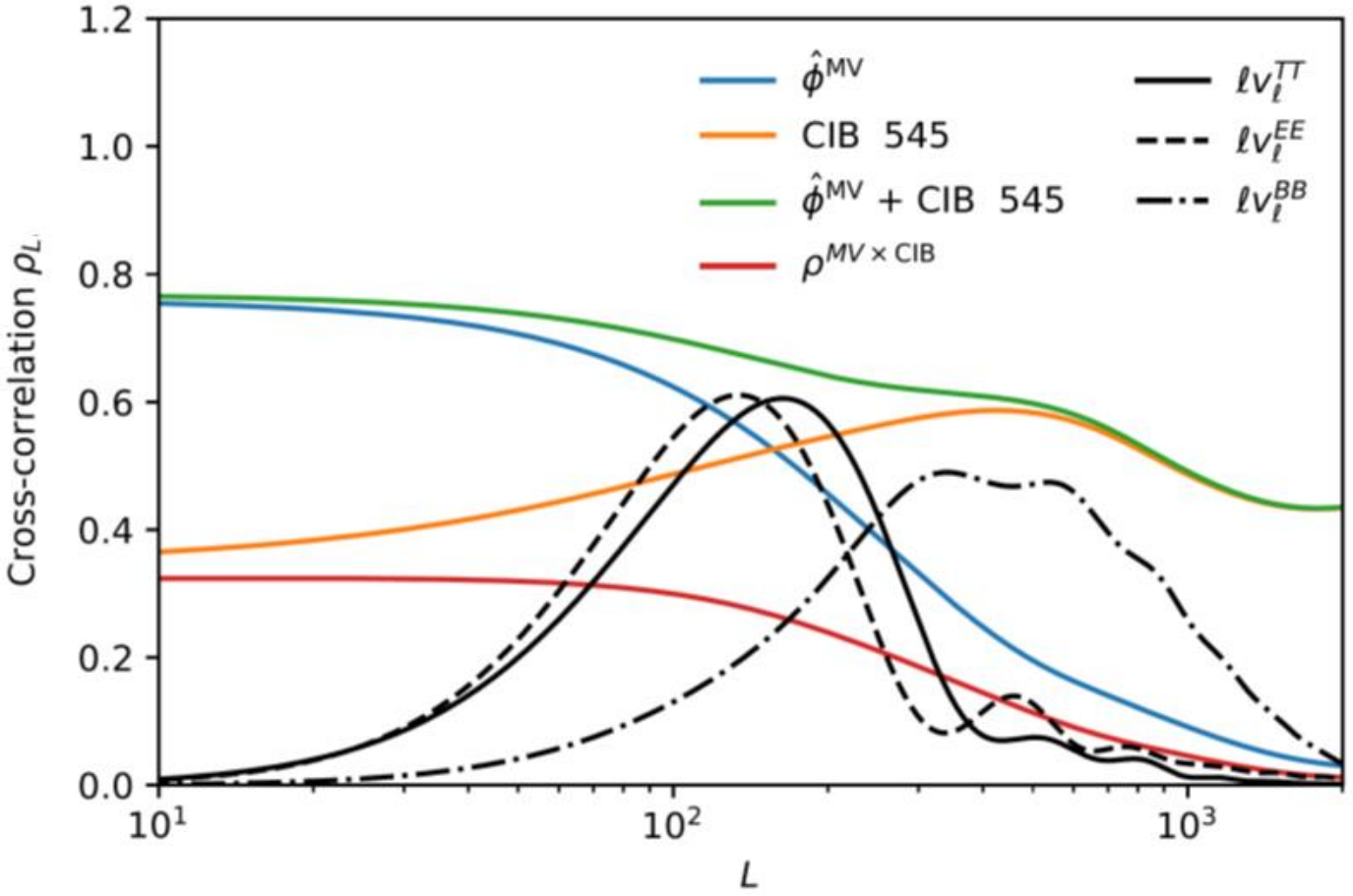


$H_0 = 67.9^{+1.2}_{-1.3}$ km s^{-1}Mpc^{-1},
$\sigma_8 = 0.811 \pm 0.019$,
$\Omega_m = 0.303^{+0.016}_{-0.018}$,
} 68 %, lensing+BAO

$H_0 = 70.7^{+2.1}_{-2.7}$ km s^{-1}Mpc^{-1}
$\sigma_8 = 0.727 \pm 0.052$
$\Omega_m = 0.348^{+0.033}_{-0.040}$
} 68%, DES lensing+BAO,

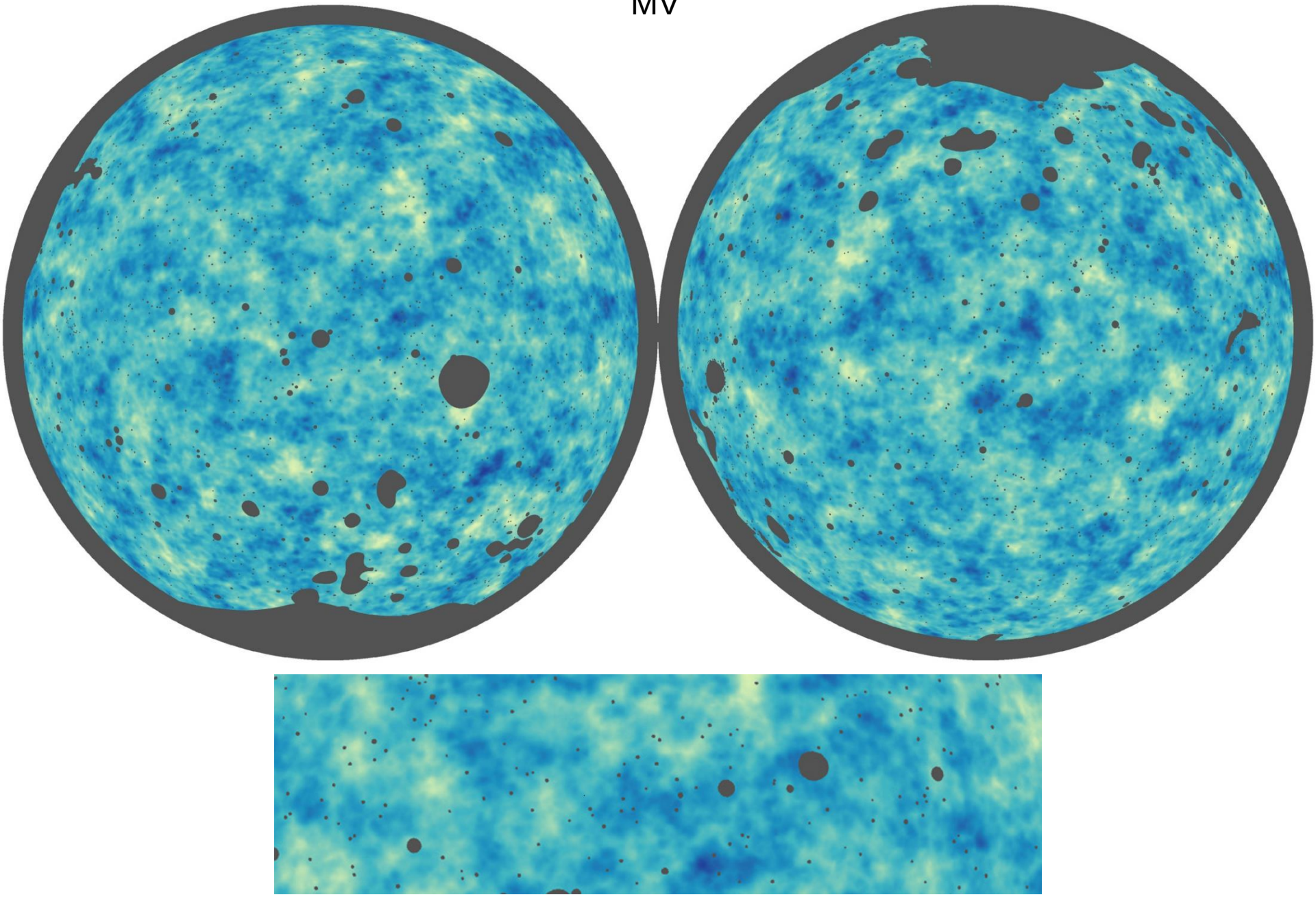
$H_0 = (67.6 \pm 1.1)$ km s^{-1}Mpc^{-1}
$\sigma_8 = 0.805 \pm 0.014$
$\Omega_m = 0.295 \pm 0.011$
} 68%, DES lensing +*Planck* lensing+BAO

Joint lensing potential using lensing reconstruction + CIB

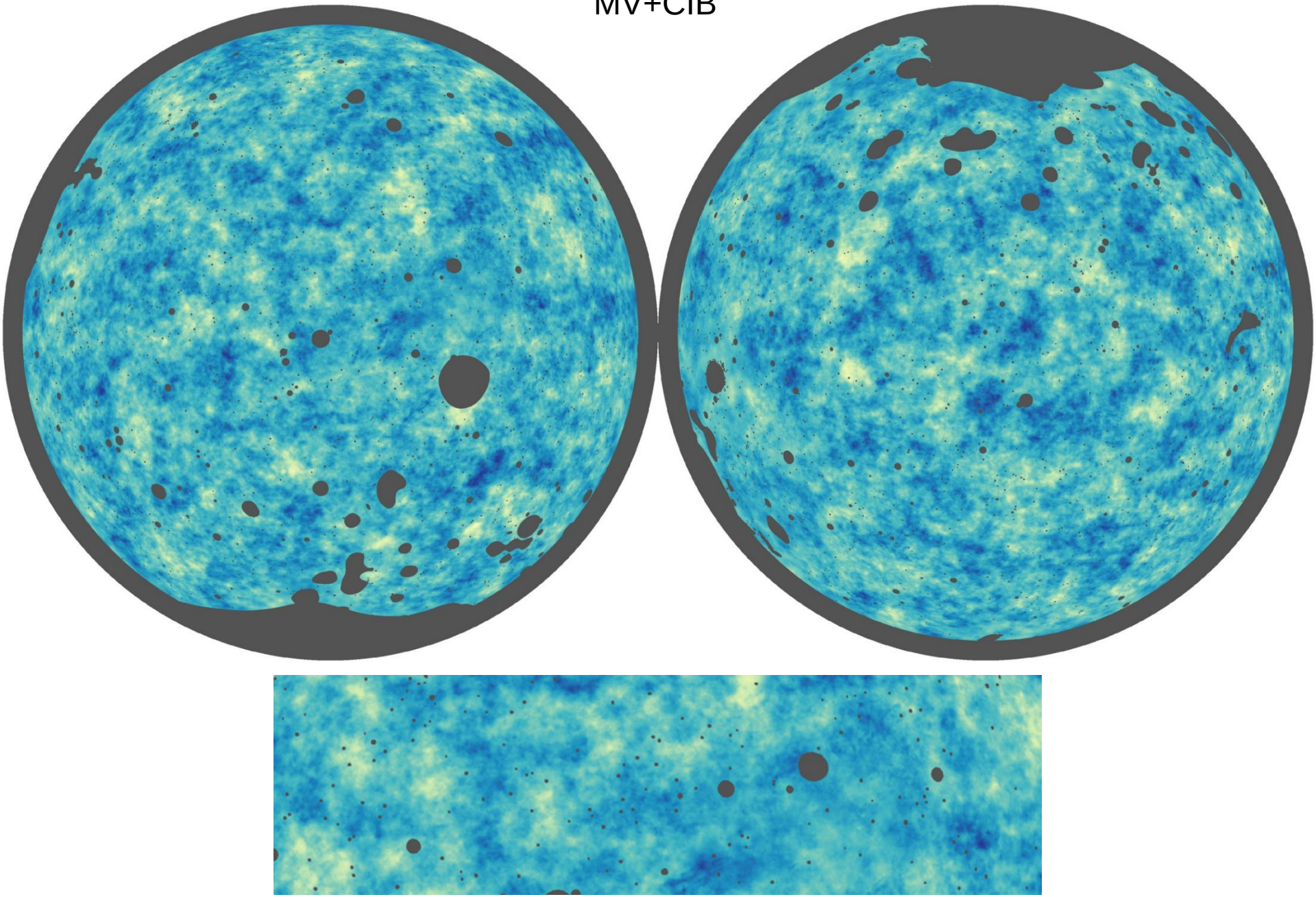


Use GNILC 353, 545 GHz CIB maps as additional tracer of lensing potential

MV

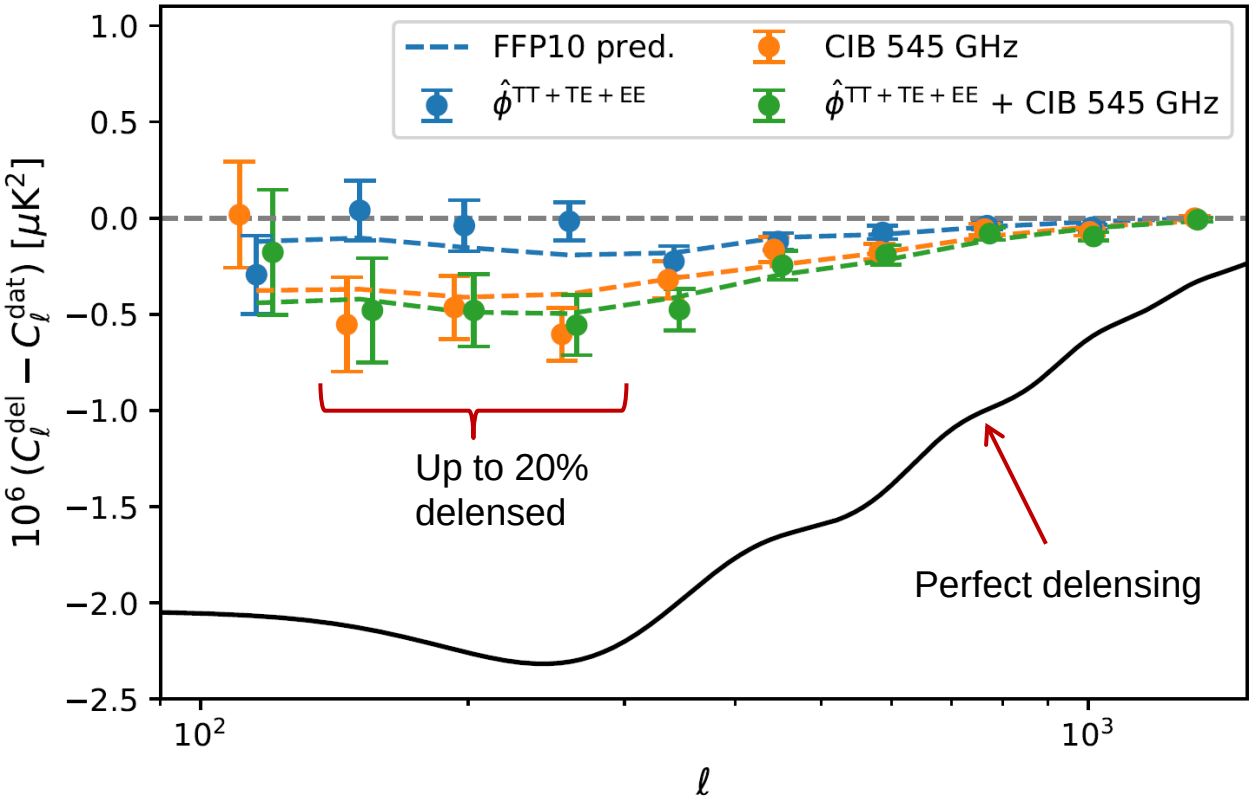


MV+CIB



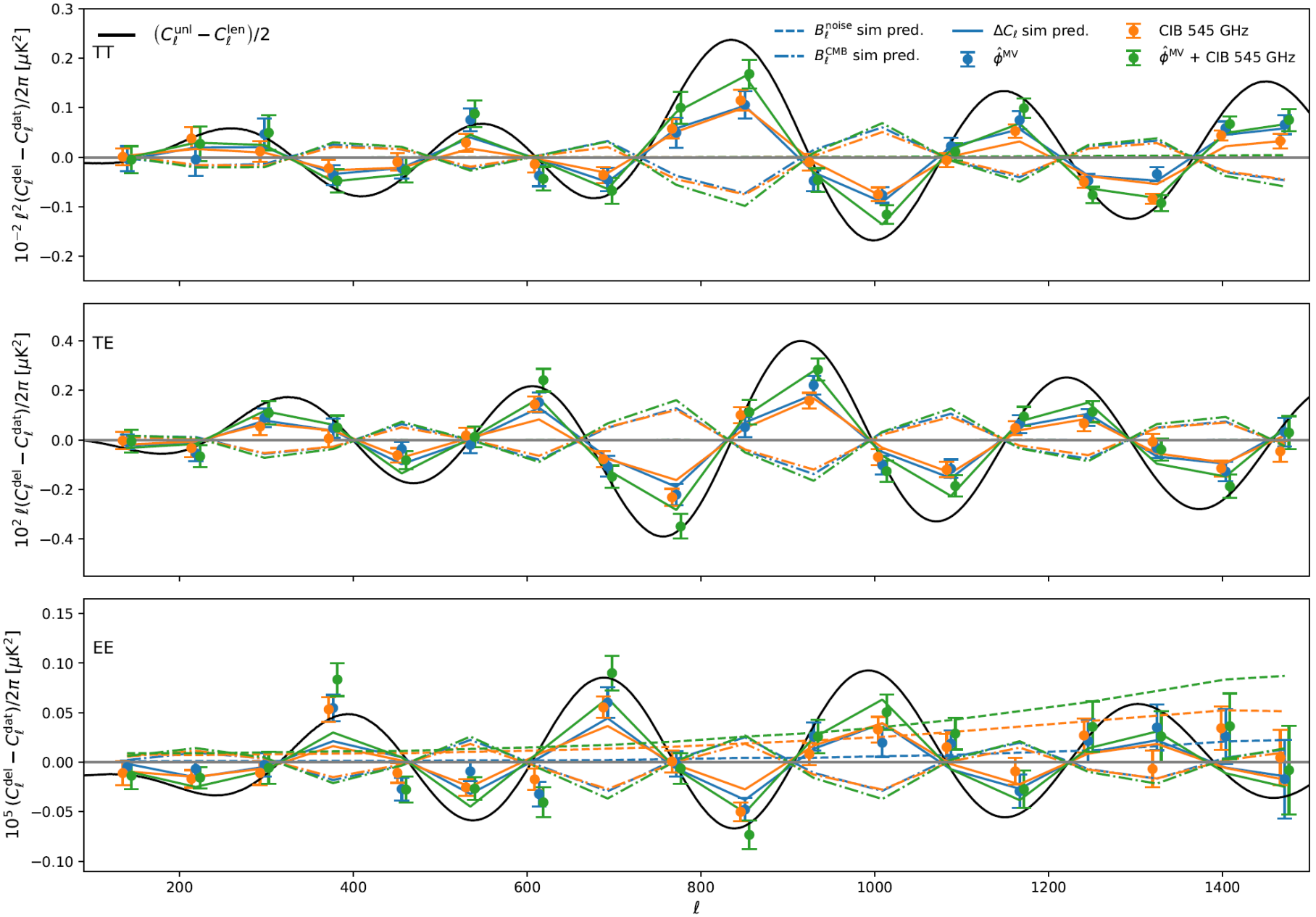
Template delensing proof of principle

(limited delensing efficiency from Planck due to E noise)



Delensing: Peak Sharpening – 40% of smoothing effect removed with MV+CIB

$$\Delta\hat{C}_{\ell,\mathrm{debias}} \equiv \hat{C}_\ell^{\mathrm{del}} - \hat{C}_\ell^{\mathrm{dat}} - B_\ell^{\mathrm{Gauss}} - B_\ell^{\mathrm{Noise}} + B_\ell^{\mathrm{CMB}}.$$



Data Products

- Lensing maps (TT, PP, MV, tSZ-deprojected, no SZ mask) and corresponding simulations
- Joint internal (MV and TT,TE,EE) + CIB lensing tracer maps and simulations
- B-mode templates on 60% sky and simulations
- Band powers, covariance, linear correction likelihood files
  (use with native support in CosmoMC, Cobaya, etc.. Planck-format “clik” version coming later)
- MCMC chains and parameter constraint tables

https://wiki.cosmos.esa.int/planck-legacy-archive/index.php/Lensing
https://pla.esac.esa.int/#cosmology

(PLA site currently buggy. Email us if you need something and can’t find it)