

PLANCK constraints on the tensor-to-scalar ratio

Planck constraints on the tensor-to-scalar ratio

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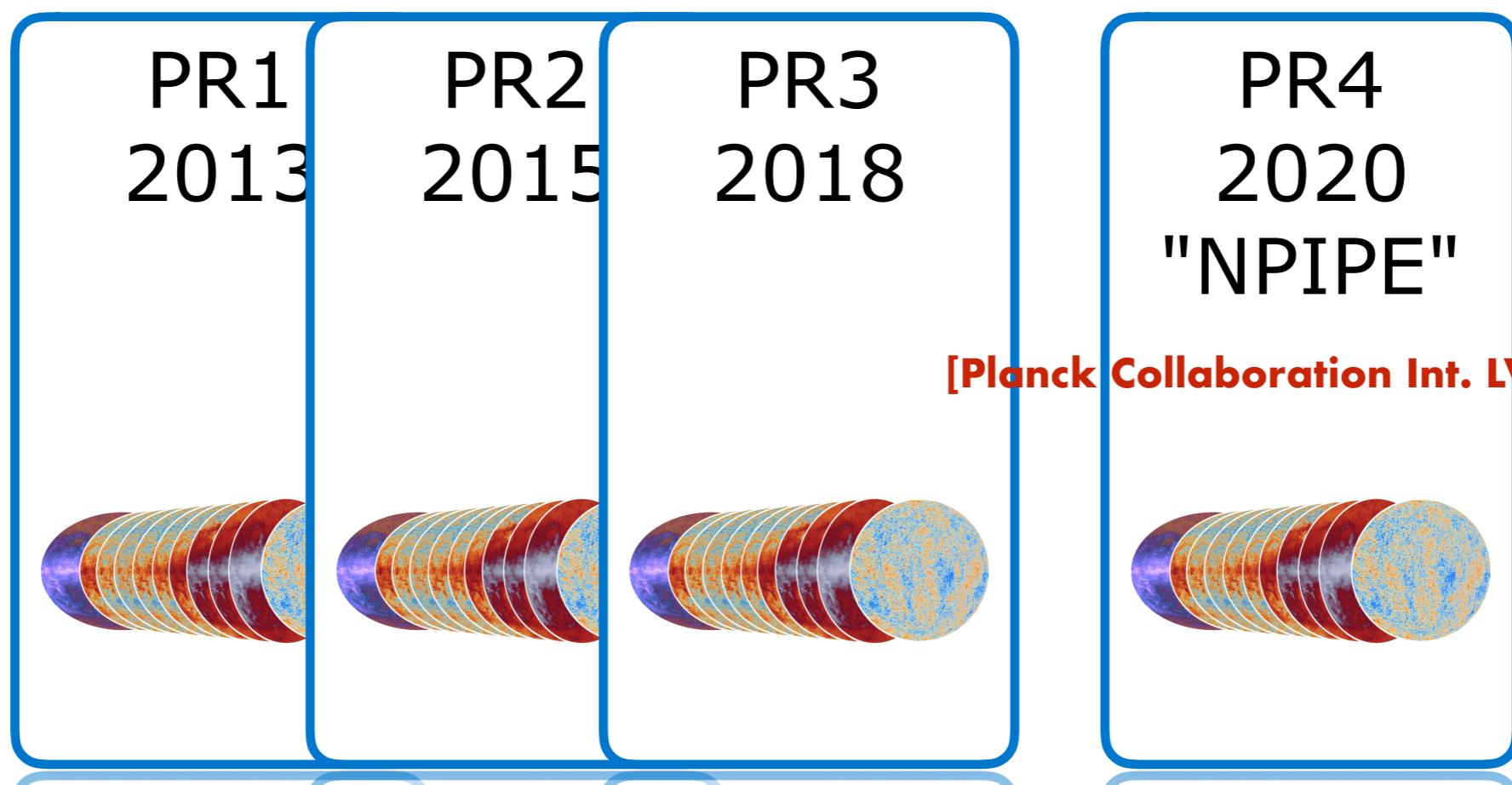
[Tristram et al. A&A 647, A128 (2021)]
[astro-ph/2010.01139](https://arxiv.org/abs/2010.01139)



PLANCK polarization data

- PLANCK detectors are sensitive to **one polarization direction**
- PLANCK scanning strategy do not allow for polarization reconstruction for each detector independently
 - need to **combine detectors** with different polarization orientation
- Any flux **mismatch** between detectors will create spurious polarization signal through well known **I-to-P leakage**.
In particular : ADC non-linearity, bandpass mismatch, calibration mismatch, ...

this is the major systematic in polarization at large scales



PLANCK Release 4

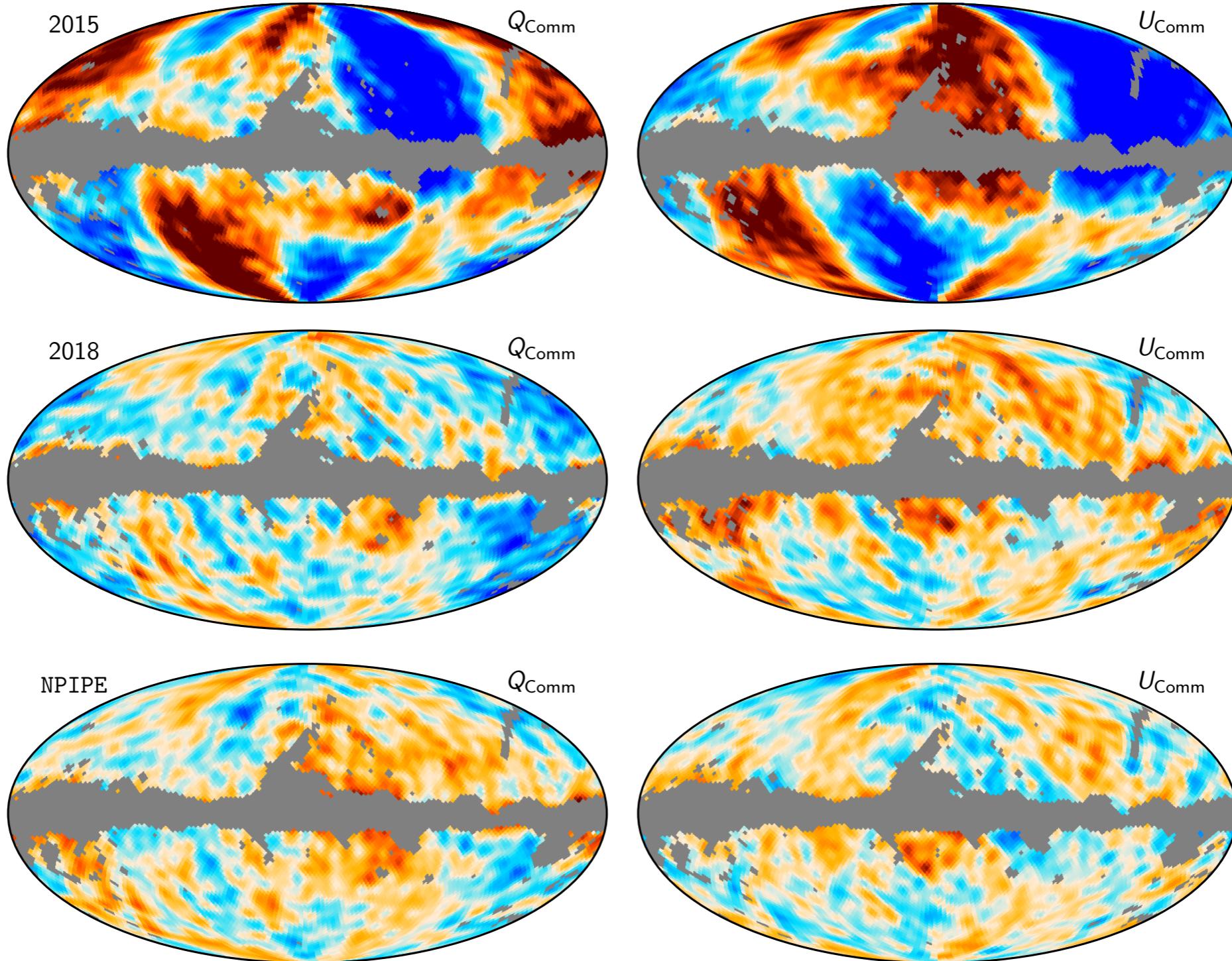
NPIPE processing

- Processing applied consistently over the whole 9 PLANCK frequencies (from 30 GHz to 857 GHz) **NEW**
- NPIPE map-making includes templates for
 - systematic effects
(time transfer-function, ADC non-linearities, Far Side Lobes, bandpass-mismatch)
 - sky-asynchronous signals (orbital dipole, zodiacal light)
- Provide frequency maps
 - **cleaner**: less residuals (compared to PR3) at the price of a **non-zero transfer function** at large scale in polarization
 - **more accurate**: less noise (compared to PR3)
 - no residuals from template resolution mismatch (as visible in PR3)
- Provide **independent** split-maps **NEW**
 - PR3: time-split (half-mission or half-ring) → correlated
 - PR4: detector-split (detset) → independent
- Provide low-resolution maps with pixel-pixel noise covariance estimates across all PLANCK frequencies **NEW**

PLANCK Release 4

CMB polarized maps

[Planck Collaboration Int. LVII (2020)]



Commander CMB Q and U maps
(large scale, 5° smoothing)

PLANCK Release 4

NPIPE simulations

a realistic simulation set is essential to properly assess polarization uncertainties especially at large angular scales

- **600 consistent simulations (frequency and split maps)**

NEW

- **Inputs**

- including instrumental noise (consistent with data-split differences)
- including models for systematics (ADC non-linearity)
- random CMB with 4π beam convolution
- foreground sky model based on Commander PLANCK solution

- **Allow for**

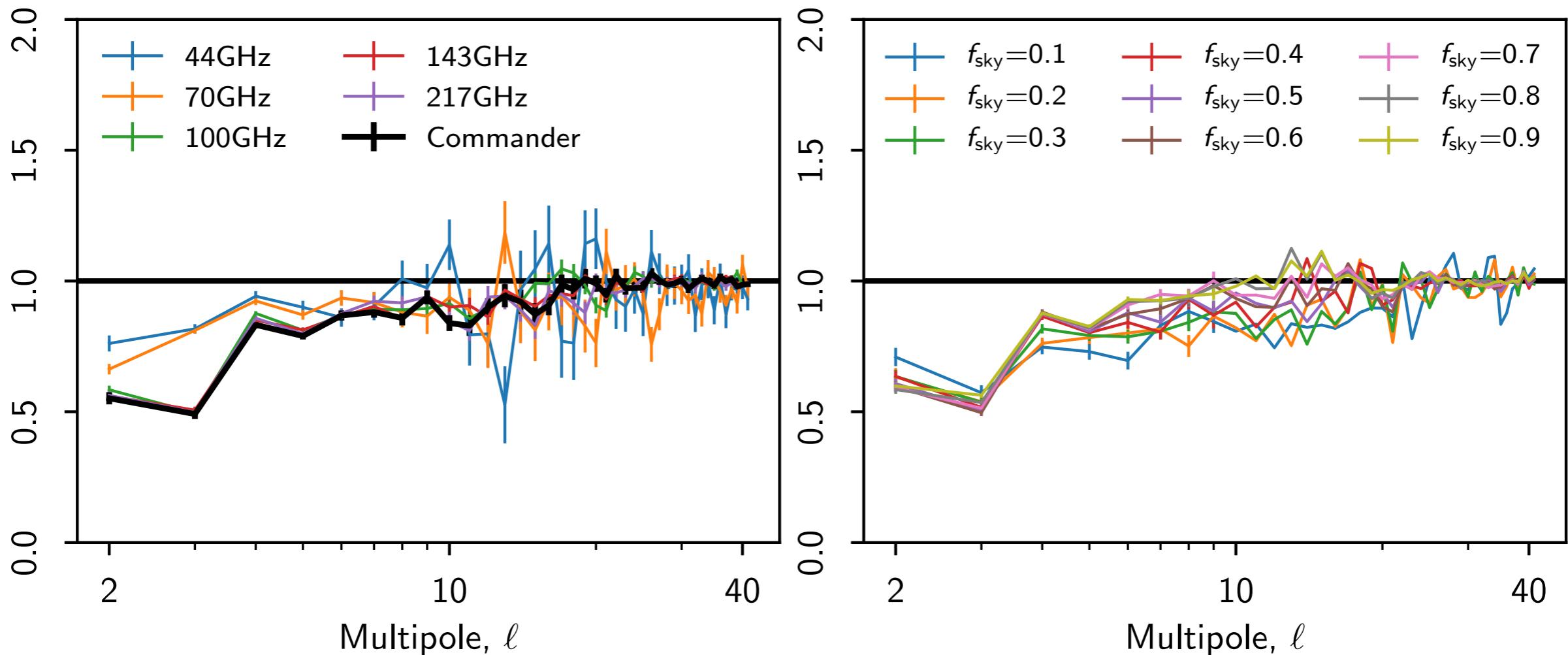
1. accurate effective description of the noise and **covariance** of the maps (including noise, instrumental systematics, foreground residuals)
no need for "a posteriori" rescaling as in PR3
2. estimation of the **transfer function** of the PLANCK processing

NPIPE simulations

processing transfer function

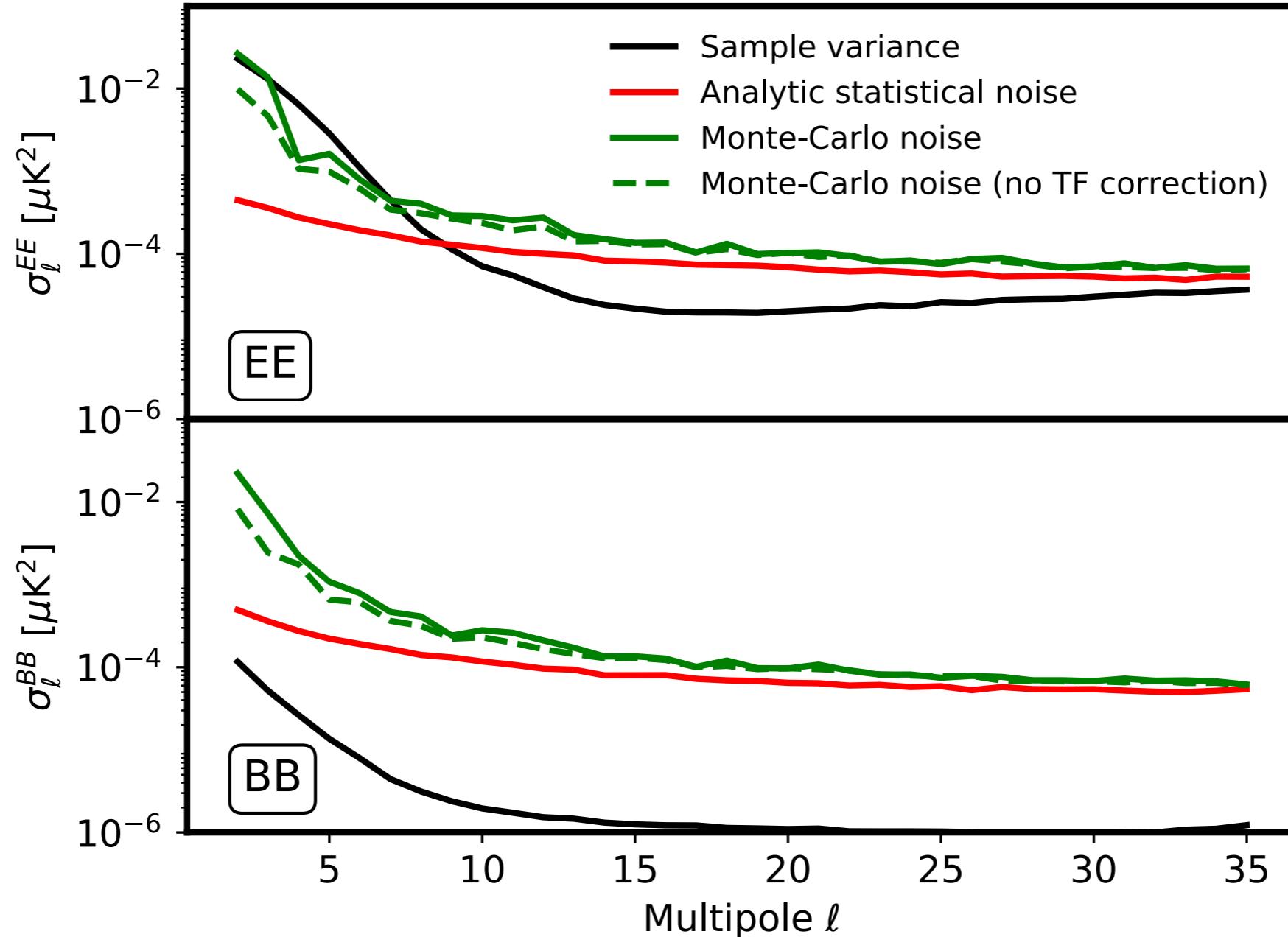
Simulations allow to characterize accurately the processing transfer-function for each frequency

- stable with frequency (less for LFI with fewer systematic templates)
- stable with sky-fraction

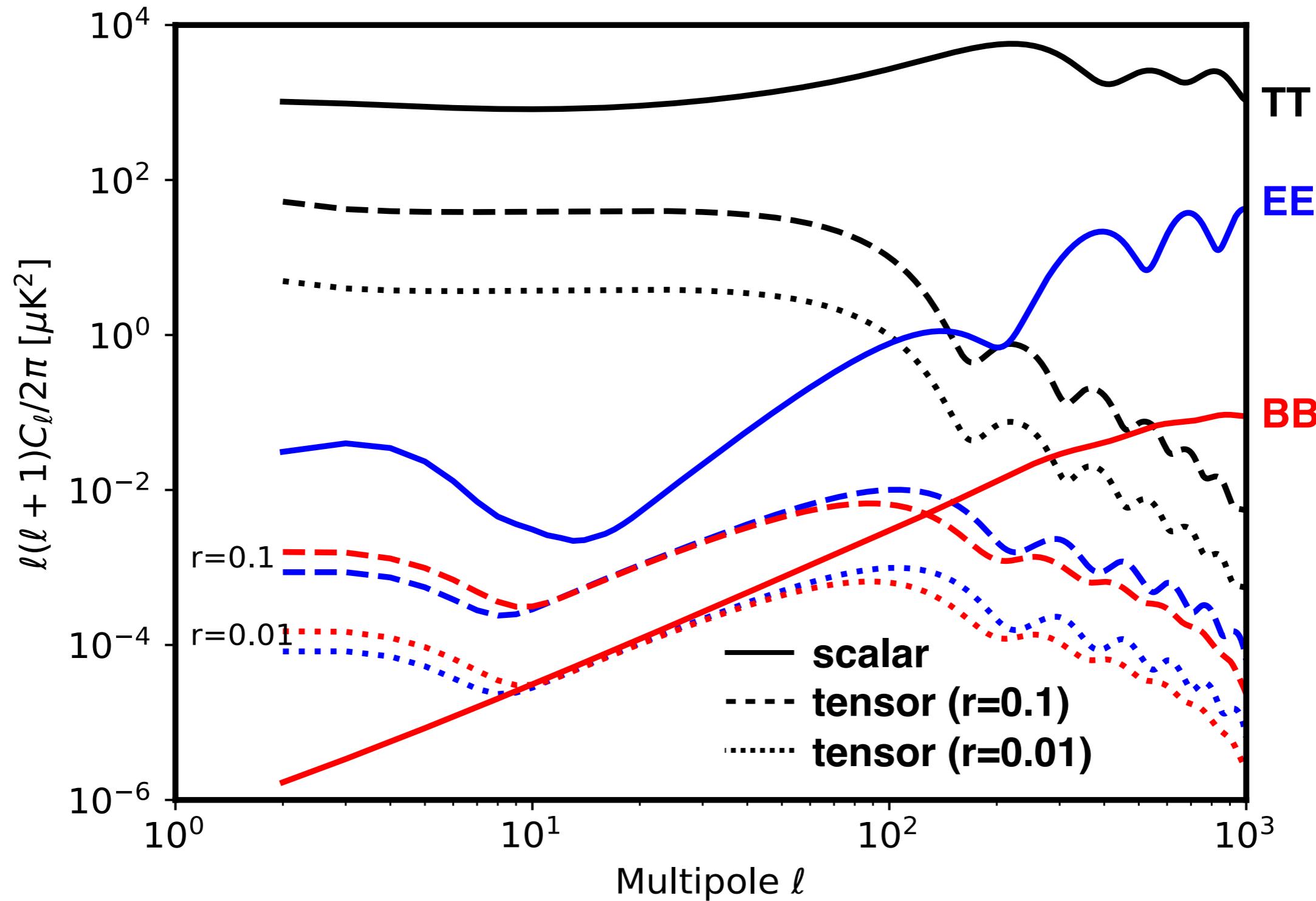


NPIPE simulations

noise estimation



Scalar v.s. Tensor fluctuations



Full E/B Likelihood (lollipop)

[Hamimeche & Lewis (2008)]

[Mangilli, Plaszczynski, Tristram (2015)]

- **Hamimeche&Lewis approximation** modified for cross-spectra
- C_ℓ not Gaussian but X_ℓ statistics is very close to Gaussianity

$$X_\ell = \sqrt{C_\ell^f + O_\ell} g\left(\frac{\tilde{C}_\ell + O_\ell}{C_\ell + O_\ell}\right) \sqrt{C_\ell^f + O_\ell}$$

with $g(x) = \sqrt{2(x - \ln x - 1)}$

\tilde{C}_ℓ is the measured spectrum

C_ℓ is the model to test

C_ℓ^f is a fiducial theoretical model

O_ℓ is the offset given by the level of noise $\Delta C_\ell \equiv \sqrt{\frac{2}{2\ell+1}} O_\ell$

- then the likelihood approximation simply reads

$$-2 \ln P(C_\ell | \tilde{C}_\ell) = \sum_{\ell\ell'} X_\ell^\top M_{\ell\ell'}^{-1} X_{\ell'}$$

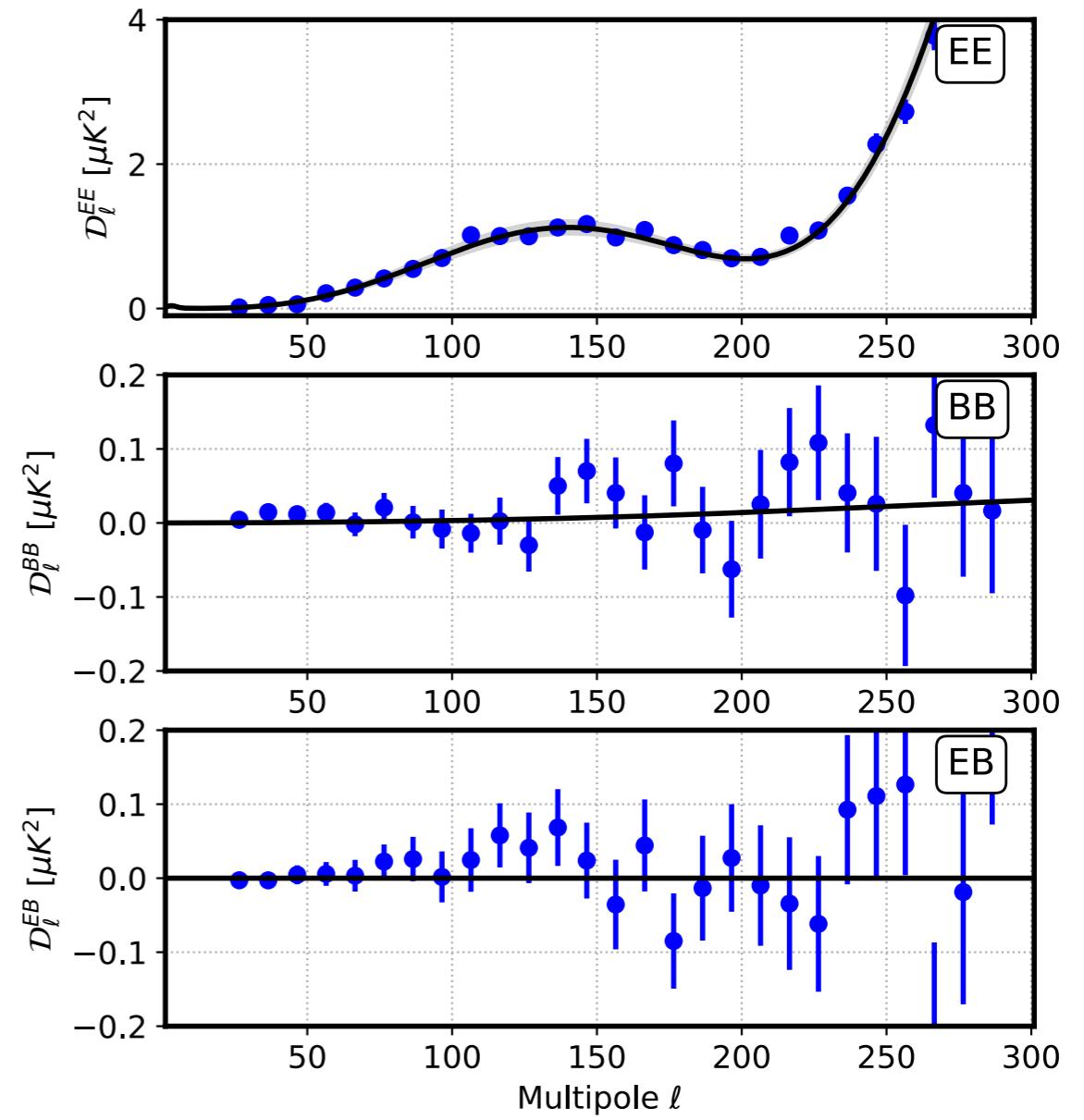
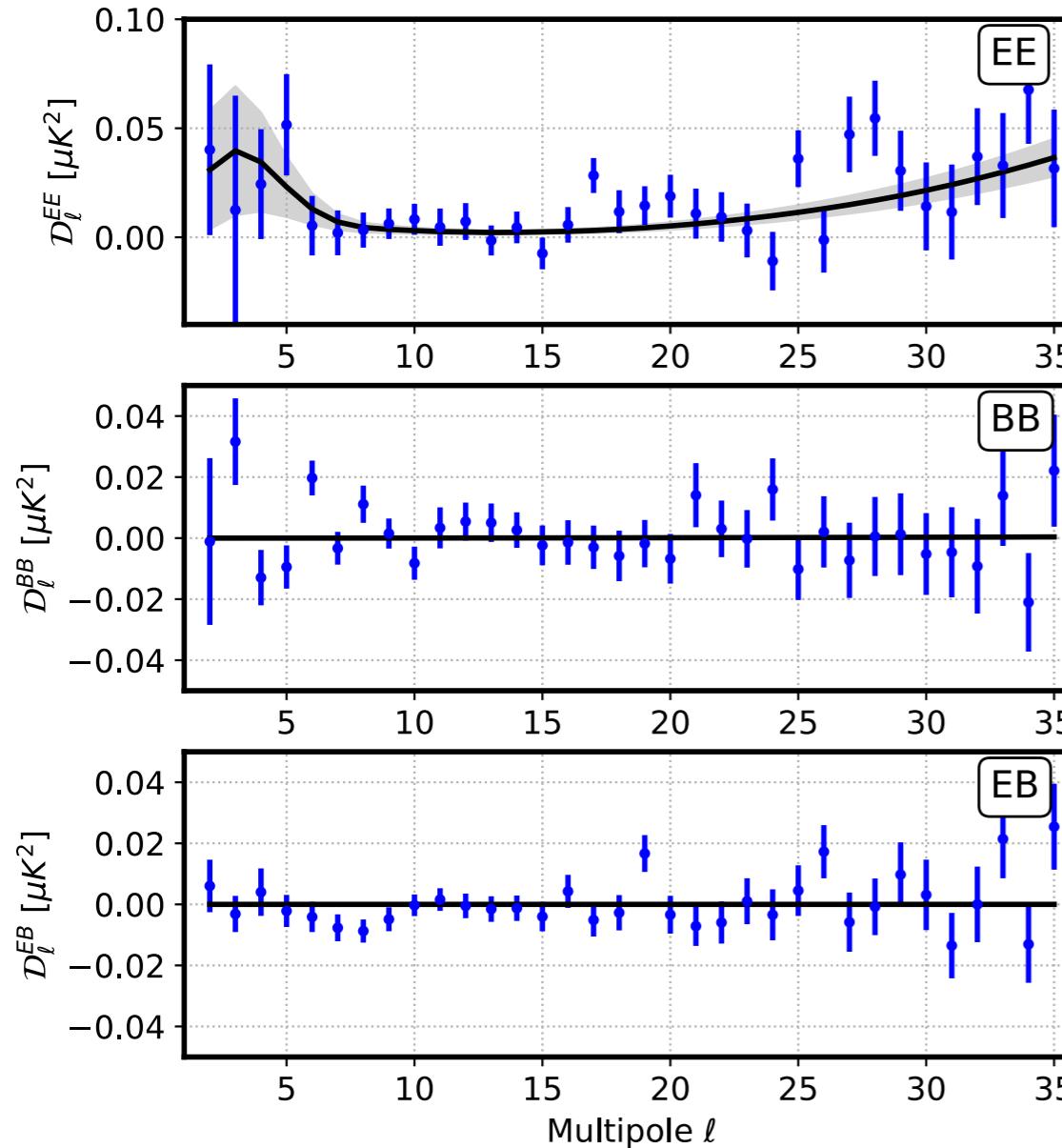
with the matrix $M_{\ell\ell'}$ being the **covariance** from the C_ℓ



[\[https://github.com/planck-npipe/lollipop\]](https://github.com/planck-npipe/lollipop)

Lollipop PLANCK power-spectra

sky fraction 50%



xQML

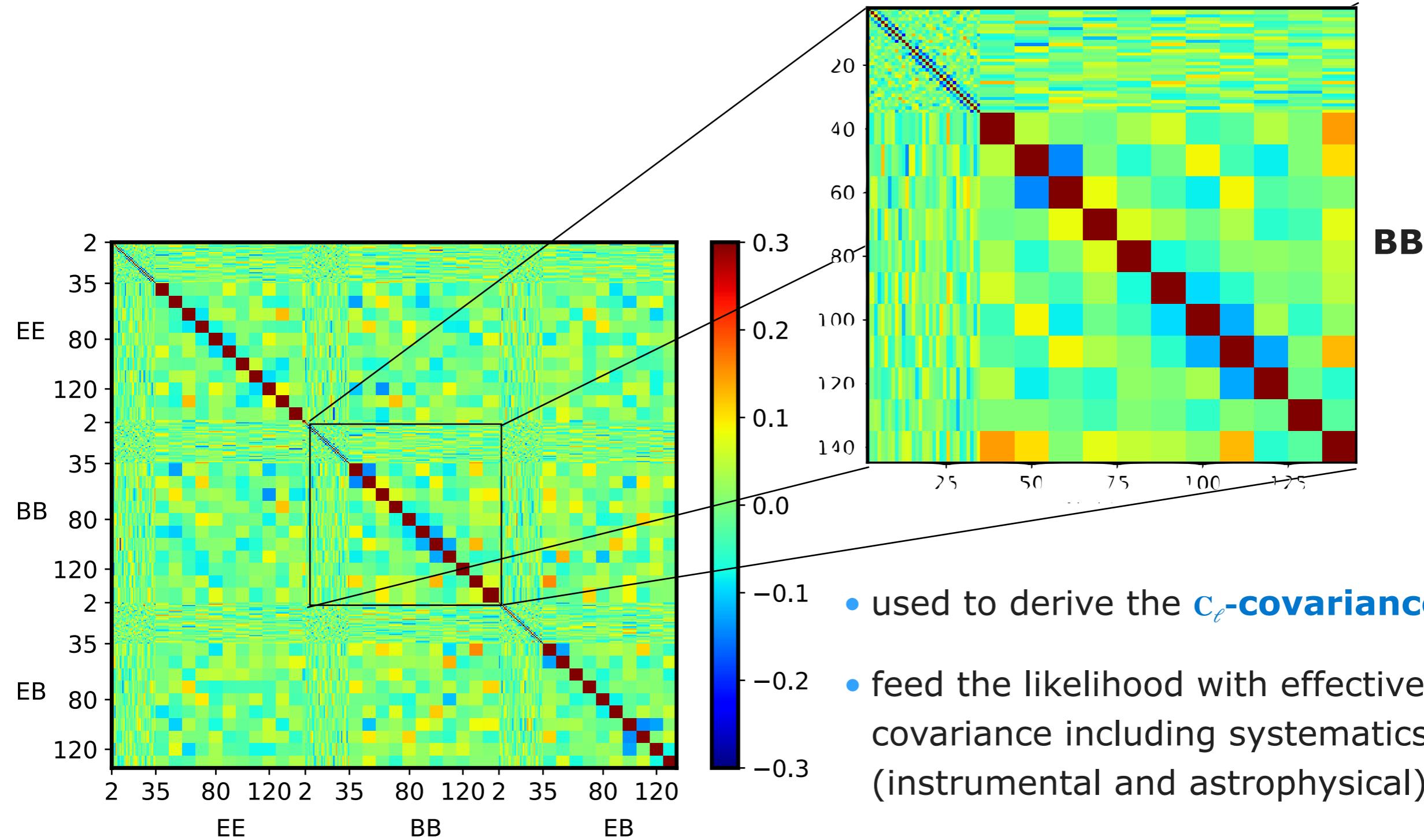
[\[https://gitlab.in2p3.fr/xQML\]](https://gitlab.in2p3.fr/xQML)

Xpol

[\[https://gitlab.in2p3.fr/tristram/Xpol\]](https://gitlab.in2p3.fr/tristram/Xpol)

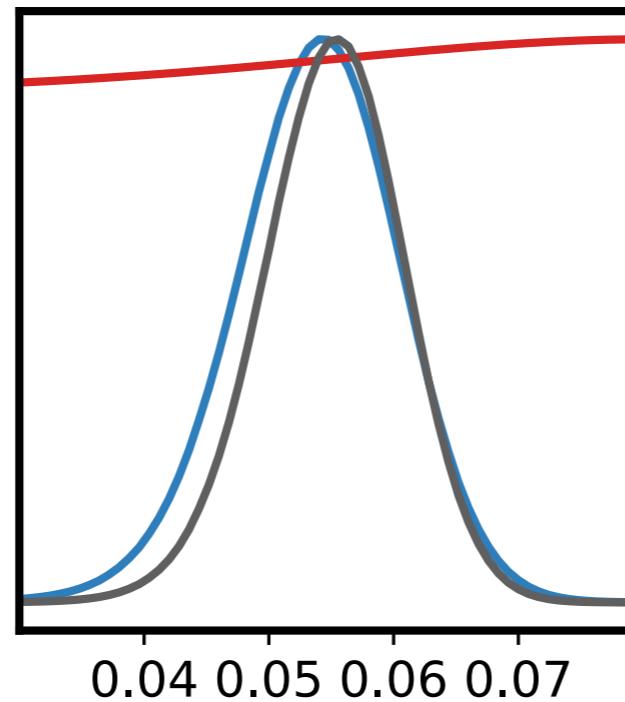
Lollipop PLANCK spectra covariance

400 simulations of CMB reconstructed independently by Commander on each set of simulated frequency maps

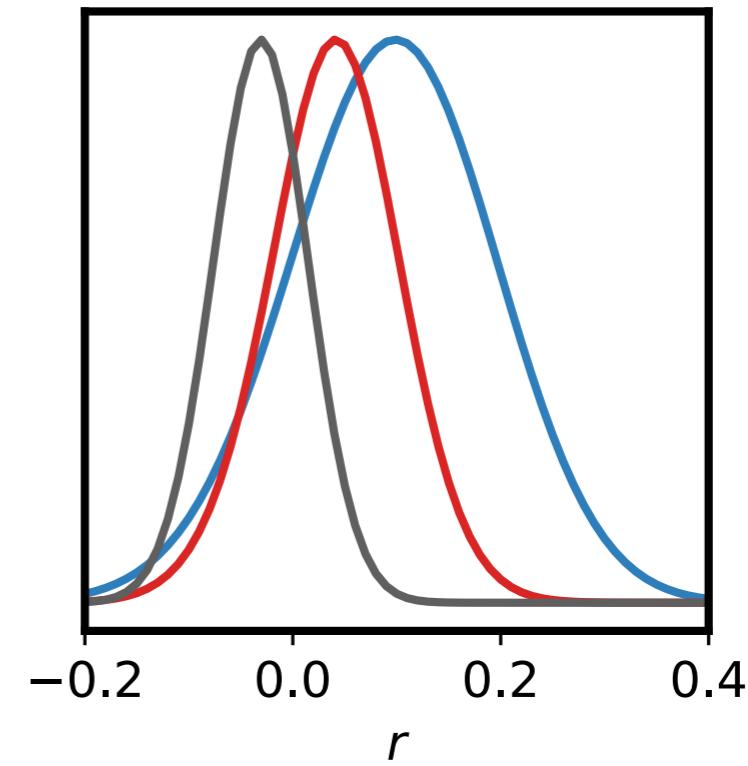
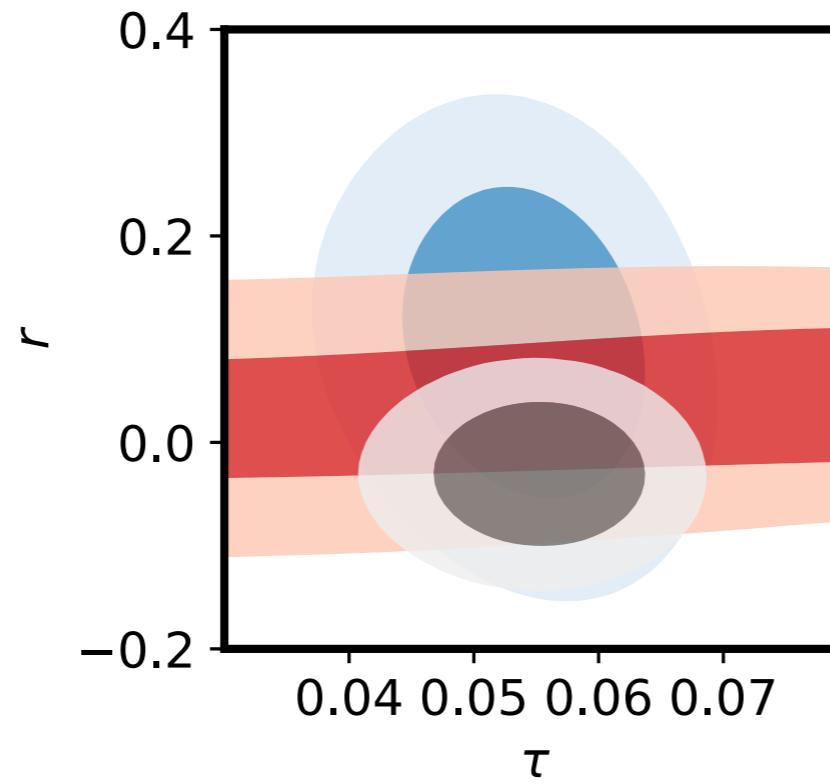


Parameter constraints

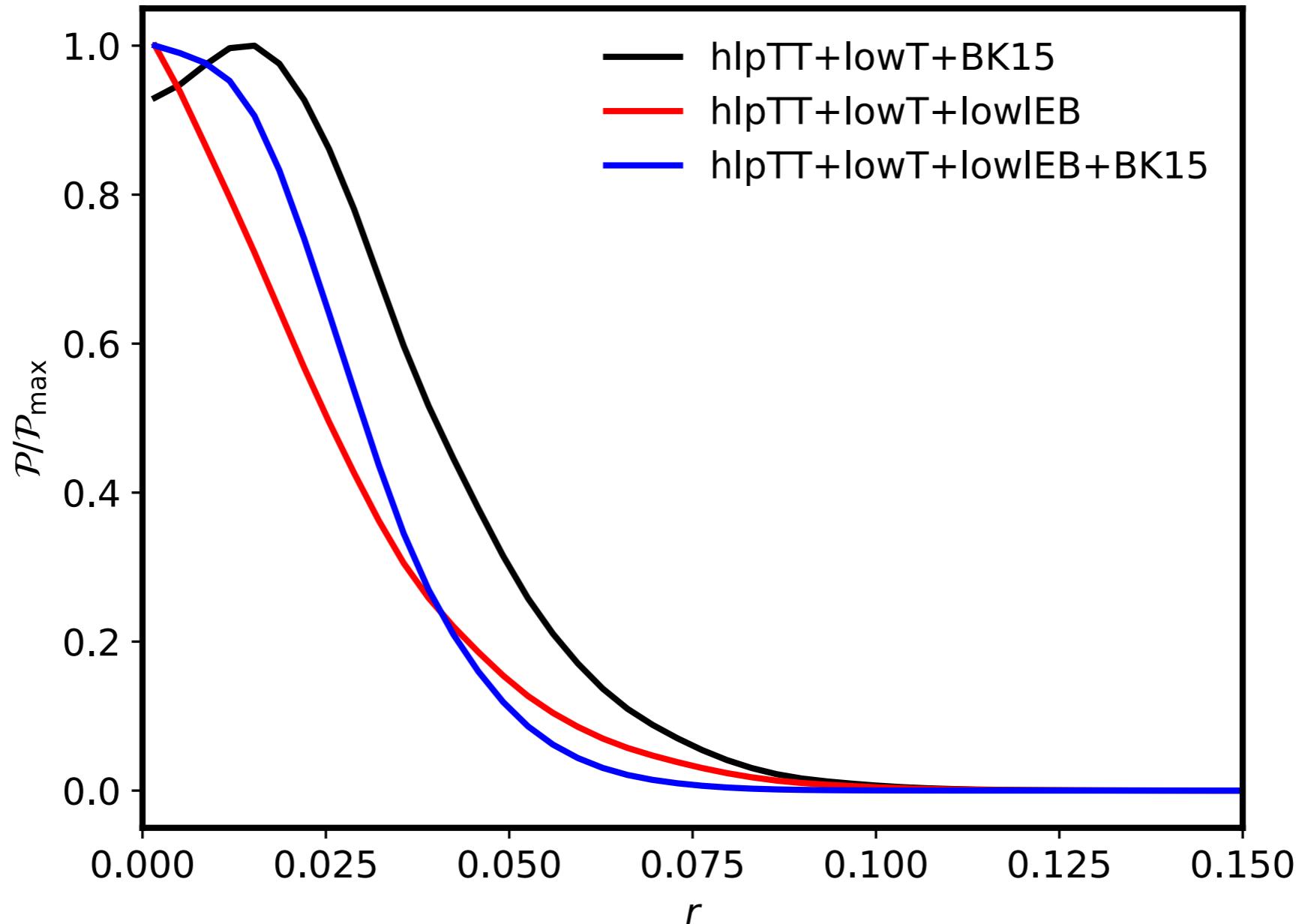
$$\tau = 0.0577 \pm 0.0056$$



EE
BB
EE+BB+EB



Results (in combination with TT)



$r_{0.05} < 0.060$ (95 % CL, hlpTT+lowT+BK15);

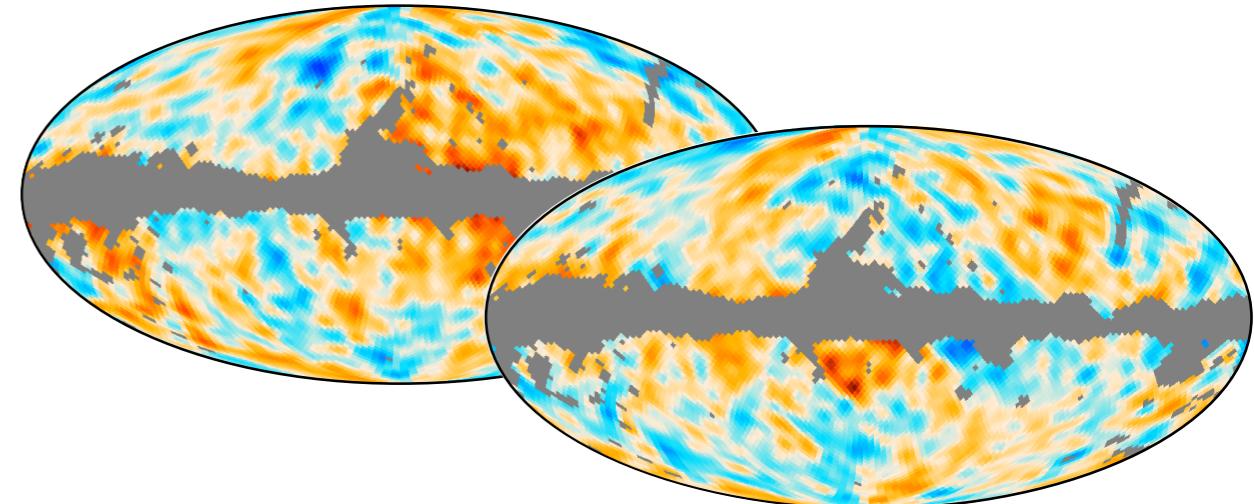
$r_{0.05} < 0.056$ (95 % CL, hlpTT+lowT+lowIEB);

$r_{0.05} < 0.044$ (95 % CL, hlpTT+lowT+lowIEB+BK15)

Conclusions

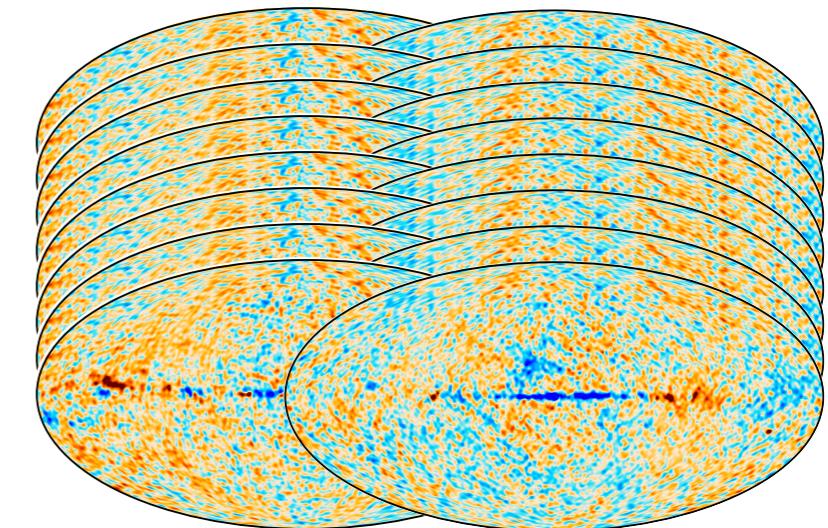
- **NPIPE maps**

- cleaner
- less noisy
- split-maps not correlated



- **NPIPE sims**

- consistent with the data
- allow for TF and variance estimation
- include uncertainties from systematics (both instrumental and astrophysical)



- **Results**

$$r_{0.05} < 0.072 \quad (\text{BICEP2/Keck})$$

1% of the sky

$$r_{0.05} < 0.069 \quad (\text{Planck EB})$$

50% of the sky

$$r_{0.05} < 0.044 \quad (\text{Planck + BK15})$$

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[<https://github.com/planck-npipe>]