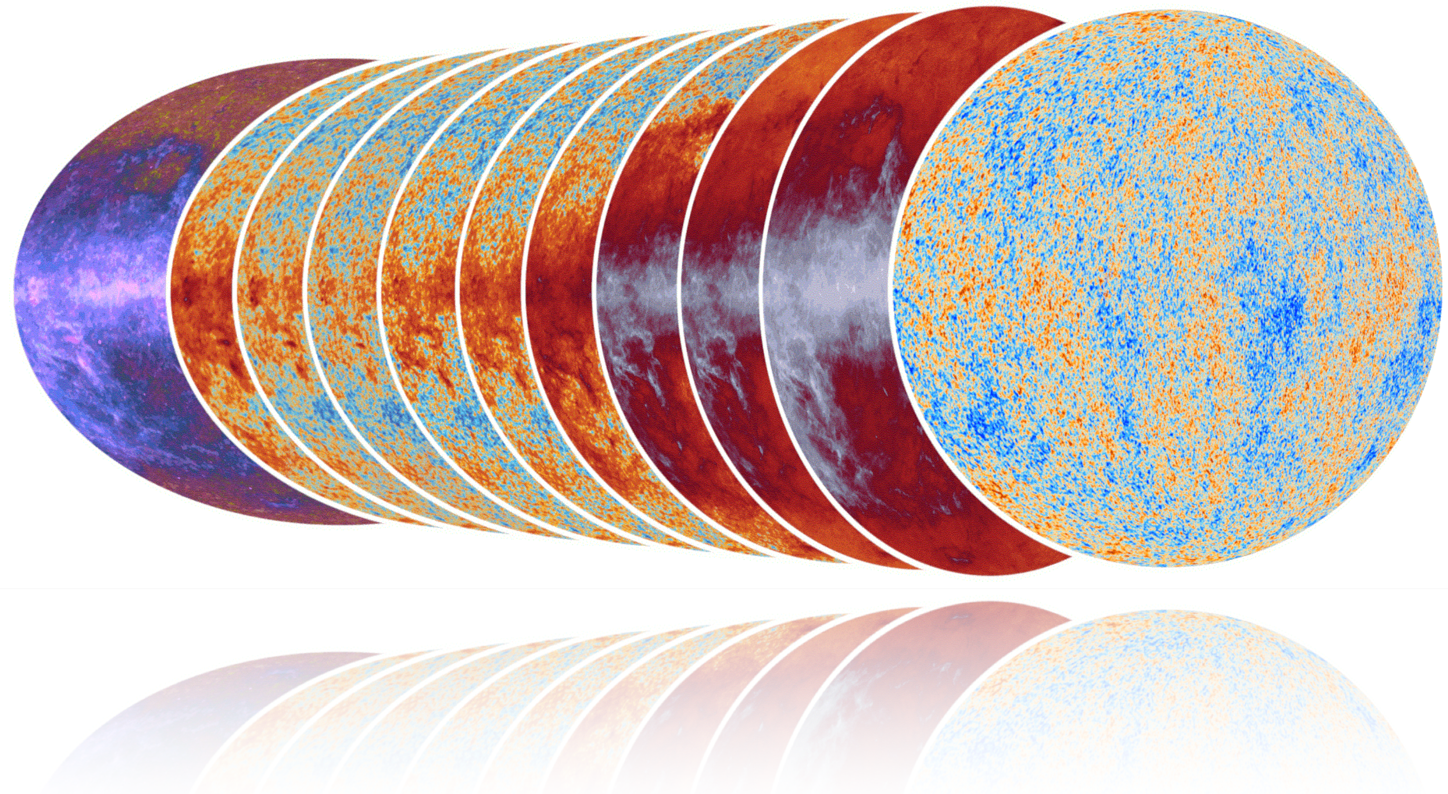

PLANCK constraints on the tensor-to-scalar ratio

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Planck constraints on the tensor-to-scalar ratio

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[Tristram et al. A&A 647, A128 (2021)]
astro-ph/2010.01139

PLANCK polarization data

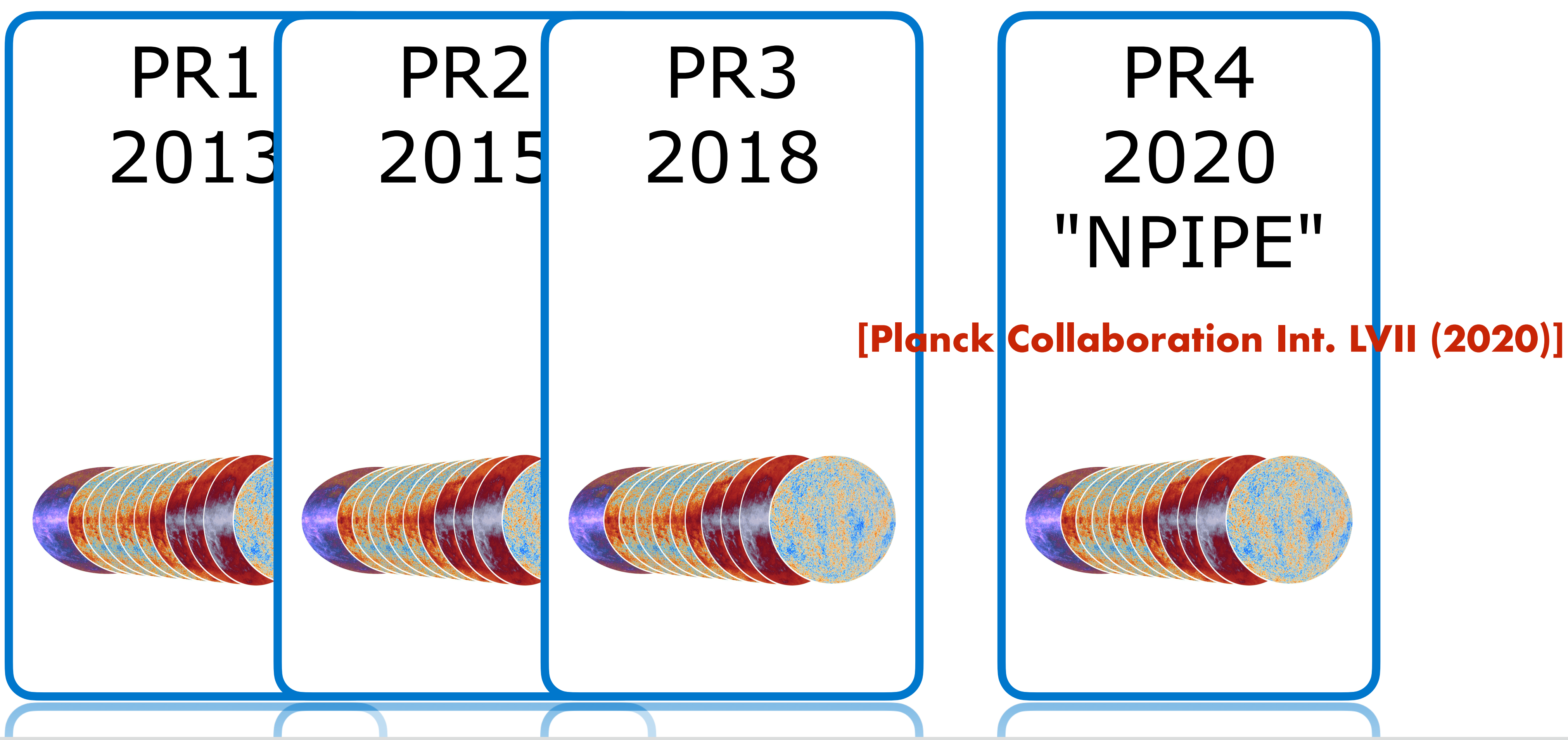
- PLANCK detectors are sensitive to **one polarization direction**
- PLANCK scanning strategy do not allow for polarization reconstruction for each detector independently

  ➡ 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



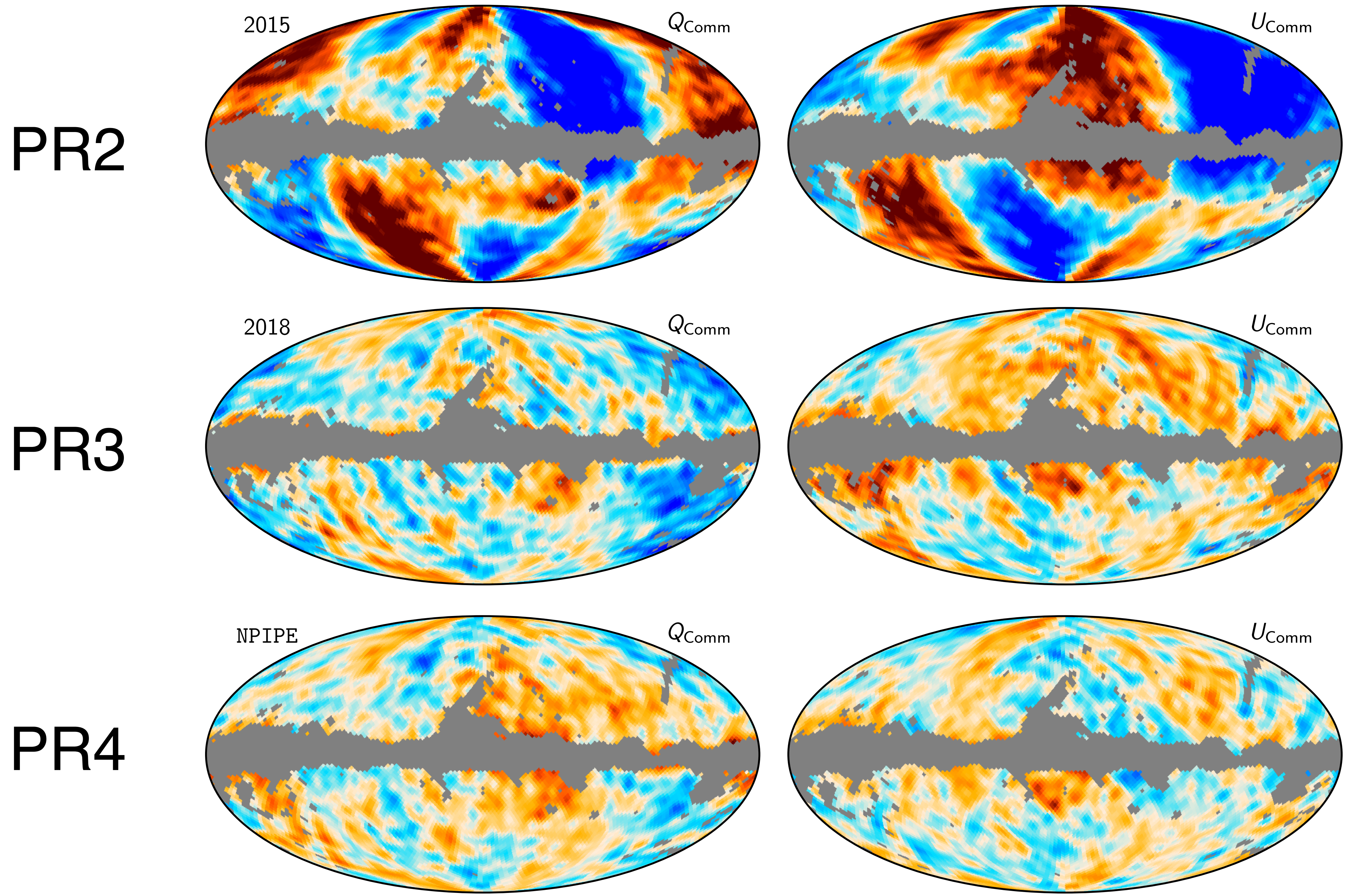
PLANCK Release 4
NPIPE processing

- **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)]



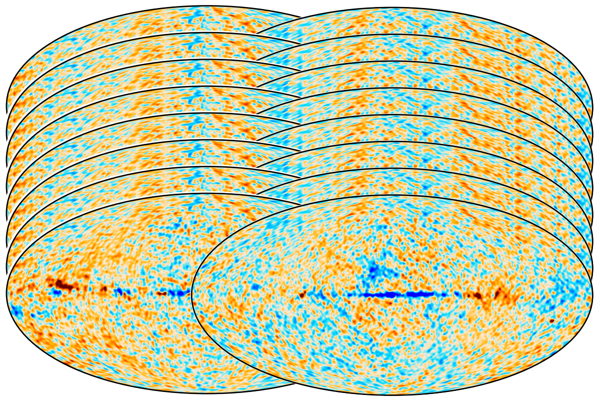
Commander CMB Q and U maps
(large scale, 5° smoothing)

PLANCK Release 4
NPIPE simulations

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

NEW

- **600 consistent simulations (frequency and split maps)**
- **Inputs**
  - including instrumental noise (consistent with data-split differences)
  - including models for systematics (ADC non-linearity)
  - random CMB with 4pi beam convolution
  - foreground sky model based on Commander PLANCK solution

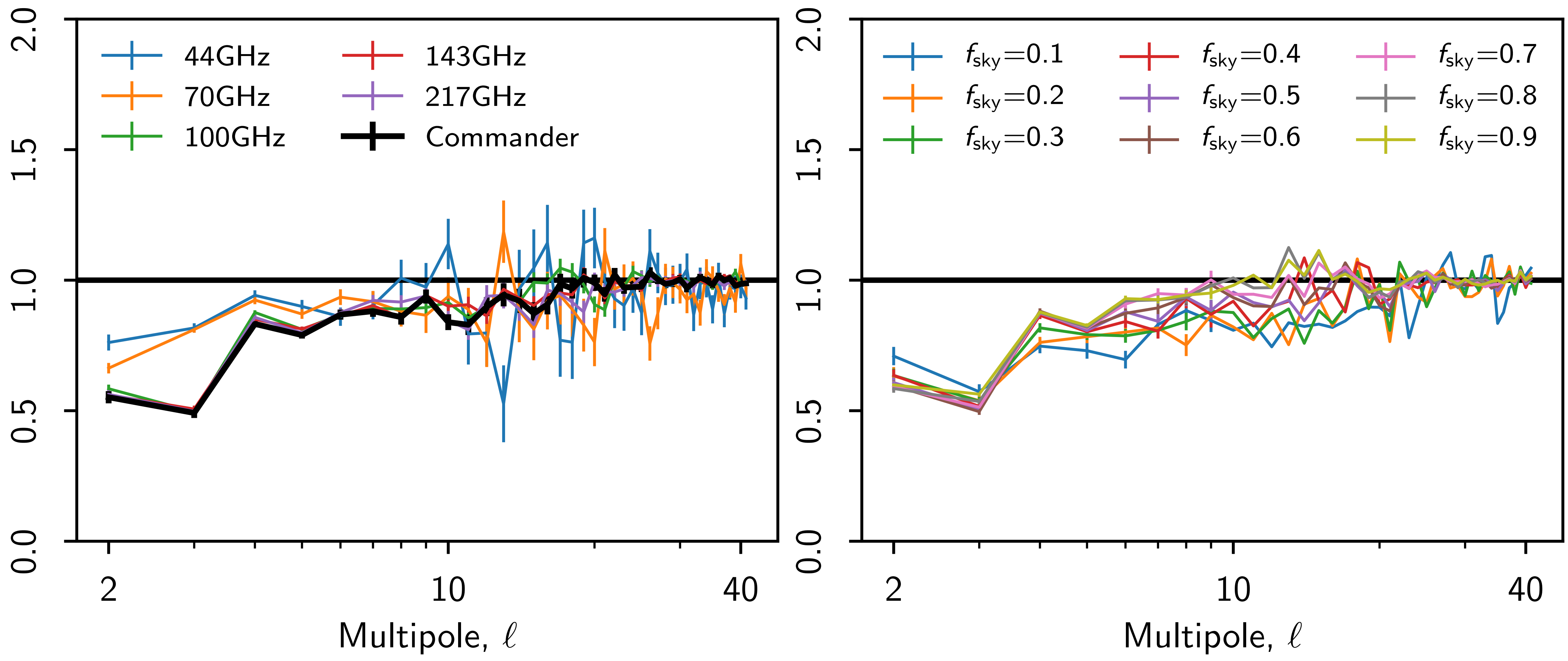


- **Allow for**
  1. accurate effective description of the noise and **covariance** of the maps (including noise, instrumental systematics, foreground residuals) no need for "a posteriori" rescaling as in PR3
  2. estimation of the **transfer function** of the PLANCK processing

NPIPE simulations
processing transfer function

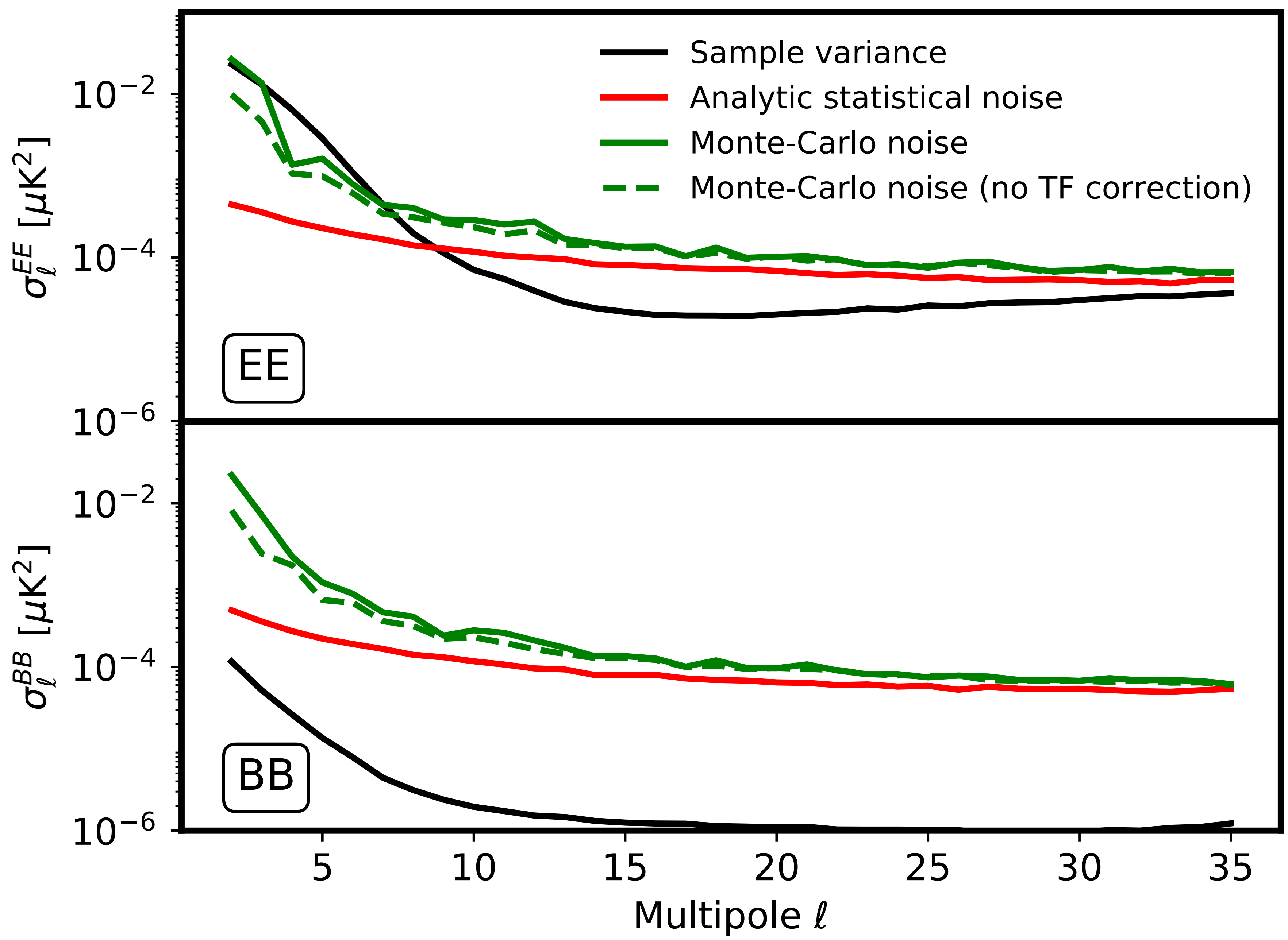
Simulations allow to characterize accurately the processing transfer-function for each frequency

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

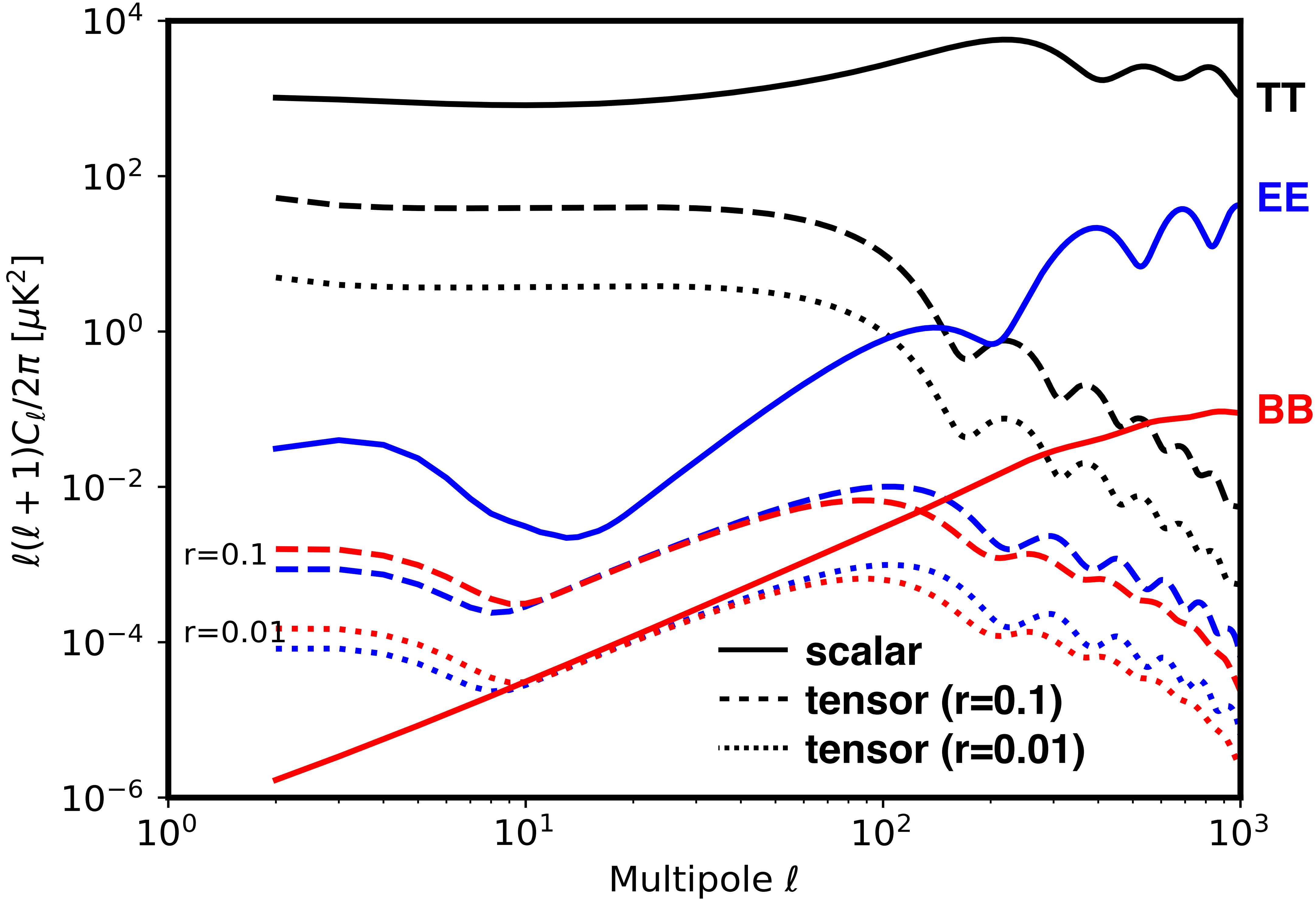


NPIPE simulations

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

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

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

$\tilde{\mathbf{C}}_\ell$ is the measured spectrum

$\mathbf{C}_\ell$ is the model to test

$\mathbf{C}_\ell^{\mathbf{f}}$ is a fiducial theoretical model

$\mathbf{O}_\ell$ 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

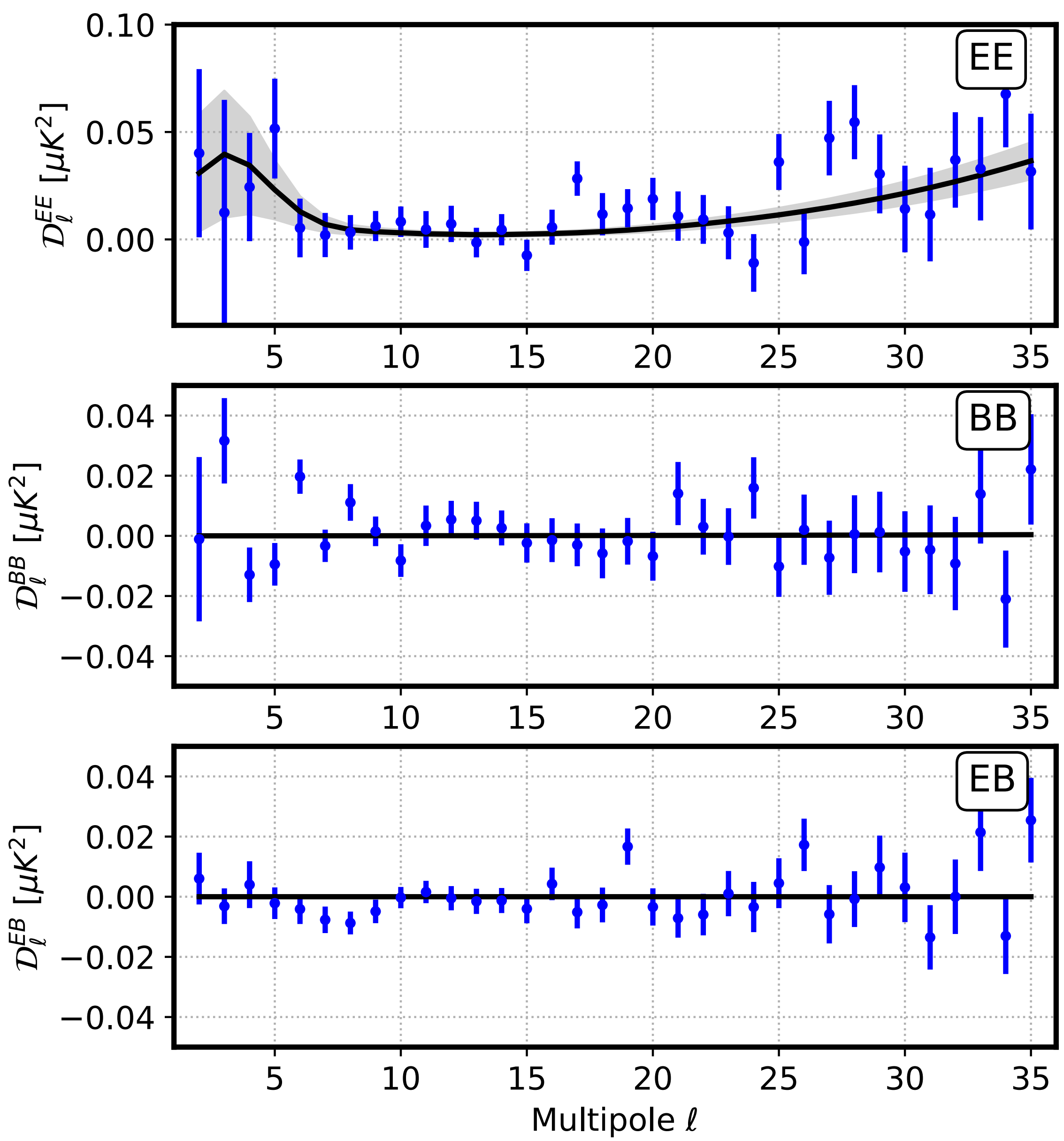
$$-2 \ln P(C_\ell | \widetilde{C}_\ell) = \sum_{\ell\ell'} X_\ell^{\mathsf{T}} M_{\ell\ell'}^{-1} X_{\ell'}$$

with the matrix $\mathbf{M}_{\ell\ell'}$ being the **covariance** from the $\mathbf{C}_\ell$

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

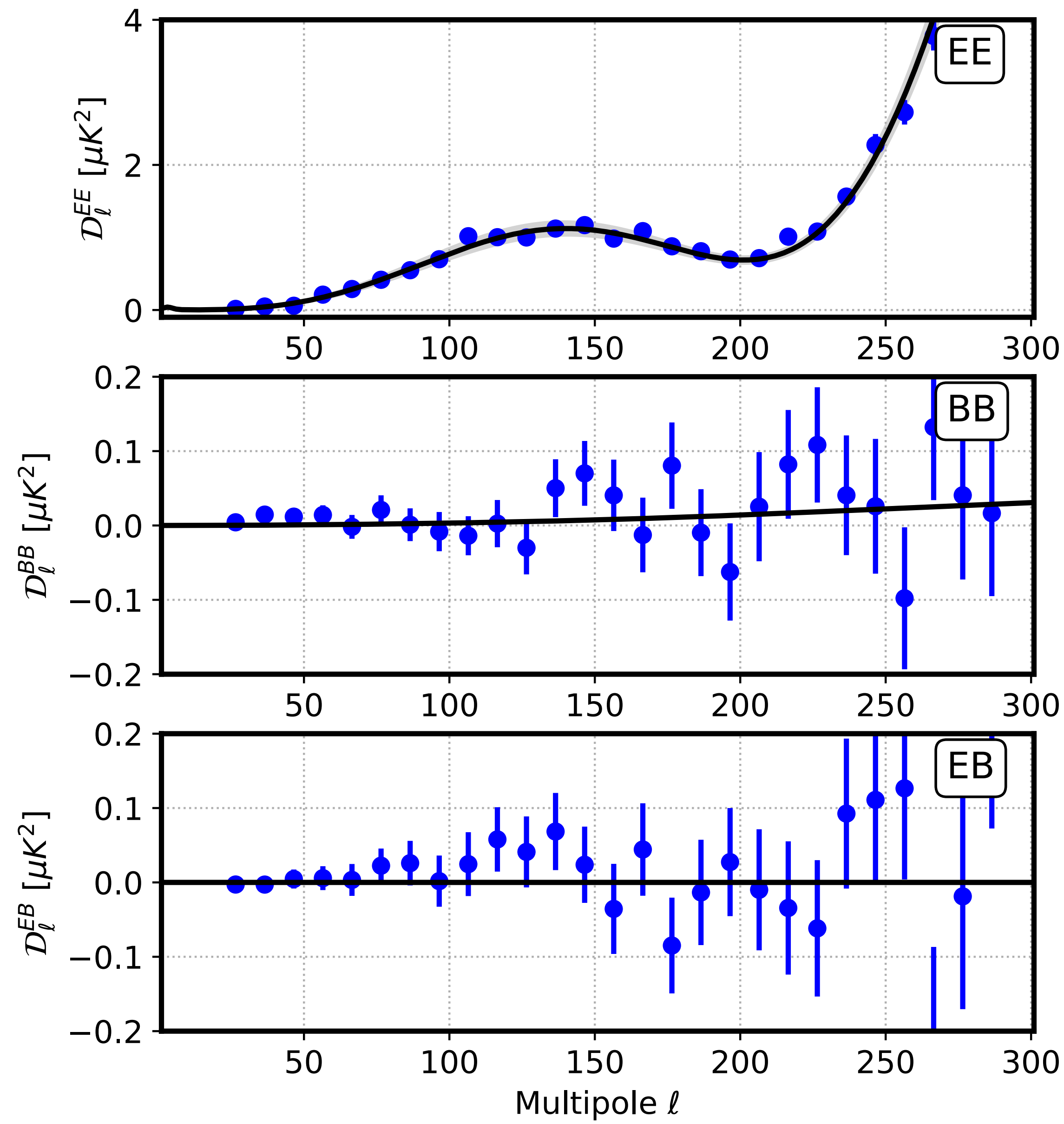
Lollipop Planck power-spectra

sky fraction 50%



xQML

[https://gitlab.in2p3.fr/xQML]

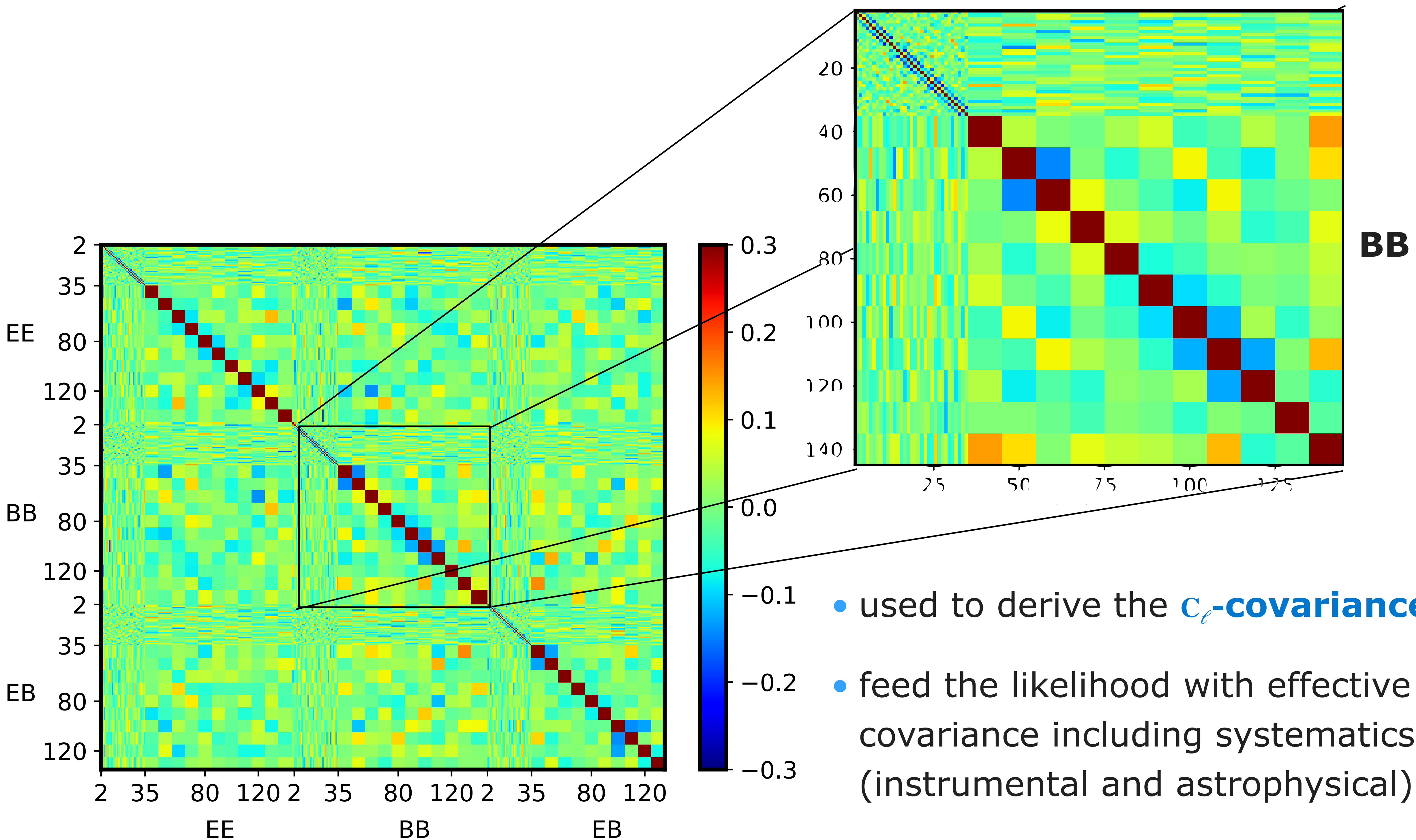


Xpol

[https://gitlab.in2p3.fr/tristram/Xpol]

Lollipop PLANCK spectra covariance

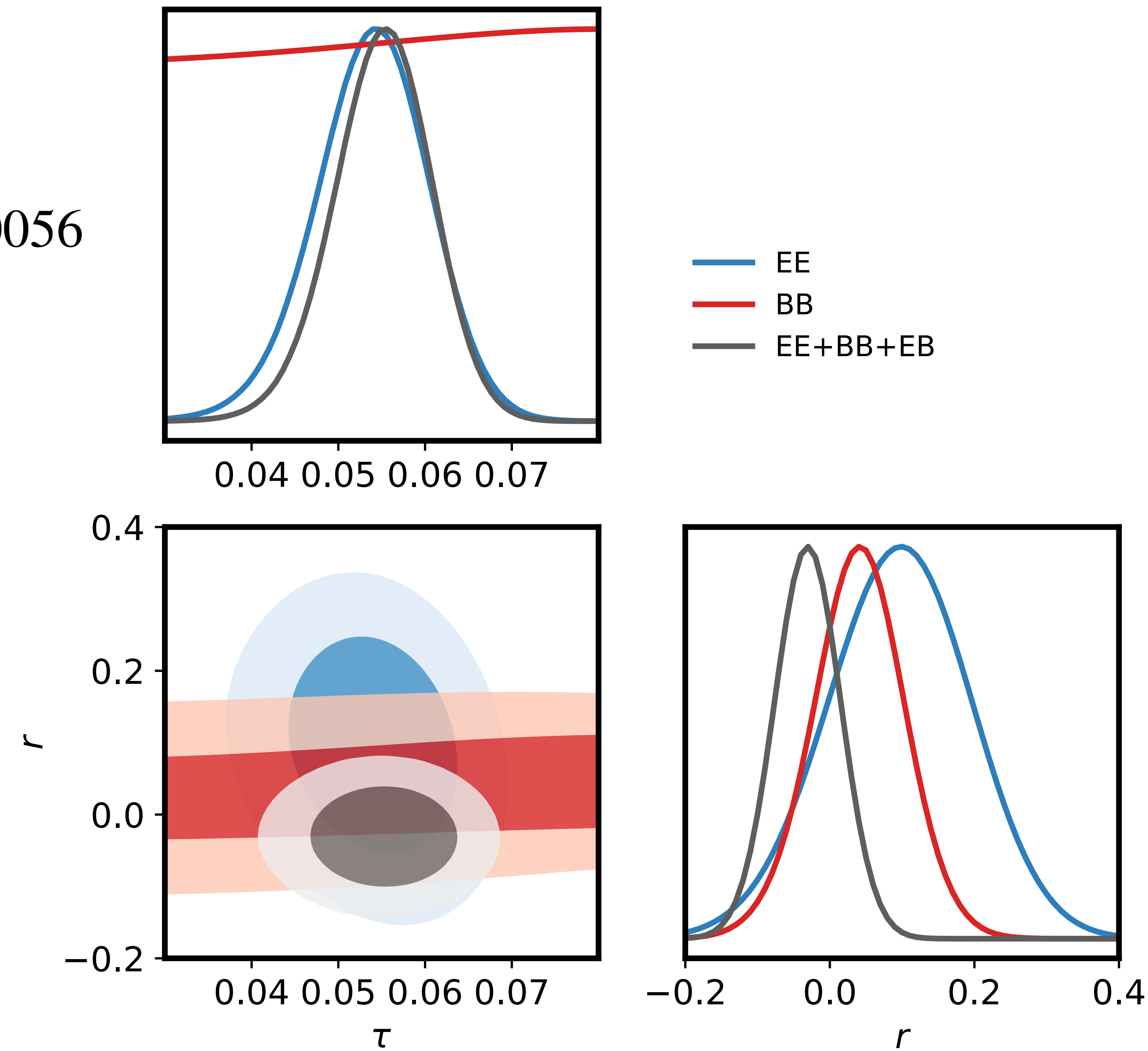
400 simulations of CMB reconstructed independently by Commander on each set of simulated frequency maps



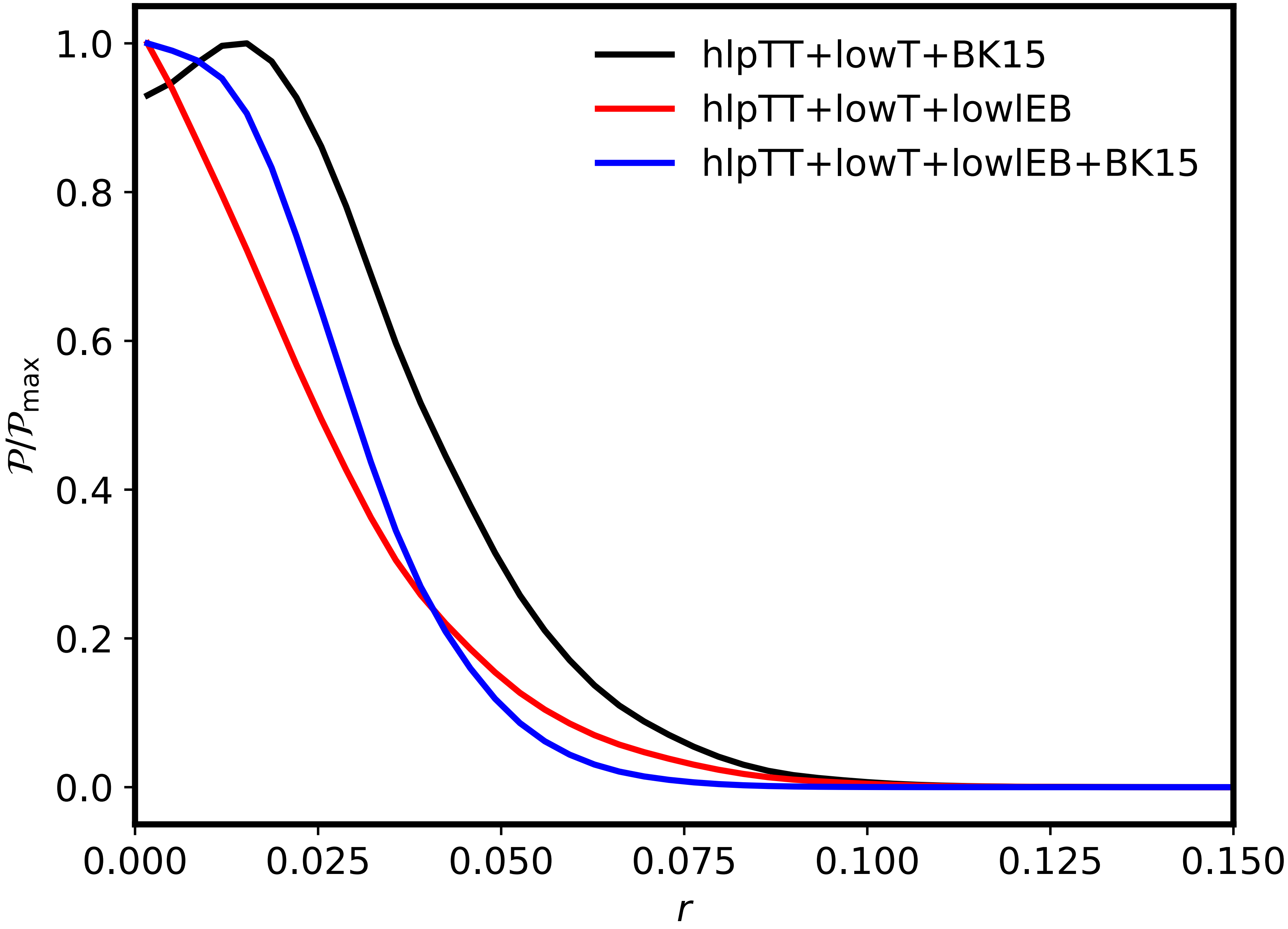
- used to derive the C_ℓ-**covariance** matrix
- feed the likelihood with effective covariance including systematics (instrumental and astrophysical)

Parameter constraints

$$\tau = 0.0577 \pm 0.0056$$



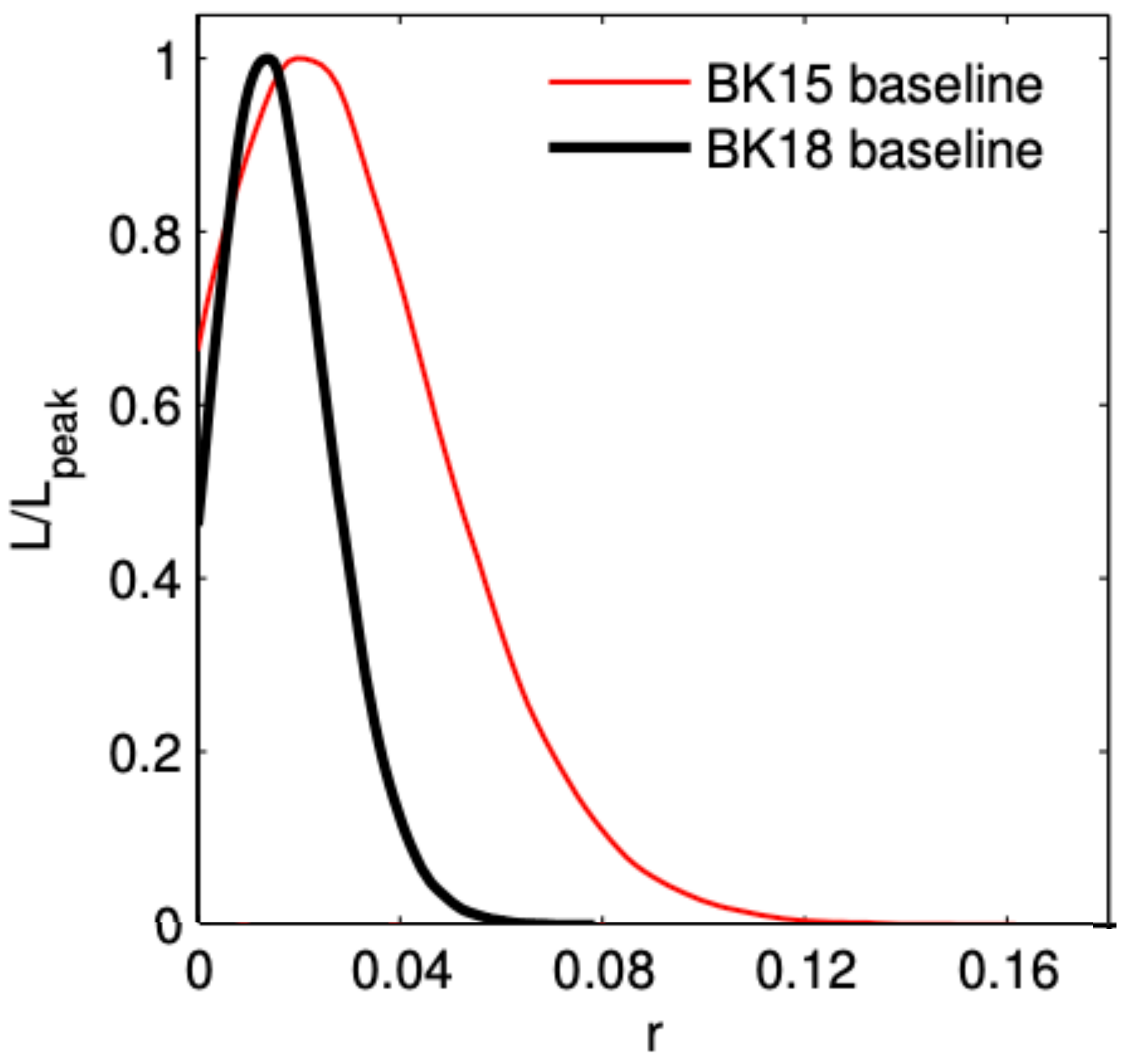
Results (in combination with TT)



$$r_{0.05} < 0.060 \quad (95\,\%\ \text{CL, hlpTT+lowT+BK15});$$
$$r_{0.05} < 0.056 \quad (95\,\%\ \text{CL, hlpTT+lowT+lowlEB});$$
$$r_{0.05} < 0.044 \quad (95\,\%\ \text{CL, hlpTT+lowT+lowlEB+BK15})$$

Last news from BICEP/Keck

[Ade et al. 2021, PhRvL, 127, 151301]

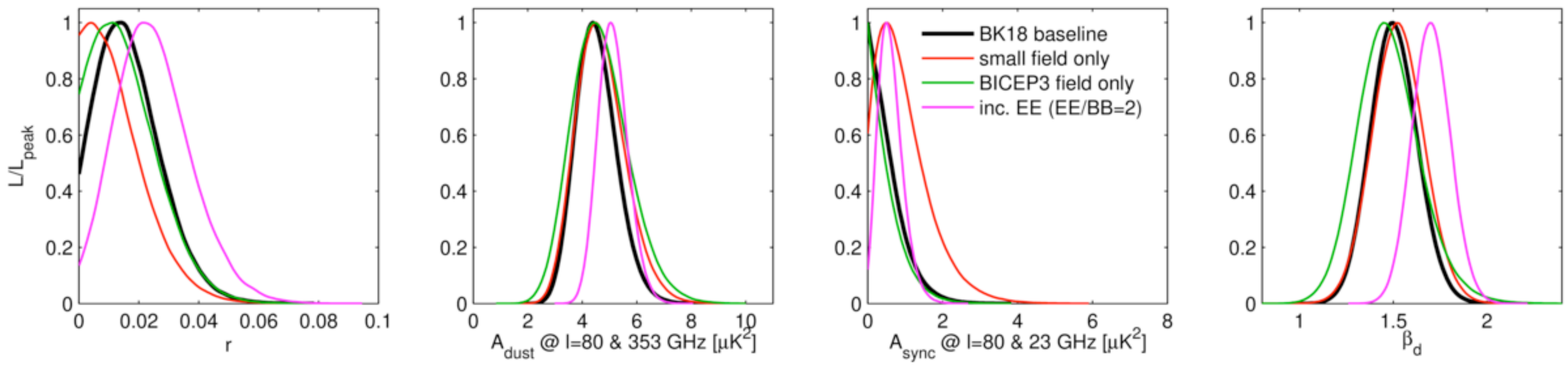


$r_{0.05} < 0.12$ (BKP)

$r_{0.05} < 0.09$ (BK14)

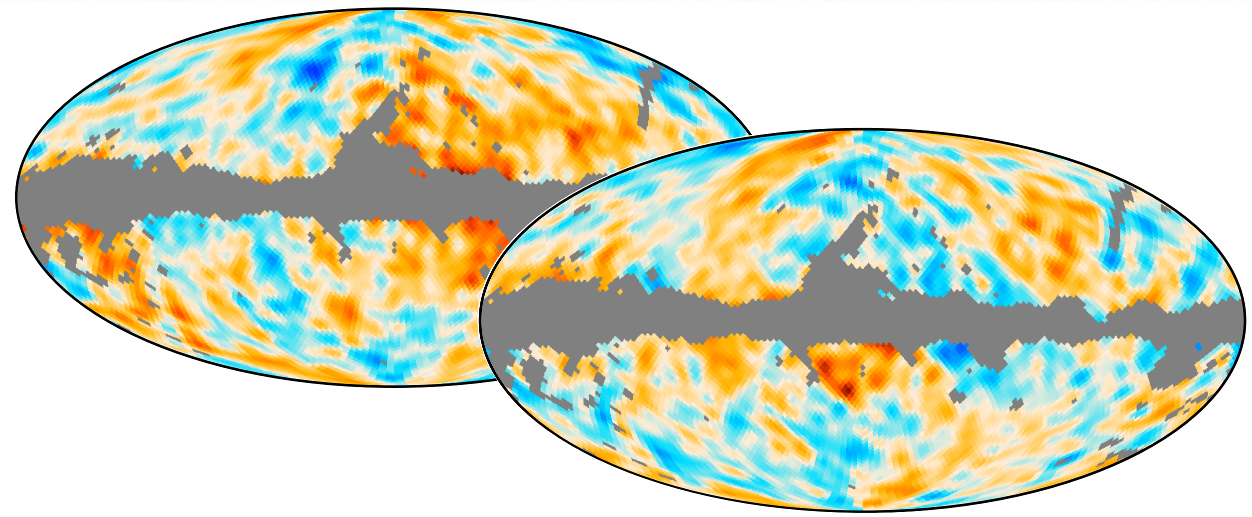
$r_{0.05} < 0.07$ (BK15)

$r_{0.05} < 0.036$ (BK18) using Planck NPIPE maps at 30, 44, 143, 217 and 353 GHz

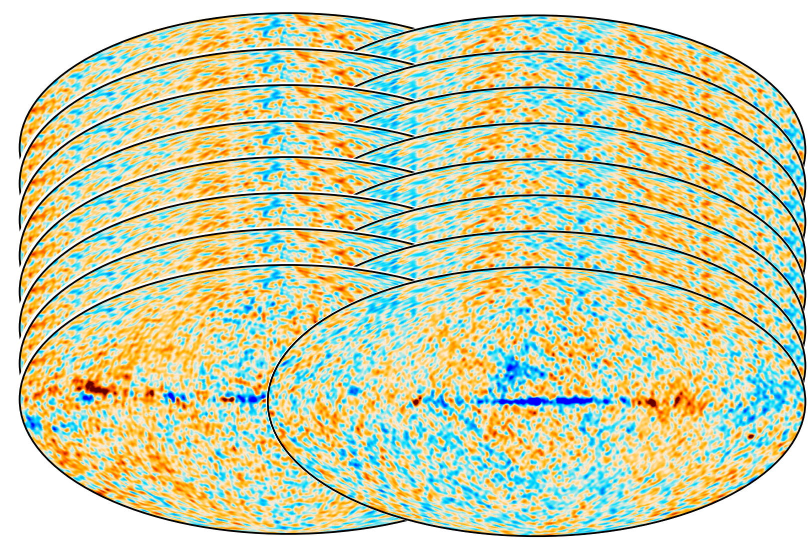


Conclusions

- **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**

$r_{0.05} < 0.072$ BICEP2/Keck 2015 (2018) 1% of the sky

$r_{0.05} < 0.069$ Planck EB (2020) 50% of the sky

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

[Tristram et al. A&A 647, A128 (2021)]
astro-ph/2010.01139

$r_{0.05} < 0.036$ BICEP/Keck 2018 (2021) 1% of the sky