Work package 7: Science exploitation

Simone Paradiso

On behalf of WP7
and the BeyondPlanck collaboration

BeyondPlanck final review meeting, December 15th, 2020

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776282

Work package 7: scientific exploitation

This WP aims at two main objectives:

- development of tools for the likelihood analysis of the improved maps, which are able to fully propagate the uncertainties from residual instrumental systematics and component separation all the way to the cosmological parameters
- perform the final cosmological analysis of the maps, either alone or with other cosmological datasets.

Outcome

- A code for the analysis of BeyondPlanck CMB maps.
- A new set of CMB maps.
- A likelihood for extracting information on cosmological parameters.
- Cosmological parameter estimates with end-to-end error propagation, with a focus on the optical depth of reionisation.
- Scientific papers.

These products have been provided in three deliverables

WP7 deliverables

- 7.1 : Cosmological interpretation module for integration in the main pipeline.
- 7.2 : Scientific characterization of maps, including power spectra and cosmological parameter constraints.
- 7.3 : Scientific papers for publication in peer-review journals.

Cosmological interpretation Module

Developing the tools for BeyondPlanck's cosmological interpretation.

- Foreground cleaning
- Power spectrum estimation
- Likelihood evaluation

Deliverable received on March 12th , 2019 and approved on January 22nd , 2020.

BeyondPlanck Likelihood

- Overall coverage of the multipoles from $\ell = 2$ up to $\ell = 600$ in TT spectrum.
- Information from polarization E modes, and cross-correlation TE, from multipoles in the range $[2 - 8]$.

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Low-ℓ pixel-based Likelihood on a KL compressed basis

TT-TE-EE in $2 \leq \ell \leq 8$

$$P(C_\ell|\hat{s}_{CMB}) \propto \frac{e^{-\frac{1}{2}\,\hat{s}^t{}_{CMB}(S(C_\ell)+N)^{-1}\,\hat{s}_{CMB}}}{|S(C_\ell)+N|^{\frac{1}{2}}}$$

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Low-ℓ pixel-based Likelihood on a KL compressed basis

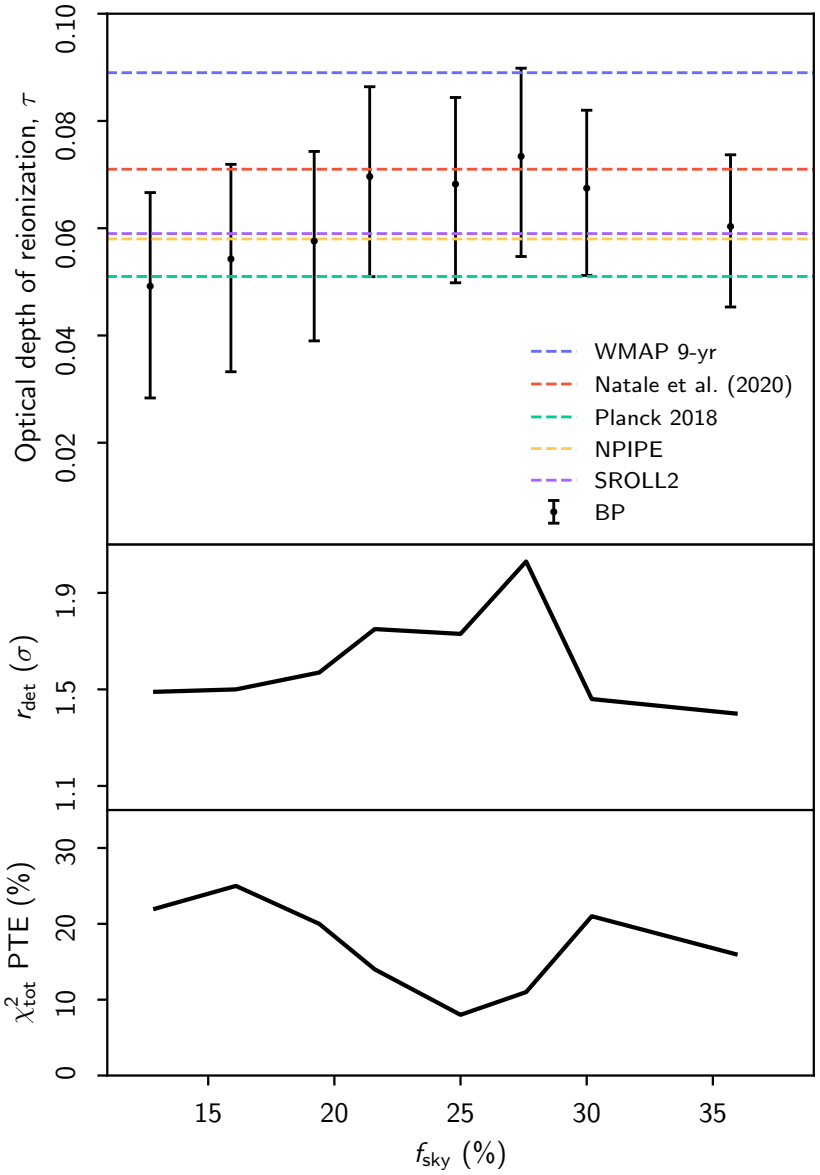
TT-TE-EE in $2 \leq \ell \leq 8$

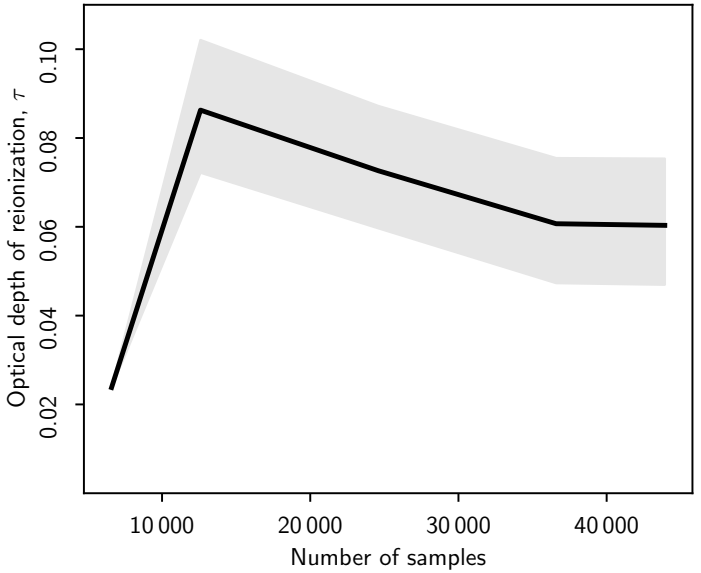
High-ℓ likelihood based upon Gaussianized Blackwell-Rao estimator

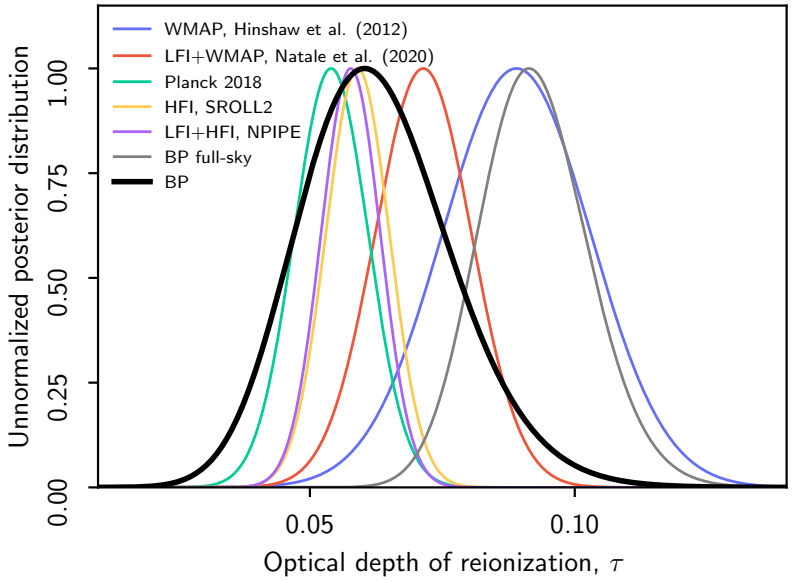
TT only in $9 \leq \ell \leq 600$

$$P(C_\ell|\hat{s}_{CMB}) \propto \frac{e^{-\frac{1}{2}\,\hat{s}^t{}_{CMB}(S(C_\ell)+N)^{-1}\,\hat{s}_{CMB}}}{|S(C_\ell)+N|^{\frac{1}{2}}}$$

BP low-ℓ likelihood results







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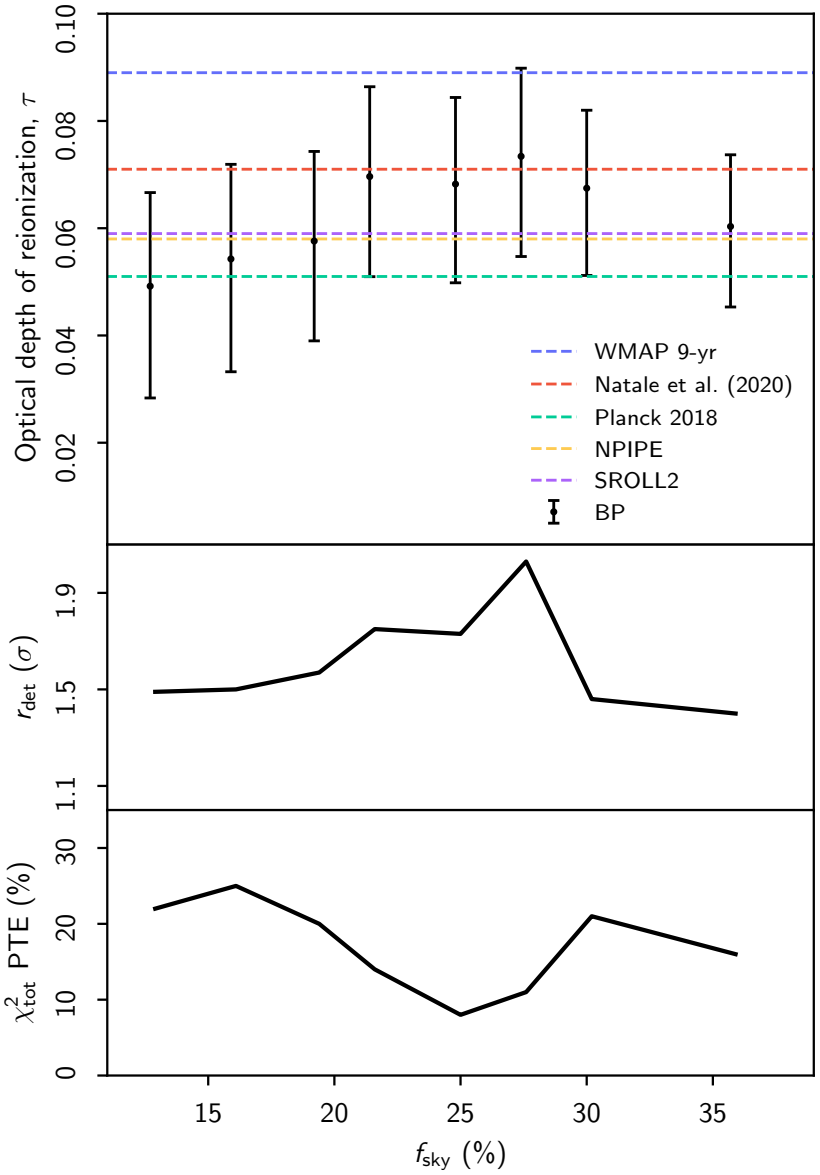

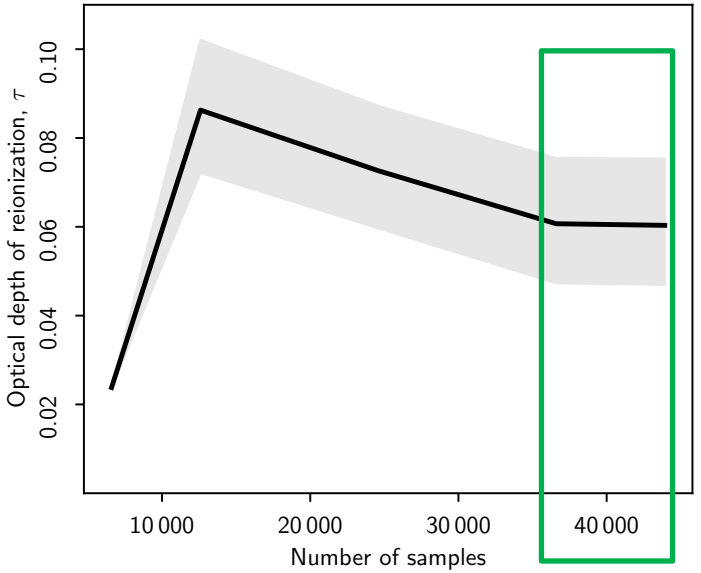

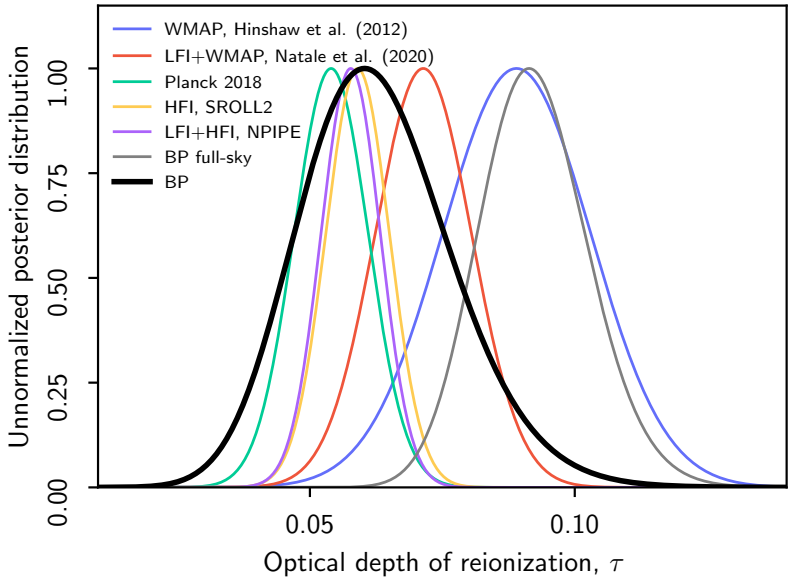

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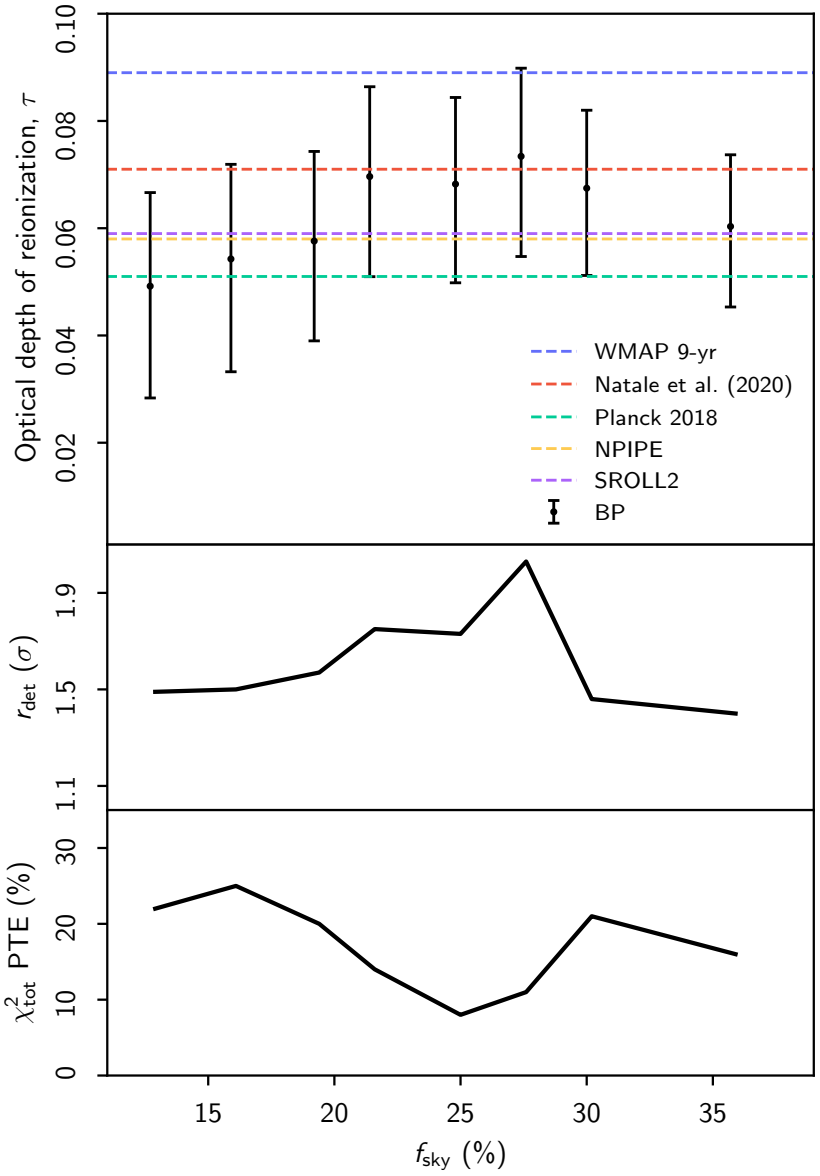

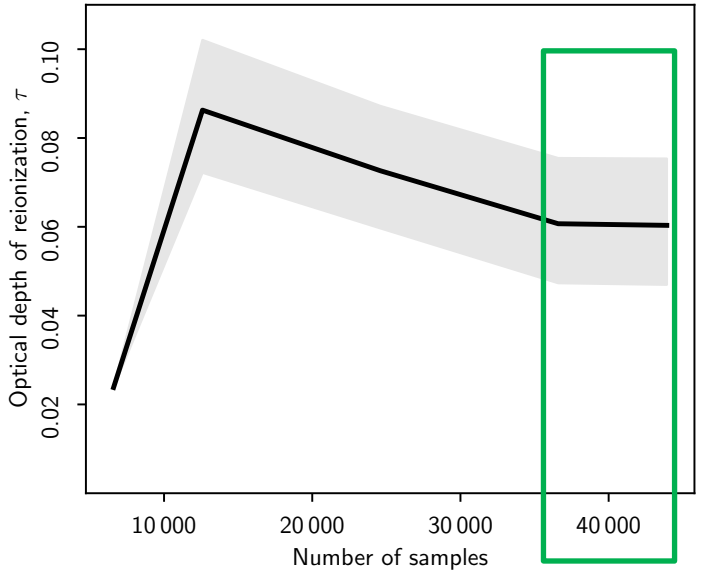

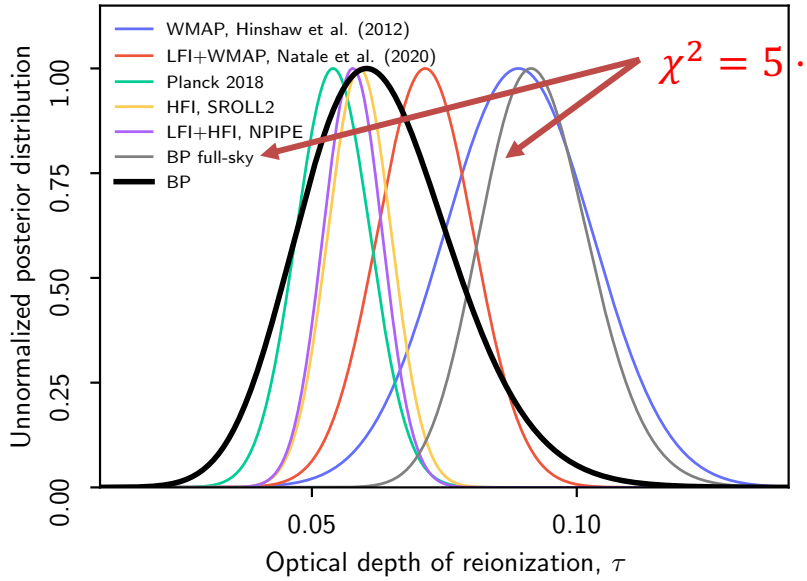

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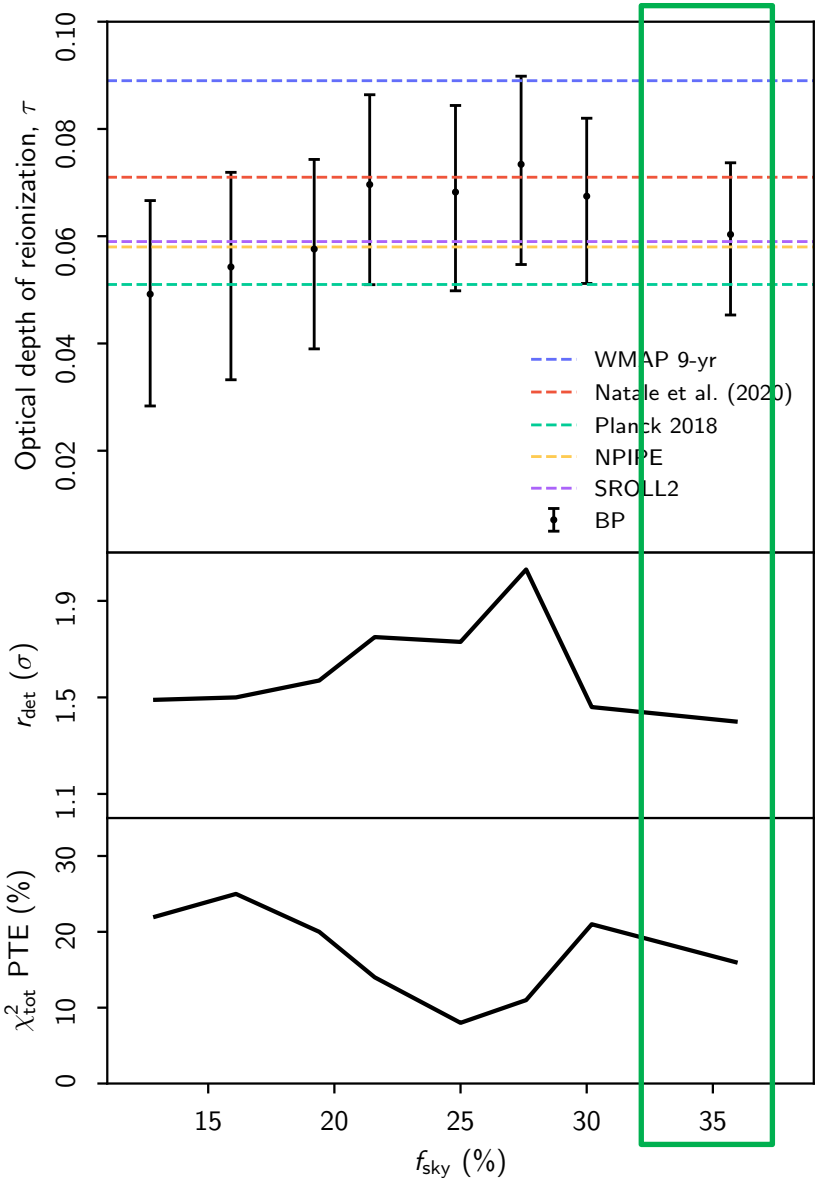

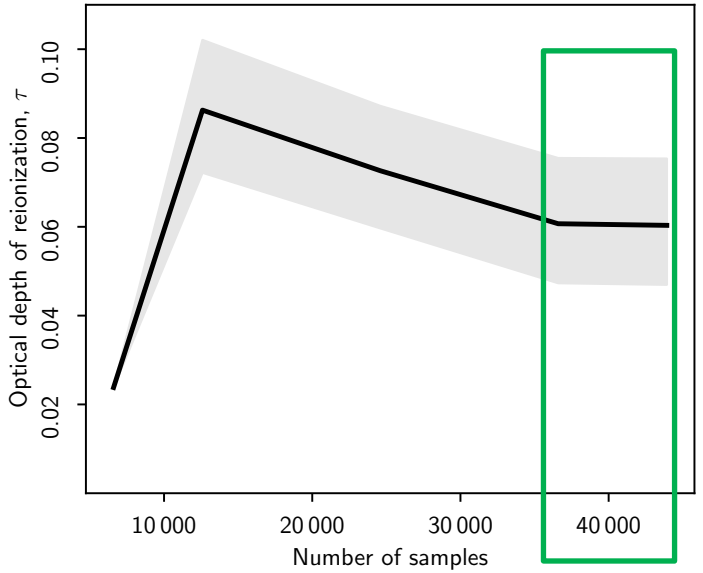

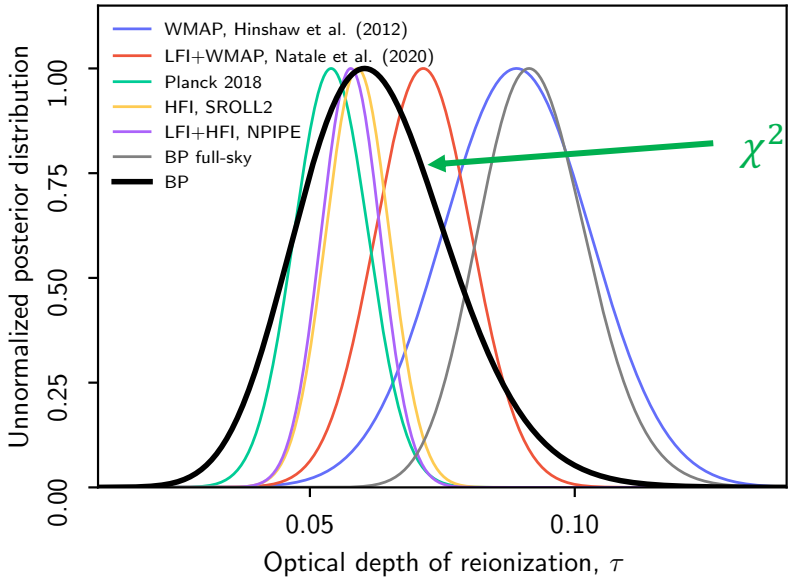

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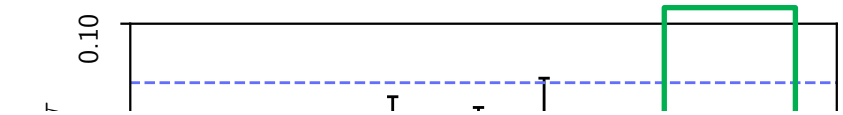
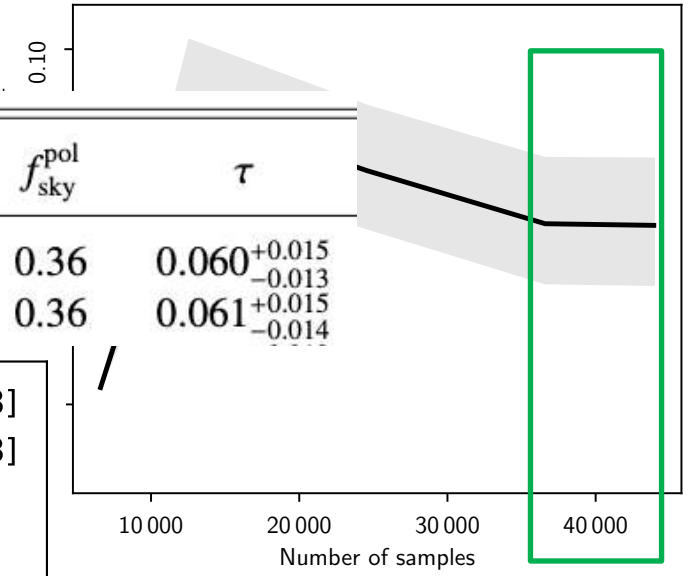
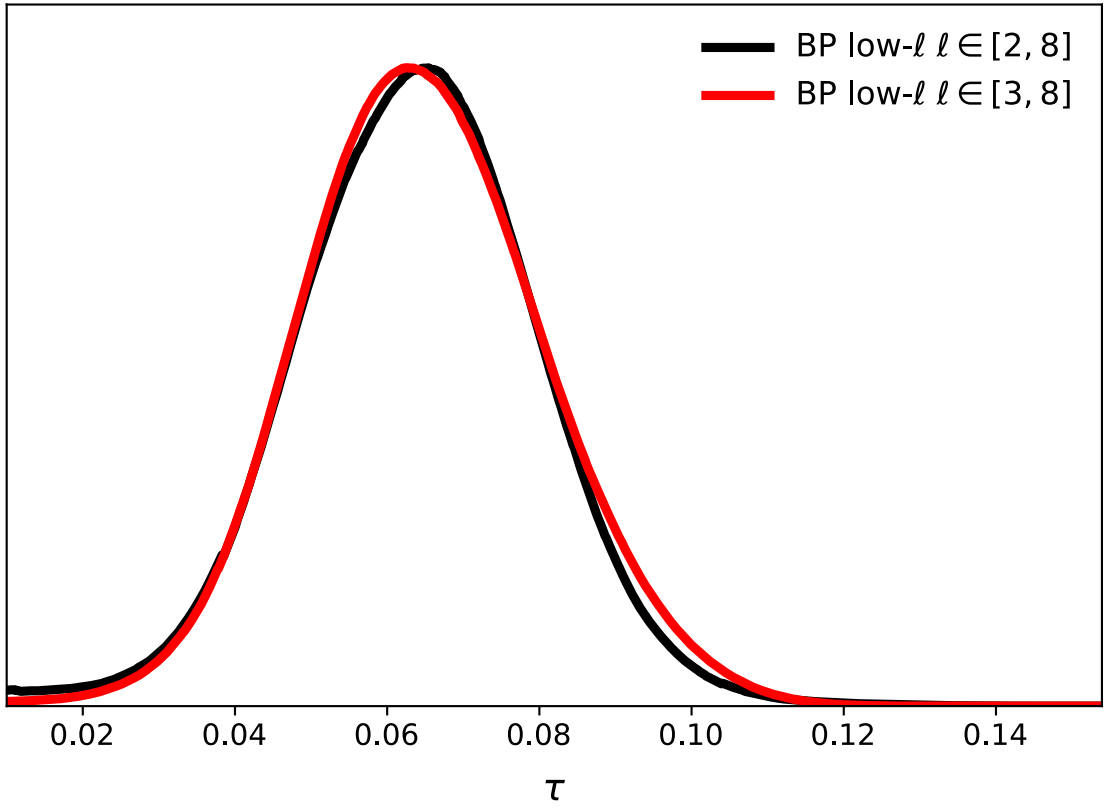
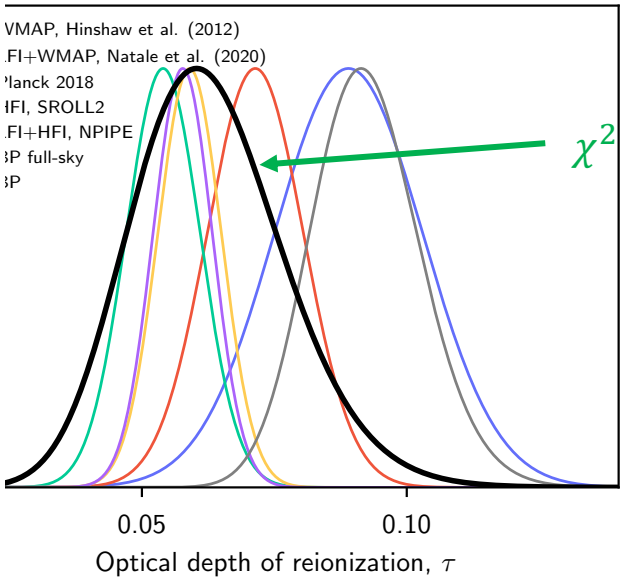




Analysis Name	Data Sets	$f_{\rm sky}^{\rm pol}$	τ
BeyondPlanck, $\ell = 2$–8	LFI, *WMAP Ka–V*	0.36	$0.060^{+0.015}_{-0.013}$
BeyondPlanck, $\ell = 3$–8	LFI, *WMAP Ka–V*	0.36	$0.061^{+0.015}_{-0.014}$





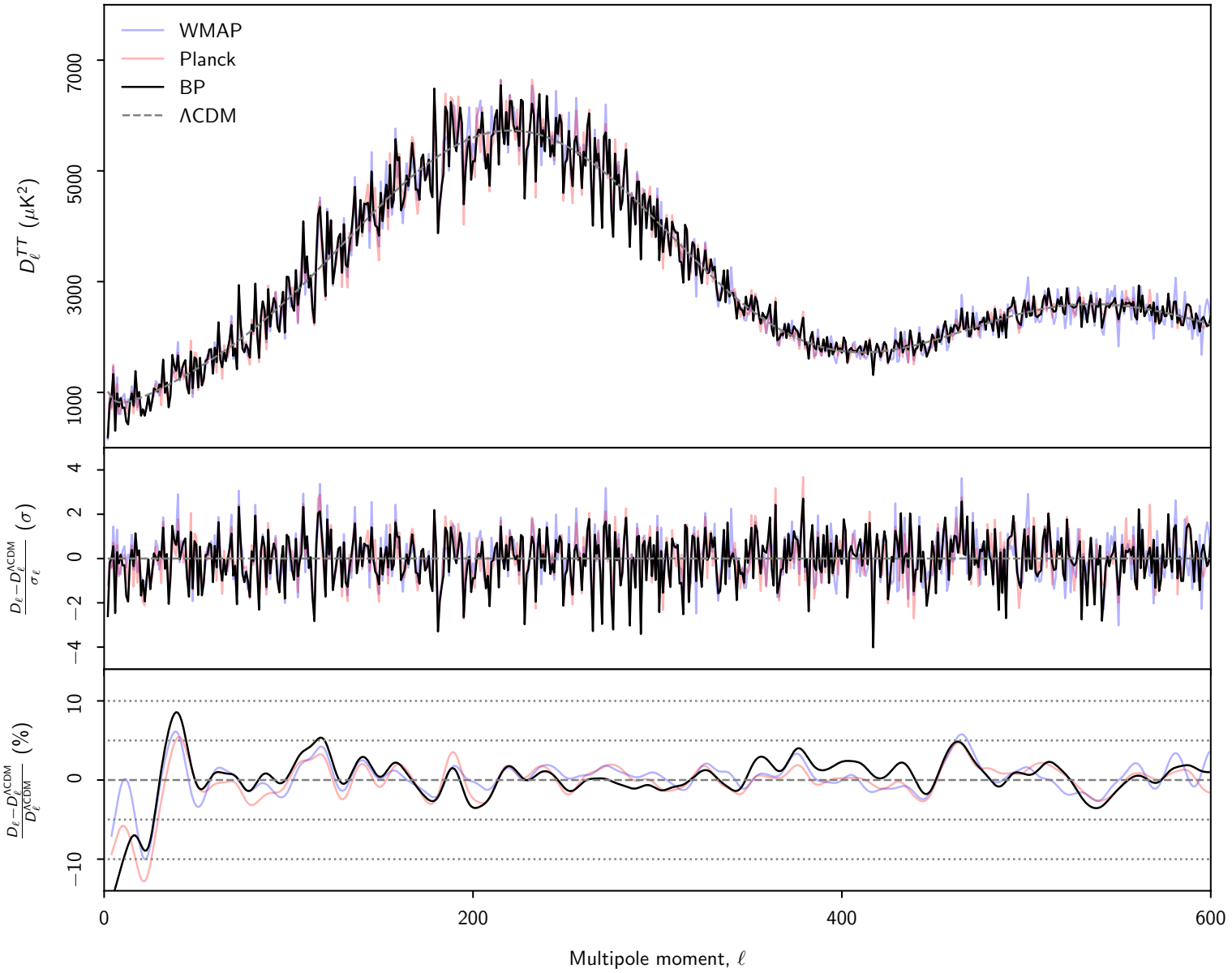
$\chi^2 = 0.16$

BP high-ℓ likelihood results

Stable parameter estimates up to $\ell = 600$

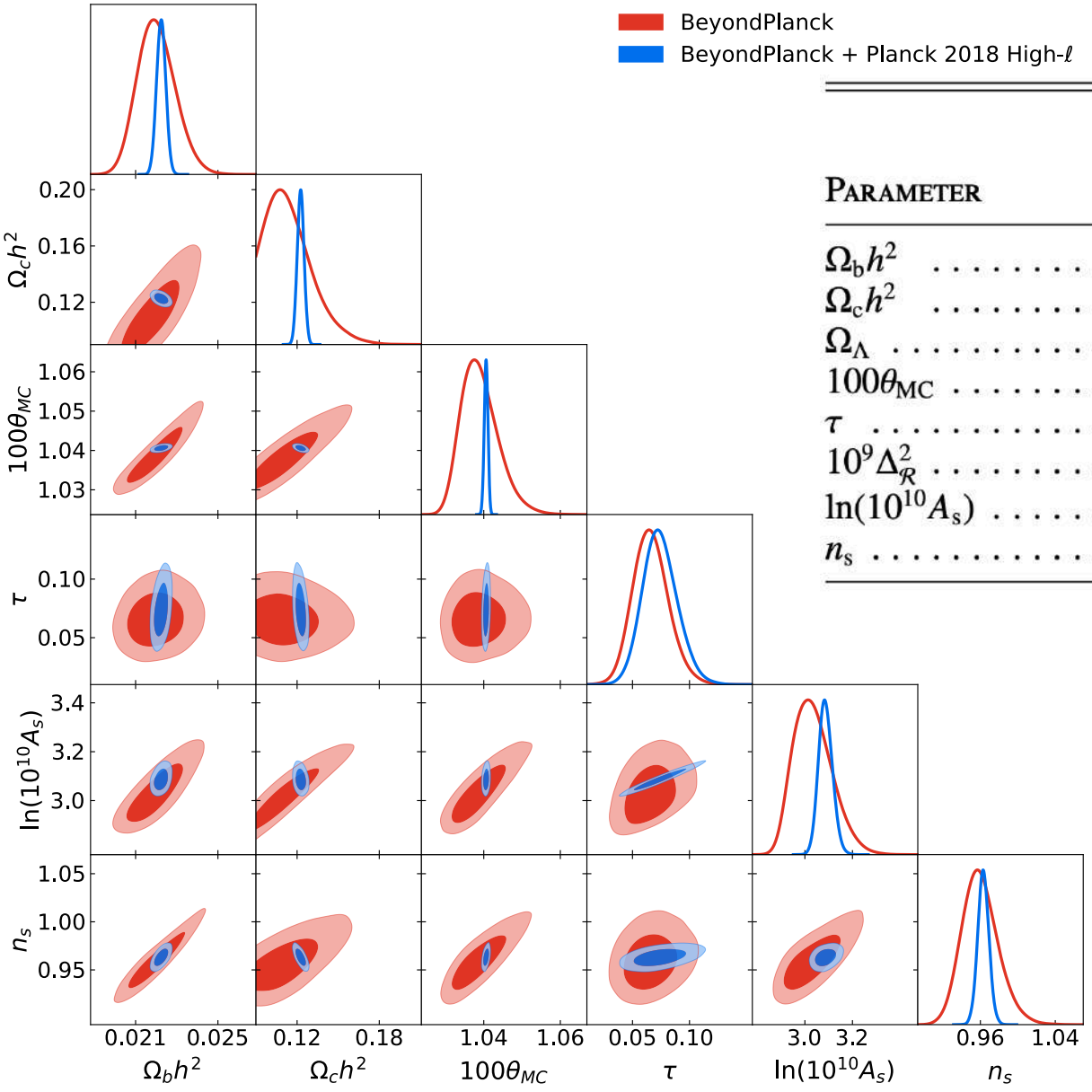
Parameter	BeyondPlanck GBR $\ell_{\max} = 400$	BeyondPlanck GBR $\ell_{\max} = 600$	Δ
$\Omega_b h^2$	0.0229 ± 0.0018	0.0227 ± 0.0013	0.1σ
$\Omega_c h^2$	0.129 ± 0.028	0.116 ± 0.018	0.5σ
$100\theta_{MC}$	1.049 ± 0.011	1.041 ± 0.006	0.7σ
$A_s e^{-2\tau}$	2.01 ± 0.26	1.85 ± 0.15	0.6σ
n_s	1.011 ± 0.054	0.980 ± 0.036	0.6σ

BP high-ℓ likelihood results



Colombo et al. 2020

Full BeyondPlanck likelihood results



Parameter	BeyondPlanck $\ell \leq 600$	BeyondPlanck $+Planck\ \ell > 600$
$\Omega_b h^2$	0.02202 ± 0.00091	0.02224 ± 0.00022
$\Omega_c h^2$	0.115 ± 0.017	0.1224 ± 0.0025
Ω_Λ	...	...
$100\theta_{MC}$	1.0390 ± 0.0049	1.04061 ± 0.00048
τ	0.066 ± 0.016	0.074 ± 0.015
$10^9 \Delta_{\mathcal{R}}^2$	...	...
$\ln(10^{10}A_s)$	3.035 ± 0.080	3.087 ± 0.029
n_s	0.960 ± 0.020	0.9632 ± 0.0060

Full BeyondPlanck likelihood results

Parameter	BeyondPlanck		*Planck* 2018		*WMAP*	
	$\ell \leq 600$	$+Planck\ \ell > 600$	Estimate	$\Delta(\sigma)$	Estimate	$\Delta(\sigma)$
$\Omega_b h^2$	0.02202 ± 0.00091	0.02224 ± 0.00022	0.02237 ± 0.00015	-0.4	0.02243 ± 0.00050	-0.5
$\Omega_c h^2$	0.115 ± 0.017	0.1224 ± 0.0025	0.1200 ± 0.0012	-0.3	0.1147 ± 0.0051	0
Ω_Λ	...	...	...	...	0.721 ± 0.025	...
$100\theta_{MC}$	1.0390 ± 0.0049	1.04061 ± 0.00048	1.04092 ± 0.00031	-0.4	...	...
τ	0.066 ± 0.016	0.074 ± 0.015	0.054 ± 0.007	0.8	0.089 ± 0.0014	-1.5
$10^9 \Delta^2_{\mathcal{R}}$	...	...	...	...	2.41 ± 0.10	...
$\ln(10^{10} A_s)$	3.035 ± 0.080	3.087 ± 0.029	3.044 ± 0.014	-0.1	...	...
n_s	0.960 ± 0.020	0.9632 ± 0.0060	0.9649 ± 0.0042	-0.3	0.972 ± 0.013	-0.6

Full BeyondPlanck likelihood results

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	$\ell \leq 600$	$+$*Planck* $\ell > 600$	Estimate	$\Delta(\sigma)$	Estimate	$\Delta(\sigma)$
$\Omega_b h^2$	0.02202 ± 0.00091	0.02224 ± 0.00022	0.02237 ± 0.00015	-0.4	0.02243 ± 0.00050	-0.5
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Ω_Λ	...	...	...	...	0.721 ± 0.025	...
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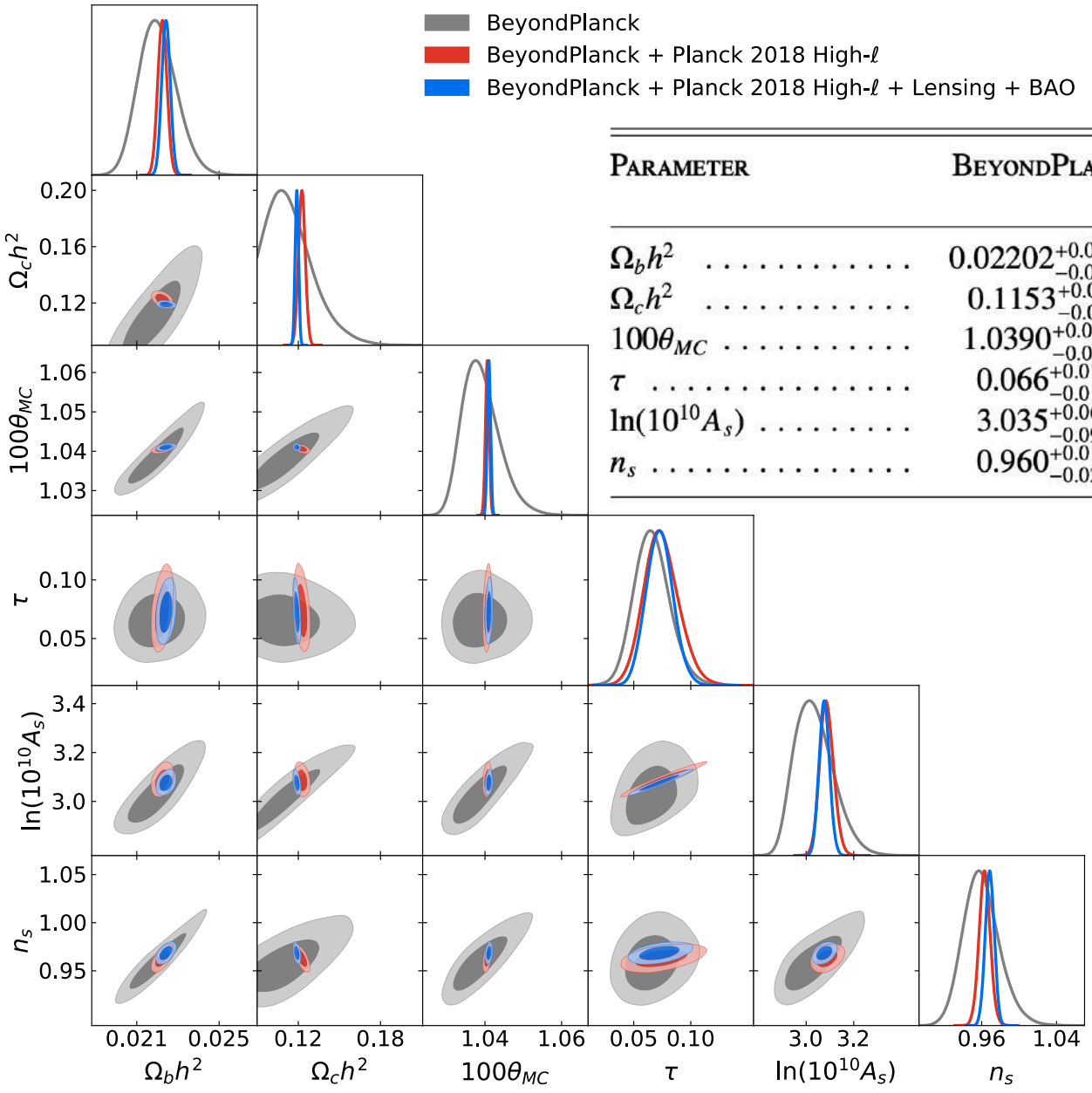
Full BeyondPlanck likelihood results

Only LFI and WMAP → major contribution to larger uncertainties

Parameter	BeyondPlanck		*Planck* 2018		*WMAP*	
	$\ell \leq 600$	+*Planck* $\ell > 600$	Estimate	$\Delta(\sigma)$	Estimate	$\Delta(\sigma)$
$\Omega_b h^2$	0.02202 ± 0.00091	0.02224 ± 0.00022	0.02237 ± 0.00015	-0.4	0.02243 ± 0.00050	-0.5
$\Omega_c h^2$	0.115 ± 0.017	0.1224 ± 0.0025	0.1200 ± 0.0012	-0.3	0.1147 ± 0.0051	0
Ω_Λ	...	...	...	...	0.721 ± 0.025	...
$100\theta_{MC}$	1.0390 ± 0.0049	1.04061 ± 0.00048	1.04092 ± 0.00031	-0.4	...	...
τ	0.066 ± 0.016	0.074 ± 0.015	0.054 ± 0.007	0.8	0.089 ± 0.0014	-1.5
$10^9 \Delta^2_{\mathcal{R}}$	...	...	...	...	2.41 ± 0.10	...
$\ln(10^{10} A_s)$	3.035 ± 0.080	3.087 ± 0.029	3.044 ± 0.014	-0.1	...	...
n_s	0.960 ± 0.020	0.9632 ± 0.0060	0.9649 ± 0.0042	-0.3	0.972 ± 0.013	-0.6

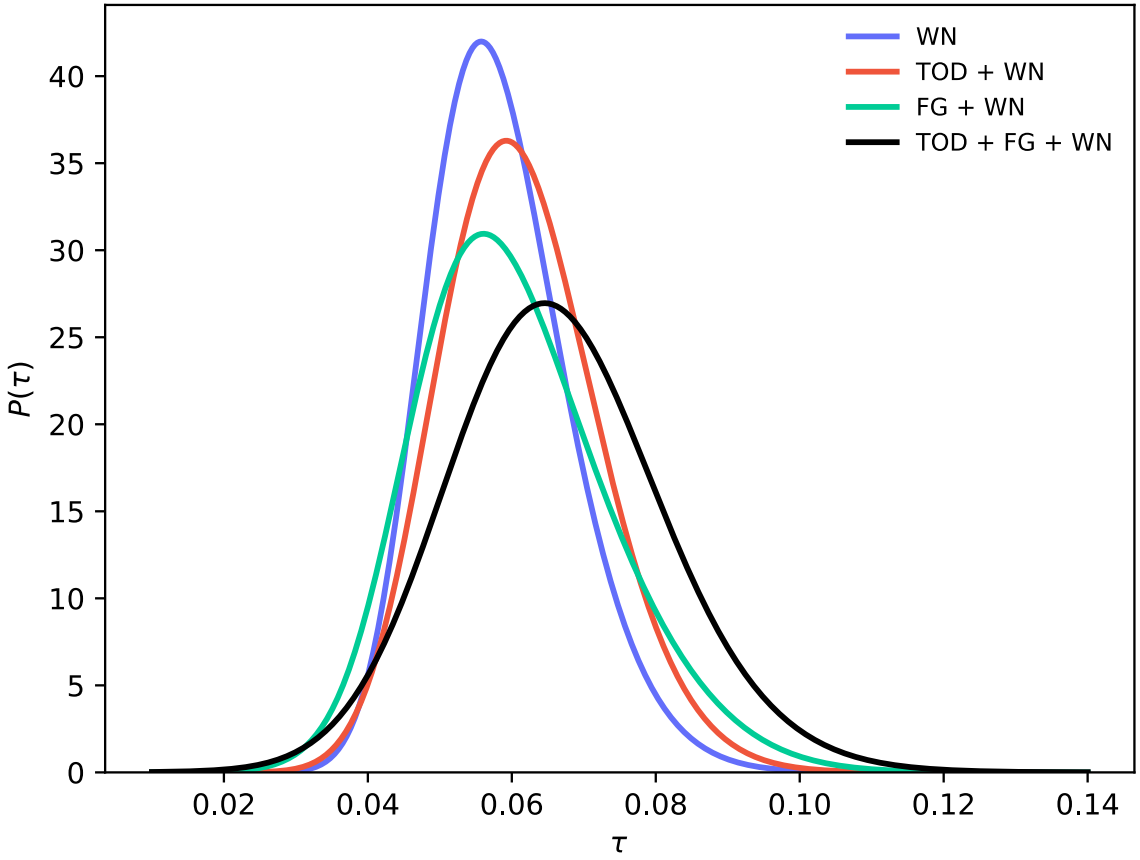
BeyondPlanck + Planck 2018 + Lensing + BAO



Parameter	BeyondPlanck	BeyondPlanck + *Planck*	BeyondPlanck + *Planck* + Lensing + BAO
$\Omega_b h^2$	$0.02202^{+0.00087}_{-0.00099}$	0.02224 ± 0.00022	0.02237 ± 0.00020
$\Omega_c h^2$	$0.1153^{+0.084}_{-0.022}$	0.1226 ± 0.0025	0.1189 ± 0.0012
$100\theta_{MC}$	$1.0390^{+0.0037}_{-0.0056}$	1.04061 ± 0.00048	1.04098 ± 0.00041
τ	$0.066^{+0.014}_{-0.017}$	$0.074^{+0.014}_{-0.016}$	0.072 ± 0.012
$\ln(10^{10}A_s)$	$3.035^{+0.064}_{-0.095}$	$3.087^{+0.027}_{-0.031}$	3.075 ± 0.022
n_s	$0.960^{+0.017}_{-0.021}$	0.9632 ± 0.0060	0.9687 ± 0.0048

End-to-end error propagation

Propagating uncertainties through the whole processing up to cosmological parameter estimation



End-to-end error propagation

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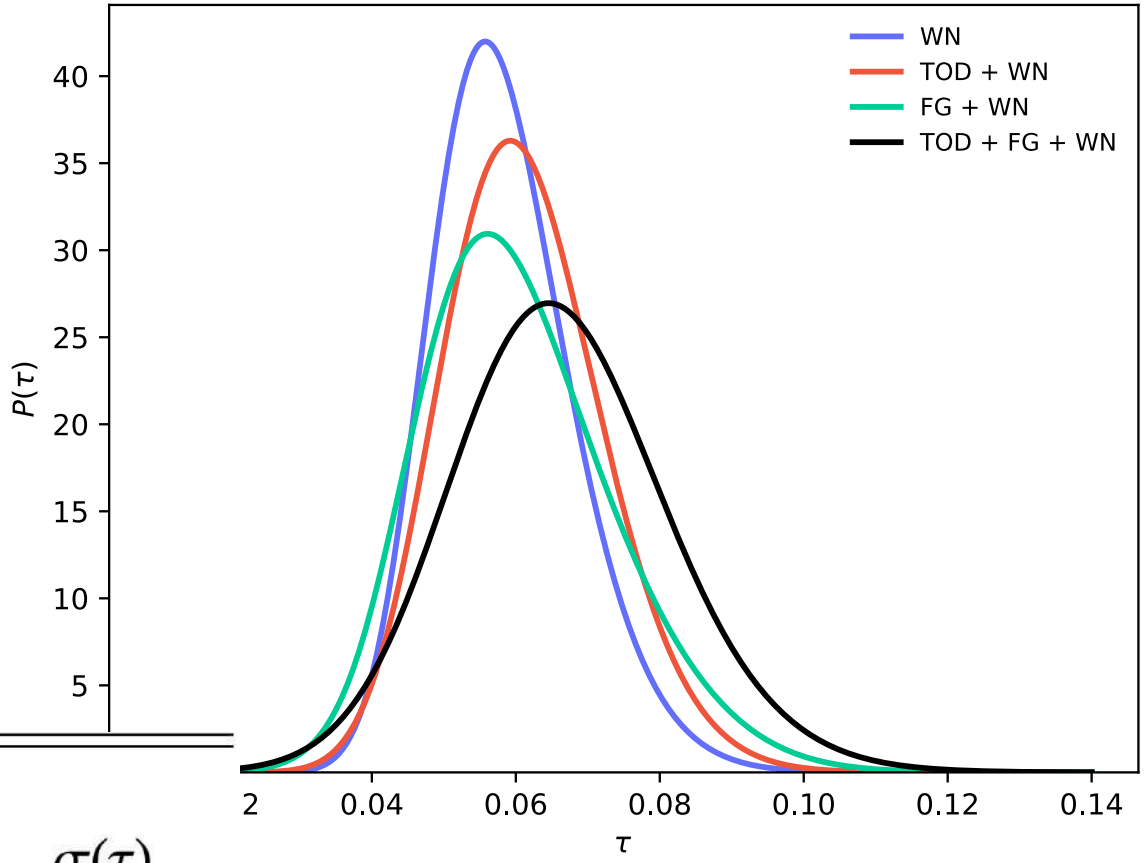


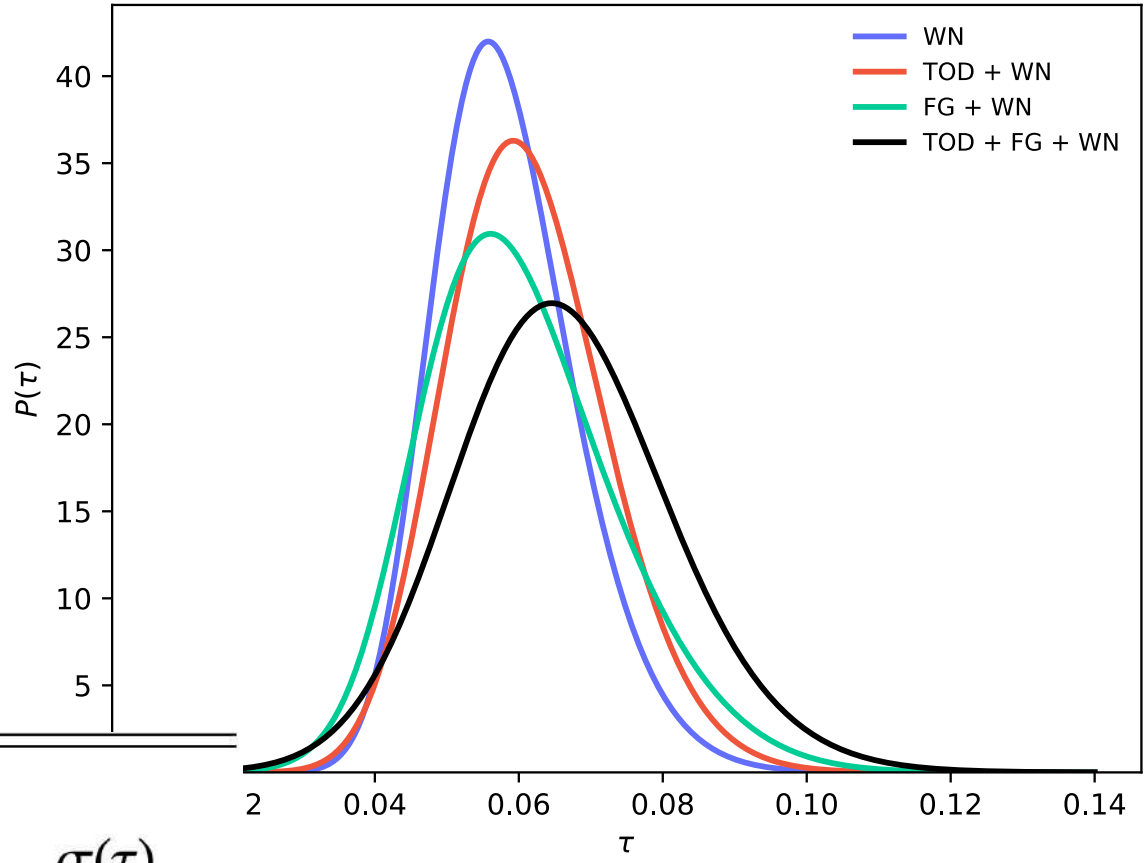
Low-resolution resampling marginalization	τ_{max}	$\sigma(\tau)$
WN	0.0557	0.0095
TOD + WN	0.0592	0.0109
FG + WN	0.0561	0.0130
TOD + FG + WN	0.0646	0.0148

End-to-end error propagation

Propagating uncertainties through the whole processing up to cosmological parameter estimation

Marginalisation over noise parameters, along with foreground and TOD ones!

$$\sigma_{CV} \sim 0.003 - 0.004$$



Low-resolution resampling marginalization	$\tau_{\max}$	$\sigma(\tau)$
WN	0.0557	0.0095
TOD + WN	0.0592	0.0109
FG + WN	0.0561	0.0130
TOD + FG + WN	0.0646	0.0148

FG+WN coupling leads to error under-estimation!

Paper release

These results are summarised and being published in BeyondPlanck collaboration, 2020.

A more in depth discussion will be presented in upcoming papers.

All the papers are being published on A&A, and gathered on BeyondPlanck webpage:

https://beyondplanck.science/products/publications/

Person month effort

Name	EU funded	In Kind
University of Milan	46.5	18
University of Oslo	15	1.5
TOTAL	**61.50**	**19.50**
BUDGETED	**60.00**	
DEVIATION	**1.5**	

Funding

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776282

- "*BeyondPlanck*"
  - COMPET-4 program
  - PI: Hans Kristian Eriksen
  - Grant no.: 776282
  - Period: Mar 2018 to Nov 2020

Collaborating projects:

- "*bits2cosmology*"
  - ERC Consolidator Grant
  - PI: Hans Kristian Eriksen
  - Grant no: 772 253
  - Period: April 2018 to March 2023
- "*Cosmoglobe*"
  - ERC Consolidator Grant
  - PI: Ingunn Wehus
  - Grant no: 819 478
  - Period: June 2019 to May 2024