SPT-3G D1: CMB TT/TE/EE power spectra and cosmology from 2019 and 2020 observations of the Main field

Etienne Camphuis

for the SPT-3G collaboration

European Research Council
Established by the European Commission

Wei Quan (Argonne)

Lennart Balkenhol (IAP)

Ali R. Khalife (IAP)

Paper on arXiv today !

SPT-3G D1: CMB temperature and polarization power spectra and cosmology from 2019 and 2020 observations of the SPT-3G Main field

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(SPT-3G Collaboration)

The SPT-3G collaboration

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U.S. DEPARTMENT of ENERGY

Outline

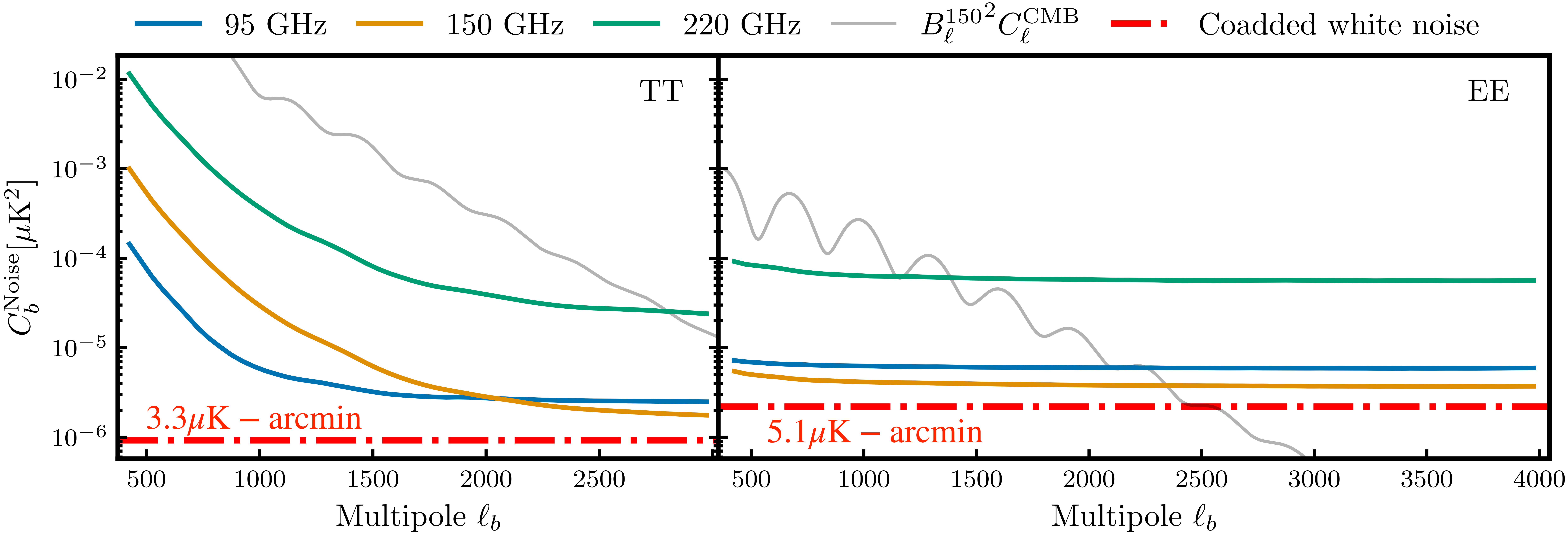
(1) From maps to band powers, to cosmology.

(2) TT/TE/EE cosmological fit.

(3) Combination with SPT-3G lensing and CMB data sets.

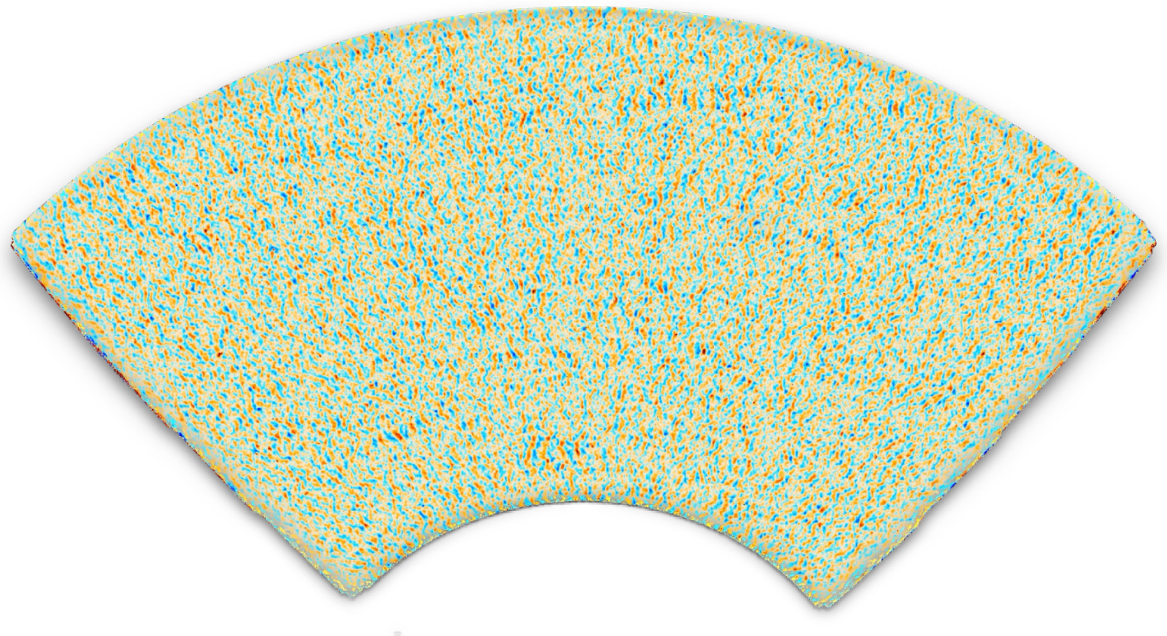
(4) Combination with DESI DR2 BAO data.

SPT-3G D1 maps : deepest for TT/TE/EE analysis



SPT-3G D1 is signal-dominated in polarization until $\ell = 2500$.

SPT-3G D1 pipeline : highlights



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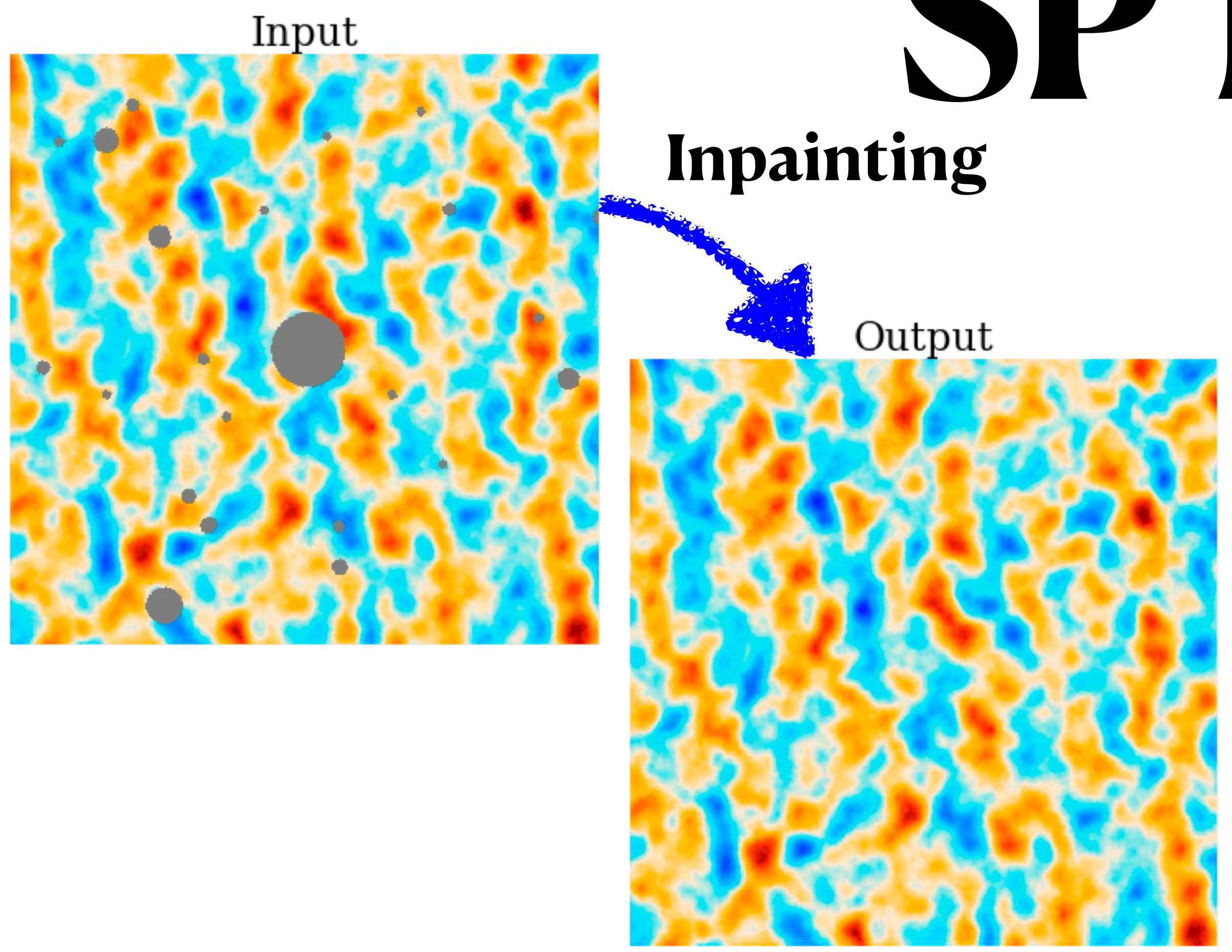
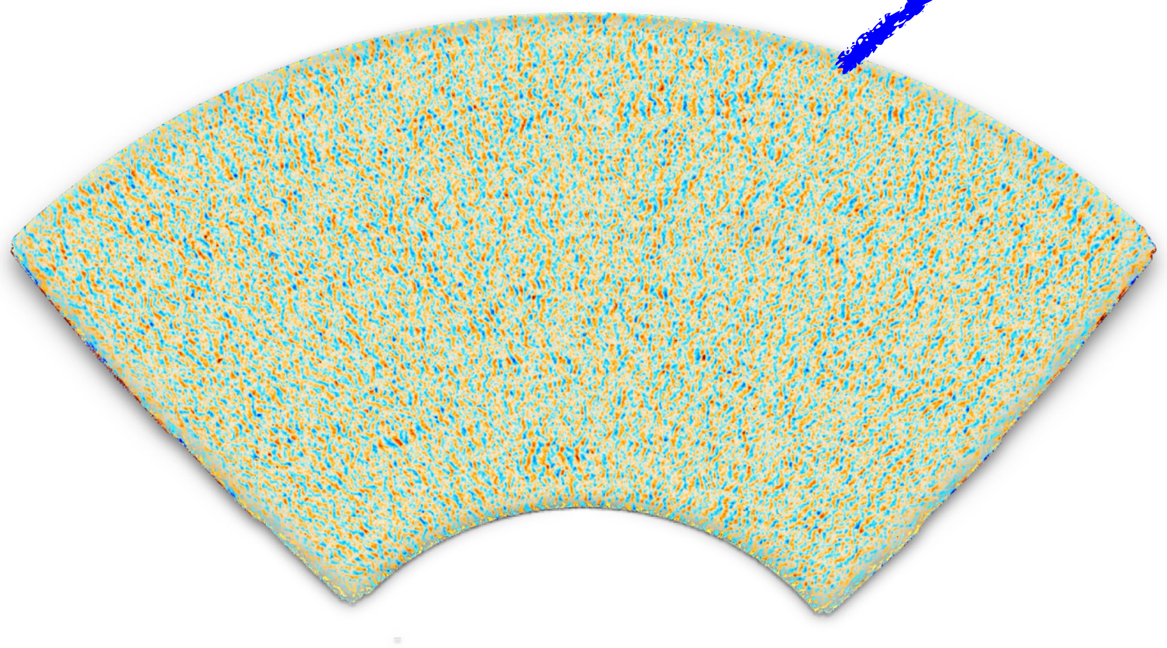


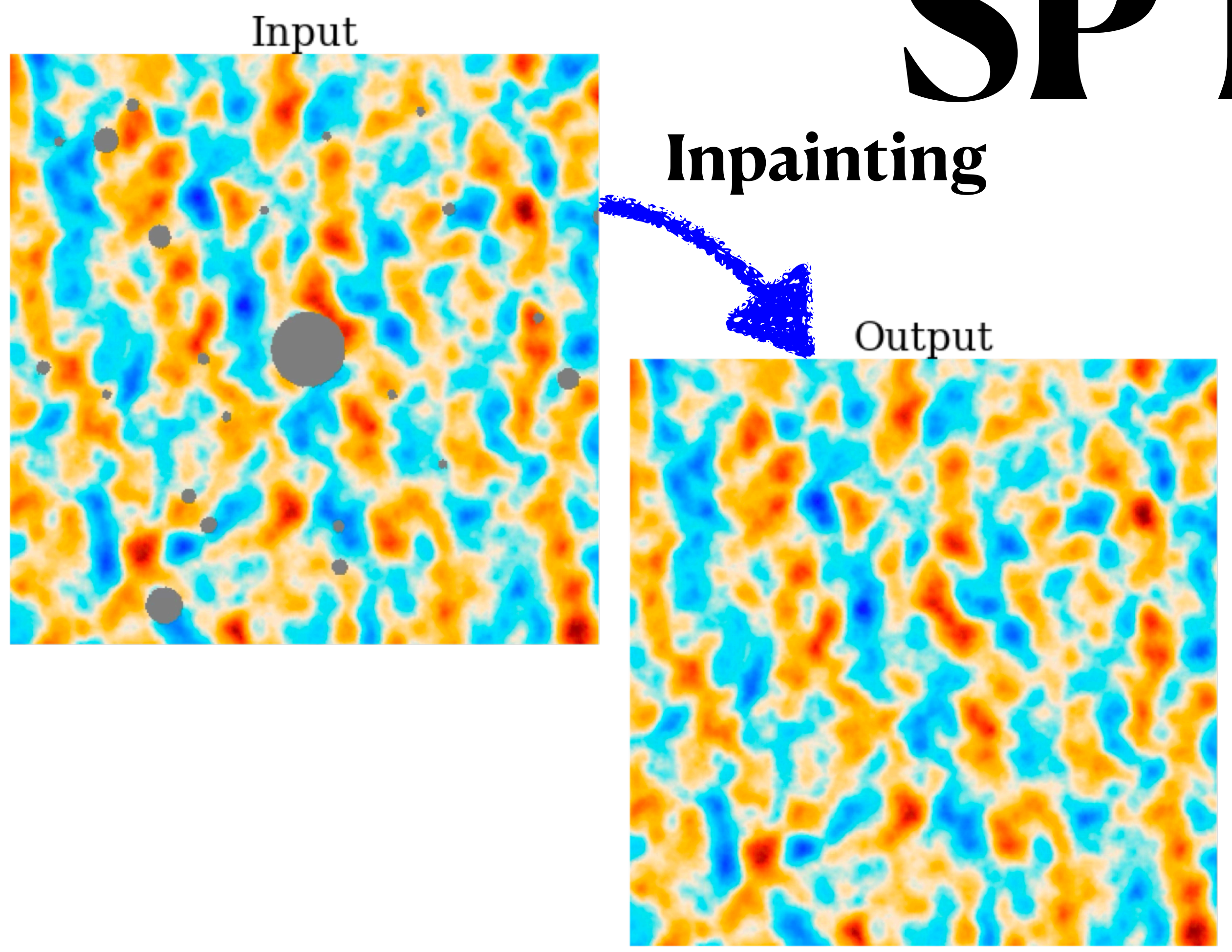
Improved beam modeling

$D_\ell^{\rm TT}, D_\ell^{\rm TE}, D_\ell^{\rm EE}$



2000 QuickMock simulations to model the transfer function

SPT-3G D1 pipeline : highlights



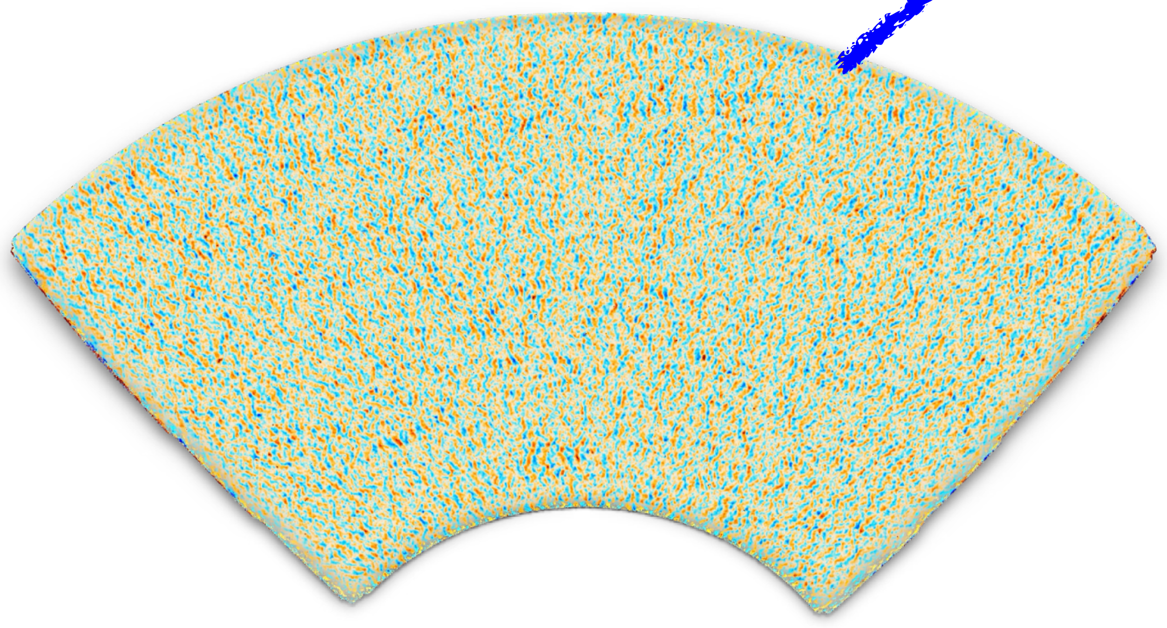
Improved beam modeling

$D_\ell^{TT}, D_\ell^{TE}, D_\ell^{EE}$

Semi-analytical covariance matrices

« Lite » likelihood

$H_0, \Omega_c h^2, \dots$



2000 QuickMock simulations to model the transfer function

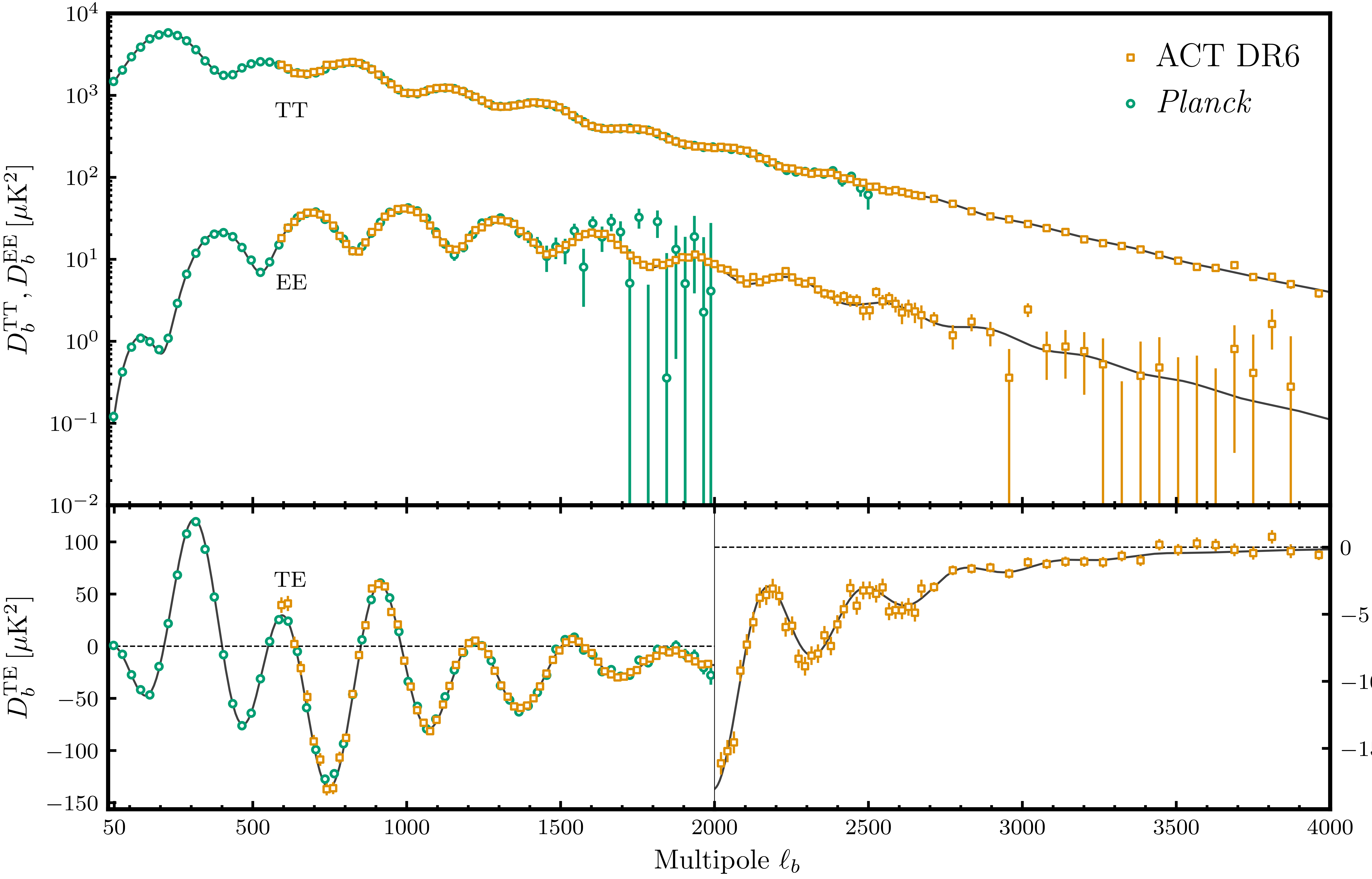
candl

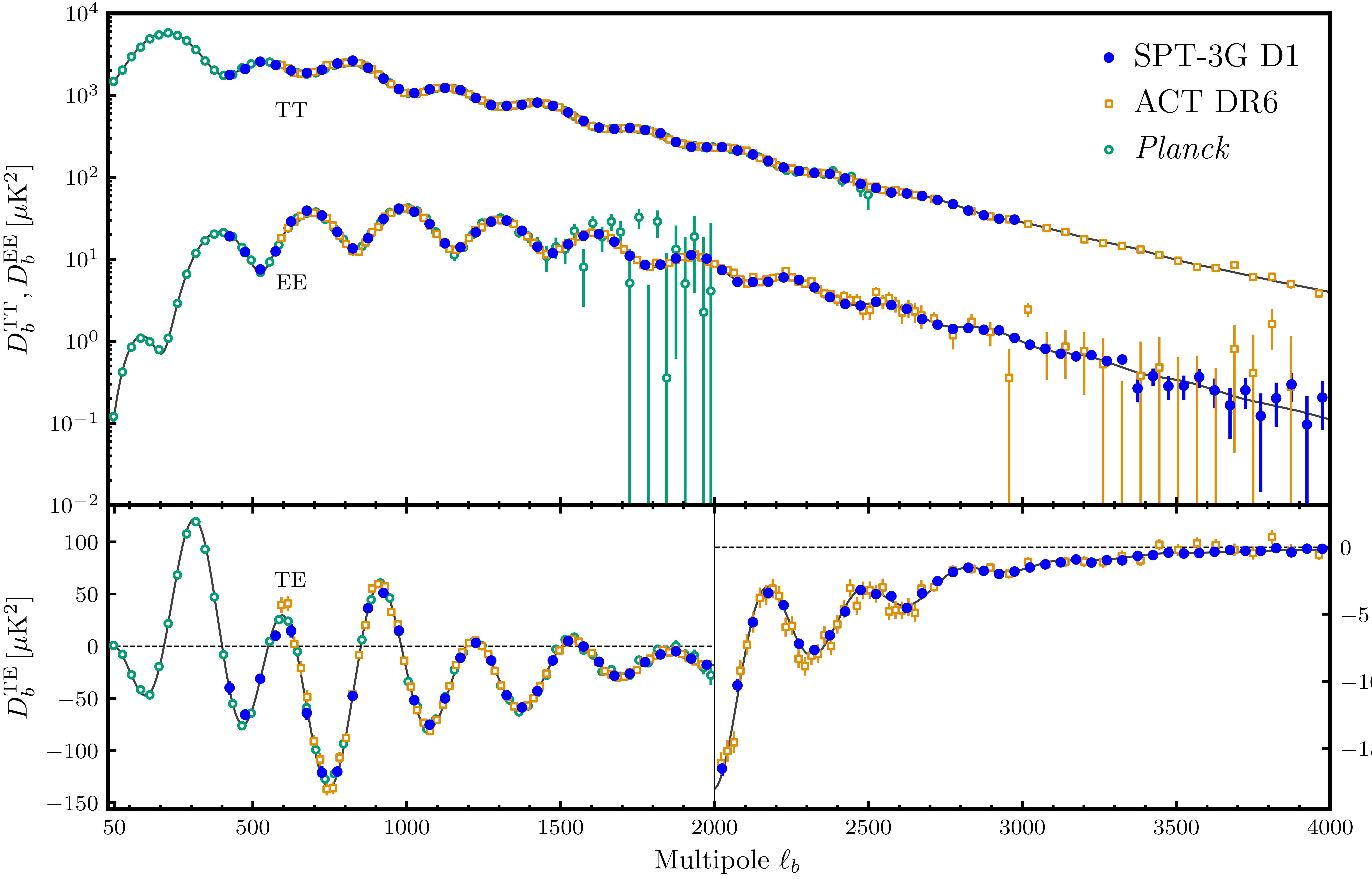
https://github.com/Lbalkenhol/candl

https://github.com/dpiras/cosmopower-jax

OLÉ

https://github.com/svenguenther/OLE/


ACT DR6
Planck
TT
EE
TE
$D_b^{\mathrm{TT}}, D_b^{\mathrm{EE}}\,[\mu\mathrm{K}^2]$
$D_b^{\mathrm{TE}}\,[\mu\mathrm{K}^2]$
Multipole ℓ_b


SPT-3G D1
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Planck
TT
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D_b^{TT}, D_b^{EE} [μK^2]
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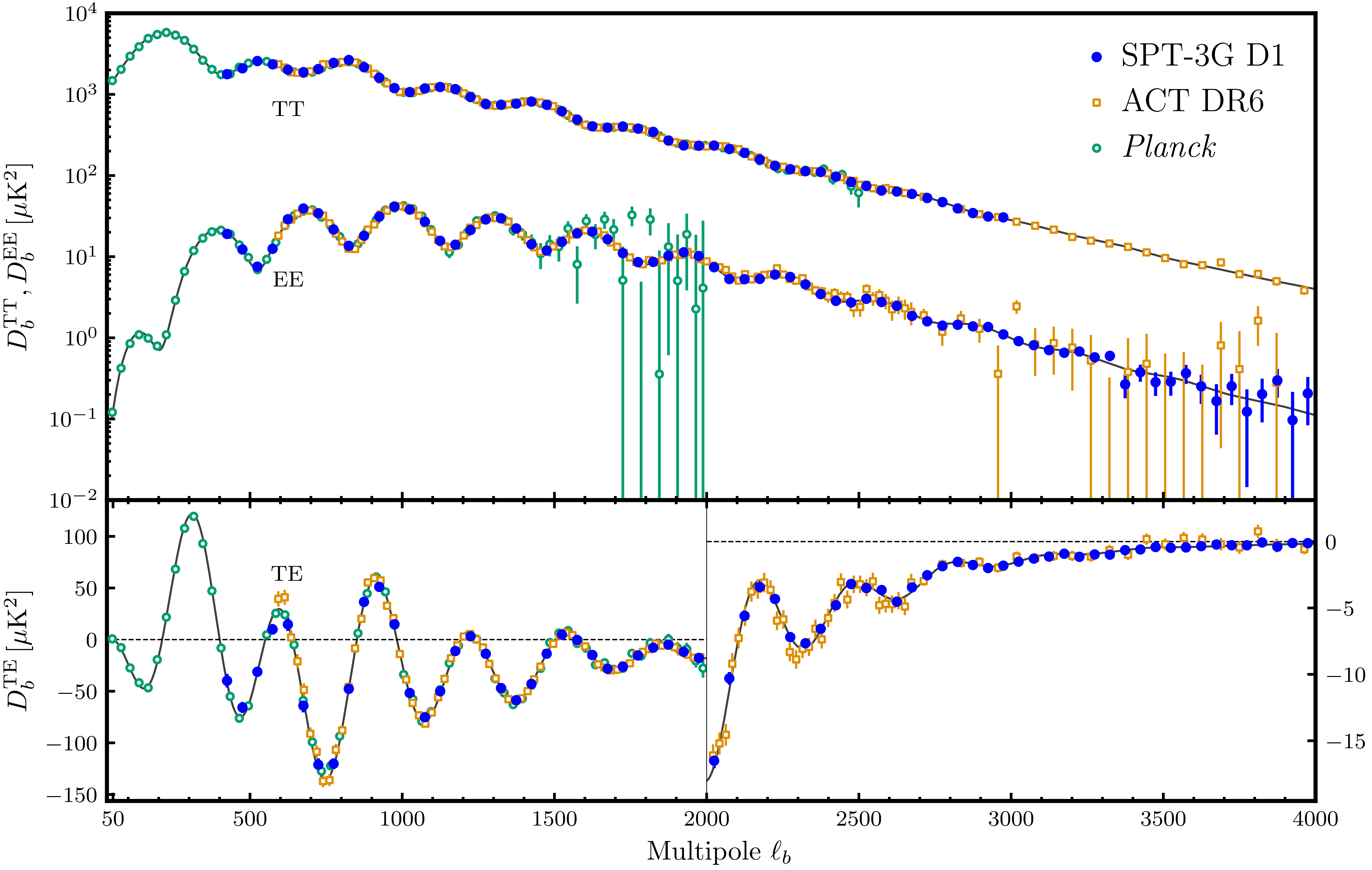
Data set extends from 400 to 3000 in TT

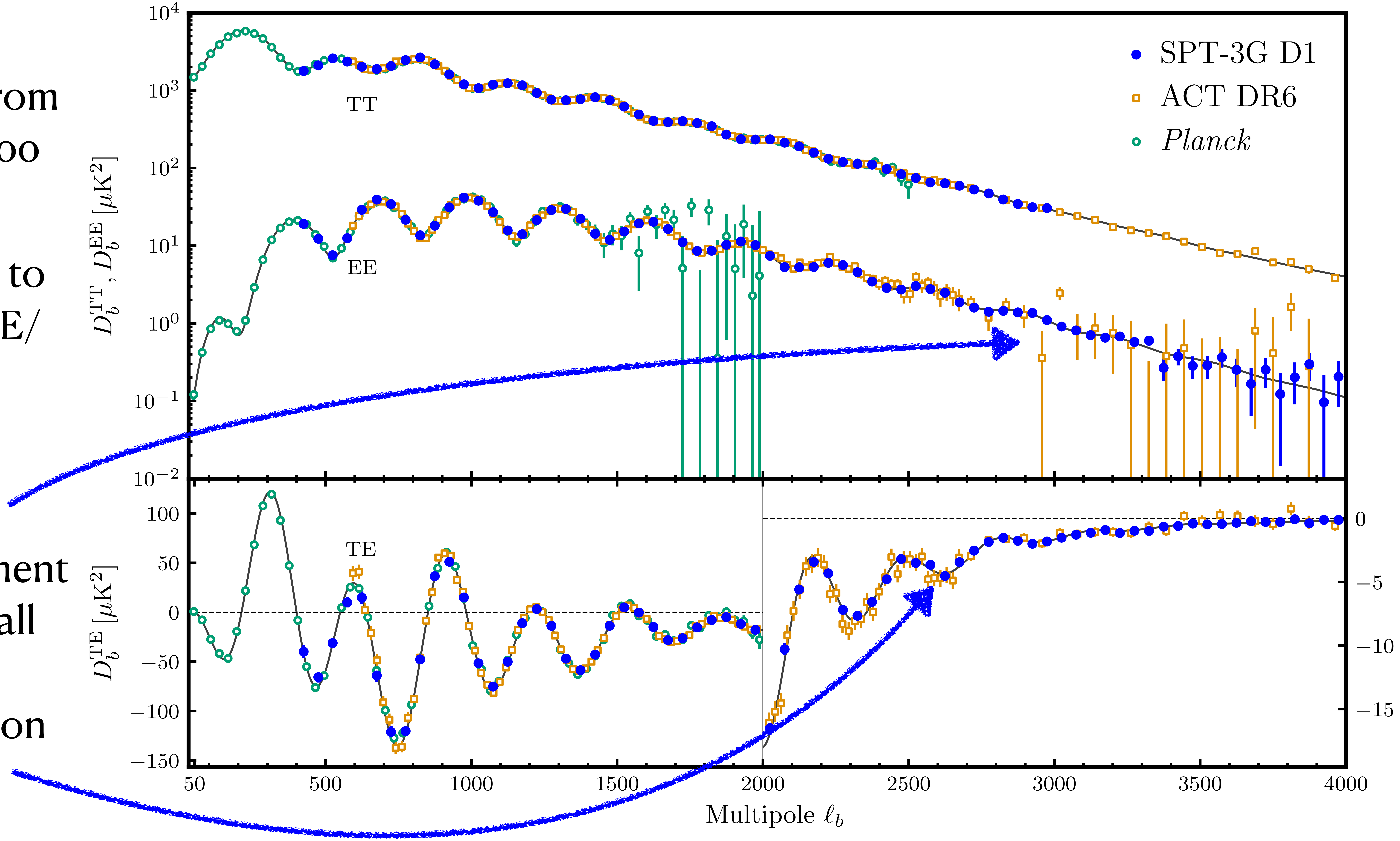
From 400 to 4000 in TE/EE



Data set extends from 400 to 3000 in TT

From 400 to 4000 in TE/ EE

Precise measurement of the small scales in polarization

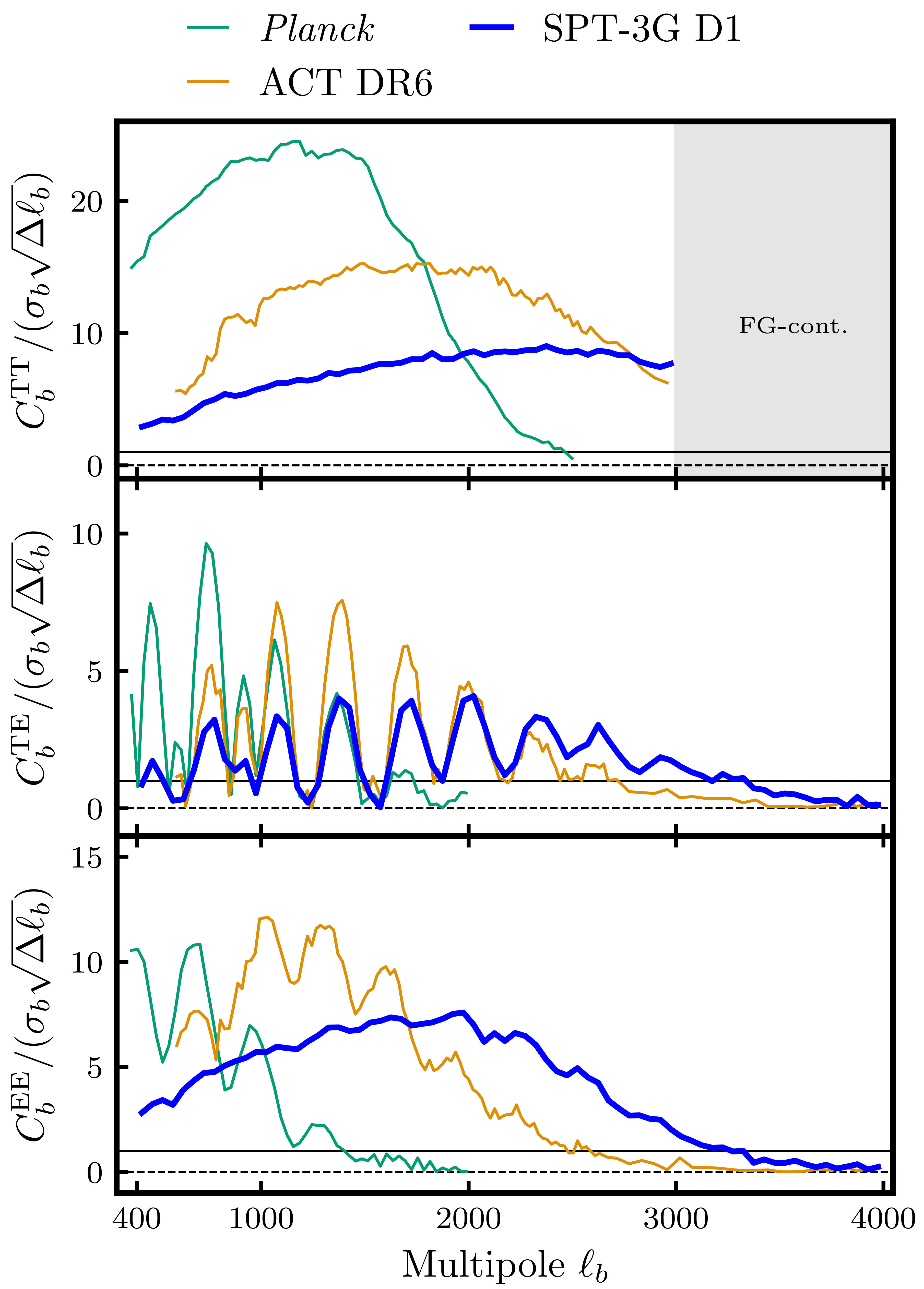


Signal-to-noise ratio

Experiment	Sky fraction [%]	Coadded noise [uK-arcmin]
Planck	100	35
ACT DR6	45	10
SPT-3G D1	4	3.3

SPT-3G D1 provides the tightest band powers:

- **In TE, at $\ell \in [2200,4000]$,**
- **In EE, at $\ell \in [1800,4000]$.**



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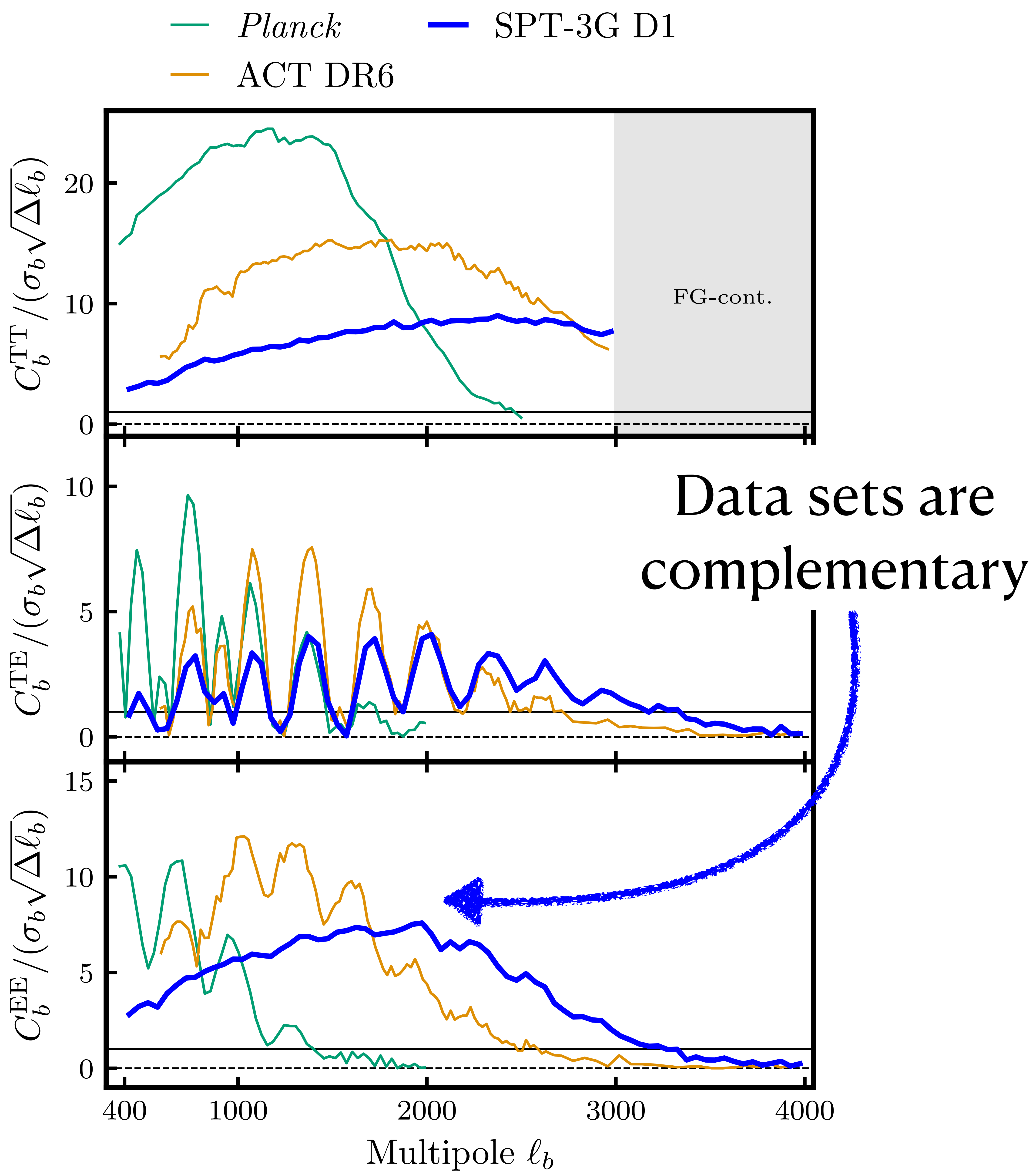

Pipeline validation

Blind pipeline

- We first validate band powers, using blind null tests.
- We then validate the likelihood, with simulations and parameter null tests.

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  - (1) Quadrupolar beam leakage,
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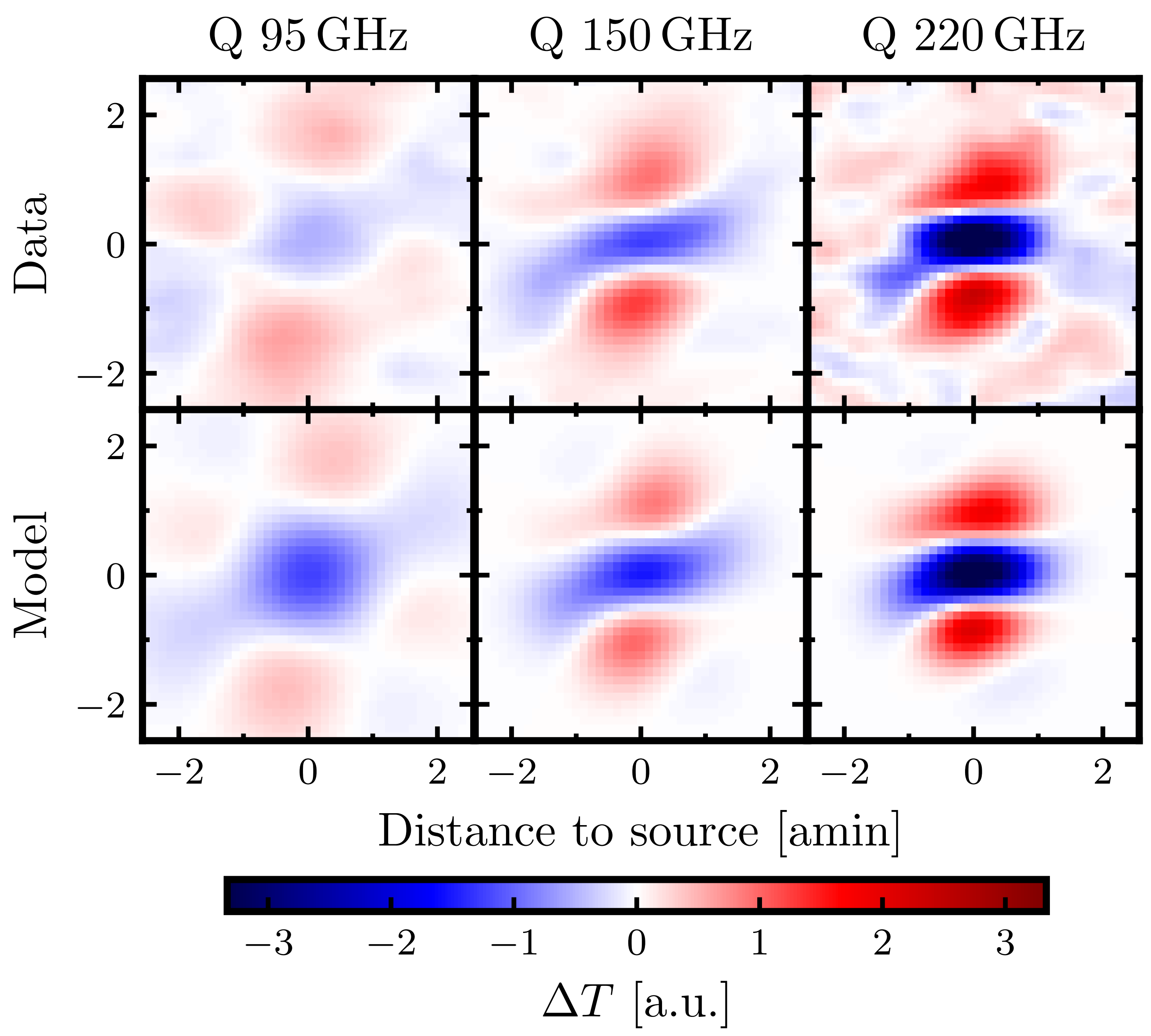

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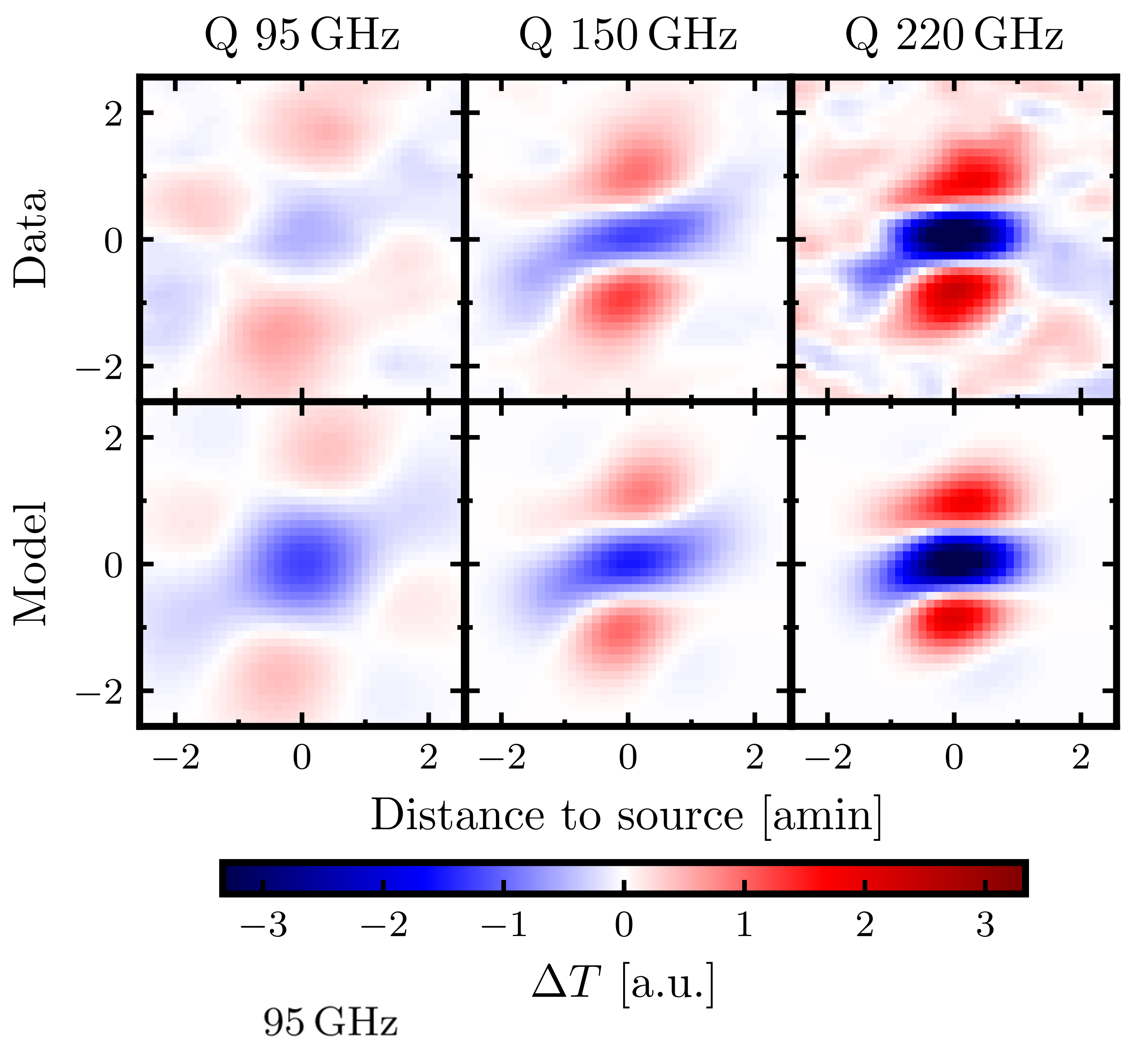

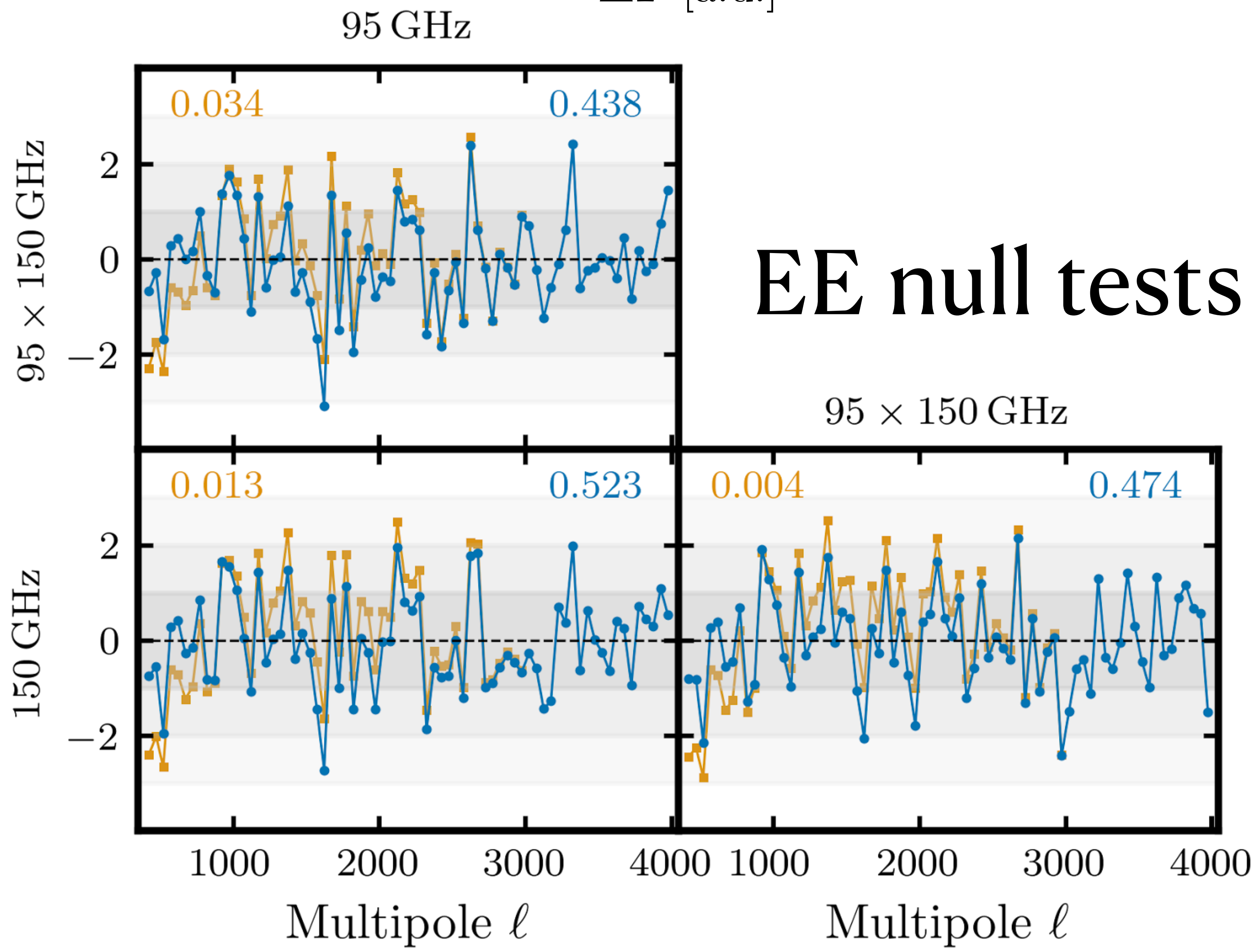

EE null tests

Pipeline validation

Blind pipeline

- We first validate band powers, using blind null tests.
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- **We unblinded when we passed all the tests.**
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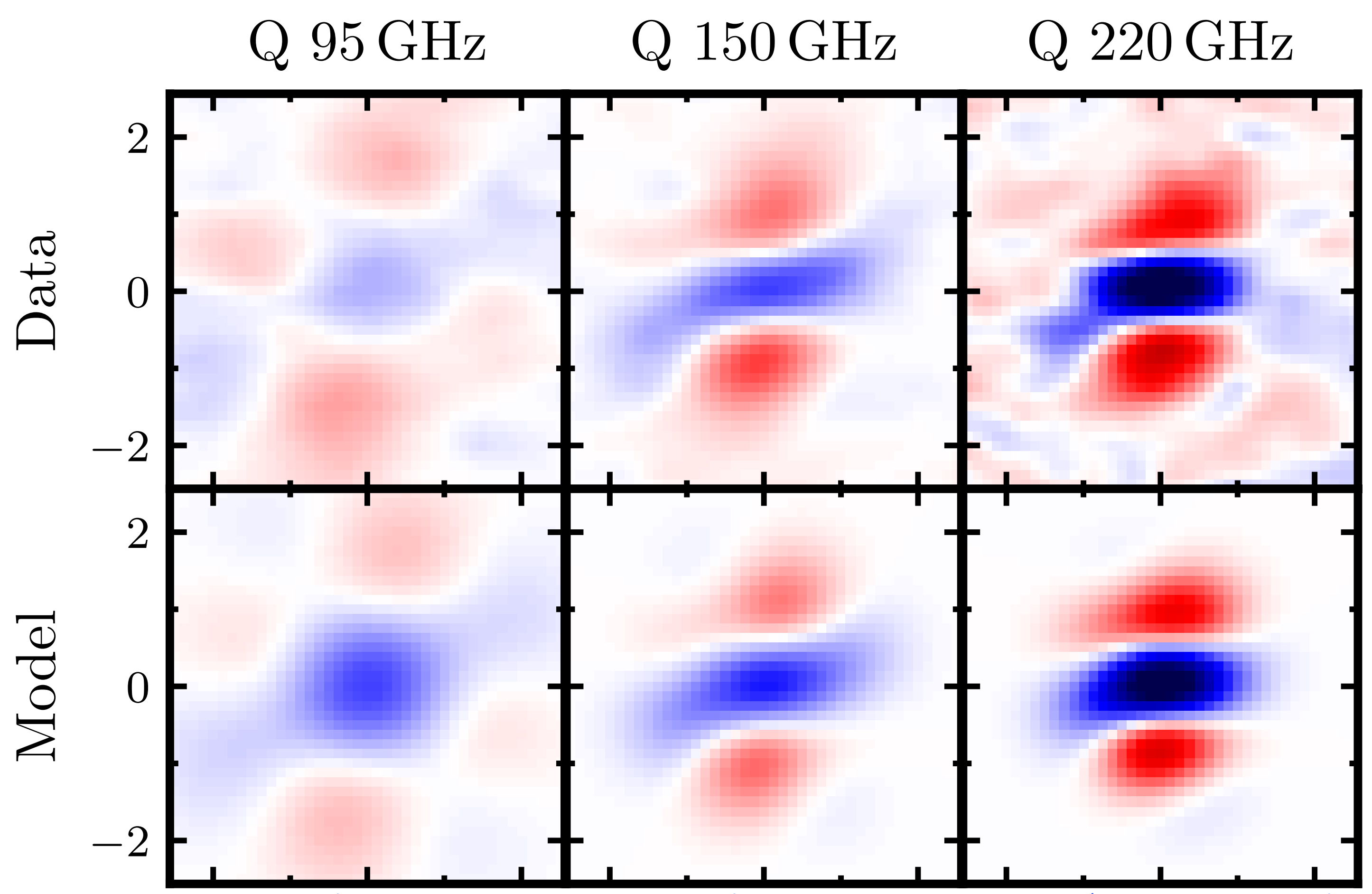
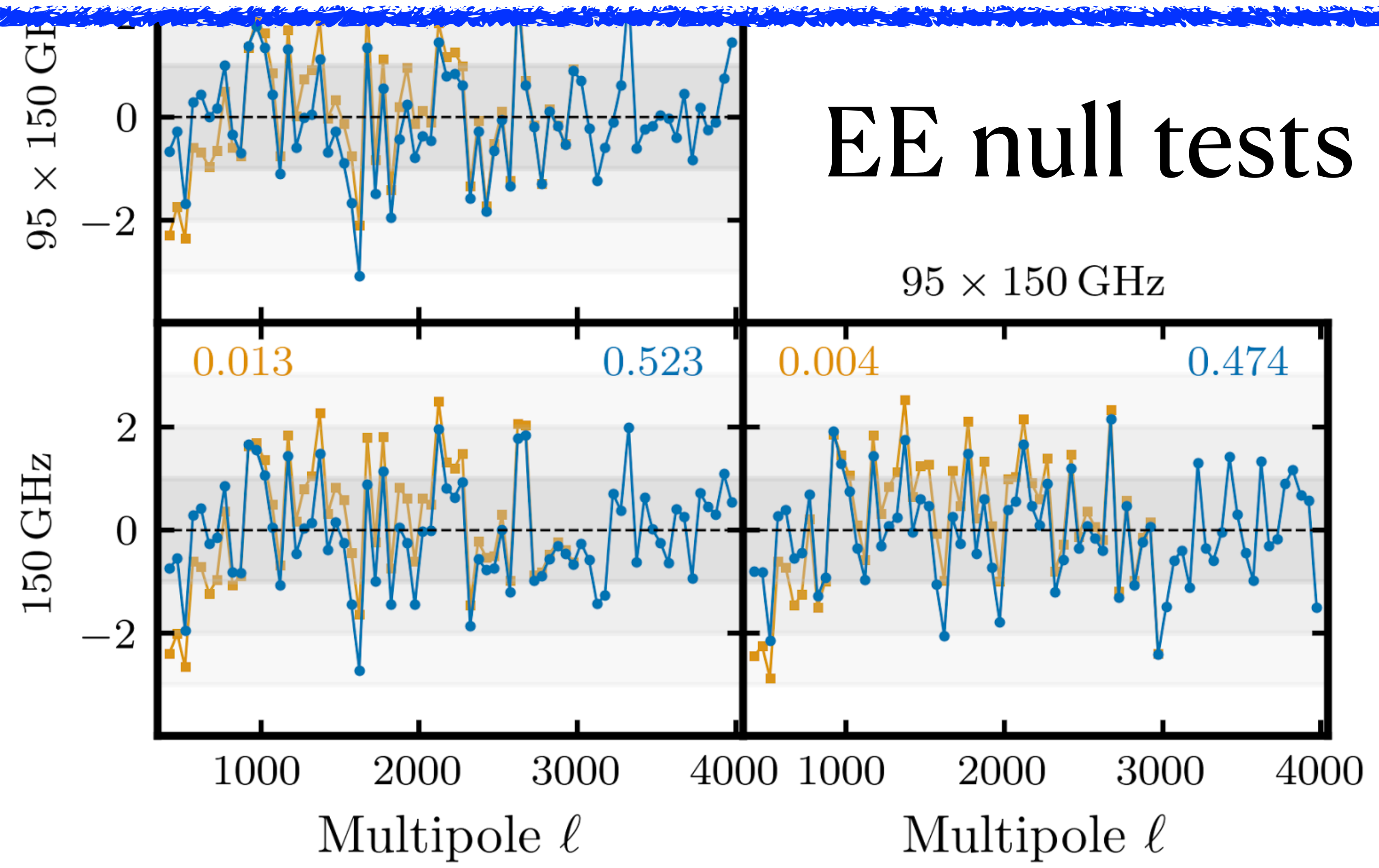


We find cosmology independent evidence for including those in the data model.

EE null tests

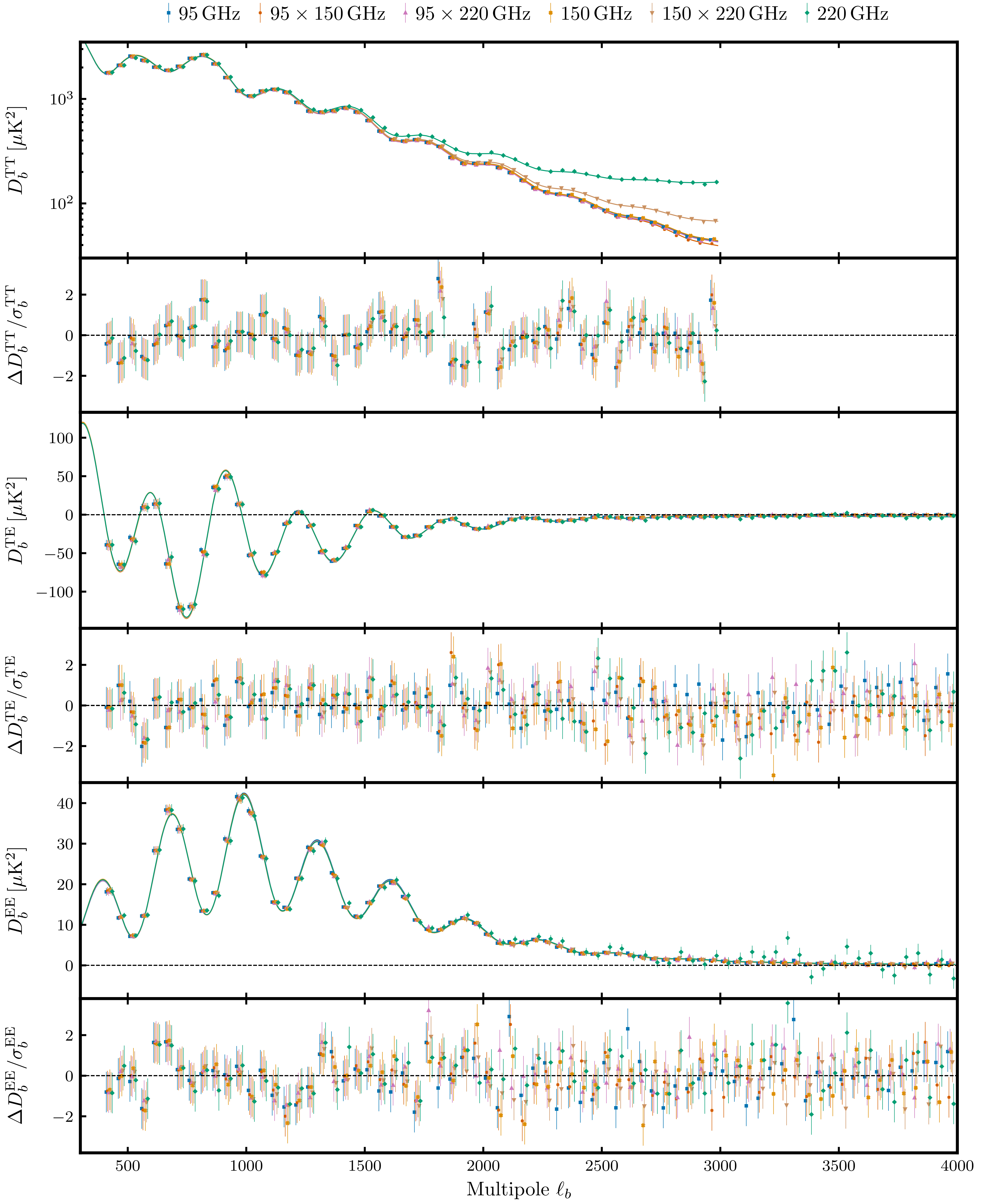


ΛCDM fit

ΛCDM is a good fit to the SPT-3G D1 data

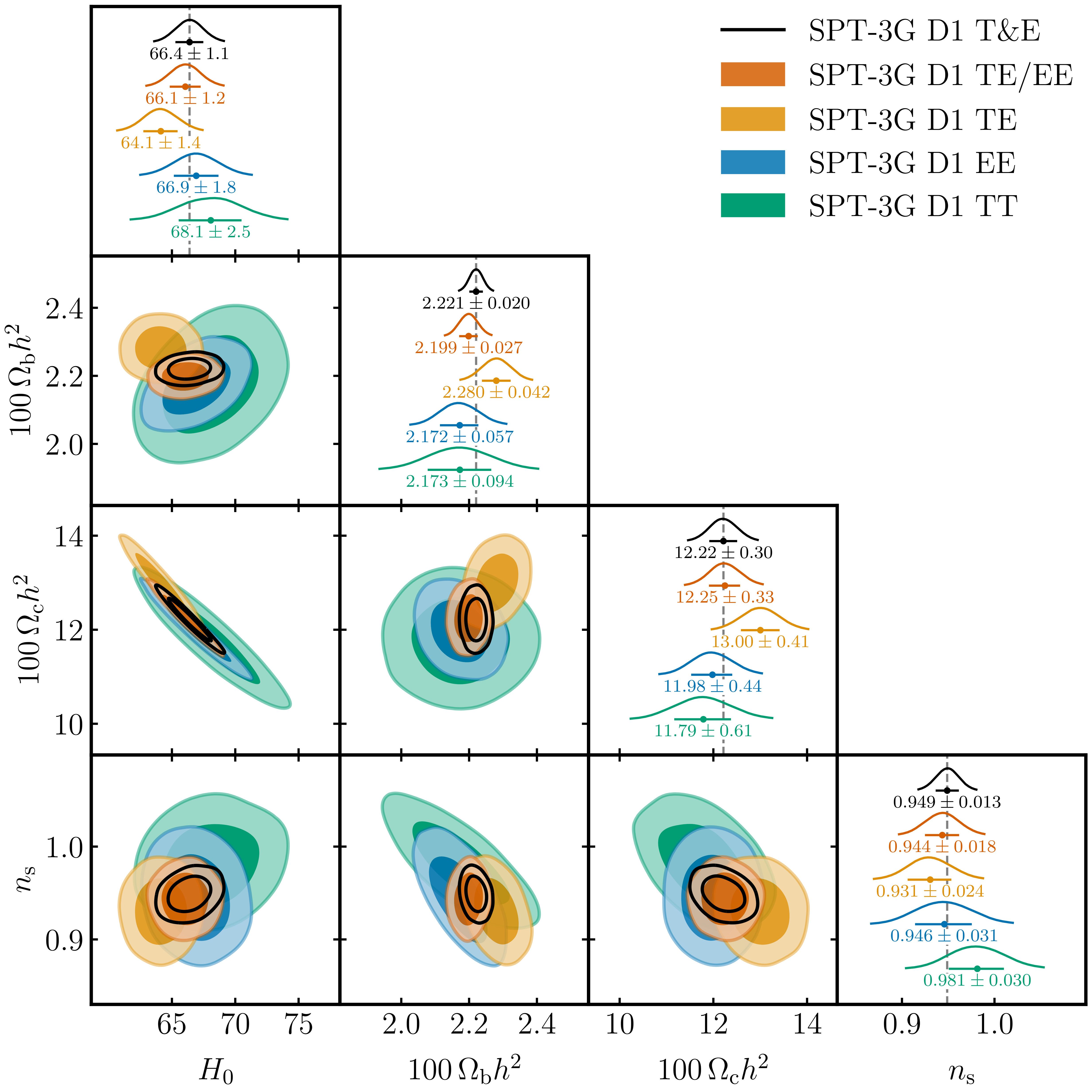
χ^2(ndof): 1359(1362)

PTE = 52%



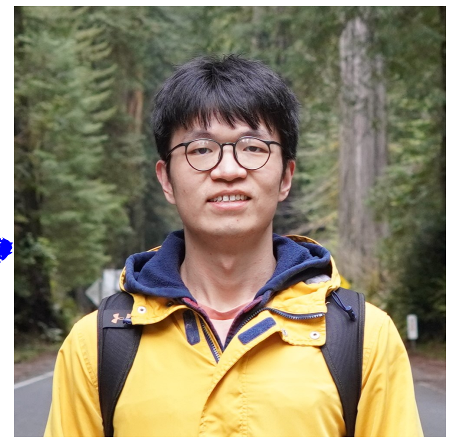
ΛCDM fit

- ΛCDM provides a good fit to TT, TE and EE individually:
  - TT : 267(291) and PTE = 84%,
  - TE : 631(633) and PTE = 51%,
  - EE : 429(421) and PTE = 38%.
- TT, TE and EE ΛCDM parameters agree.
- **Combining with lensing yields tighter constraints.**



Data sets

- **SPT-3G D1**:
  - SPT-3G Main field T&E* data.
  - ΦΦ band-powers from Ge et al, [SPT-3G], 2024.

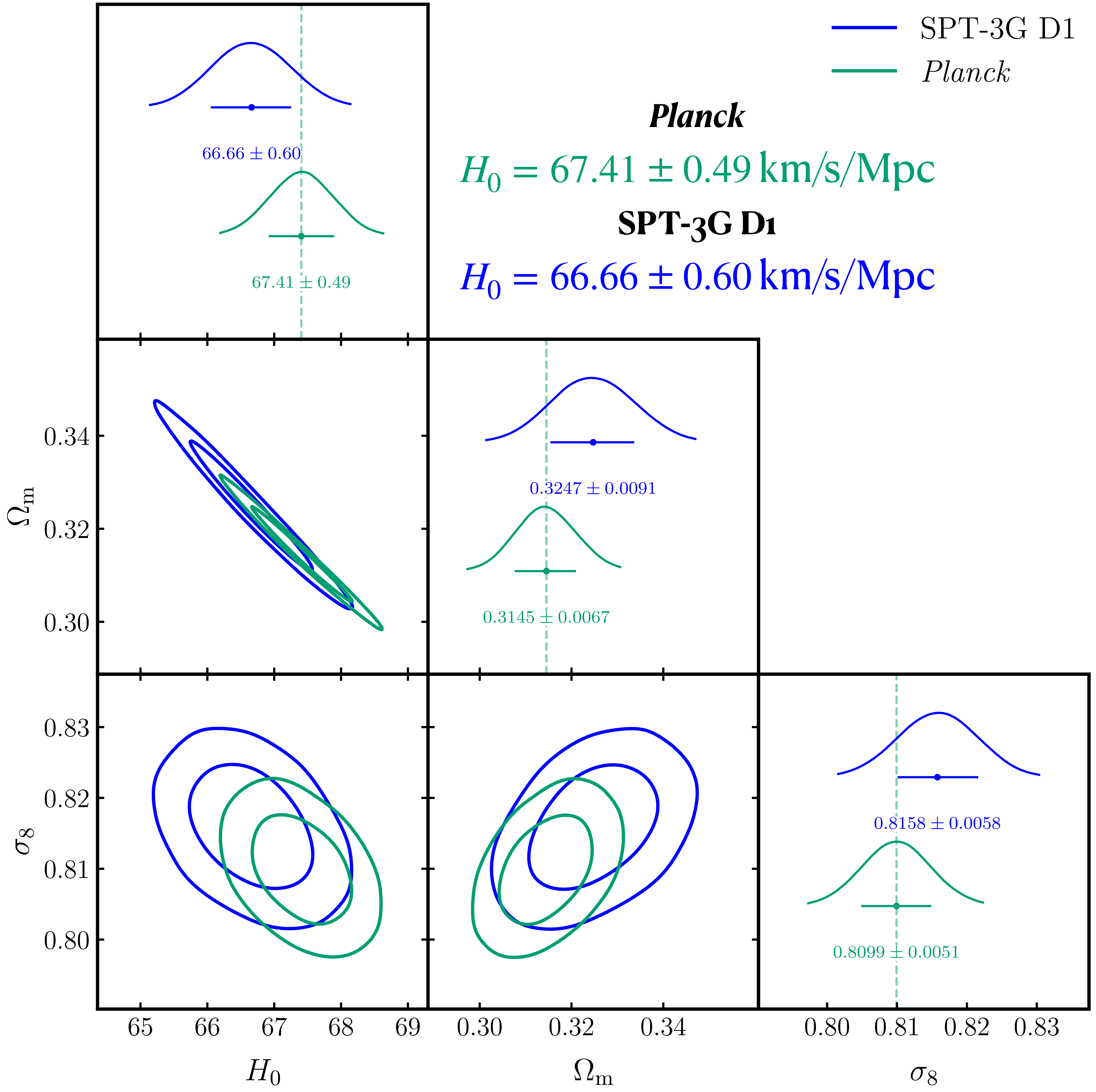


- ***Planck***: Planck 2018 (PR3) [high-ℓ T&E + low-ℓ TT] (Planck Collaboration et al., 2018) + PR4 ΦΦ band-powers (Carron et al, 2022).
- **ACT DR6**: ACT DR6 T&E (Louis et al [ACT], 2025) + ACT DR6 ΦΦ band-powers (Madhavacheril et al [ACT], 2023; Qu et al [ACT], 2023).
- **SPT+ACT**: SPT-3G D1 + ACT DR6.
- **CMB-SPA**: SPT-3G D1 + P-ACT T&E (Louis et al [ACT], 2025) + P-ACT ΦΦ (Carron, 2022).
- $\tau_{\rm reio} \sim \mathcal{N}(0.051, 0.006)$: used for all the data sets above (Akrami et al [Planck], 2020).

ΛCDM

With just 4% of the sky, SPT-3G's constraints on H_0 and σ_8 are within 25% of *Planck*'s.

- SPT-3G D1 and Planck agree at $0.4\,\sigma$.
- SPT-3G D1 agrees with ACT DR6 at $1.1\,\sigma$.
- Indication of the robustness of CMB science.
- This is a formidable test for ΛCDM.



Planck

$H_0 = 67.41 \pm 0.49\,\mathrm{km/s/Mpc}$

SPT-3G D1

$H_0 = 66.66 \pm 0.60\,\mathrm{km/s/Mpc}$

ΛCDM

For the first time, the combined constraining power of SPT+ACT reaches *Planck*'s precision.

Planck

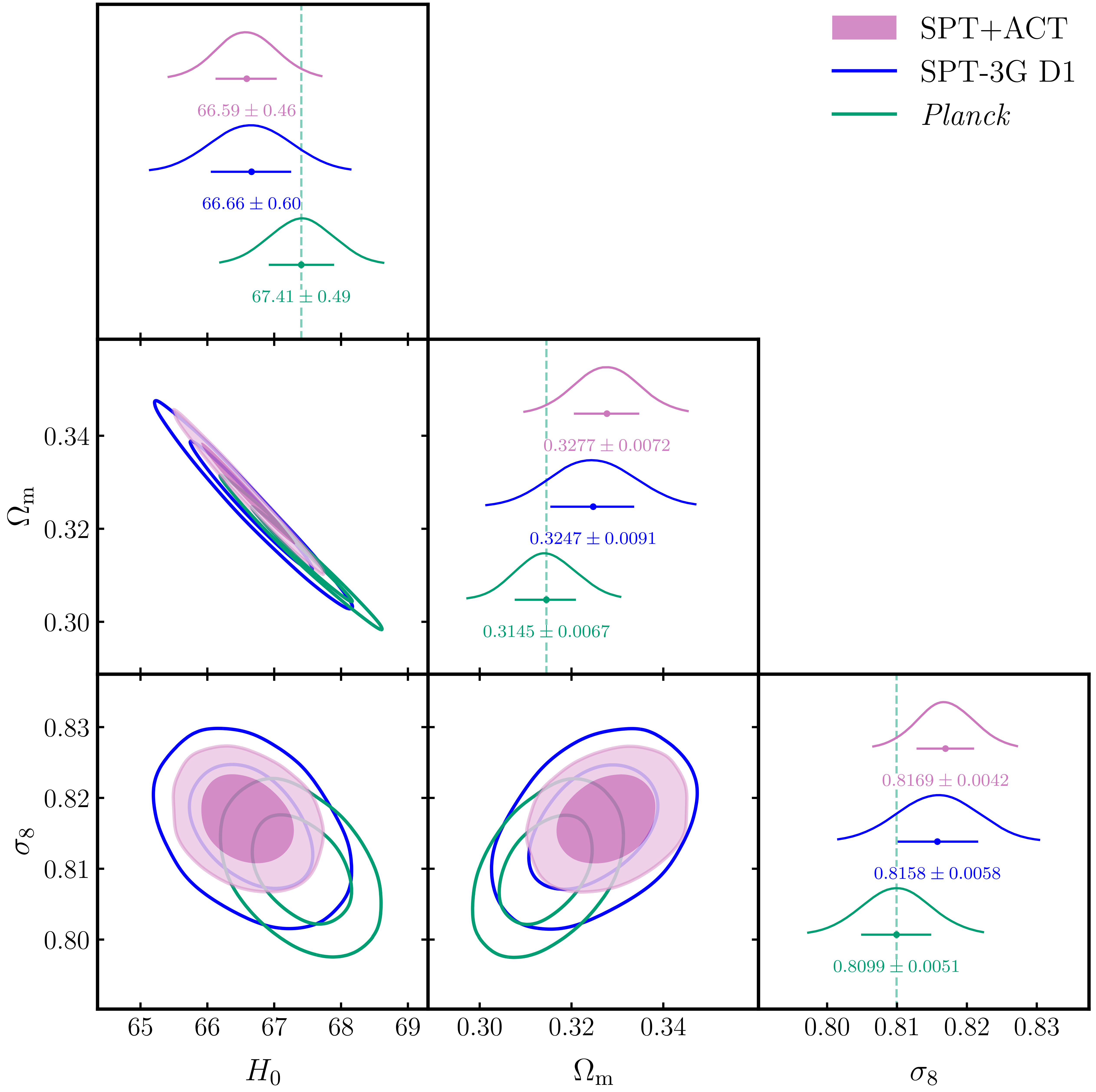
$H_0 = 67.41 \pm 0.49\,\mathrm{km/s/Mpc}$

SPT-3G D1

$H_0 = 66.66 \pm 0.60\,\mathrm{km/s/Mpc}$

SPT+ACT

$H_0 = 66.59 \pm 0.46\,\mathrm{km/s/Mpc}$



ΛCDM

CMB-SPA yields the most precise determination of ΛCDM parameters from CMB alone.

Planck

$H_0 = 67.41 \pm 0.49\,\mathrm{km/s/Mpc}$

SPT-3G D1

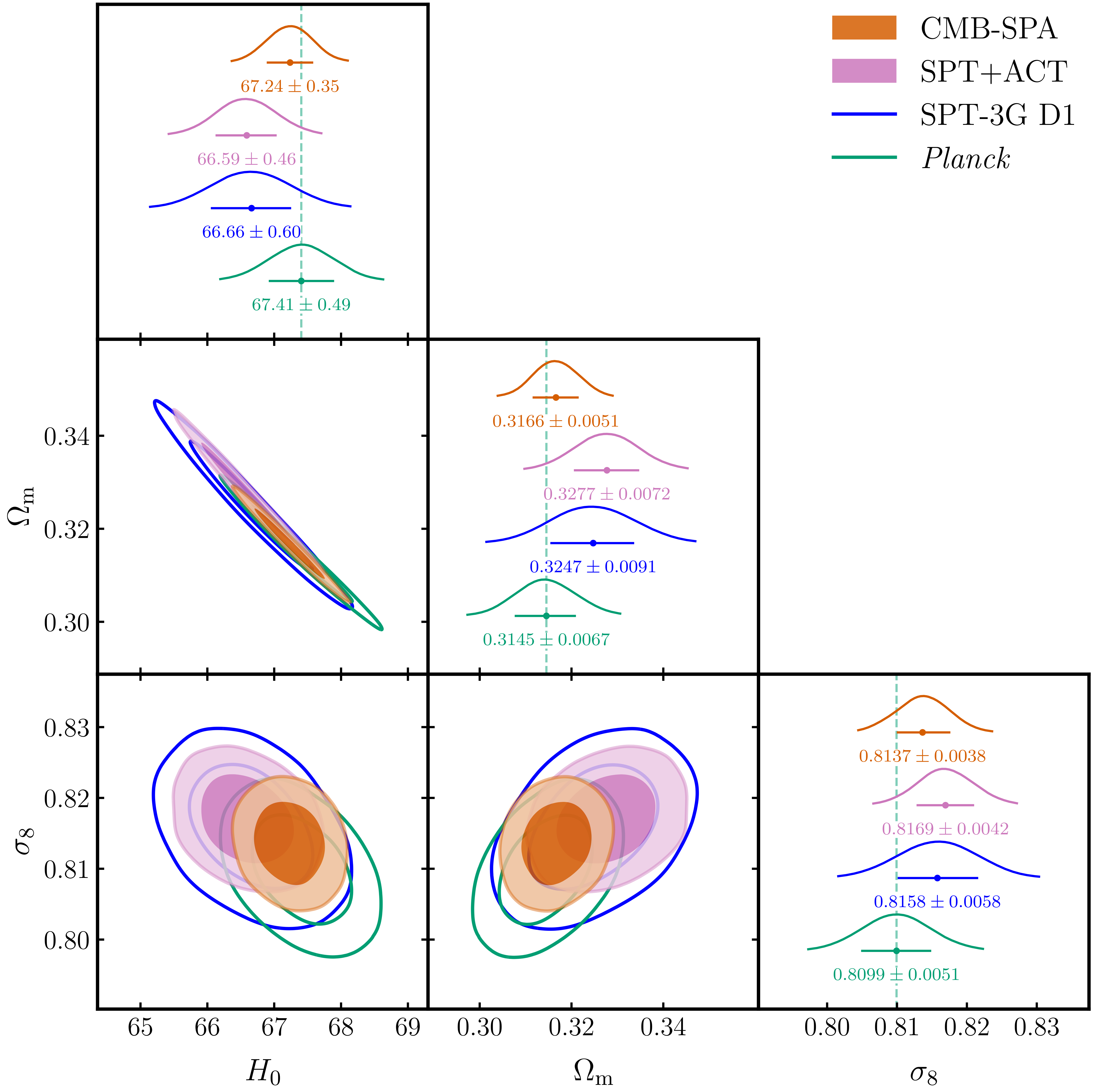
$H_0 = 66.66 \pm 0.60\,\mathrm{km/s/Mpc}$

SPT+ACT

$H_0 = 66.59 \pm 0.46\,\mathrm{km/s/Mpc}$

CMB-SPA

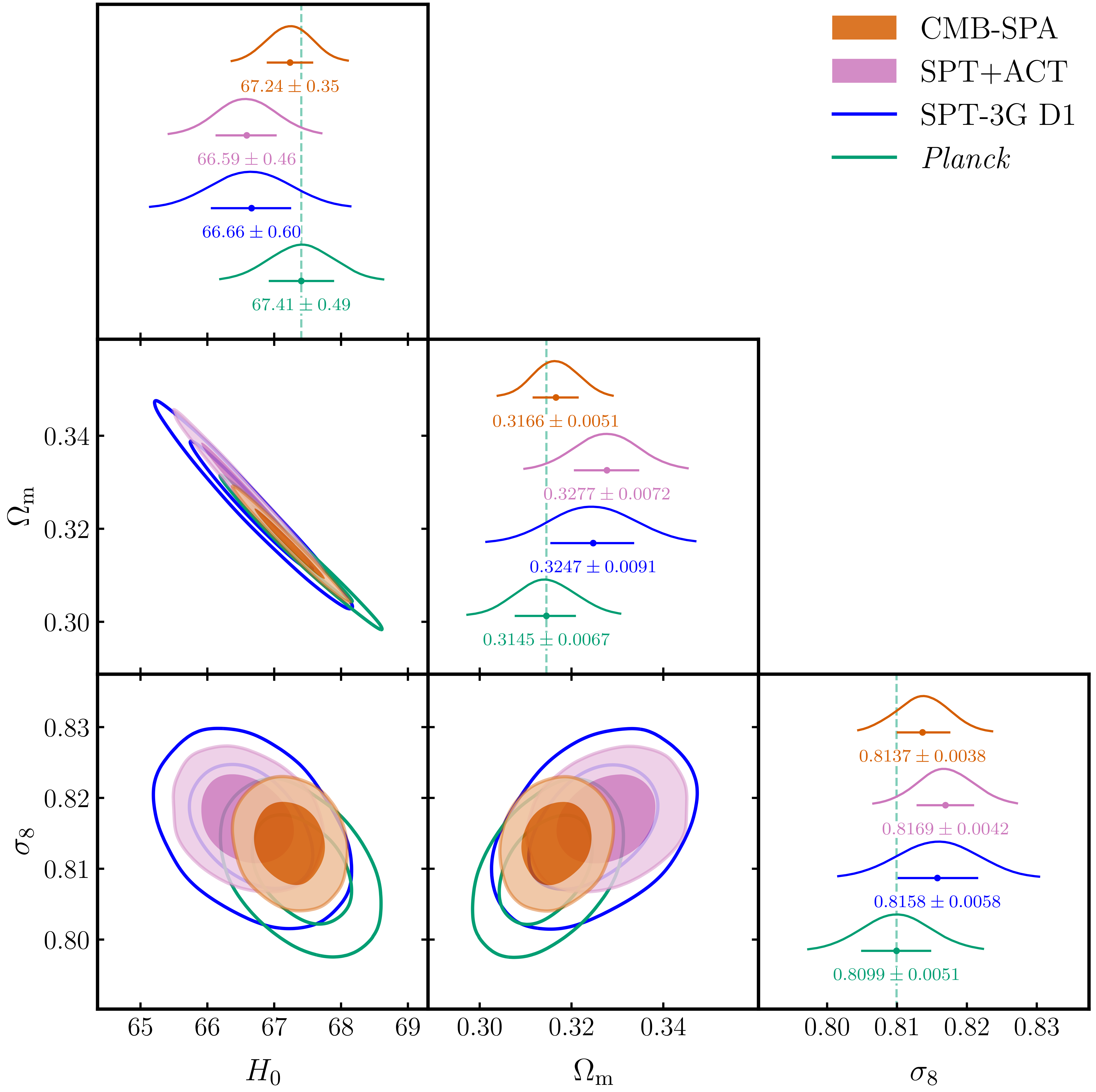
$H_0 = 67.24 \pm 0.35\,\mathrm{km/s/Mpc}$



ΛCDM

CMB-SPA yields the most precise determination of ΛCDM parameters from CMB alone.

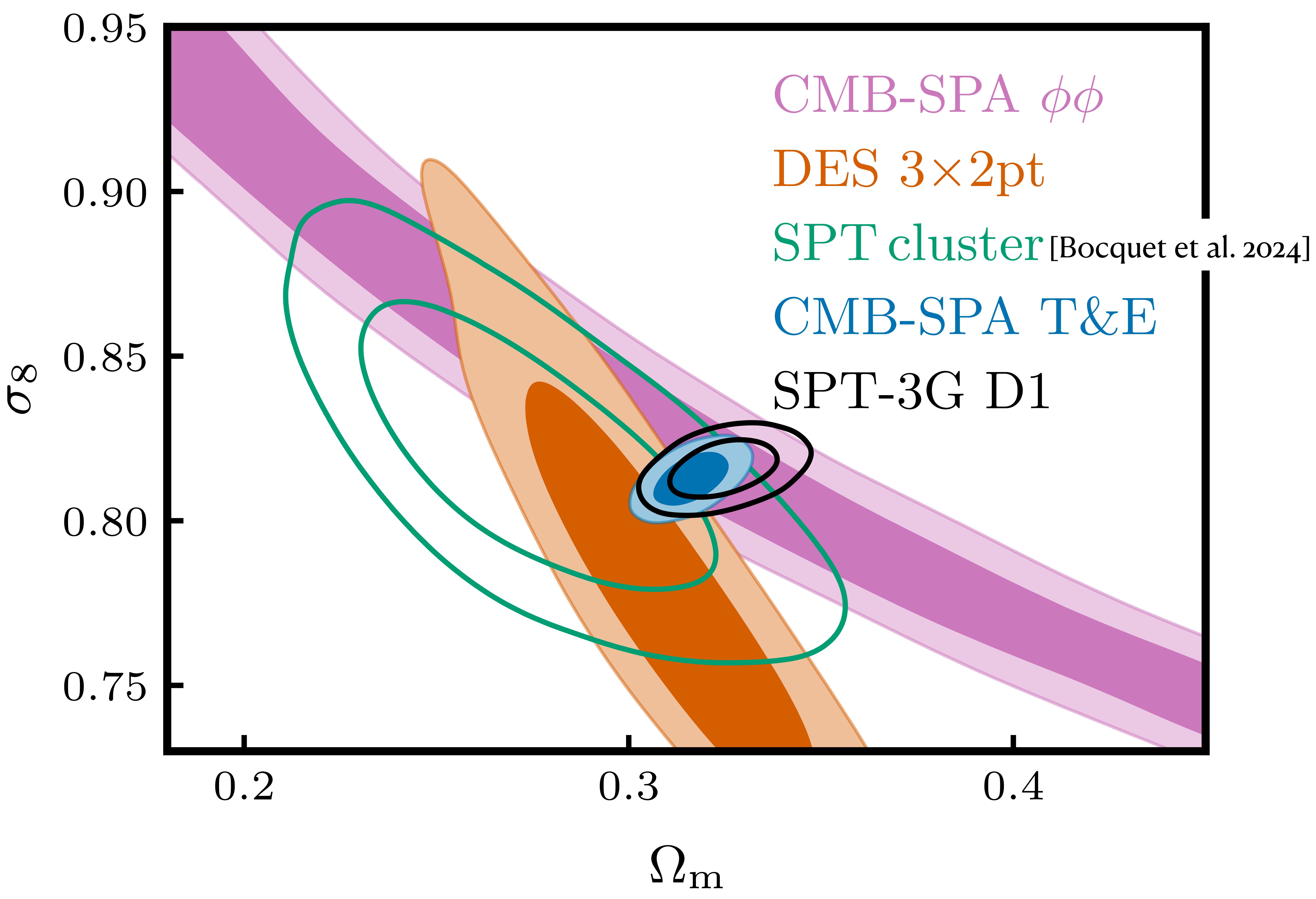
We do not find any statistically significant deviation from ΛCDM from CMB data alone.



σ_8-Ω_m

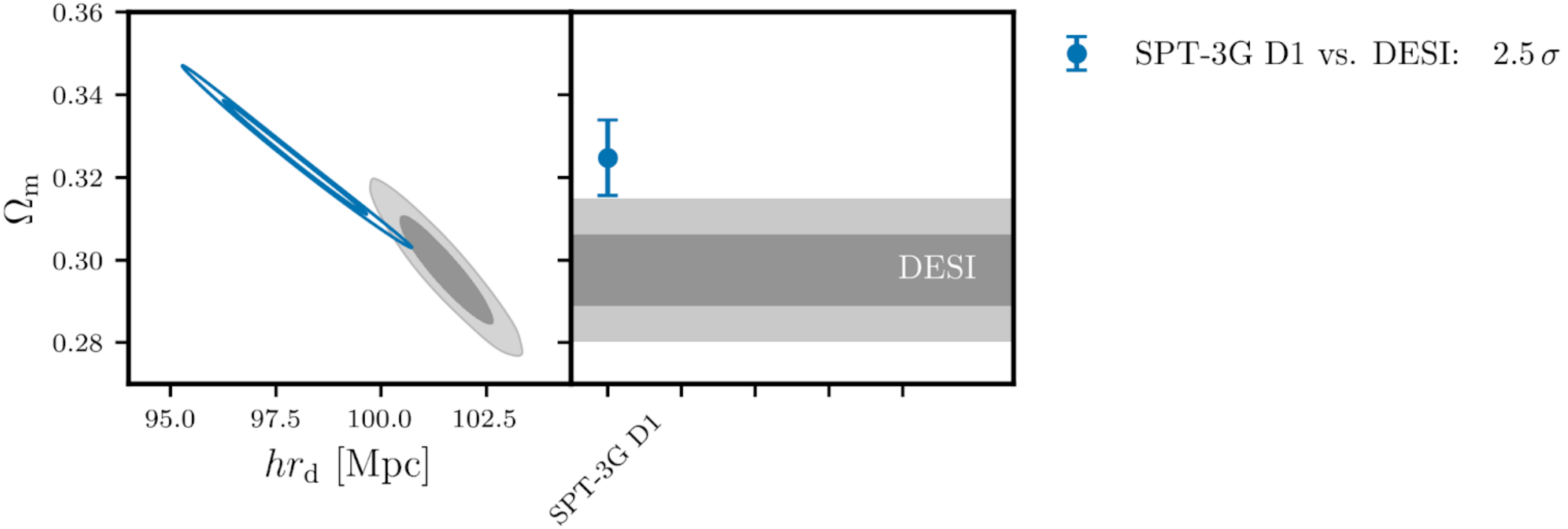
- **SPT-3G D1 alone, with only 4% of the sky, constrain σ_8 almost as well as Planck.**
- A variety of probes, spanning a wide range of epochs, are consistent with each other (including the latest KiDS-legacy cosmic shear results, KiDS collaboration, 2025).

$$\left.\begin{aligned}\sigma_8 &= 0.8137 \pm 0.0038,\\ \Omega_m &= 0.3166 \pm 0.0051\end{aligned}\right\}$$ **for CMB-SPA T&E&ϕ**



Evaluating the consistency of CMB and DESI DR2 data in ΛCDM

Growing discrepancy between CMB and BAO data.



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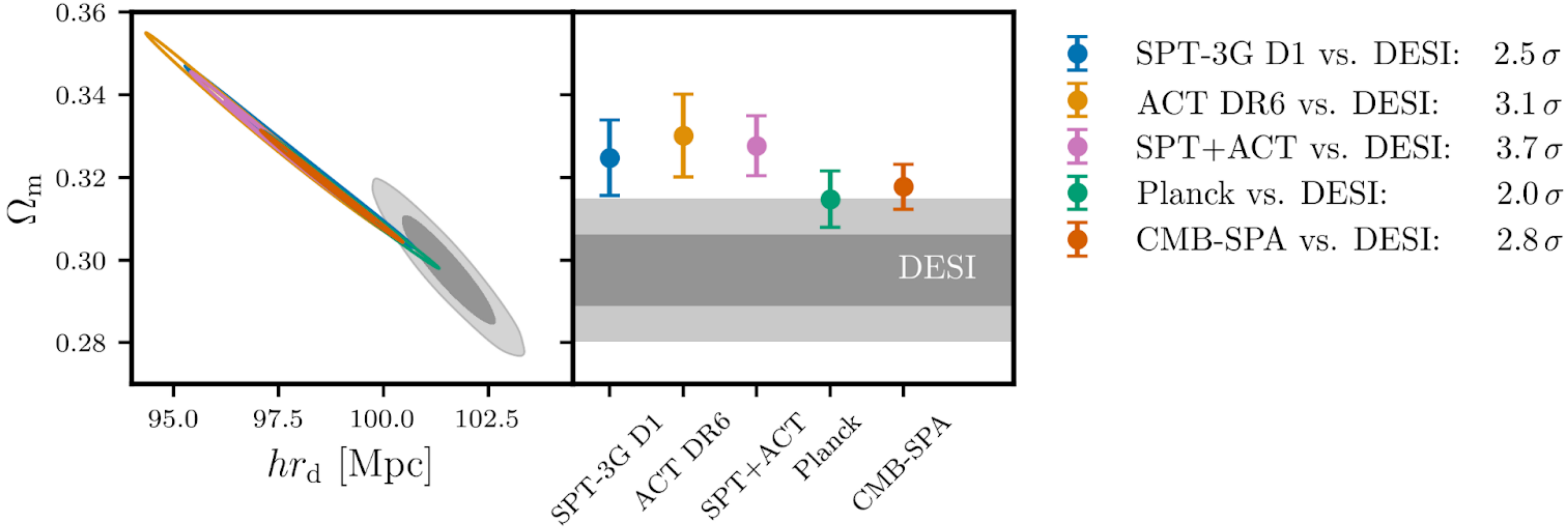
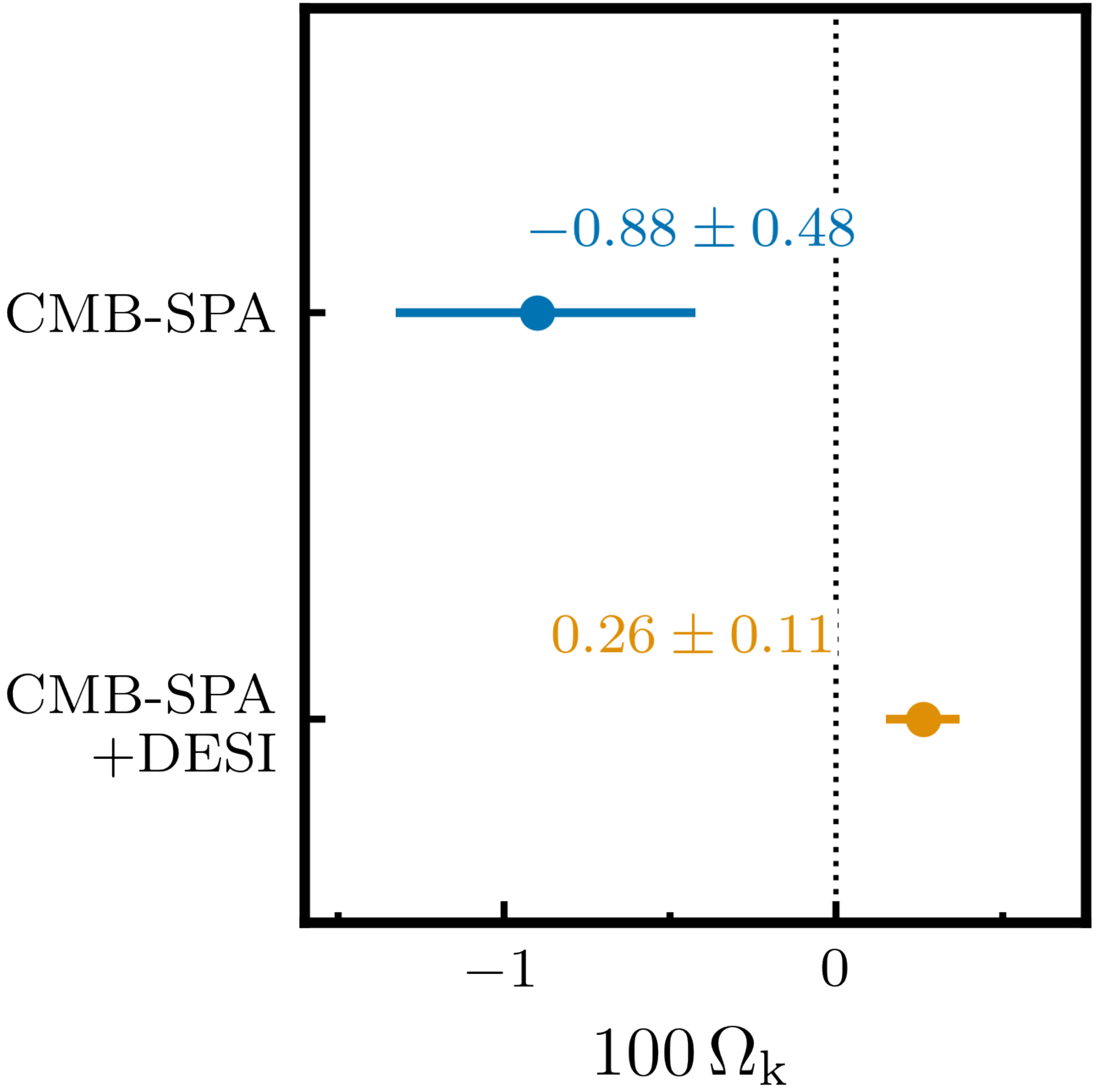


- Given borderline differences, joint analyses to be performed with caution

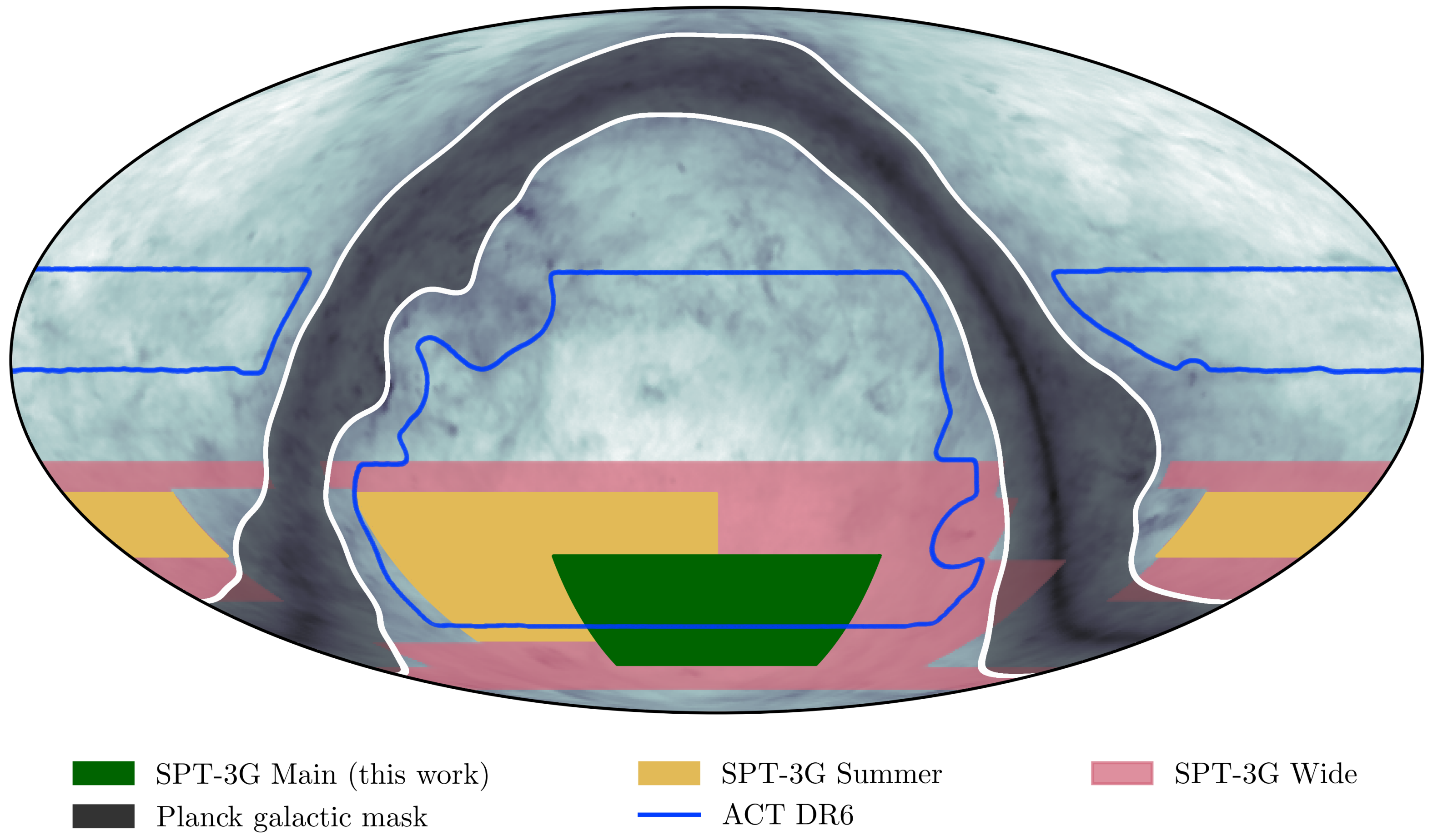
Differences between CMB and DESI can be accommodated by 2-3σ deviations from ΛCDM.

Model Class	Preference over ΛCDM
Rescaling of lensing in CMB	3.1σ
Light relics	<1.5σ
Modified recombination	2.0σ
Spatial curvature	**2.5σ**
Spatial curvature and electron mass	2.1σ
Neutrino mass	2.8σ
Dynamical dark energy	3.2σ

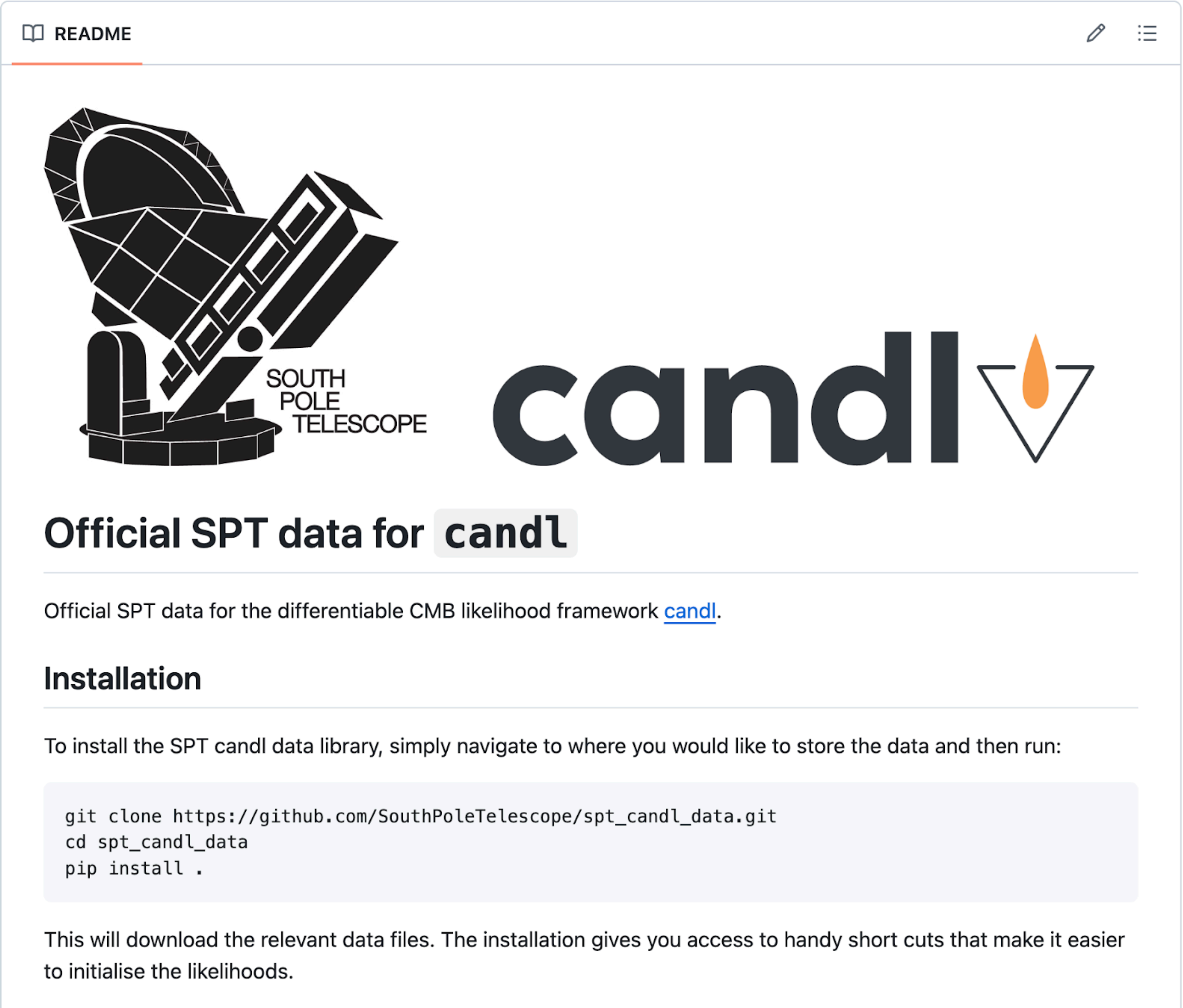


Conclusions

- **SPT-3G D1 is only the beginning !**
  More data, QE T+P lensing (see Yuuki's talk)



- **Please checkout paper, results, and likelihood at https://pole.uchicago.edu/public/data/camphuis25**
- Likelihood is public, please use it !



README

Official SPT data for `candl`

Official SPT data for the differentiable CMB likelihood framework candl.

Installation

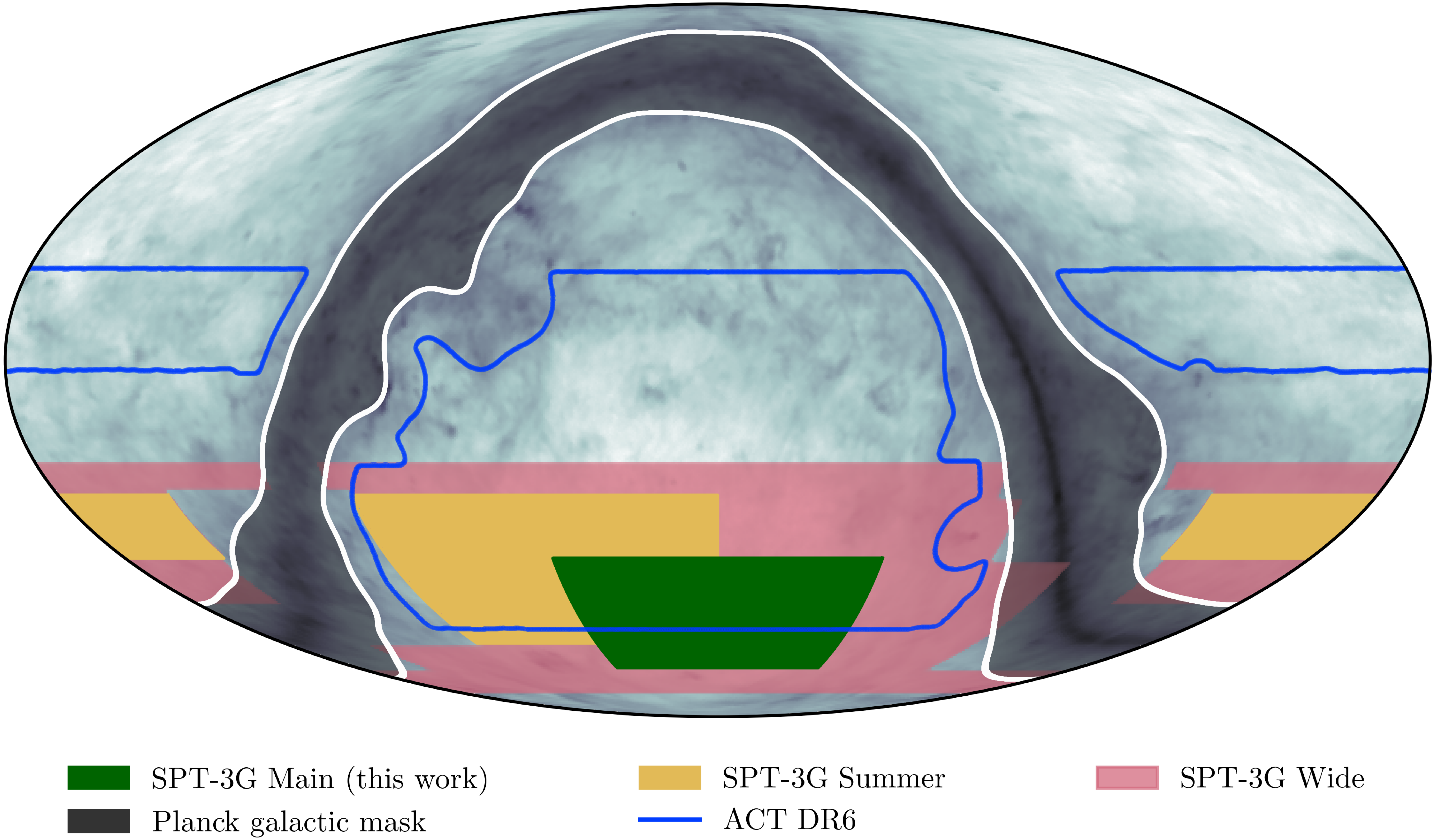
To install the SPT candl data library, simply navigate to where you would like to store the data and then run:

```
git clone https://github.com/SouthPoleTelescope/spt_candl_data.git
cd spt_candl_data
pip install .
```

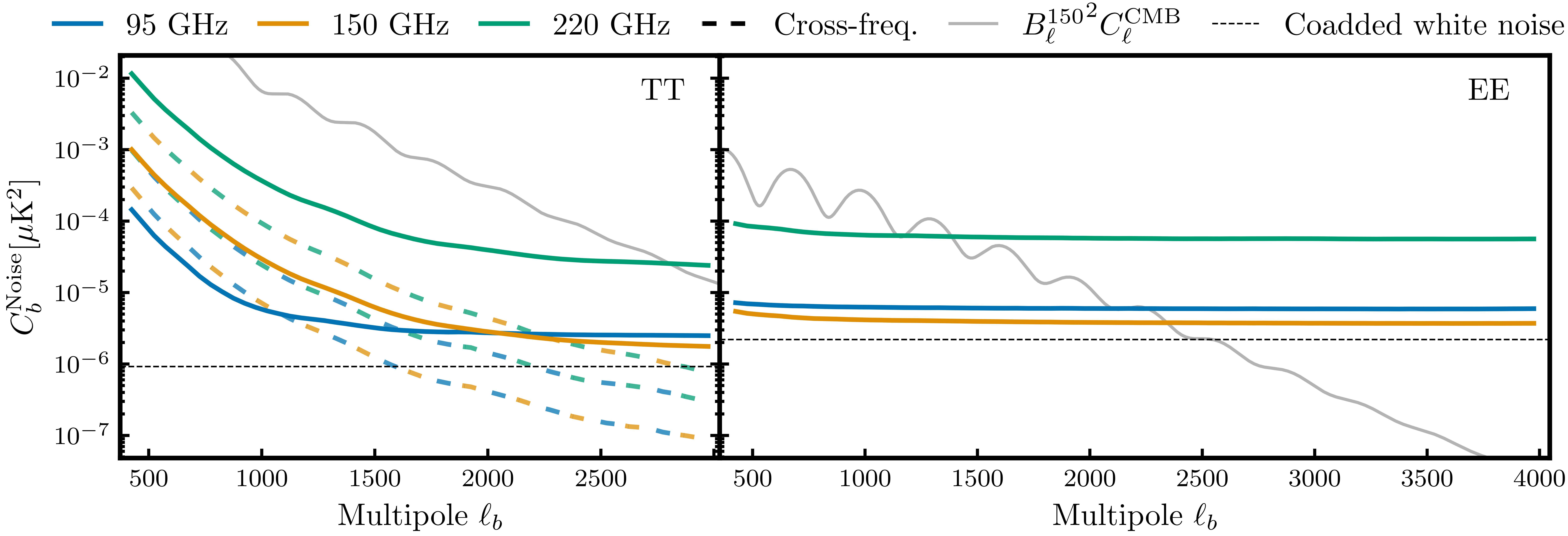
This will download the relevant data files. The installation gives you access to handy short cuts that make it easier to initialise the likelihoods.

Back-up

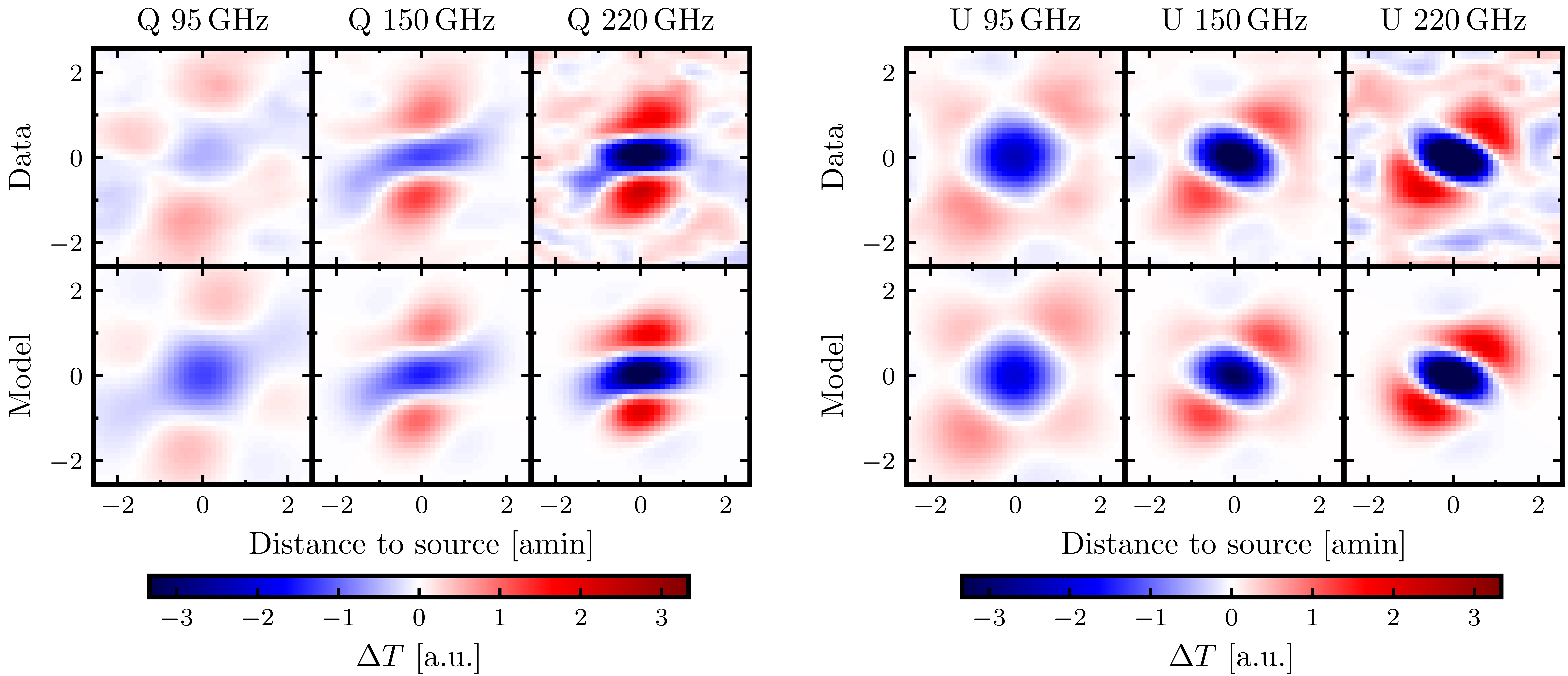
Pipeline


SPT-3G Main (this work)
SPT-3G Summer
SPT-3G Wide
Planck galactic mask
ACT DR6

Noise band powers



Quadrupolar beam leakage



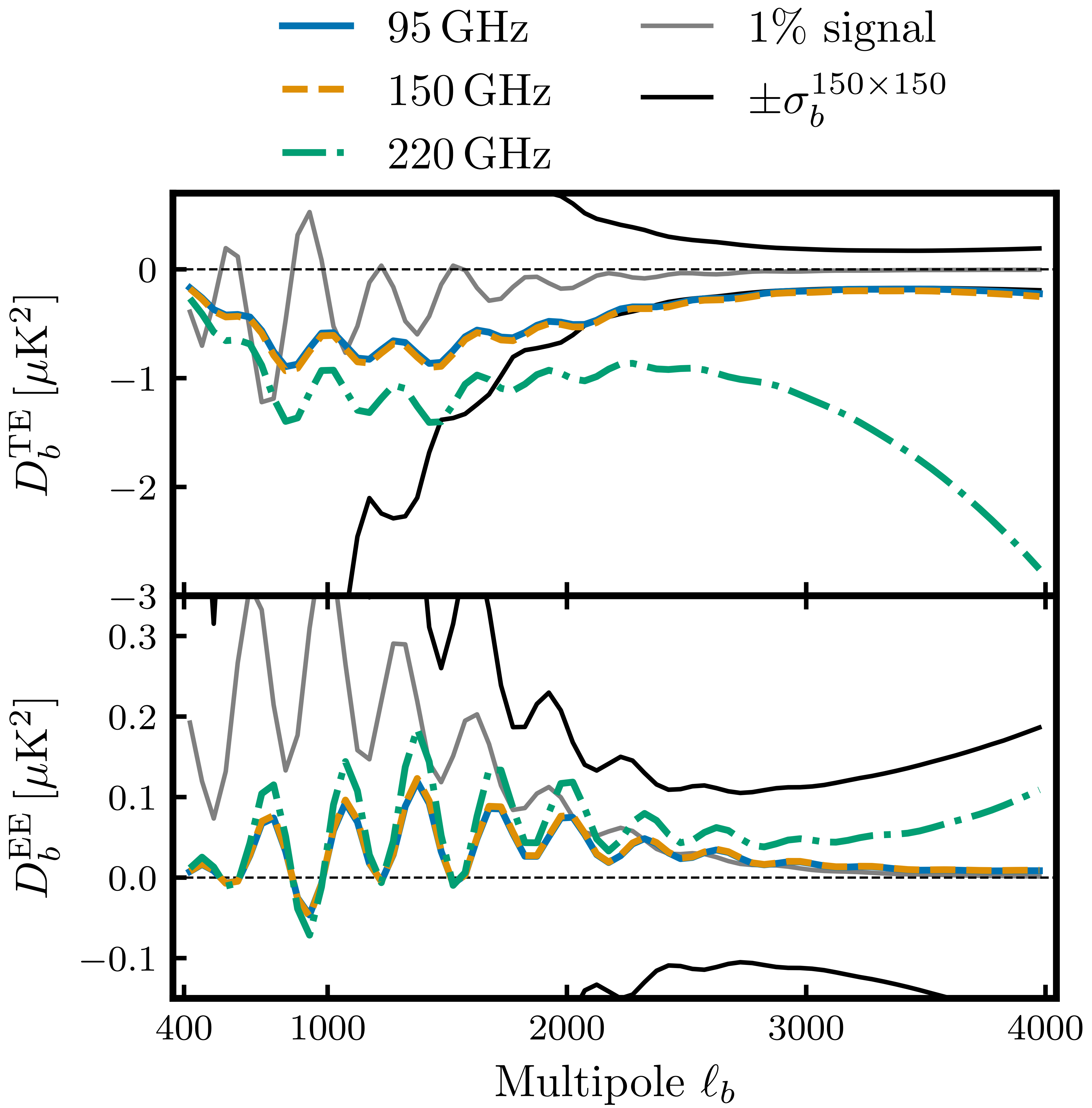
Quadrupolar beam leakage

$$B^{\mathrm{T}\to\mathrm{Q};\mu}(x,y) = B_{\sigma_\mu}(x,y)\sum_{m+n} a^{\mathrm{T}\to\mathrm{Q};\mu}_{m,n} H_{m,n}\left(\frac{x}{\sigma_\mu},\frac{y}{\sigma_\mu}\right),$$

$$B^{\mathrm{T}\to\mathrm{U};\mu}(x,y) = B_{\sigma_\mu}(x,y)\sum_{m+n} a^{\mathrm{T}\to\mathrm{U};\mu}_{m,n} H_{m,n}\left(\frac{x}{\sigma_\mu},\frac{y}{\sigma_\mu}\right)$$

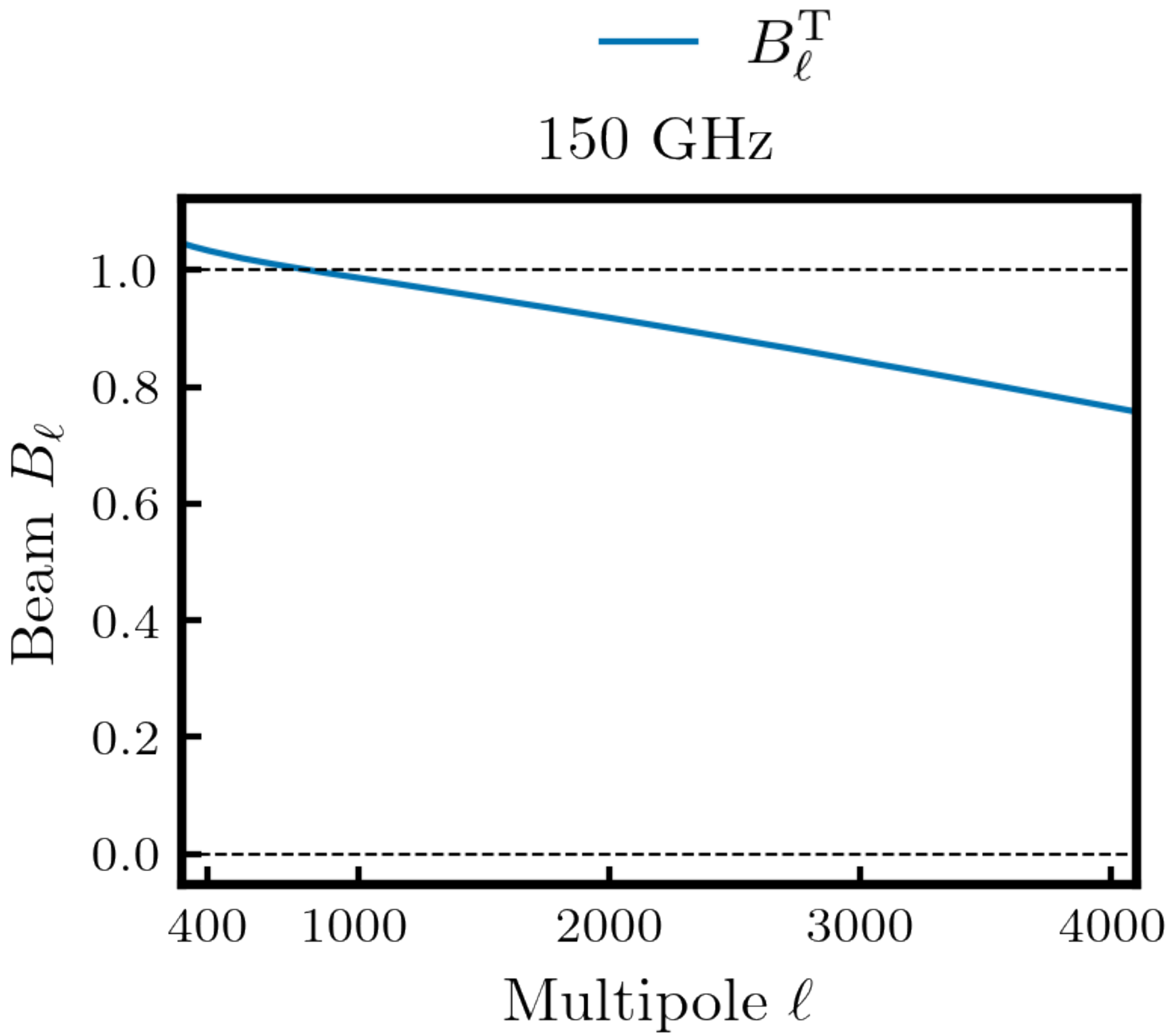
$$\epsilon_2^\mu = \left(a_{2,0}^{\mathrm{T}\to\mathrm{Q};\mu} - a_{0,2}^{\mathrm{T}\to\mathrm{Q};\mu} + a_{1,1}^{\mathrm{T}\to\mathrm{U};\mu}\right)/2.$$

$$\begin{aligned} C_\ell^{\mathrm{TE};\mu\nu;\mathrm{leak}} &= \epsilon_2^\nu \sigma_\nu^2 \ell^2 C_\ell^{\mathrm{TT};\mu\nu}, \\ C_\ell^{\mathrm{EE};\mu\nu;\mathrm{leak}} &= \epsilon_2^\mu \sigma_\mu^2 \ell^2 C_\ell^{\mathrm{TE};\mu\nu} + \epsilon_2^\nu \sigma_\nu^2 \ell^2 C_\ell^{\mathrm{ET};\mu\nu} \\ &\quad + \epsilon_2^\mu \epsilon_2^\nu \sigma_\mu^2 \sigma_\nu^2 \ell^4 C_\ell^{\mathrm{TT};\mu\nu}, \end{aligned}$$



Beams

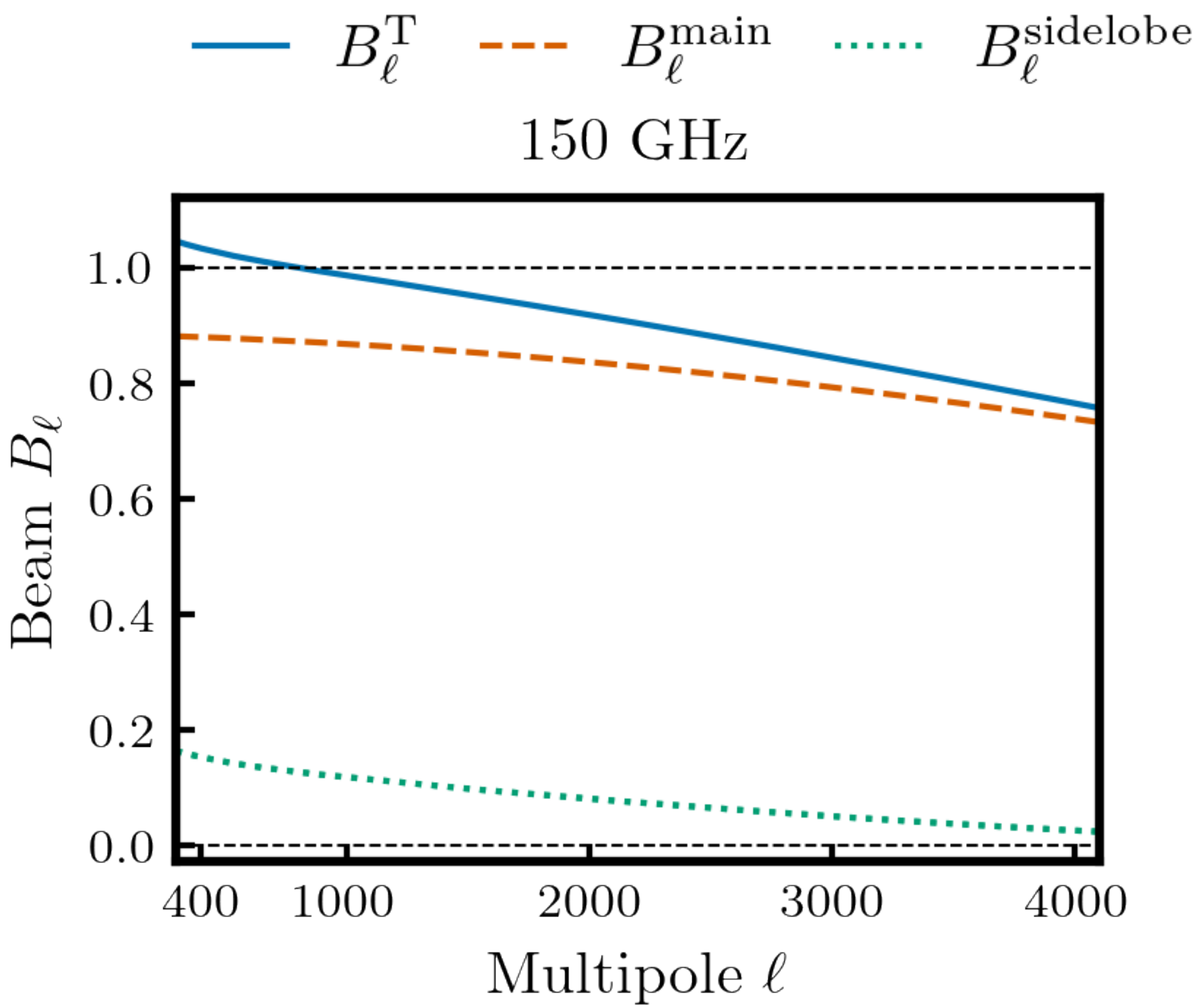
Temperature beams



Beams

$$B_\ell^{\mathrm{T}} \equiv B_\ell^{\mathrm{main}} + B_\ell^{\mathrm{sidelobe}}$$

Temperature beams



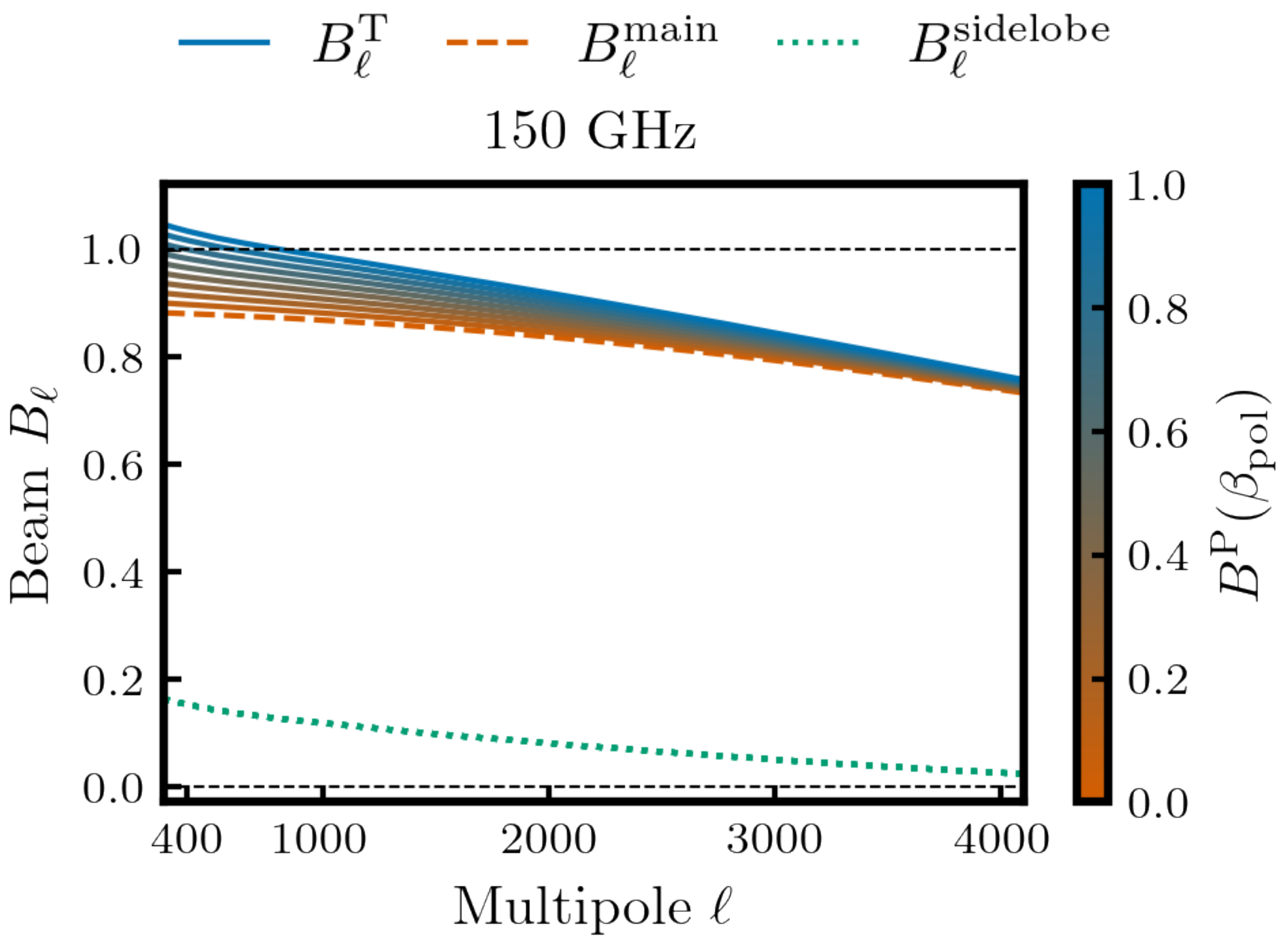
Beams

Polarized beams

- Sidelobe polarization efficiency can be lower than the main beam polarization efficiency

$$B_\ell^{\mathrm{T}} \equiv B_\ell^{\mathrm{main}} + B_\ell^{\mathrm{sidelobe}}$$

$$B_\ell^{\mathrm{P}}(\beta_{\mathrm{pol}}) \equiv B_\ell^{\mathrm{main}} + \beta_{\mathrm{pol}} B_\ell^{\mathrm{sidelobe}}$$

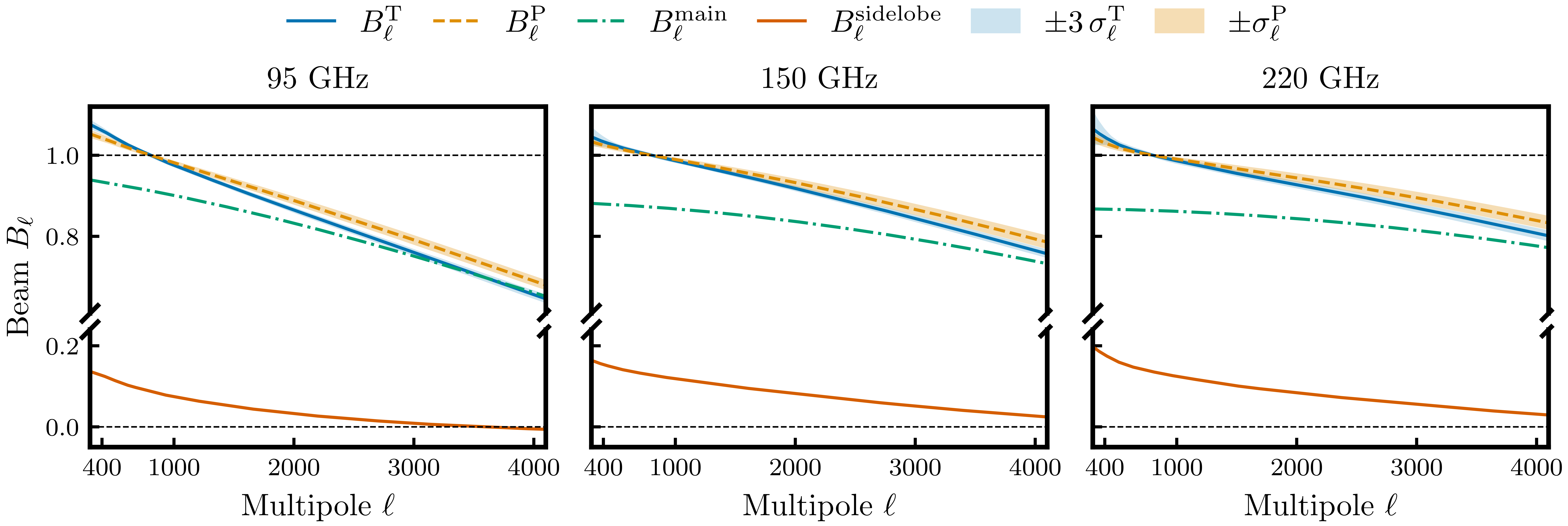


Beams

$$B_\ell^{\mathrm{T}} \equiv B_\ell^{\mathrm{main}} + B_\ell^{\mathrm{sidelobe}}$$

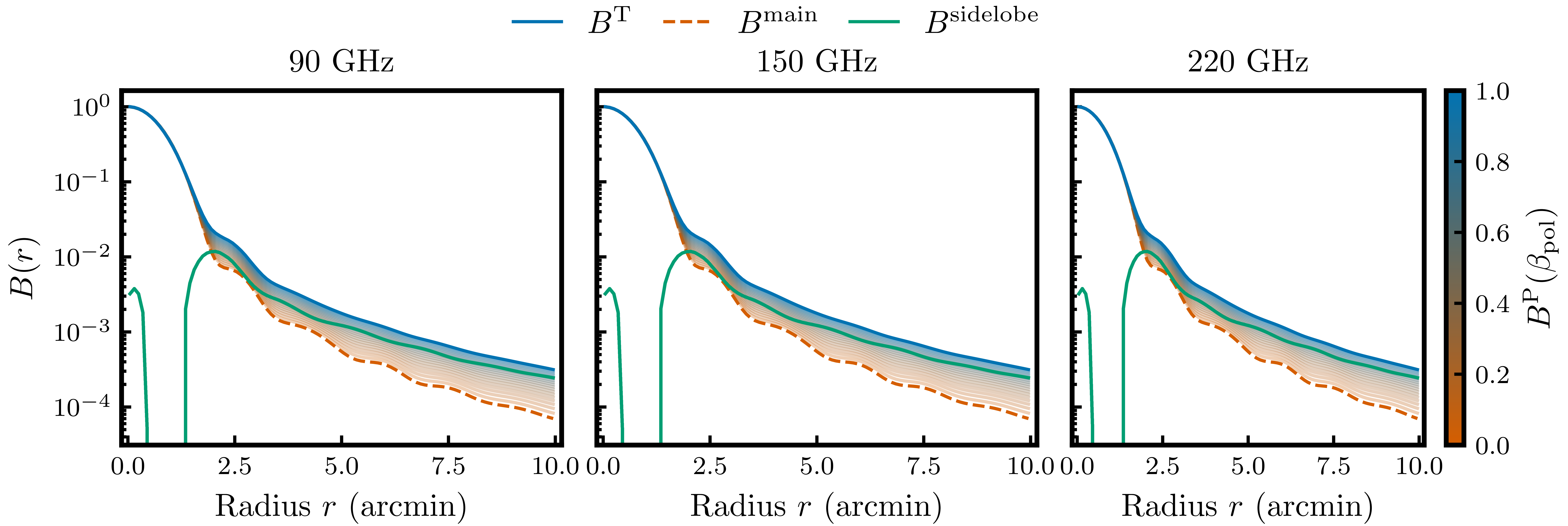
$$B_\ell^{\mathrm{P}}(\beta_{\mathrm{pol}}) \equiv B_\ell^{\mathrm{main}} + \beta_{\mathrm{pol}} B_\ell^{\mathrm{sidelobe}}$$

- Sidelobe polarization efficiency can be lower than the main beam polarization efficiency



Real space beams

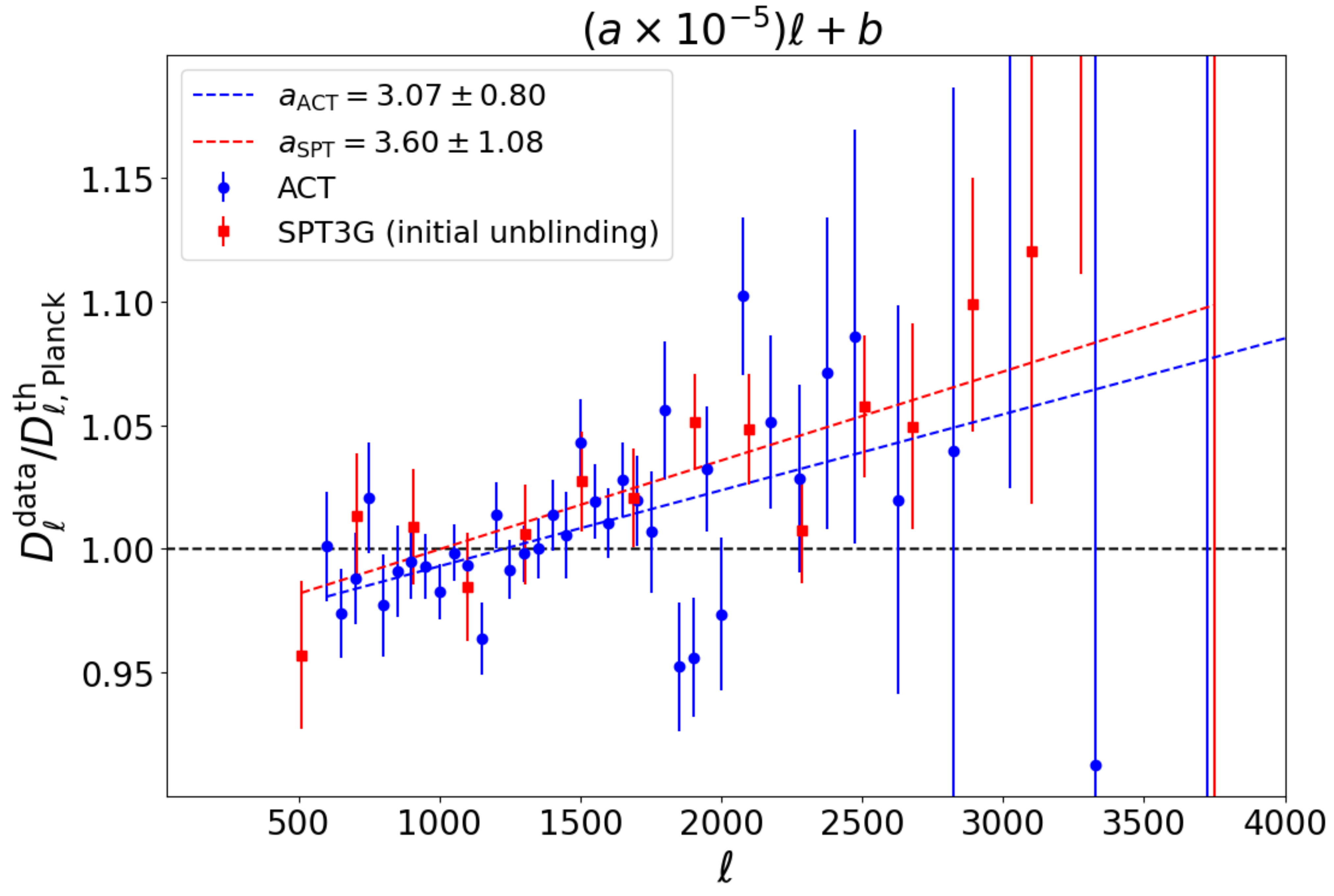
- Sidelobe polarization efficiency can be lower than the main beam polarization efficiency



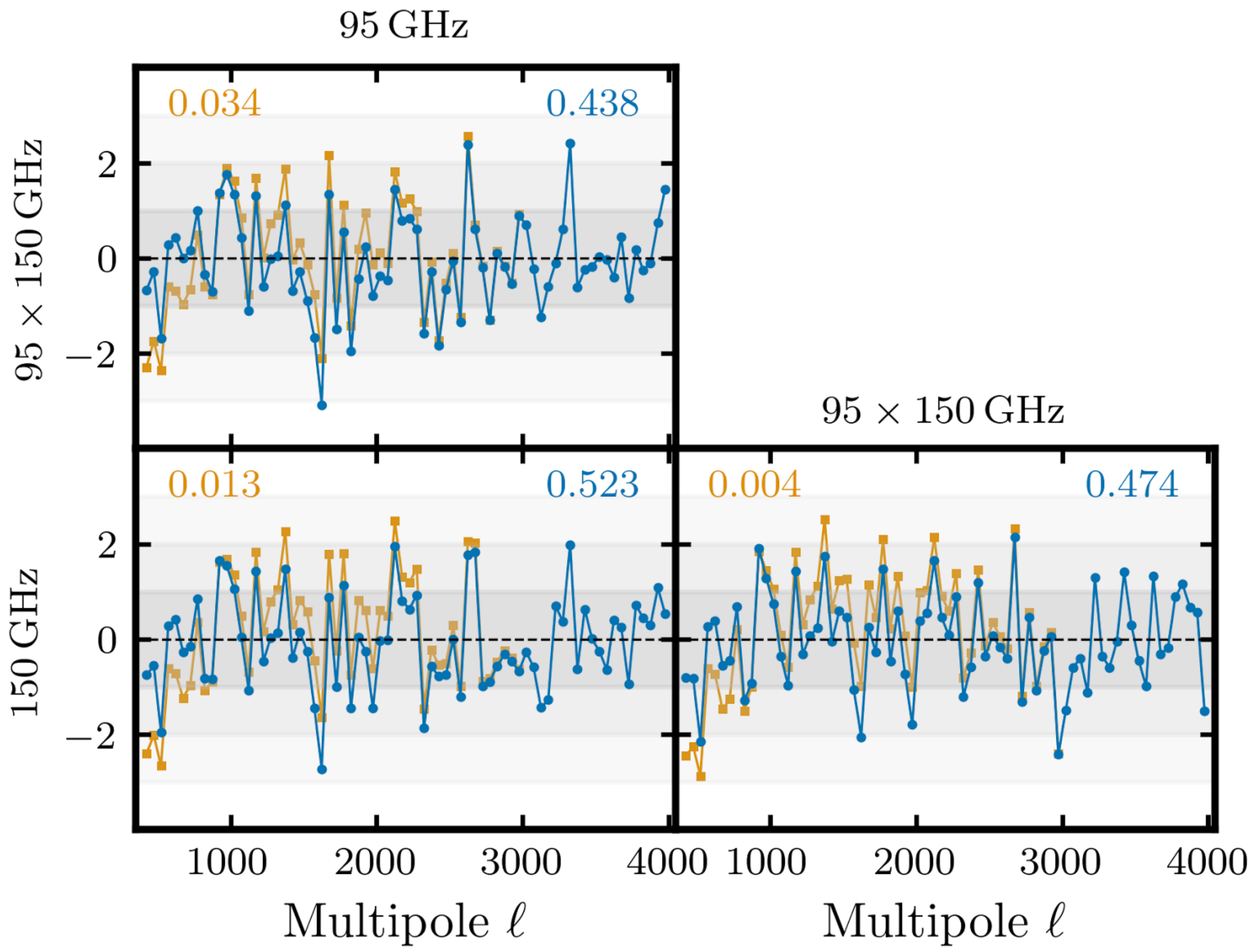
In this plot it appears we are correcting the small scales.

The polarized beams model first targets the large scales.

Credit: T. Louis

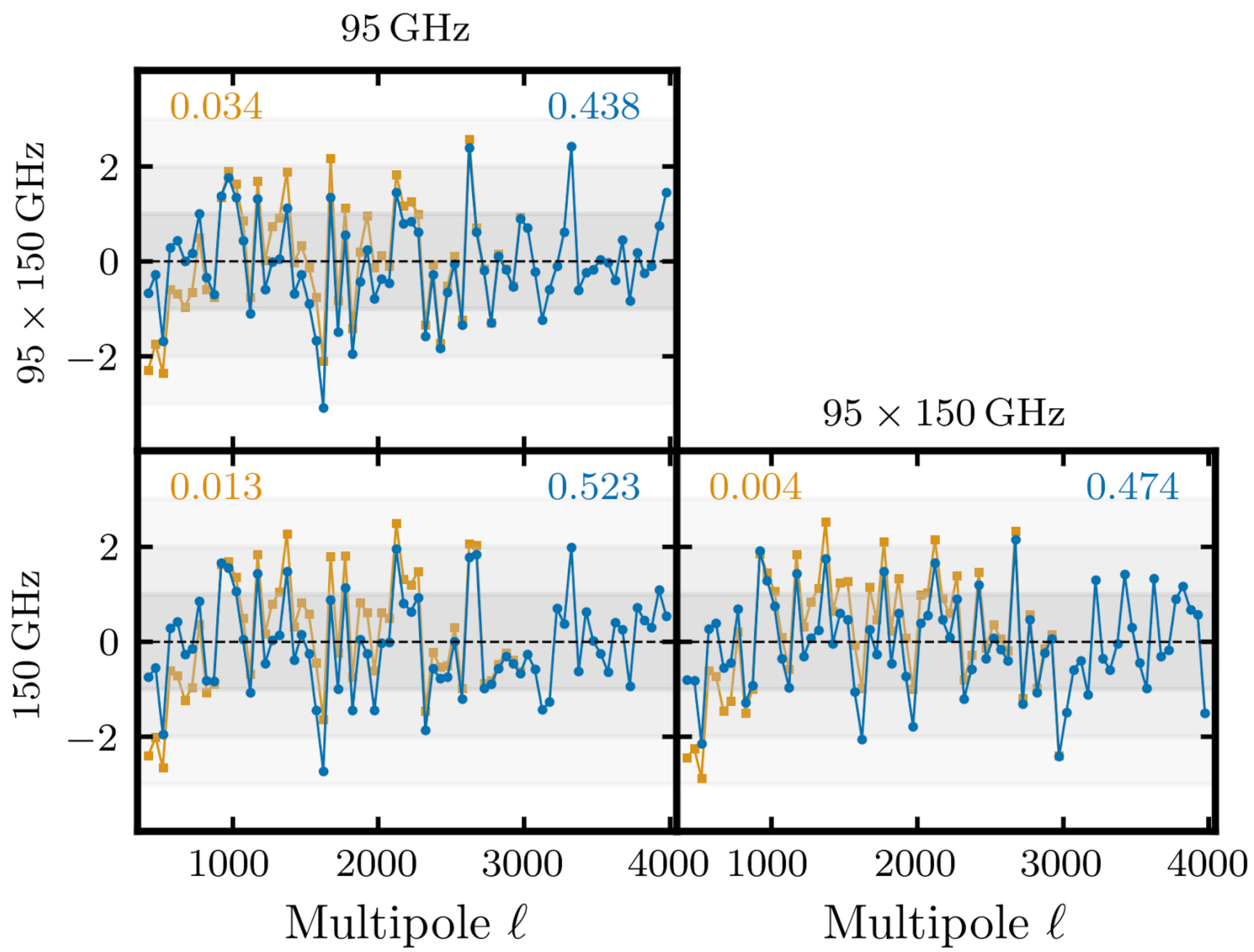


EE null tests (SPT-3G D1)

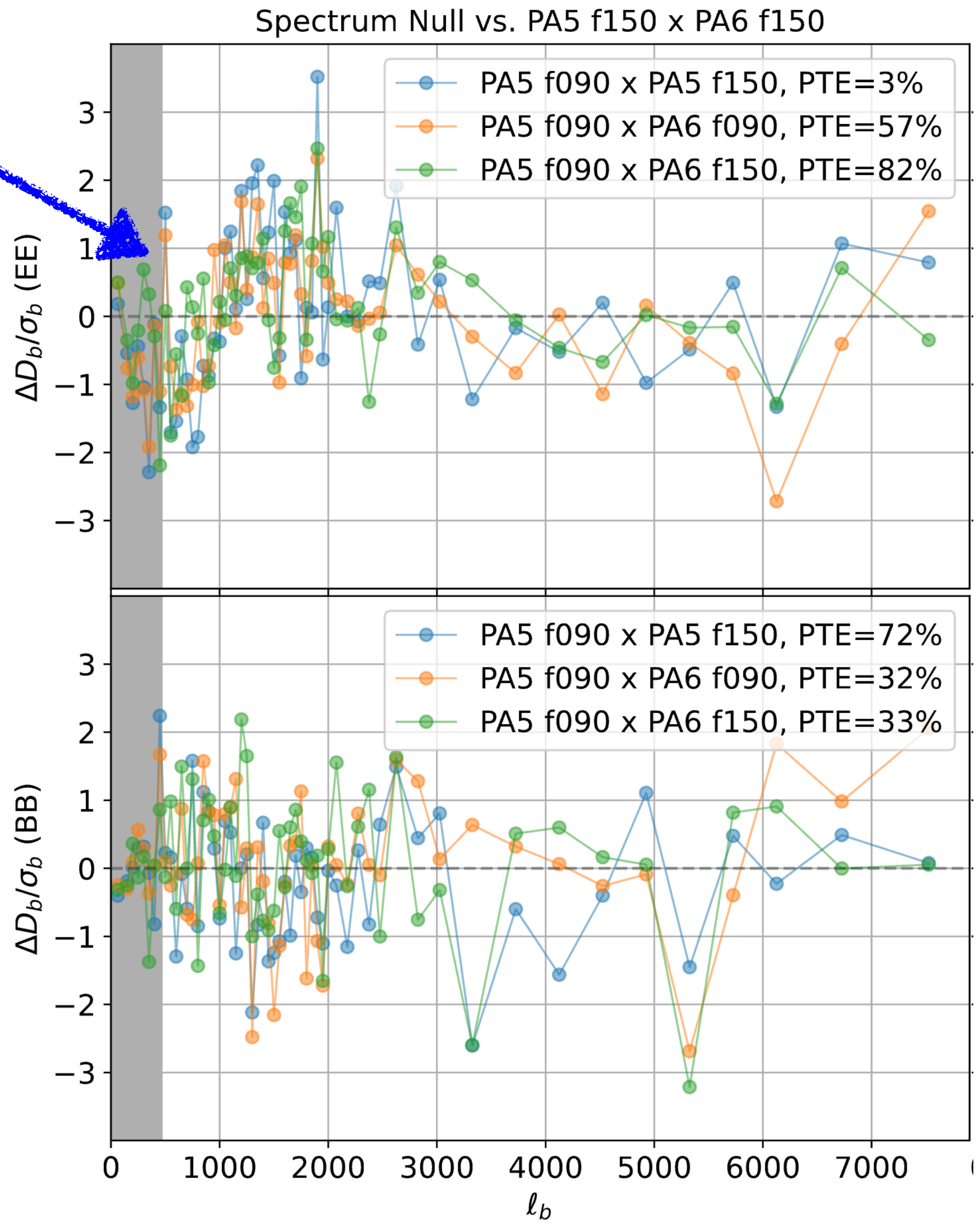


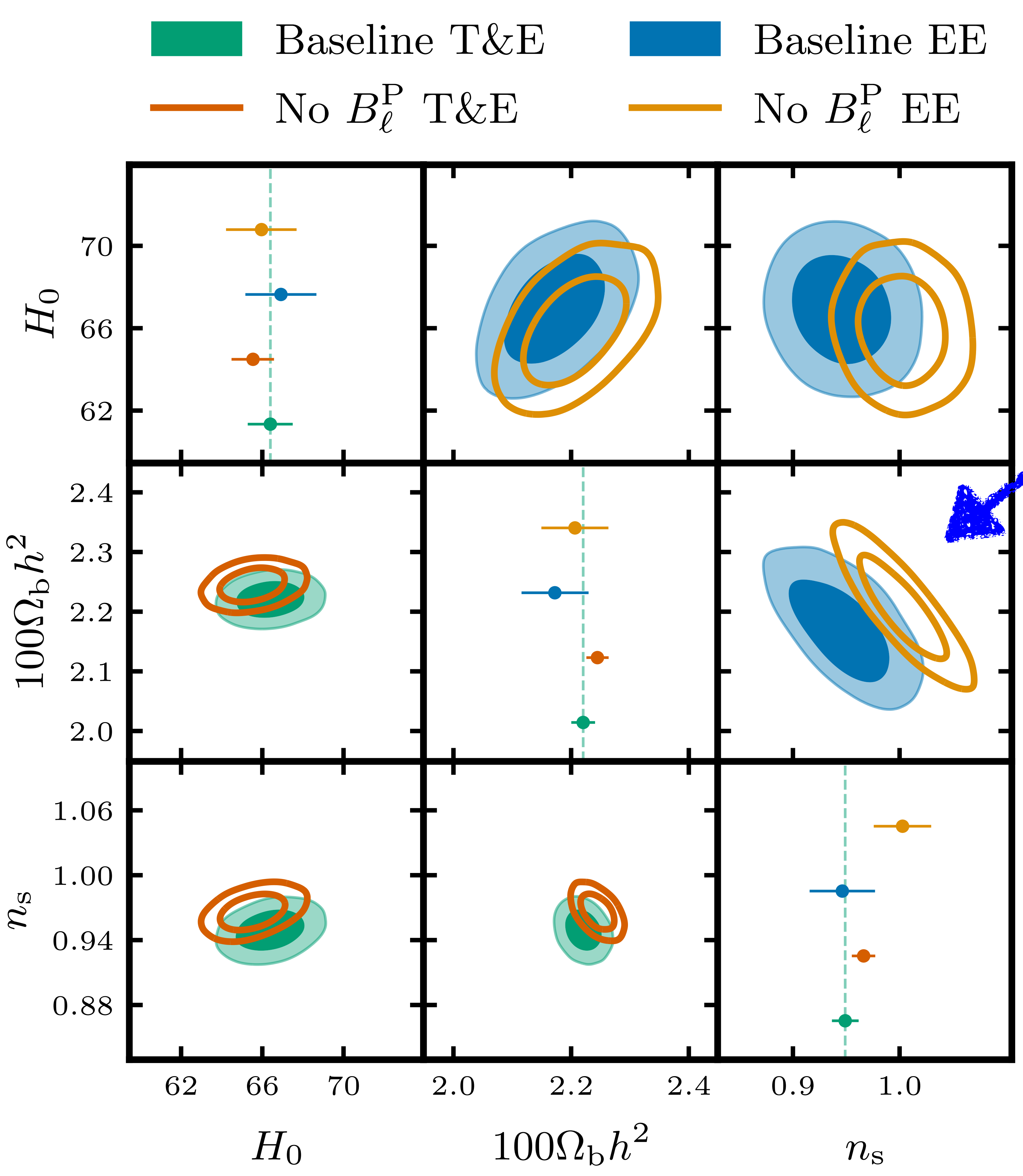
Unknown systematic effect, which led to additional ell cuts in ACT DR6

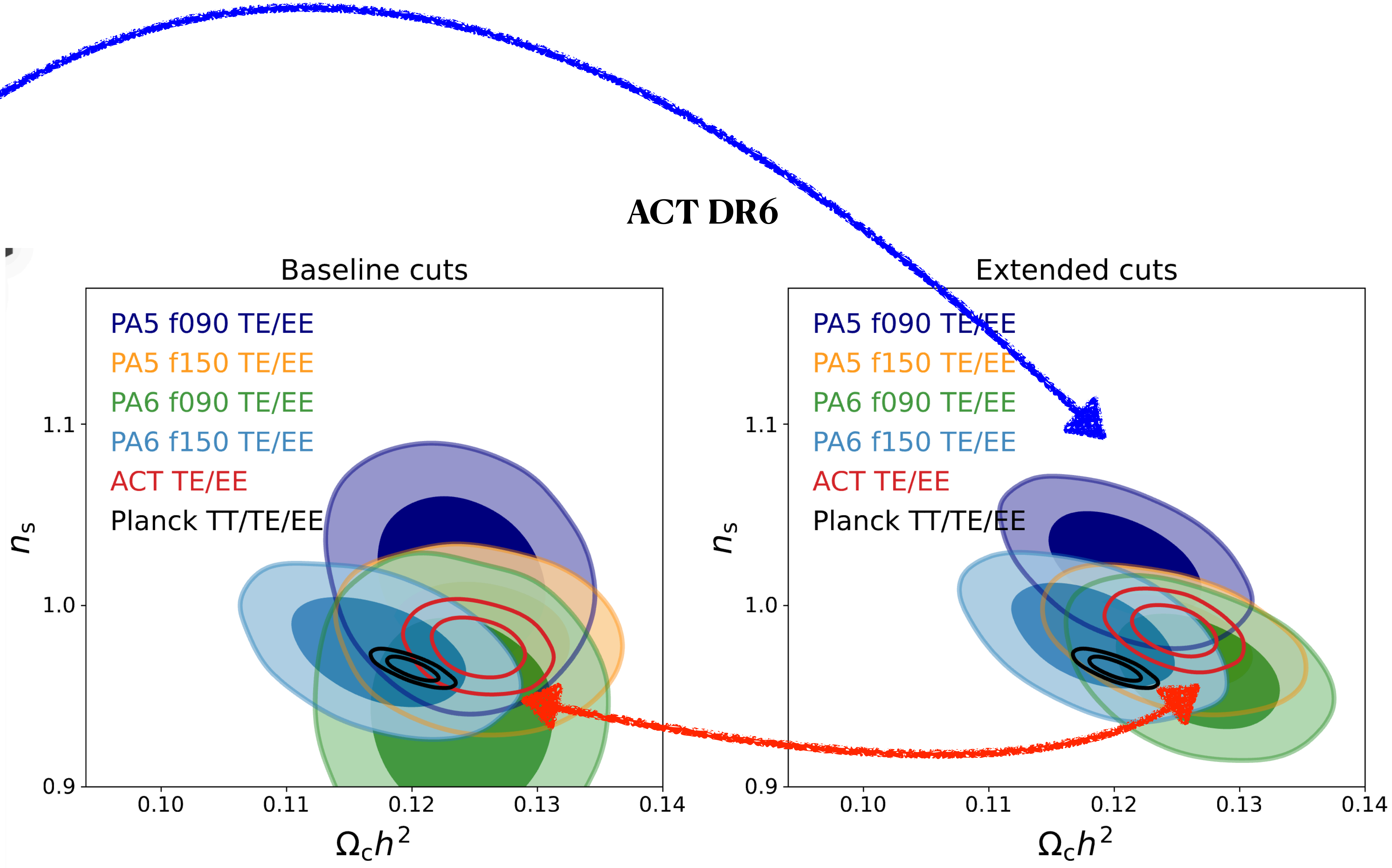
EE null tests (SPT-3G D1)



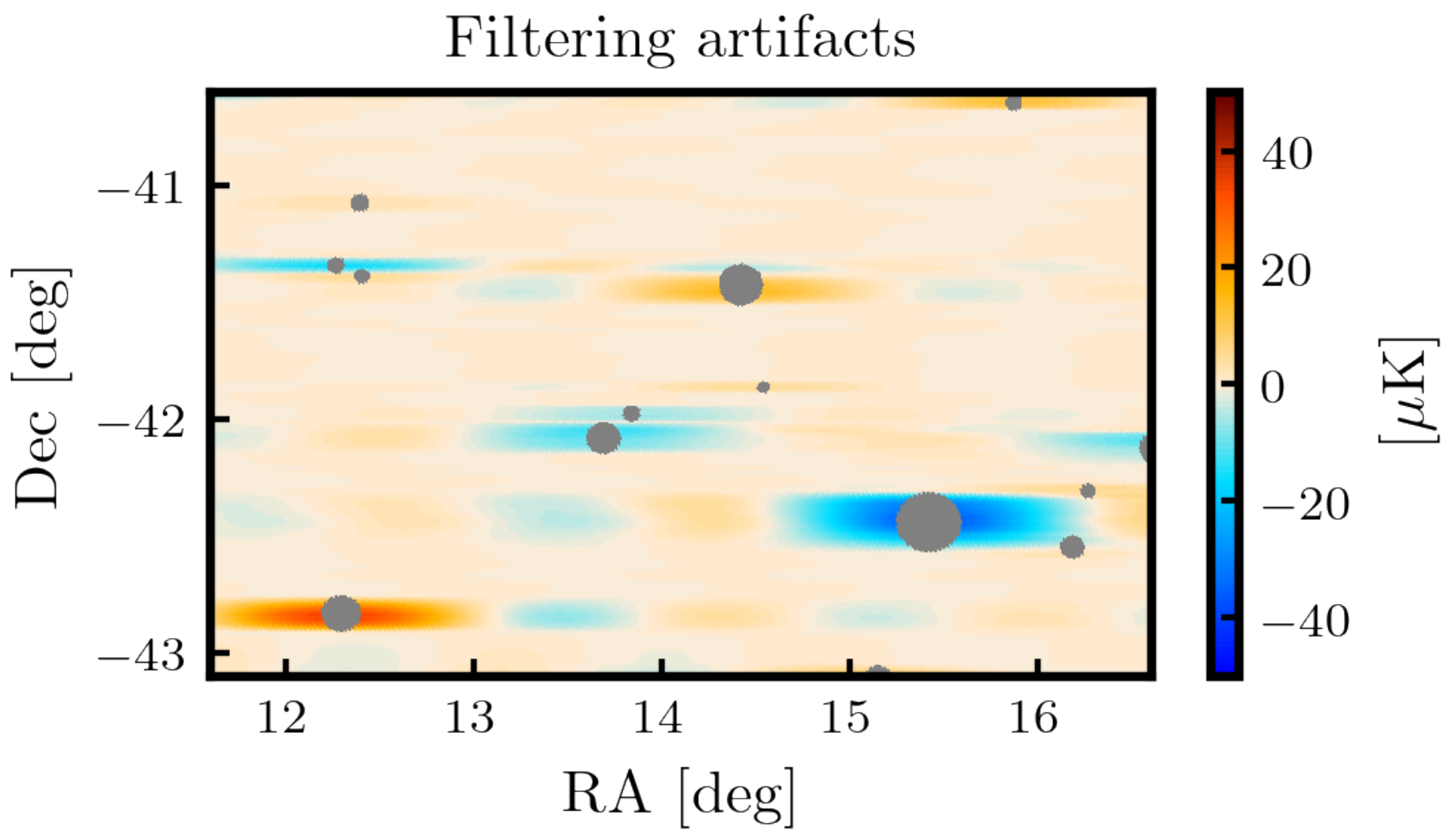
EE null tests (ACT DR6, Louis et al. 2025)

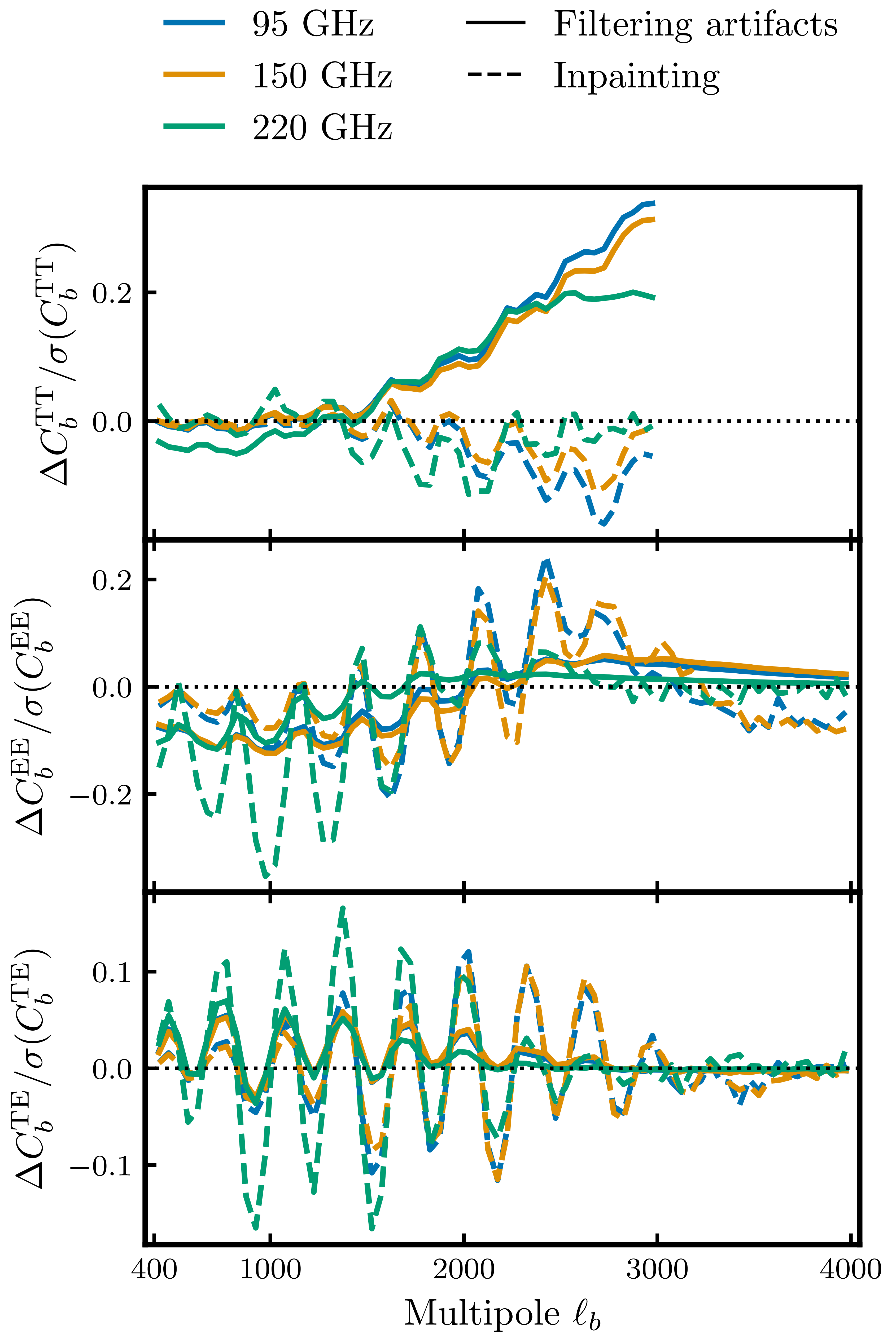



Baseline T&E
Baseline EE
No B_ℓ^P T&E
No B_ℓ^P EE
H_0
$100\Omega_b h^2$
n_s


ACT DR6
Baseline cuts
Extended cuts
PA5 f090 TE/EE
PA5 f150 TE/EE
PA6 f090 TE/EE
PA6 f150 TE/EE
ACT TE/EE
Planck TT/TE/EE
n_s
$\Omega_c h^2$

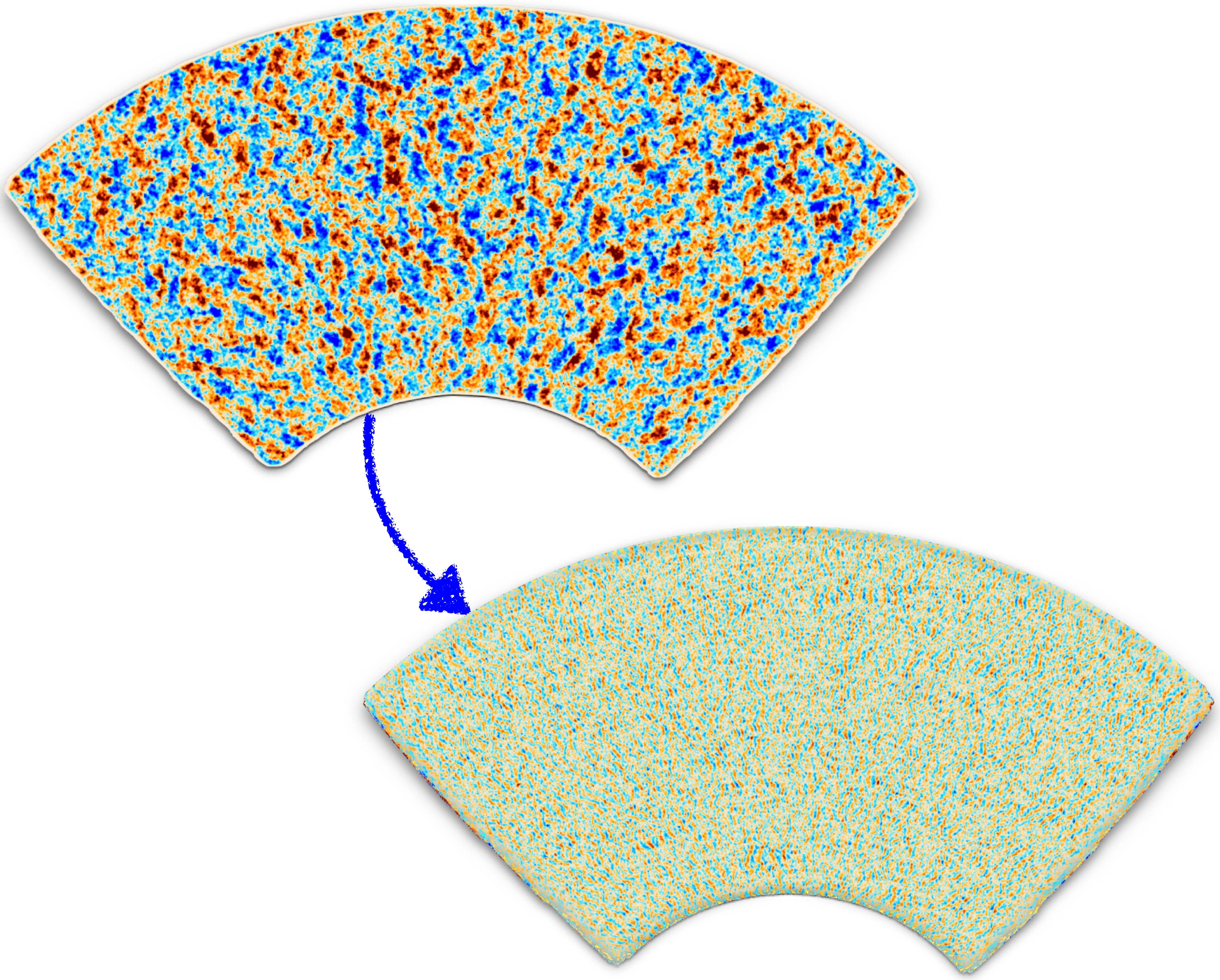
Filtering artifacts

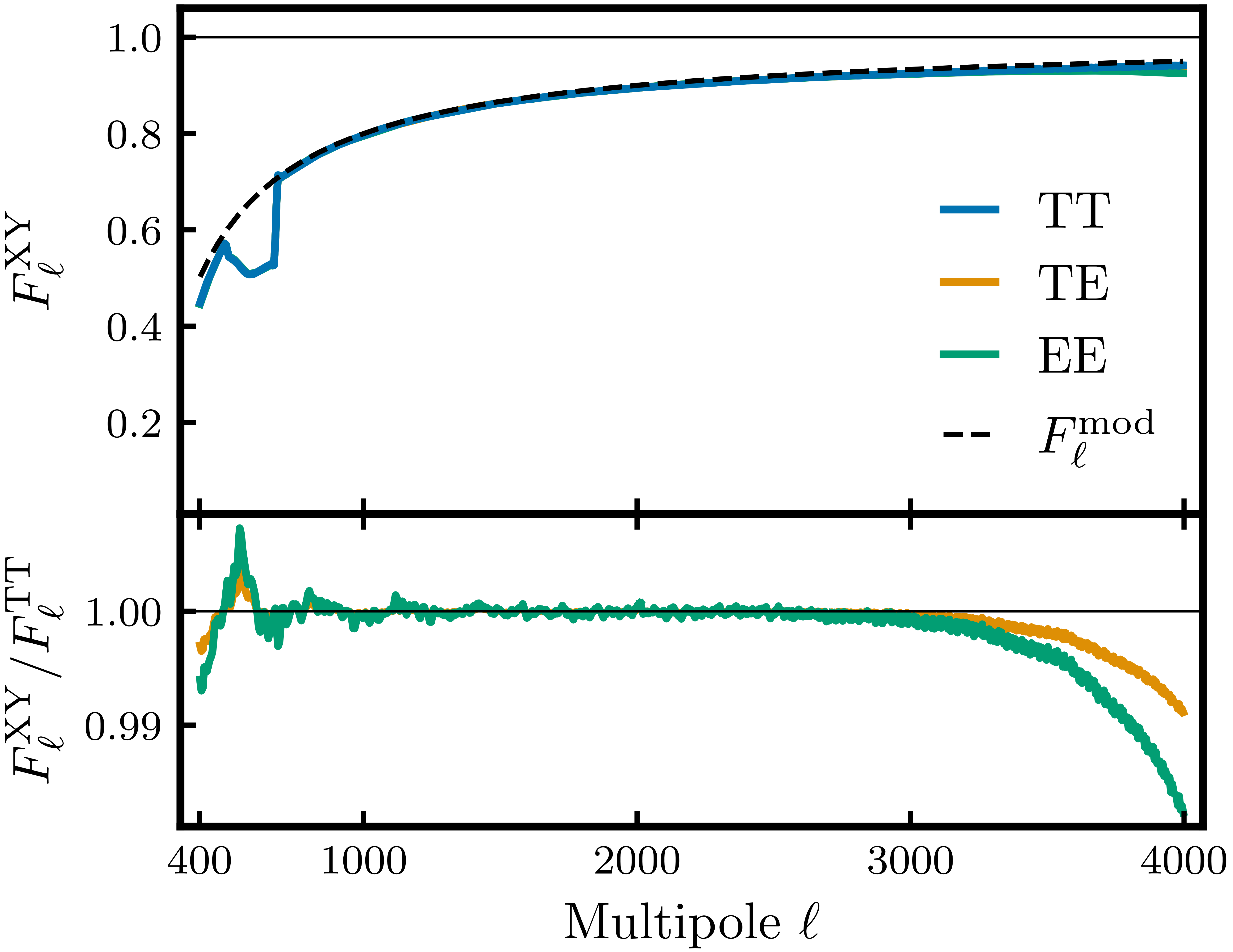




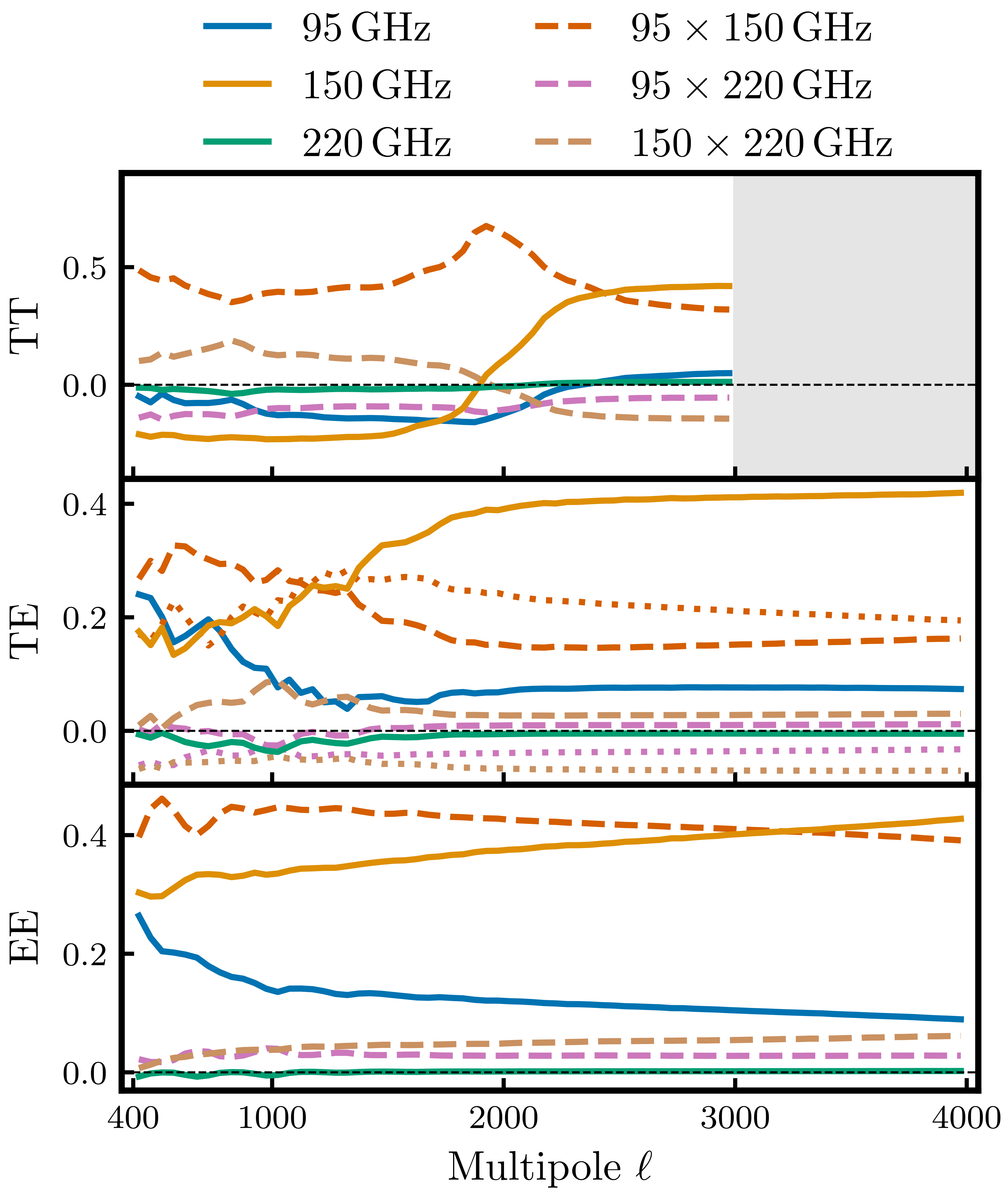
Transfer function

Measured on 2000 QuickMock fast simulations

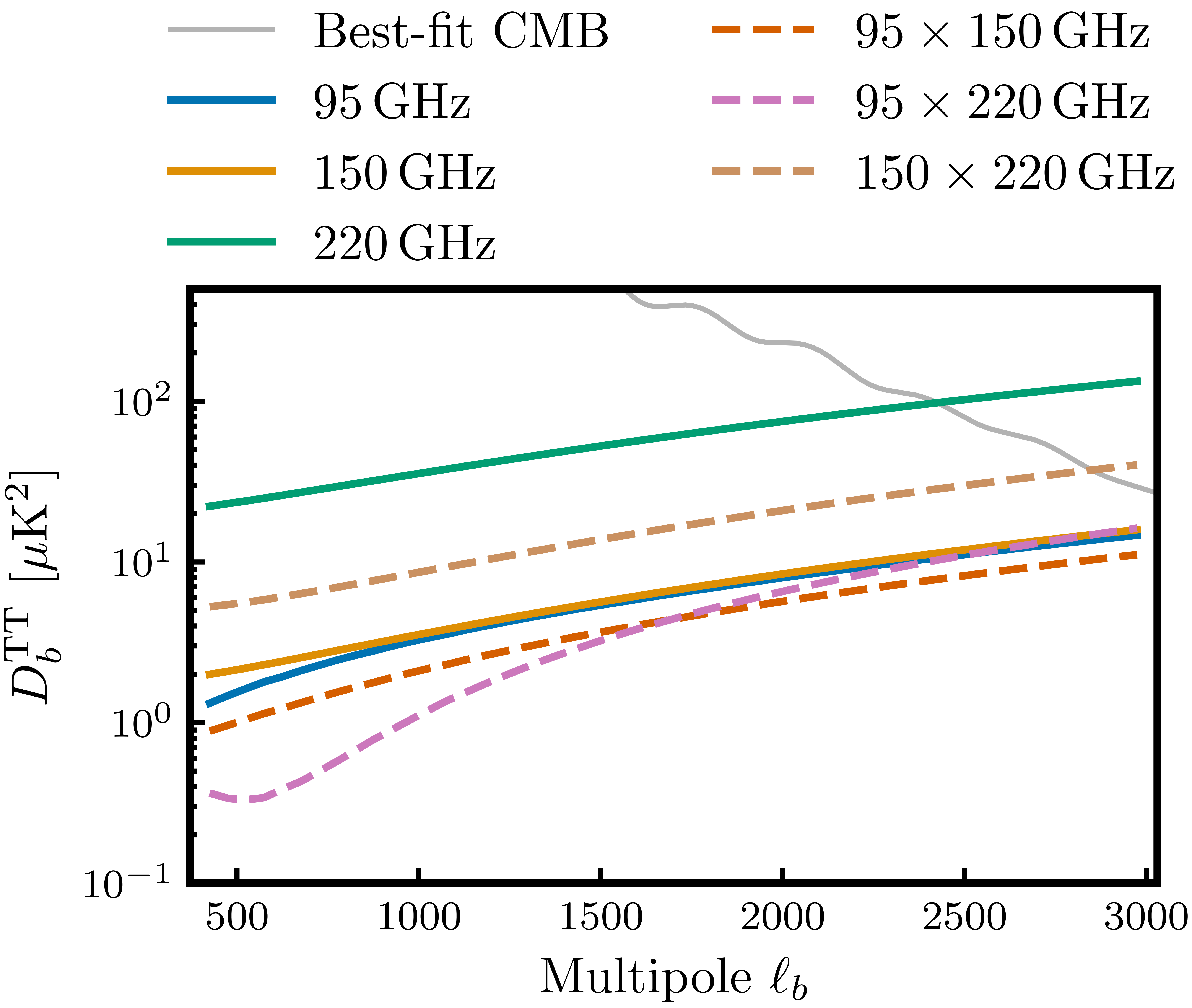


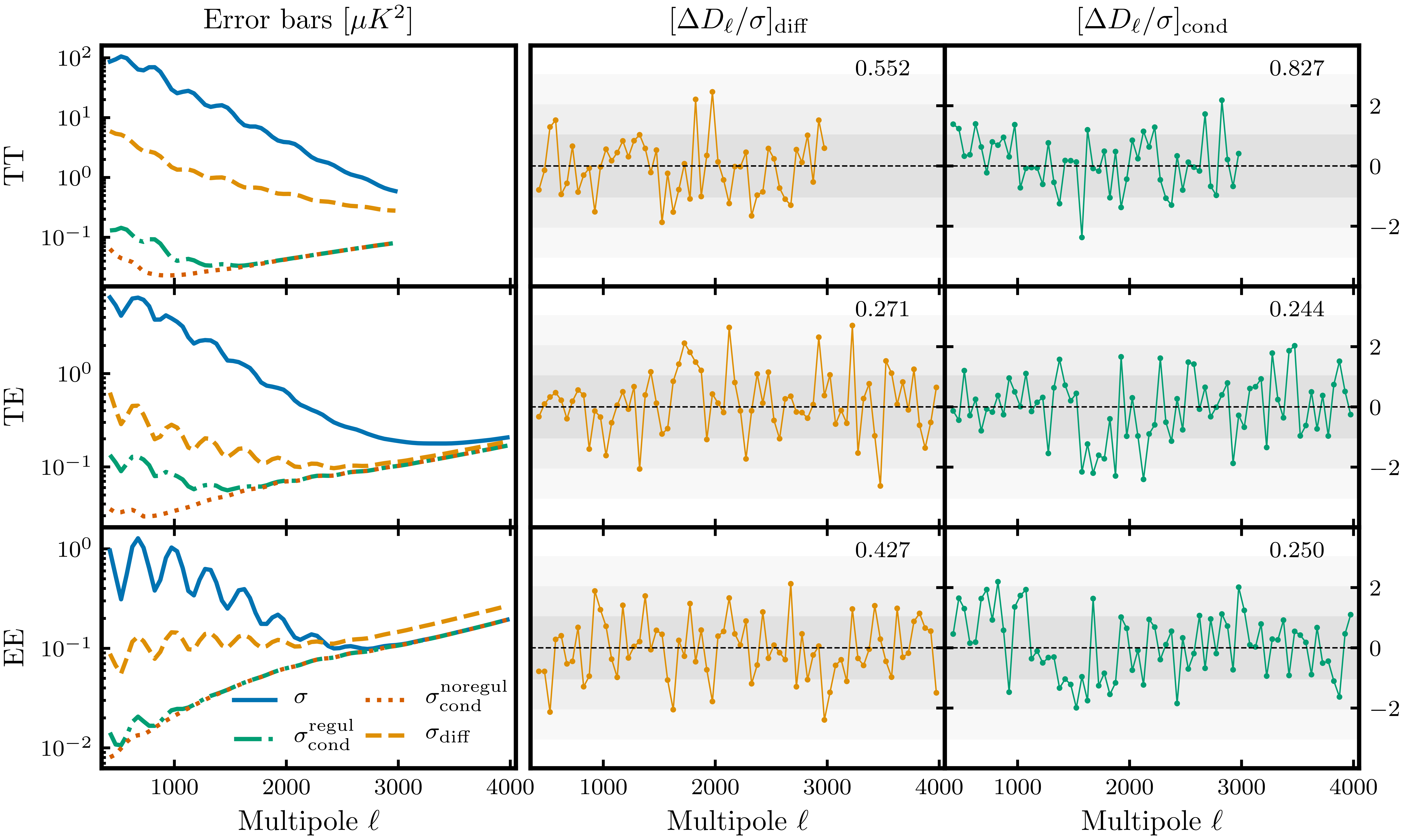


Mixing matrix



Foregrounds




Error bars [μK^2]
$[\Delta D_\ell/\sigma]_{\rm diff}$
$[\Delta D_\ell/\sigma]_{\rm cond}$
TT
TE
EE
0.552
0.827
0.271
0.244
0.427
0.250
σ
$\sigma_{\rm cond}^{\rm regul}$
$\sigma_{\rm cond}^{\rm noregul}$
$\sigma_{\rm diff}$
Multipole ℓ
Multipole ℓ
Multipole ℓ

Likelihood

https://github.com/Lbalkenhol/candl

$$-\ln \mathcal{L}(\hat{C}|C^{\mathrm{model}}(\theta)) \propto \frac{1}{2}\left[\hat{C}_b - C_b^{\mathrm{model}}(\theta)\right] \Sigma^{-1}_{bb'} \left[\hat{C}_{b'} - C_{b'}^{\mathrm{model}}(\theta)\right]$$

Foreground and nuisance model improved over SPT-3G 2018

CLASS

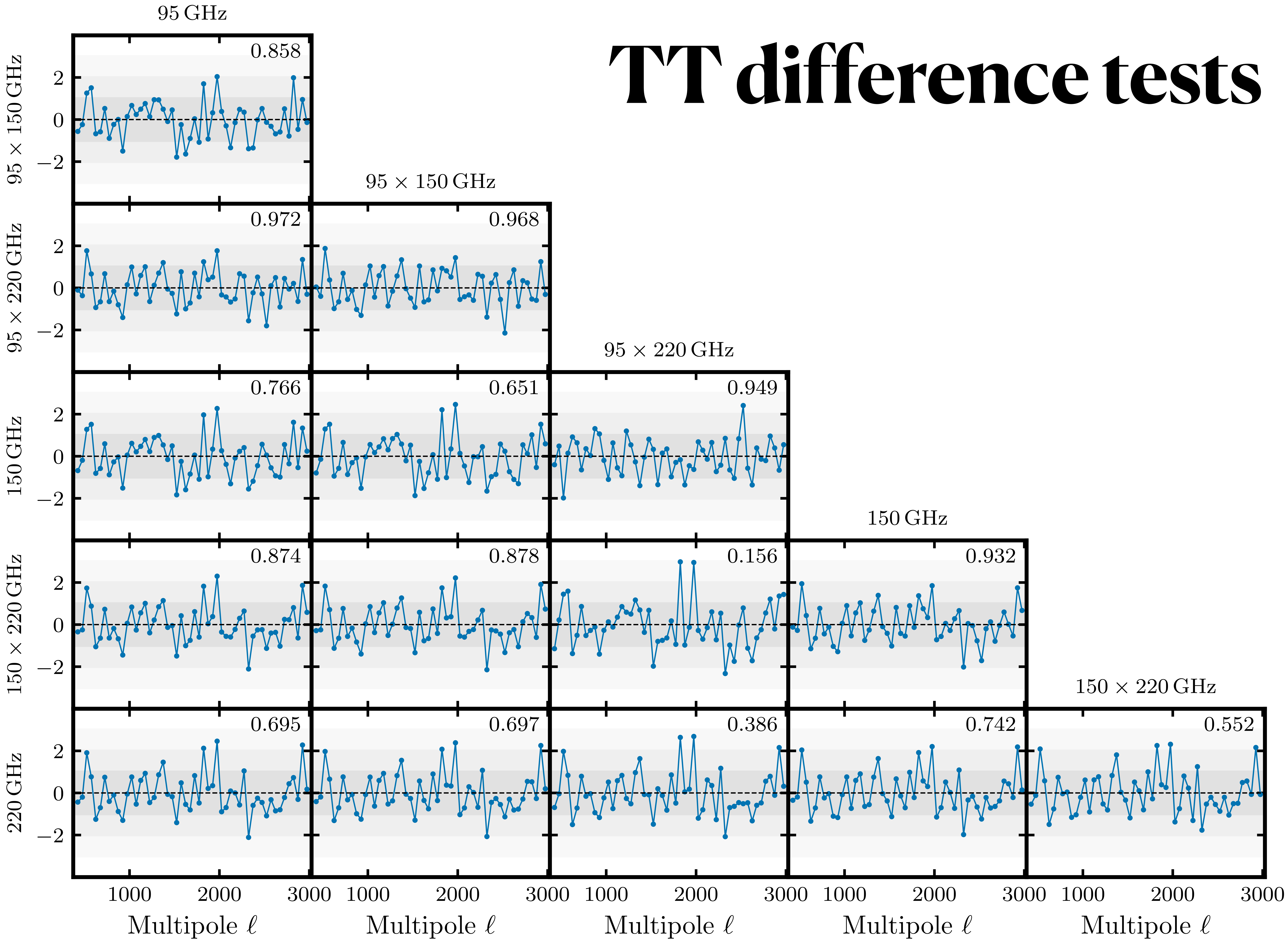
CAMB

http://ascl.net/1102.026
http://doi.org/10.1088/1475-7516/2011/07/034
http://doi.org/10.21105/astro.2305.06347
http://doi.org/10.1093/mnras/stac064
http://doi.org/10.48550/arXiv.2503.13183

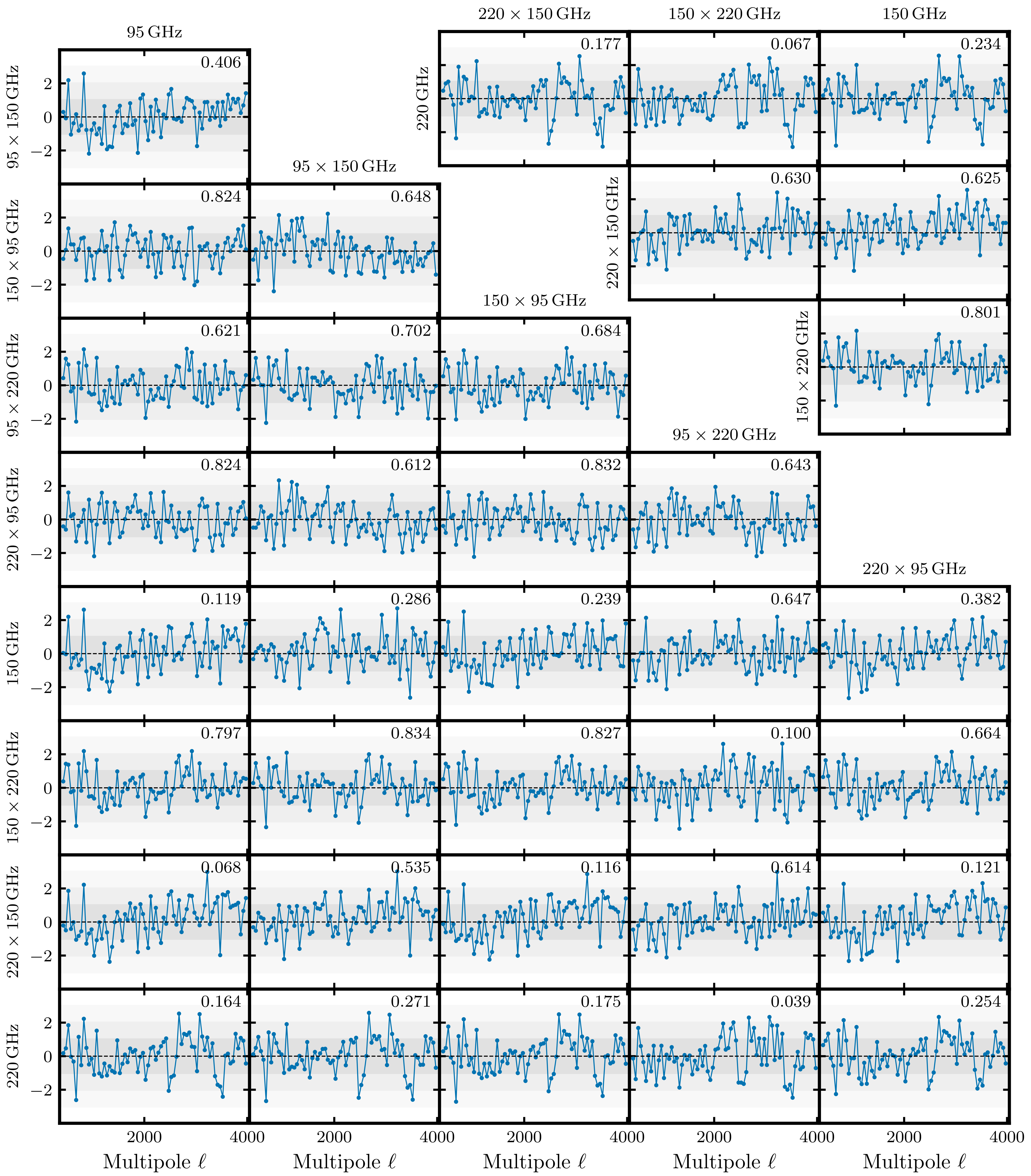
Semi-analytical covariance matrix from Camphuis et al, 2023

More details in the paper !

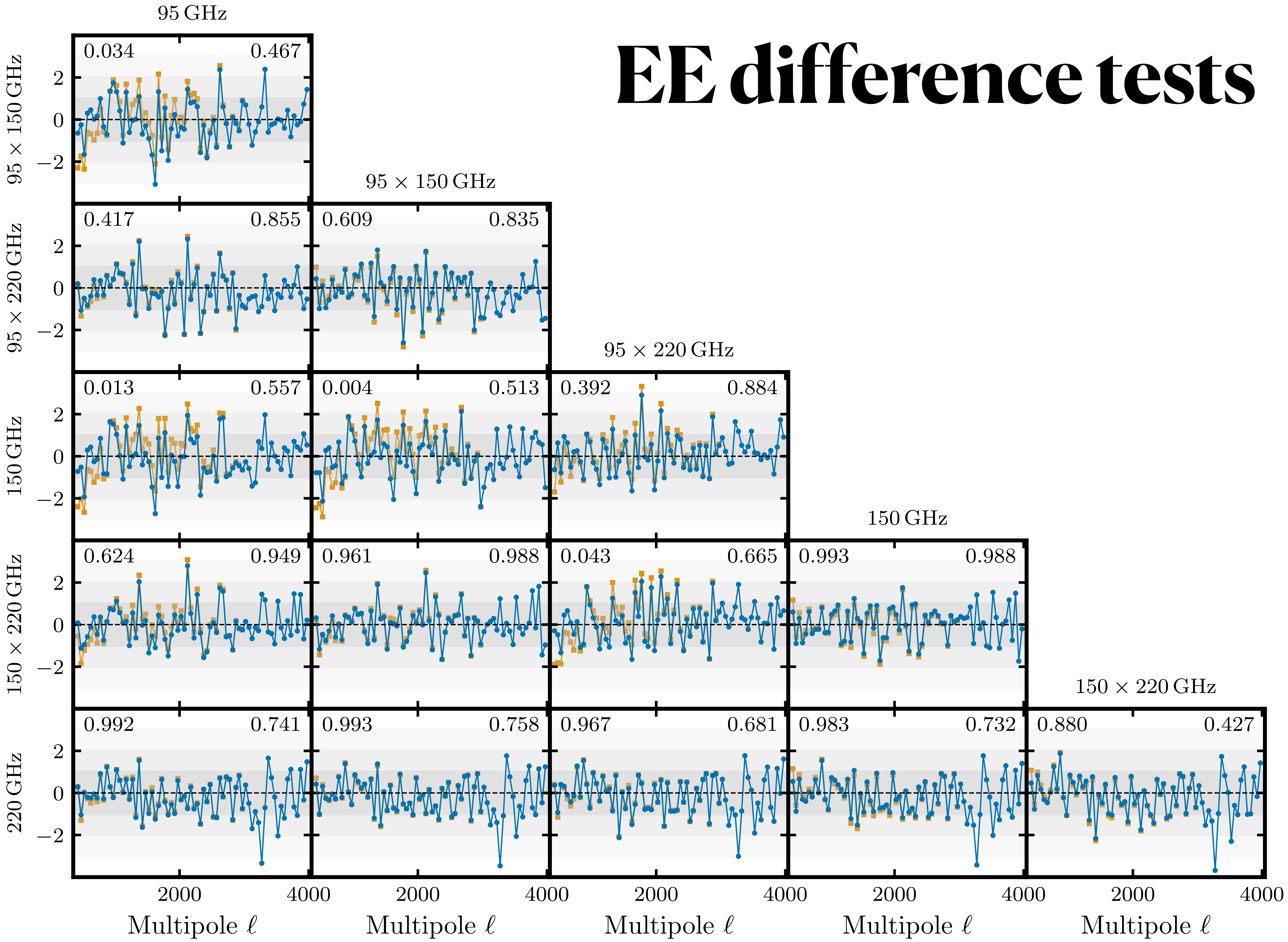
TT difference tests

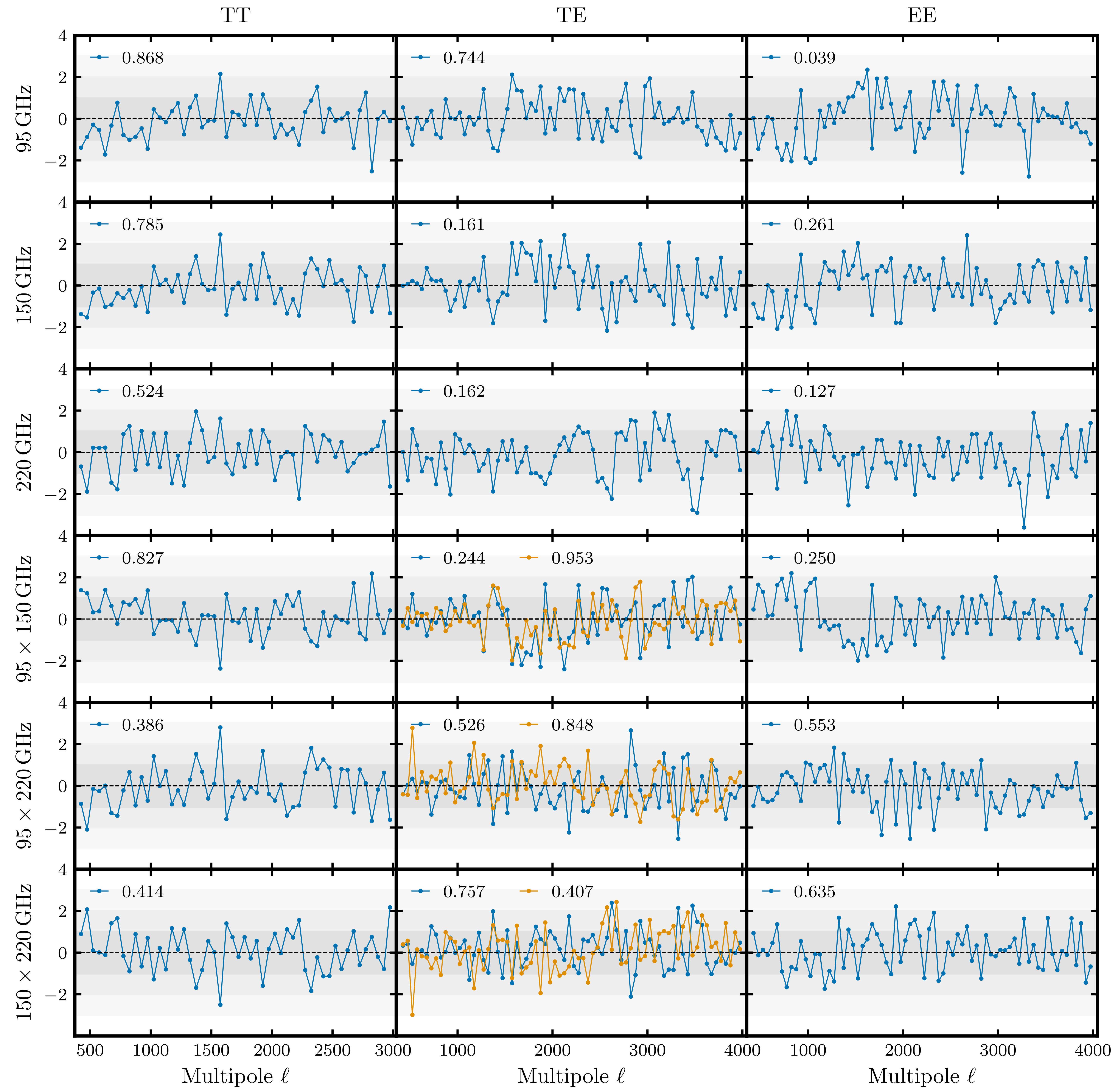


TE difference tests

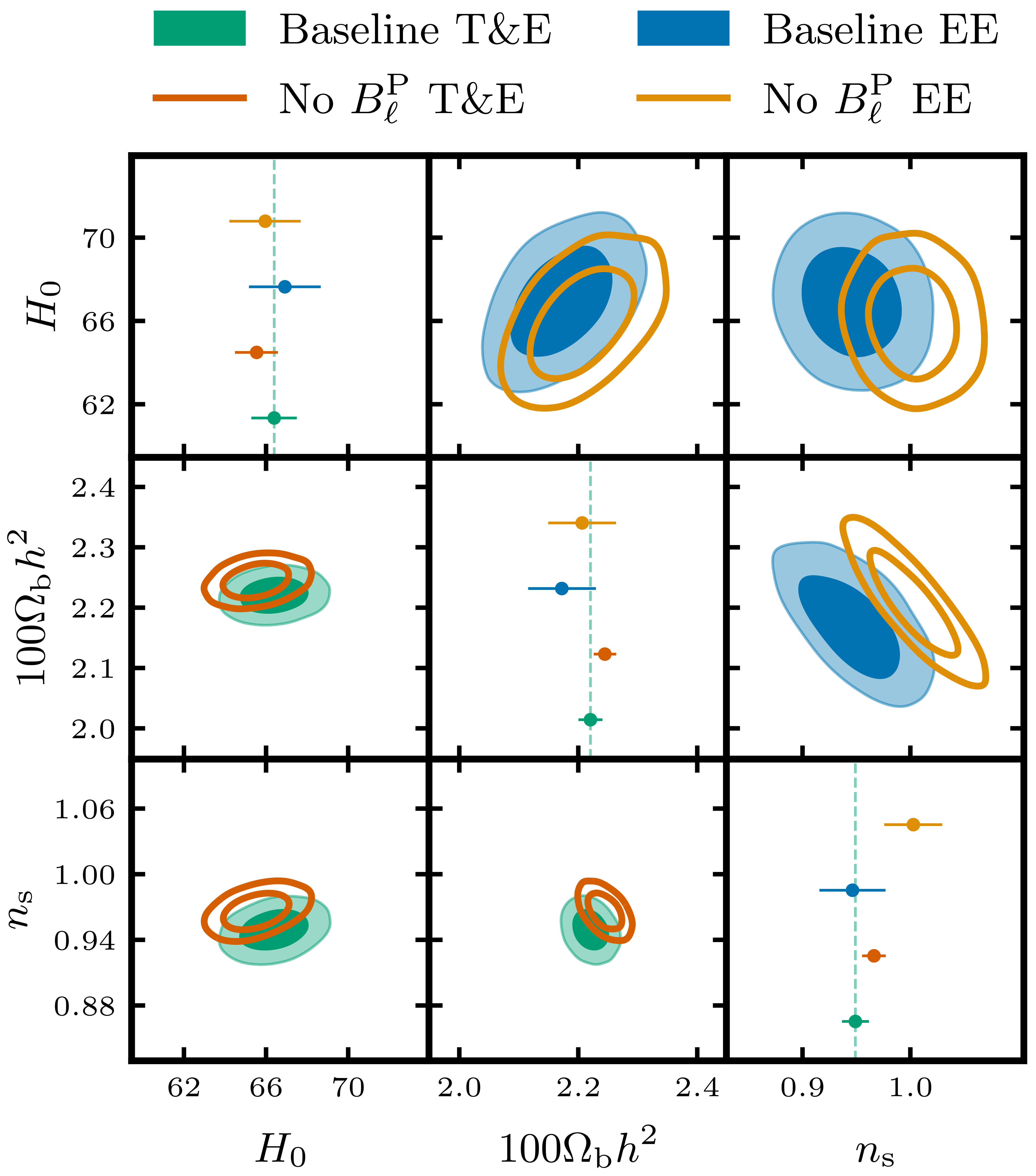


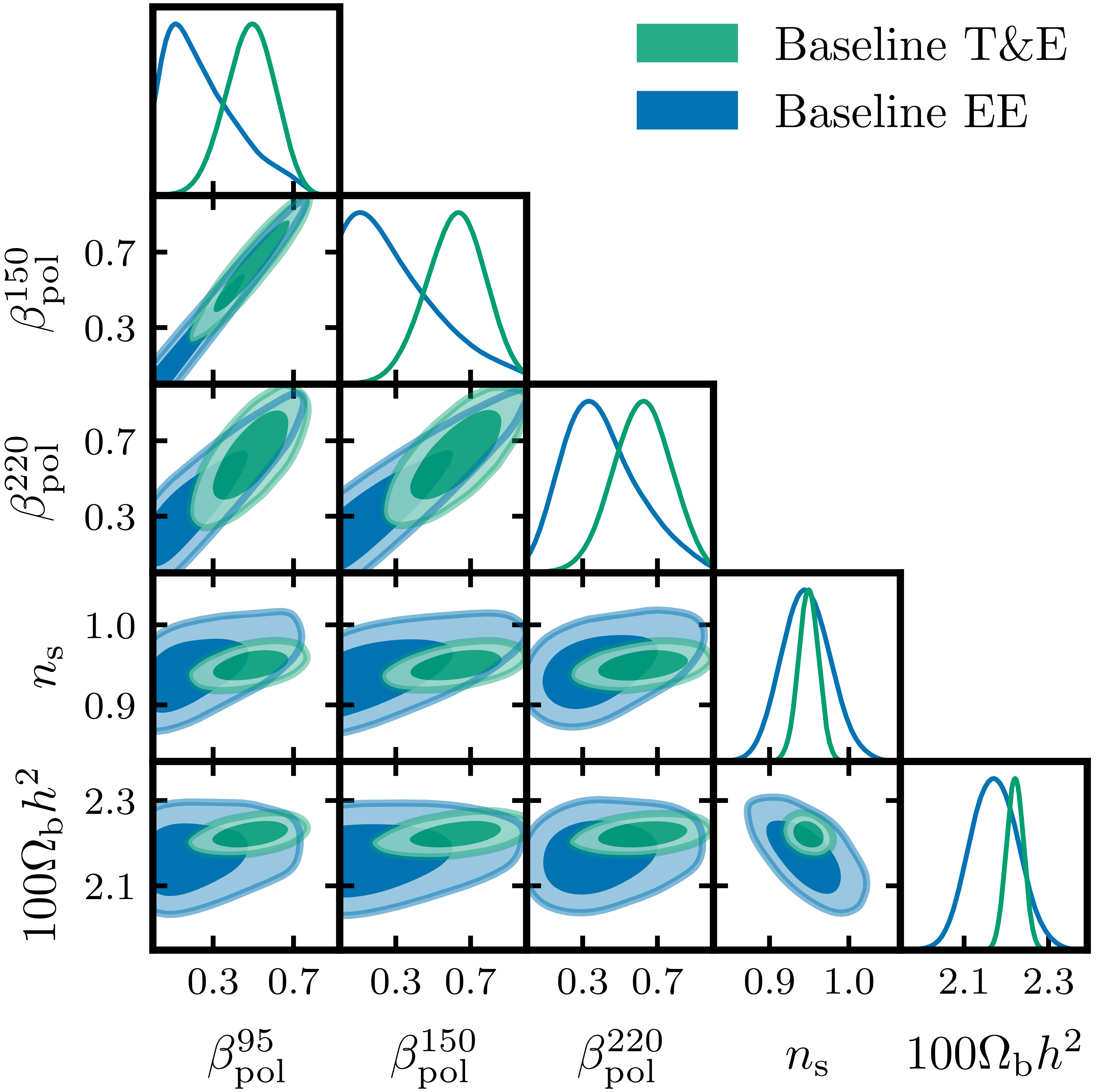
EE difference tests

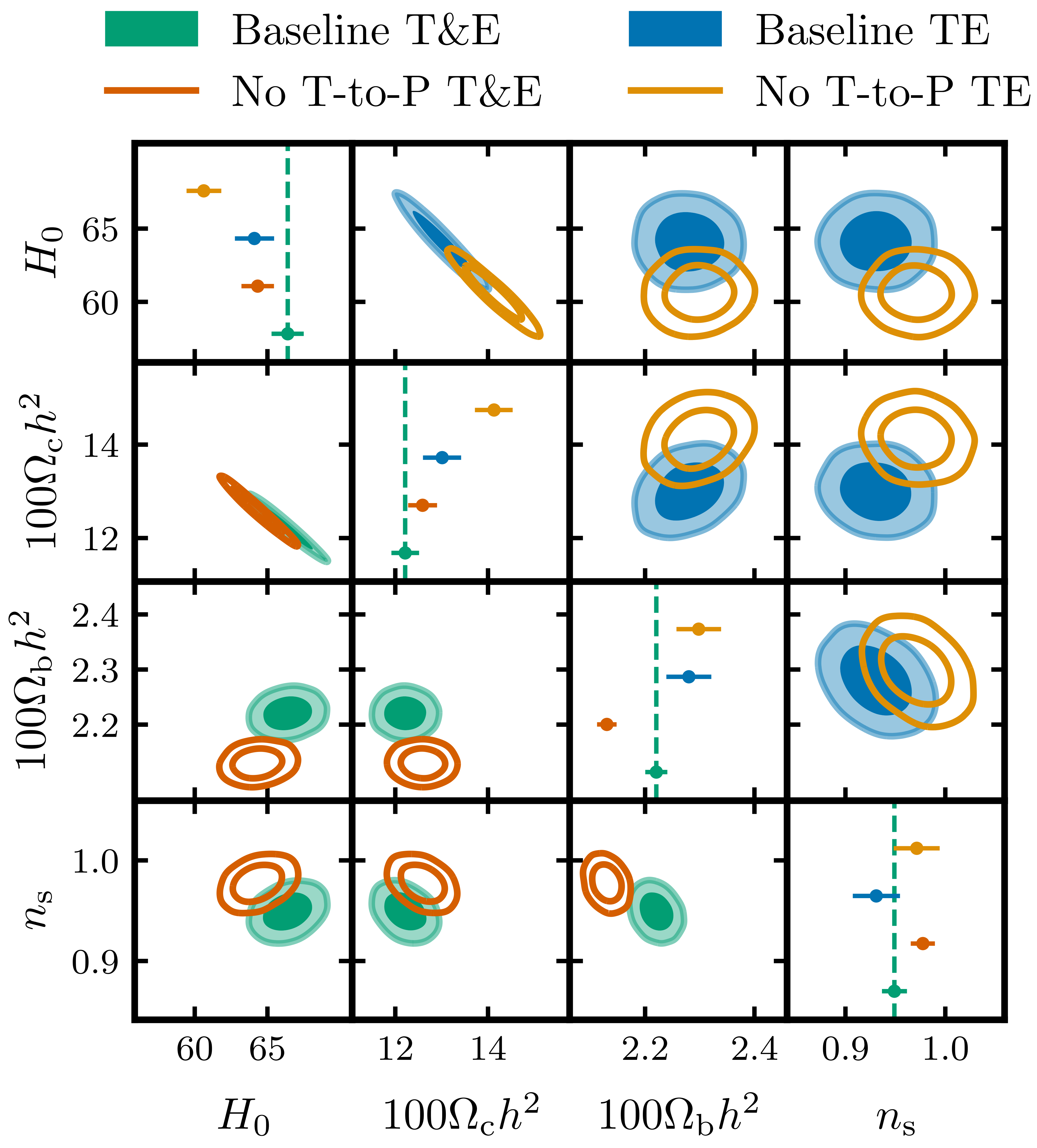




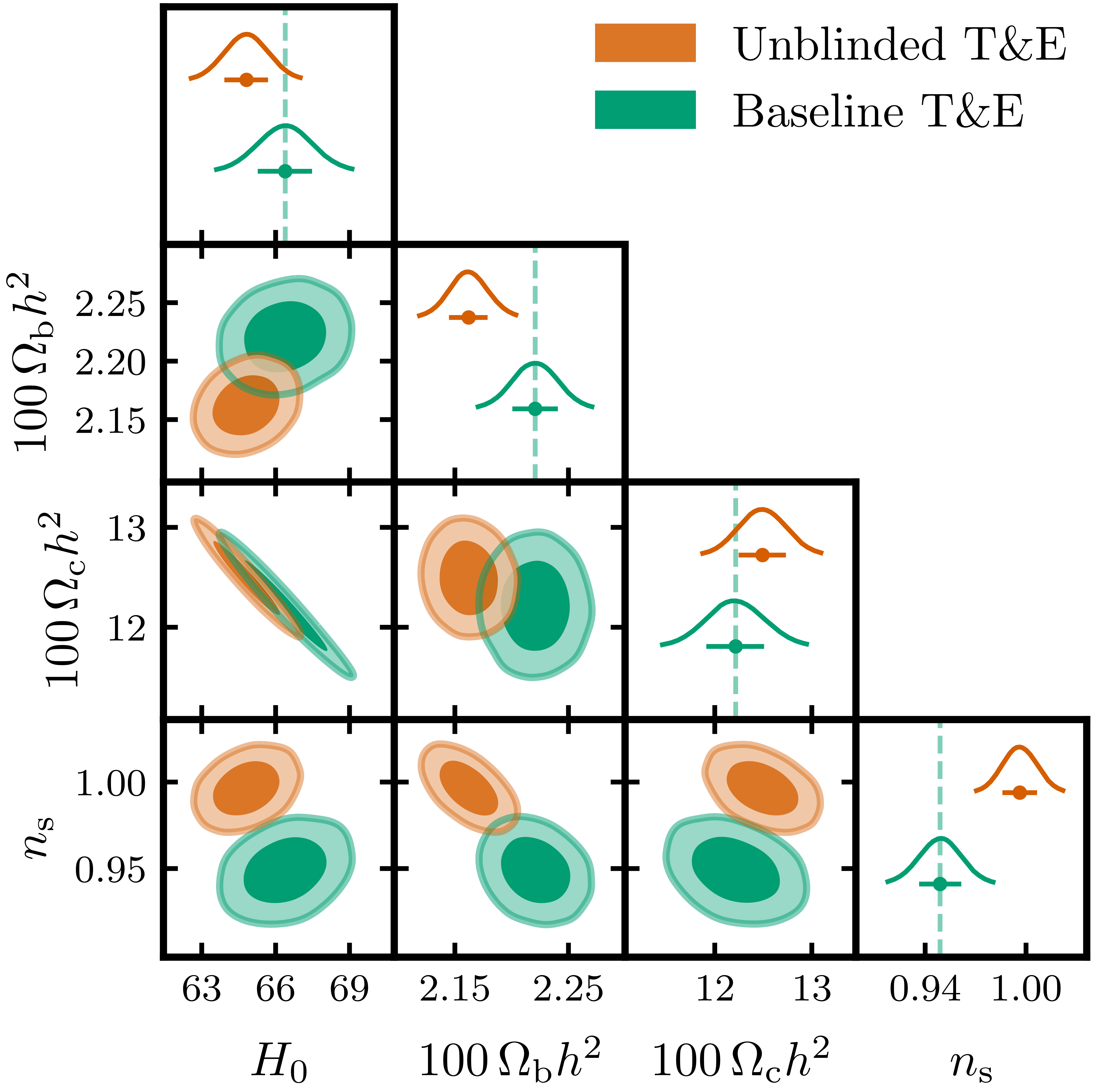
Conditional tests


Baseline T&E
Baseline EE
No B_ℓ^{P} T&E
No B_ℓ^{P} EE
H_0
70
66
62
$100\Omega_{\mathrm{b}}h^2$
2.4
2.3
2.2
2.1
2.0
n_{s}
1.06
1.00
0.94
0.88
62 66 70
2.0 2.2 2.4
0.9 1.0
H_0
$100\Omega_{\mathrm{b}}h^2$
n_{s}


Baseline T&E
Baseline EE
$\beta^{150}_{\mathrm{pol}}$
0.7
0.3
$\beta^{220}_{\mathrm{pol}}$
0.7
0.3
n_{s}
1.0
0.9
$100\Omega_{\mathrm{b}}h^2$
2.3
2.1
0.3 0.7
0.3 0.7
0.3 0.7
0.9 1.0
2.1 2.3
$\beta^{95}_{\mathrm{pol}}$
$\beta^{150}_{\mathrm{pol}}$
$\beta^{220}_{\mathrm{pol}}$
n_{s}
$100\Omega_{\mathrm{b}}h^2$



Baseline T&E
Baseline TE
No T-to-P T&E
No T-to-P TE
H_0
$100\Omega_c h^2$
$100\Omega_b h^2$
n_s
65
60
14
12
2.4
2.3
2.2
1.0
0.9
60 65
12 14
2.2 2.4
0.9 1.0

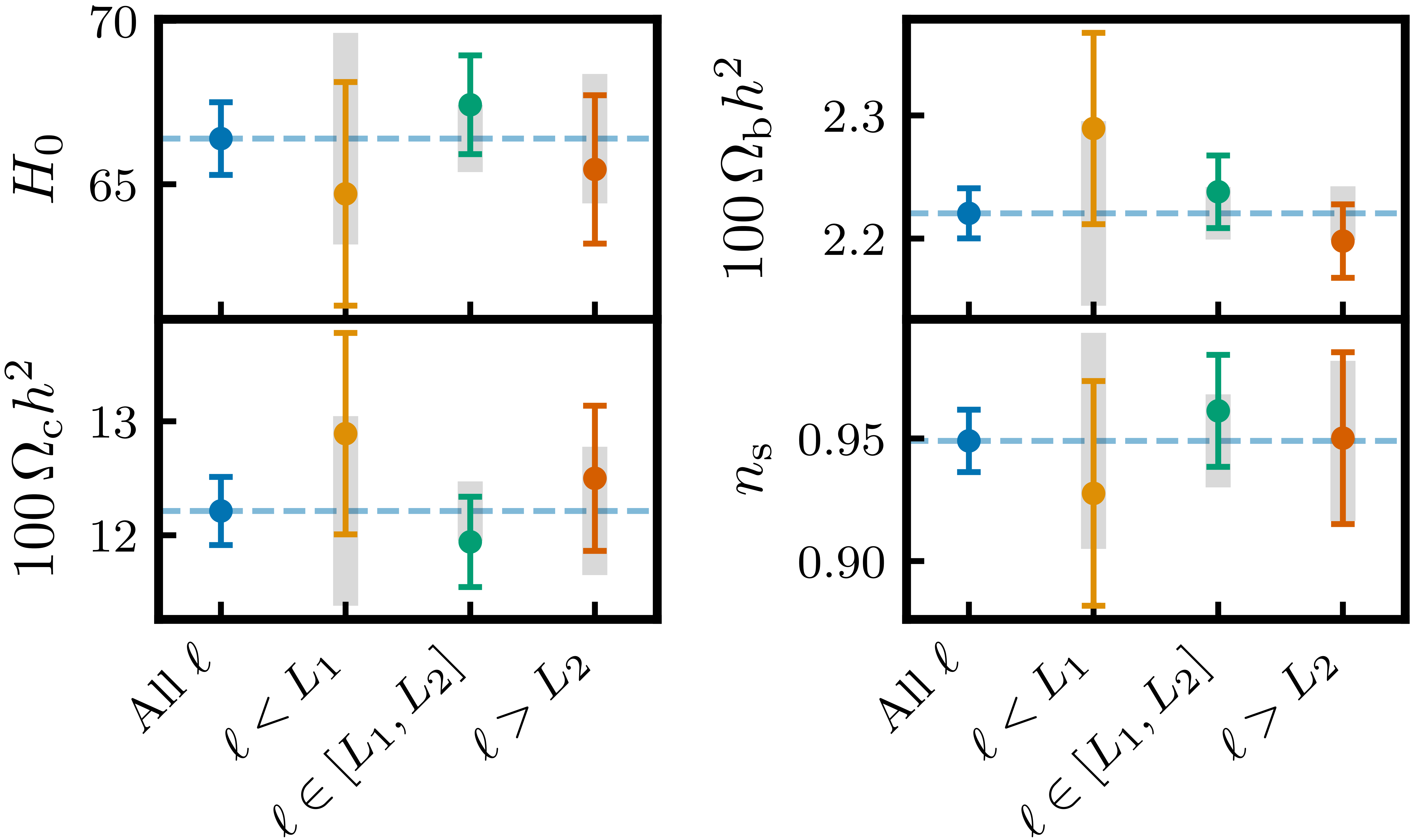


Unblinded T&E
Baseline T&E
$100\,\Omega_b h^2$
2.25
2.20
2.15
$100\,\Omega_c h^2$
13
12
n_s
1.00
0.95
63 66 69
2.15 2.25
12 13
0.94 1.00
H_0
$100\,\Omega_b h^2$
$100\,\Omega_c h^2$
n_s

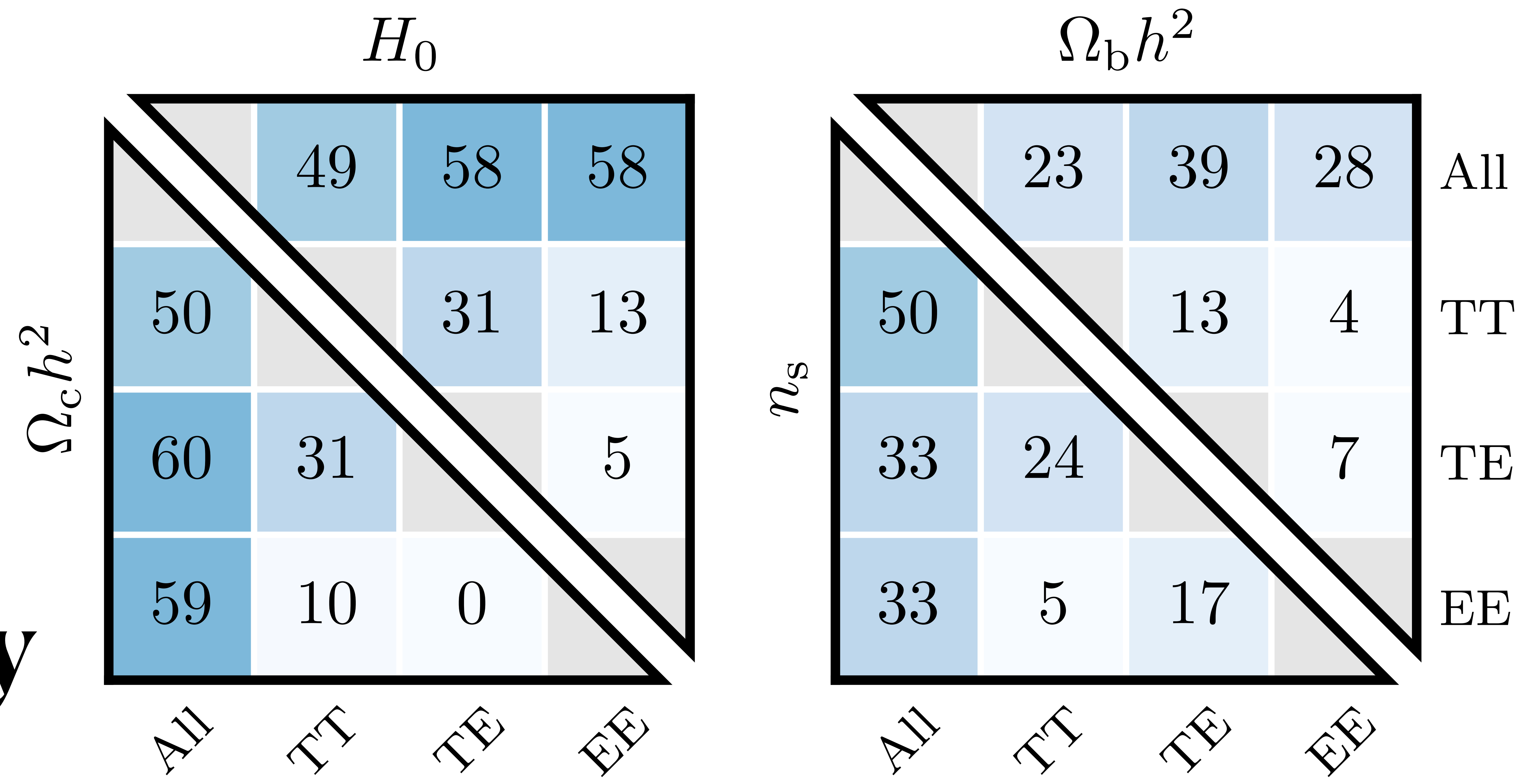
Cosmology

Consistency of ΛCDM across scales

$L_1, L_2 = 1000{,}2000$



Data set consistency



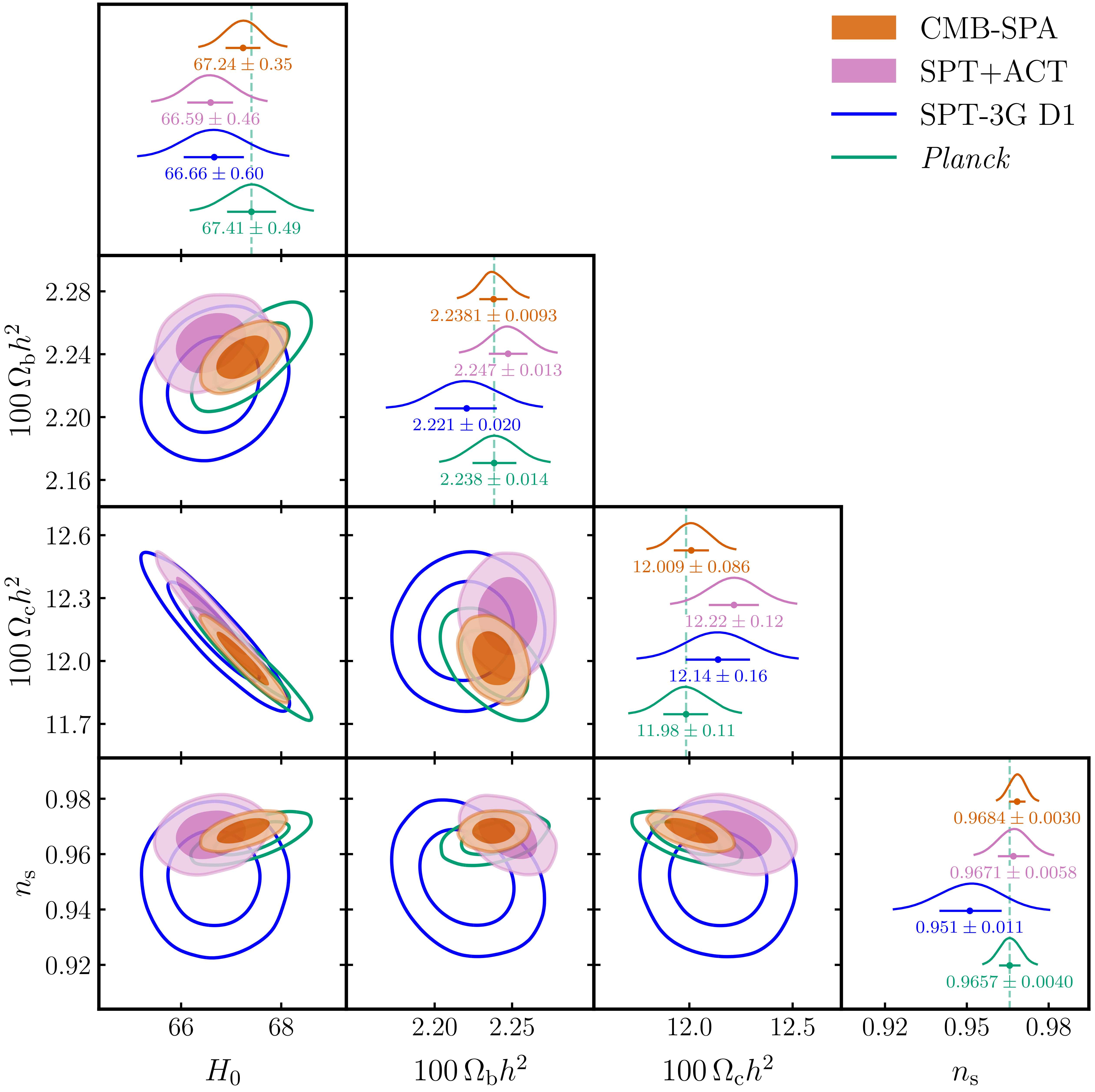
Spectrum	**All**	**TT**	**TE**	**EE**
All	-	$0.4\,\sigma$	$1.2\,\sigma$	$0.6\,\sigma$
TT	0.67	-	$1.0\,\sigma$	$0.3\,\sigma$
TE	0.22	0.31	-	$1.0\,\sigma$
EE	0.57	0.78	0.33	-

ΛCDM

Parameter	***Planck***	**SPT-3G D1**	**ACT DR6**	**SPT+ACT**	**SPT+*Planck***	**CMB-SPA**
Sampled						
$10^4\theta_s^\star$	104.184 ± 0.029	104.171 ± 0.060	104.157 ± 0.030	104.158 ± 0.025	104.176 ± 0.026	104.162 ± 0.023
$100\,\Omega_b h^2$	2.238 ± 0.014	2.221 ± 0.020	2.257 ± 0.016	2.247 ± 0.013	2.230 ± 0.011	2.2381 ± 0.0093
$100\,\Omega_c h^2$	11.98 ± 0.11	12.14 ± 0.16	12.26 ± 0.17	12.22 ± 0.12	12.050 ± 0.089	12.009 ± 0.086
n_s	0.9657 ± 0.0040	0.951 ± 0.011	0.9682 ± 0.0069	0.9671 ± 0.0058	0.9636 ± 0.0035	0.9684 ± 0.0030
$\log(10^{10}\,A_s)$	3.042 ± 0.011	3.054 ± 0.015	3.038 ± 0.012	3.042 ± 0.011	3.046 ± 0.010	3.0479 ± 0.0099
τ_{reio}	0.0535 ± 0.0056	0.0506 ± 0.0059	0.0513 ± 0.0060	0.0514 ± 0.0059	0.0538 ± 0.0054	0.0559 ± 0.0055
Derived						
H_0 [km/s/Mpc]	67.41 ± 0.49	66.66 ± 0.60	66.51 ± 0.64	66.59 ± 0.46	67.07 ± 0.38	67.24 ± 0.35
Age [Gyr]	13.797 ± 0.022	13.826 ± 0.027	13.797 ± 0.021	13.805 ± 0.016	13.812 ± 0.017	13.805 ± 0.014
$10^9\,A_s e^{-2\tau_{reio}}$	1.883 ± 0.010	1.915 ± 0.021	1.884 ± 0.013	1.889 ± 0.011	1.8890 ± 0.0092	1.8843 ± 0.0060
Ω_Λ	0.6854 ± 0.0067	0.6753 ± 0.0091	0.670 ± 0.010	0.6722 ± 0.0072	0.6810 ± 0.0054	0.6833 ± 0.0051
Ω_m	0.3145 ± 0.0067	0.3246 ± 0.0091	0.330 ± 0.010	0.3277 ± 0.0072	0.3189 ± 0.0054	0.3166 ± 0.0051
r_d [Mpc]	147.13 ± 0.25	146.92 ± 0.47	146.20 ± 0.46	146.43 ± 0.34	147.06 ± 0.23	147.07 ± 0.22
σ_8	0.8099 ± 0.0051	0.8158 ± 0.0058	0.8171 ± 0.0055	0.8169 ± 0.0042	0.8132 ± 0.0042	0.8137 ± 0.0038

ΛCDM

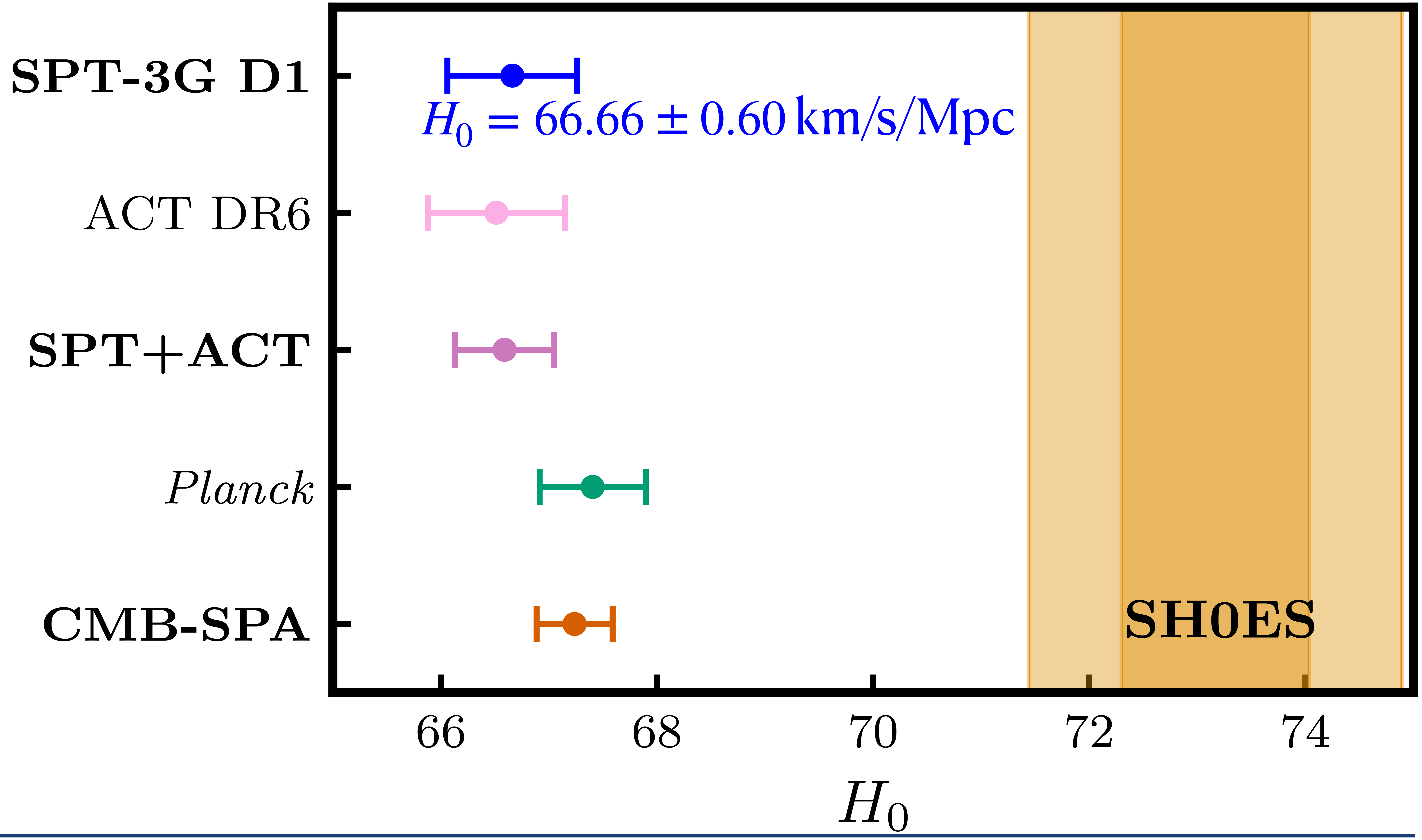
CMB-SPA yields the most precise determination of ΛCDM parameters from a single probe. All three experiments agree with each other within $1.1\,\sigma$.



H_0 tension with SH0ES

Breuval et al., 2024
$H_0 = 73.17 \pm 0.86$ km/s/Mpc

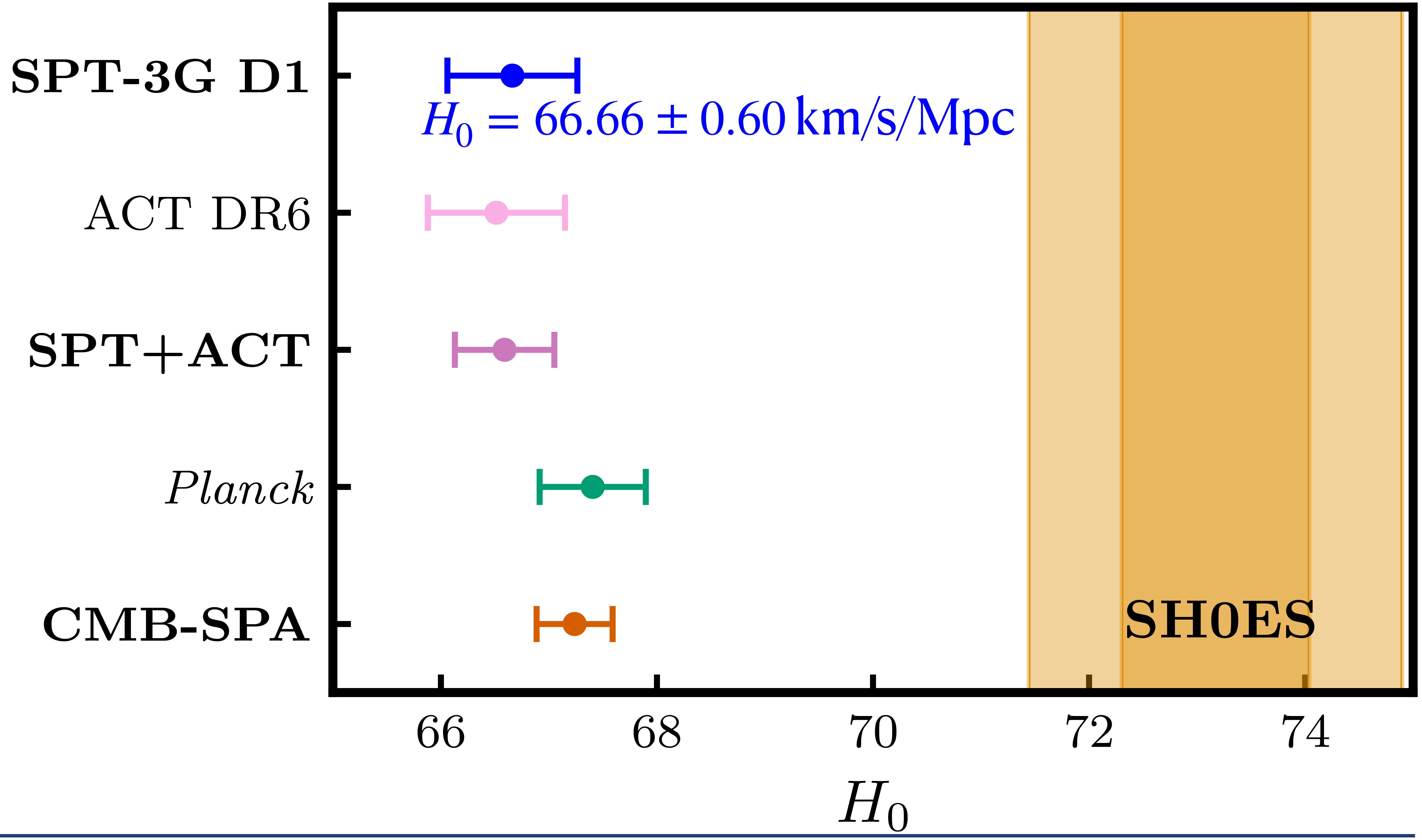
- Hubble tension at **6.2σ** from SPT-3G alone.
- SPT+ACT and CMB-SPA are at **6.8σ** and **6.4σ** tension, respectively.



H_0 tension

$$H_0 = 66.66 \pm 0.60\,\mathrm{km\,s^{-1}\,Mpc^{-1}}\ \text{for SPT-3G D1},$$
$$H_0 = 66.59 \pm 0.46\,\mathrm{km\,s^{-1}\,Mpc^{-1}}\ \text{for SPT+ACT},$$
$$H_0 = 67.24 \pm 0.35\,\mathrm{km\,s^{-1}\,Mpc^{-1}}\ \text{for CMB-SPA}.$$

- Hubble tension at **6.2σ** from SPT-3G alone.
- SPT+ACT and CMB-SPA are at **6.8σ** and **6.4σ** tension, respectively.



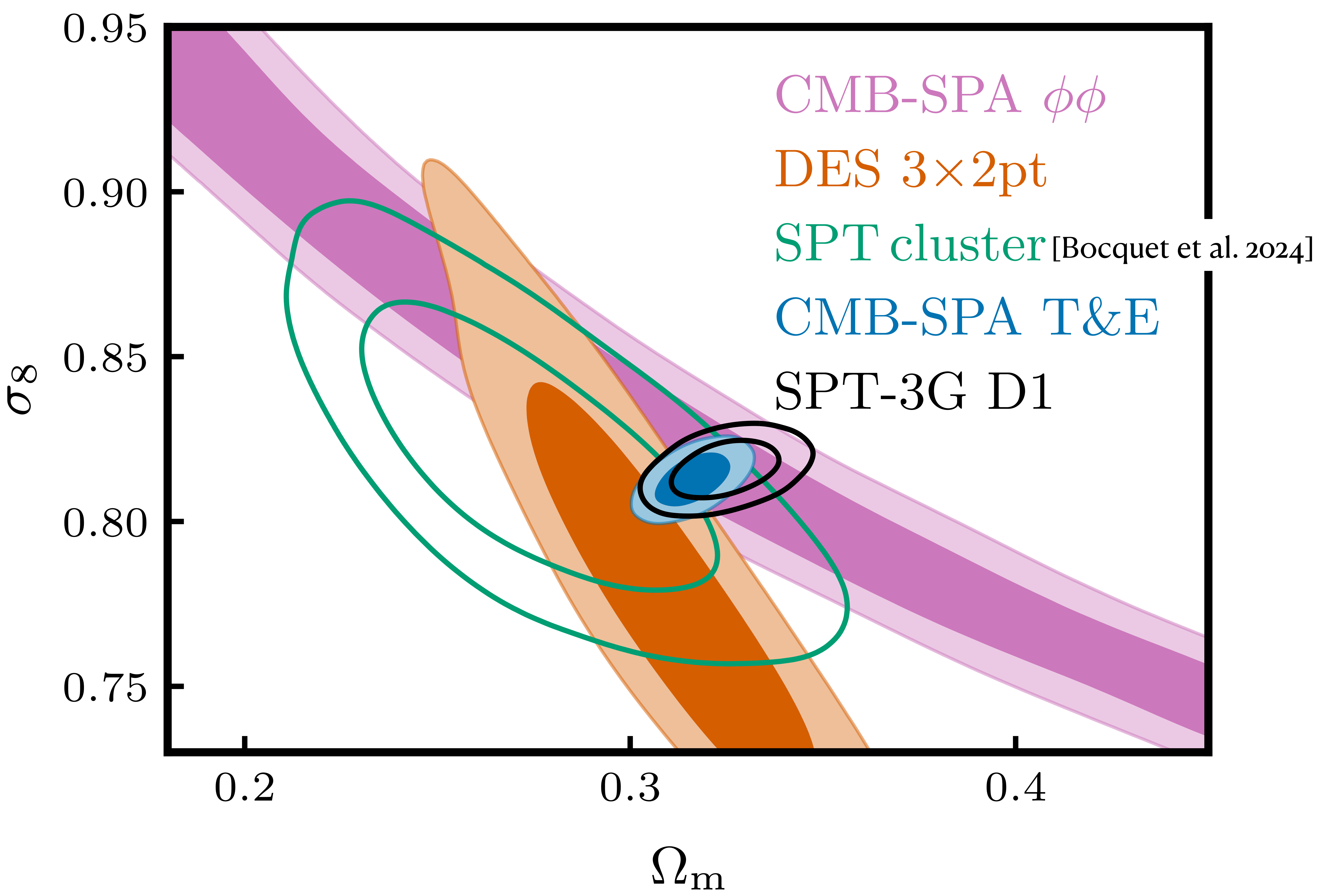
σ_8-Ω_m

$$\left.\begin{array}{l}\sigma_8 = 0.8158 \pm 0.0058,\\ \Omega_m = 0.3246 \pm 0.0091\end{array}\right\} \text{ for SPT-3G D1,}$$

$$\left.\begin{array}{l}\sigma_8 = 0.8169 \pm 0.0042,\\ \Omega_m = 0.3277 \pm 0.0072\end{array}\right\} \text{ for SPT+ACT,}$$

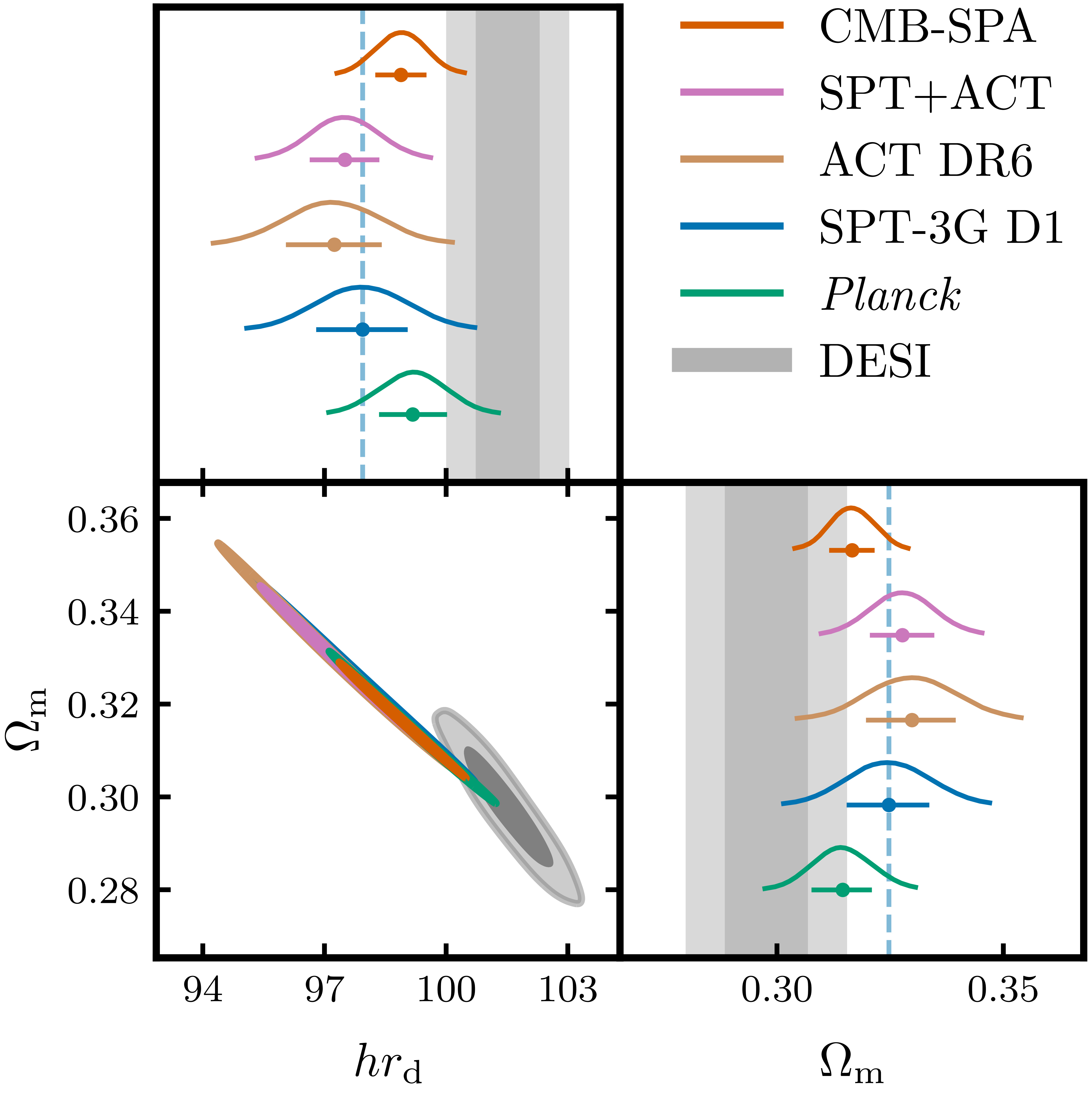
$$\left.\begin{array}{l}\sigma_8 = 0.8137 \pm 0.0038,\\ \Omega_m = 0.3166 \pm 0.0051\end{array}\right\} \text{ for CMB-SPA.}$$

$$\left.\begin{array}{l}\sigma_8 = 0.8137 \pm 0.0038,\\ \Omega_m = 0.3166 \pm 0.0051\end{array}\right\} \textbf{ for CMB-SPA T\&E\&}\phi$$



Consistency of CMB and BAO in ΛCDM

	$100\,\Omega_m$	hr_d [Mpc]	Distance to DESI
CMB-SPA	31.66 ± 0.50	98.89 ± 0.63	$2.8\,\sigma$
SPT+ACT	32.77 ± 0.72	97.51 ± 0.87	$3.7\,\sigma$
SPT+*Planck*	31.89 ± 0.54	98.63 ± 0.67	$3.0\,\sigma$
ACT DR6	33.0 ± 1.0	97.2 ± 1.2	$3.1\,\sigma$
SPT-3G D1	32.47 ± 0.91	97.9 ± 1.1	$2.5\,\sigma$
Planck	31.45 ± 0.67	99.18 ± 0.84	$2.0\,\sigma$
DESI	29.76 ± 0.87	101.52 ± 0.73	



Consistency of CMB and BAO in ΛCDM

	$100\,\Omega_m$	hr_d [Mpc]	Distance to DESI
CMB-SPA	31.66 ± 0.50	98.89 ± 0.63	$2.8\,\sigma$
SPT+ACT	32.77 ± 0.72	97.51 ± 0.87	$3.7\,\sigma$
SPT+*Planck*	31.89 ± 0.54	98.63 ± 0.67	$3.0\,\sigma$
ACT DR6	33.0 ± 1.0	97.2 ± 1.2	$3.1\,\sigma$
SPT-3G D1	32.47 ± 0.91	97.9 ± 1.1	$2.5\,\sigma$
Planck	31.45 ± 0.67	99.18 ± 0.84	$2.0\,\sigma$
DESI	29.76 ± 0.87	101.52 ± 0.73	

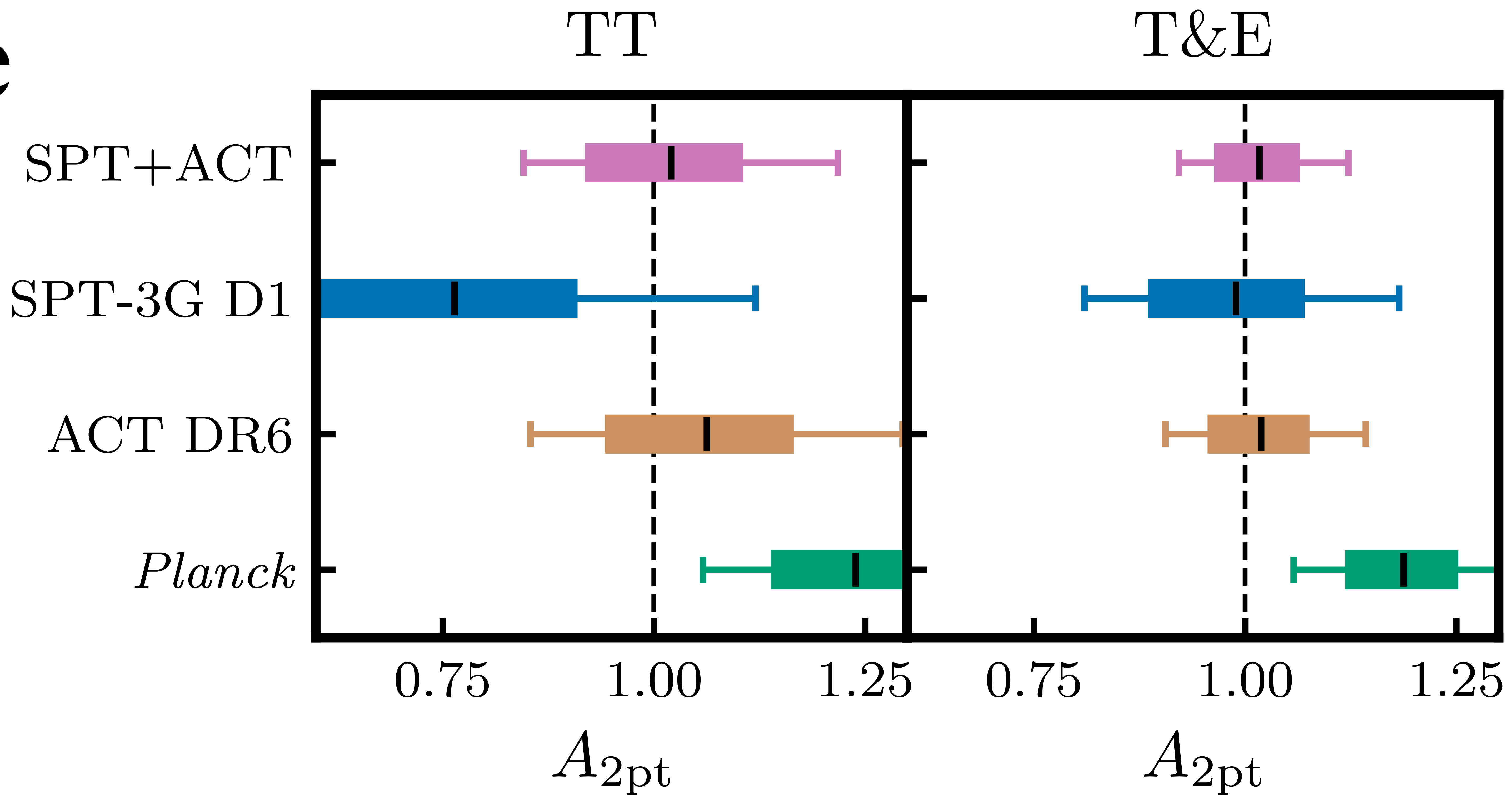
Parameter	**SPT-3G D1 + DESI**	**CMB-SPA + DESI**
Sampled		
$10^4\theta_s^\star$	104.227 ± 0.056	104.180 ± 0.022
$100\,\Omega_b h^2$	2.218 ± 0.022	2.2452 ± 0.0089
$100\,\Omega_c h^2$	11.749 ± 0.079	11.813 ± 0.058
n_s	0.949 ± 0.012	0.9728 ± 0.0027
$\log(10^{10} A_s)$	3.066 ± 0.014	3.0574 ± 0.0094
τ_{reio}	0.0559 ± 0.0056	0.0625 ± 0.0050
Derived		
H_0 [km s^{-1} Mpc^{-1}]	68.21 ± 0.31	68.06 ± 0.24
Age [Gyr]	13.795 ± 0.025	13.783 ± 0.012
$10^9 A_s e^{-2\tau_{reio}}$	1.920 ± 0.021	1.8773 ± 0.0055
Ω_Λ	0.6983 ± 0.0039	0.6950 ± 0.0033
Ω_m	0.3017 ± 0.0039	0.3049 ± 0.0033
r_d [Mpc]	147.99 ± 0.33	147.51 ± 0.17
σ_8	0.8079 ± 0.0059	0.8120 ± 0.0038

Lensing amplitude

$$\left.\begin{aligned} A_{2pt} &= 0.986^{+0.078}_{-0.097} \\ A_{recon} &= 0.974^{+0.081}_{-0.11} \end{aligned}\right\} \text{ for SPT-3G D1,}$$

$$\left.\begin{aligned} A_{2pt} &= 1.026 \pm 0.048 \\ A_{recon} &= 0.990 \pm 0.050 \end{aligned}\right\} \text{ for SPT+ACT,}$$

$$\left.\begin{aligned} A_{2pt} &= 1.083 \pm 0.037 \\ A_{recon} &= 1.048 \pm 0.031 \end{aligned}\right\} \text{ for CMB-SPA.}$$



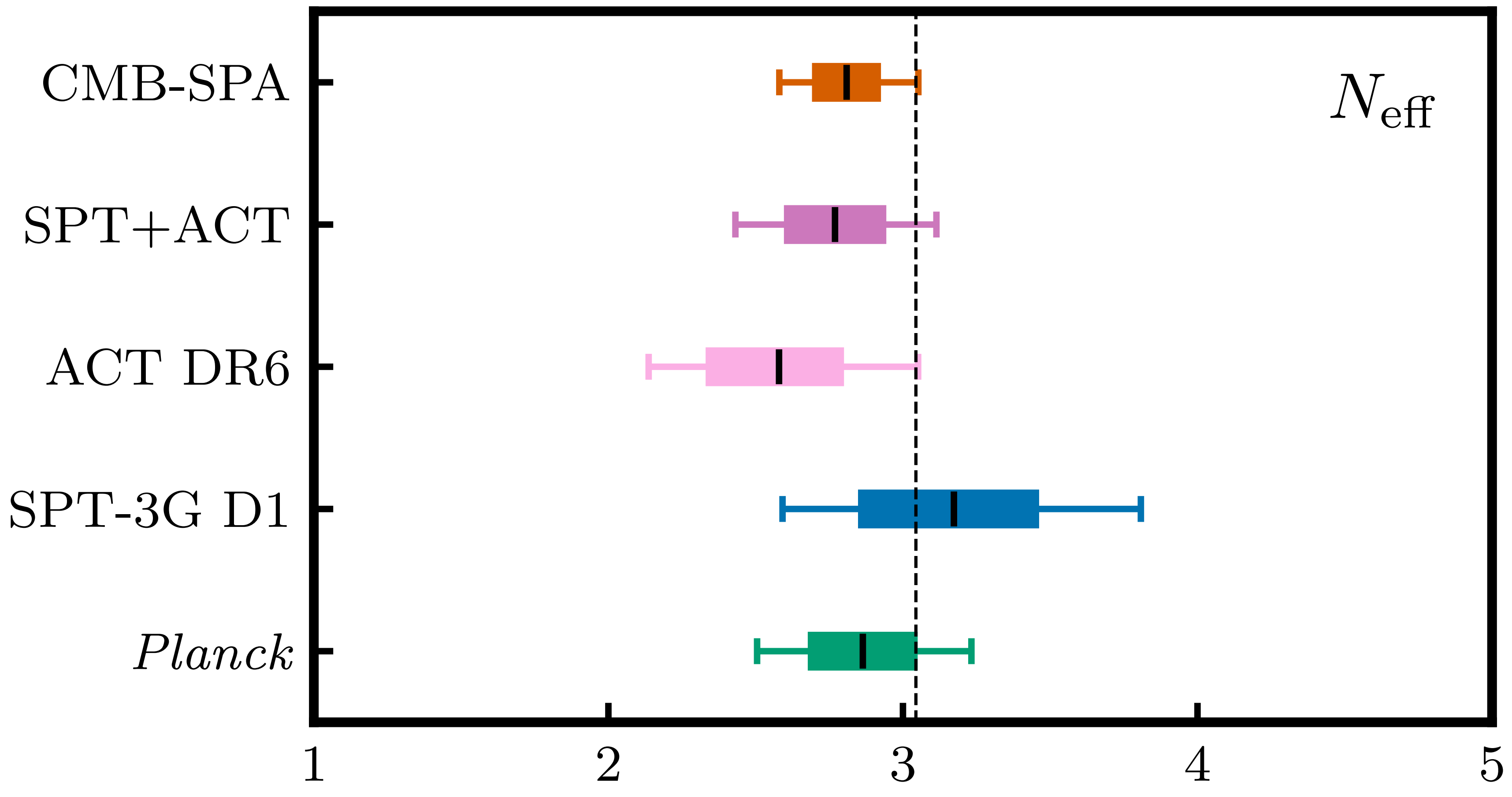
$$A_{lens} = 1.084 \pm 0.035 \text{ for SPT-3G D1 + DESI,}$$
$$A_{lens} = 1.092 \pm 0.026 \text{ for SPT+ACT + DESI,}$$
$$A_{lens} = 1.084 \pm 0.024 \text{ for CMB-SPA + DESI.}$$

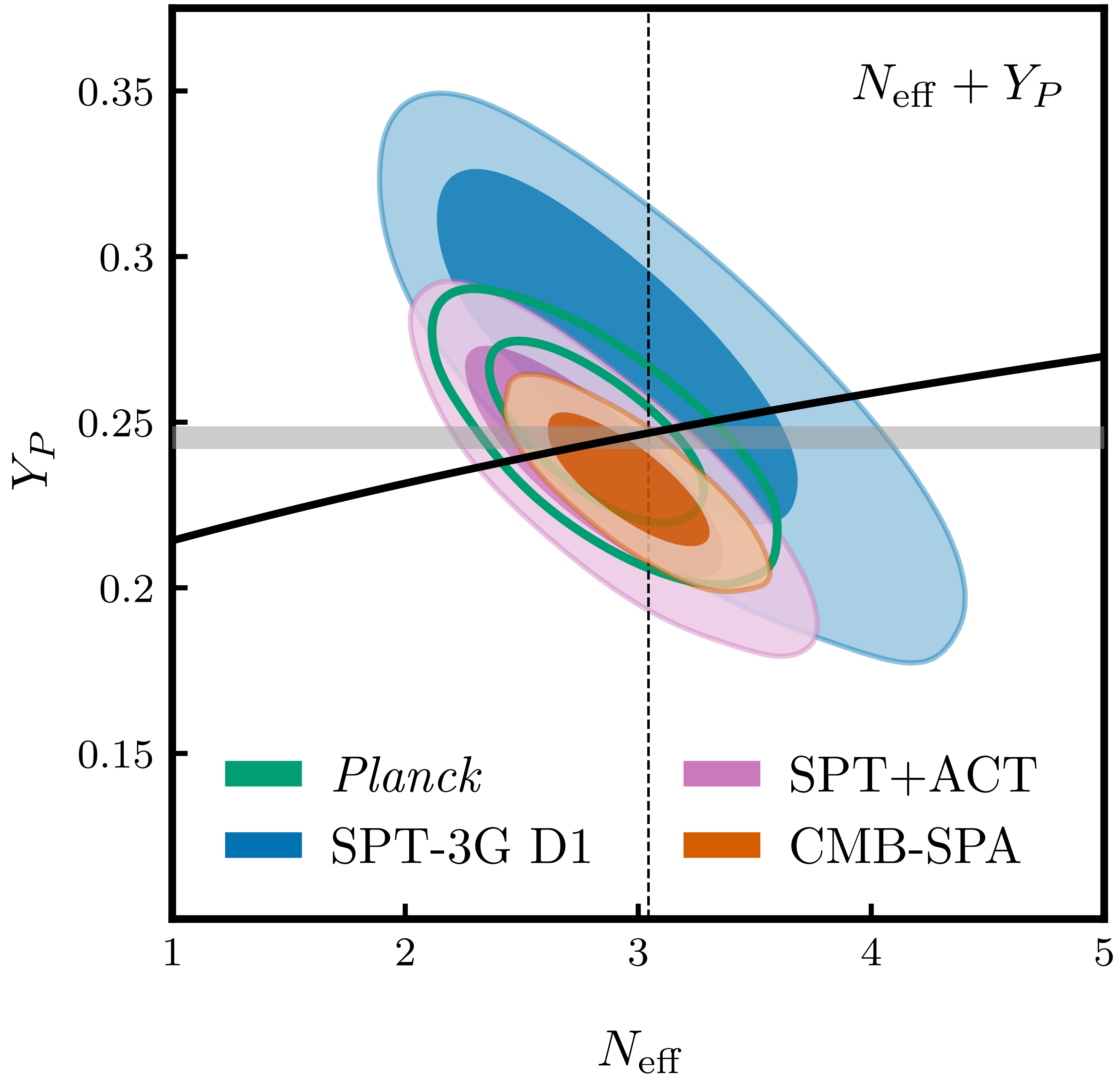
Data Set	TT	T&E
SPT+ACT	$A_{2pt} = 1.014 \pm 0.098$	$A_{2pt} = 1.016^{+0.048}_{-0.054}$
SPT-3G D1	$A_{2pt} = 0.76^{+0.15}_{-0.19}$	$A_{2pt} = 0.991^{+0.083}_{-0.10}$
ACT DR6	$A_{2pt} = 1.06^{+0.10}_{-0.12}$	$A_{2pt} = 1.020 \pm 0.060$
Planck	$A_{2pt} = 1.239 \pm 0.095$	$A_{2pt} = 1.185 \pm 0.067$

New light particles

$$N_{\rm eff} = 3.17^{+0.29}_{-0.33} \text{ for SPT-3G D1},$$
$$N_{\rm eff} = 2.77 \pm 0.17 \text{ for SPT+ACT},$$
$$N_{\rm eff} = 2.81 \pm 0.12 \text{ for CMB-SPA}.$$

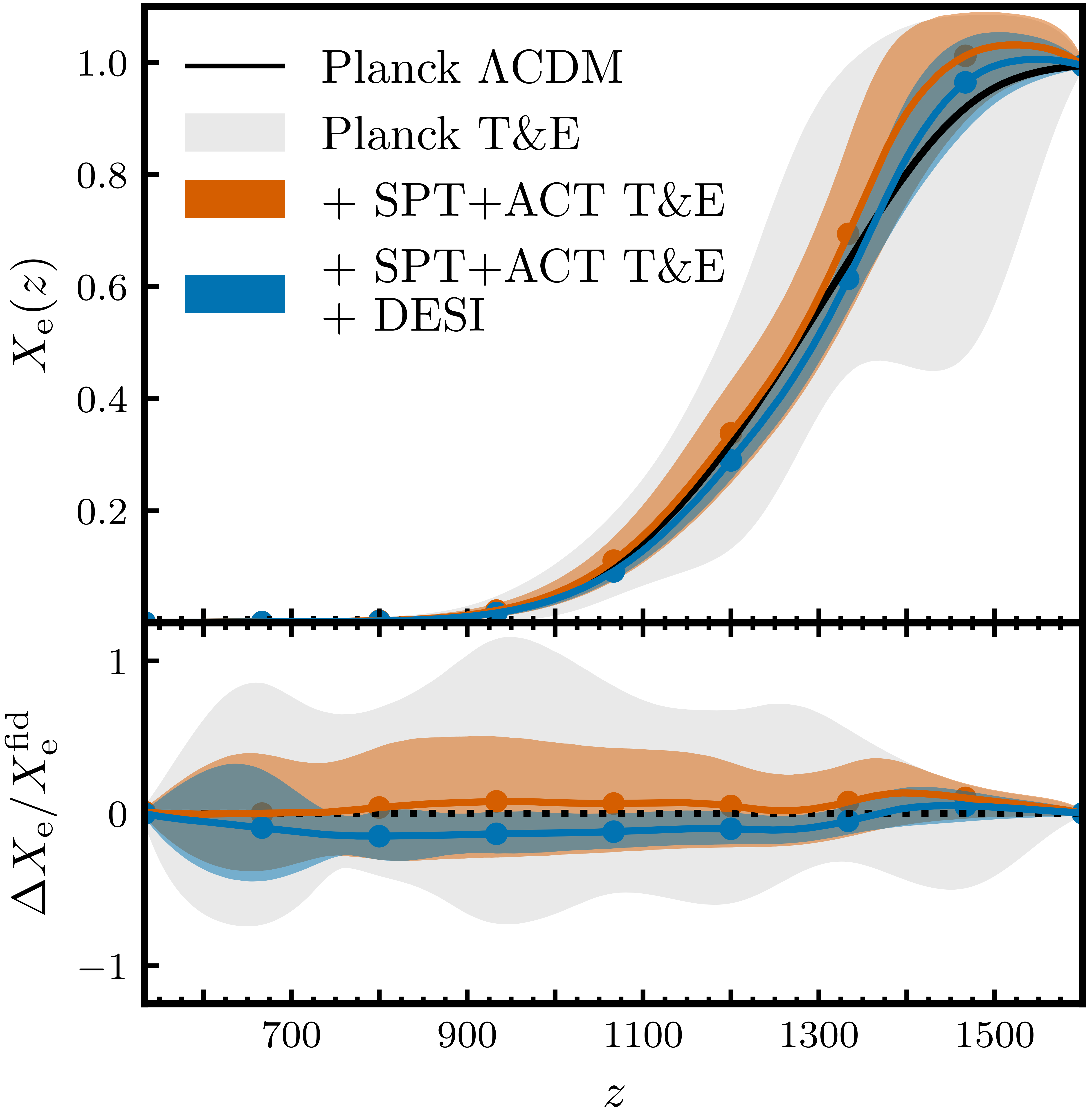
$$\left.\begin{aligned} N_{\rm eff} &= 2.97^{+0.40}_{-0.64} \\ Y_{\rm P} &= 0.269^{+0.040}_{-0.030} \end{aligned}\right\} \text{ for SPT-3G D1},$$
$$\left.\begin{aligned} N_{\rm eff} &= 2.85^{+0.32}_{-0.40} \\ Y_{\rm P} &= 0.236^{+0.025}_{-0.021} \end{aligned}\right\} \text{ for SPT+ACT},$$
$$\left.\begin{aligned} N_{\rm eff} &= 2.99^{+0.22}_{-0.26} \\ Y_{\rm P} &= 0.231 \pm 0.014 \end{aligned}\right\} \text{ for CMB-SPA}.$$



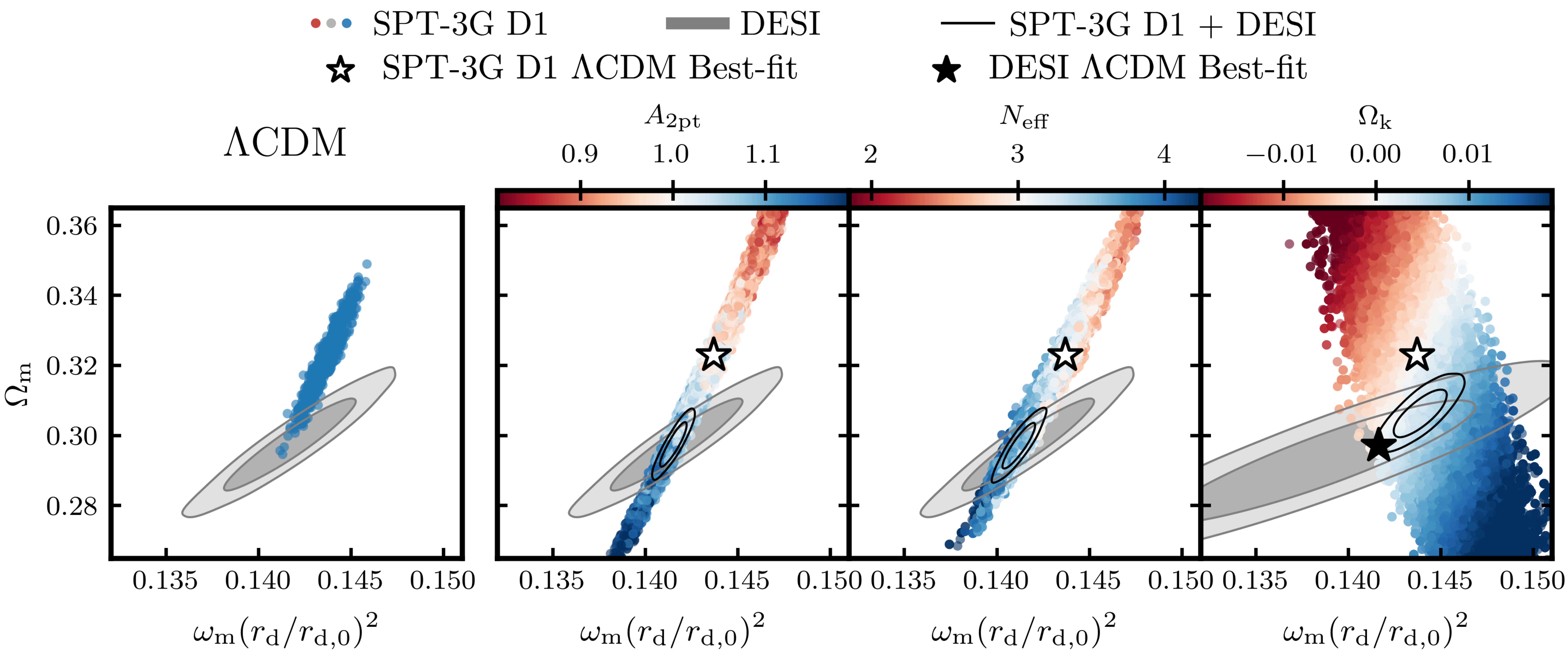


Modified Recombination

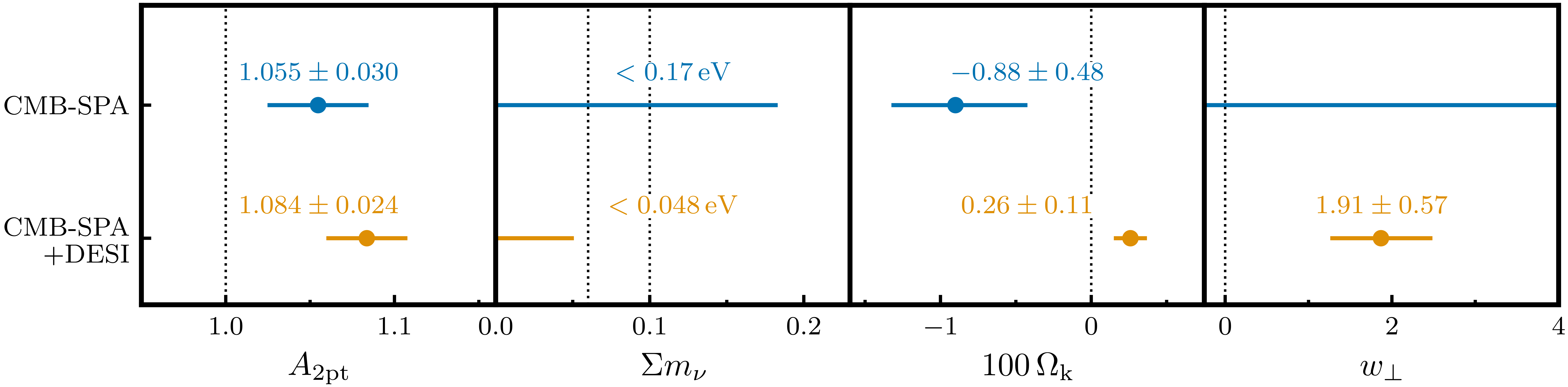
[Lynch et al., 2024]



Constraints from CMB and BAO data on extended cosmological models



Constraints from CMB and BAO data on extended cosmological models



Constraints from CMB and BAO data on extended cosmological models

Model	CMB-SPA χ^2_{CMB}	DESI χ^2_{DESI}	CMB-SPA+DESI χ^2_{CMB}	CMB-SPA+DESI χ^2_{DESI}	CMB-SPA+DESI $\chi^2_{\mathrm{CMB+DESI}}$
ΛCDM	1550.9	10.3	1556.0	14.8	1570.7
A_{lens}	1548.9 $(2.0, 1.4\,\sigma)$	-	1550.4	10.9	1561.2 $(9.5, 3.1\,\sigma)$
ModRec	$(8.9, 1.1\,\sigma)$	-	(12.0)	(2.2)	$(14.2, 2.0\,\sigma)$
Ω_{k}	1549.5 $(1.4, 1.2\,\sigma)$	10.0 $(0.3, 0.6\,\sigma)$	1553.5	10.9	1564.4 $(6.3, 2.5\,\sigma)$
$\Omega_{\mathrm{k}} + m_{\mathrm{e}}$	-	-	1553.6	10.3	1563.9 $(6.8, 2.1\,\sigma)$
Σm_ν	1551.0 $(-0.1, 0.0\,\sigma)$	-	1551.2	11.8	1562.9 $(7.8, 2.8\,\sigma)$
$w_0 w_a$	-	5.6 $(4.7, 1.7\,\sigma)$	1550.0	7.3	1557.3 $(13.5, 3.2\,\sigma)$

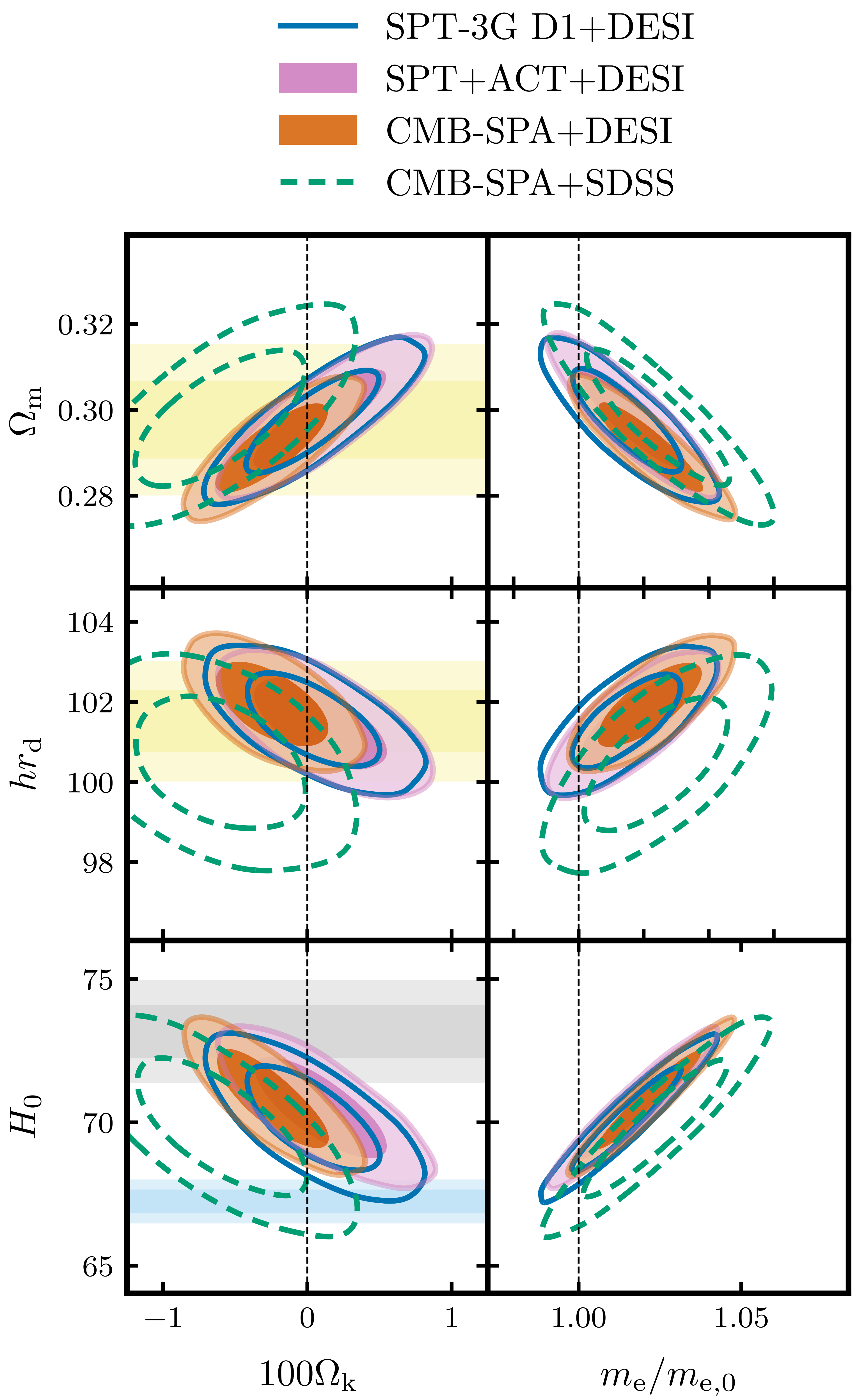
$$\Omega_K$$

$$100\Omega_k = 0.2^{+1.5}_{-1.2} \text{ for SPT-3G D1,}$$
$$100\Omega_k = -0.06^{+0.81}_{-0.70} \text{ for SPT+ACT,}$$
$$100\Omega_k = -0.88 \pm 0.48 \text{ for CMB-SPA.}$$

$$100\Omega_k = 0.40 \pm 0.18 \text{ for SPT-3G D1} + \text{DESI,}$$
$$100\Omega_k = 0.51 \pm 0.17 \text{ for SPT+ACT} + \text{DESI,}$$
$$100\Omega_k = 0.26 \pm 0.11 \text{ for CMB-SPA} + \text{DESI.}$$

m_e-Ω_K

Parameters	SPT-3G D1 +DESI	SPT+ACT +DESI	CMB-SPA +DESI
$H_0\,[\mathrm{km\,s^{-1}\,Mpc^{-1}}]$	70.1 ± 1.2	70.5 ± 1.2	70.6 ± 1.1
$100\,\Omega_m$	29.74 ± 0.79	29.83 ± 0.78	29.20 ± 0.68
$hr_d\,[\mathrm{Mpc}]$	102.5 ± 0.8	101.4 ± 0.7	101.9 ± 0.7
$100\left(\frac{m_e}{m_{e,0}} - 1\right)$	1.5 ± 1.1	1.6 ± 1.1	1.97 ± 0.98
$100\,\Omega_k$	0.04 ± 0.31	0.10 ± 0.30	-0.21 ± 0.25
$Q_{\mathrm{MPCL}}^{\mathrm{SH0ES}}\,[\sigma]$	2.3	2.0	1.9



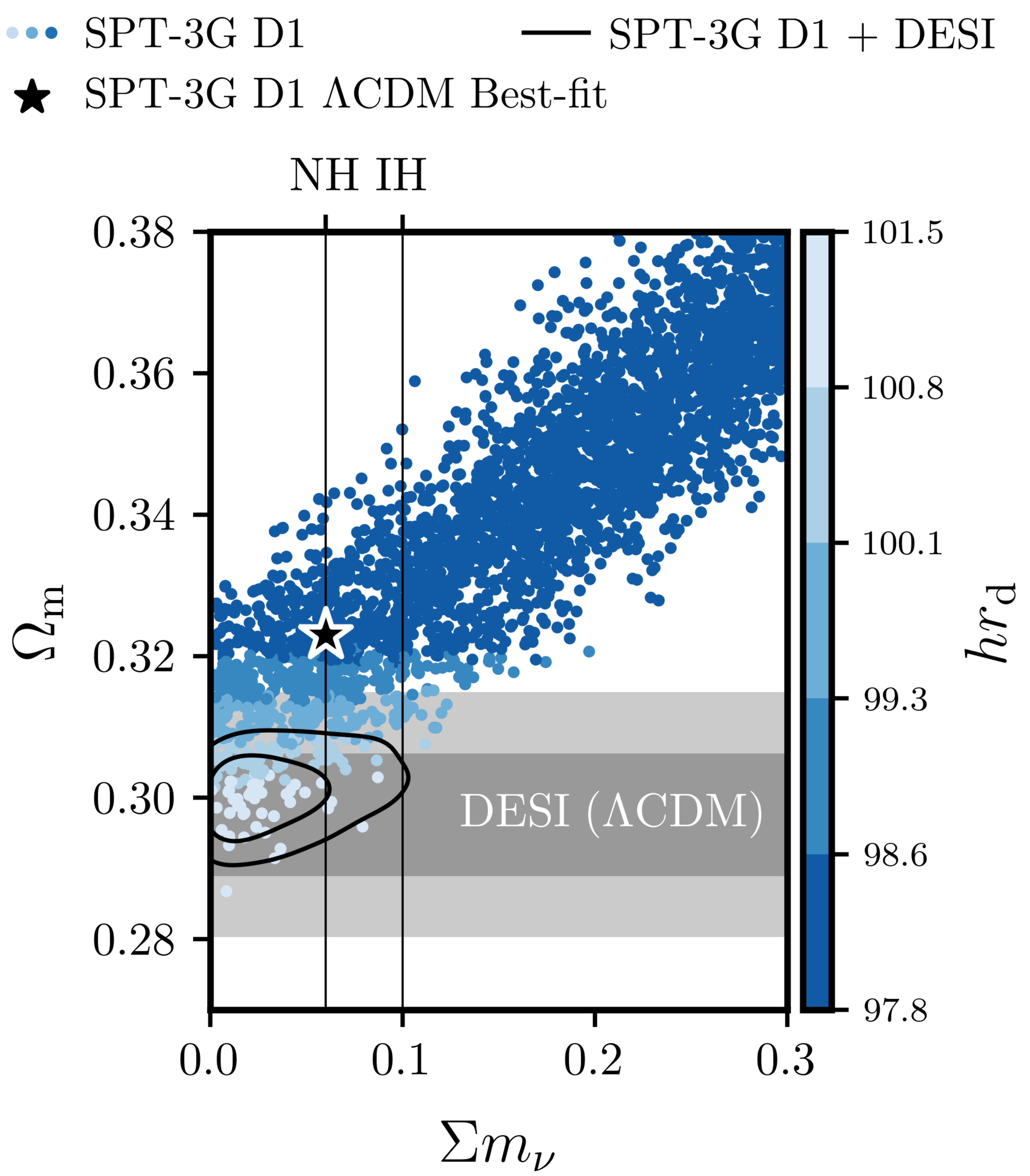
$$\sum m_\nu$$

CMB only

$$\Sigma m_\nu < 0.77\,\text{eV for SPT-3G D1,}$$
$$\Sigma m_\nu < 0.58\,\text{eV for SPT+ACT,}$$
$$\Sigma m_\nu < 0.17\,\text{eV for CMB-SPA.}$$

CMB + DESI

$$\Sigma m_\nu < 0.081\,\text{eV for SPT-3G D1 + DESI,}$$
$$\Sigma m_\nu < 0.048\,\text{eV for CMB-SPA + DESI.}$$



w_0-w_a

CMB-SPA + DESI (2.9 sigma)

$$w_0 = -0.41 \pm 0.20,$$
$$w_a = -1.78 \pm 0.55.$$

$w_\perp = 1.91 \pm 0.57$ **for CMB-SPA+DESI**