

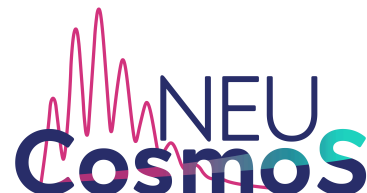
SPT-3G D1

CMB Temperature and Polarization Power Spectra and Cosmology from 2019-2020 Observations of the SPT-3G Main Field Part III

Lennart Balkenhol (IAP, Paris)
for the SPT-3G collaboration



European Research Council
Established by the European Commission



Lennart Balkenhol | CMB-France 7 | October 13th, 2025



arxiv:2506.20707

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

Etienne Camphuis



Wei Quan



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Nicholas Huang



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Cynthia Trendafilova



Silvia Galli



Tom Crawford



SPT-3G Collaboration



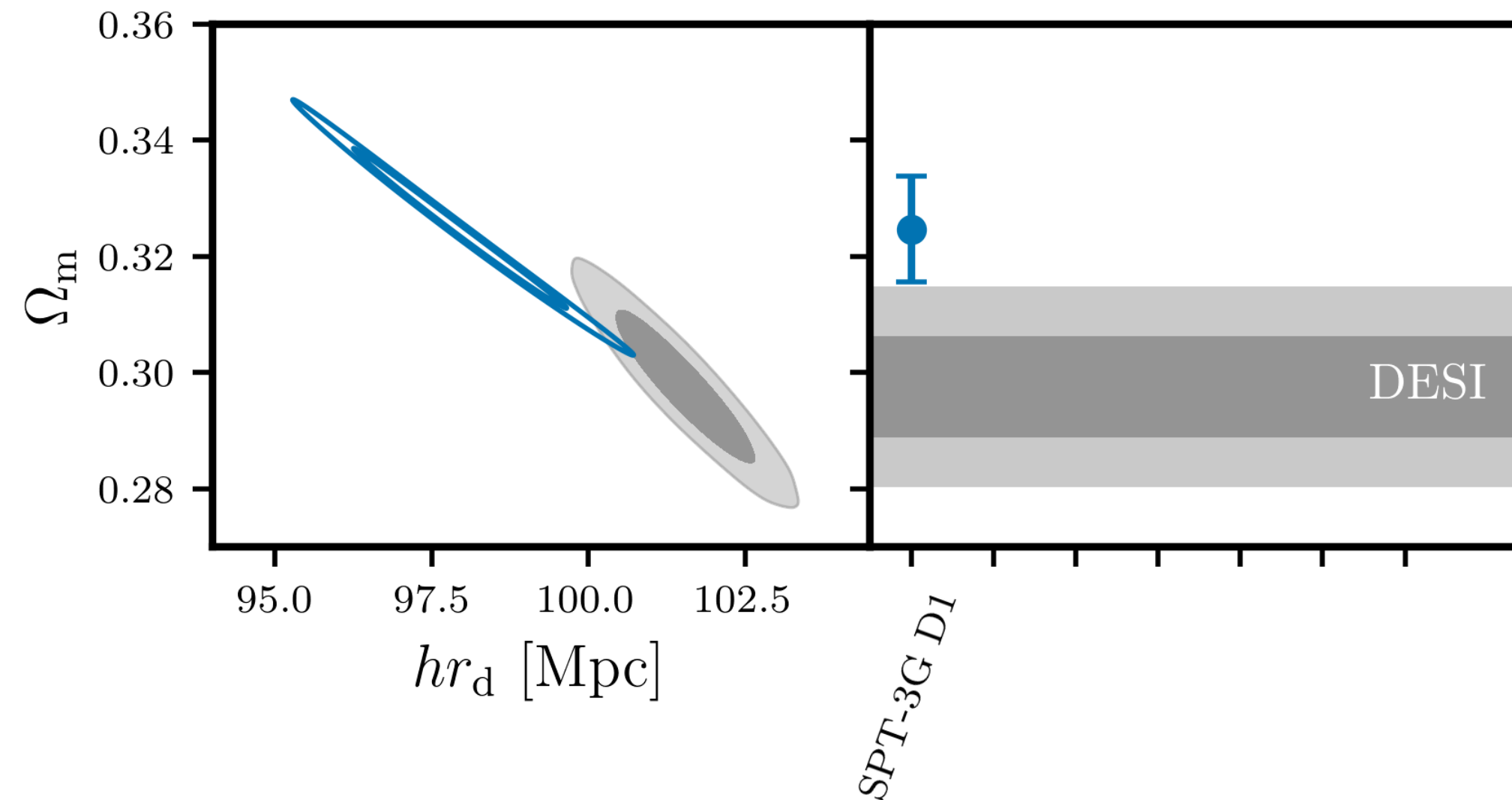
Outline

- (1) SPT-3G D1 maps and TT/TE/EE band powers
- (2) Likelihood and Λ CDM fit
- (3) Cosmology with SPT-3G lensing and CMB data sets
- (4) Cosmology with DESI DR2 BAO data**
- (5) SPT-3G D1 BB
- (6) Future of SPT-3G



Evaluating the consistency of CMB and DESI DR2 data in Λ CDM

Growing discrepancy between CMB and BAO data.

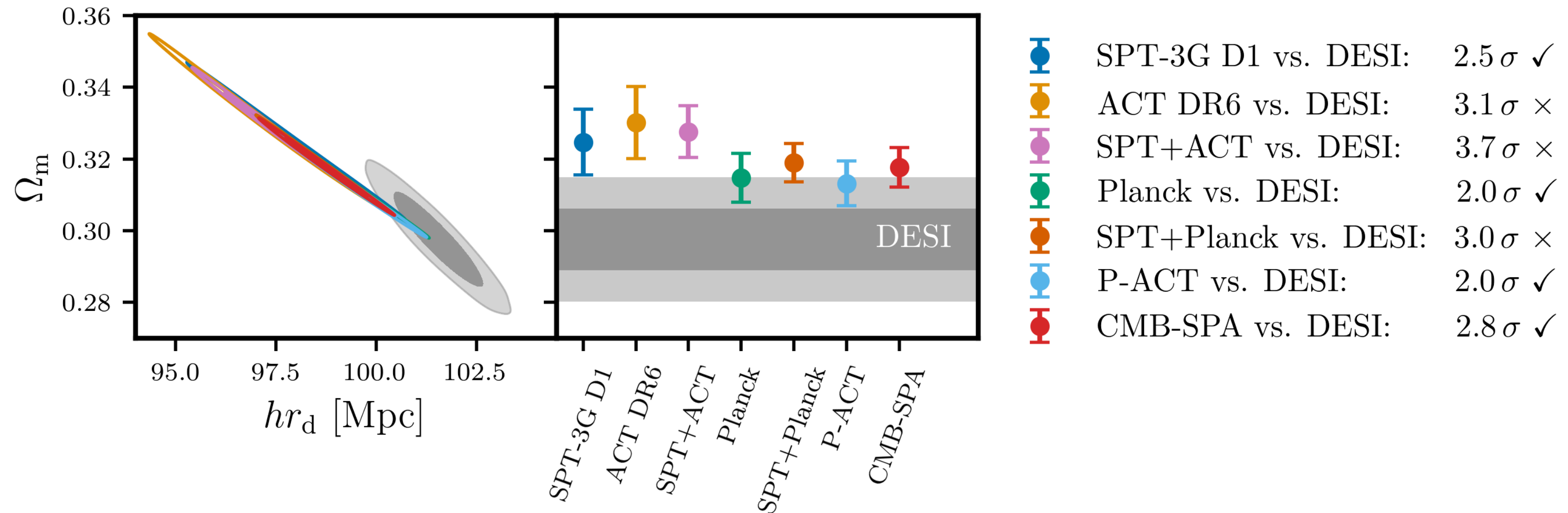


 SPT-3G D1 vs. DESI: 2.5σ ✓

DESI: [arxiv:2503.14739](https://arxiv.org/abs/2503.14739), [arxiv2503.14738](https://arxiv.org/abs/2503.14738)

Evaluating the consistency of CMB and DESI DR2 data in Λ CDM

Growing discrepancy between CMB and BAO data.



- Given borderline differences, joint analyses should be performed with caution
 - Interpret joint n_s results w.r.t. inflation with a grain of salt ([arxiv:2507.12459](https://arxiv.org/abs/2507.12459))

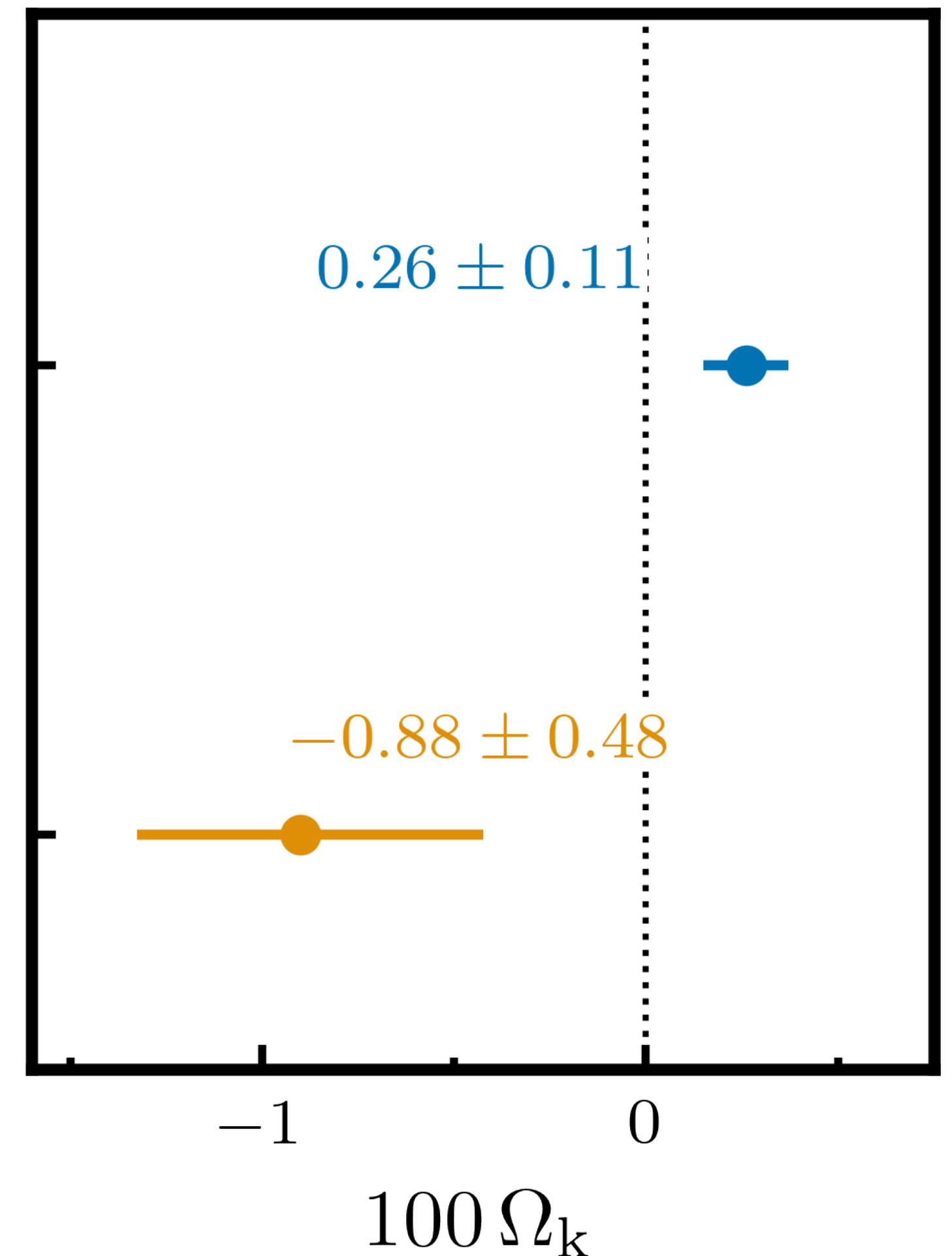
DESI: [arxiv:2503.14739](https://arxiv.org/abs/2503.14739), [arxiv2503.14738](https://arxiv.org/abs/2503.14738)

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

Model Class	Preference over Λ CDM
Rescaling of lensing in CMB	3.1 σ
Light relics	<1.5 σ
Modified recombination	2.0 σ
Spatial curvature	2.5σ
Spatial curvature and varying electron mass	2.1 σ
Neutrino mass	2.8 σ
Dynamical dark energy	3.2 σ
Axion early dark energy	$\sim 3\sigma$

CMB-SPA
+DESI

CMB-SPA



Constraints from CMB and DESI

- With current data, **no definitive evidence for a breakdown of Λ CDM**
 - Evidence is moderate, 3σ -level
 - So far no detection by individual probe
 - Statistical fluctuation or systematic origin not ruled out

More data needed for a stronger judgement (CMB, BAO, others)

Likelihood is public

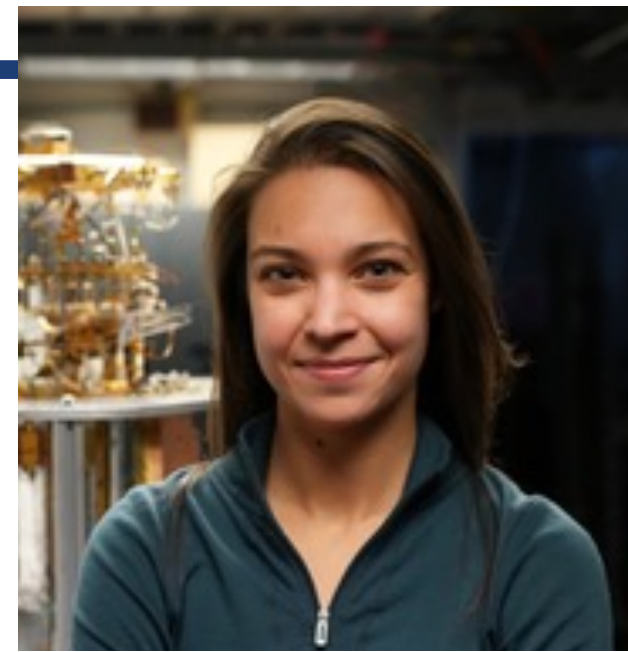
https://github.com/SouthPoleTelescope/spt_candl_data

MCMC chains are public

https://lambda.gsfc.nasa.gov/product/spt/spt3g_d1_bandp_liklyhood_info.html

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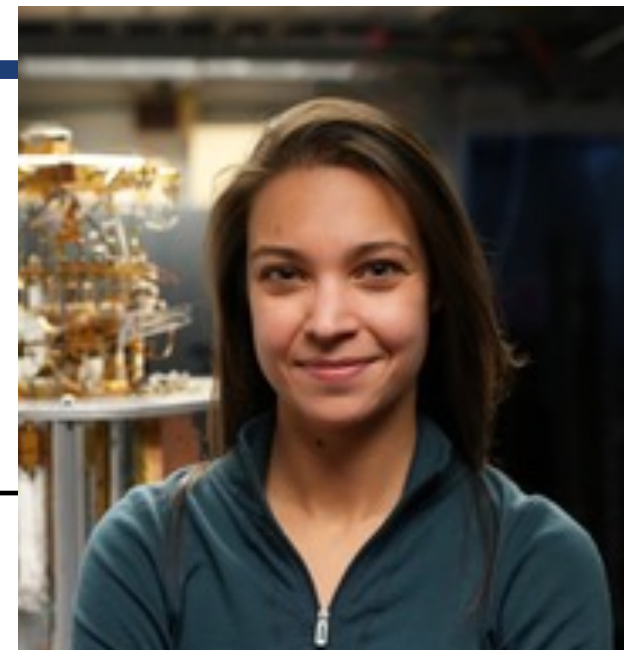
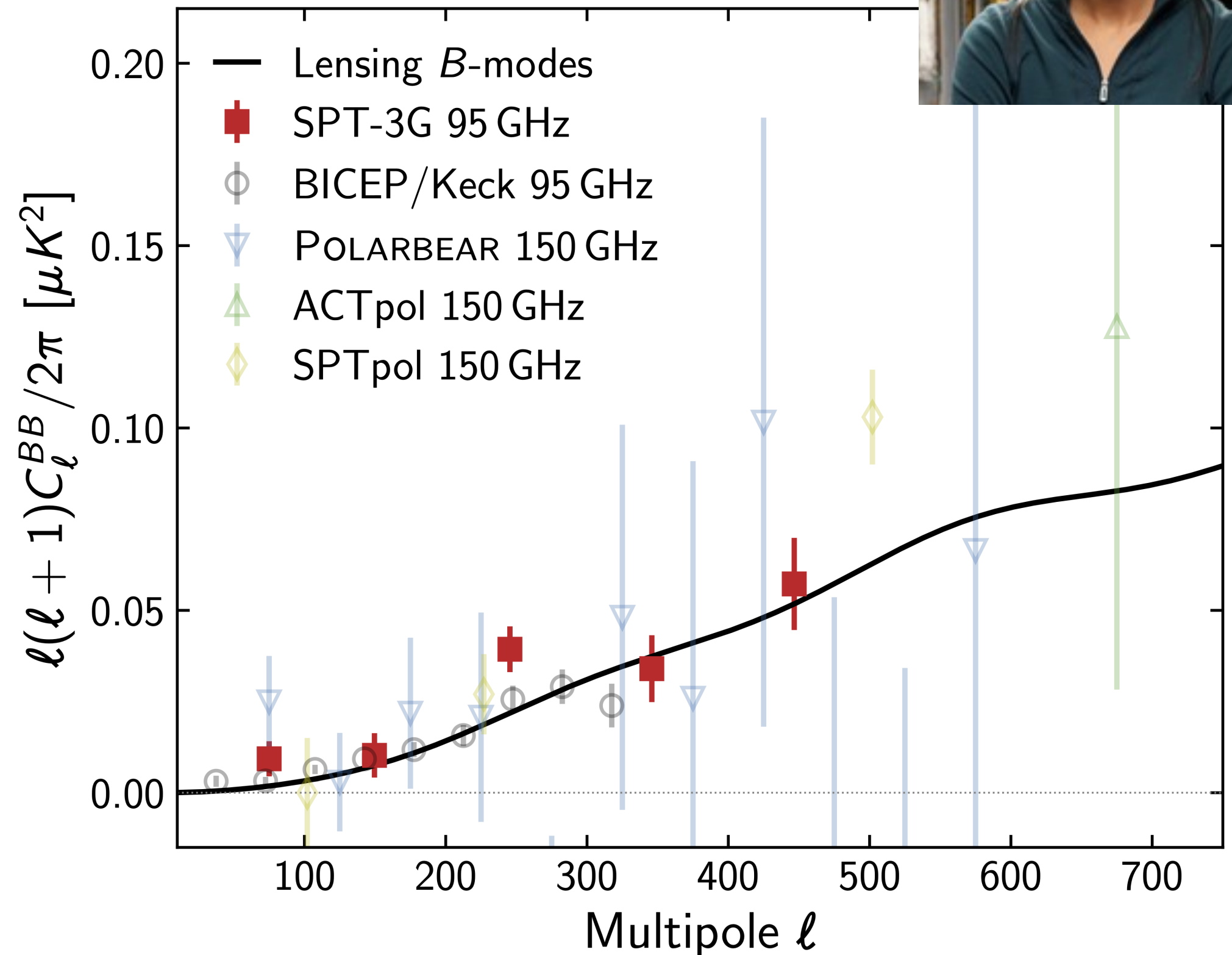


Constraints on Inflationary Gravitational Waves with Two Years of SPT-3G Data

J. A. Zebrowski et al., 2025

- Using the SPT-3G D1 data, focusing on the large scale B-modes, we find $r < 0.25$ from SPT-3G alone
- Proof of concept for LAT-based large scale B-mode analysis, with development of new analysis techniques (namely for polarized atmosphere)

[arxiv:2505.02827](https://arxiv.org/abs/2505.02827)



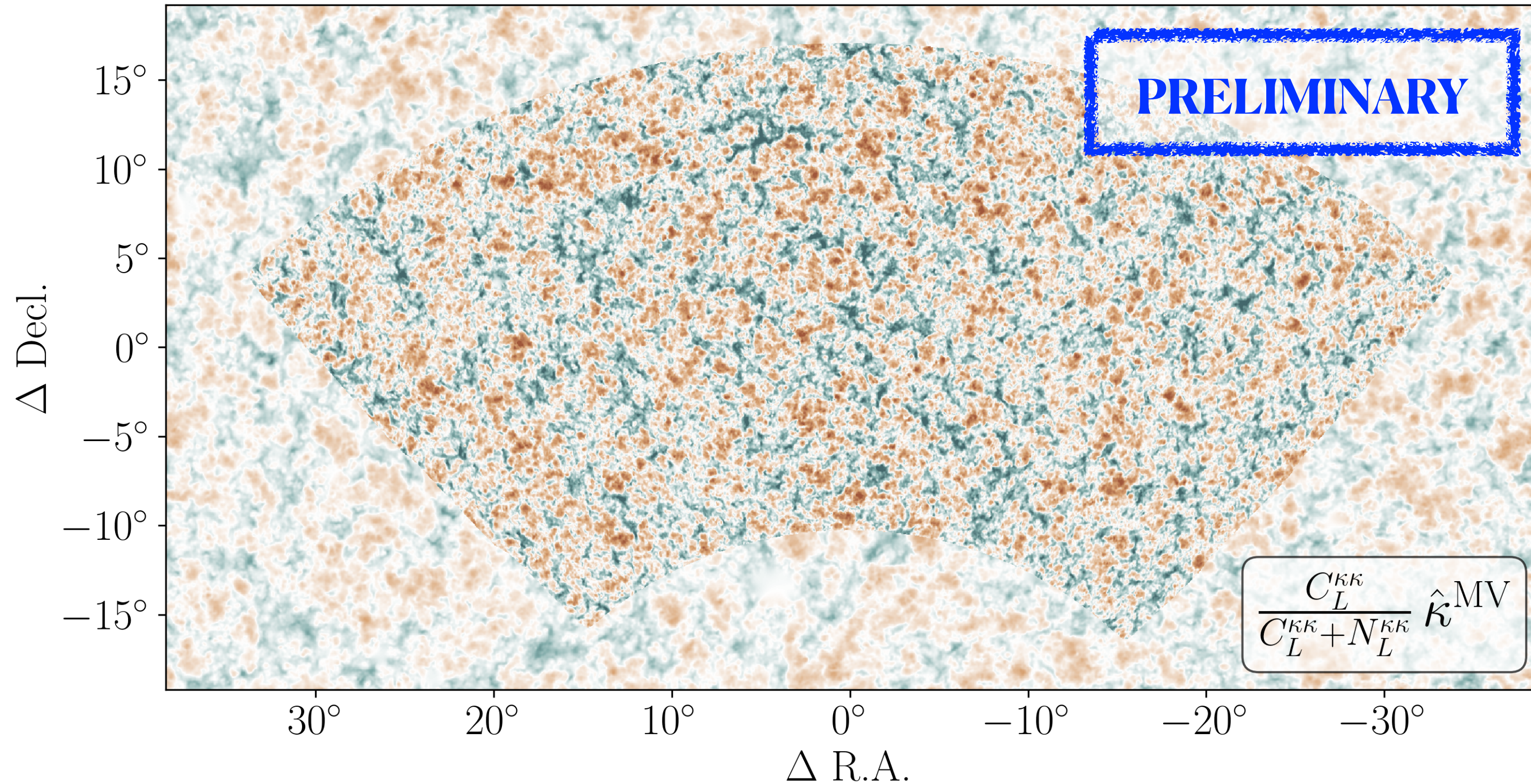
Outline



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SPT-3G D1 QE

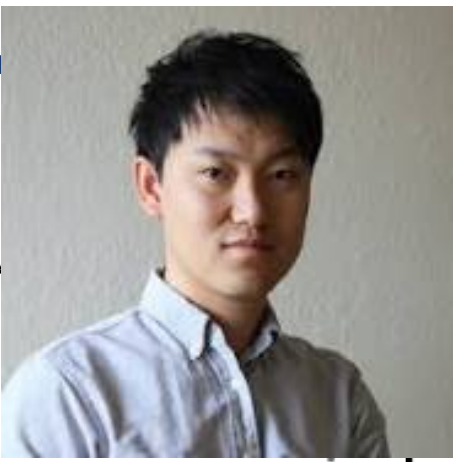
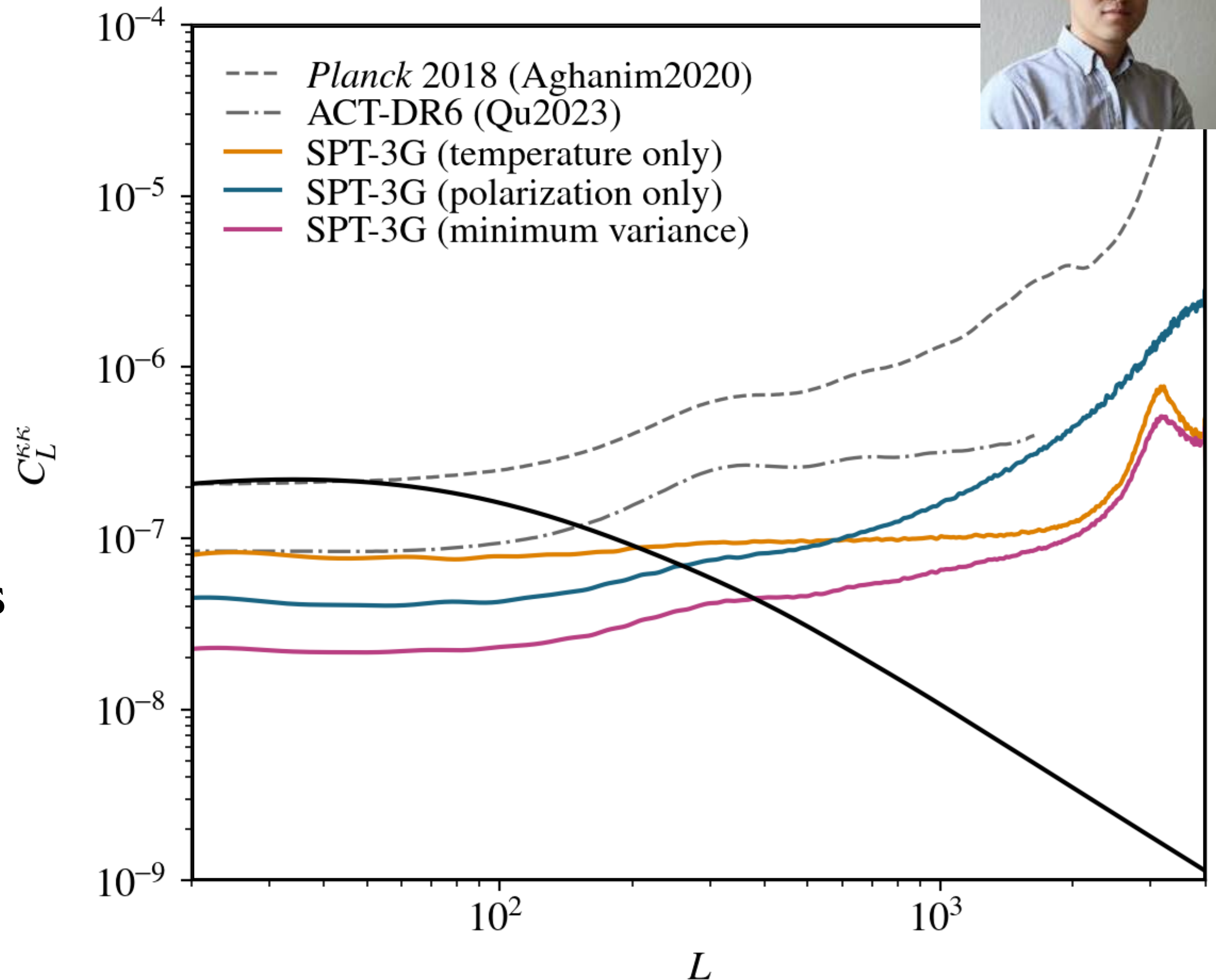
SPT vs. Planck Convergence: Signal-Dominated Scales



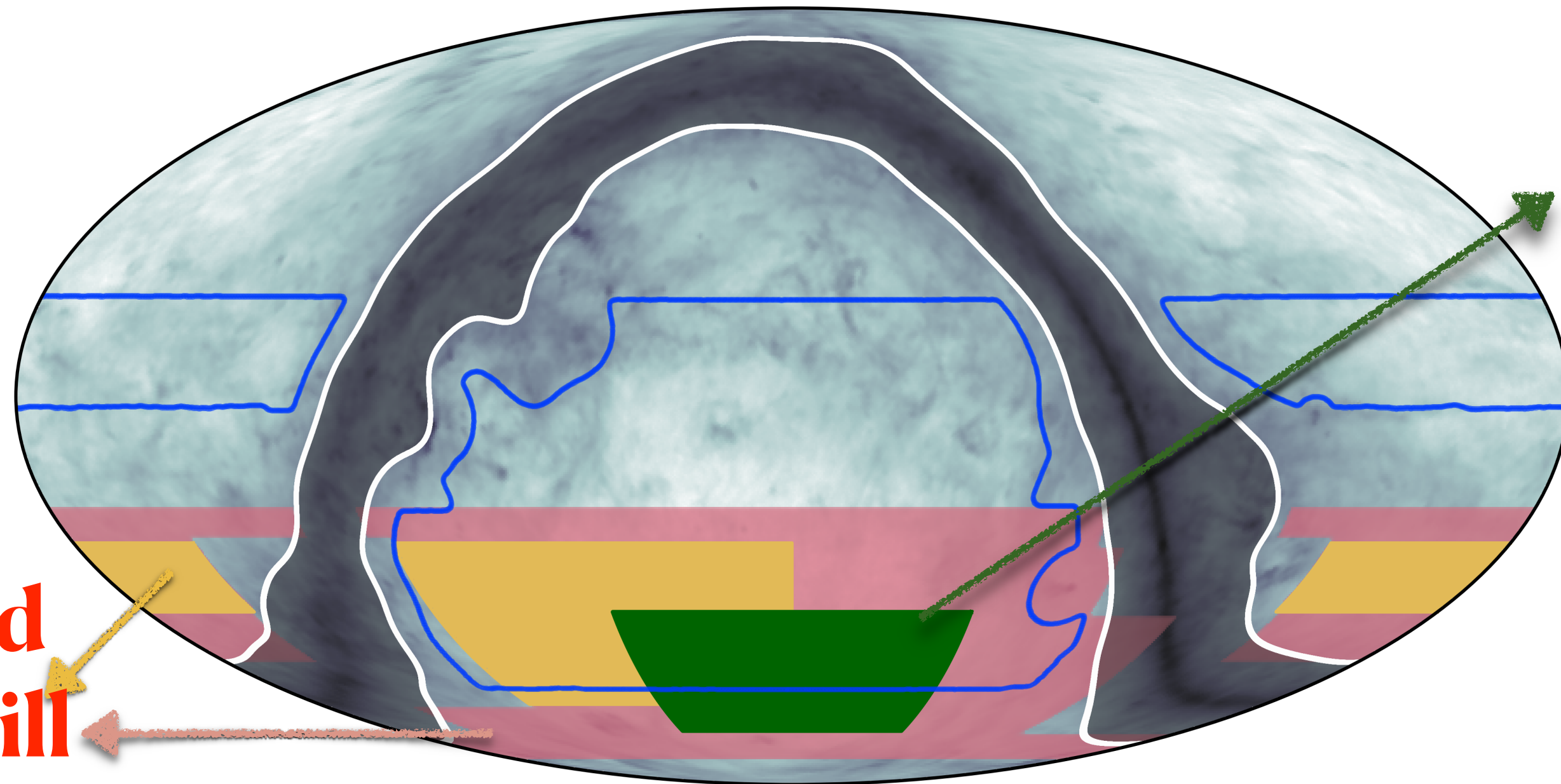
SPT-3G D1 QE

Work led by Y. Omori, F. Bianchini,
W.L.K.Wu, Y. Nakato ++

- SPT-3G D1 maps
- Uses **both temperature and polarization**, but polarization dominates at large angular scales.
- Will be used for cross-correlations with LSS surveys (DES/Euclid/Rubin etc.), as well as delensing BICEP/Keck.



Credit: Federica Guidi



**Main field
(All we just
discussed)**

**Summer and
Wide field will
bring in more
data**

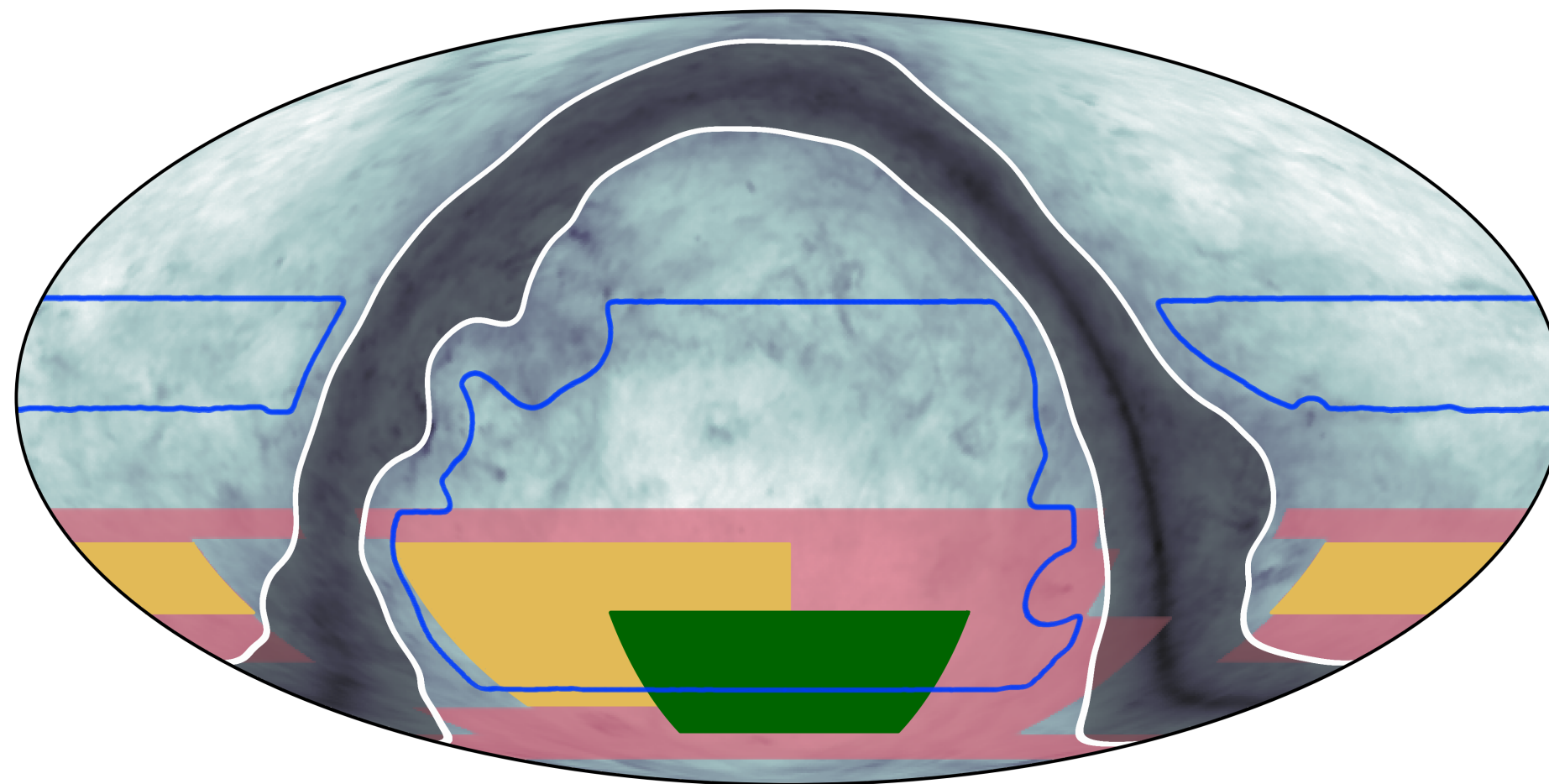
■ SPT-3G Main (this work)
■ Planck galactic mask

■ SPT-3G Summer
— ACT DR6

■ SPT-3G Wide

Extended fields

With SPT-3G

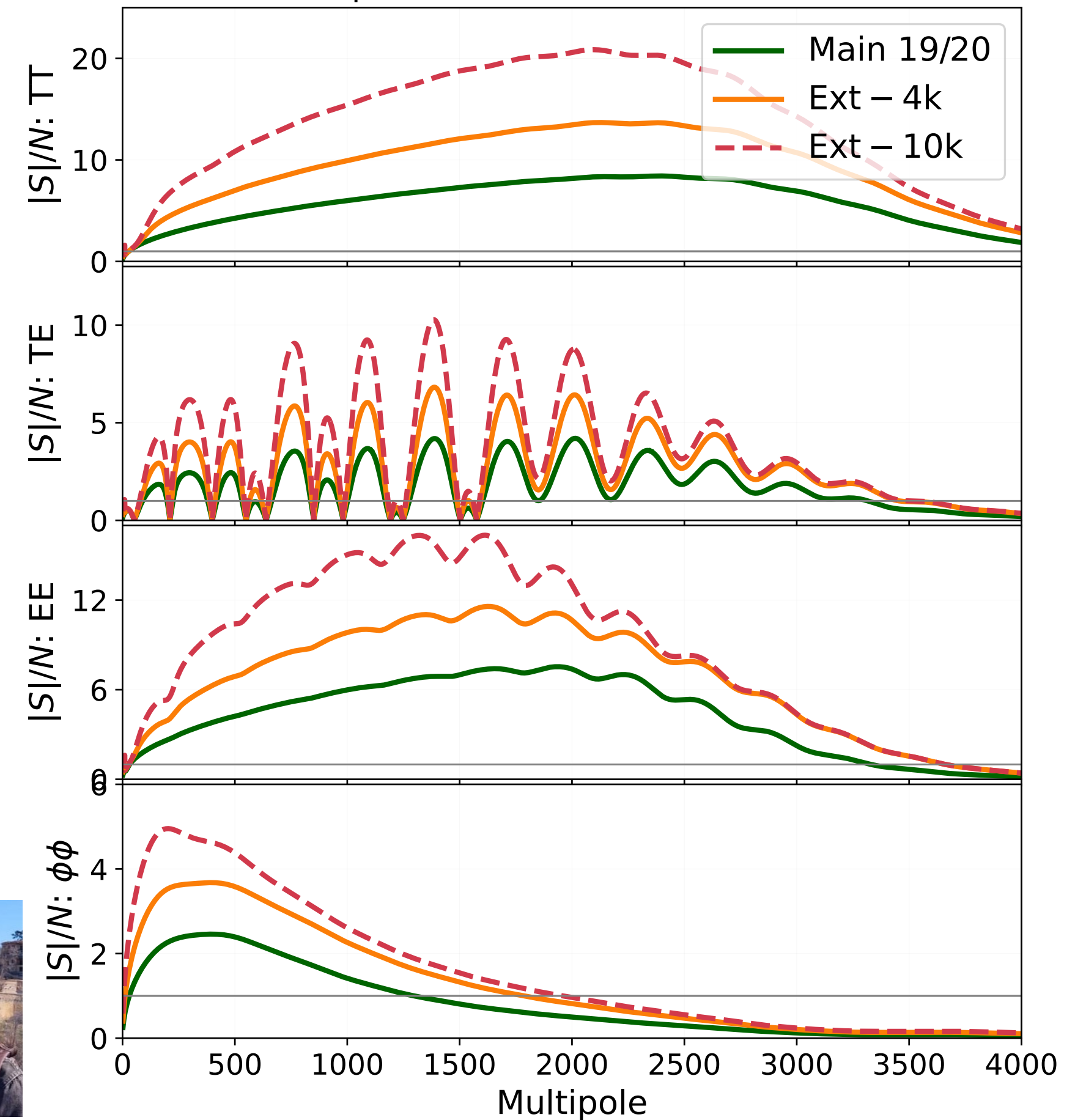


■ SPT-3G Main (this work) ■ SPT-3G Summer ■ SPT-3G Wide
■ Planck galactic mask — ACT DR6

- **Ext-4k: main + summer (F. Guidi, IAP)**
- **Ext-10k: main + summer + wide (A. Vitrier, IAP)**



SNR curves
Adapted from [Prabhu et al., 2024]

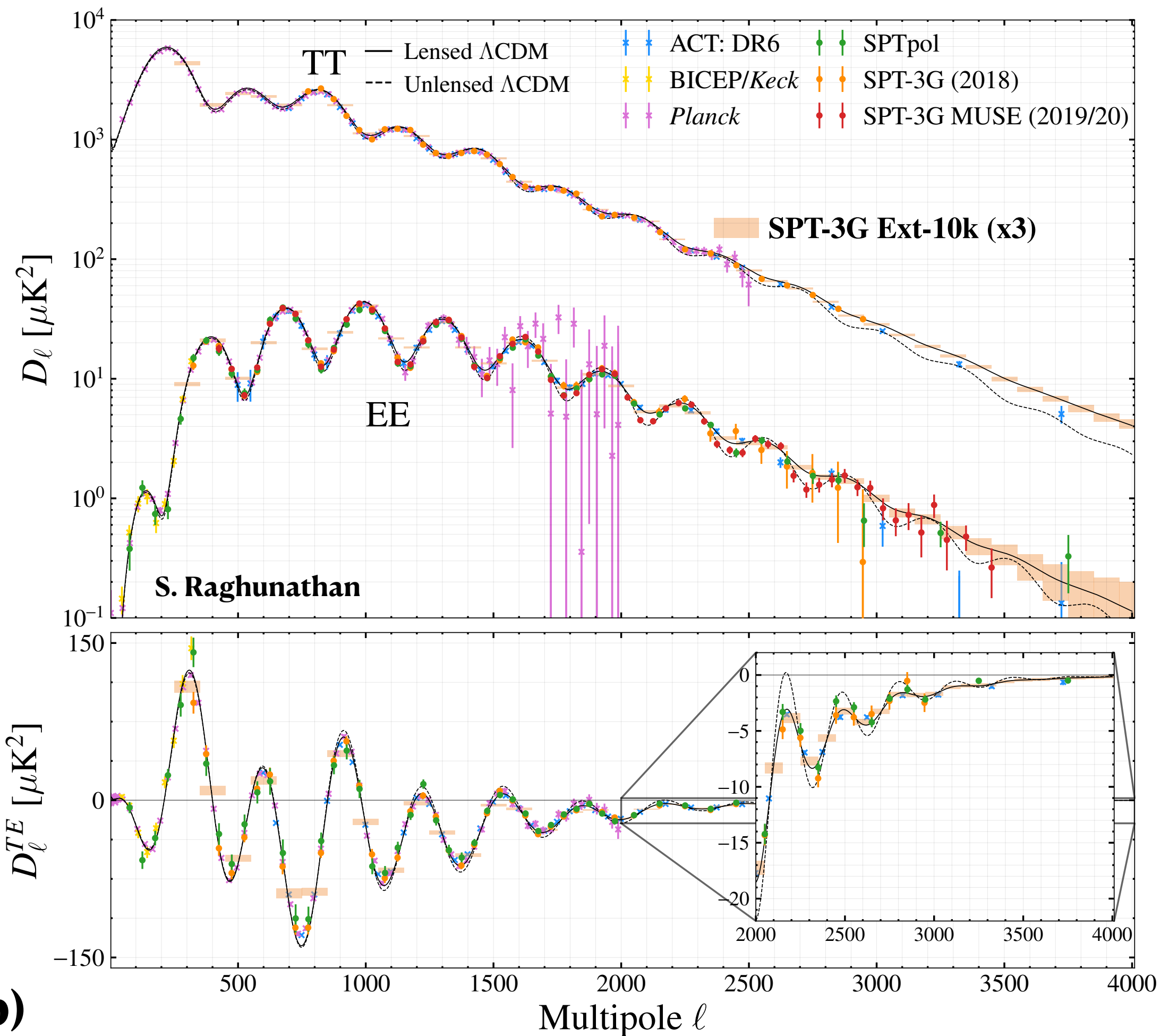


Extended fields

With SPT-3G

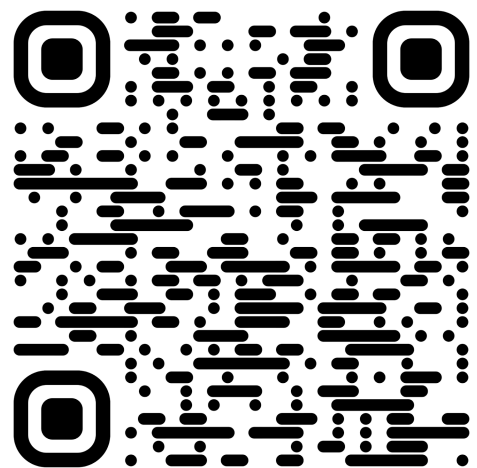
- **Ext-10k: main + summer + wide**
- Combined Ext-10k survey will improve on Planck constraints by as much as
 - 2x for Λ CDM parameters
 - 3x for single-parameter extensions!

arxiv:2403.17925, Vitrier et al. (in prep)

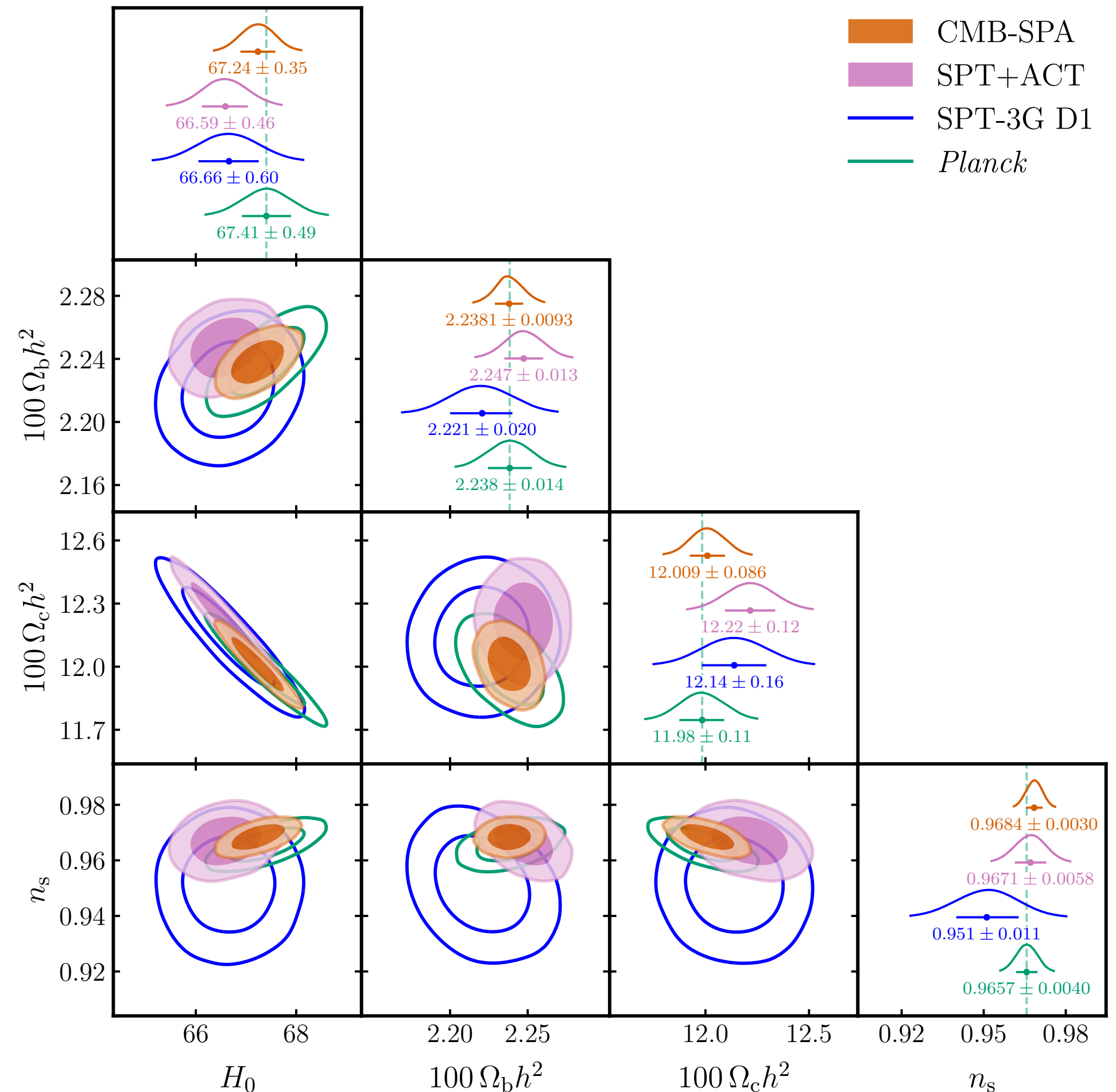


Conclusions

- SPT-3G D1 data provide the tightest measurement of TE and EE on the small scales
- CMB data is well described by Λ CDM and provides tight constraints on cosmological parameters
- Ground-based experiments have comparable constraining power as *Planck*
- Growing discrepancy between CMB and DESI data, which projects on Λ CDM extensions
- **SPT-3G D1 is only the beginning for SPT-3G!**



- Please checkout paper and likelihood at
<https://pole.uchicago.edu/public/data/camphuis25>



Back-up

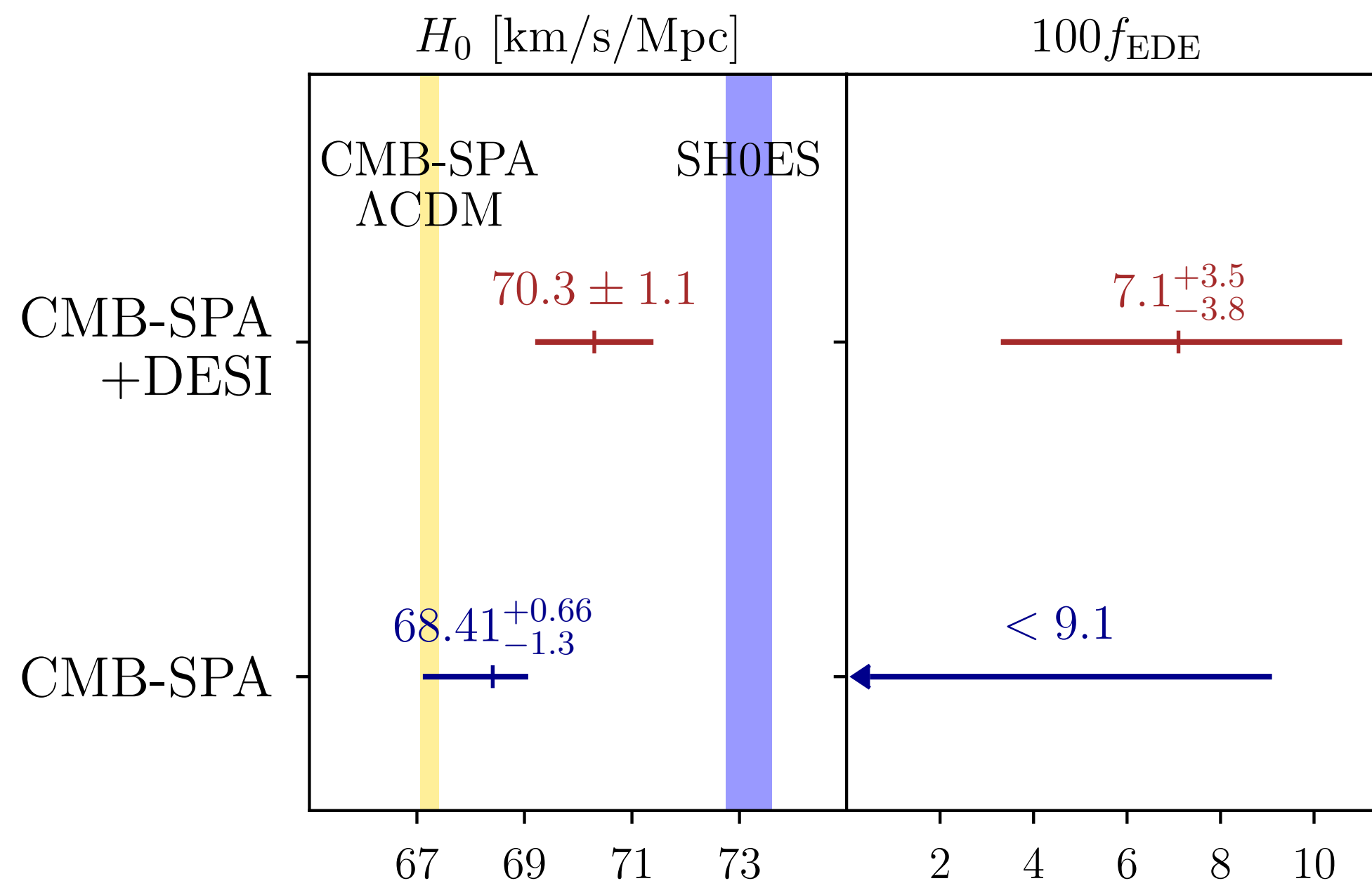
Λ CDM

Parameter	<i>Planck</i>	SPT-3G D1	ACT DR6	SPT+ACT	SPT+ <i>Planck</i>	CMB-SPA
<i>Sampled</i>						
$10^4 \theta_s^*$	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
<i>Derived</i>						
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
$10^9 A_s e^{-2\tau_{\text{reio}}}$	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

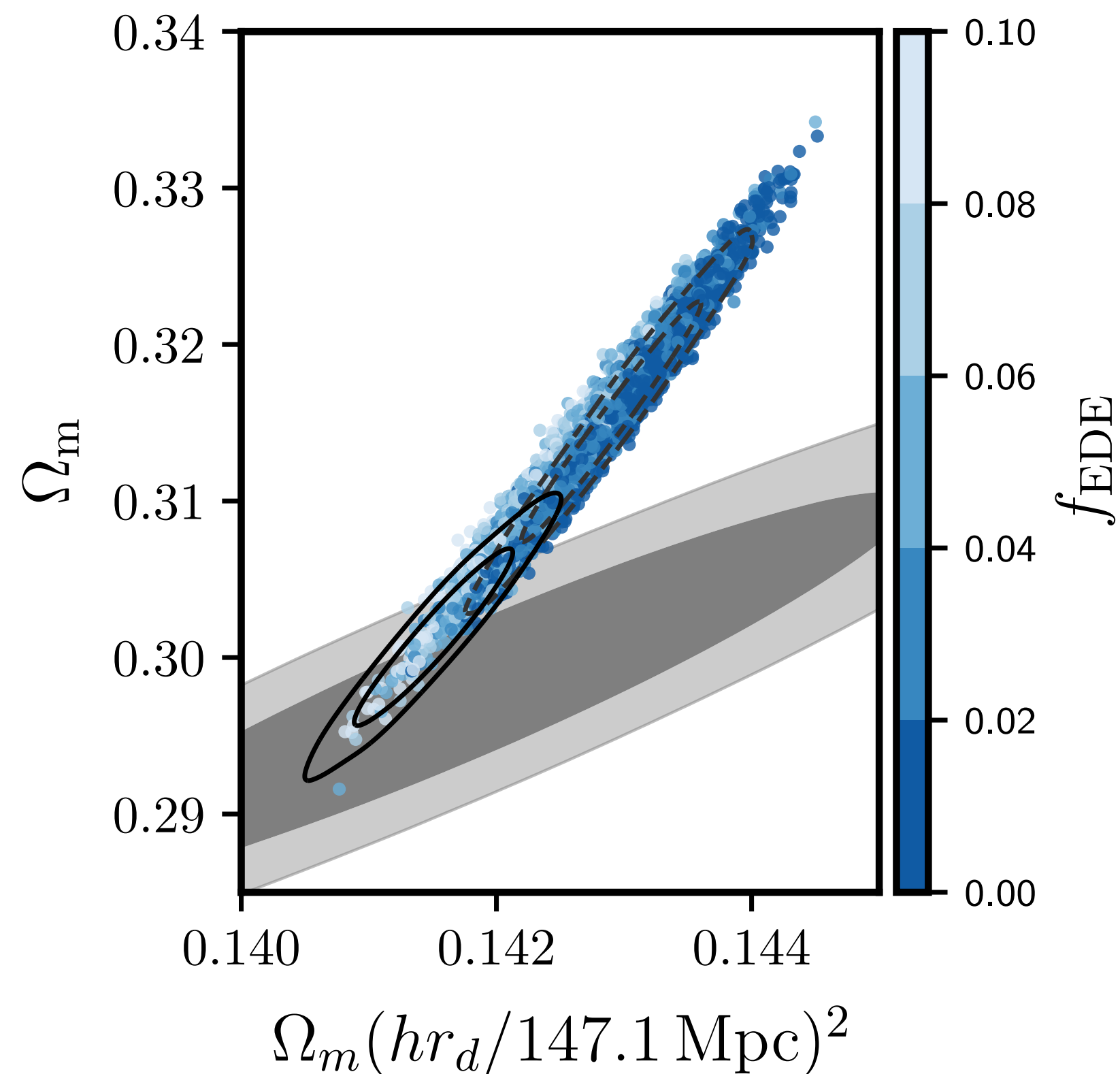


Axion early dark energy

Khalife et al., arxiv:2507.23355



--- Λ CDM: CMB-SPA $\bullet\bullet$ EDE: CMB-SPA
 — Λ CDM: DESI — EDE: CMB-SPA + DESI



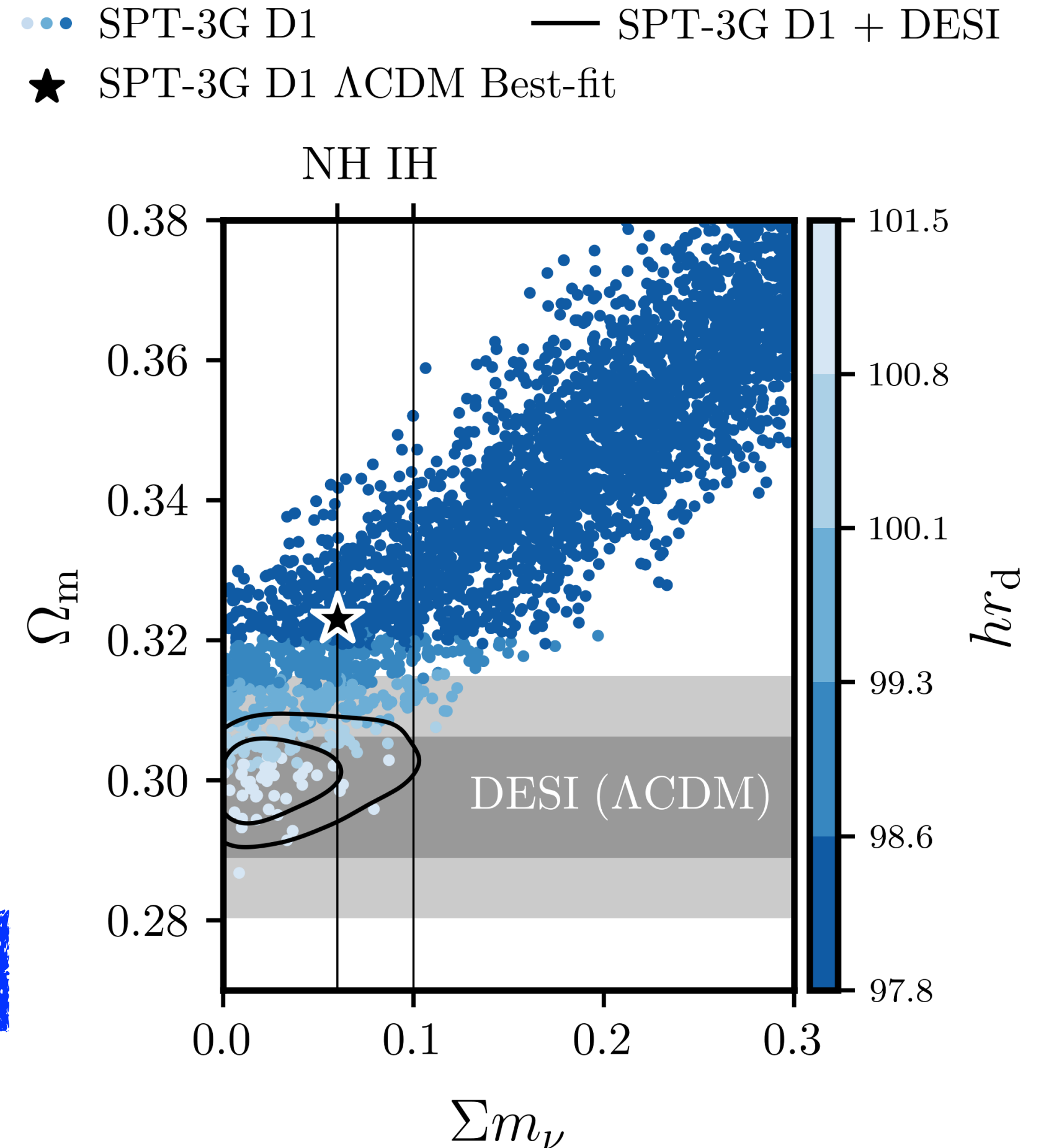
$$\Sigma m_\nu$$

CMB only (95% C.L.)

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

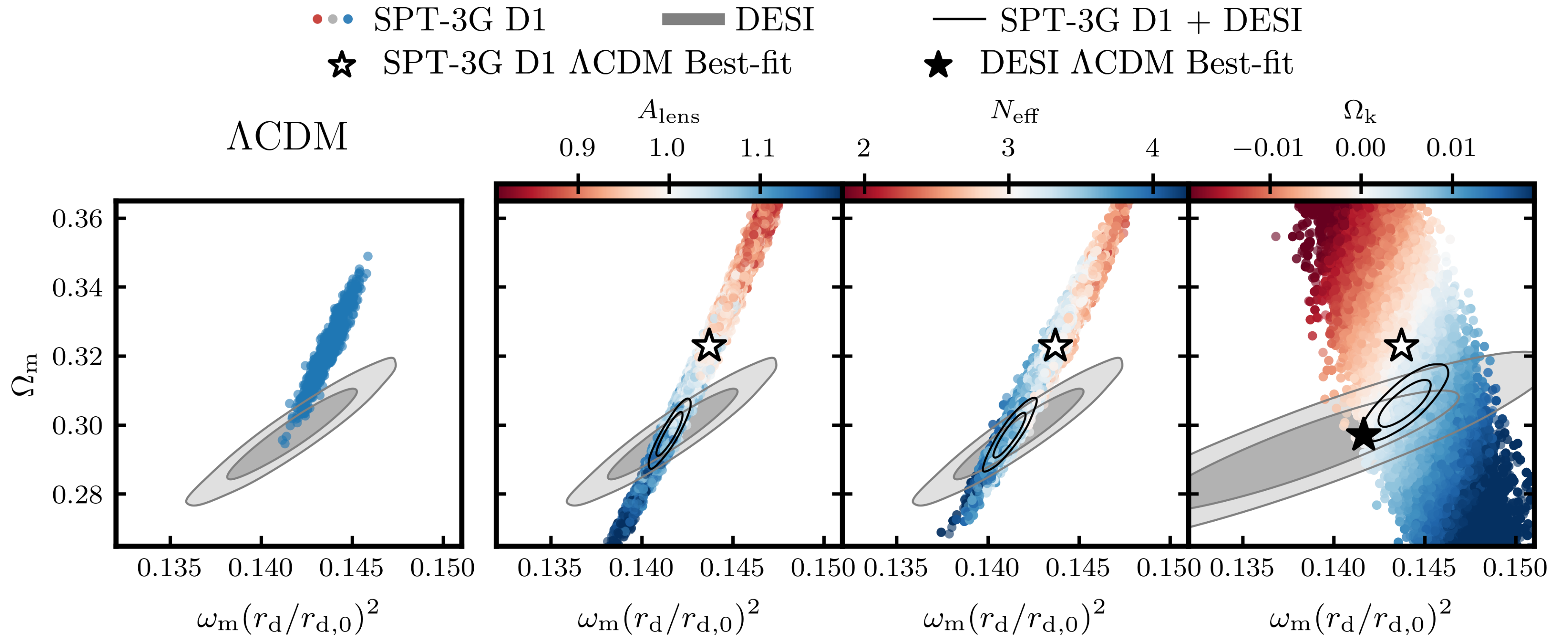
CMB + DESI (95% C.L.)

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



Combining CMB and BAO data

Discrepancy can project on Λ CDM extensions

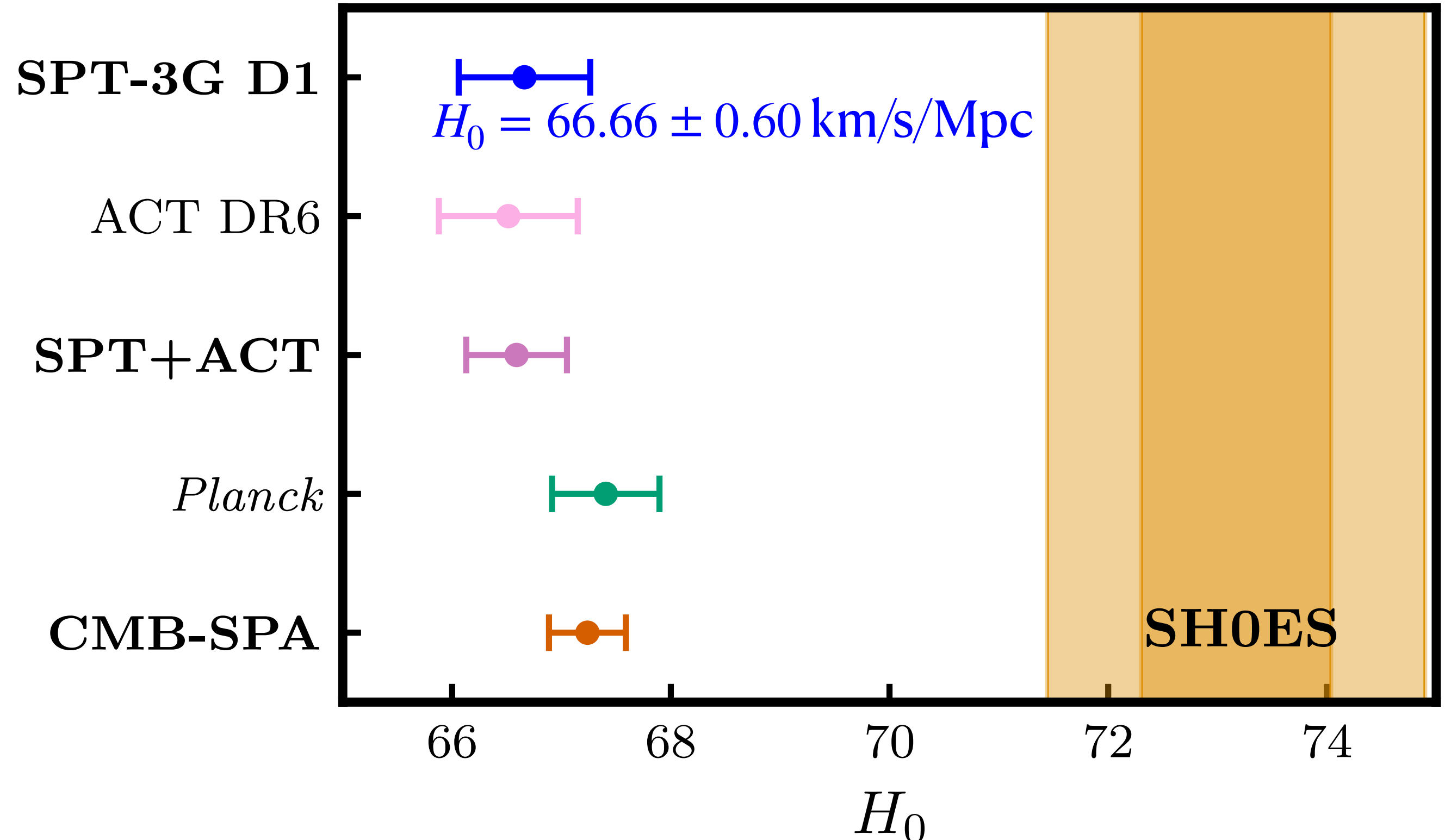


H_0 tension with SH0ES

Breuval et al., 2024

$$H_0 = 73.17 \pm 0.86 \text{ km/s/Mpc}$$

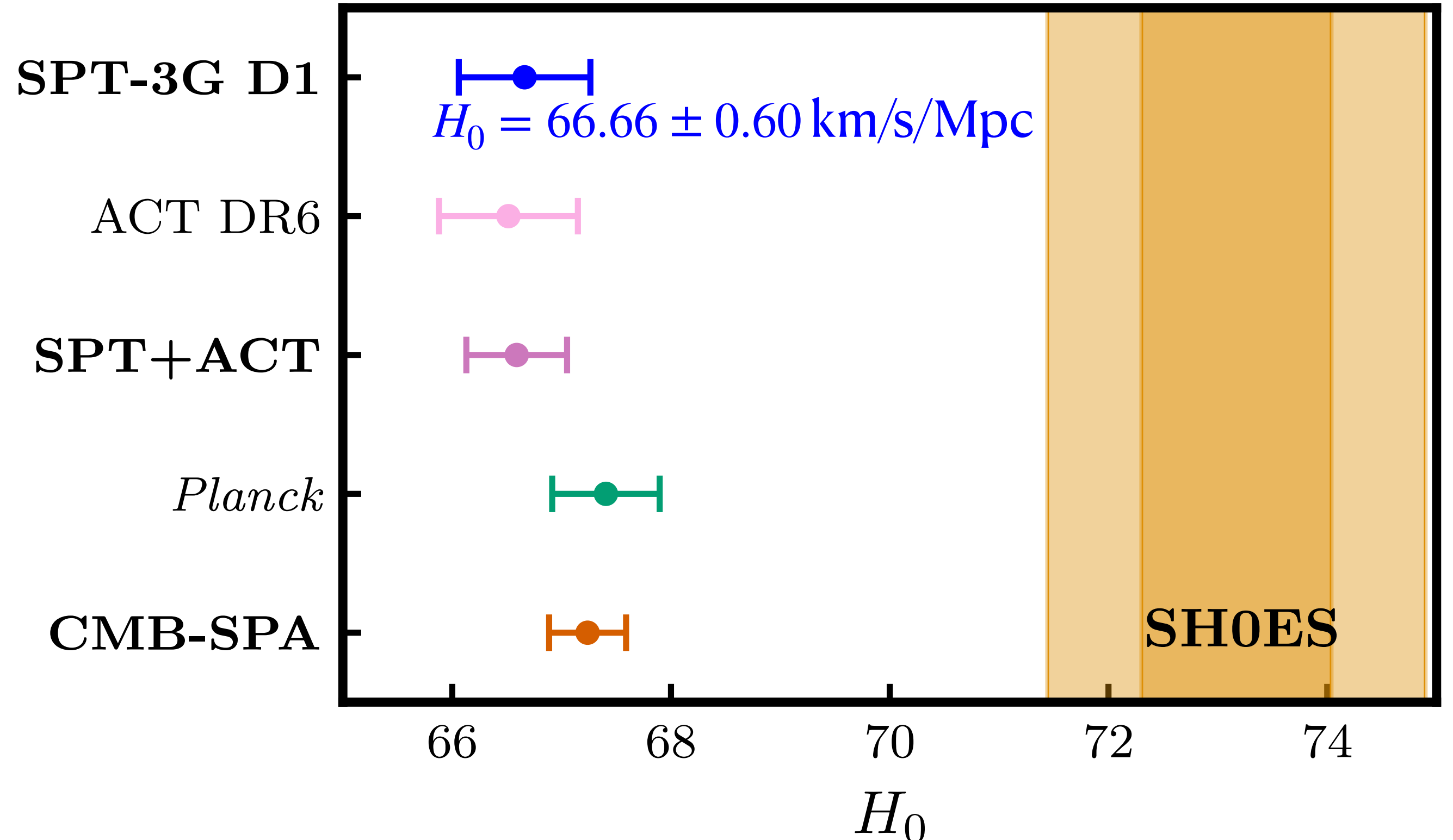
- Hubble tension at 6.2σ from SPT-3G alone.
- SPT+ACT and CMB-SPA are at 6.8σ and 6.4σ tension, respectively.



H_0 tension

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



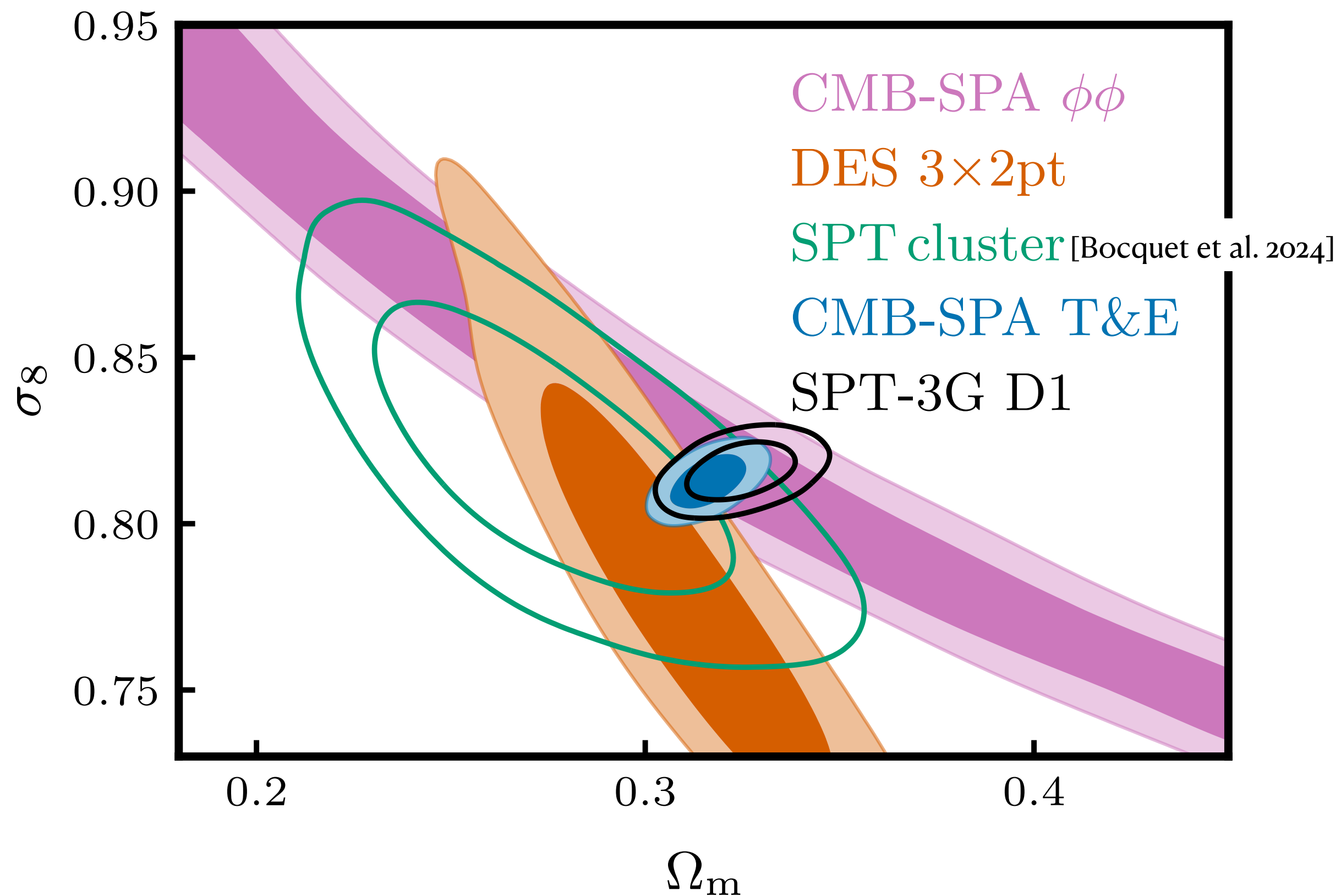
σ_8 - Ω_m

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

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

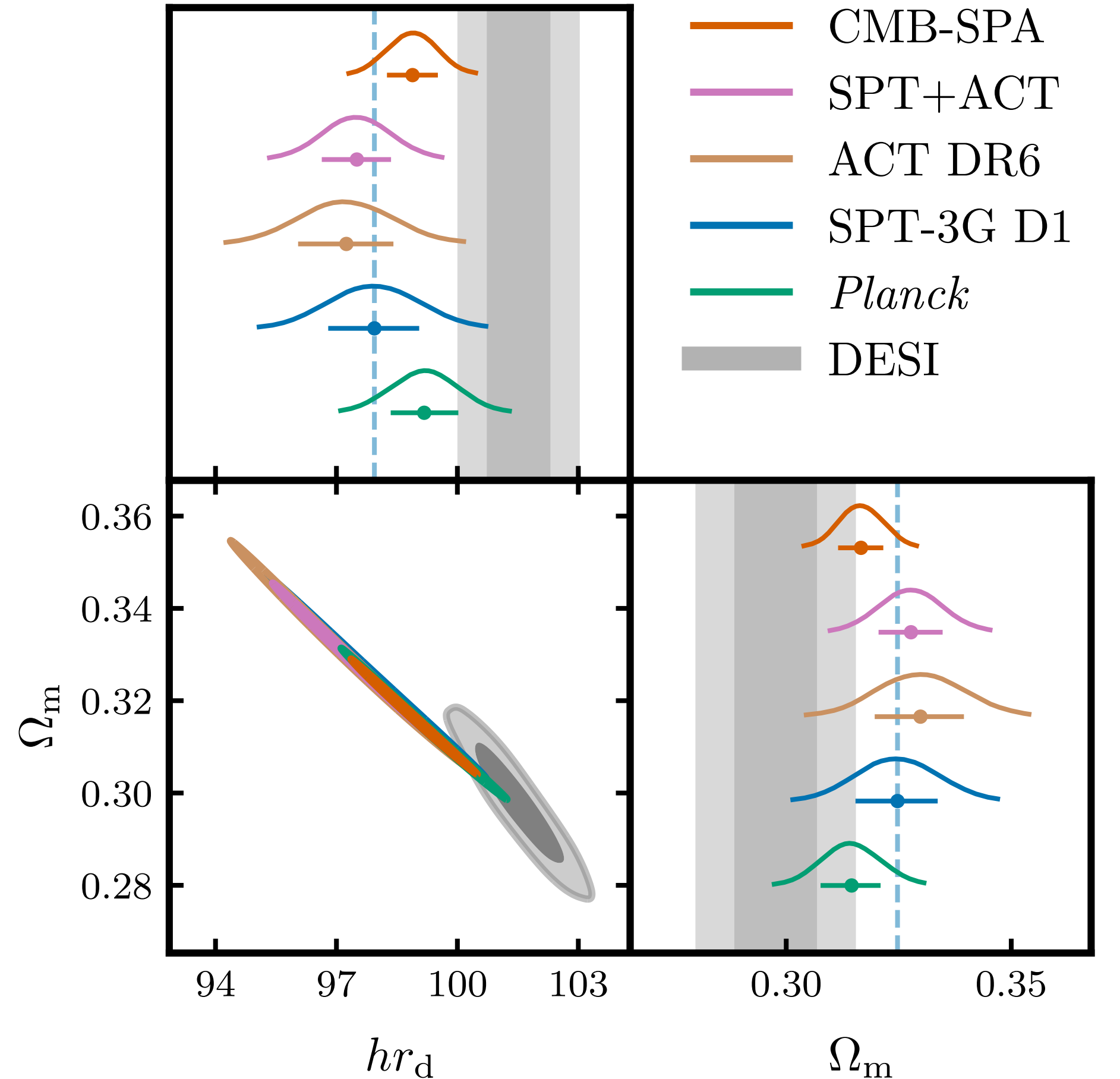
$$\left. \begin{array}{l} \sigma_8 = 0.8137 \pm 0.0038, \\ \Omega_m = 0.3166 \pm 0.0051 \end{array} \right\} \text{ for CMB-SPA.}$$

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



Consistency of CMB and BAO in Λ CDM

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



Consistency of CMB and BAO in Λ CDM

	$100\,\Omega_{\rm m}$	$hr_{\rm d}$ [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+ <i>Planck</i>	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	$2.5\,\sigma$
<i>Planck</i>	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
<i>Sampled</i>		
$10^4\theta_{\rm s}^{\star}$	104.227 ± 0.056	104.180 ± 0.022
$100\,\Omega_{\rm b}h^2$	2.218 ± 0.022	2.2452 ± 0.0089
$100\,\Omega_{\rm c}h^2$	11.749 ± 0.079	11.813 ± 0.058
$n_{\rm s}$	0.949 ± 0.012	0.9728 ± 0.0027
$\log(10^{10}\,A_{\rm s})$	3.066 ± 0.014	3.0574 ± 0.0094
$\tau_{\rm reio}$	0.0559 ± 0.0056	0.0625 ± 0.0050
<i>Derived</i>		
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
$10^9\,A_{\rm s}e^{-2\tau_{\rm reio}}$	1.920 ± 0.021	1.8773 ± 0.0055
Ω_{Λ}	0.6983 ± 0.0039	0.6950 ± 0.0033
$\Omega_{\rm m}$	0.3017 ± 0.0039	0.3049 ± 0.0033
$r_{\rm d}$ [Mpc]	147.99 ± 0.33	147.51 ± 0.17
σ_8	0.8079 ± 0.0059	0.8120 ± 0.0038

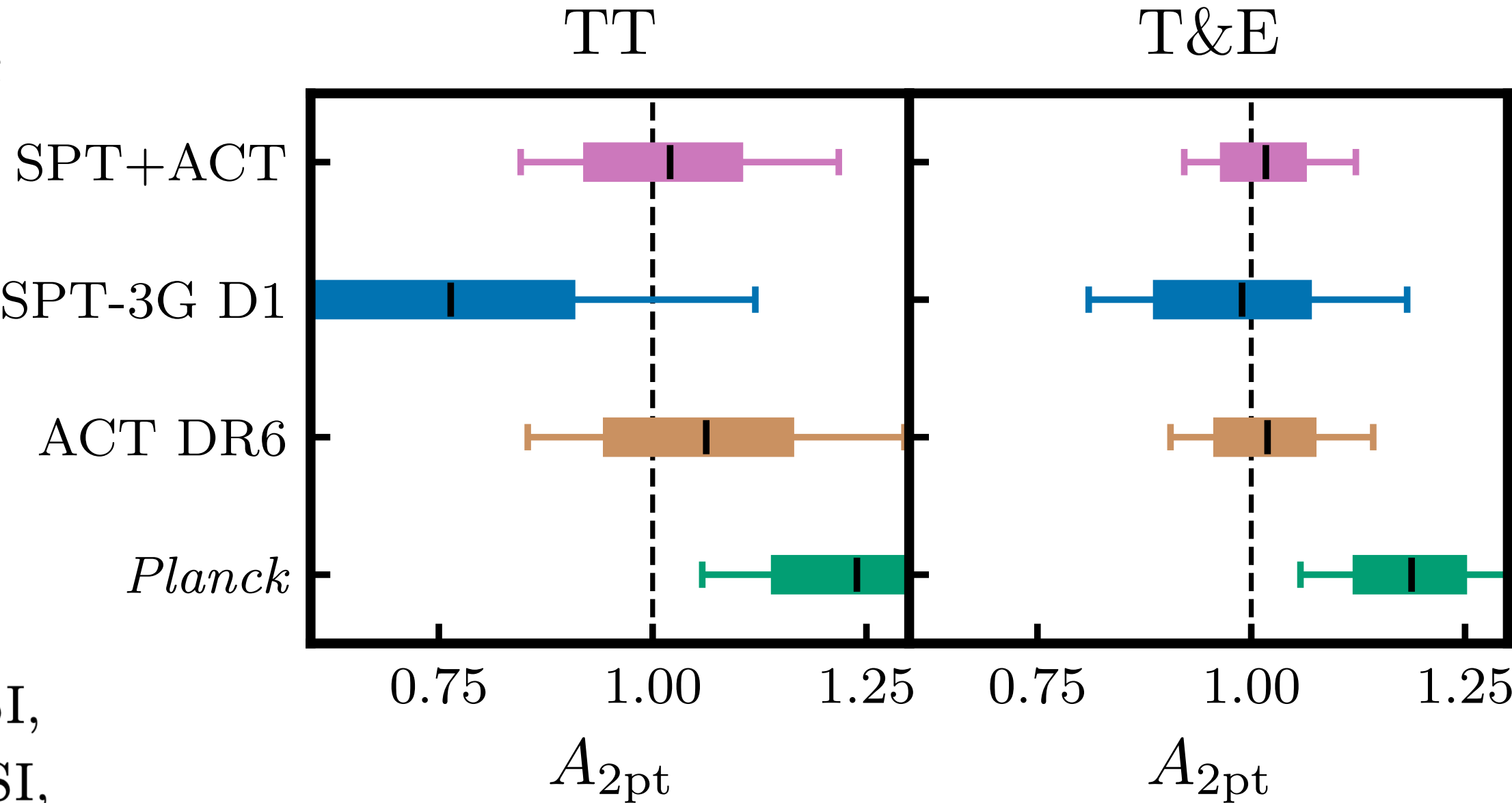
Lensing amplitude

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

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

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

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



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

New light particles

$$N_{\text{eff}} = 3.17^{+0.29}_{-0.33} \text{ for SPT-3G D1,}$$

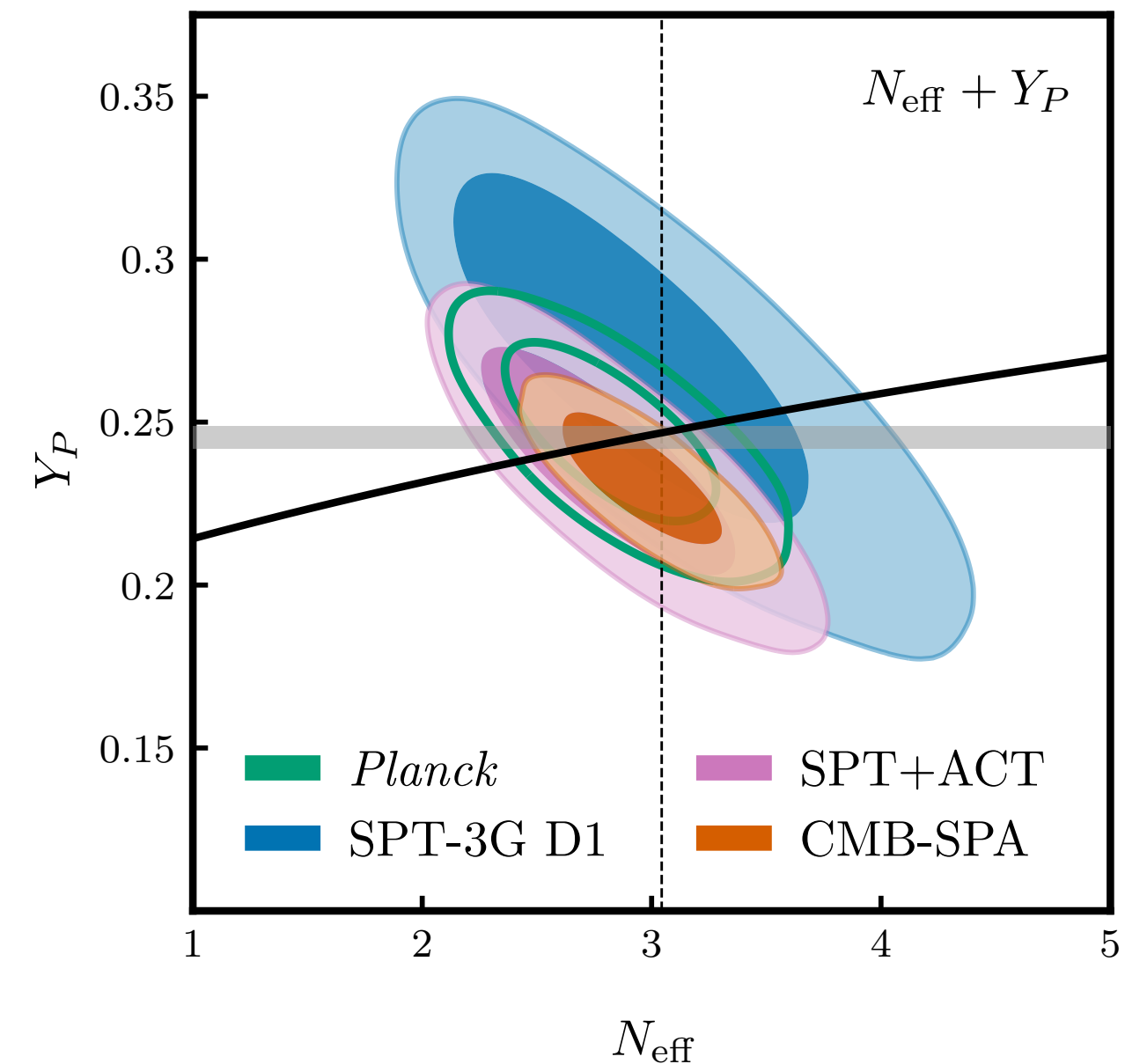
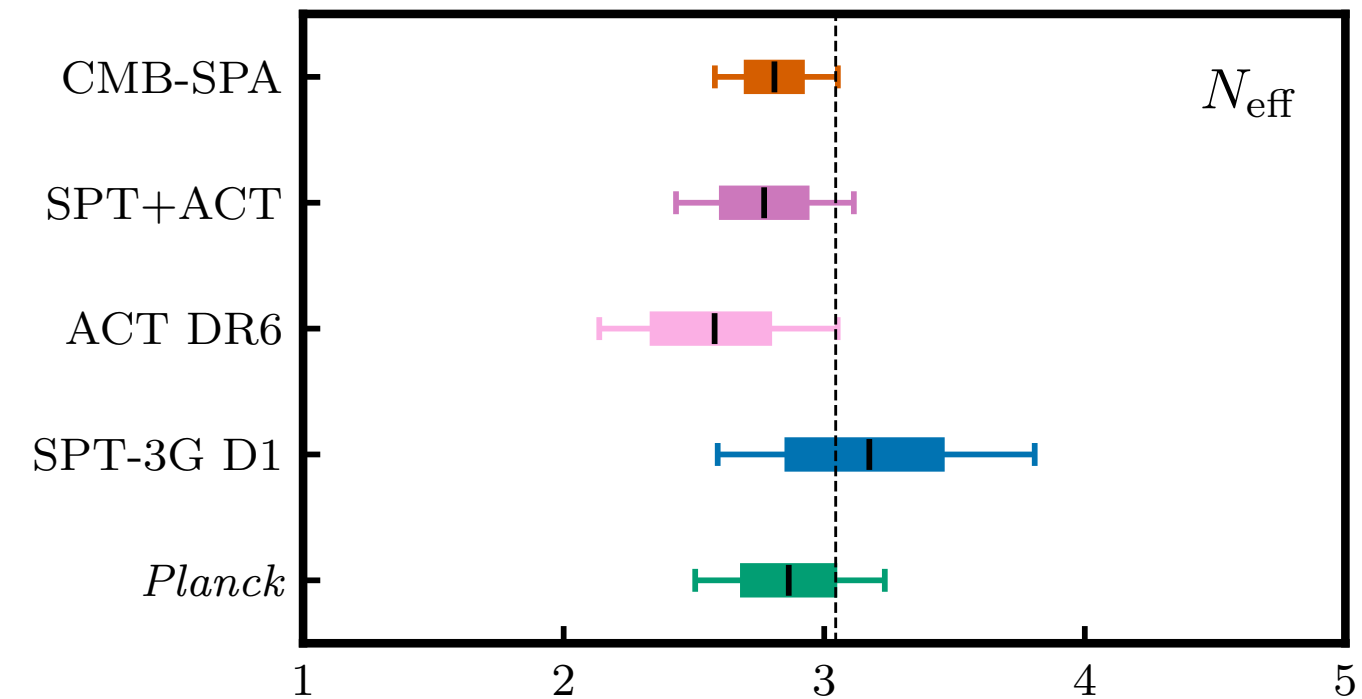
$$N_{\text{eff}} = 2.77 \pm 0.17 \text{ for SPT+ACT,}$$

$$N_{\text{eff}} = 2.81 \pm 0.12 \text{ for CMB-SPA.}$$

$$\left. \begin{array}{l} N_{\text{eff}} = 2.97^{+0.40}_{-0.64} \\ Y_P = 0.269^{+0.040}_{-0.030} \end{array} \right\} \text{ for SPT-3G D1,}$$

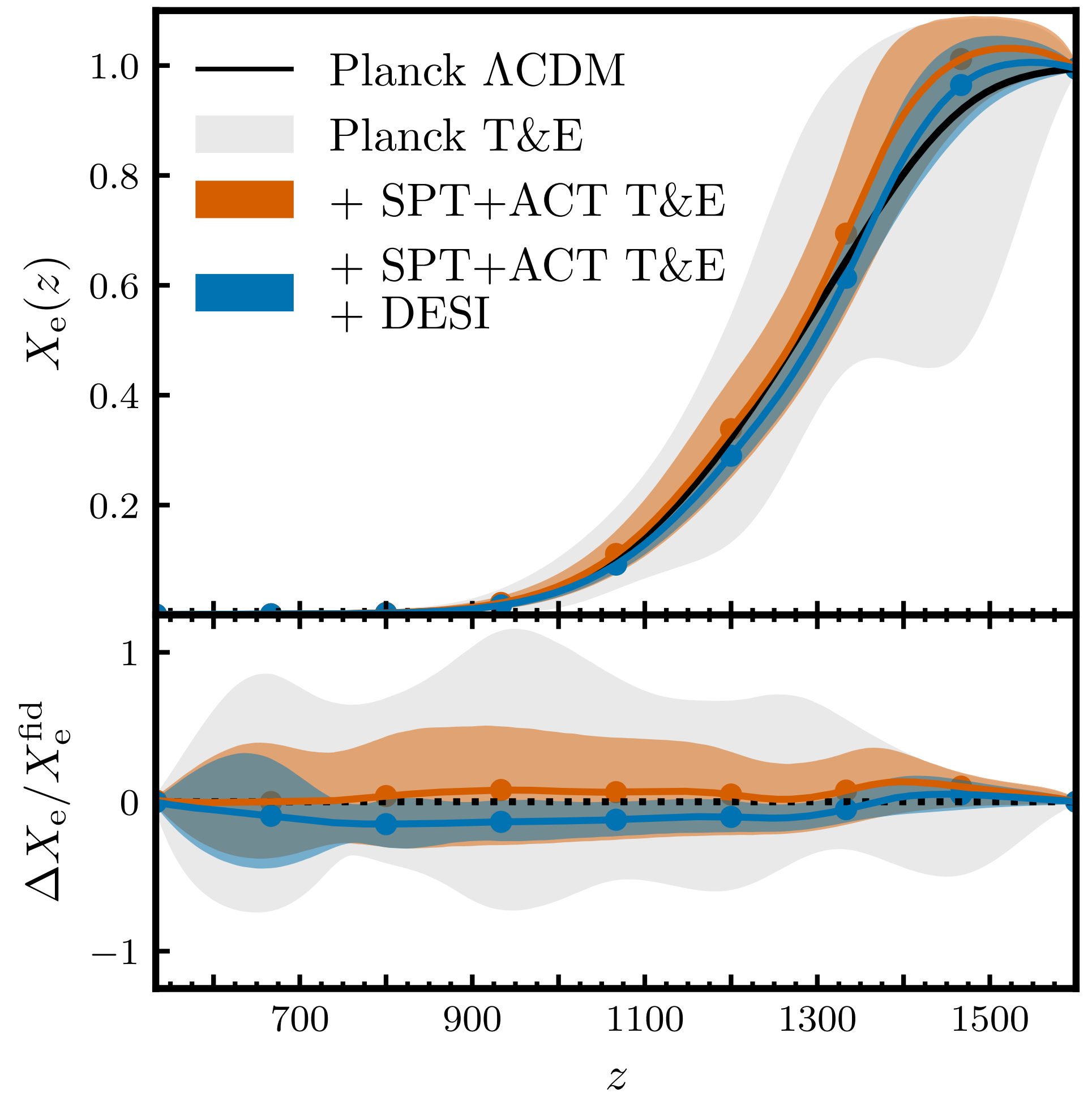
$$\left. \begin{array}{l} N_{\text{eff}} = 2.85^{+0.32}_{-0.40} \\ Y_P = 0.236^{+0.025}_{-0.021} \end{array} \right\} \text{ for SPT+ACT,}$$

$$\left. \begin{array}{l} N_{\text{eff}} = 2.99^{+0.22}_{-0.26} \\ Y_P = 0.231 \pm 0.014 \end{array} \right\} \text{ for CMB-SPA.}$$

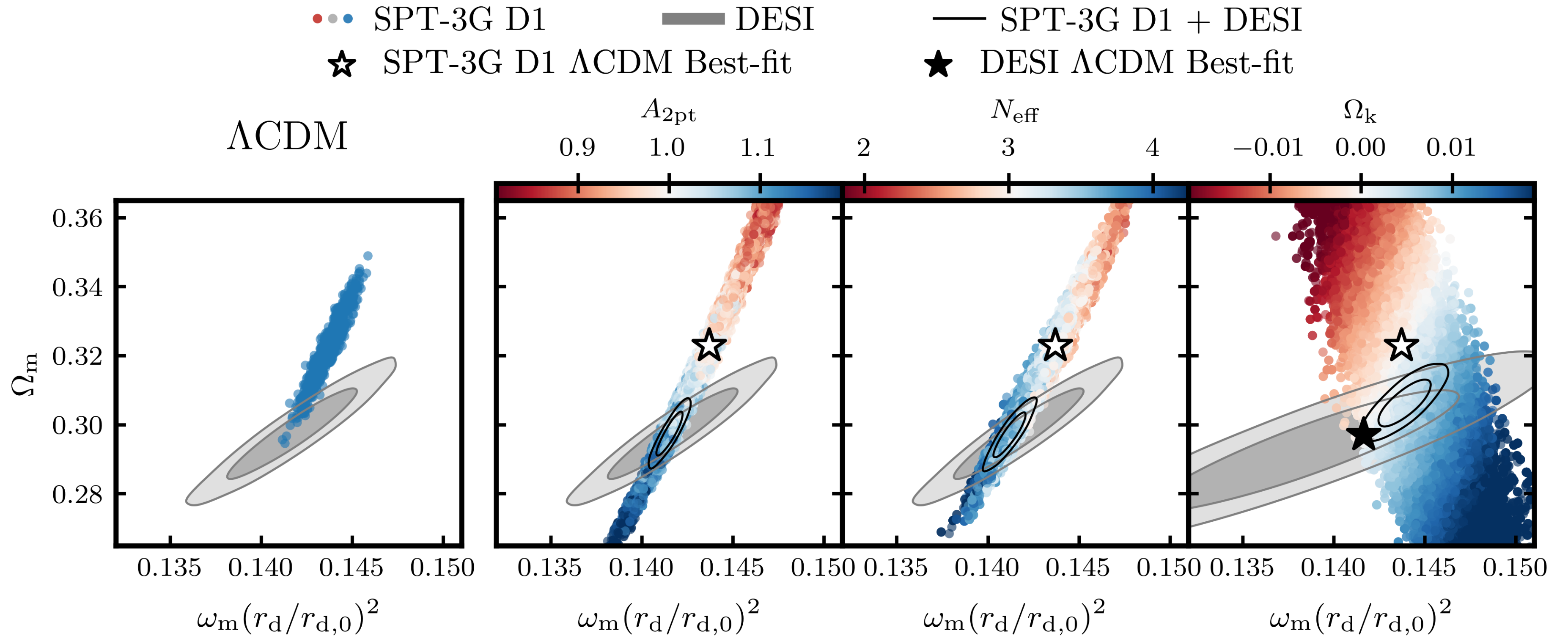


Modified Recombination

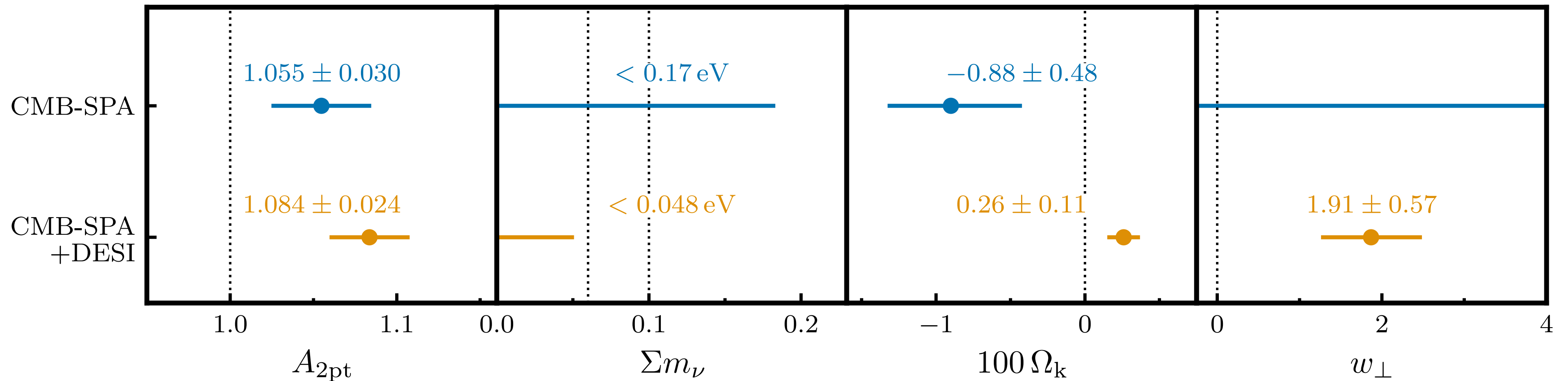
[Lynch et al., 2024]



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

Ω_K

$$100\Omega_k = 0.2^{+1.5}_{-1.2} \text{ for SPT-3G D1,}$$

$$100\Omega_k = -0.06^{+0.81}_{-0.70} \text{ for SPT+ACT,}$$

$$100\Omega_k = -0.88 \pm 0.48 \text{ for CMB-SPA.}$$

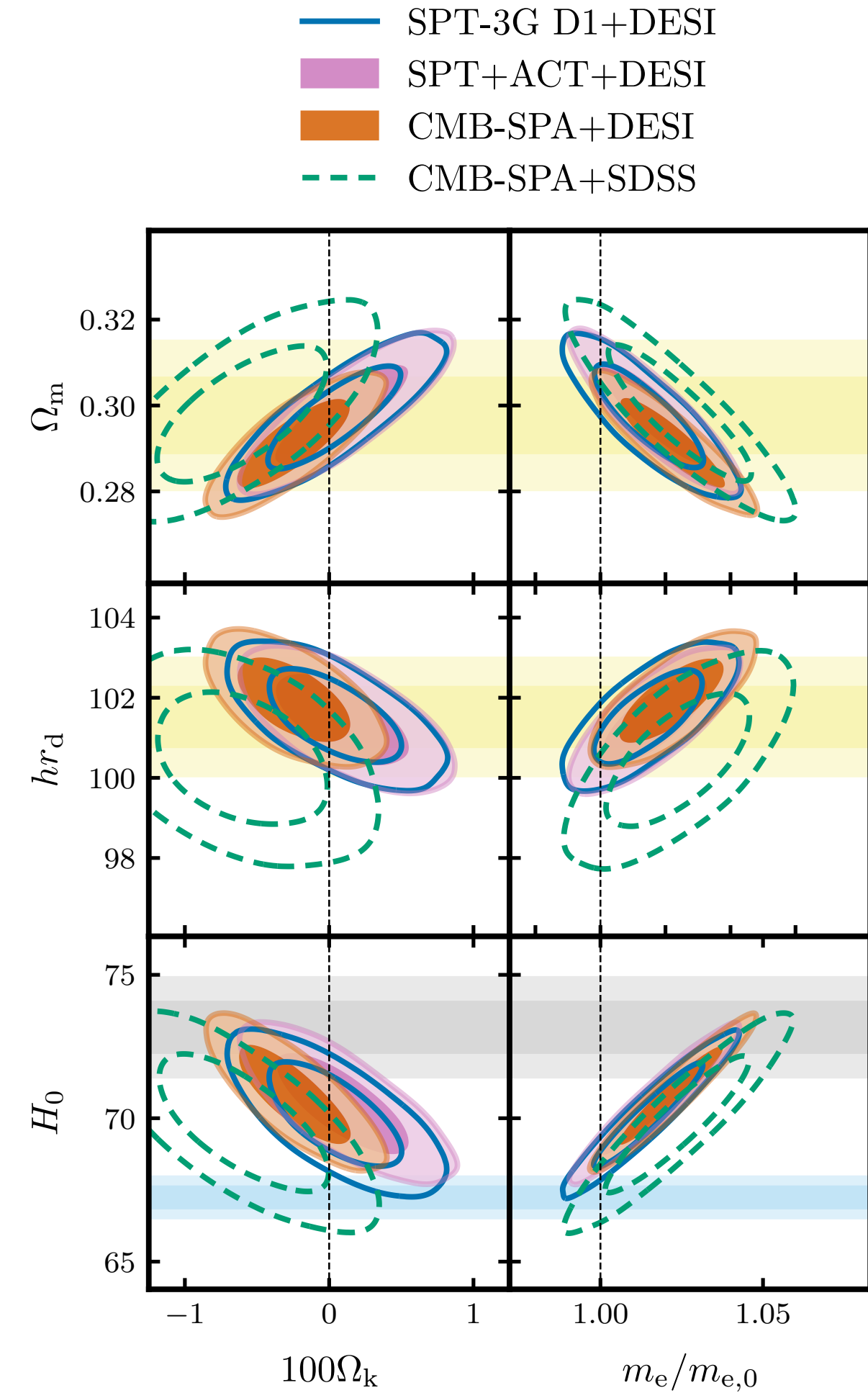
$$100\Omega_k = 0.40 \pm 0.18 \text{ for SPT-3G D1 + DESI,}$$

$$100\Omega_k = 0.51 \pm 0.17 \text{ for SPT+ACT + DESI,}$$

$$100\Omega_k = 0.26 \pm 0.11 \text{ for CMB-SPA + DESI.}$$

$$m_e - \Omega_K$$

Parameters	SPT-3G D1 +DESI	SPT+ACT +DESI	CMB-SPA +DESI
$H_0 [\text{km s}^{-1} \text{ Mpc}^{-1}]$	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
$hr_d [\text{Mpc}]$	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
$Q_{\text{MPCL}}^{\text{SHOES}} [\sigma]$	2.3	2.0	1.9



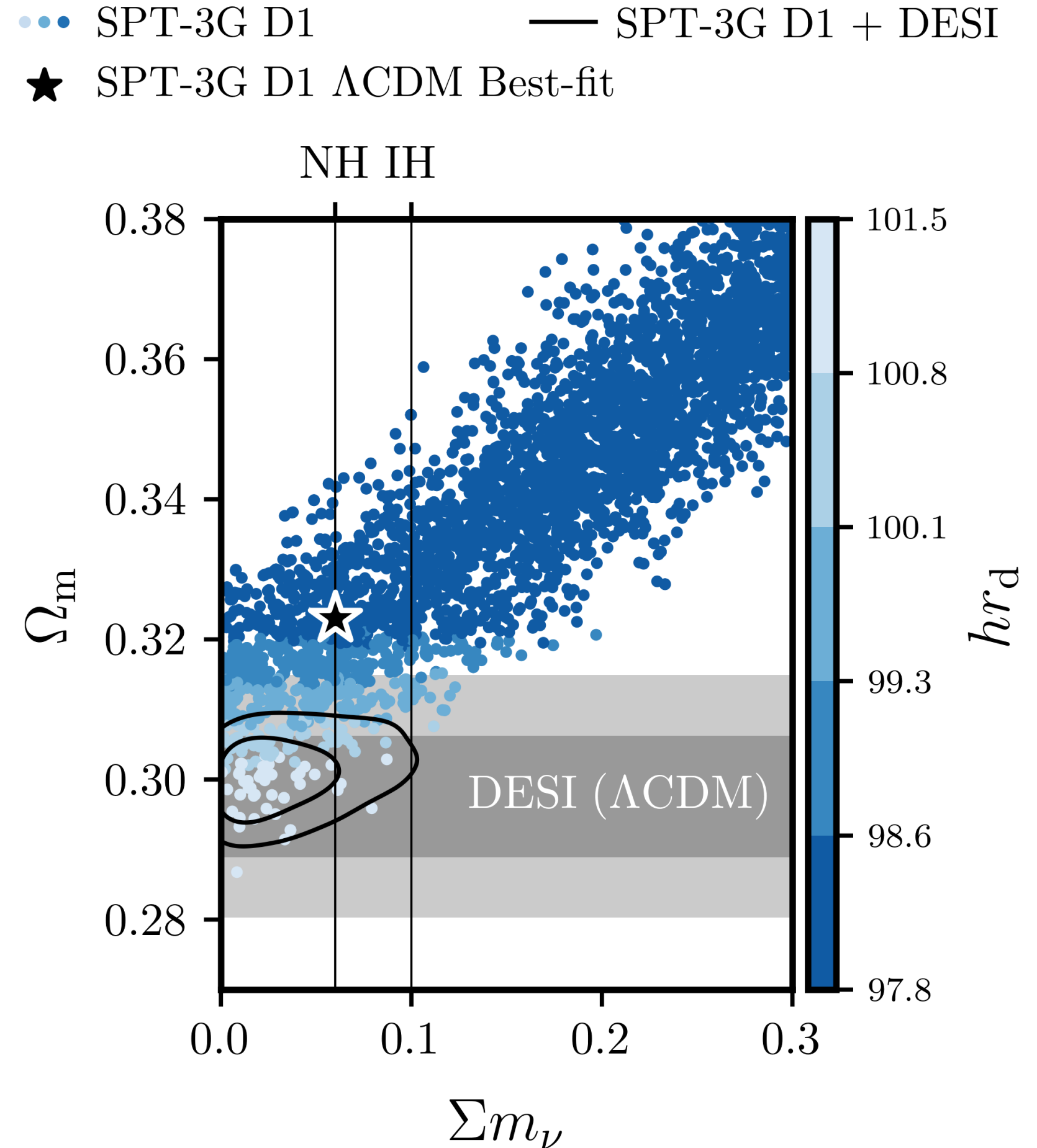
$$\Sigma m_\nu$$

CMB only

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

CMB + DESI

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



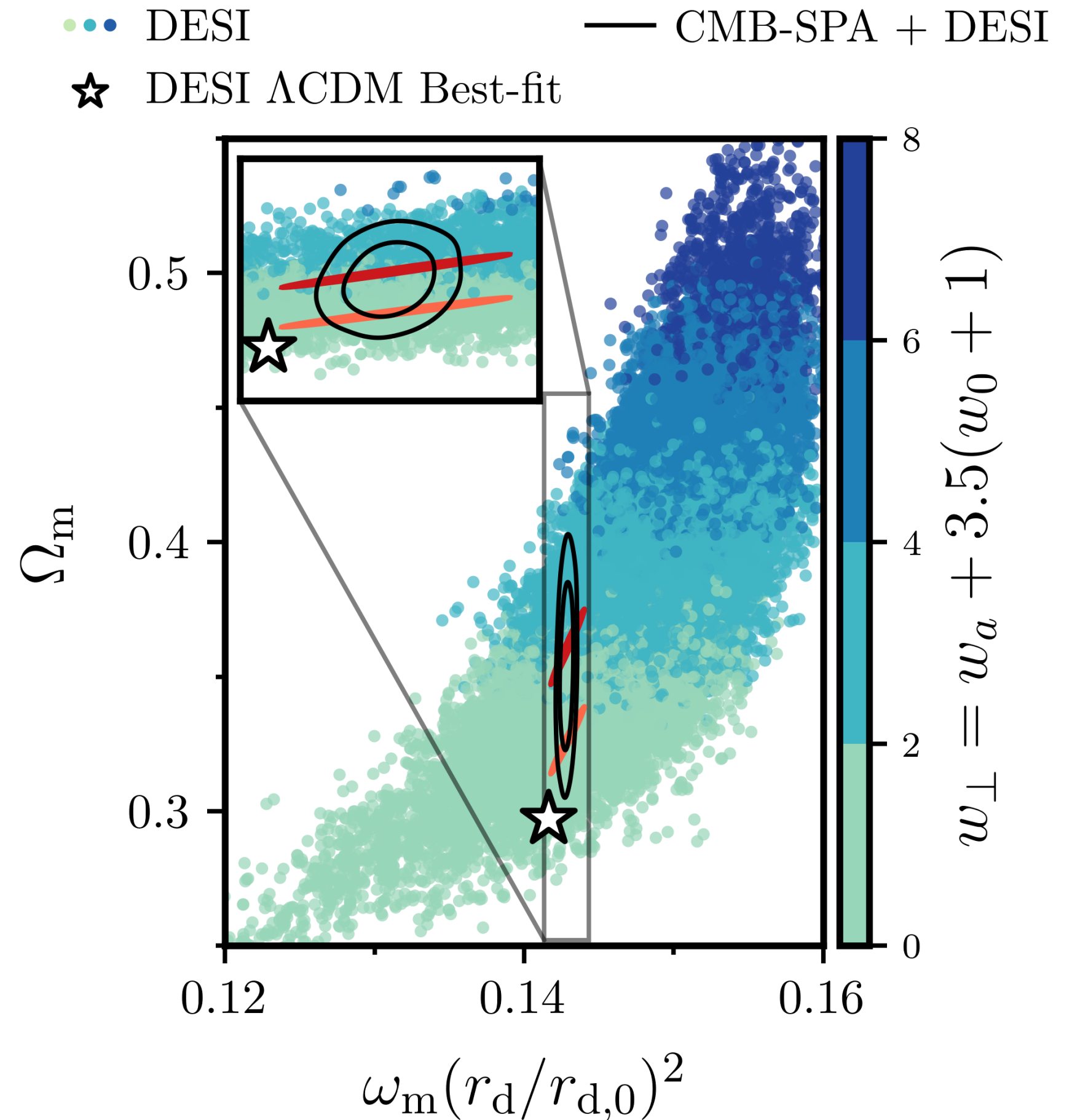
$$w_0 - w_a$$

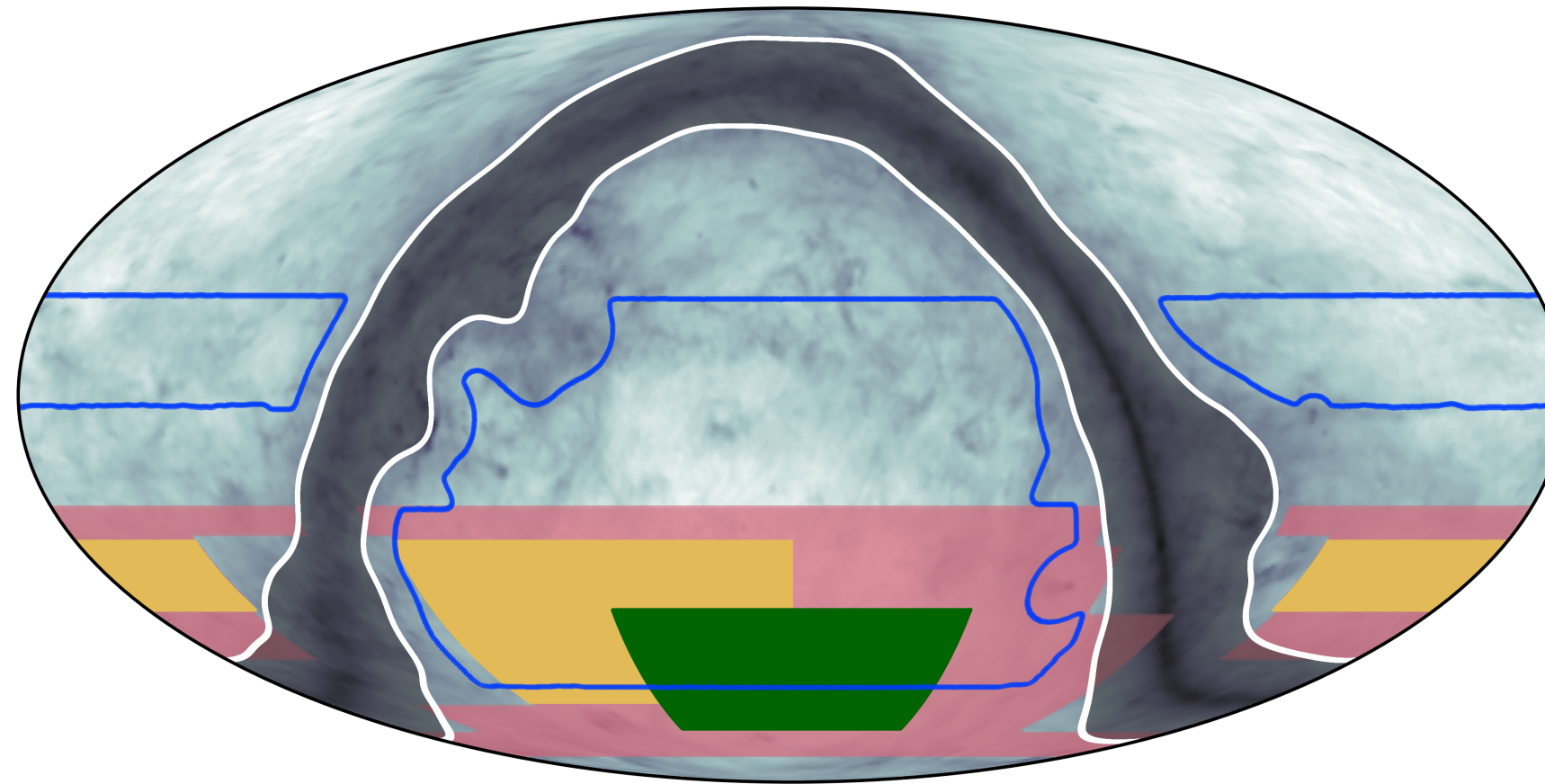
CMB-SPA + DESI (2.9 sigma)

$$w_0 = -0.41 \pm 0.20,$$

$$w_a = -1.78 \pm 0.55.$$

$$w_{\perp} = 1.91 \pm 0.57 \text{ for CMB-SPA+DESI}$$





■ SPT-3G Main (this work)
■ Planck galactic mask

■ SPT-3G Summer
— ACT DR6

■ SPT-3G Wide

- Extending with Summer

- 2019-2023
- 2600 deg²
- 6.6 uK-arcmin

- Extending with Wide

- 2024
- 6000 deg²
- 8.8 uK-arcmin

- Deeper in Main

- 2019-2023 + 2025-2026 (+?)
- 1500 deg²
- 1.6 uK-arcmin

Full SPT-3G forecasts

[Prabhu et al., 2024]

