South Pole Telescope

Latest Results And Future Prospects

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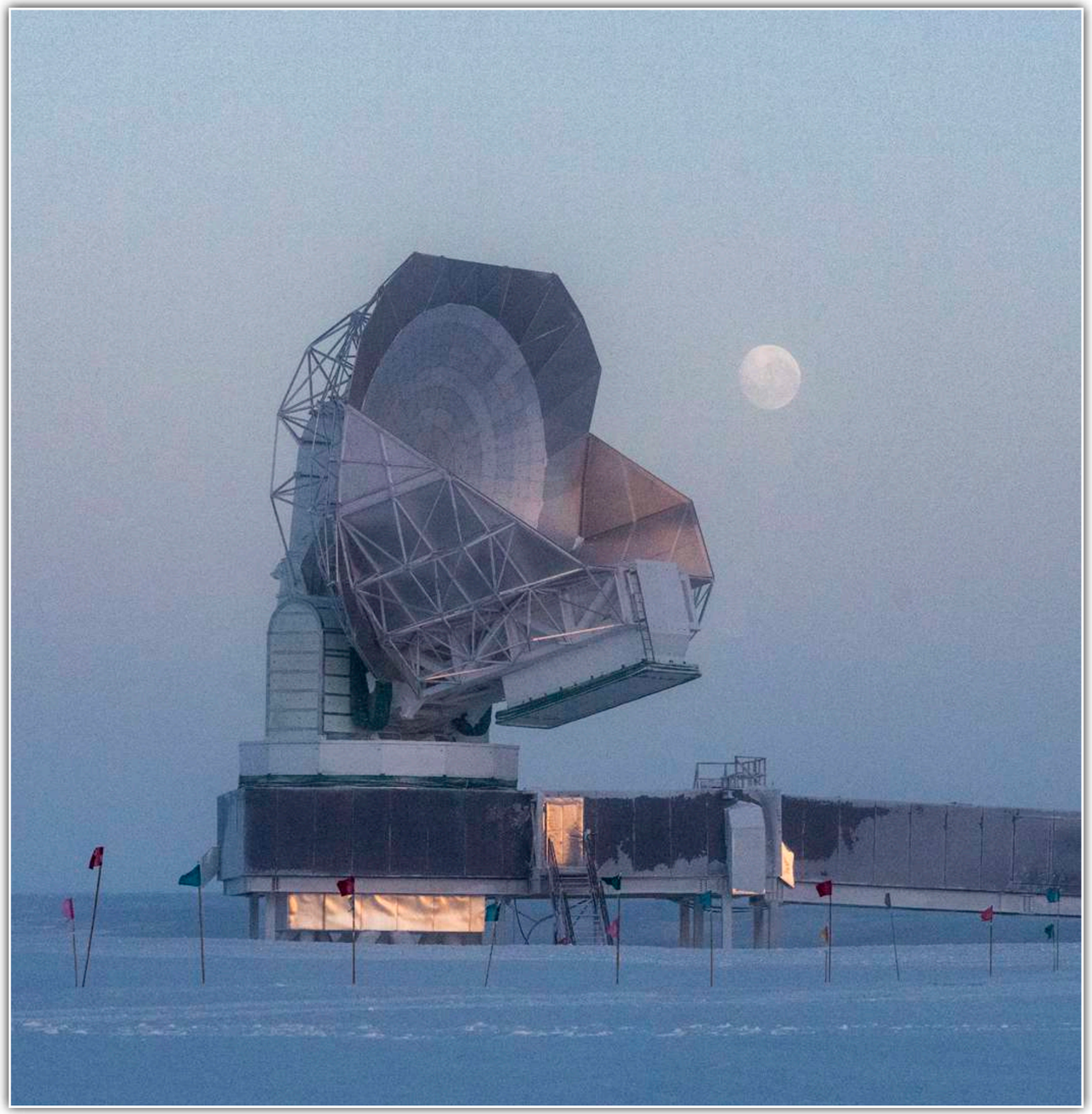
GDR Coϕ 4
2/6/2026

Image Credit: Aman Chokshi

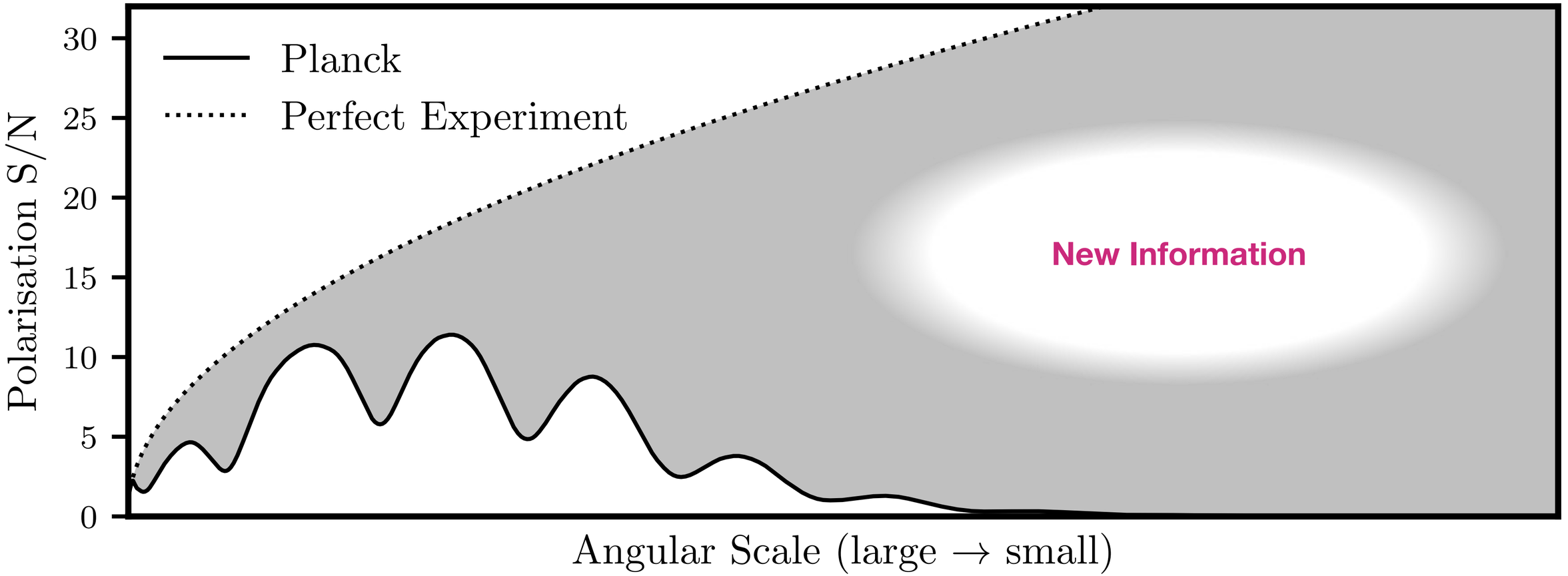
Overview

1. South Pole Telescope introduction
2. SPT-3G D1 Cosmology
3. Primordial gravitational waves
4. Anisotropic cosmic birefringence
5. Outlook
6. Conclusions



Credit: A. Chokshi

We are not done with the CMB



South Pole Telescope

- 10m telescope at the geographic south pole (Amundsen-Scott station)
- Dedicated CMB telescope
- Cold, dry weather, high altitude make for great microwave observations
- Operating since 2007

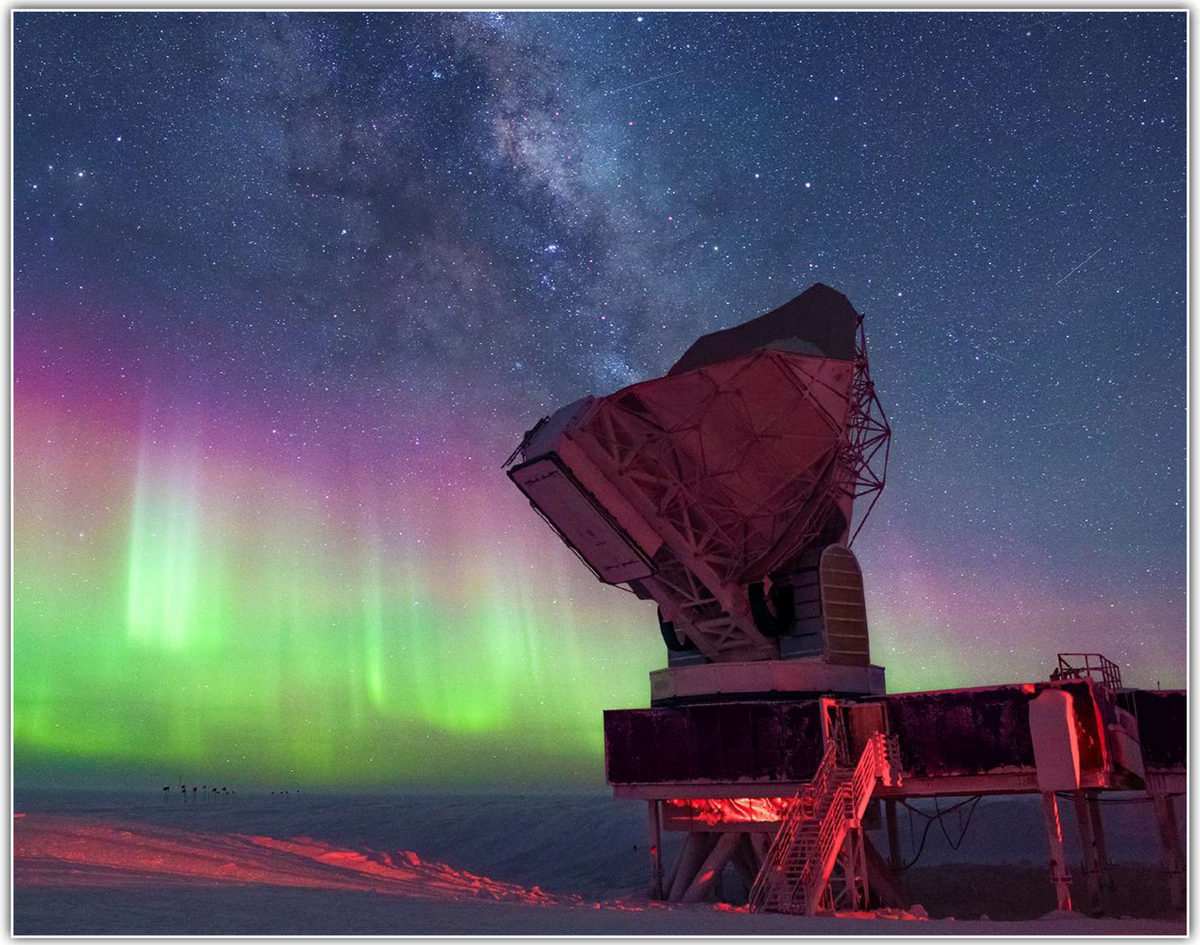
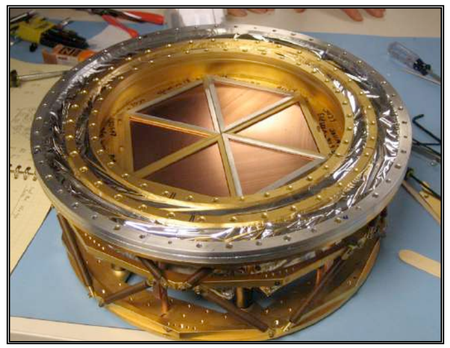


Image Credit: Aman Chokshi

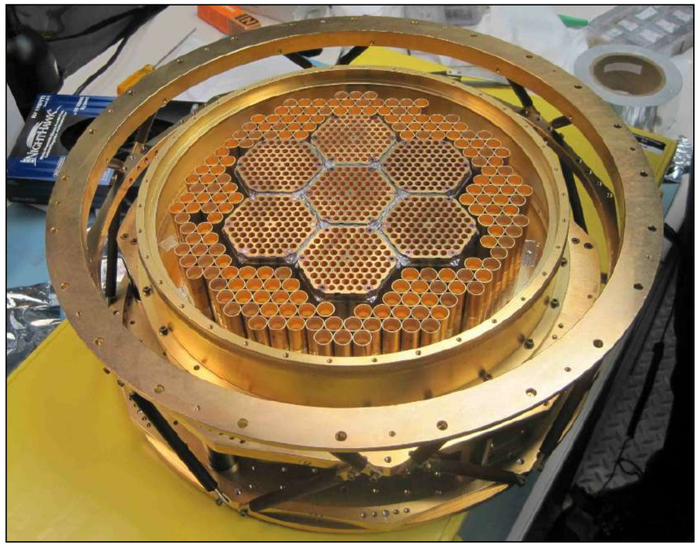
Kavli Institute
for Cosmological Physics
at the University of Chicago

SPT Cameras

2007-2011: SPT-SZ
960 Detectors,
Intensity only



2012-2016: SPTpol
1600 Detectors,
Intensity and Polarisation

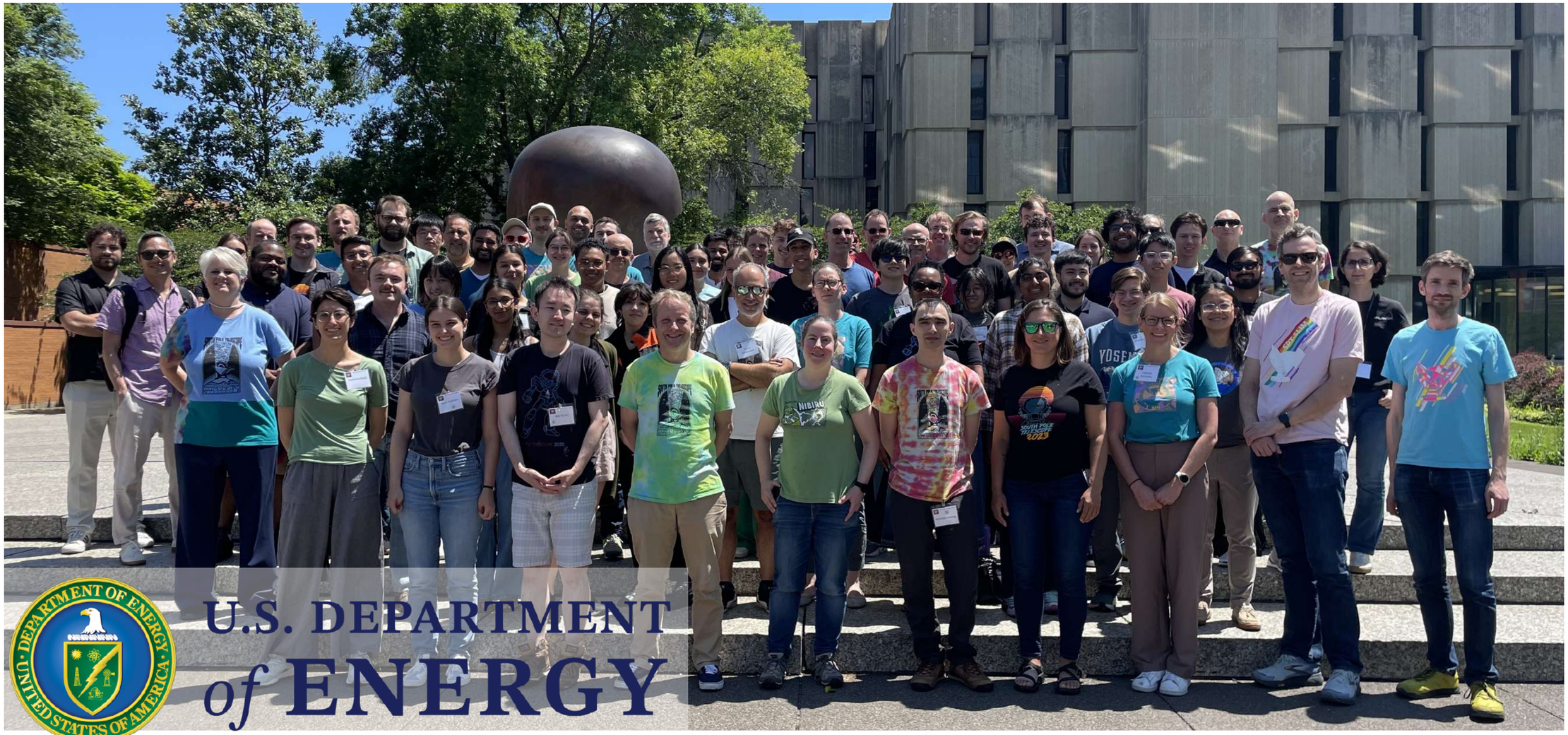


Since 2017: SPT-3G
16,000 Detectors,
Intensity and Polarisation

Credit: Brad Benson

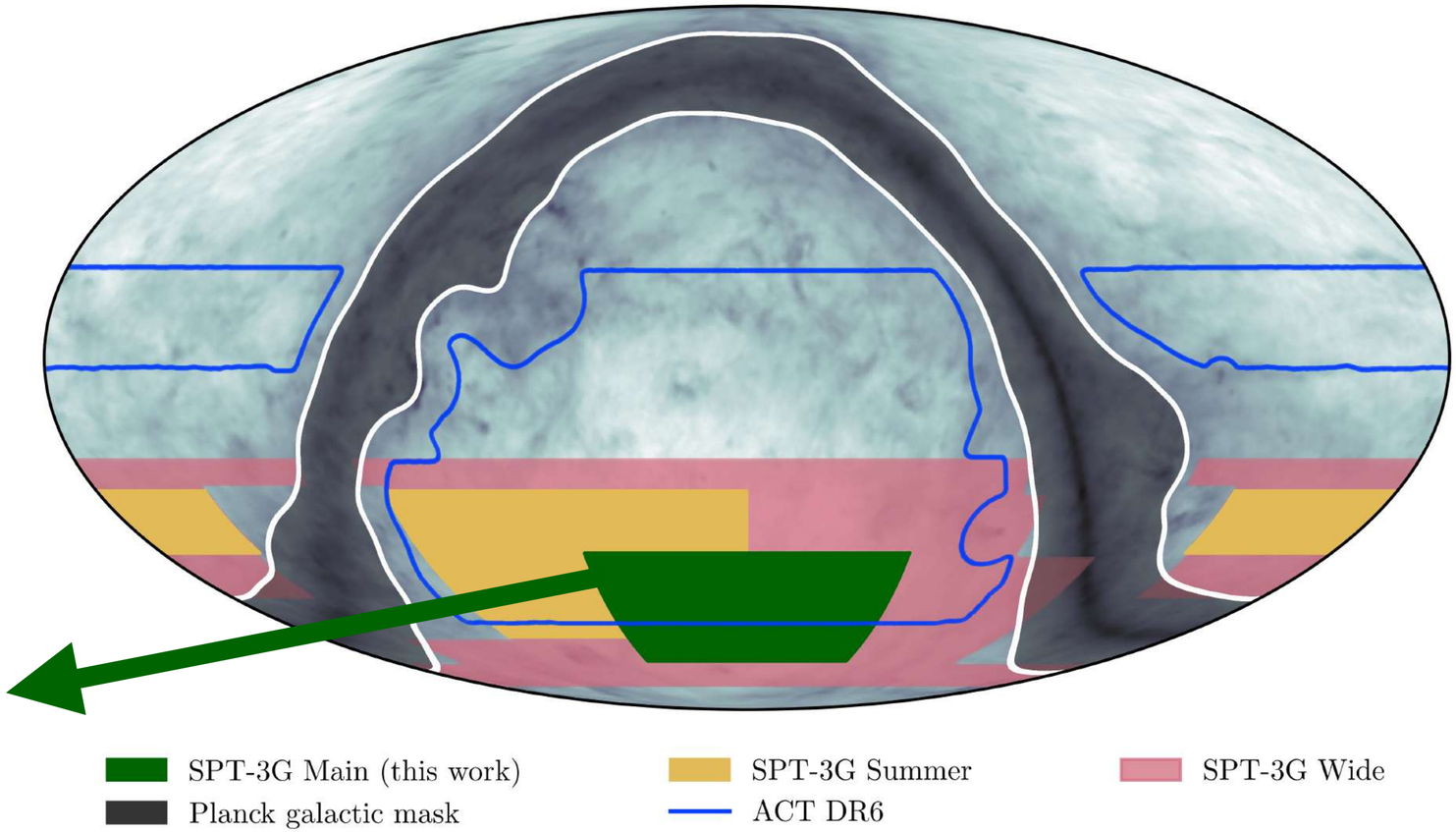
The SPT-3G collaboration

~100 members (~60 students and postdocs) from 33 institutions

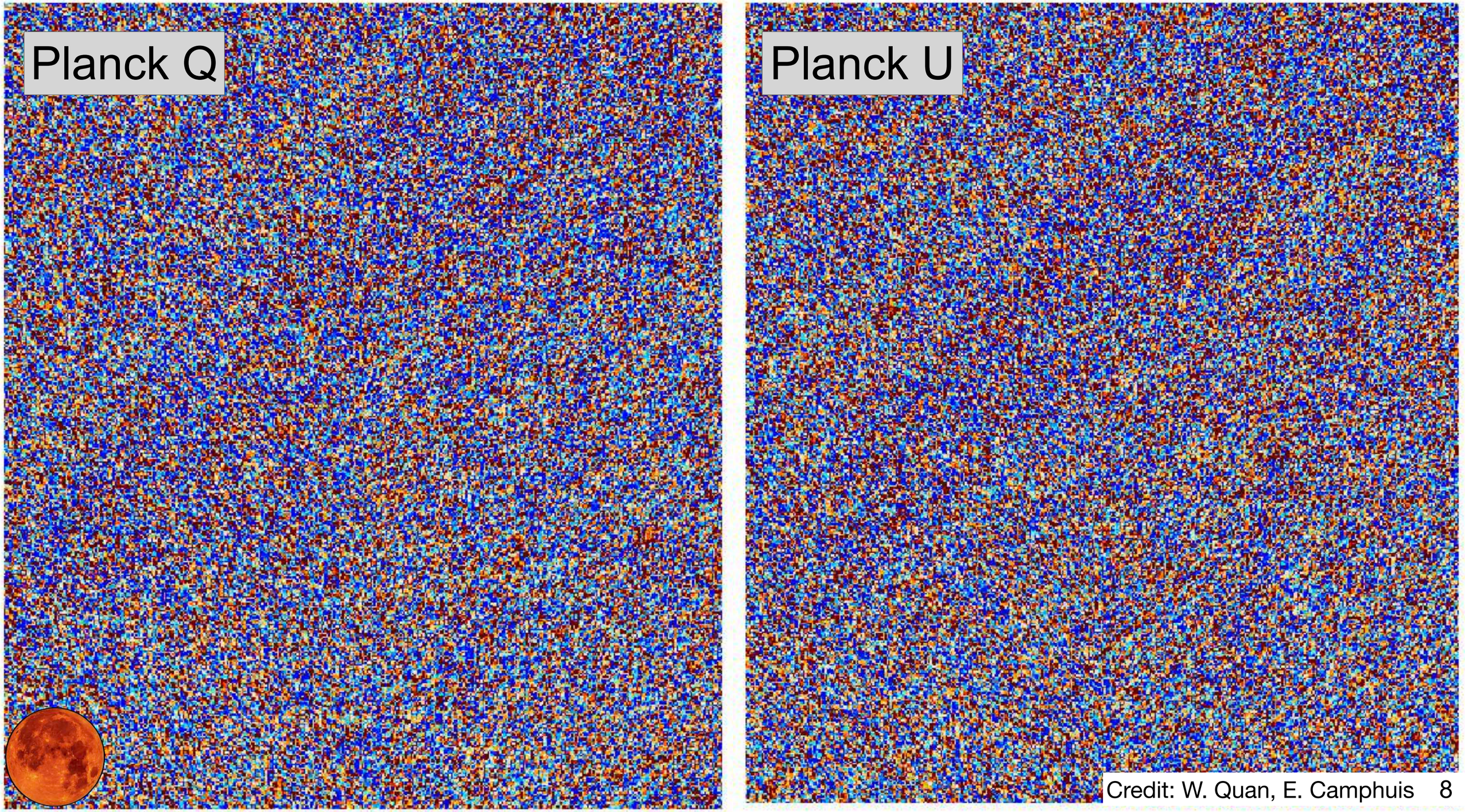


SPT-3G: Survey Fields

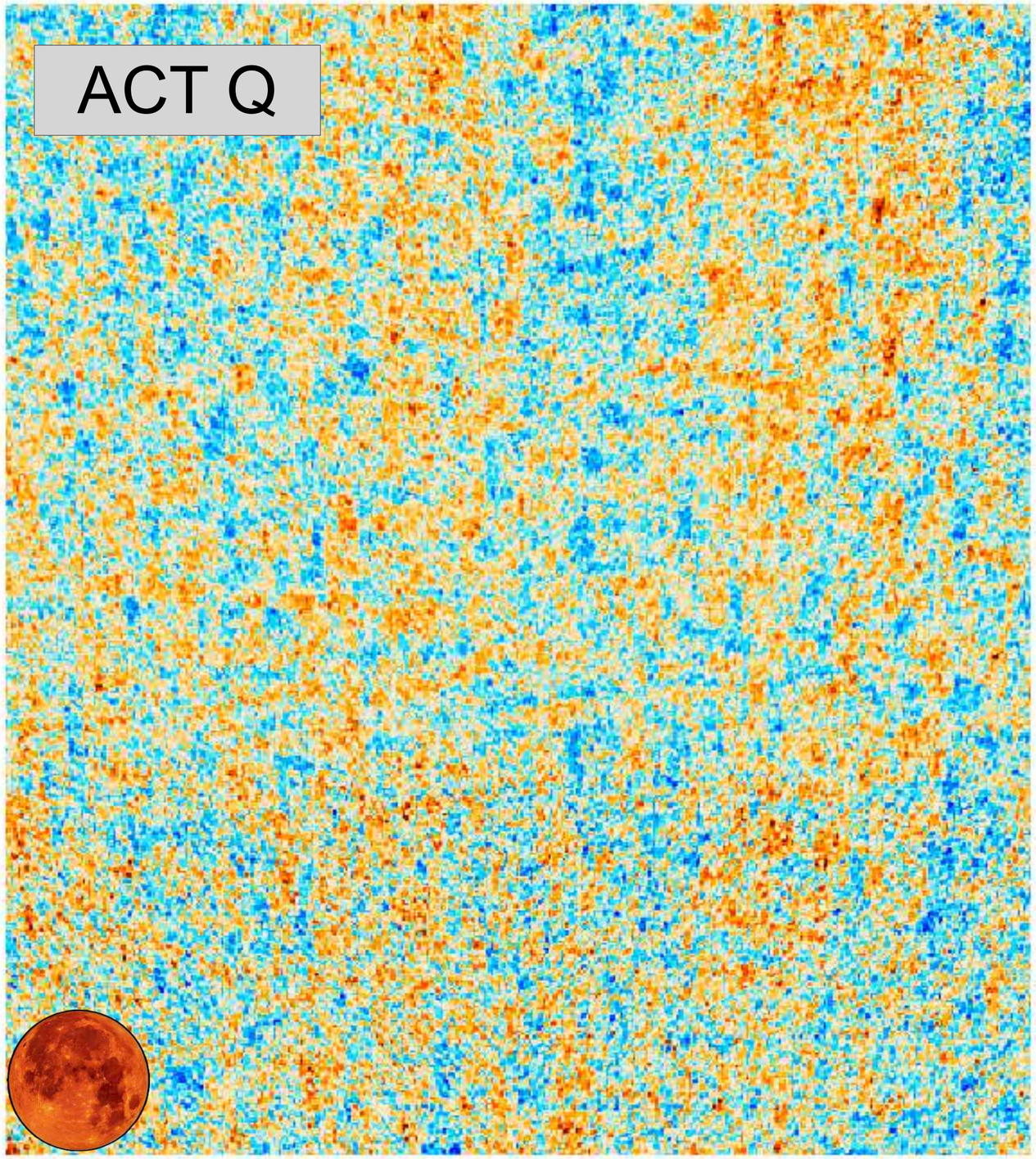
Data Set	Sky fraction [%]	Coadded noise [uK-arcmin]
Planck	100	28
ACT DR6	45	10
SPT-3G D1	**4**	**3.3**

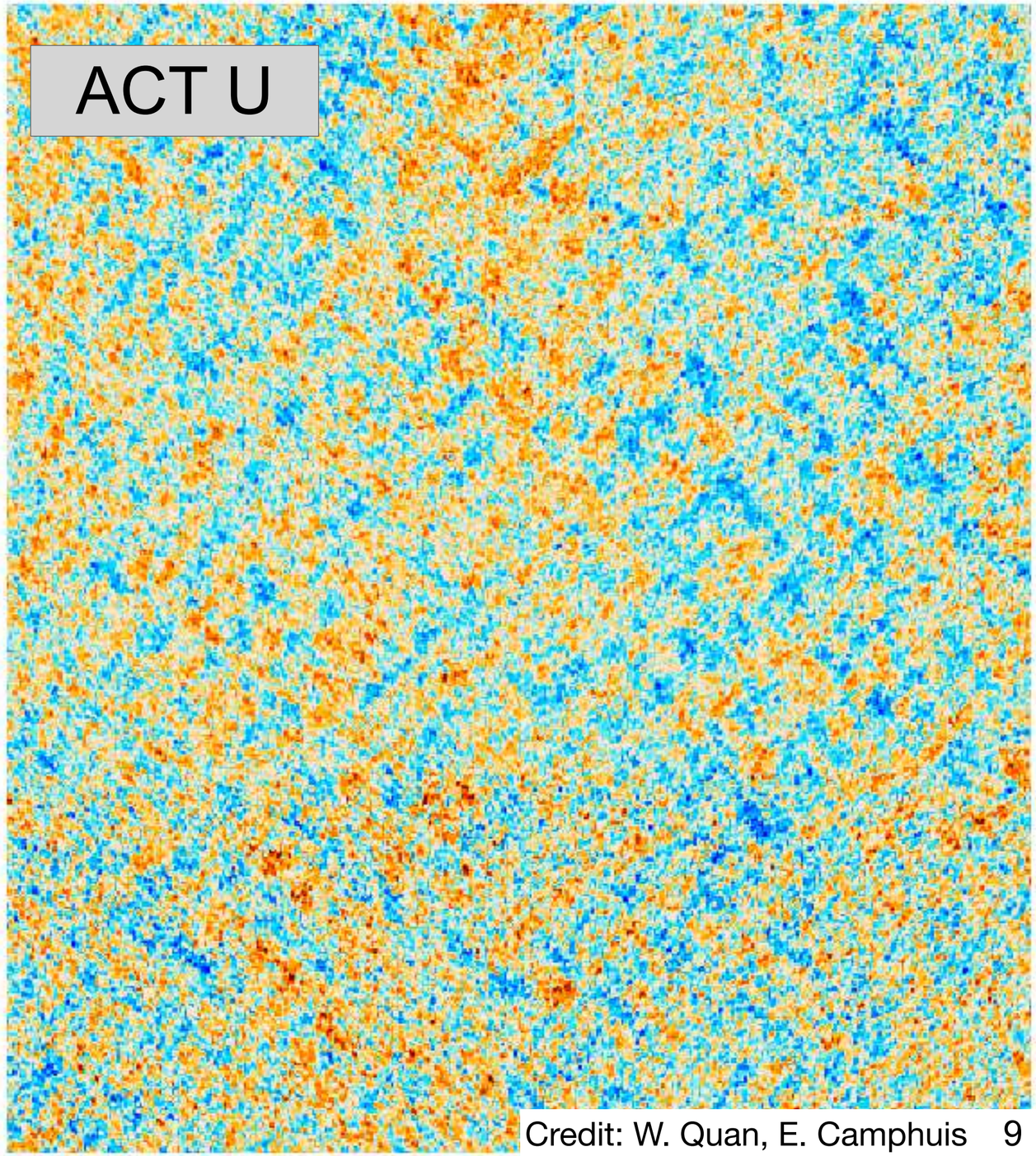


SPT-3G D1 is signal-dominated in polarisation until $\ell = 2500$



Credit: W. Quan, E. Camphuis





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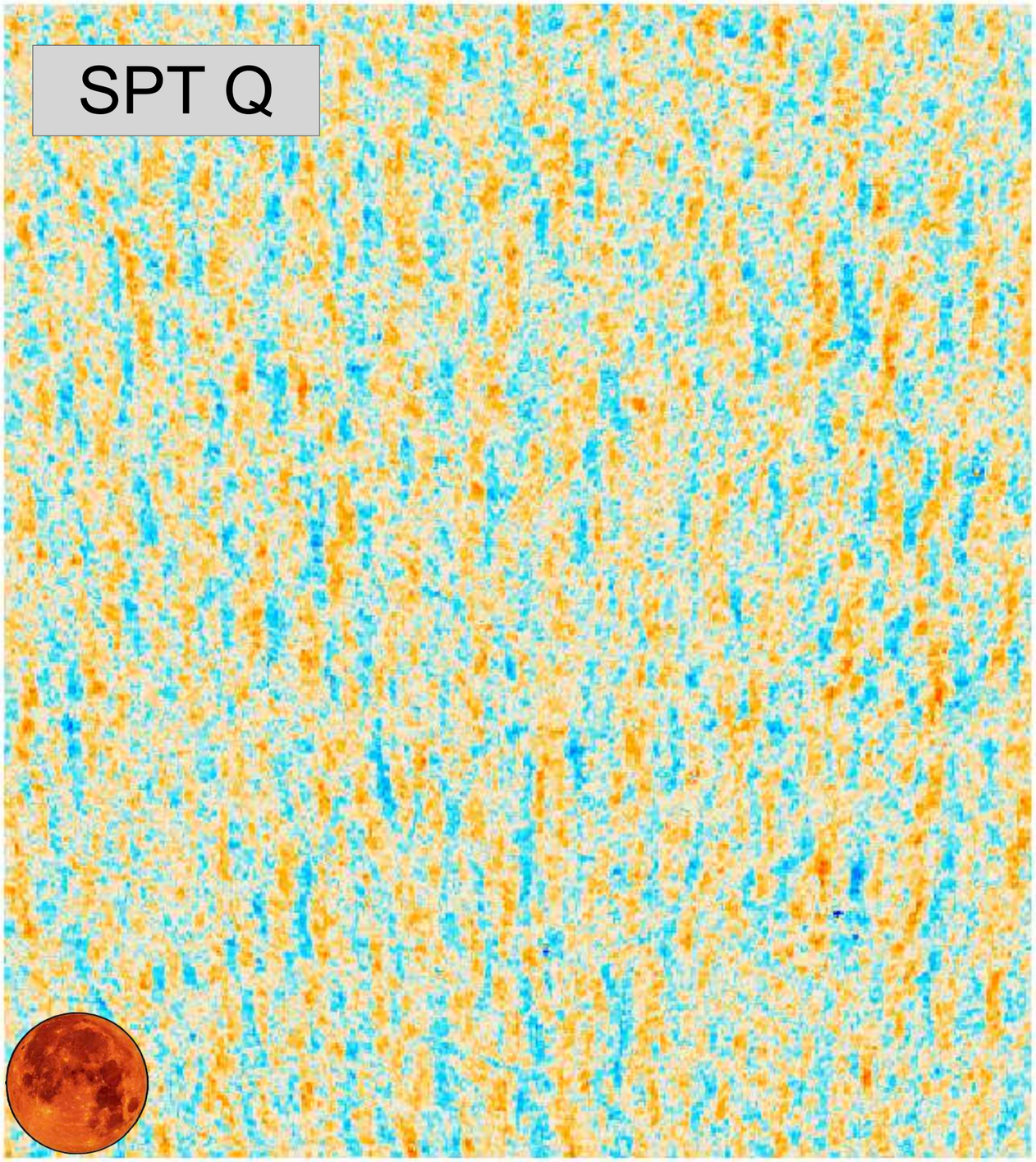
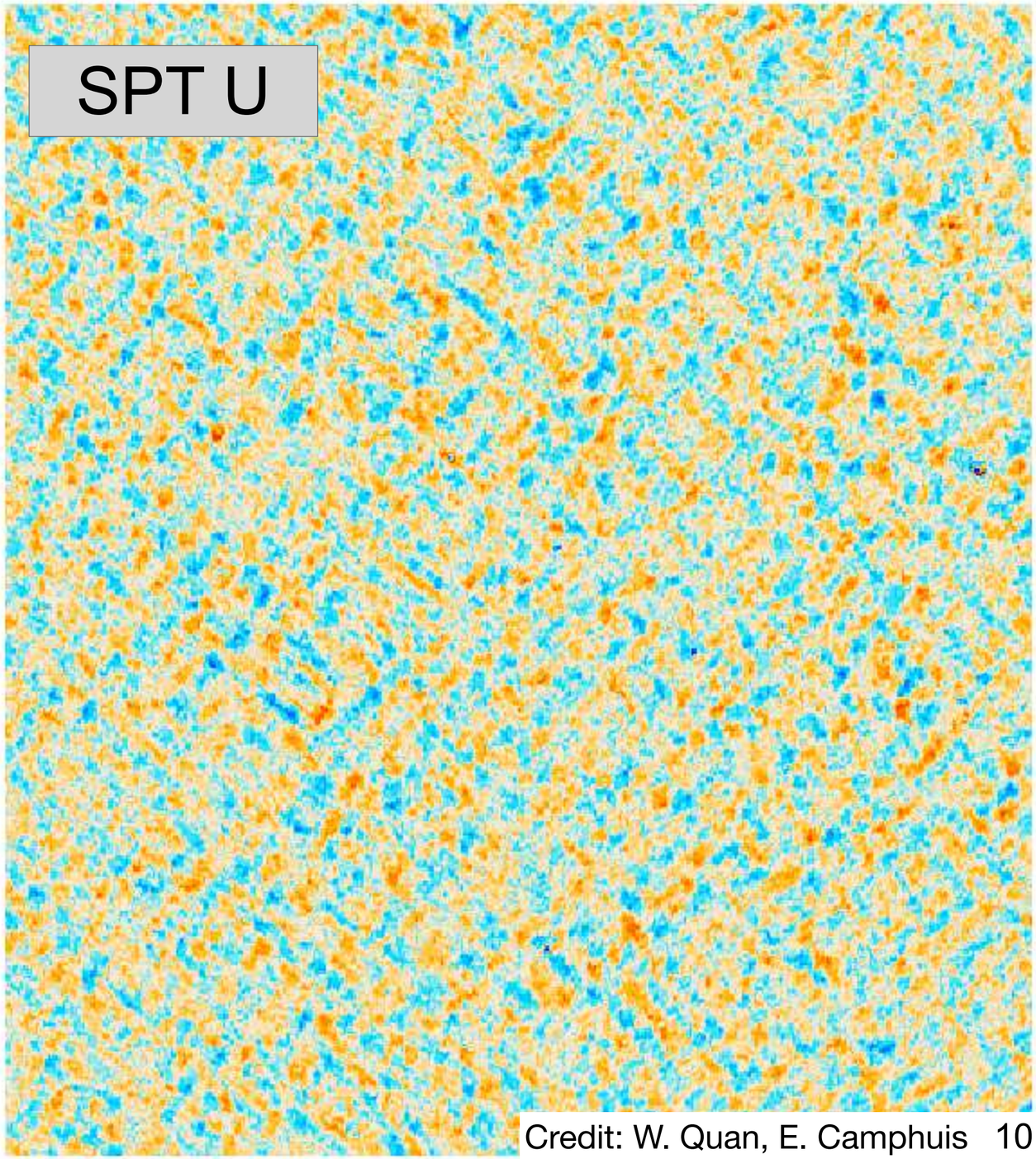




Credit: W. Quan, E. Camphuis

Camphuis et al. 2025
(arXiv:2411.06000)
Quan et al. 2026
(arXiv:2603.20163)

E. Camphuis

W. Quan

SPT-3G D1
ACT DR6
Planck

TT
EE
TE

Best EE to date!

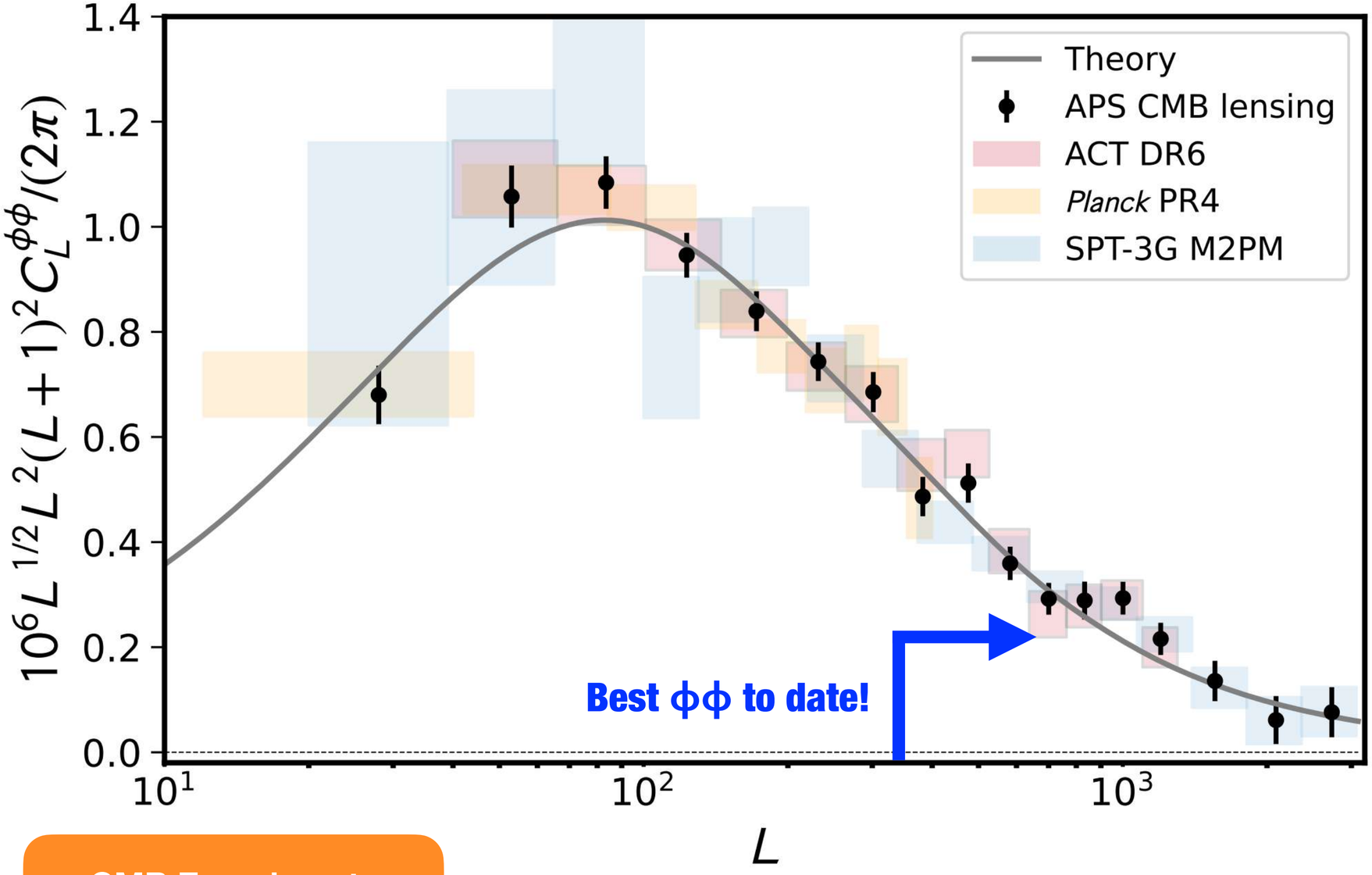
Best TE to date!

$D_b^{\mathrm{TT}}, D_b^{\mathrm{EE}}\ [\mu\mathrm{K}^2]$

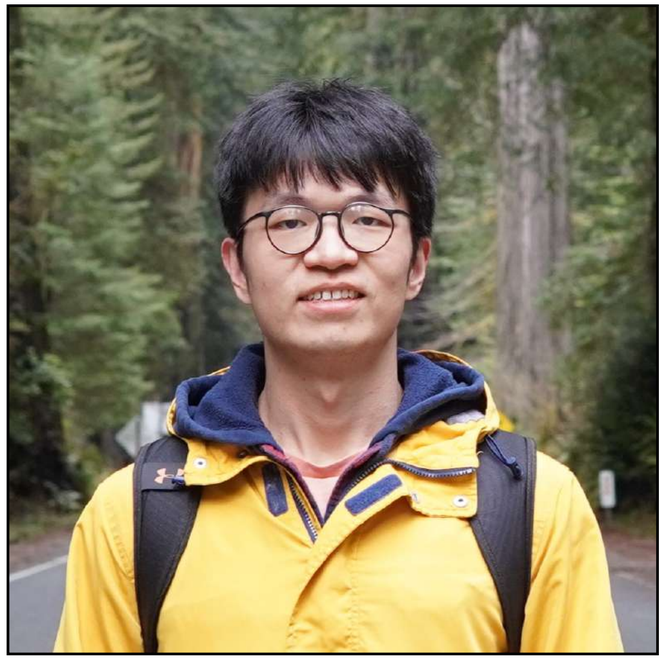
$D_b^{\mathrm{TE}}\ [\mu\mathrm{K}^2]$

Multipole ℓ_b

CMB Experiments are complementary



F. Ge et al. 2024 (arXiv:2411.06000)



F. Ge

CMB Experiments are complementary

Credit: Qu et al. 2025

SPT-3G D1 Cosmology

E. Camphuis

Ali R. Khalife

Fei Ge

Federica Guidi

Nicholas Huang

Gabe Lynch

Yuuki Omori

W. Quan

Cynthia Trendafilova

Silvia Galli

Tom Crawford

Full cosmology results in **Camphuis et al. 2025** (arxiv:2506.20707, published in PRD)

Maps are public:
Quan et al. 2026 (arxiv:2603.20163)

K. Benabed

Memories collected at
https://tinyurl.com/karimbenabed
or via IAP website

Pipeline Improvements

- Inpainting point sources (Camphuis et al. in prep.)
- Transfer function modelling (Hivon et al. in prep.)
- Systematic model
- Semi-analytic covariance code (Camphuis et al. 2022, arXiv:2204.13721)
- Differentiable likelihood (w/ JAX): candl (Balkenhol et al. 2024, arXiv:2401.13433)
- Improved CMB-only likelihood (Balkenhol 2024, arXiv:2412.00826)
- ML-based emulators for inference (CosmoPower, OLÉ)
- Blinding

1. **SPT data are well described by ΛCDM**

2. **H_0 and σ_8 error bars from SPT-3G D1 are within 25% of Planck's (4% vs 80% f_{sky})**

3. **The SPT+ACT combination reaches Planck precision**

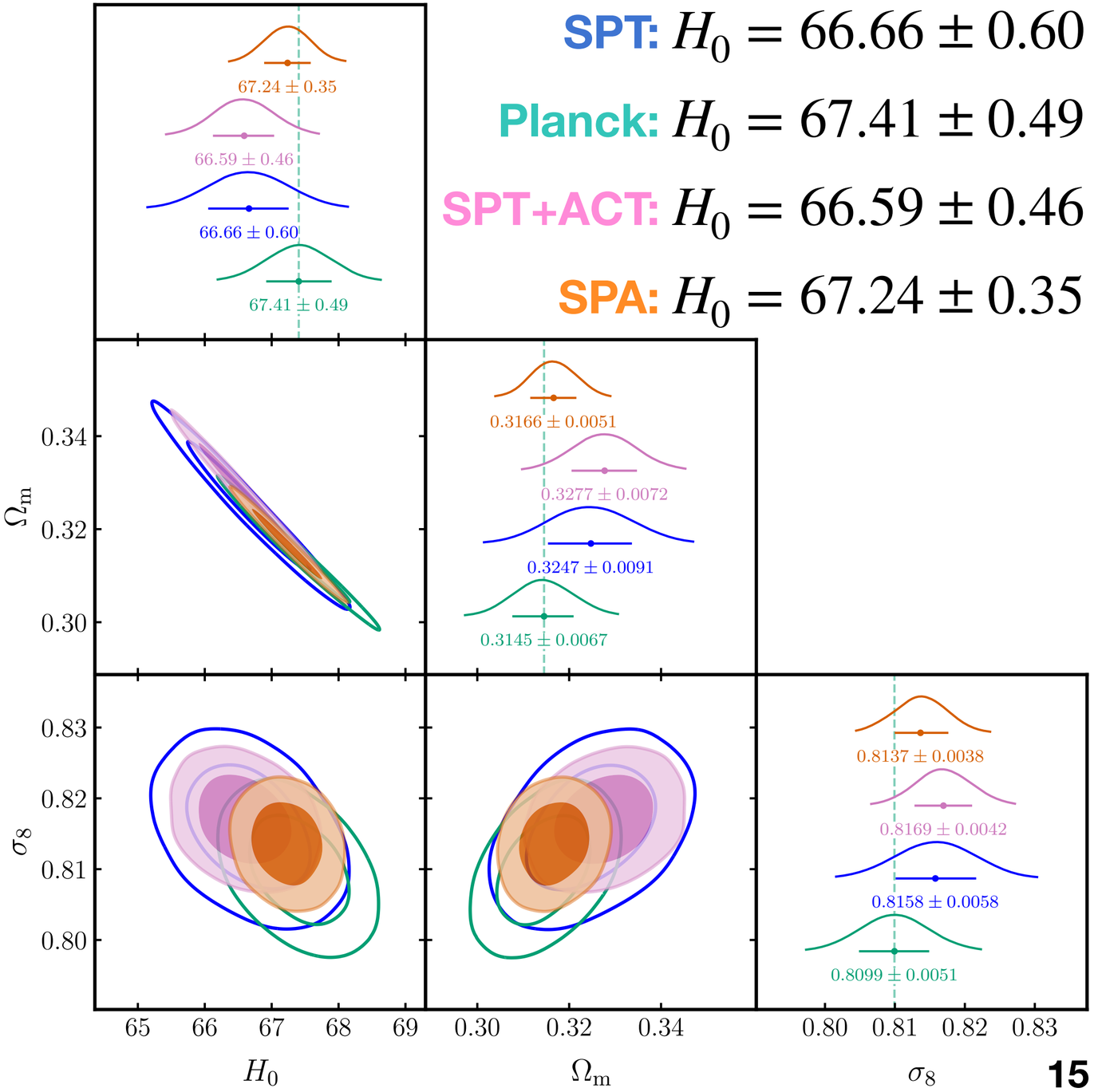
4. **CMB data are consistent**

SPT: $H_0 = 66.66 \pm 0.60$

Planck: $H_0 = 67.41 \pm 0.49$

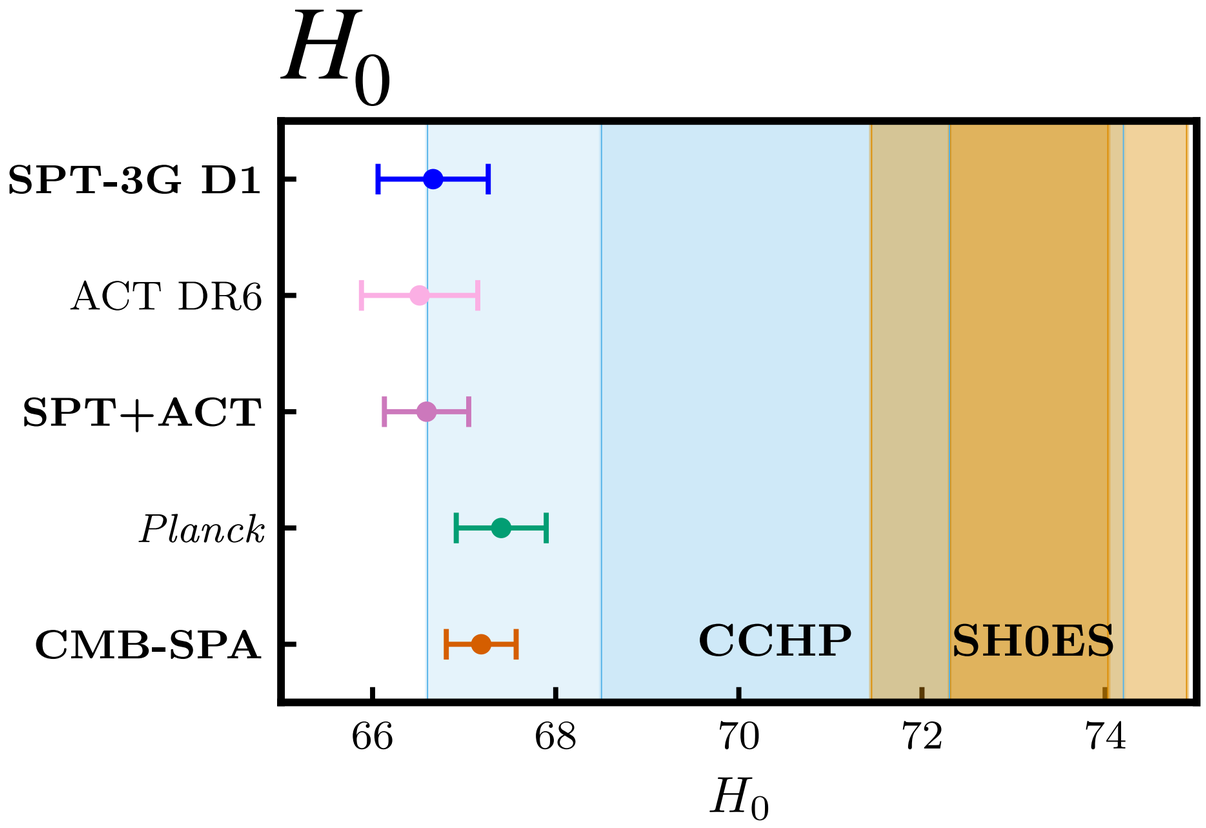
SPT+ACT: $H_0 = 66.59 \pm 0.46$

SPA: $H_0 = 67.24 \pm 0.35$



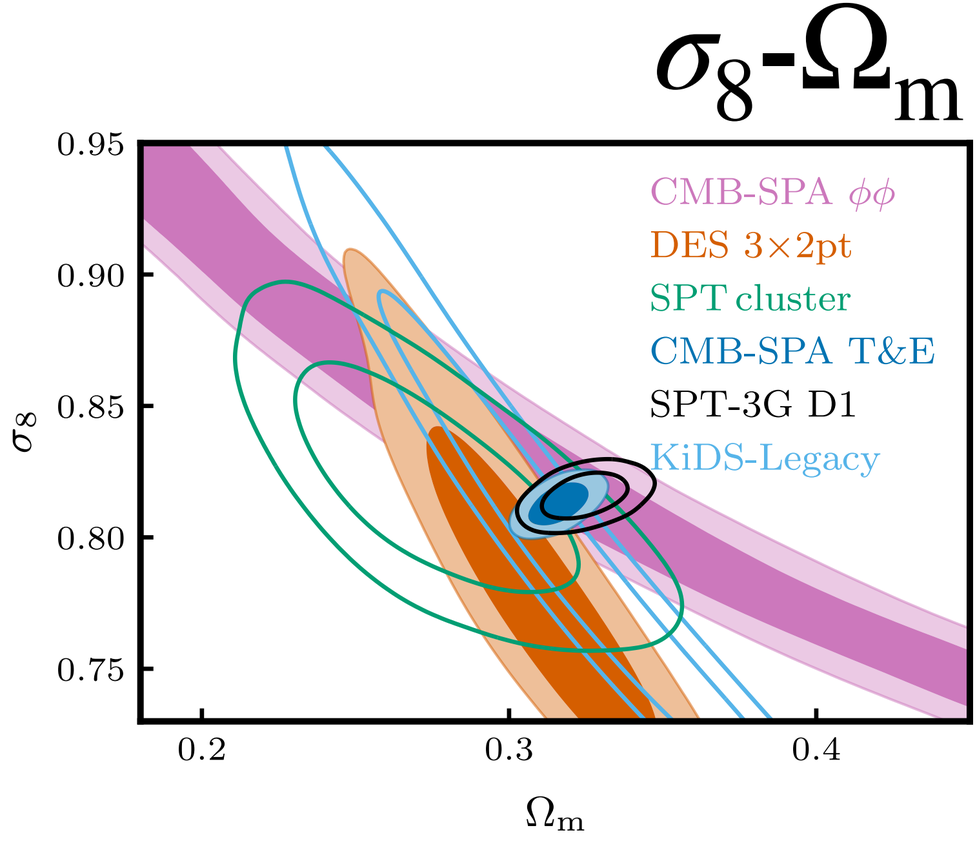
Credit: Camphuis et al. 2025

Contemporary Tensions



SPT independently*
confirms H_0 tension at 6.2σ
(at 4.9σ using TE/EE only)

*calibration based on Planck



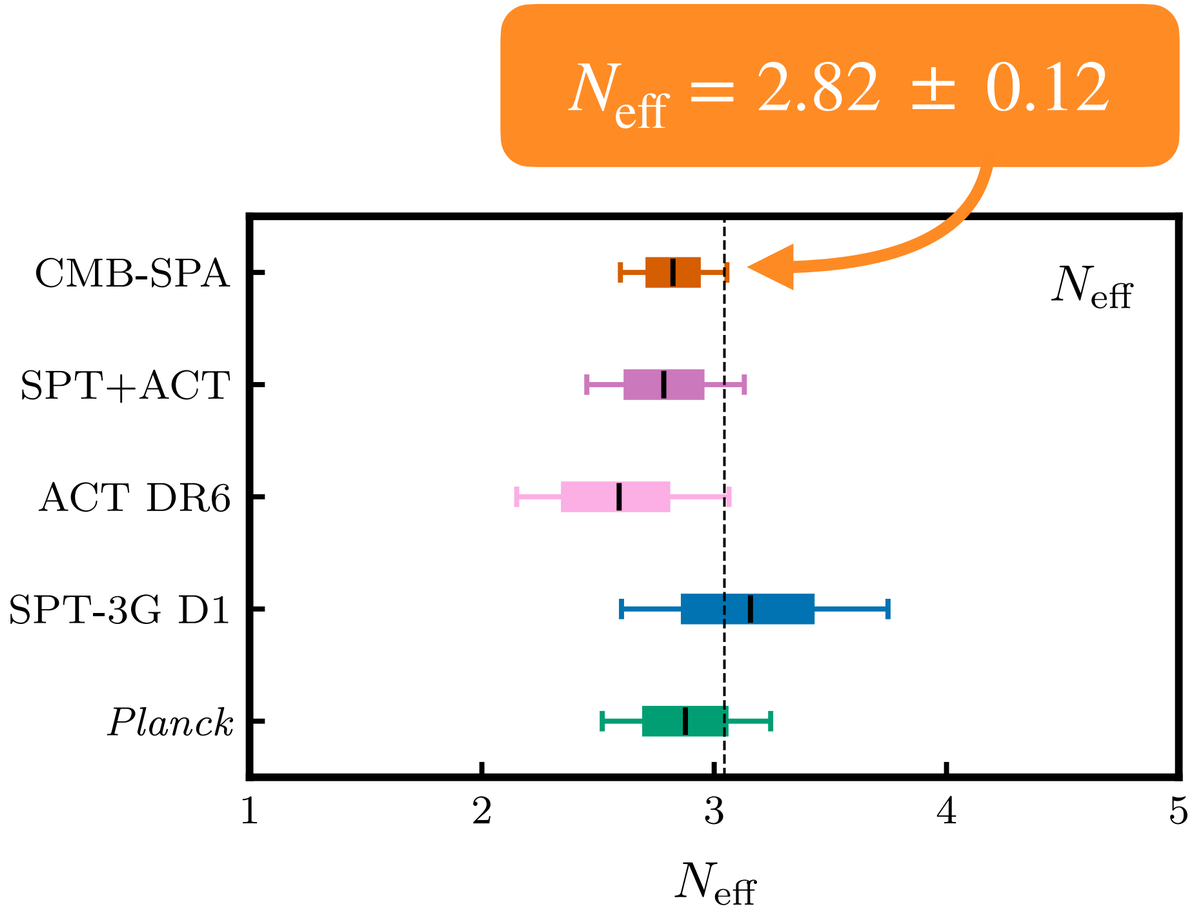
S_8 consistent across probes,
tension fizzling out?

Credit: Camphuis et al. 2025

CMB Data Limits ΛCDM Extensions

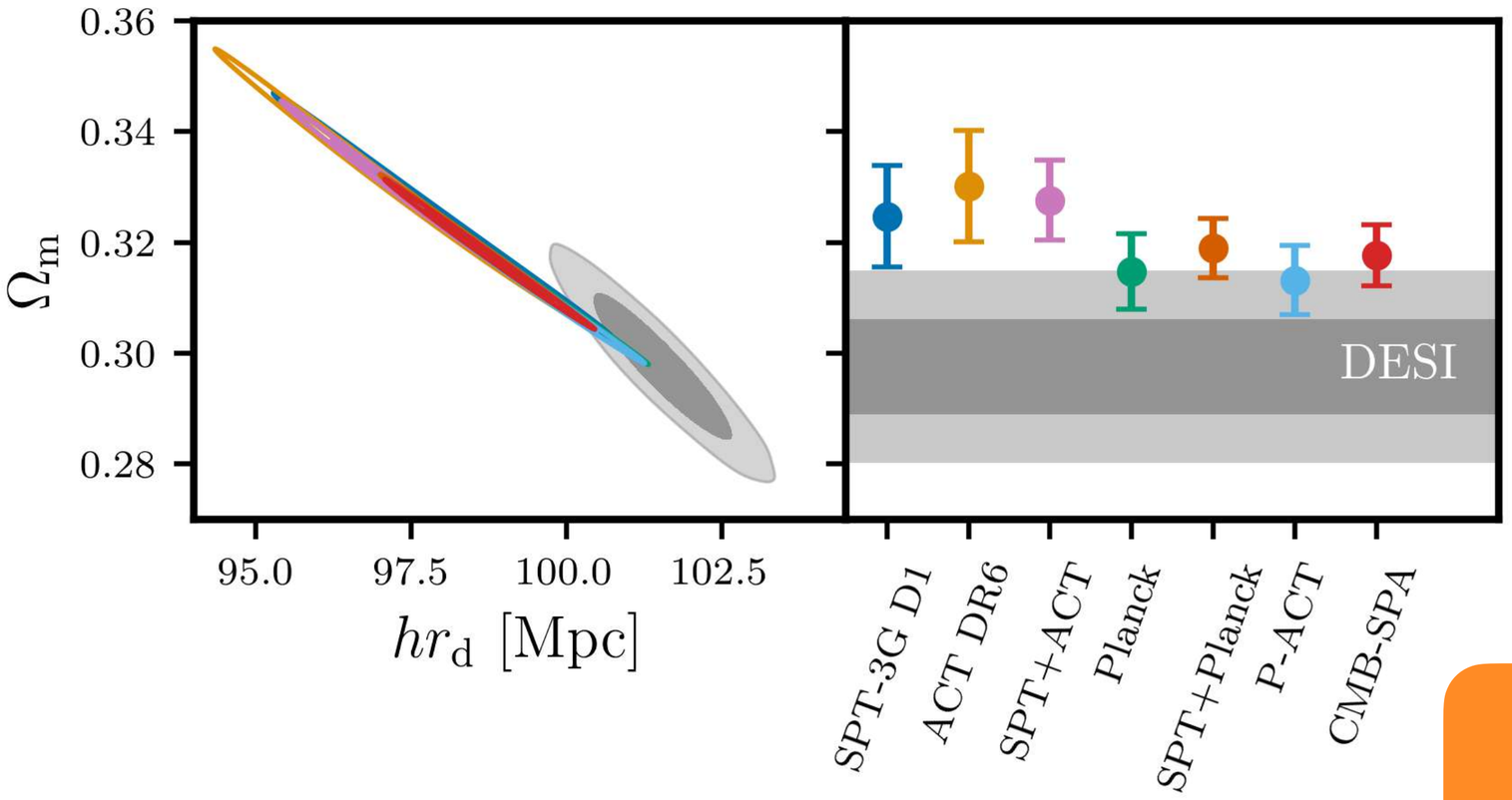
Models tested:

- New light particles ($N_{\rm eff}$, Y_P, $N_{\rm eff} + Y_P$)
- Signature of lensing ($A_{\rm lens}$ & variations)
- Neutrino mass: $\Sigma m_\nu < 0.19\,{\rm eV}$
- Mean spatial curvature: $\Omega_k \sim 0$ at 2σ
- Modified Recombination
  - Model: Lynch et al. 2024 (arXiv:2404.05715)
- Early dark energy $f_{\rm EDE} < 0.091$
  - Results: Khalife et al. 2025 (arXiv:2507.23355)



Credit: Camphuis et al. 2025

CMB And DESI BAO Are Borderline Consistent in ΛCDM



SPT-3G D1 vs. DESI:	$2.5\,\sigma$	✓
ACT DR6 vs. DESI:	$3.1\,\sigma$	×
SPT+ACT vs. DESI:	$3.7\,\sigma$	×
Planck vs. DESI:	$2.0\,\sigma$	✓
SPT+Planck vs. DESI:	$3.0\,\sigma$	×
P-ACT vs. DESI:	$2.0\,\sigma$	✓
CMB-SPA vs. DESI:	$2.8\,\sigma$	✓

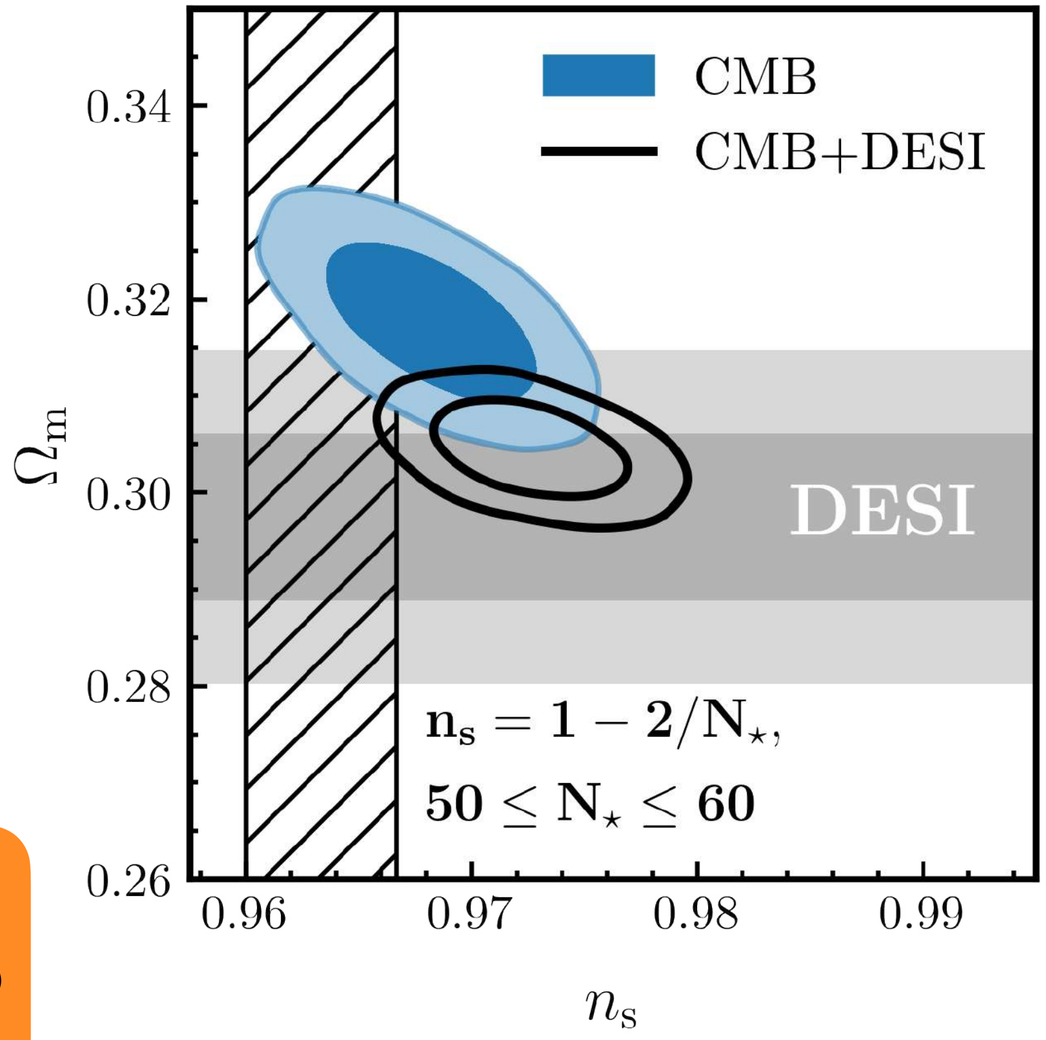
Joint analyses should be performed with caution

DESI: arxiv:2503.14739, arxiv2503.14738

Some caveats of τ prior and lensing likelihood details apply

Approach CMB+BAO Inflation Constraints With Caution

- **<u>Differences pull n_s high in joint analysis</u>**
  - For CMB data, n_s is (-) correlated with Ω_m and (+) with hr_d (up to 70%)
- **<u>CMB+DESI n_s is high w.r.t. predictions of Starobinsky R^2, Higgs, α-attractors</u>**
  - More compatible with monomial potentials, polynomial α-attractors



n_s shift driven by data differences, interpret results with a grain of salt
(Ferreira, …, Balkenhol et al. 2025, arxiv:2507.12459)

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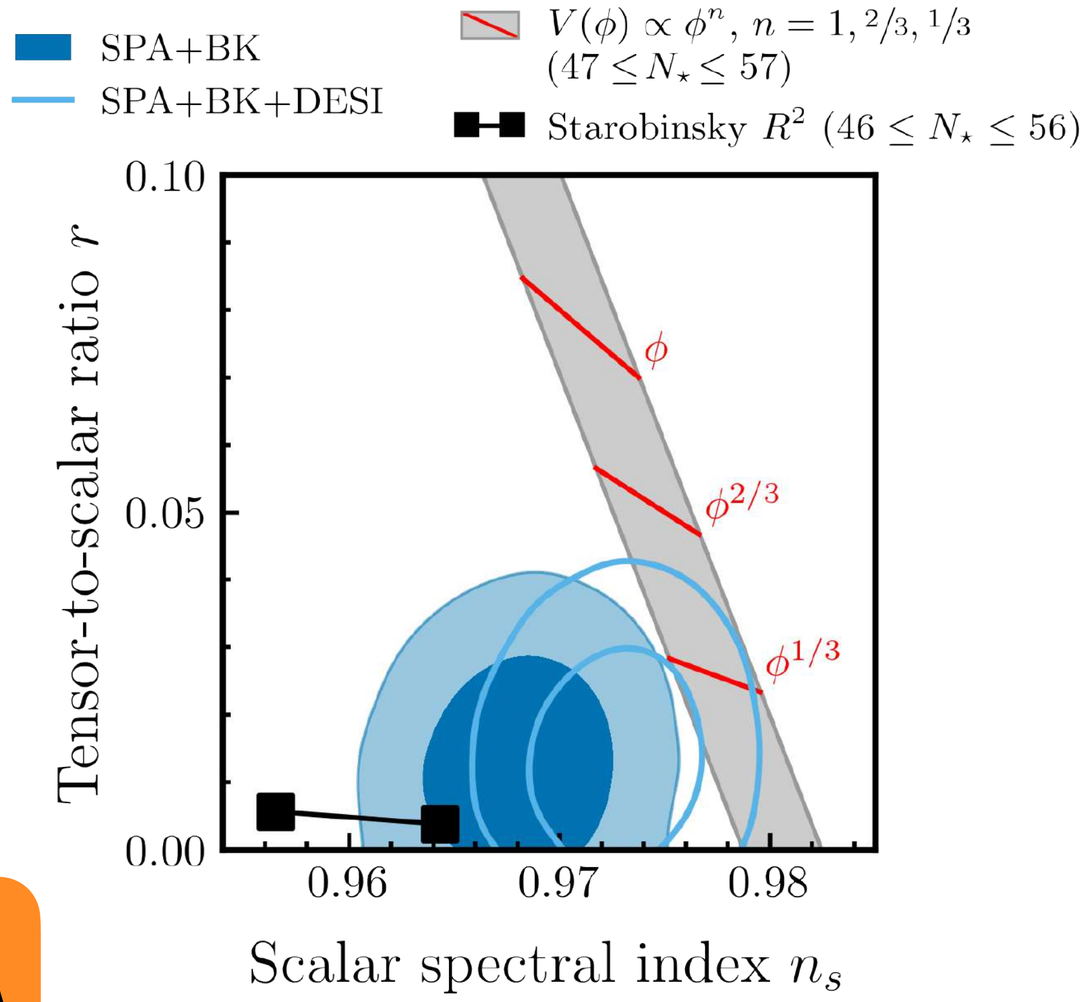
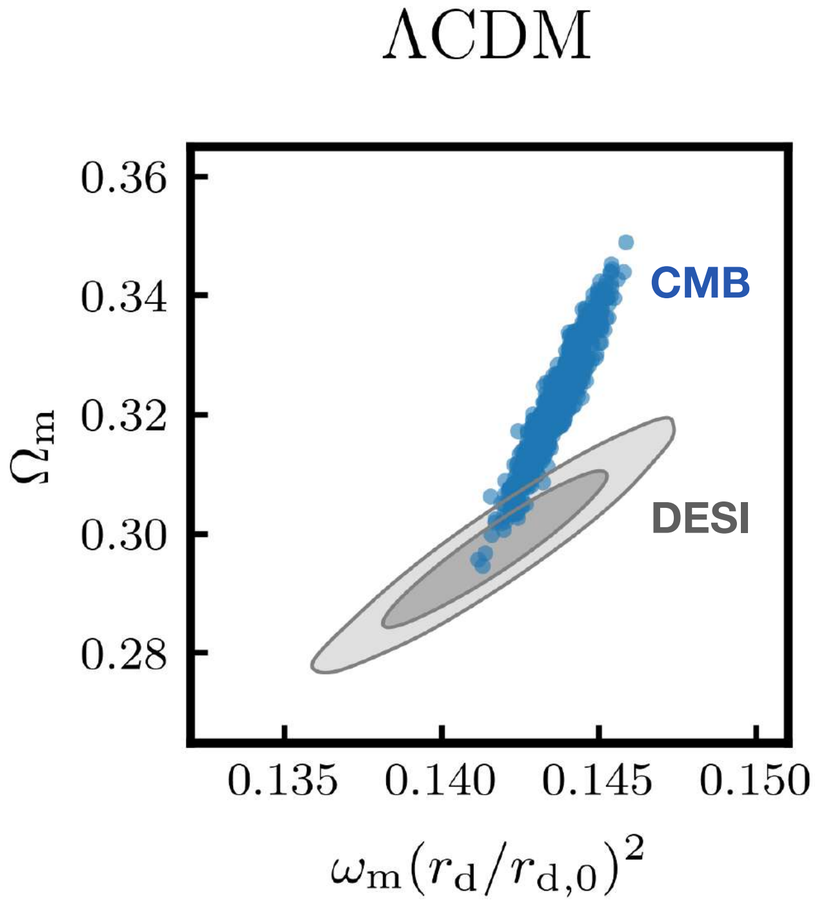


Credit: Balkenhol et al. 2025 <u>arXiv:2512.10613</u>

Differences Between CMB and DESI Translate To ΛCDM Extensions At 2-3σ

Model Class	Preference over ΛCDM
Rescaling of lensing in CMB	2.6σ
Light relics	<1.5σ
Modified recombination	1.8σ
Spatial curvature	2.1σ
Spatial curvature + varying electron mass	2.1σ
Zero neutrino mass	2.1σ
Dynamical dark energy	3.0σ
Dynamical dark energy w/ SN data	3.2σ*
Axion early dark energy	2.5σ
Thawing quintessence dark energy + axion early dark energy w/ SN data**	2.5σ



*Popovich et al. 2025 arXiv:2511.07517
**Jhaveri et al. 2026 arXiv:2604.08530

See Camphuis et al. 2025 (2506.20707), **Khalife et al. 2025** (2507.23355) **for details**

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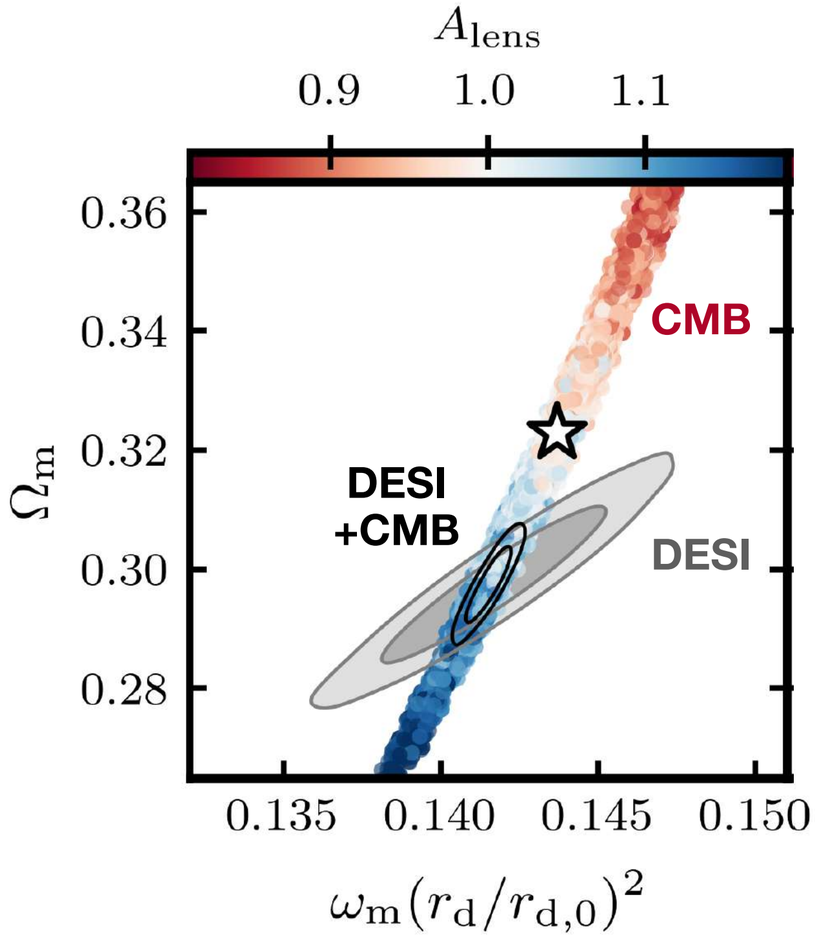

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More Data Needed For Clarity On CMB vs. BAO

With current data, **no definitive evidence for a breakdown of ΛCDM**

- Statistical fluctuation
  - Frequentist significance is moderate at ~3σ
  - Bayesian evidence is weaker, at most 5:1
    (w_0w_a: Popovic et al. 2025 arXiv:2511.07517 Ong et al. 2026 arXiv:2603.05472)
- Always careful about unknown systematic effects

More data needed for stronger jugement
(CMB, DES, DESI, Euclid, Rubin, Roman, …)

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With current data, r … n of ΛCDM

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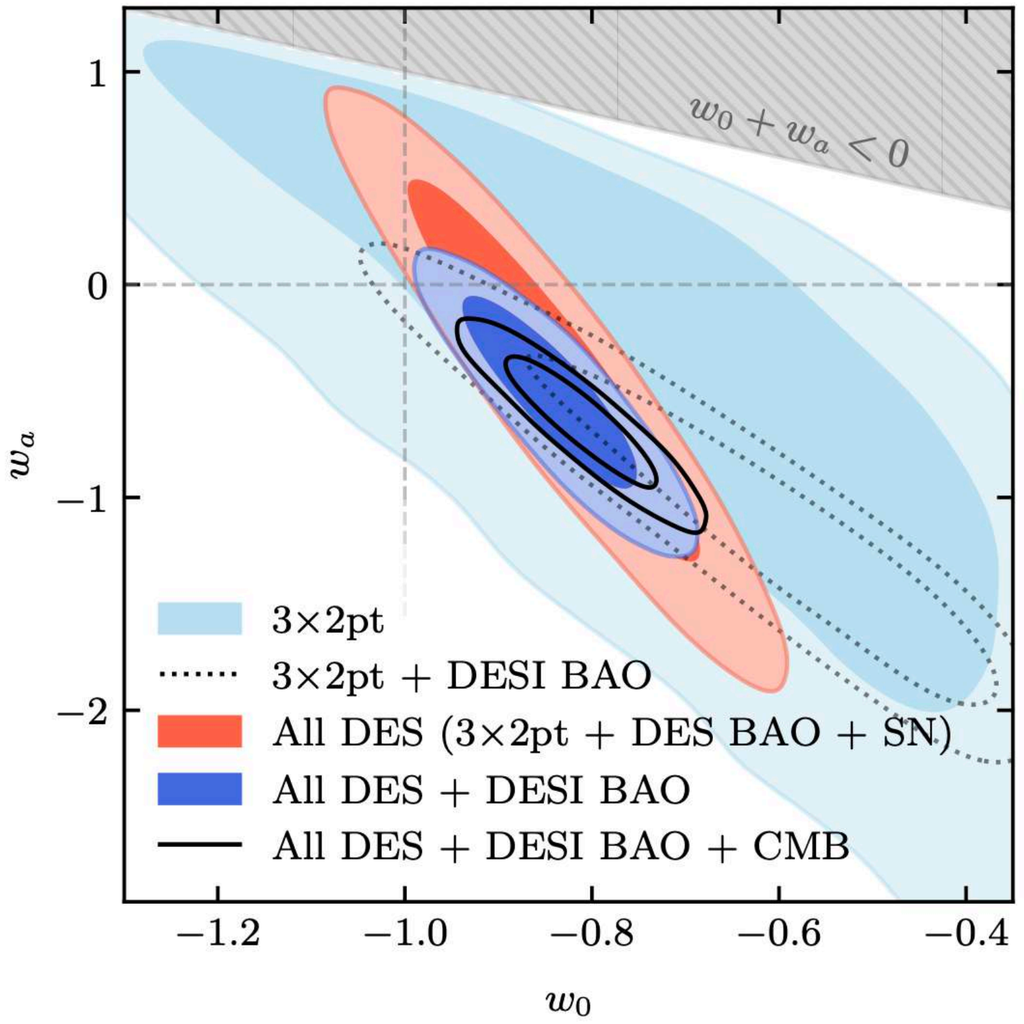
  - Bayesian eviden … arXiv:2511.0751 … l. 2025
- Always careful a …

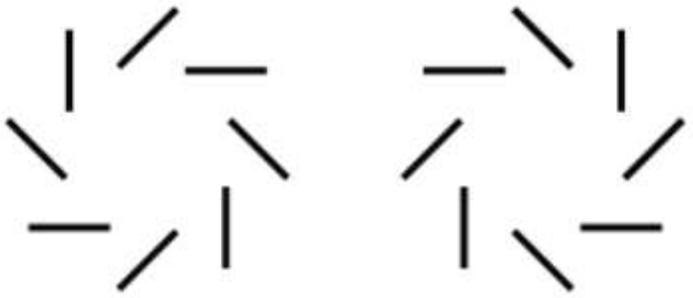


Mor… …ment
(C… …)

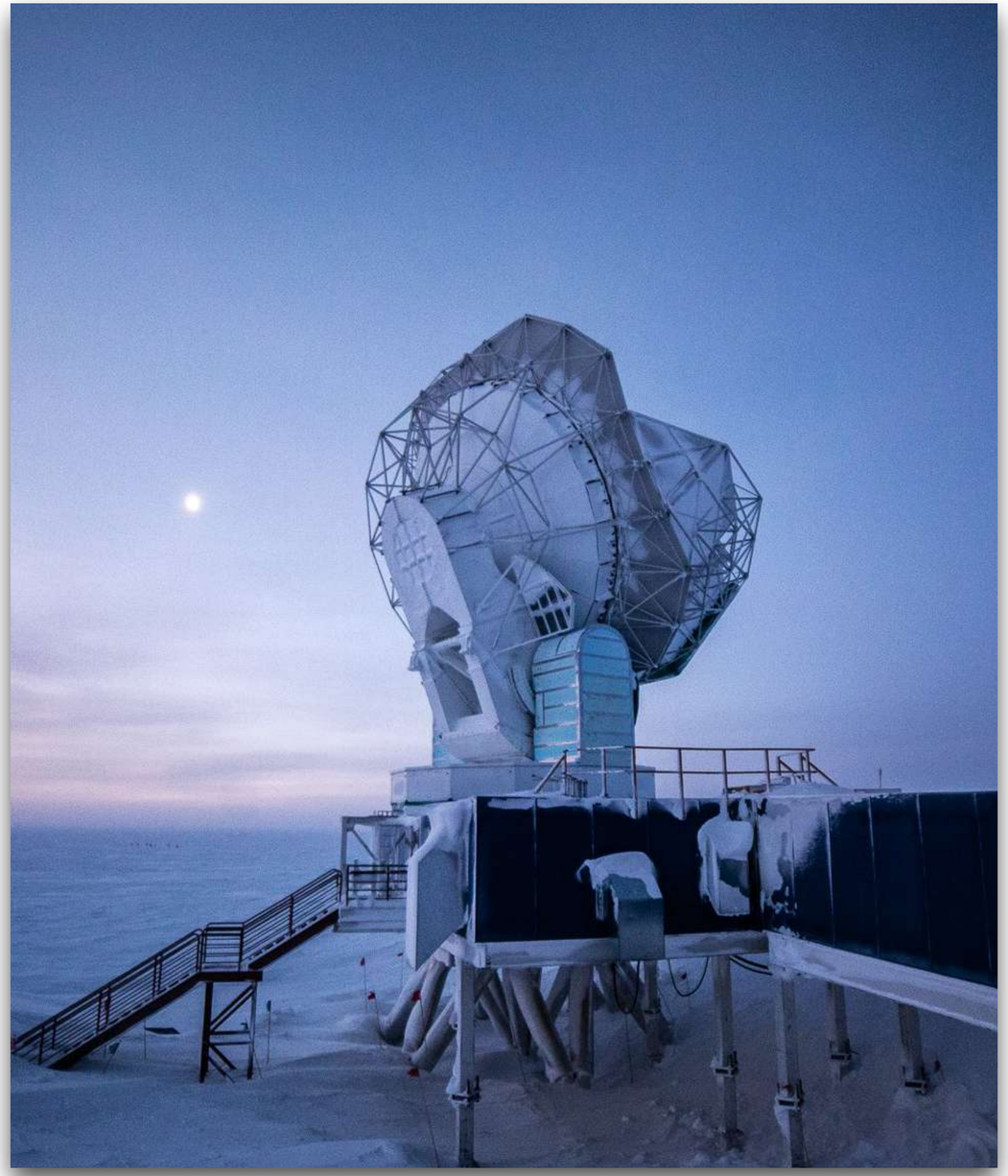
DES 6Y dynamical dark energy paper, Abbott et al. 2026, arXiv:2605.27221

Primordial Gravitational Waves

B-mode Polarisation Pattern



Credit: Lazear et al. 2014



Credit: Kevin Zagorski

SPT Data Are Crucial For Primordial Gravitational Waves

- **<u>SPT Measurement of B-mode power</u>**
  - J. A. Zebrowski et al., 2025 (arXiv:2505.02827)
- **<u>South Pole Observatory w/ BICEP/Keck</u>**
  - Current BK18 $\sigma(r) = 0.009$
  - SPT Delensing crucial to achieve further 2-3x improvement

J. Zebrowski (UChicago)

Credit: J. A. Zebrowski et al., 2025

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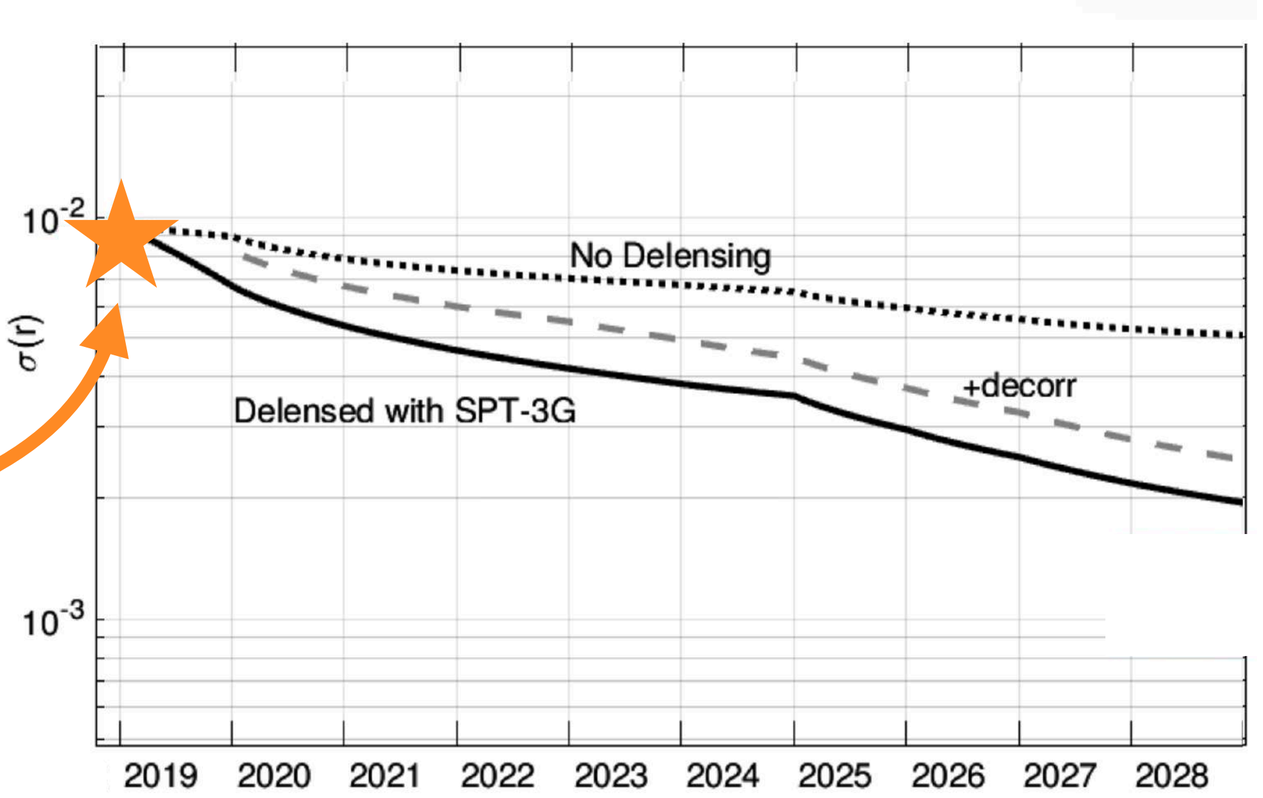

Credit: K. Wu, SPO collaboration

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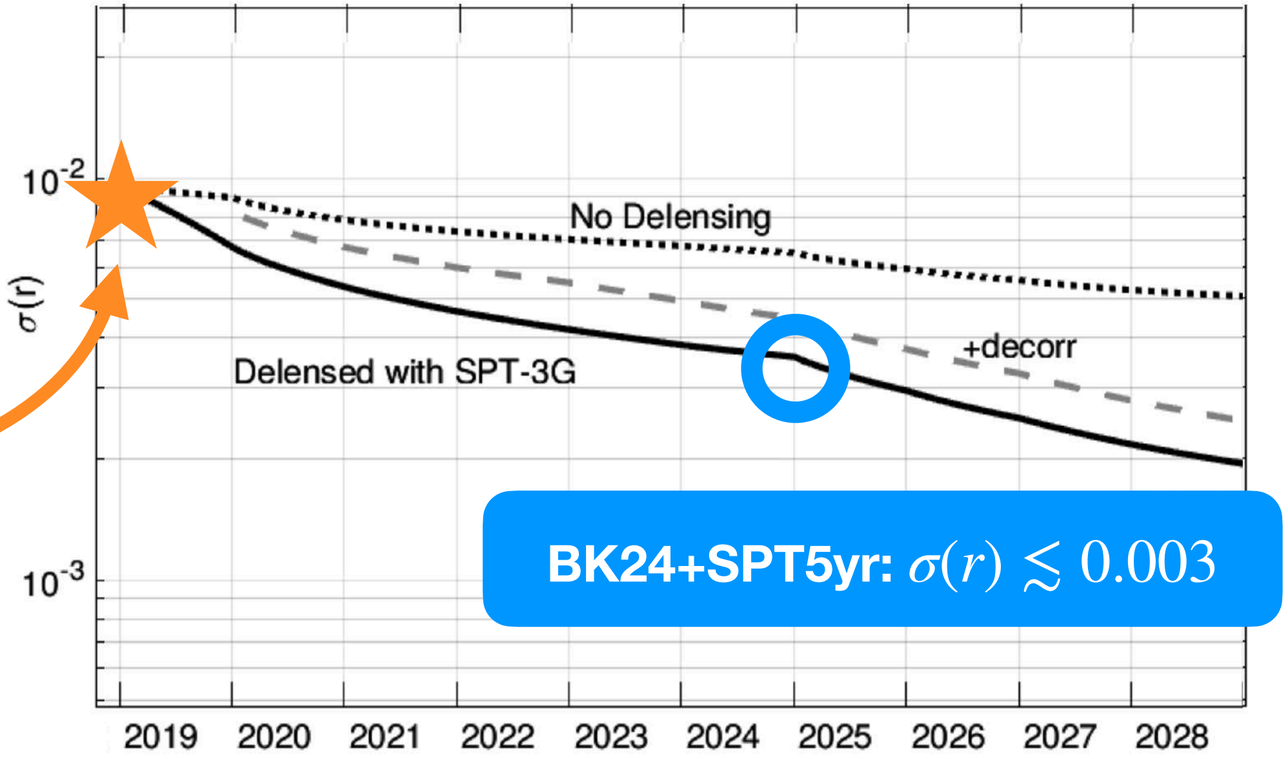

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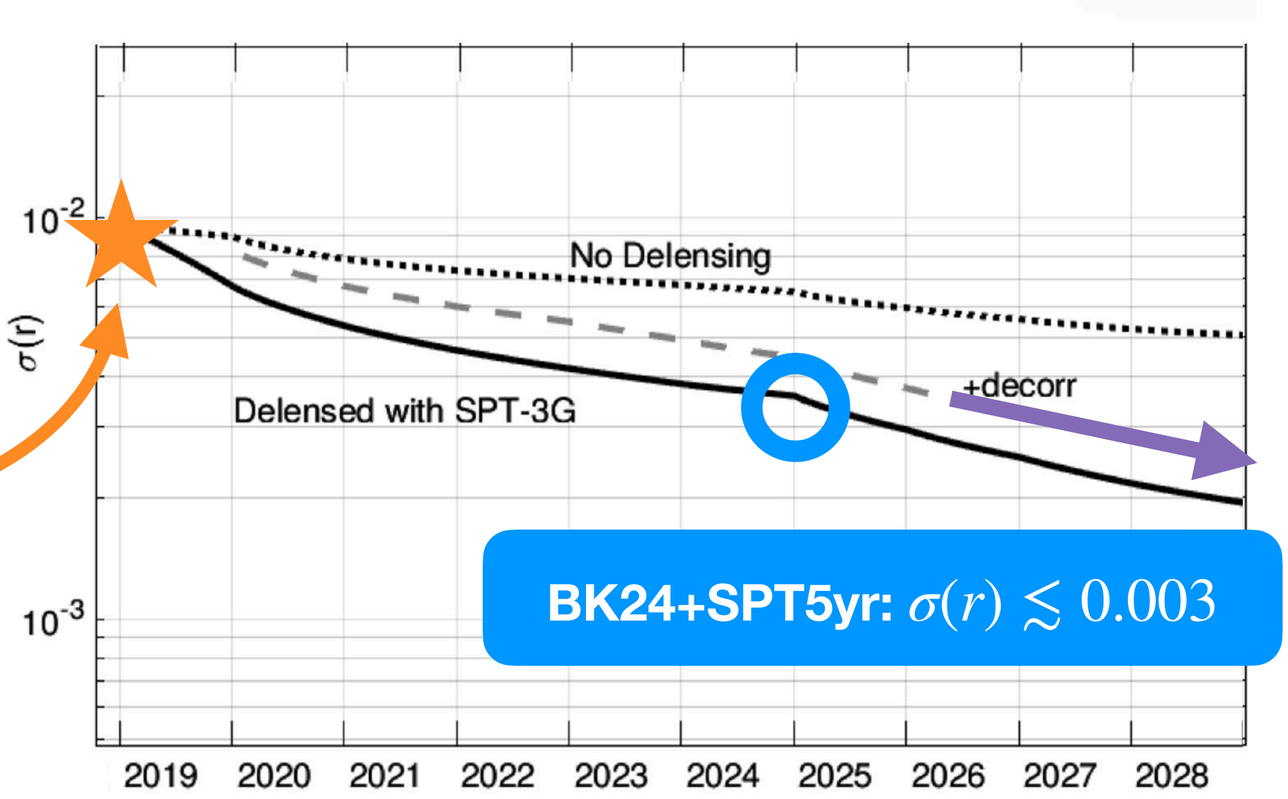
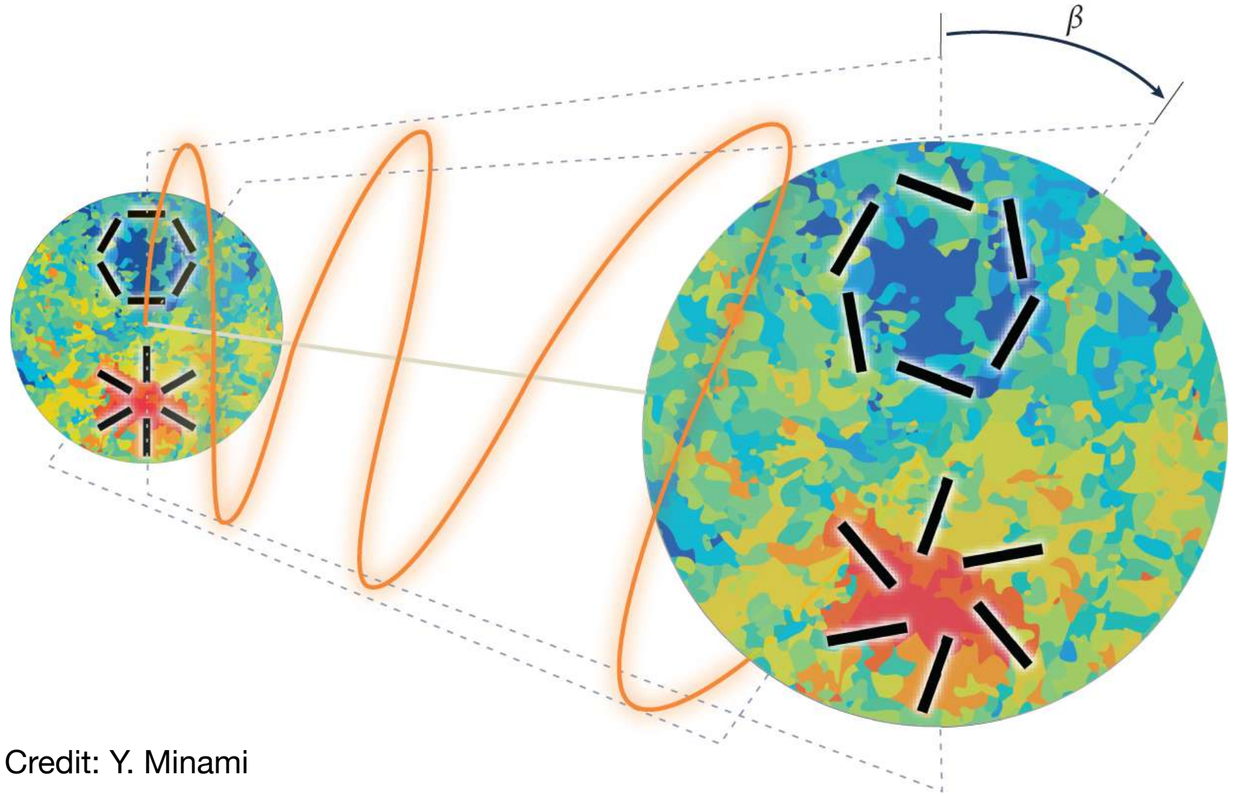


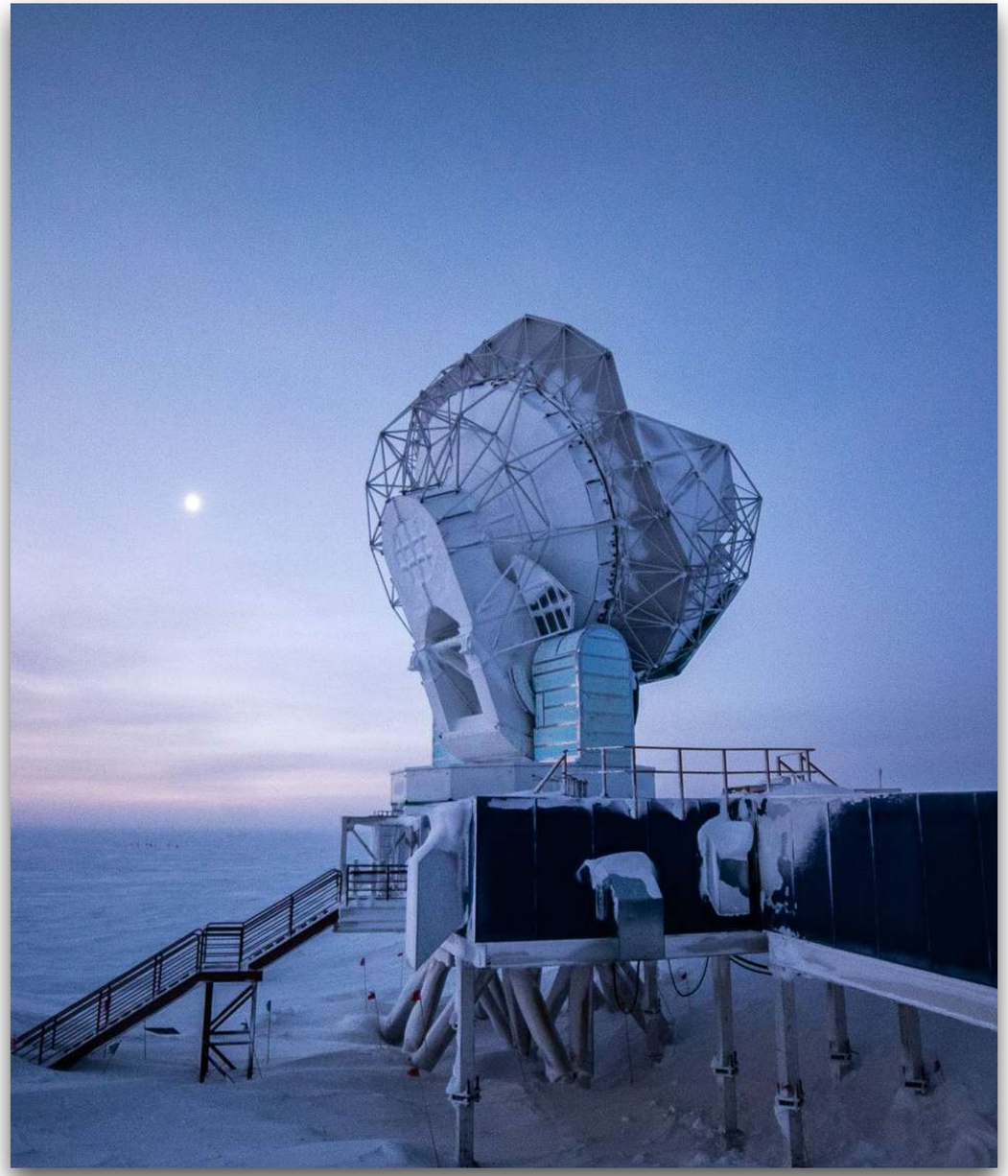
SPO to achieve $\sigma(r) = 0.001$ in the 2030s

Credit: K. Wu, SPO collaboration

Anisotropic Cosmic Birefringence



Credit: Y. Minami



Credit: Kevin Zagorski

SPT Sets Best Anisotropic Birefringence Limits

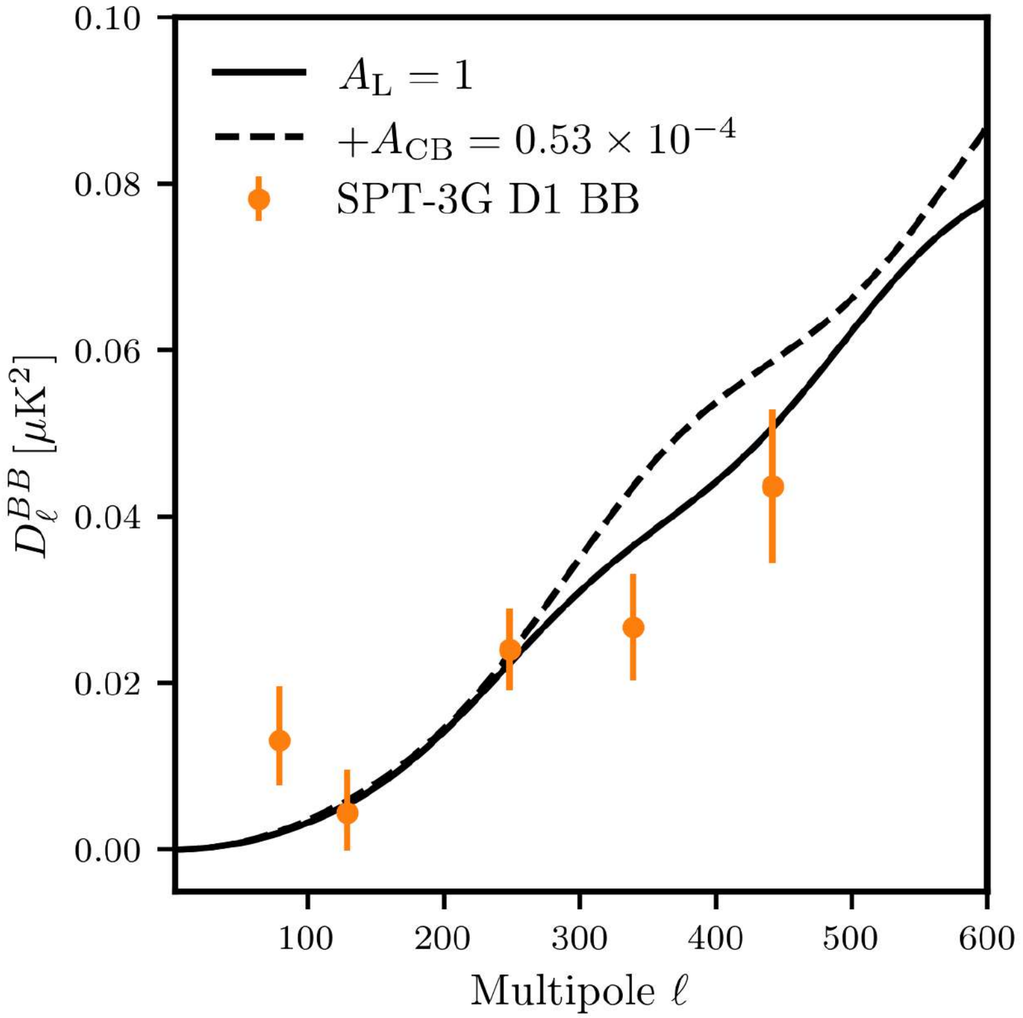
Additional B-mode power:

- Best constraints w/ this method by SPT-3G data
  - Balkenhol et al. 2025 (arXiv:2510.07928)

Induced E-B correlation:

- Best constraints, sensitive to shape of α spectrum
  - Coerver et al. in prep.

$$10^4 A_{CB} < 0.53$$



Credit: Anna Coerver, SPT

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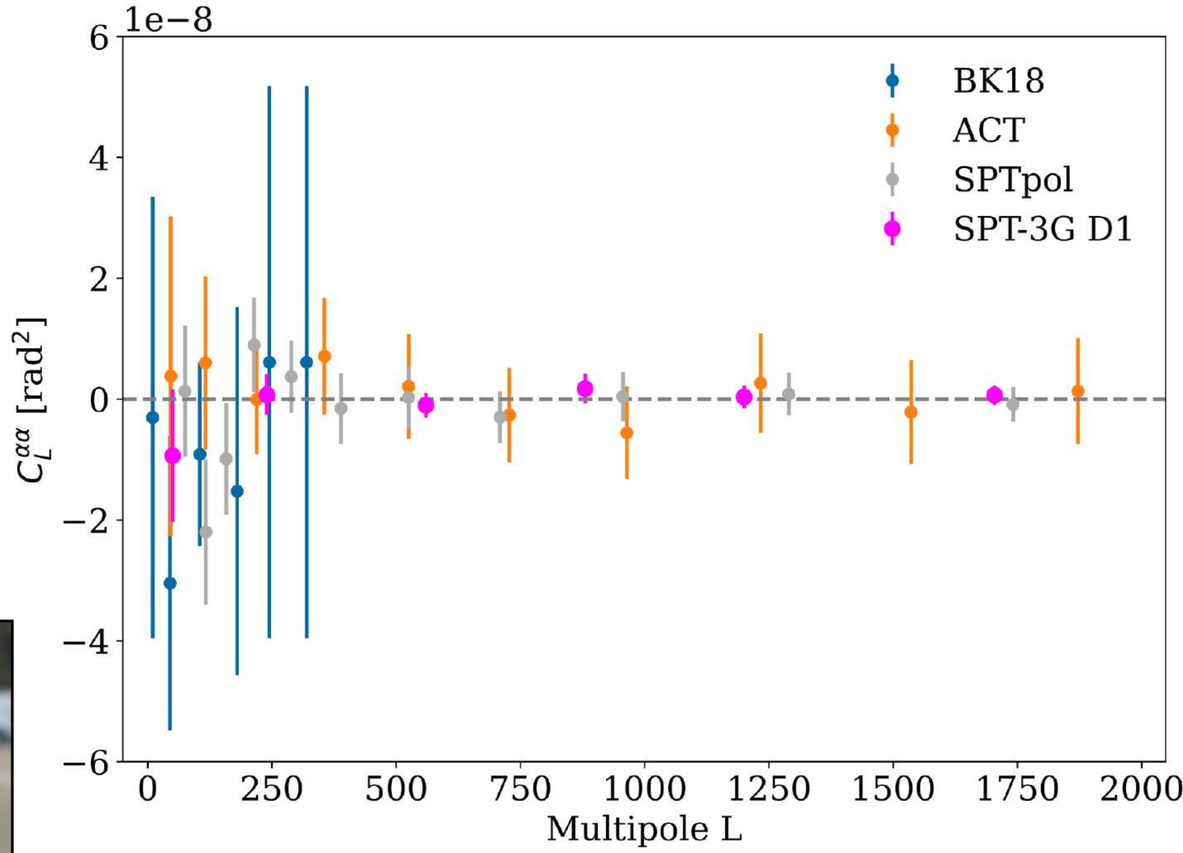
  - Coerver et al. in prep.

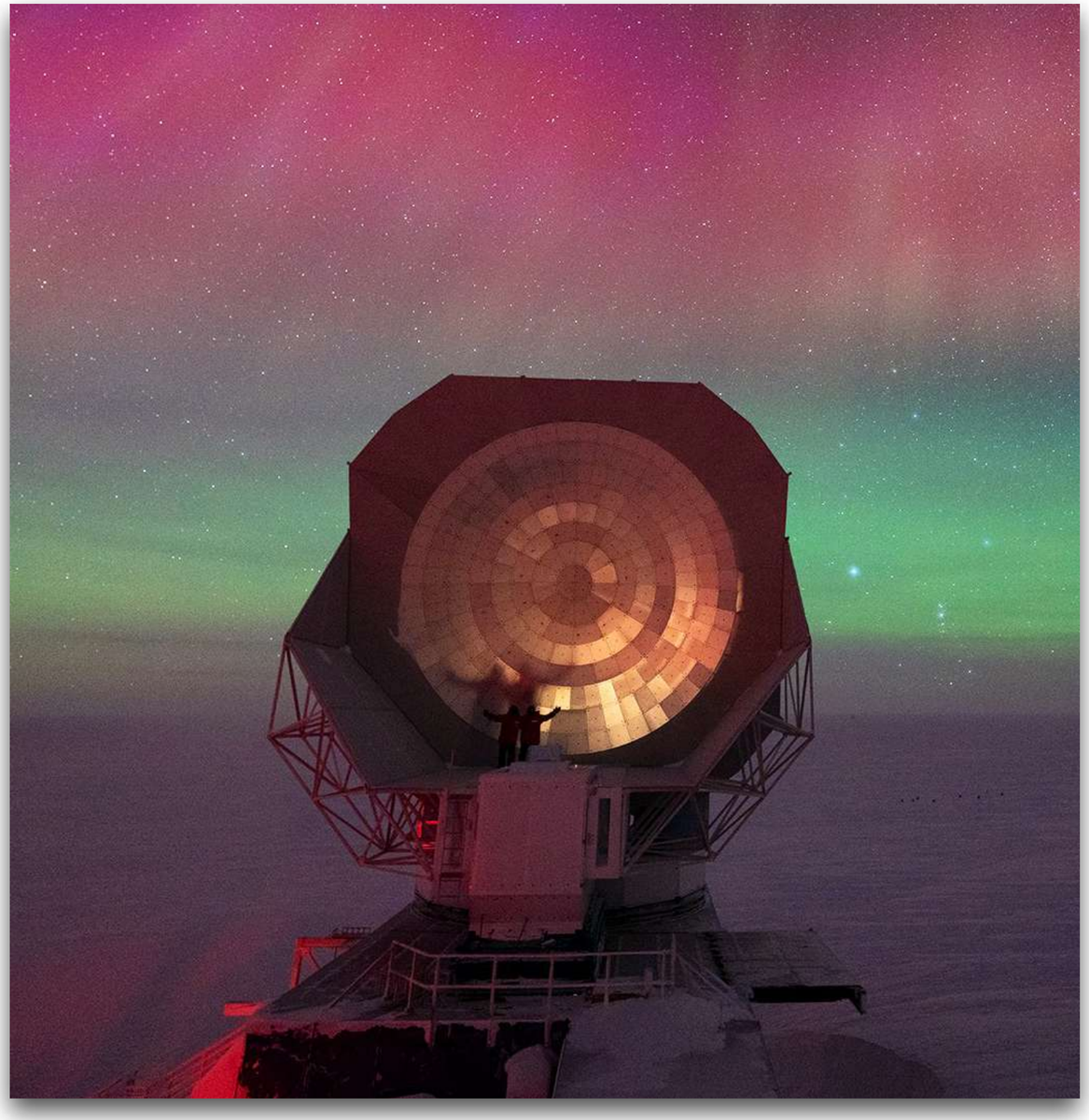
$$10^4 A_{CB} < 0.017$$



A. Coerver (Berkeley)

Credit: Anna Coerver, SPT

Outlook

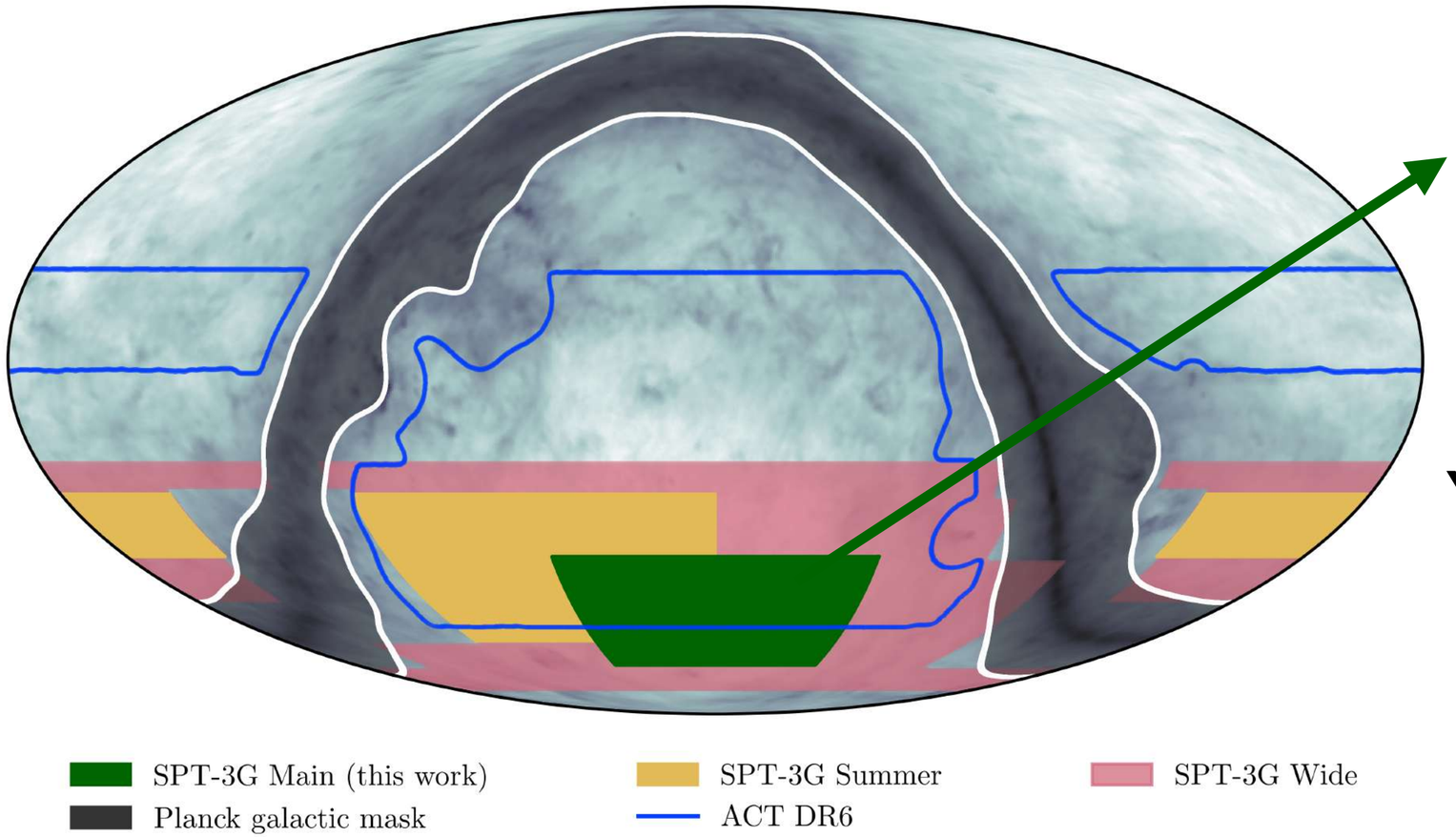


Credit: Aman Chokshi

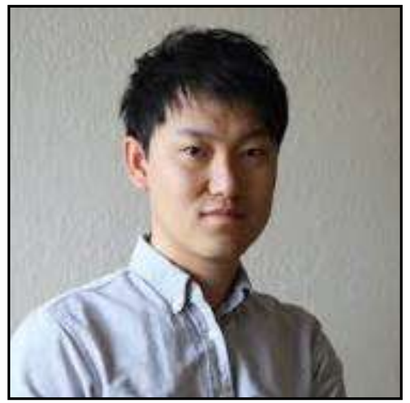
SPT Covers Many Science Cases

- **Cluster cosmology:** e.g. Bocquet et al. 2024 (arXiv:2401.02075)
- **Secondary anisotropies:** Chaubal et al. 2026 (arXiv:2601.20551)
- **Compton y-maps:** Maniyar et al. 2026 (arXiv:2602.11279)
- **tSZ power spectrum:** Raghunathan et al. 2026 (arXiv:2602.10107)
- **CMB lensing x DES sheer:** Oullette et al. in prep.
- **Euclid Deep Field South observations:** Archipley et al. 2025 (arXiv:2506.00298)
- **Transients:** e.g. Guns et al. 2021 (arXiv:2103.06166)
- **Event Horizon Telescope**
- …

SPT CMB Primary & Lensing Data On A Quarter Of The Sky



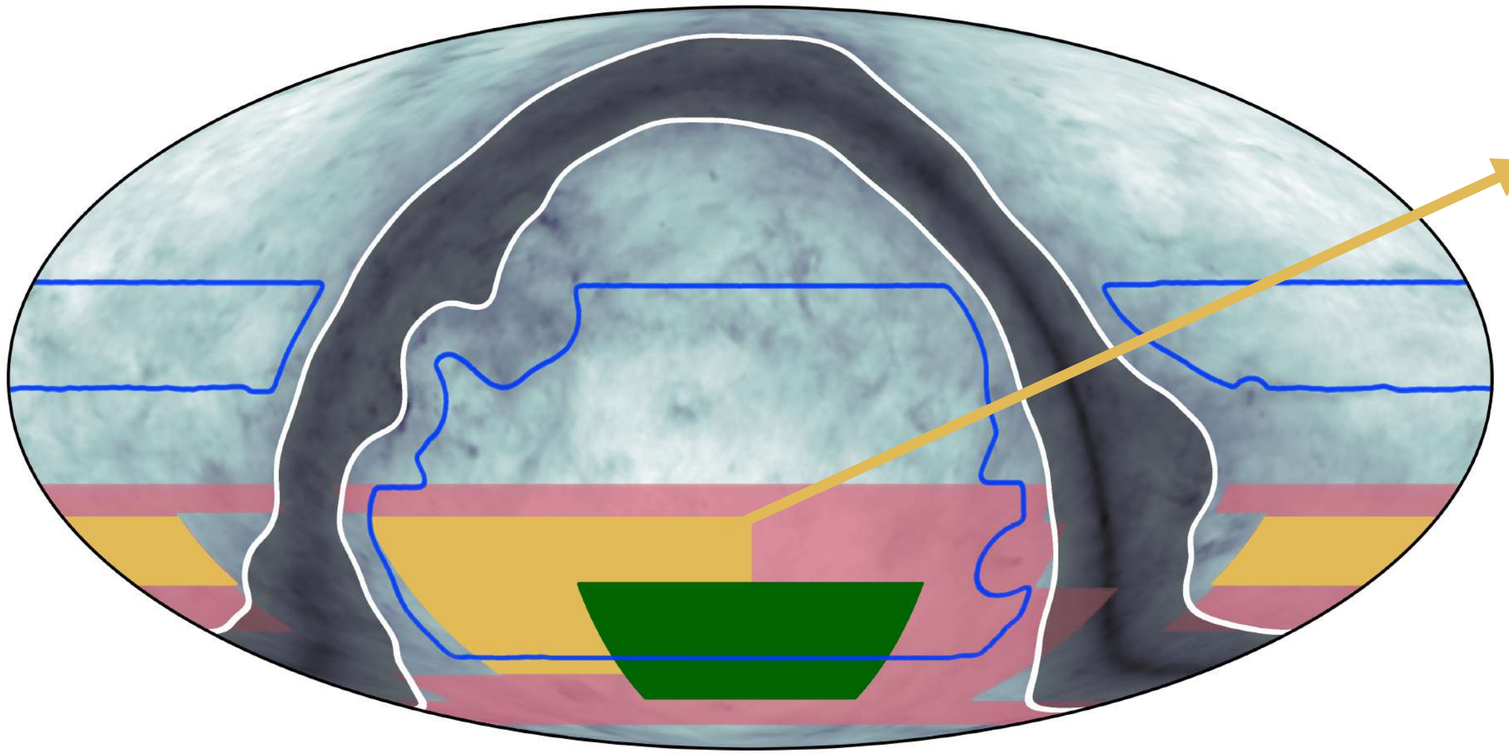
Main field lensing
Survey area: 1500 deg²



Y. Omori (UChicago), K. Wu (Caltech)

Tightest $\sigma_8\Omega_m^{0.25}$ measurement from CMB lensing to date (1.4%)

SPT CMB Primary & Lensing Data On A Quarter Of The Sky

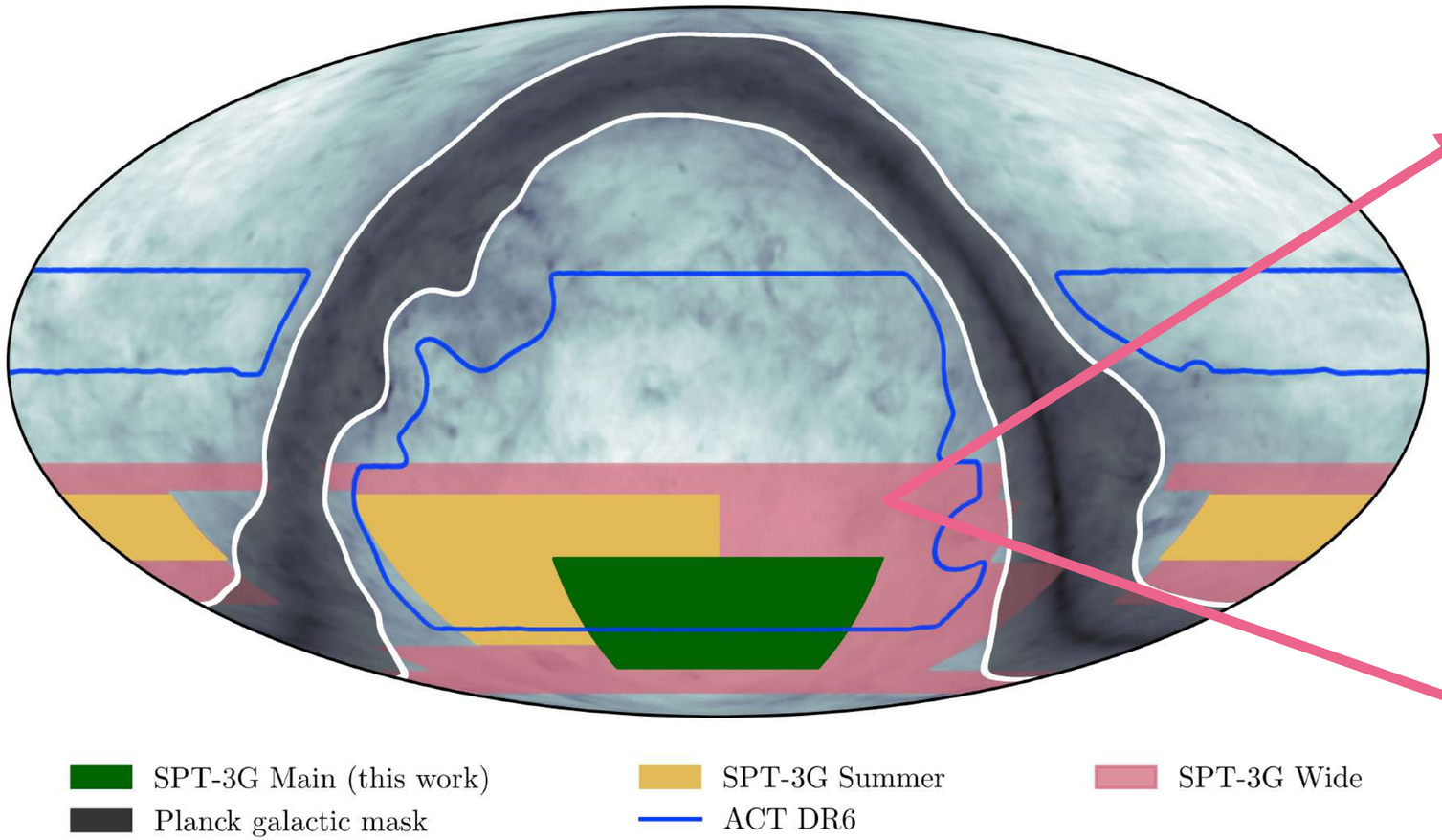


SPT-3G Main (this work)
Planck galactic mask
SPT-3G Summer
ACT DR6
SPT-3G Wide

Summer fields primary CMB
Total survey area: 4k deg²

F. Guidi (UC Davis)

SPT CMB Primary & Lensing Data On A Quarter Of The Sky



Wide fields
Total survey area: 10k deg²


Primary CMB:
Aline Vitrier (IAP), Kyra Fichman (UChicago)


Lensing:
M. Froschi (Caltech), Y. Li (UChicago)

See Virtier et al. 2025 for forecasts: arXiv:2510.24669

Conclusions

- SPT has delivered fantastic CMB data
  - CMB is consistent across exp. and with ΛCDM
  - Borderline significant differences with BAO data
- SPT data are crucial in the search for inflationary gravitational waves
- SPT sets best constraints on anisotropic birefringence
- Planned next-gen. camera with 7x mapping speed

SPT-3G is only getting started

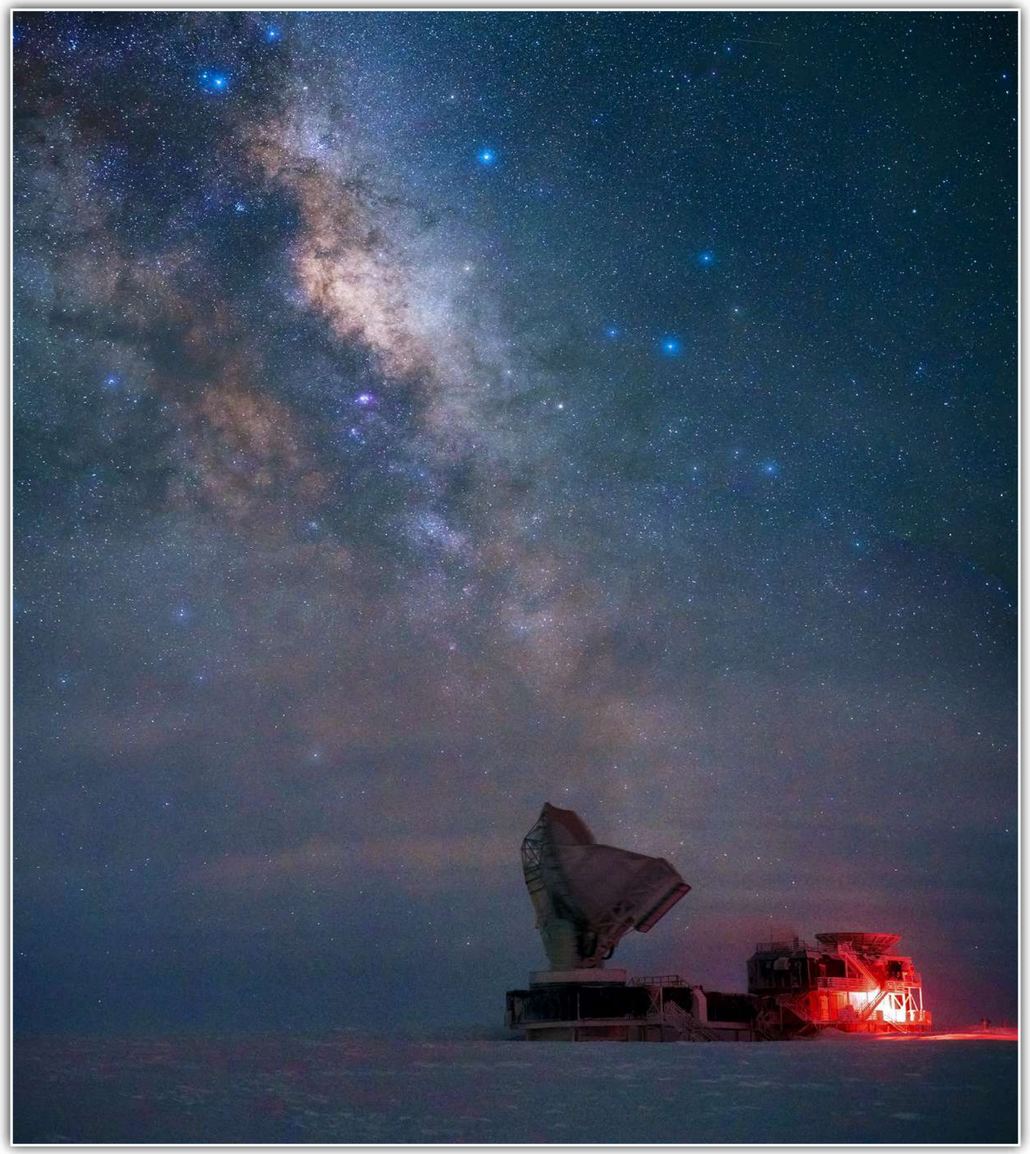
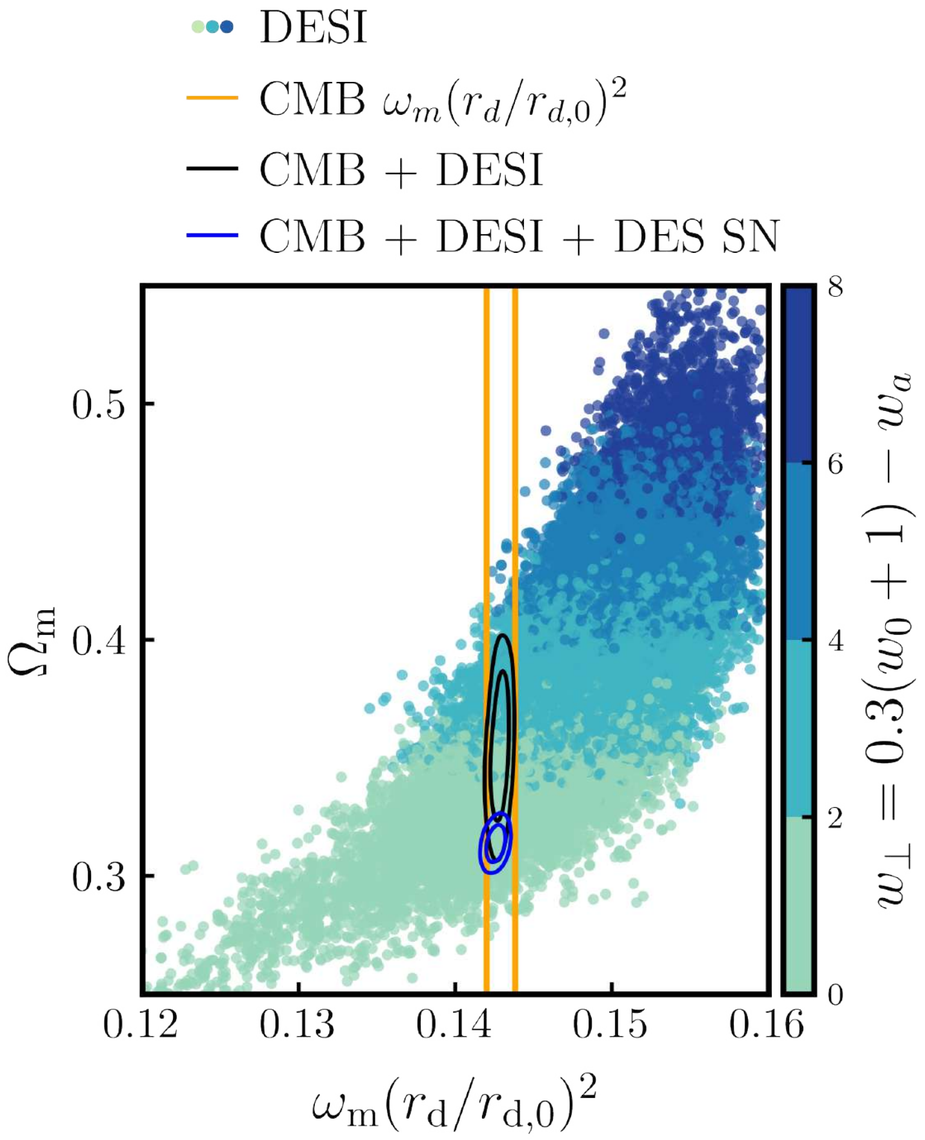


Image Credit: Aman Chokshi

BACKUP

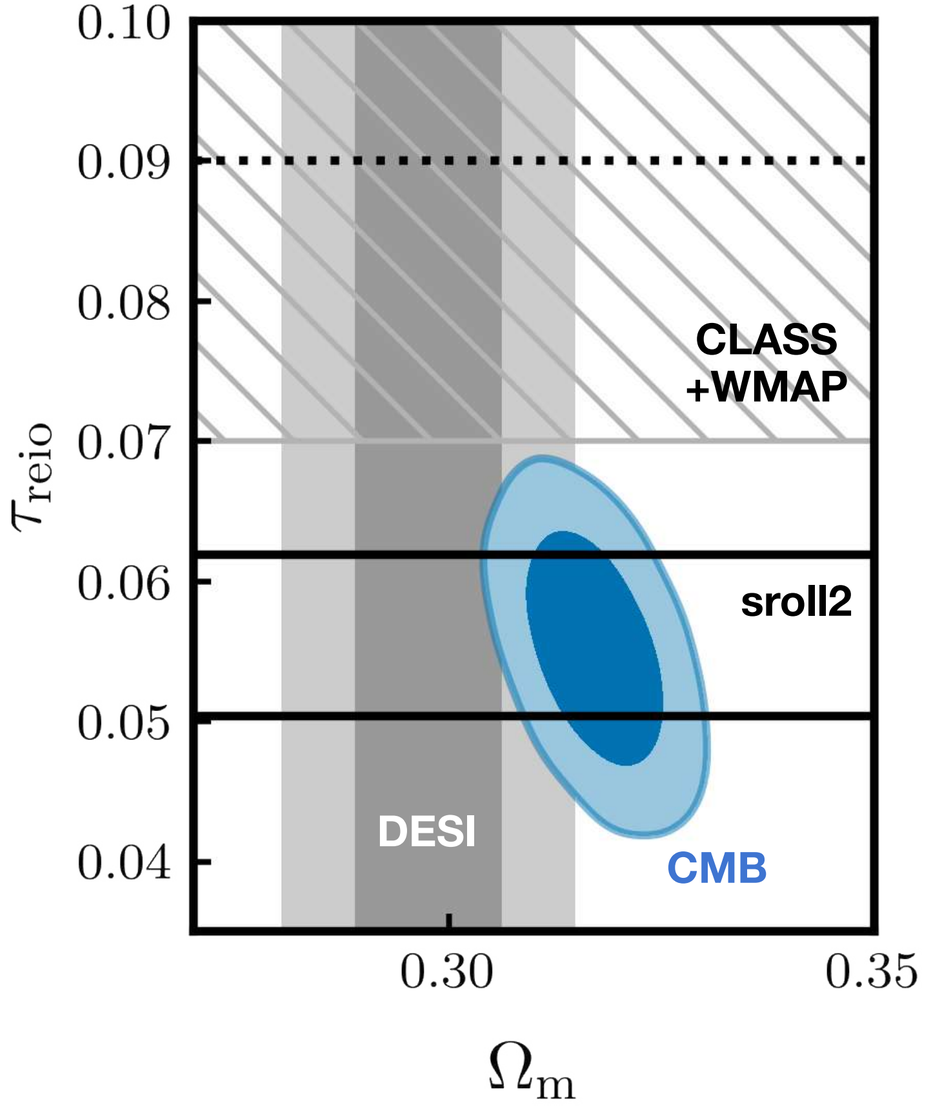
CMB-BAO differences project onto ΛCDM+

- **CMB+BAO better fit by extended models**
  - Trade differences for preference for new physics
- **What makes $w_0 w_a$ special?**
  - Using minimal CMB info suffices
  - SN data play an important role
  - No drastic consequences for inflation
- **Statistically not significant (yet?)**
  - Frequentist: $\sim 3\sigma$
  - Bayesian: weak (5:1) or no evidence for $w_0 w_a$ (Popovic et al. 2025, Ong et al. 2025)



CMB and DESI BAO are borderline consistent

- CMB and BAO are borderline consistent
- **Any caveats from the CMB side?**
  - τ prior allows for ~0.2σ variations
  - CMB lensing may cause ~0.5σ changes
- Careful with joint constraints
  - Impact on inflation landscape



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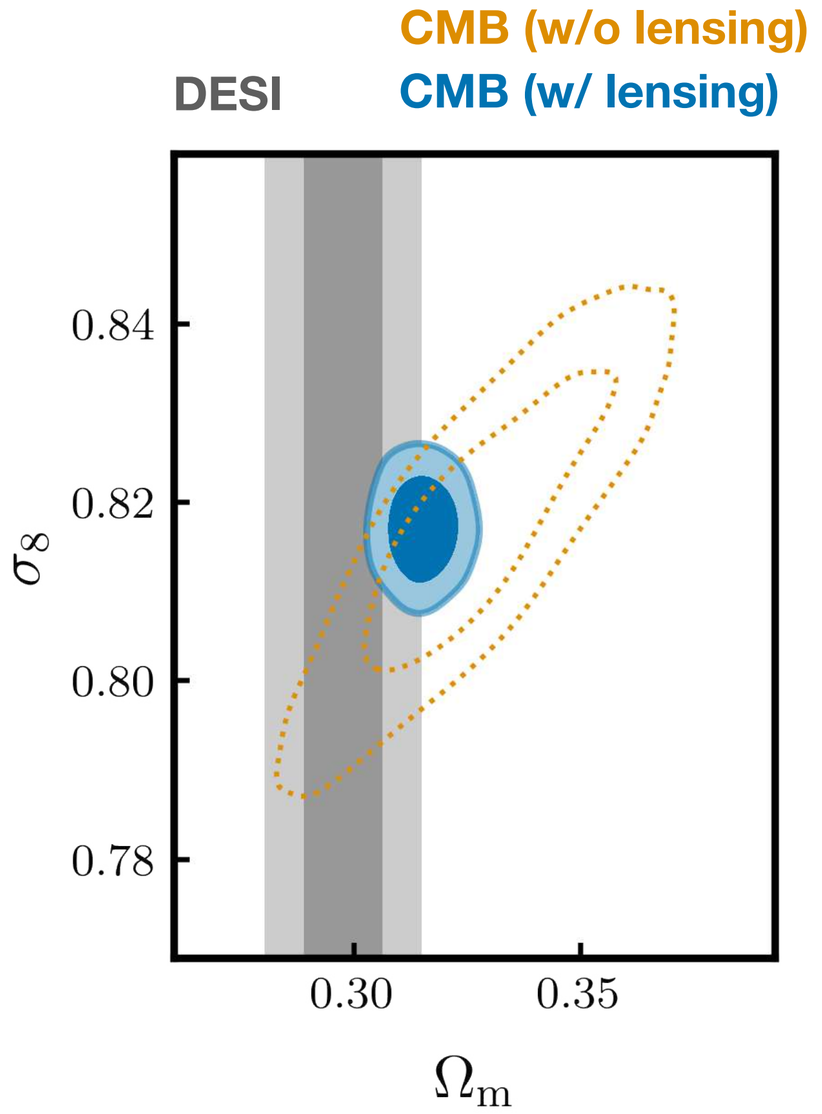

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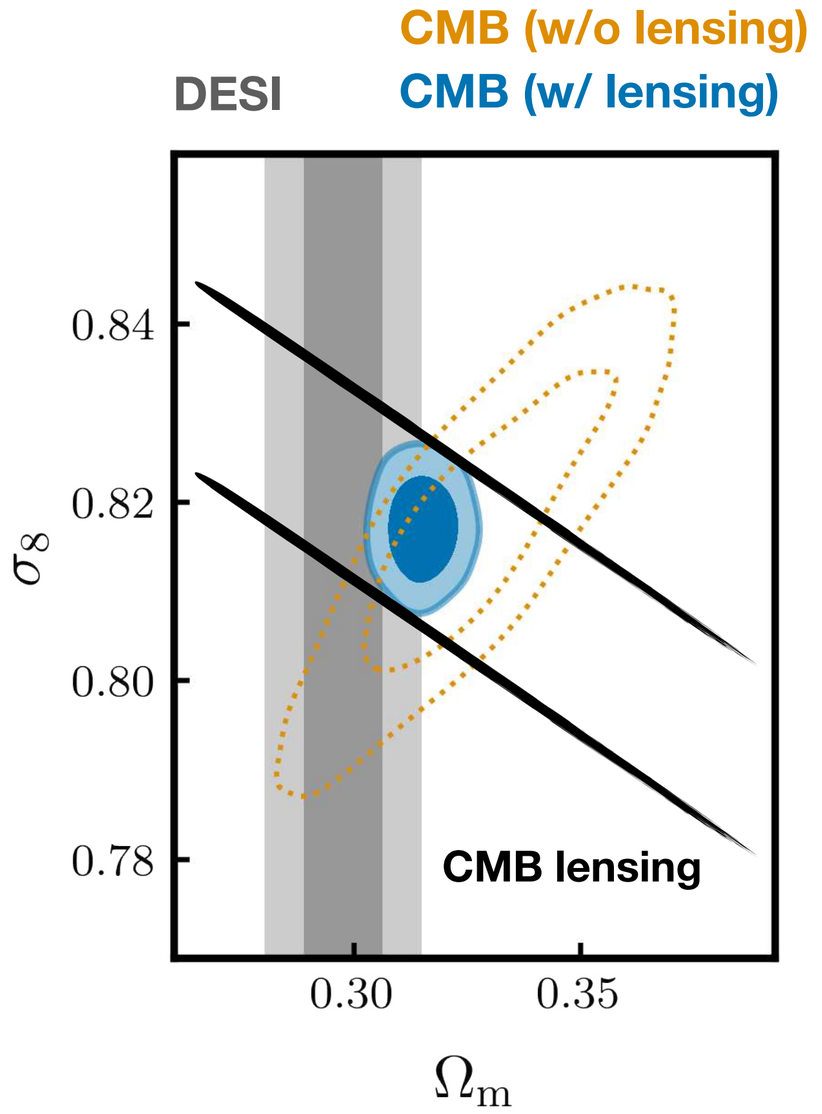


Data sets

$\tau_{\rm reio} \sim \mathcal{N}(0.051, 0.006)$ Akrami et al. [Planck], 2020

SPT:

Primary CMB:
This work
CMB Lensing:
MUSE, Ge et al. 2024

ACT:

Primary CMB:
DR6, Louis et al. 2025
CMB Lensing:
DR6, Madhavacheril et al. 2023, Qu et al. 2023

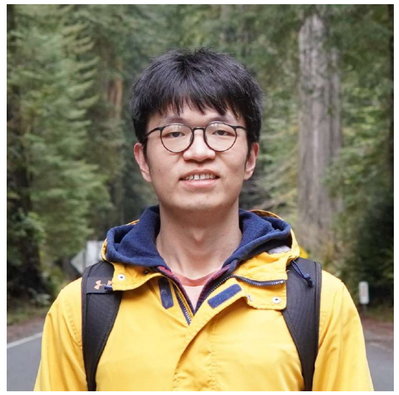
Planck:

Primary CMB:
PR3, Planck Collab., 2018, no lowE
CMB Lensing:
PR4, Carron et al., 2022

SPT+ACT

SPA:

Removing Planck high-ell primary data ("P-ACT")



F. Ge (Caltech)

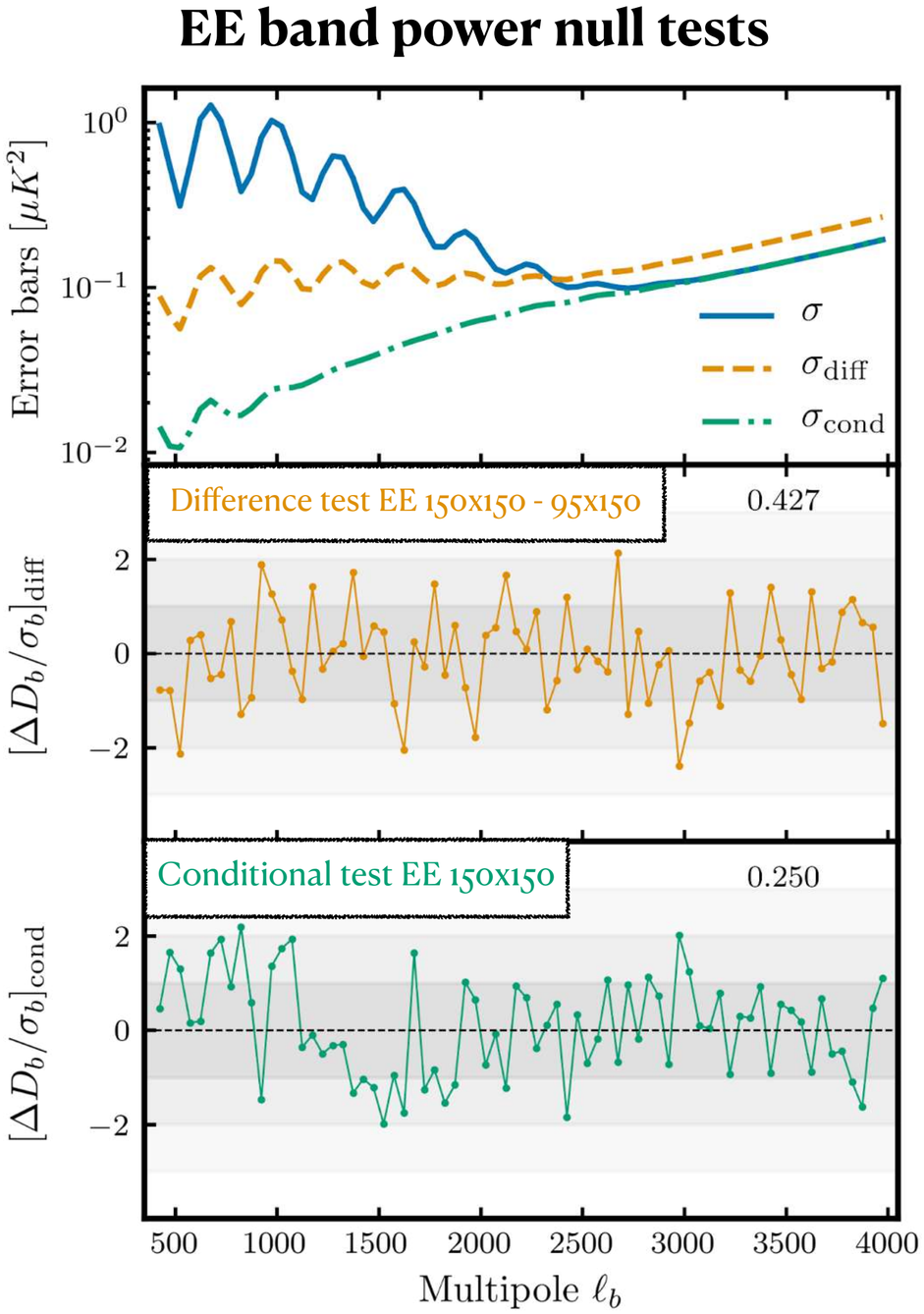
Best lensing data at $L > 350$

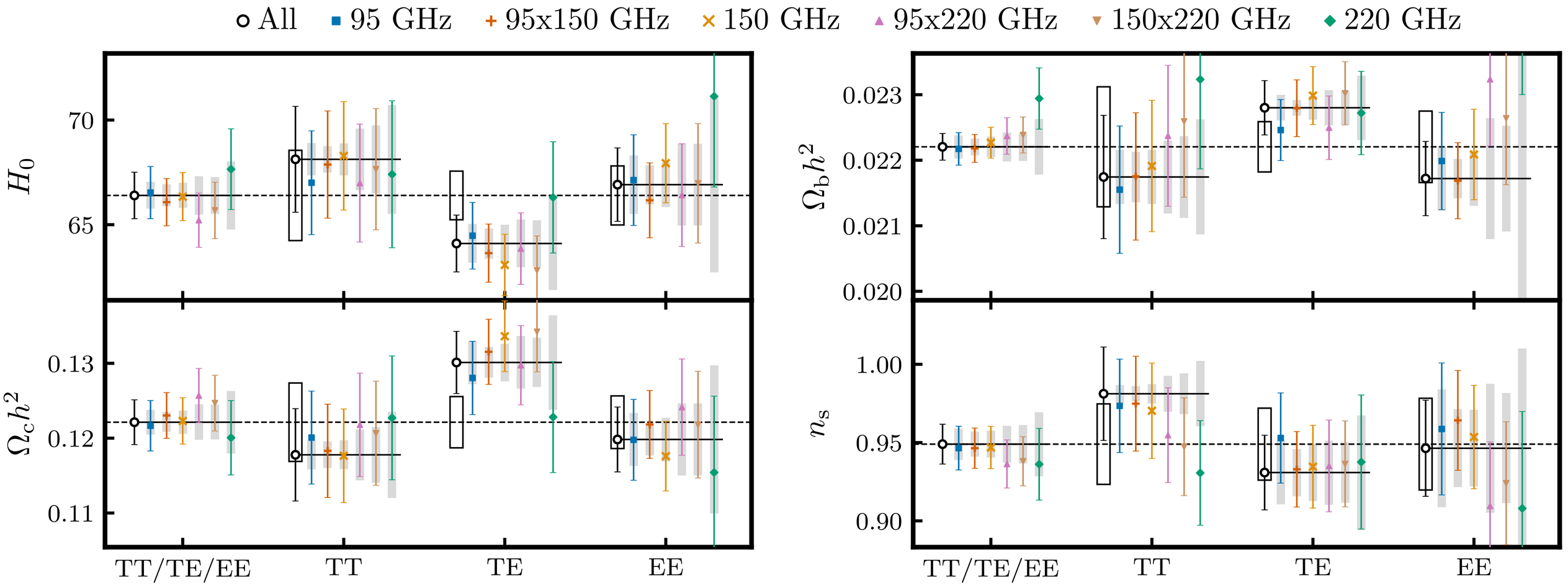
Blinding and Data Validation

Data is kept blind until null tests pass:

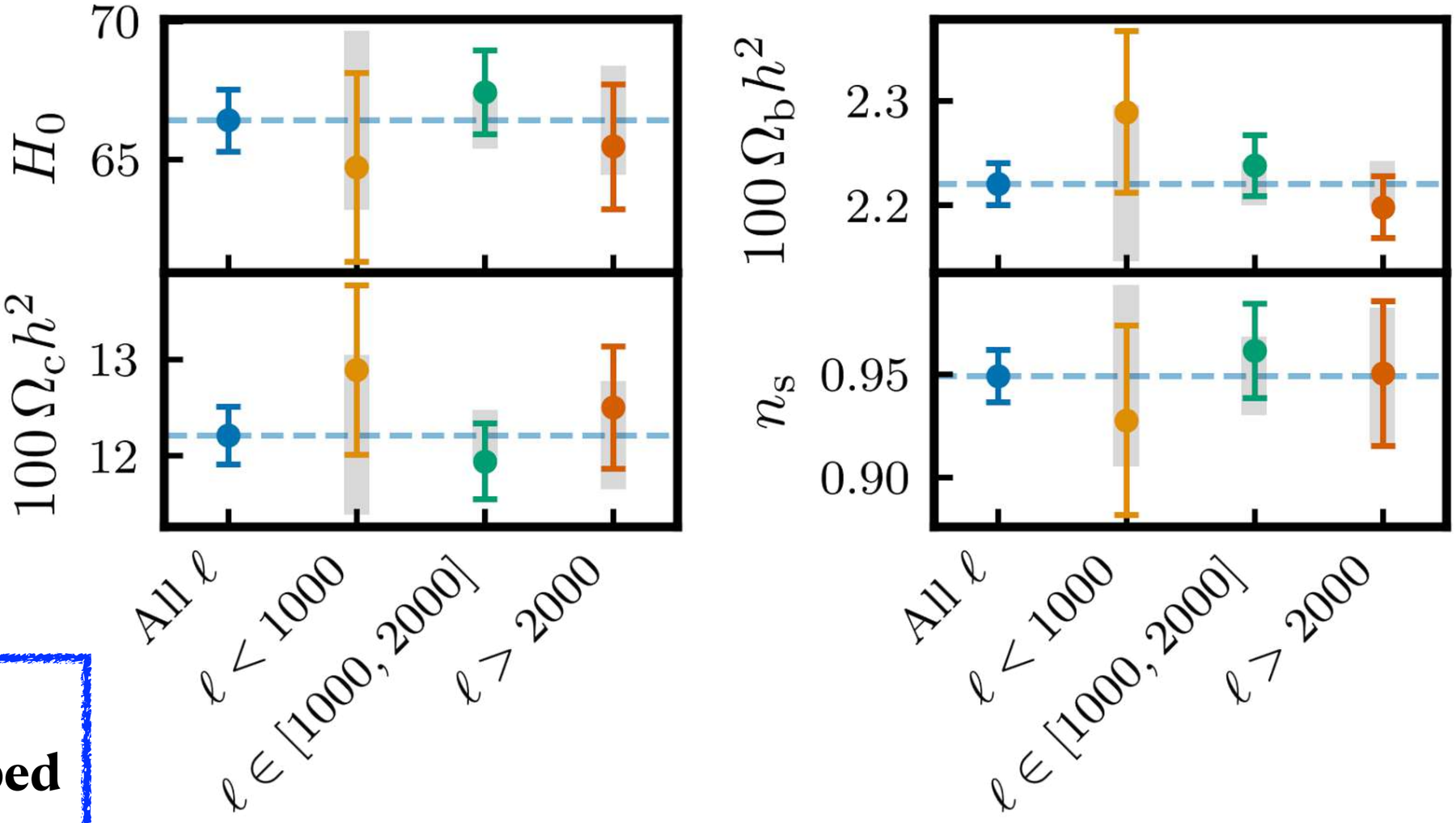
- Map level (6 tests)
- Band-power level (84 tests)
  - 66 Difference tests
  - 18 Conditional tests
- Parameter level (60 tests)

SPT-3G D1 data
pass all tests for systematics

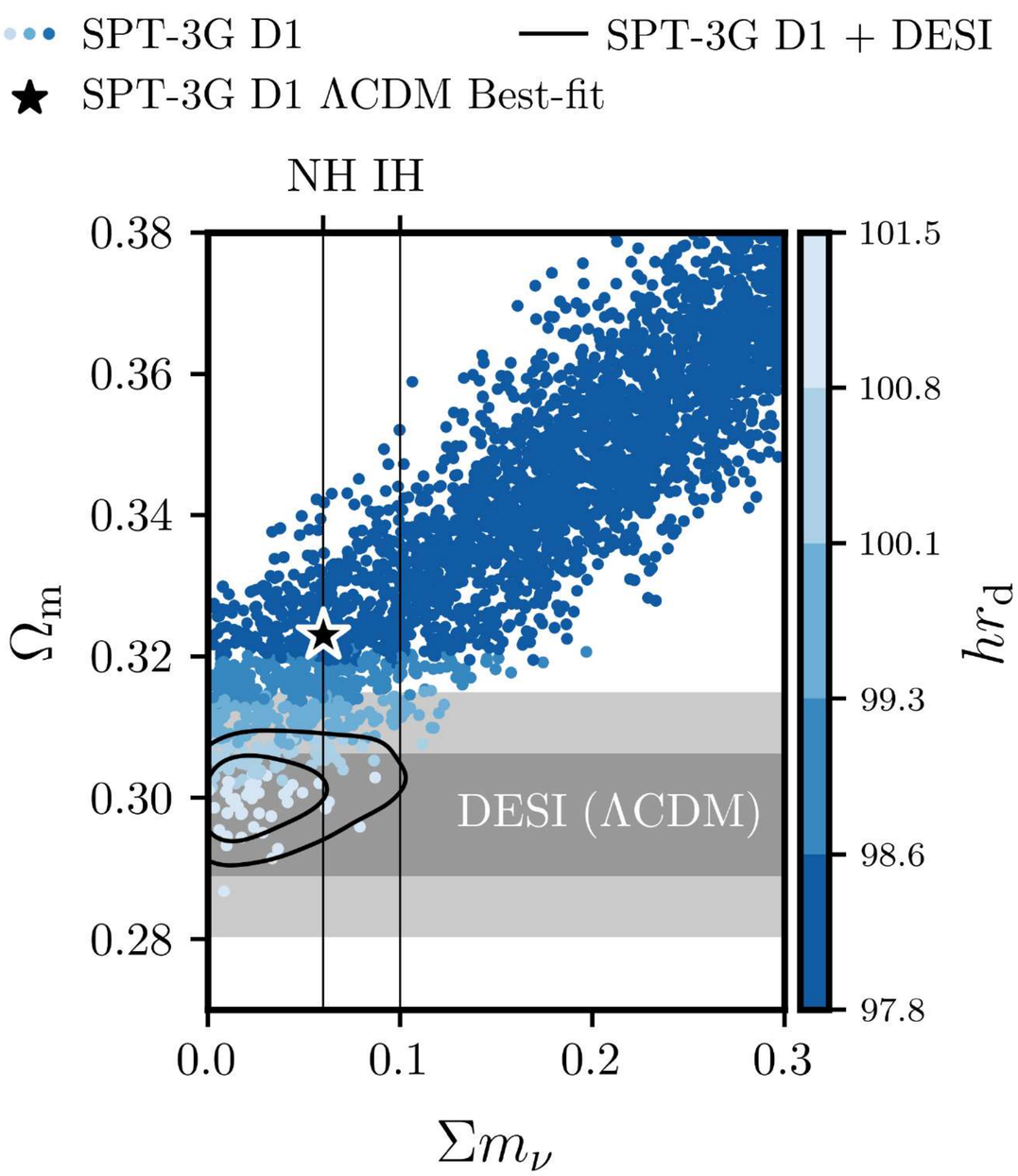


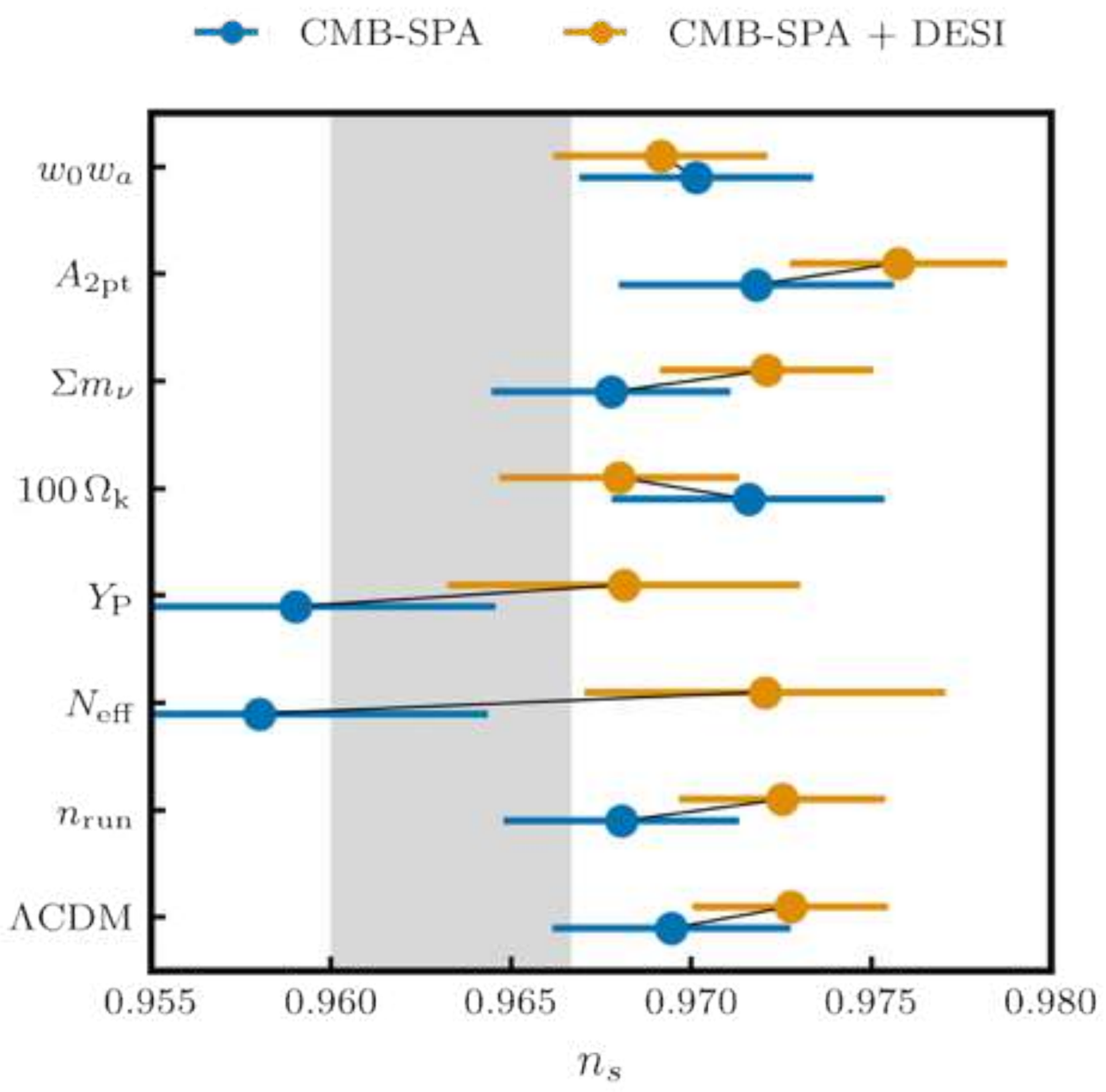

All
95 GHz
95x150 GHz
150 GHz
95x220 GHz
150x220 GHz
220 GHz
H_0
70
65
$\Omega_c h^2$
0.13
0.12
0.11
$\Omega_b h^2$
0.023
0.022
0.021
0.020
n_s
1.00
0.95
0.90
TT/TE/EE
TT
TE
EE

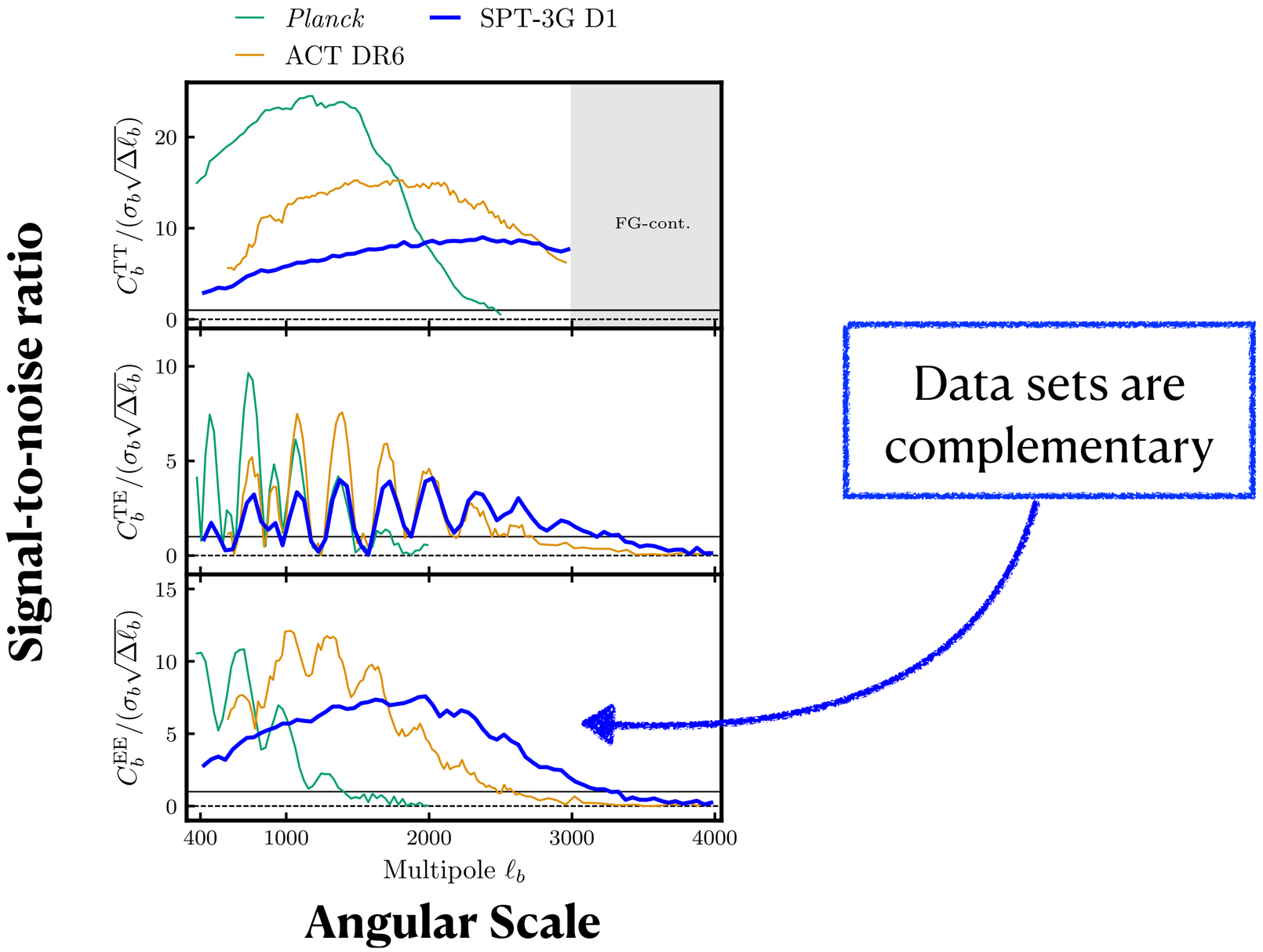
Consistency of ΛCDM across scales



SPT-3G D1 data is consistent at all probed scales

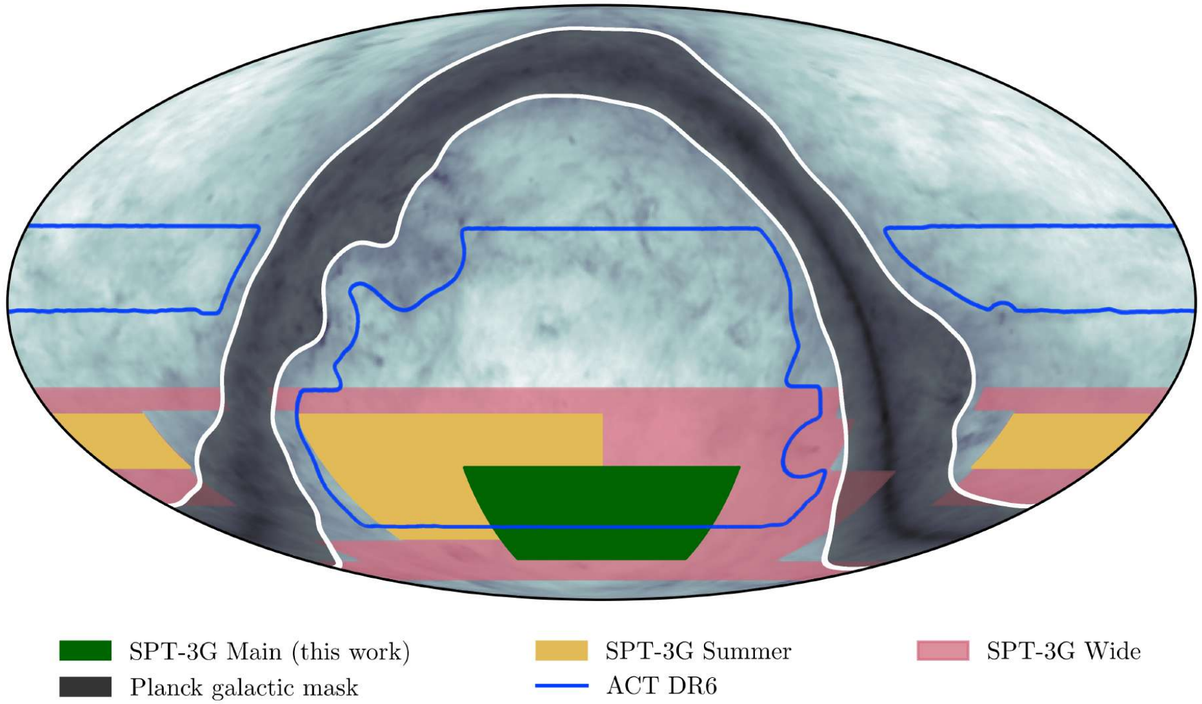

SPT-3G D1
SPT-3G D1 + DESI
SPT-3G D1 ΛCDM Best-fit
NH IH
0.38
0.36
0.34
0.32
0.30
0.28
$\Omega_{\rm m}$
DESI (ΛCDM)
0.0
0.1
0.2
0.3
Σm_ν
101.5
100.8
100.1
99.3
98.6
97.8
$hr_{\rm d}$


CMB-SPA
CMB-SPA + DESI
w_0w_a
$A_{2\mathrm{pt}}$
Σm_ν
$100\,\Omega_\mathrm{k}$
Y_P
N_eff
n_run
ΛCDM
0.955
0.960
0.965
0.970
0.975
0.980
n_s


Planck
SPT-3G D1
ACT DR6
FG-cont.
$C_b^{\mathrm{TT}}/(\sigma_b\sqrt{\Delta\ell_b})$
$C_b^{\mathrm{TE}}/(\sigma_b\sqrt{\Delta\ell_b})$
$C_b^{\mathrm{EE}}/(\sigma_b\sqrt{\Delta\ell_b})$
Multipole ℓ_b
Signal-to-noise ratio
Angular Scale
Data sets are complementary

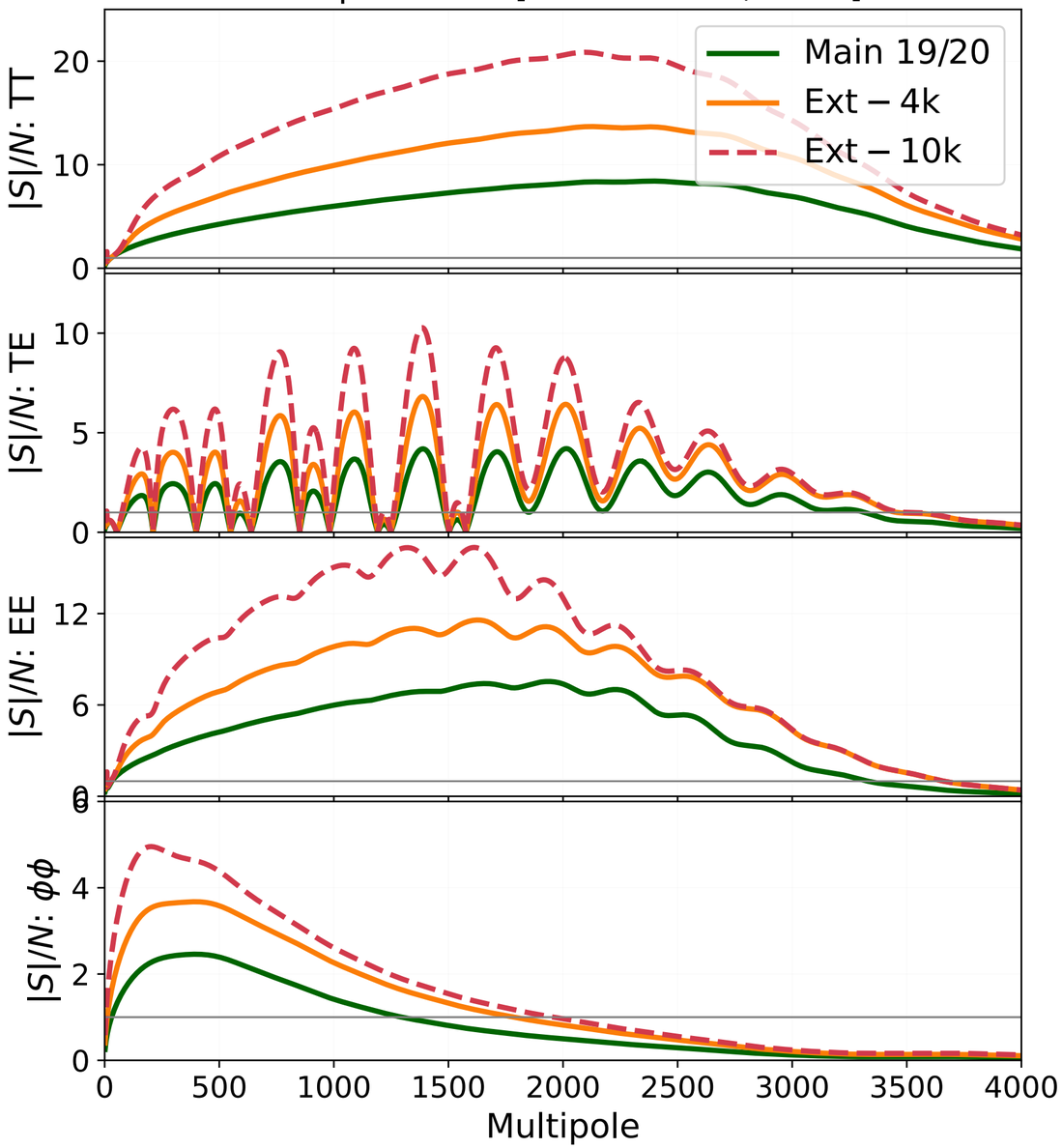
Extended fields

With SPT-3G



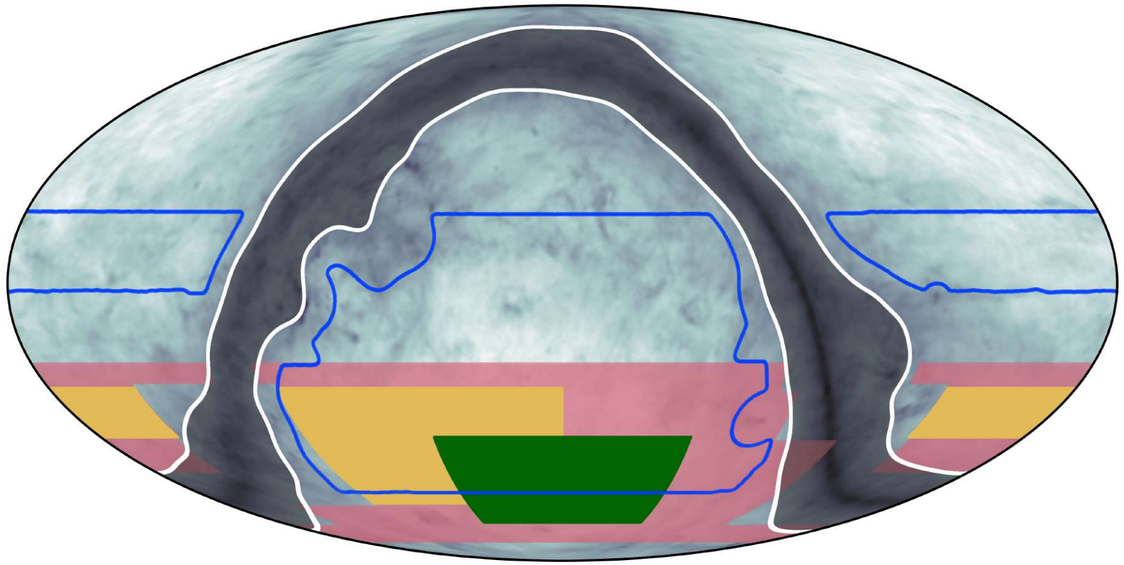
- **Ext-4k: main + summer**
- **Ext-10k: main + summer + wide**

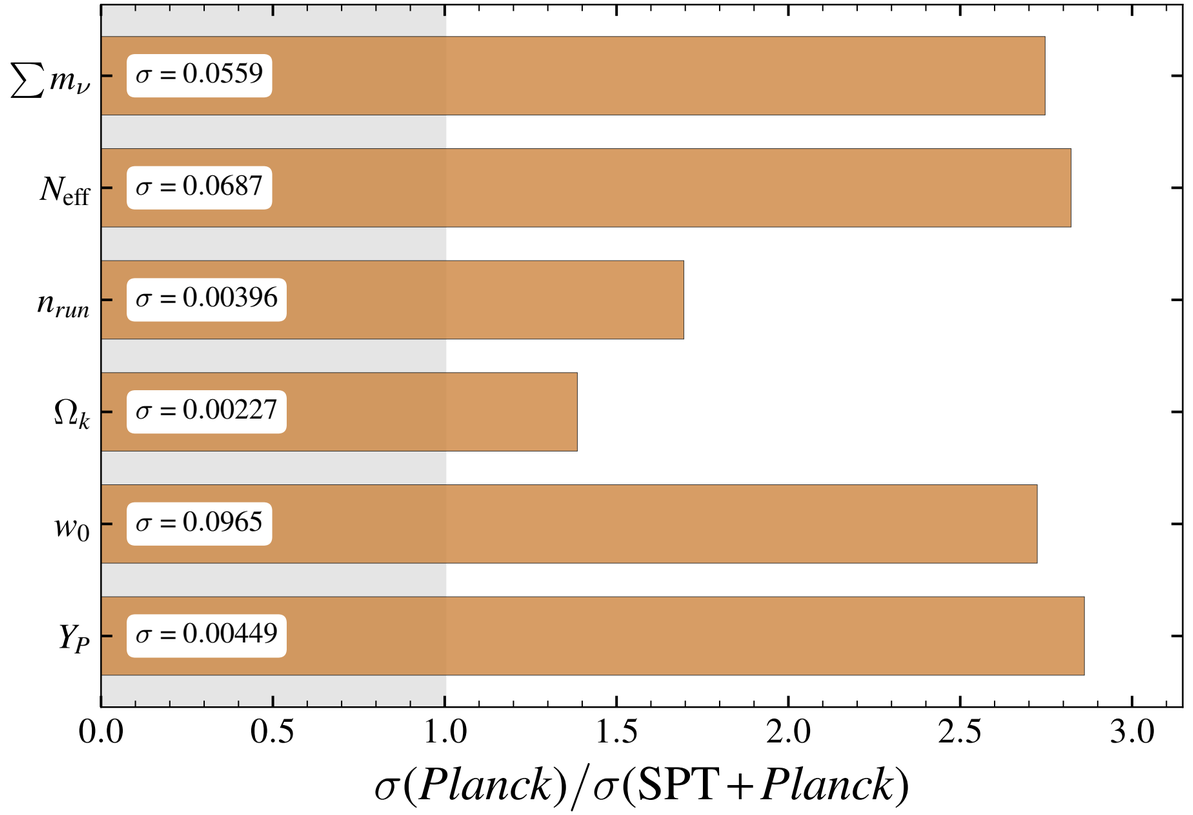
SNR curves
Adapted from [Prabhu et al., 2024]



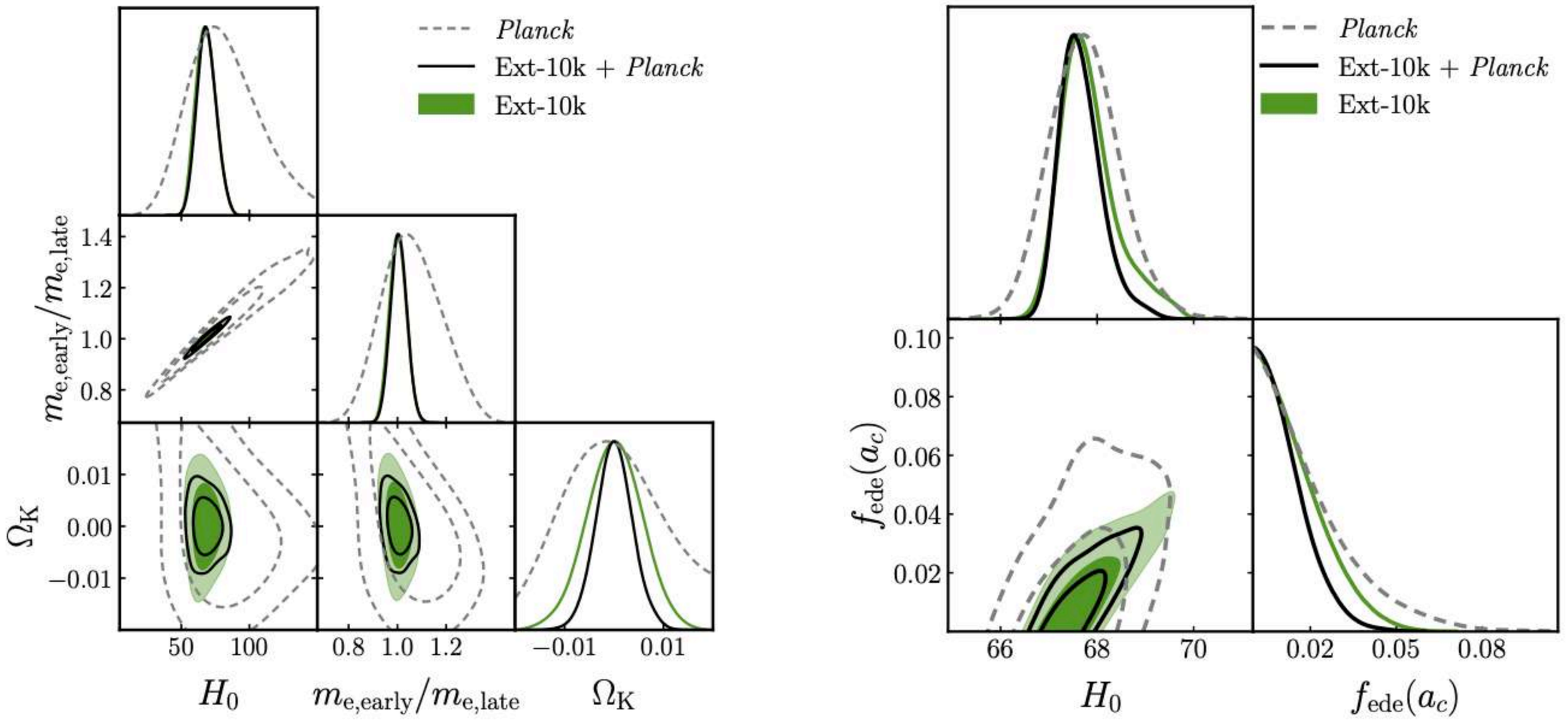
Full SPT-3G forecasts

[Prabhu et al., 2024]





SPT-3G Ext10k forecasts

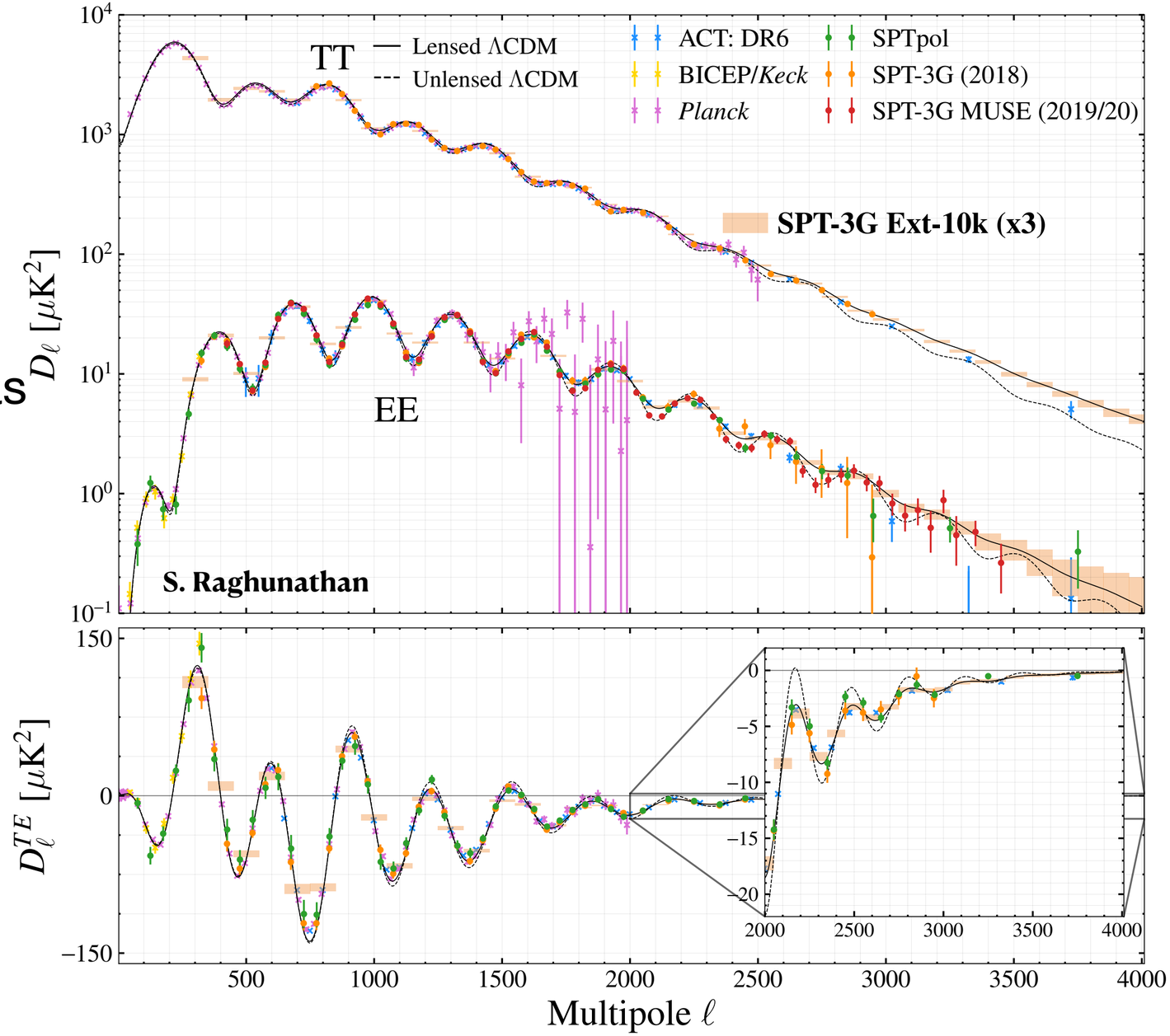


Credit: Vitrier et al. 2025

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 ΛCDM parameters
  - 3x for single-parameter extensions!



Virtier et al. https://arxiv.org/abs/2510.24669v1
Prabhu et al. https://arxiv.org/abs/2403.17925

ΛCDM

Parameter	*Planck*	SPT-3G D1	ACT DR6	SPT+ACT	SPT+*Planck*	CMB-SPA
Sampled						
$10^4\theta_{\rm s}^\star$	104.184 ± 0.029	104.171 ± 0.060	104.157 ± 0.030	104.158 ± 0.025	104.176 ± 0.026	104.162 ± 0.023
$100\,\Omega_{\rm b}h^2$	2.238 ± 0.014	2.221 ± 0.020	2.257 ± 0.016	2.247 ± 0.013	2.230 ± 0.011	2.2381 ± 0.0093
$100\,\Omega_{\rm c}h^2$	11.98 ± 0.11	12.14 ± 0.16	12.26 ± 0.17	12.22 ± 0.12	12.050 ± 0.089	12.009 ± 0.086
$n_{\rm s}$	0.9657 ± 0.0040	0.951 ± 0.011	0.9682 ± 0.0069	0.9671 ± 0.0058	0.9636 ± 0.0035	0.9684 ± 0.0030
$\log(10^{10}\,A_{\rm s})$	3.042 ± 0.011	3.054 ± 0.015	3.038 ± 0.012	3.042 ± 0.011	3.046 ± 0.010	3.0479 ± 0.0099
$\tau_{\rm reio}$	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
$10^9\,A_{\rm s}e^{-2\tau_{\rm reio}}$	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
$\Omega_{\rm m}$	0.3145 ± 0.0067	0.3246 ± 0.0091	0.330 ± 0.010	0.3277 ± 0.0072	0.3189 ± 0.0054	0.3166 ± 0.0051
$r_{\rm d}$ [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

Lensing amplitude

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

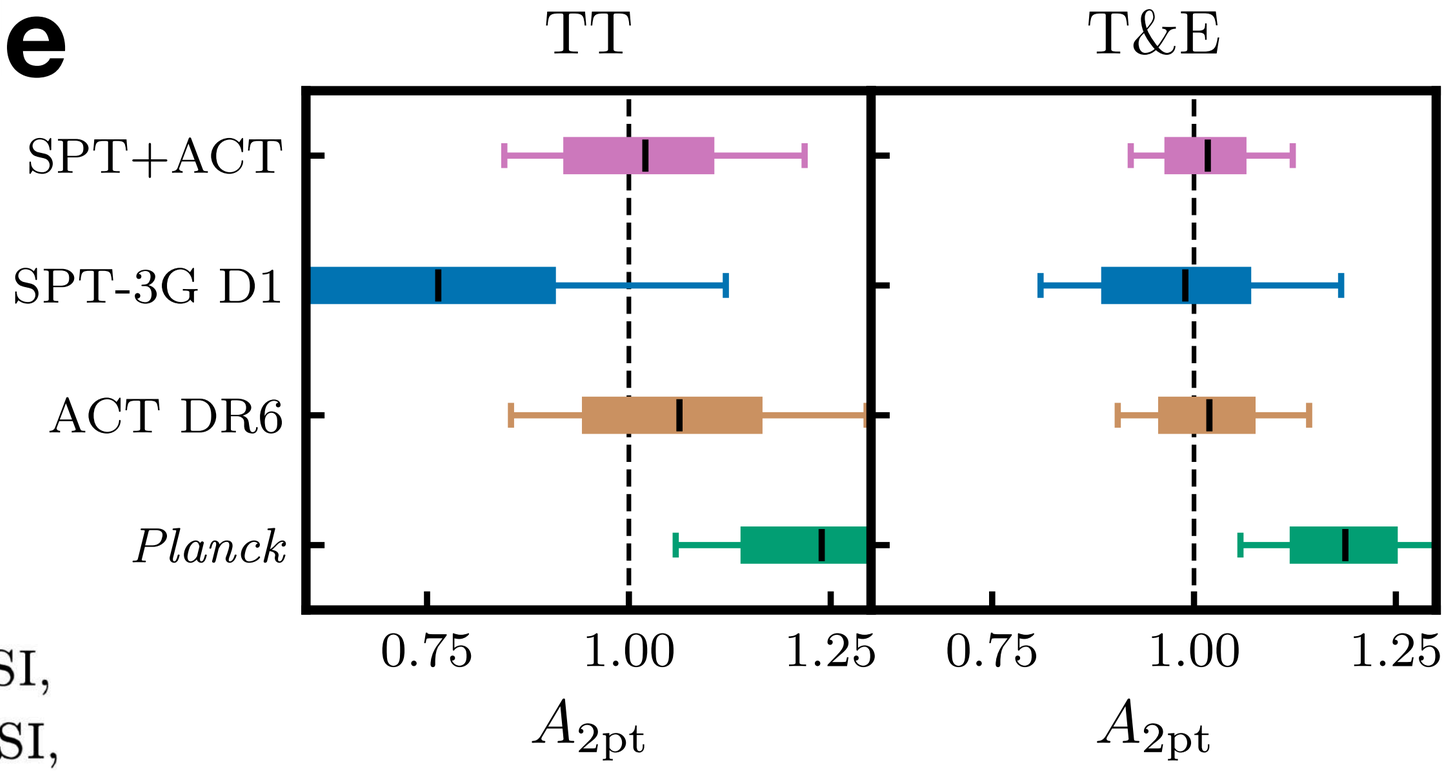
$$\left.\begin{aligned} A_{\rm 2pt} &= 1.026 \pm 0.048 \\ A_{\rm recon} &= 0.990 \pm 0.050 \end{aligned}\right\} \text{ for SPT+ACT,}$$

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

$A_{\rm lens} = 1.084 \pm 0.035$ for SPT-3G D1 + DESI,

$A_{\rm lens} = 1.092 \pm 0.026$ for SPT+ACT + DESI,

$A_{\rm lens} = 1.084 \pm 0.024$ for CMB-SPA + DESI.



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