

# CMB Power Spectra and New Physics from ACT DR6

(and beyond)

Colin Hill  
Columbia University

Pheno 2026  
University of Pittsburgh  
11 May 2026



Calabrese & JCH, et al: 2503.14454  
Louis et al: 2503.14452  
Naess et al: 2503.14451  
Beringue, Surrao, JCH, et al: 2506.06274  
2603.13226 w/ S. Goldstein



# ACT

## The Atacama Cosmology Telescope



- >5x Planck resolution. ACT&SPT only high-res CMB telescopes
- Near equator at  $-23^\circ$  lat. Access to most of the sky
- 5200 m altitude in Atacama desert, northern Chile
- Typical PWV 1.2 mm (about 3x south pole, 9x ridge A)
- Observed 2007-2022



(ca. 2021)  
Image credit:  
Debra Kellner

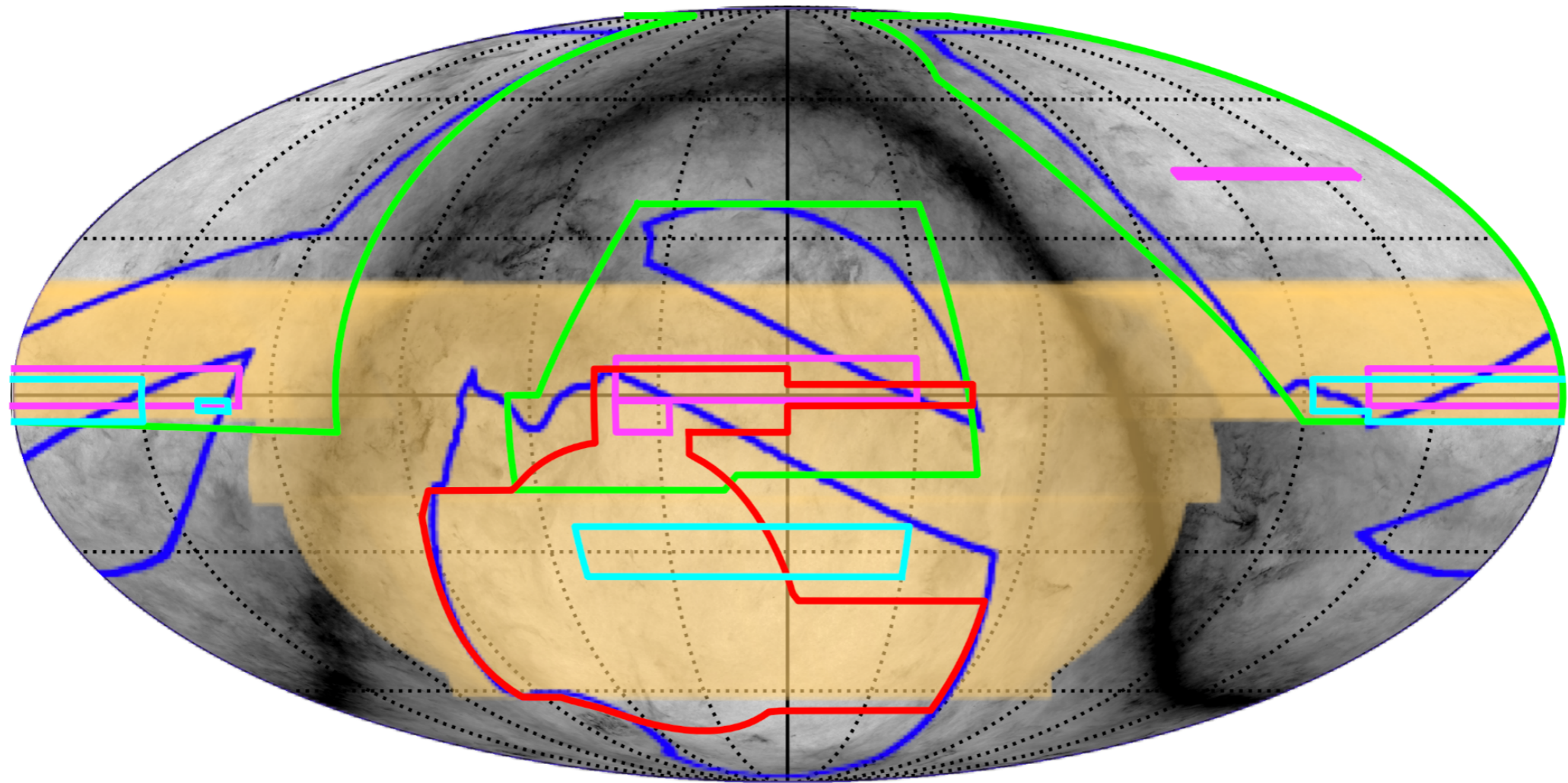
- ACT Data Release 6 = 2017-2022, 828 full days of CMB observations (44% efficiency)
- Primary dataset: night-time observations (~half of total data)
- Data released on March 18, 2025

Naess et al. (2503.14451)



# ACT

## Survey Footprints

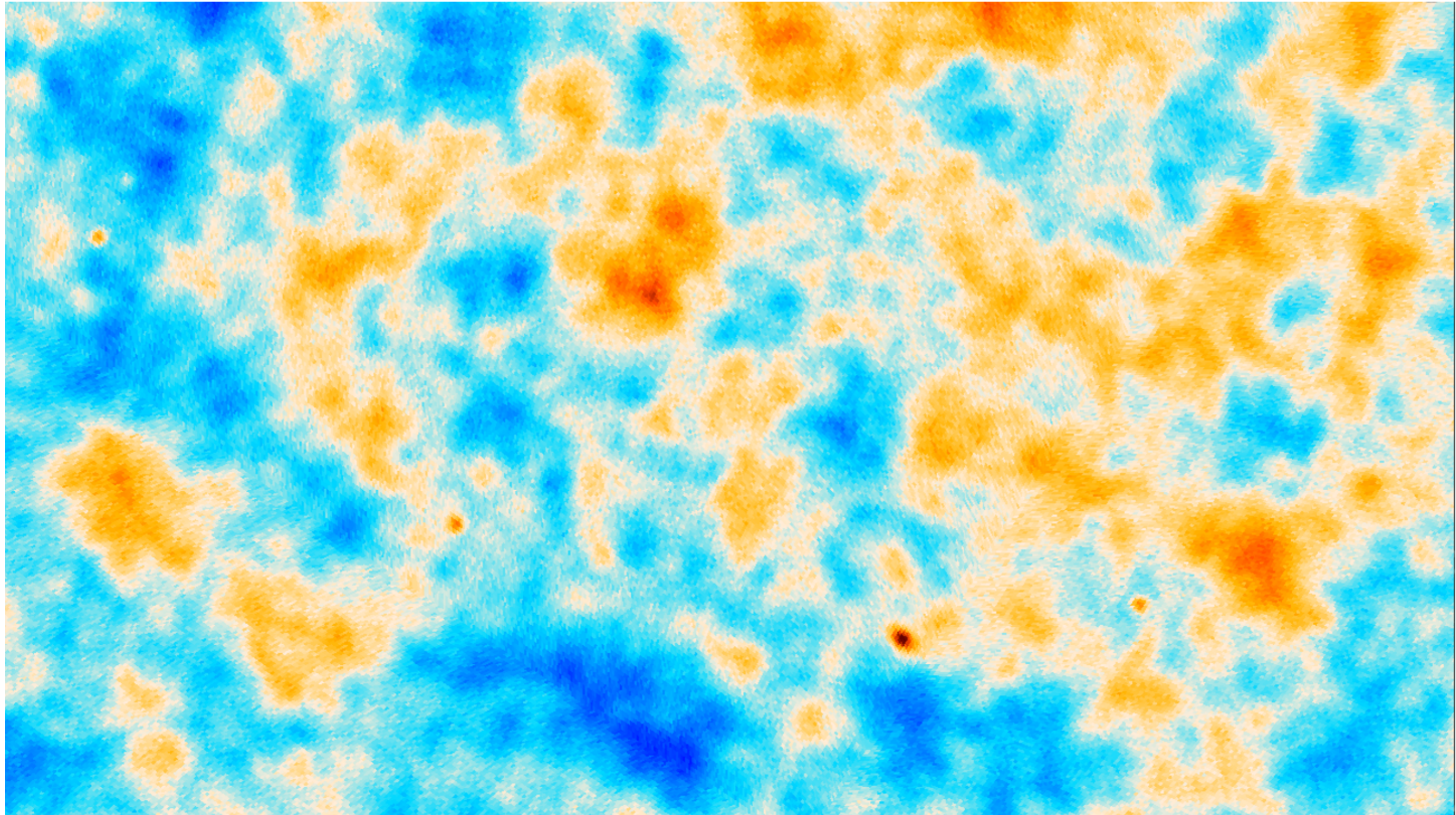


- 45% sky coverage and large overlap with other surveys
- Lower noise than *Planck* on  $\sim 19,000 \text{ deg}^2$
- On average: 3x lower polarization noise than *Planck*
- Power spectra estimated from cleanest  $\sim 10,000 \text{ deg}^2$

# Planck: Intensity

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**Planck f150 T**

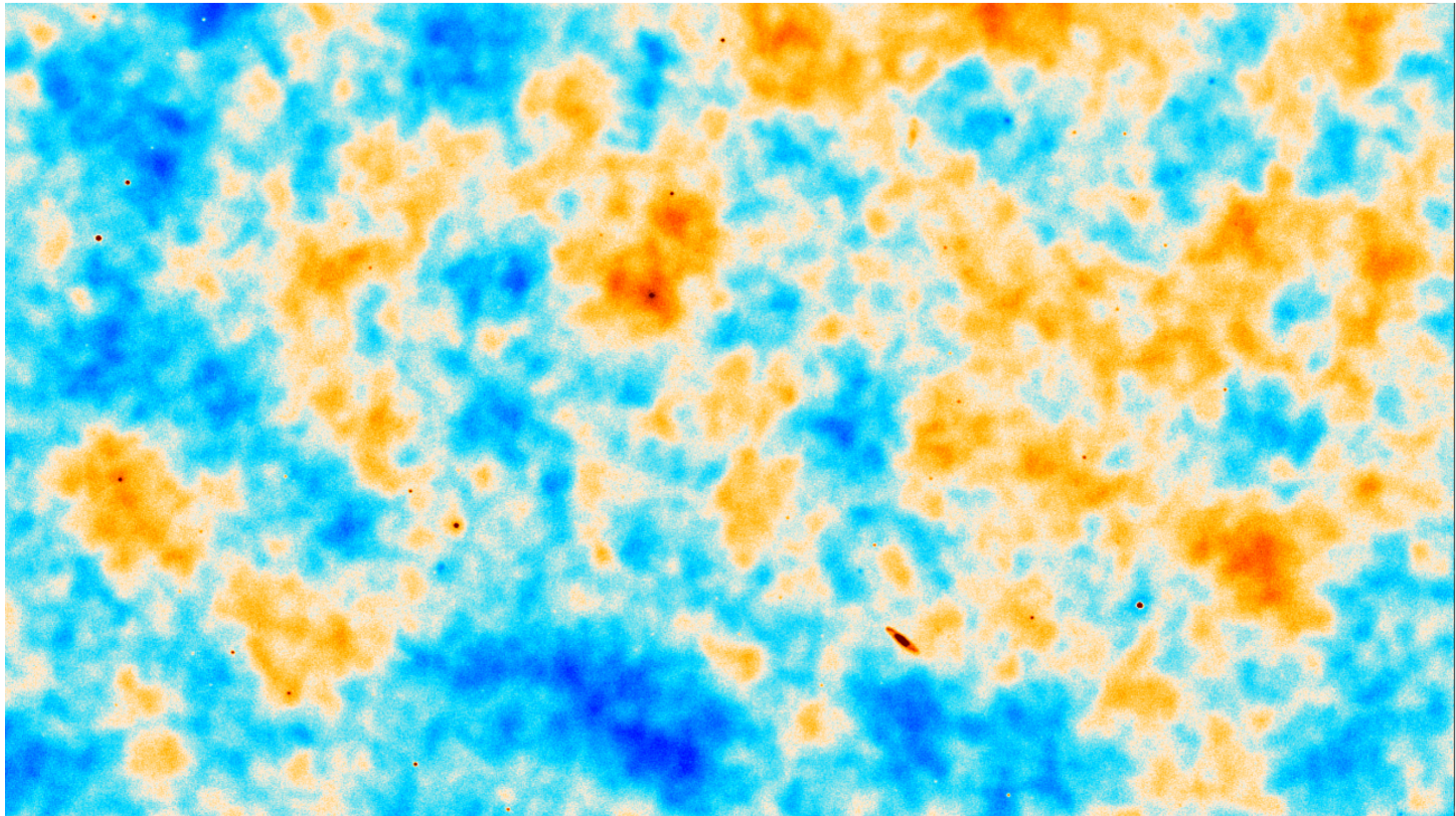


**13°×7°**

# ACT: Intensity

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**ACT + Planck f150 T**

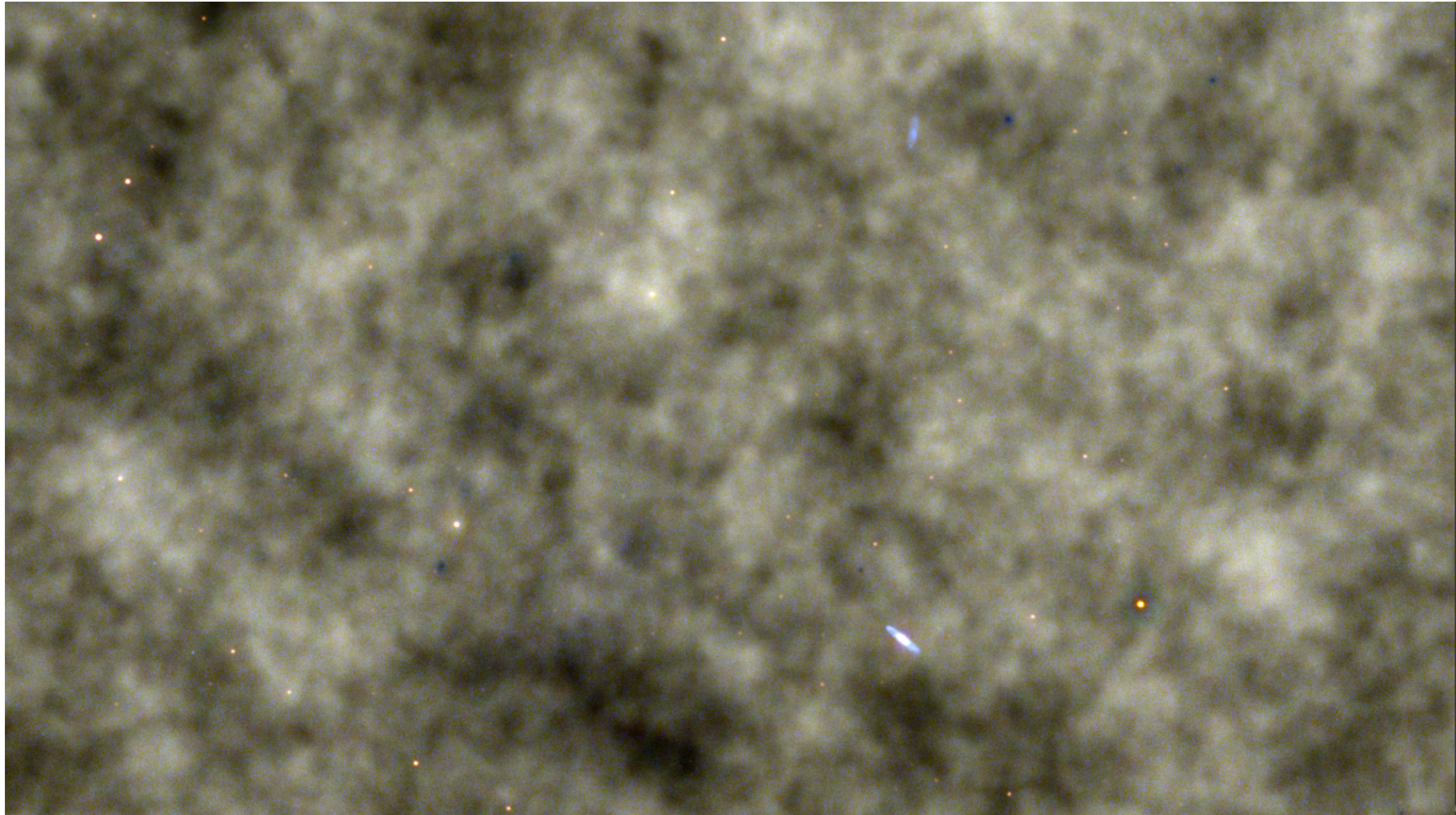


**13°x7°**

# ACT: Multifrequency Intensity

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**ACT + Planck T: R = 90 GHz; G = 150 GHz; B = 220 GHz**

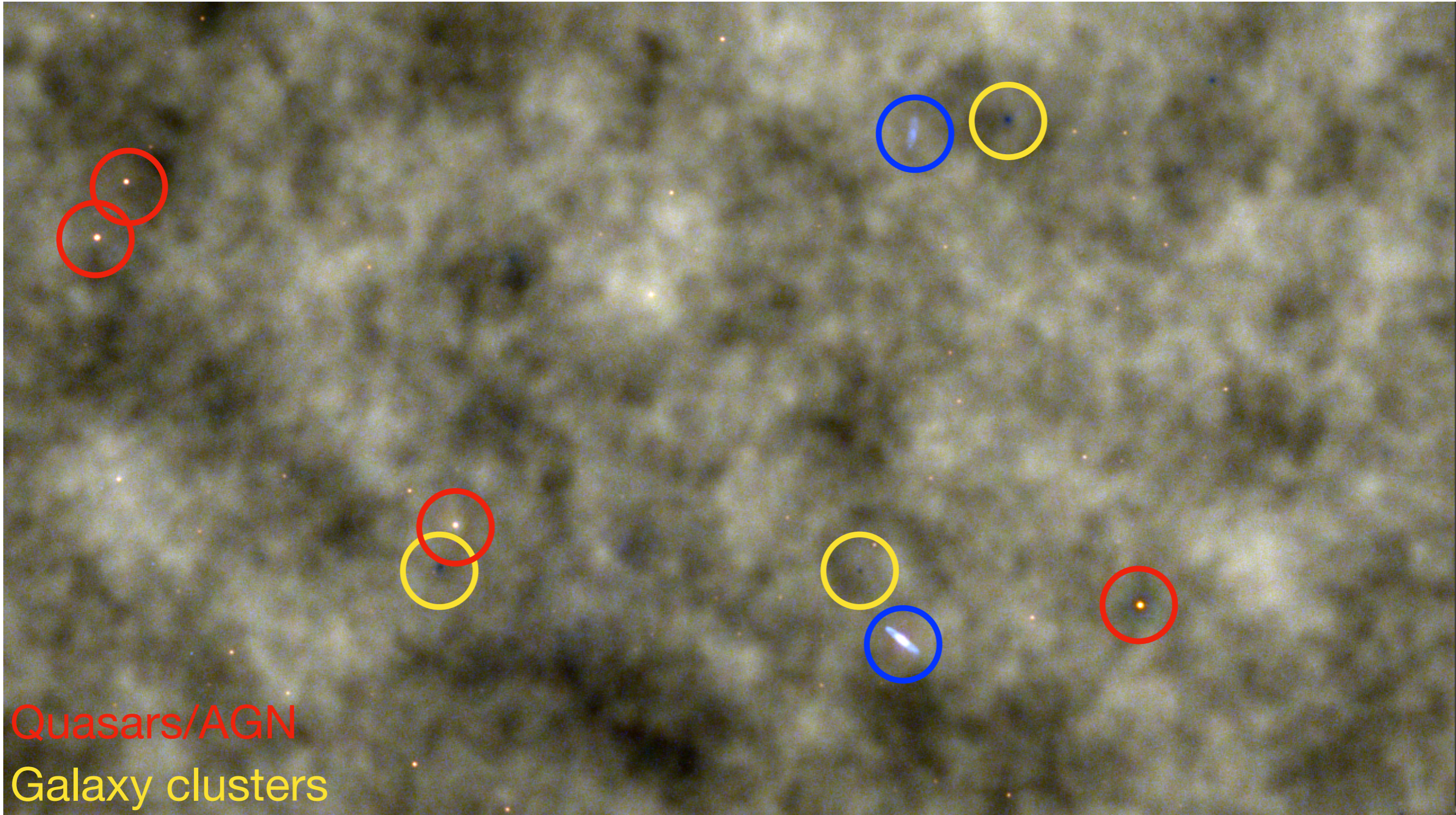


**13°×7°**

# ACT: Multifrequency Intensity

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ACT + Planck T: R = 90 GHz; G = 150 GHz; B = 220 GHz



Quasars/AGN

Galaxy clusters

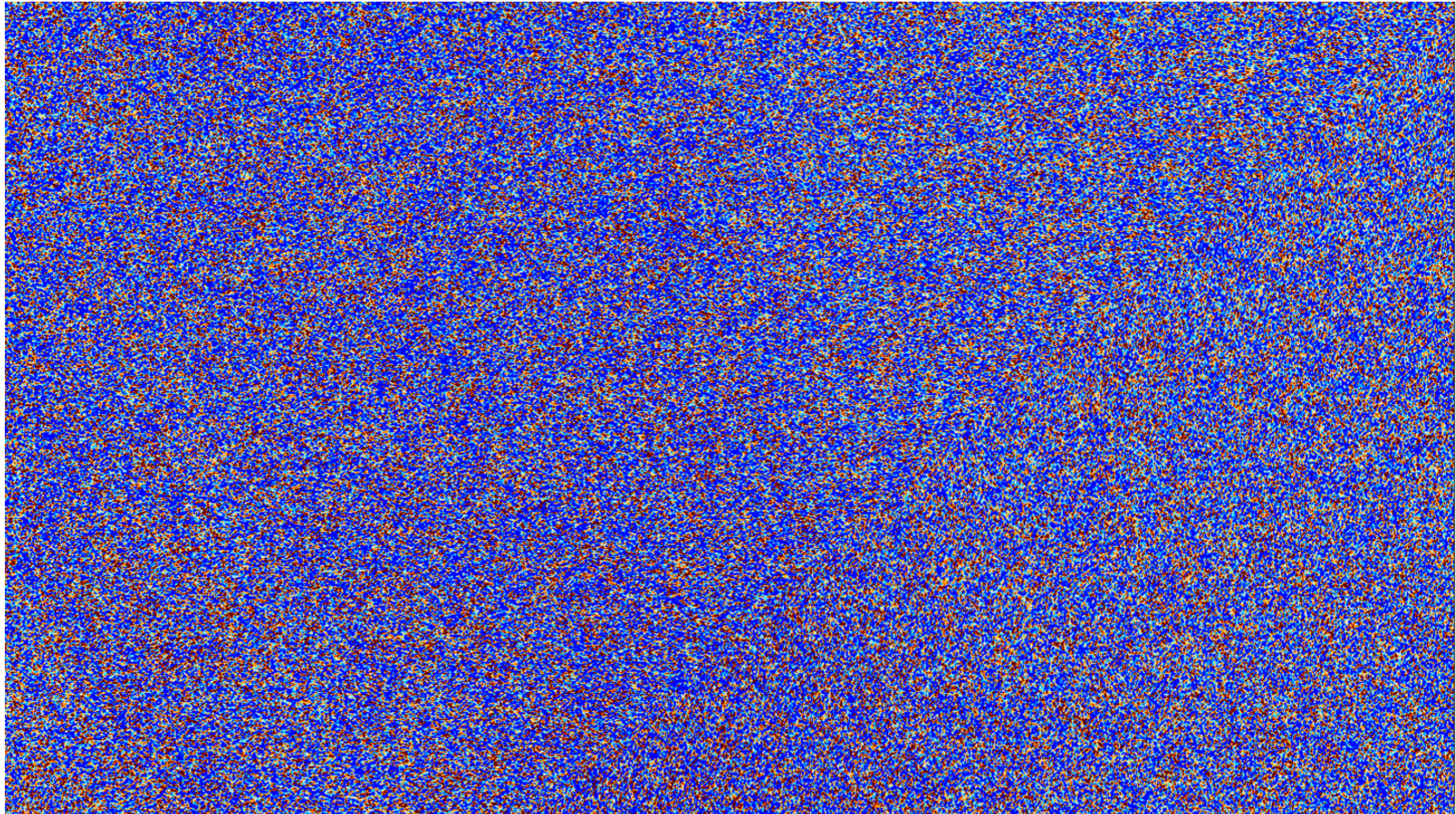
Nearby galaxies

13°x7°

# Planck: Polarization

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**Planck E**

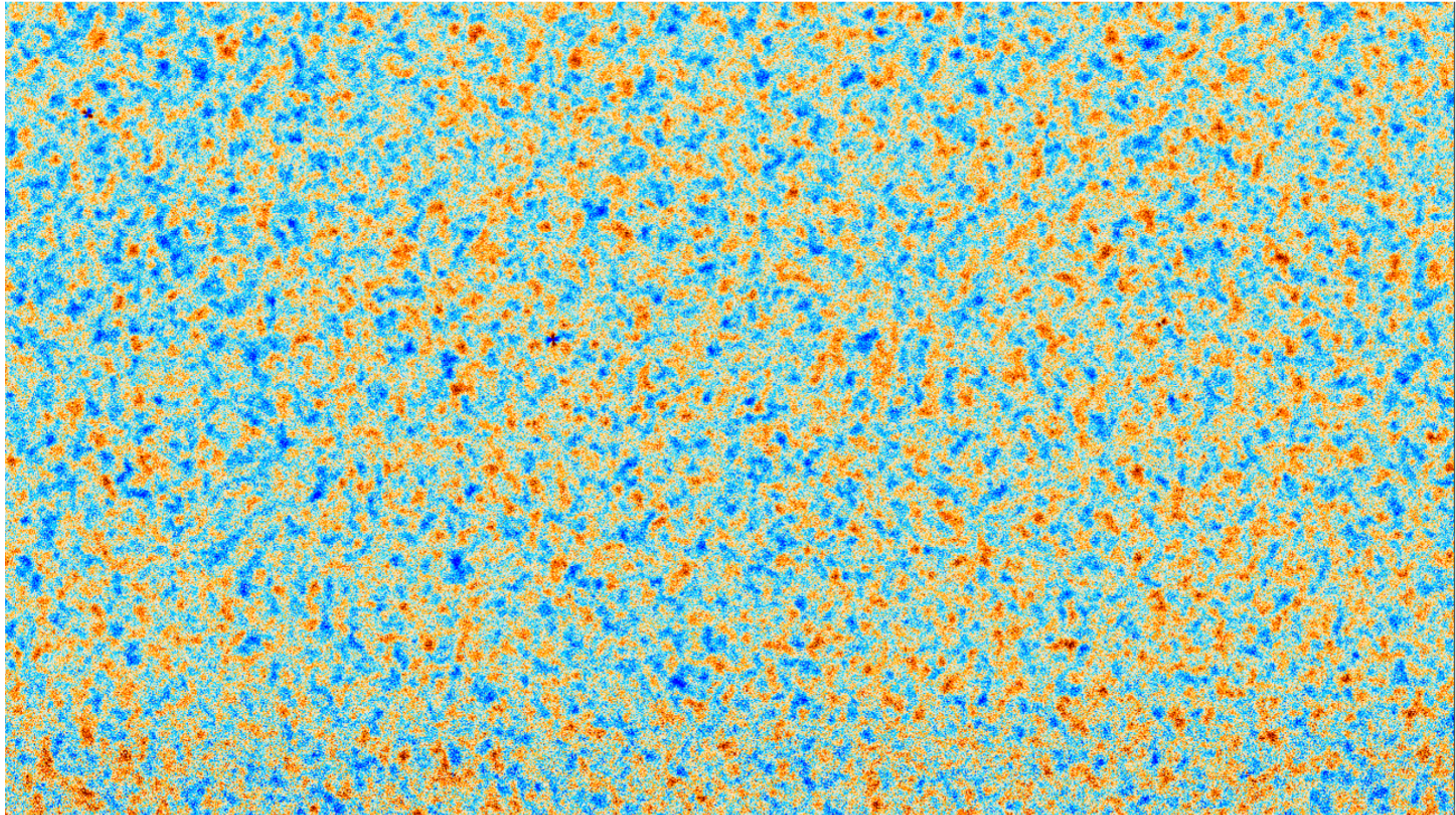


**26°×14°**

# ACT: Polarization

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**ACT + Planck E**

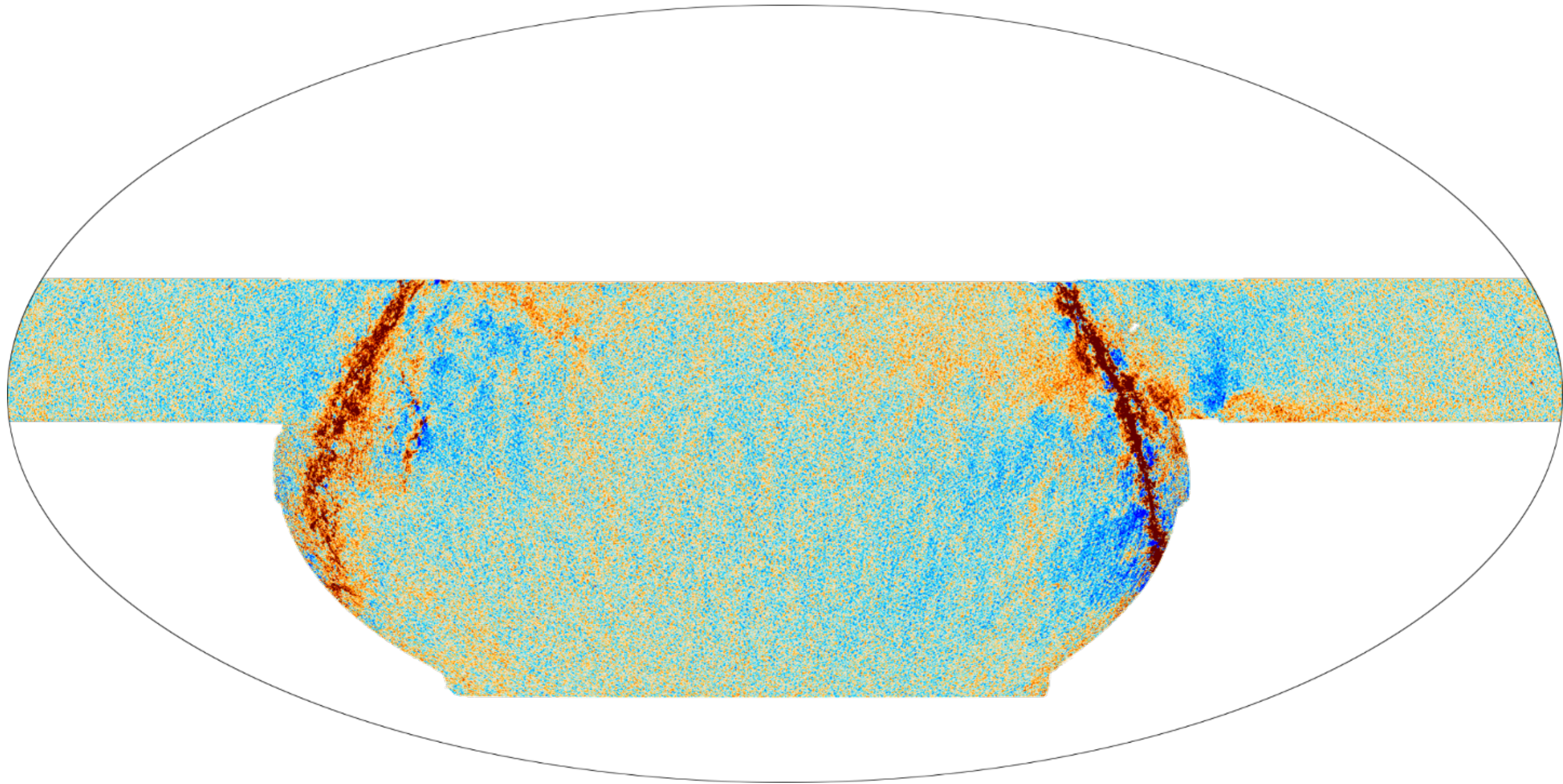


**26°×14°**

# ACT: Polarization

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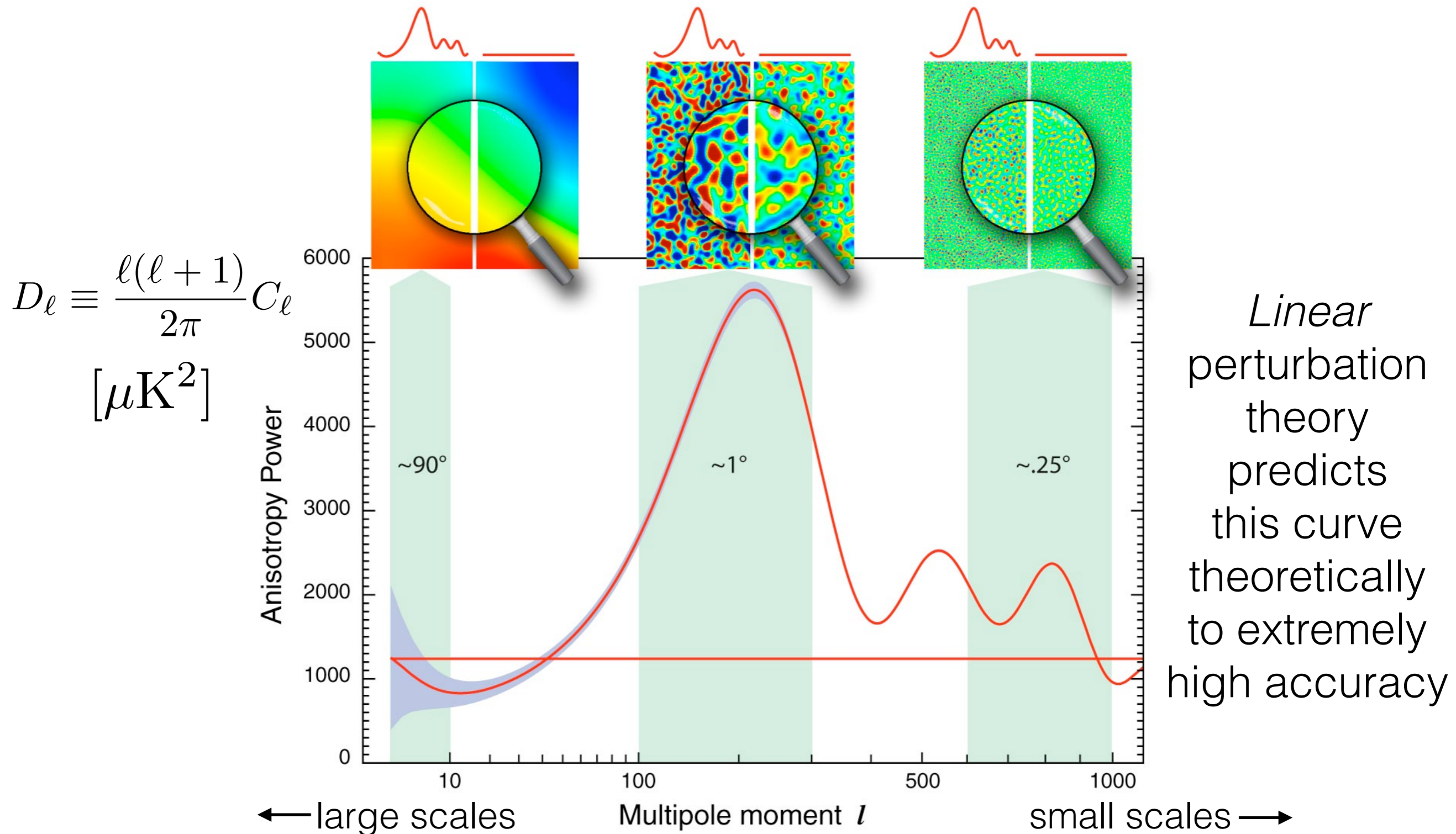
**ACT + Planck E**



**High-SNR E-mode polarization on nearly half of the sky!**

# Cosmology from the CMB

We infer cosmological parameters from CMB maps via the *angular power spectra* of fluctuations in temperature and polarization



# CMB Anisotropy Physics

- 1) Initial conditions for the perturbations (from inflation)
- 2) The “transfer function”: acoustic physics that relates the ICs to the temperature and polarization perturbations
- 3) CMB photon propagation: connecting the anisotropies we see to the conditions at the surface of last scattering

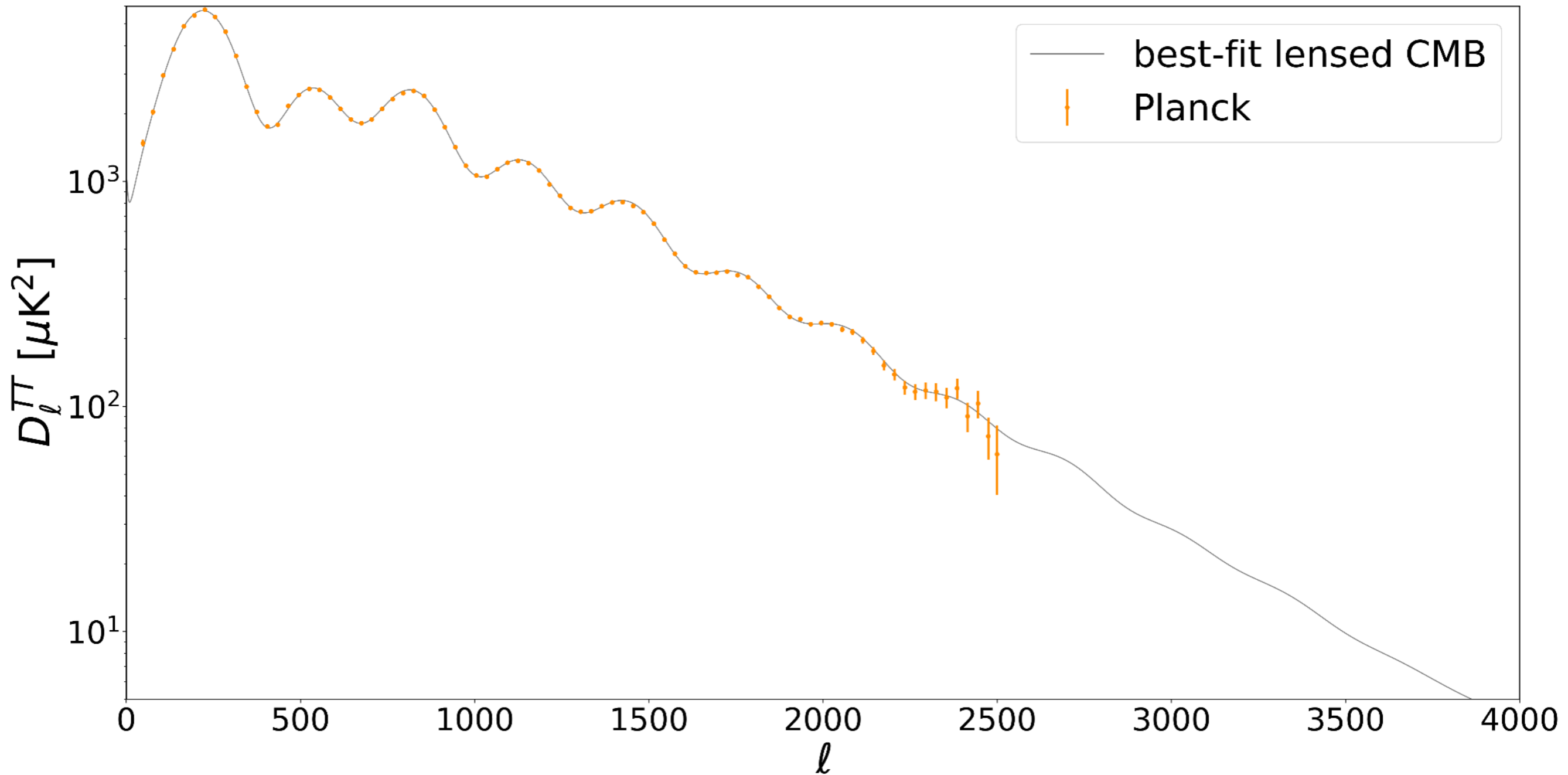
$$\mathcal{R}(\mathbf{k}, 0) \longrightarrow (\delta_r, \Phi, \mathbf{v})_{\eta_*} \longrightarrow \delta T(\hat{\mathbf{n}})$$

initial curvature perturbations      physical quantities at last scattering      observed temperature fluctuations

# Power Spectra

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**Planck TT**

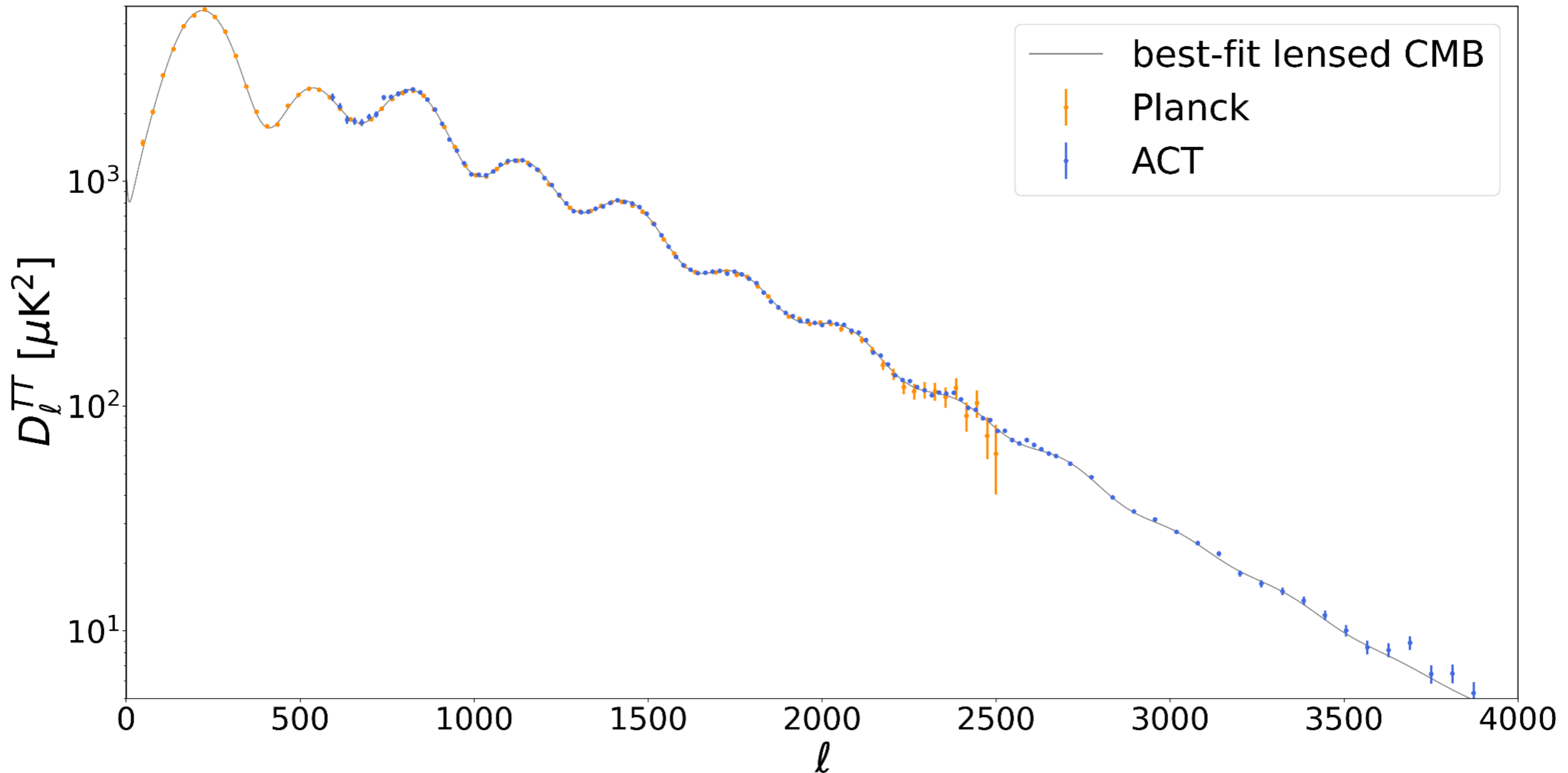


# Power Spectra

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- ACT extends Planck measurements to much smaller scales
- ACT and Planck are consistent on overlapping range

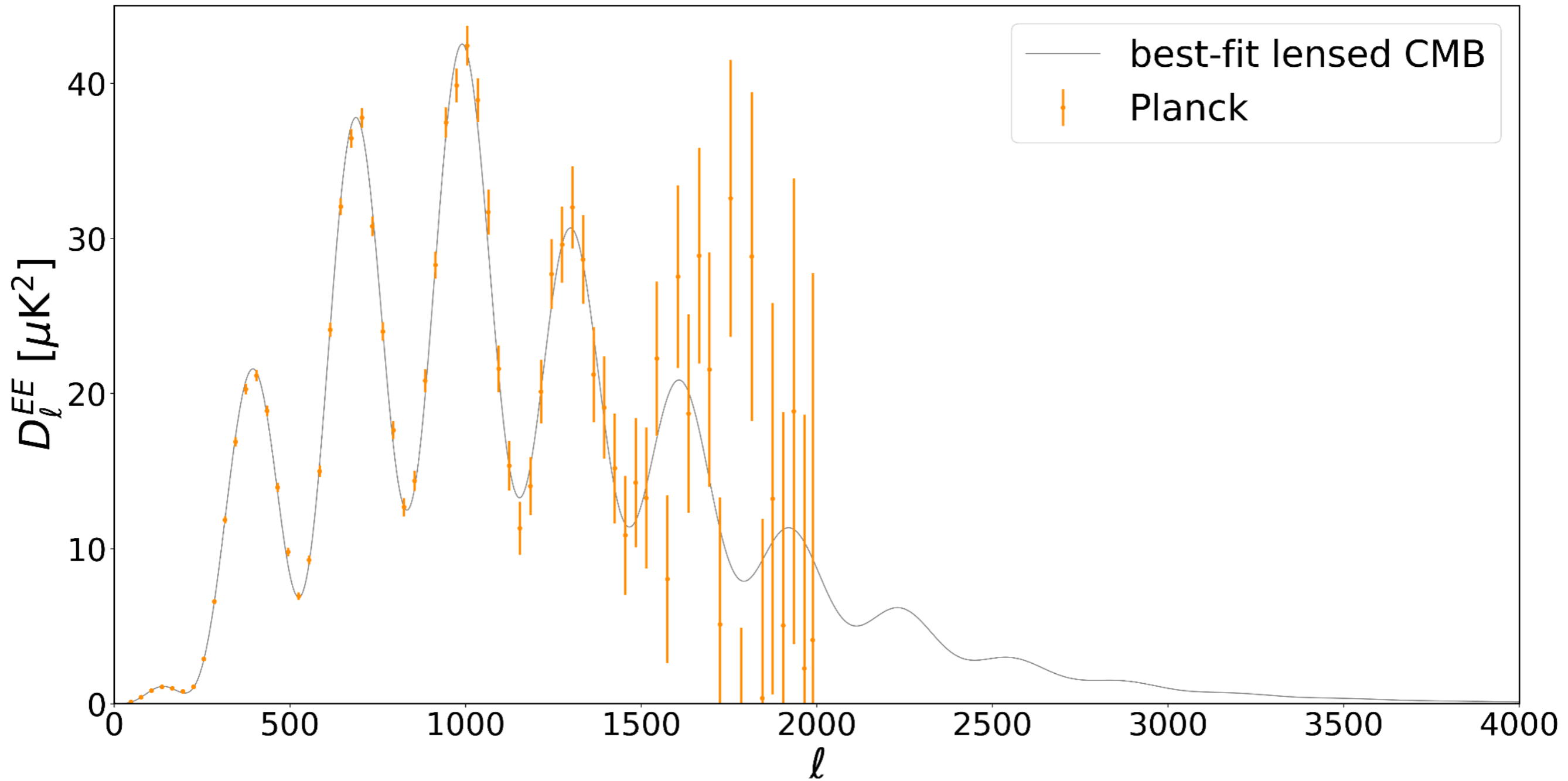
**ACT TT**



# Power Spectra

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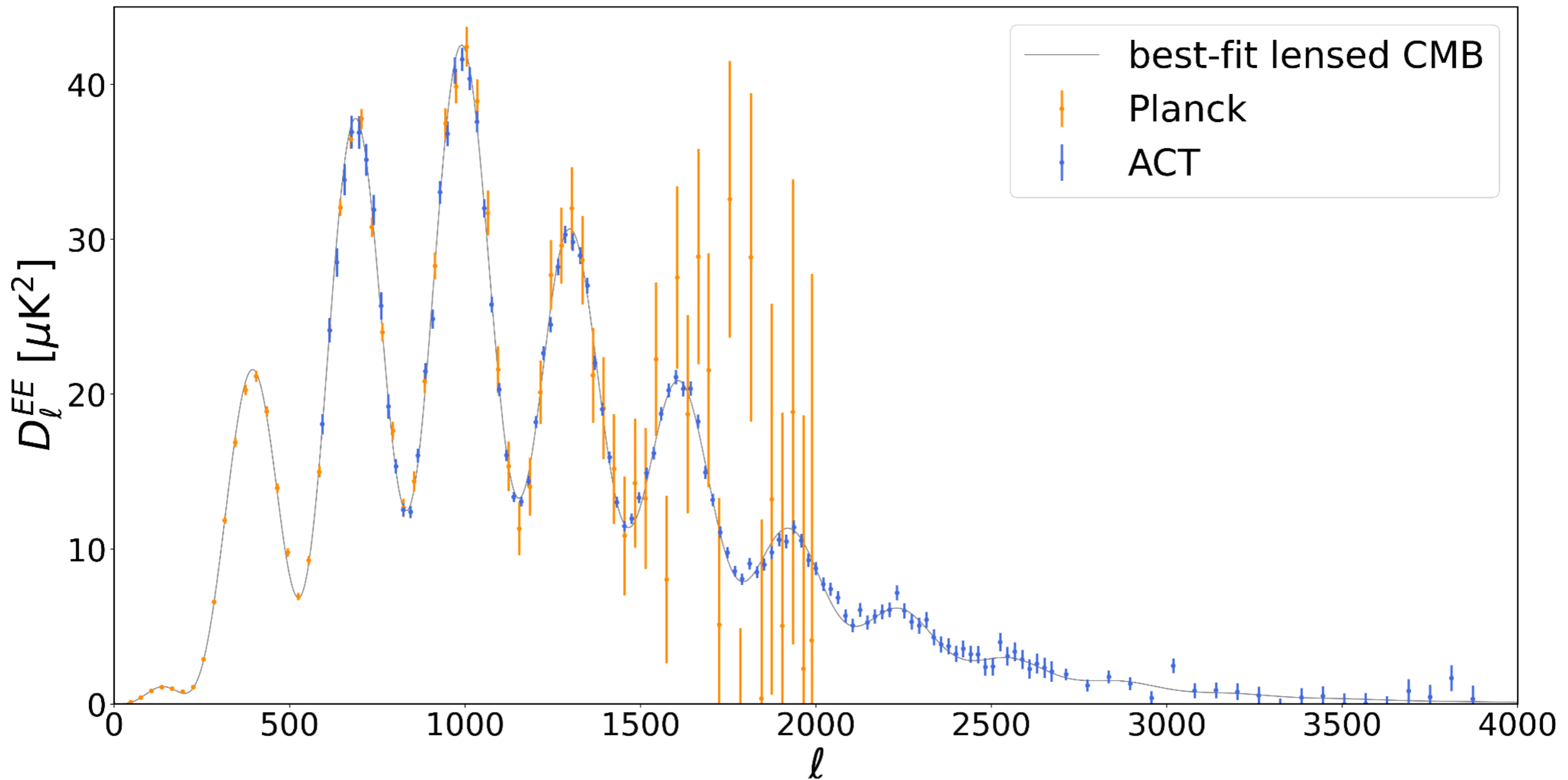
**Planck EE**



# Power Spectra

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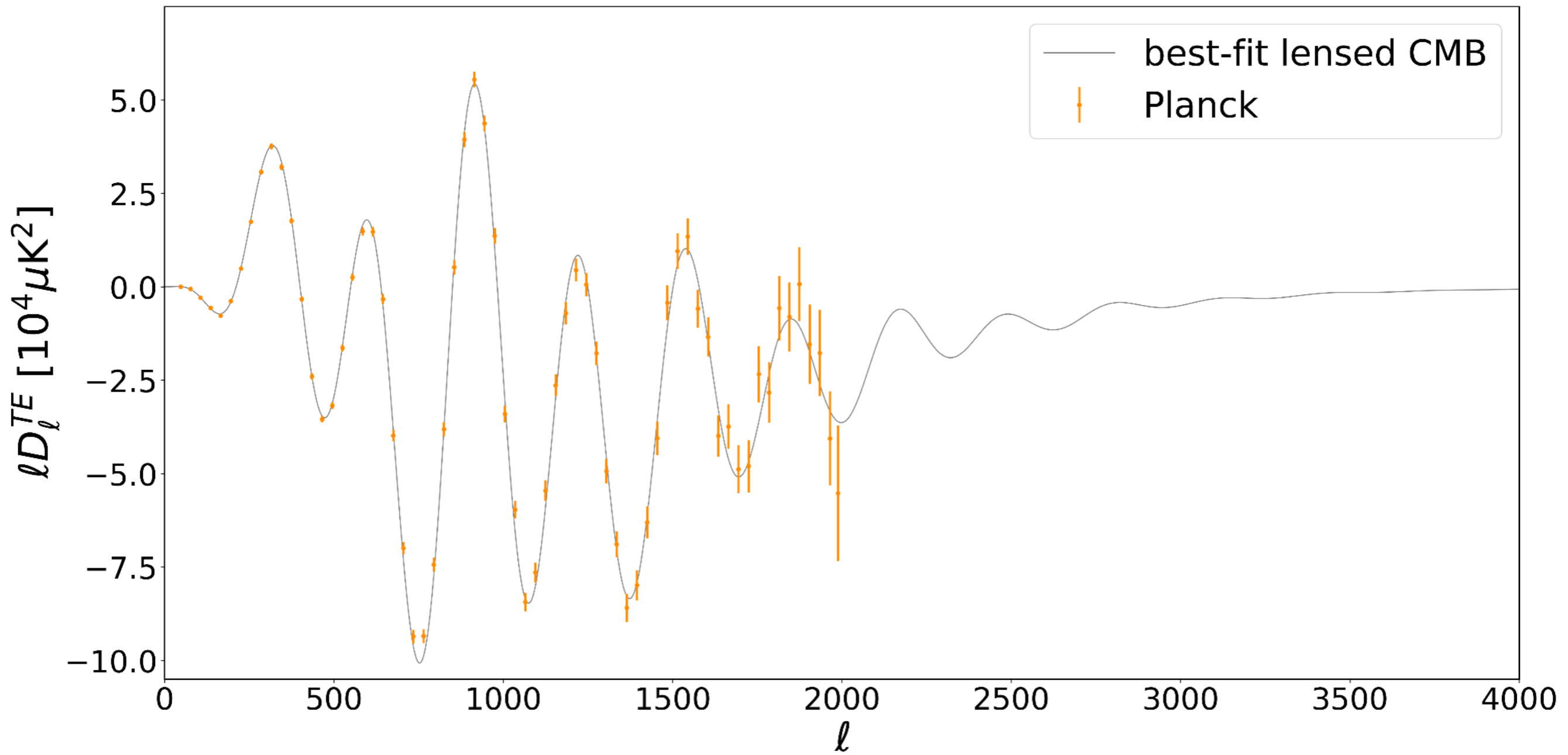
ACT DR6 EE more sensitive than Planck for multipoles  $> 600$  ( $\theta < 0.3^\circ$ ) **ACT EE**



# Power Spectra

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**Planck TE**

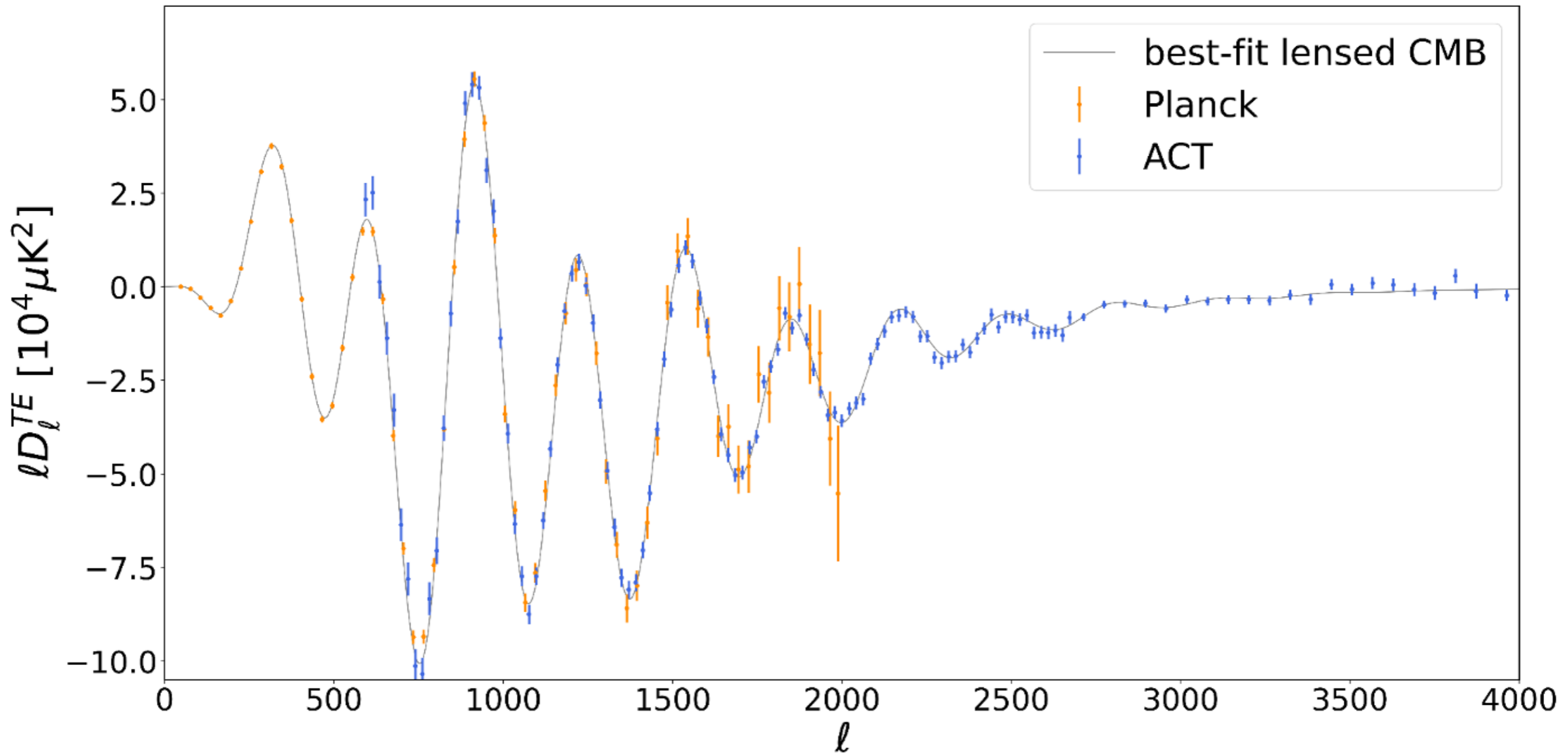


# Power Spectra

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TE data sufficiently sensitive now to constrain  $H_0$  to 1.1%  
on their own in  $\Lambda$ CDM

**ACT TE**



# Cosmological Constraints

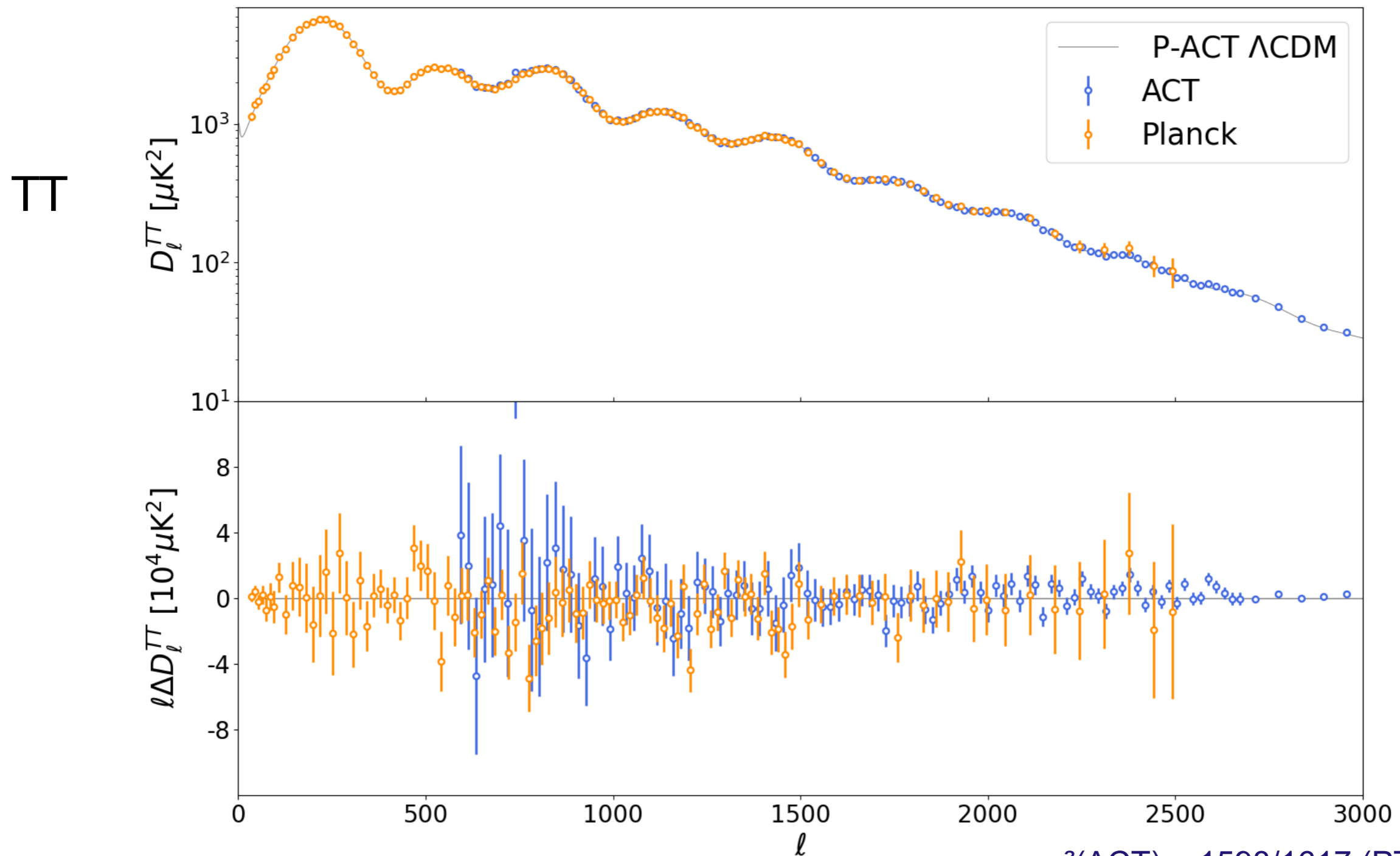
Louis, La Posta, Atkins, Jense, et al. (2025), 2503.14452  
Calabrese & JCH, Jense, La Posta, et al. (2025), 2503.14454

# Cosmological Constraints

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$\Lambda$ CDM provides an excellent fit to both  
Planck and ACT DR6, separately and jointly

+ consistency between constraints  
inferred separately from TT, TE, EE



$\chi^2(\text{ACT}) = 1598/1617$  (PTE = 63%)

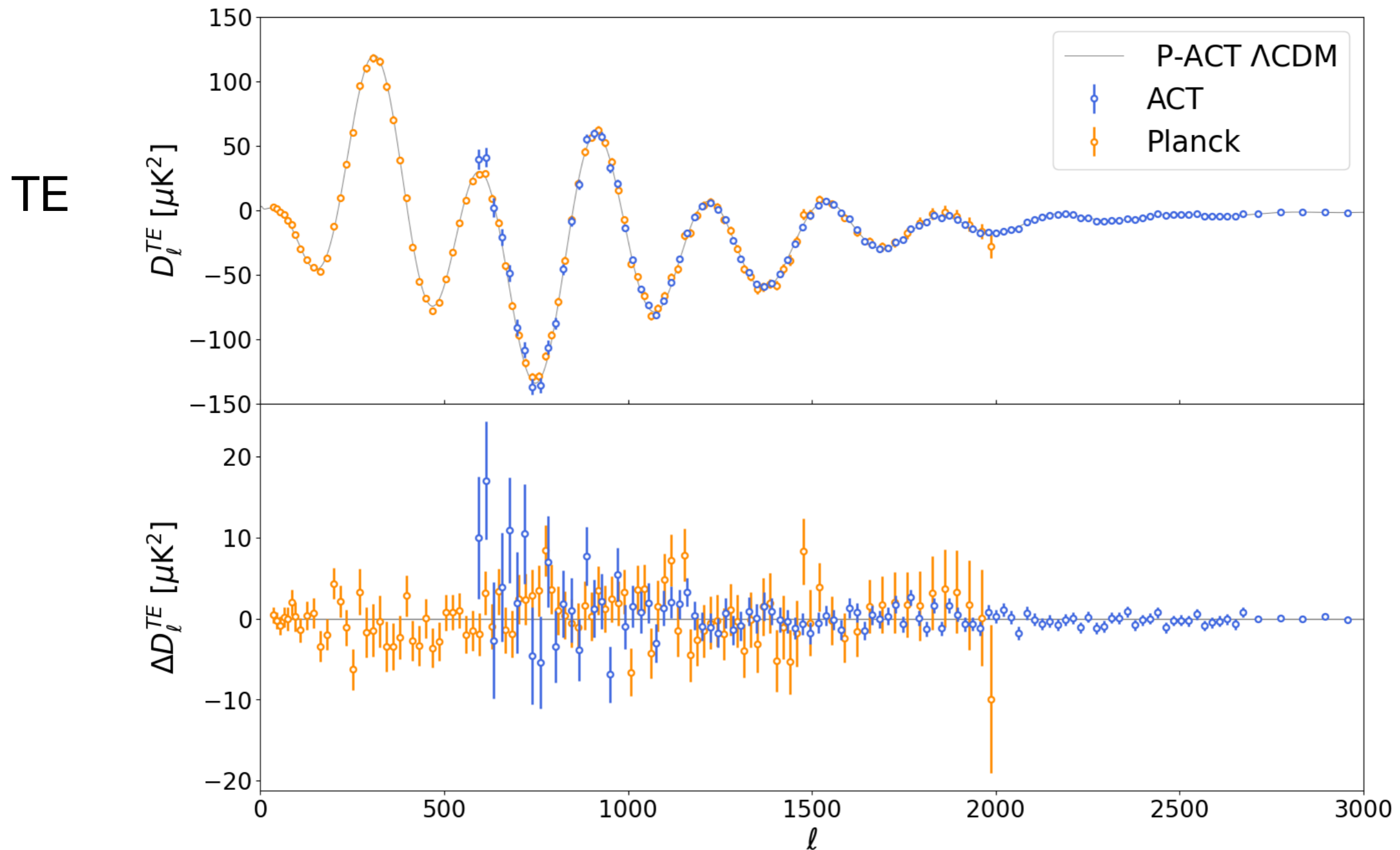
$\chi^2(\text{P-ACT}) = 1842/1897$  (PTE = 81%)

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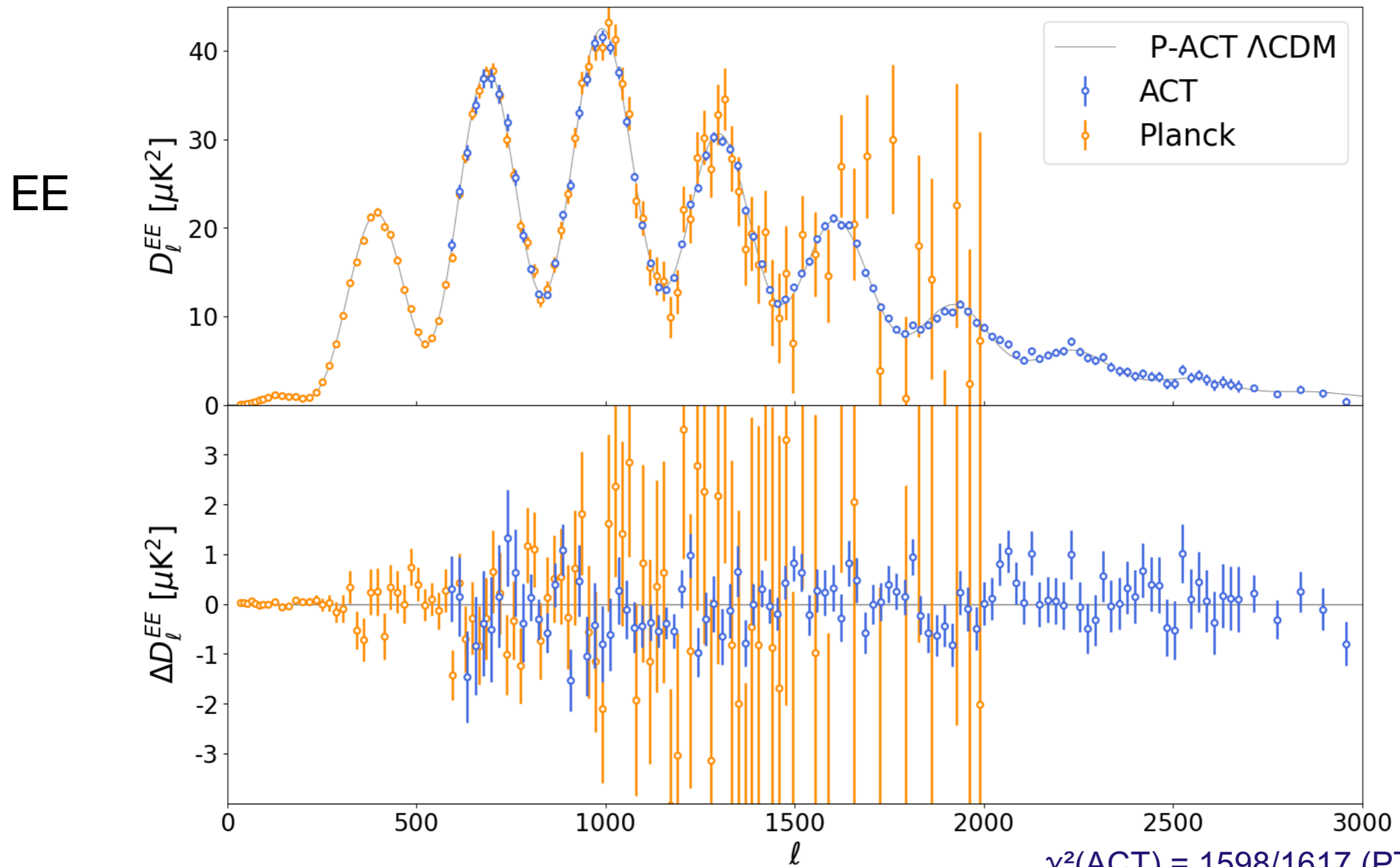
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$$\chi^2(\text{P-ACT}) = 1842/1897 \text{ (PTE} = 81\%)$$

# Cosmological Constraints: $\Lambda$ CDM

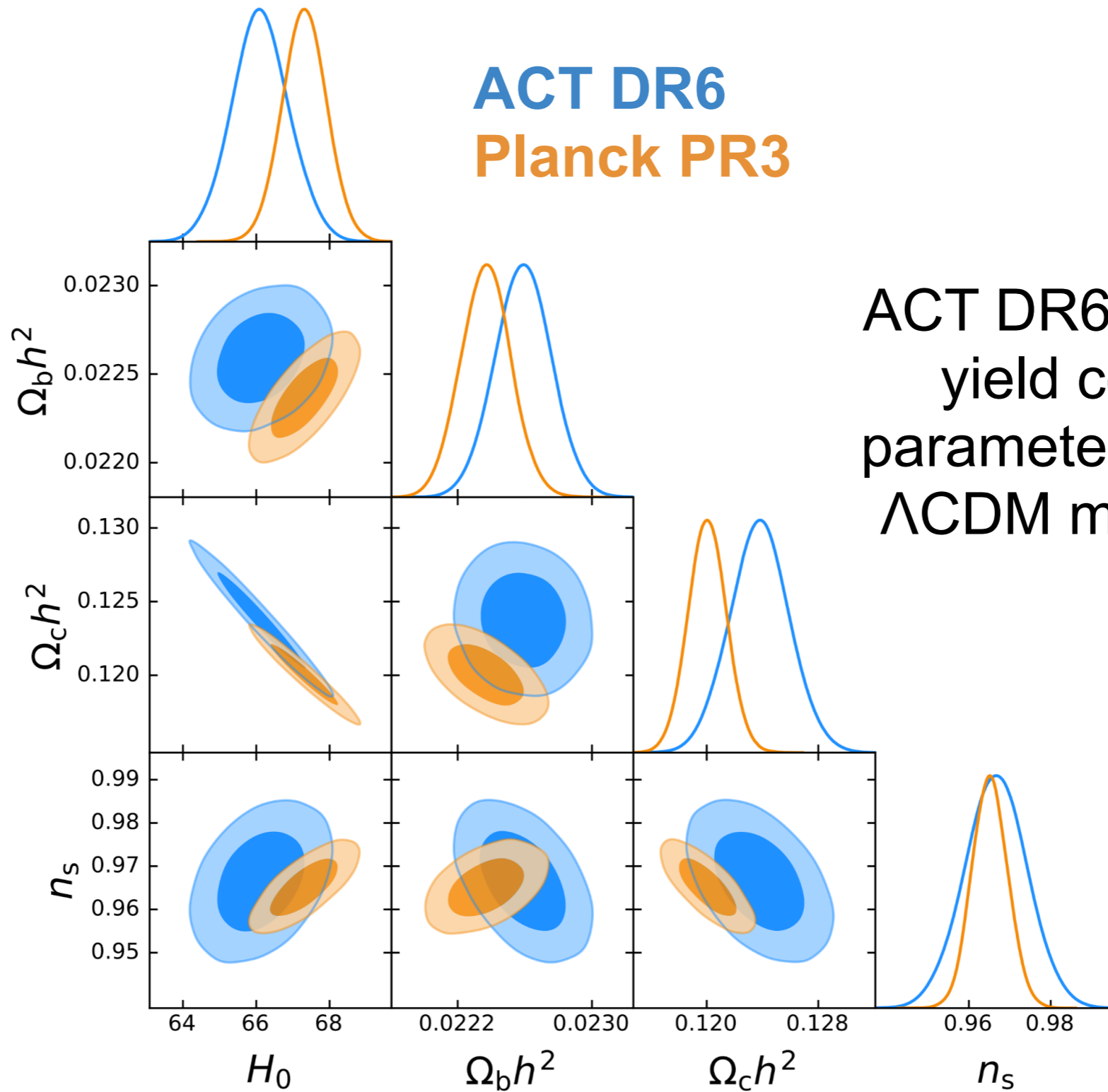
**ACT DR6**  
**Planck PR3**

ACT DR6 and Planck  
yield consistent  
parameters within the  
 $\Lambda$ CDM model ( $1.6\sigma$ )

baryon  
density

dark matter  
density

spectral index  
of scalar  
perturbation  
power spectrum



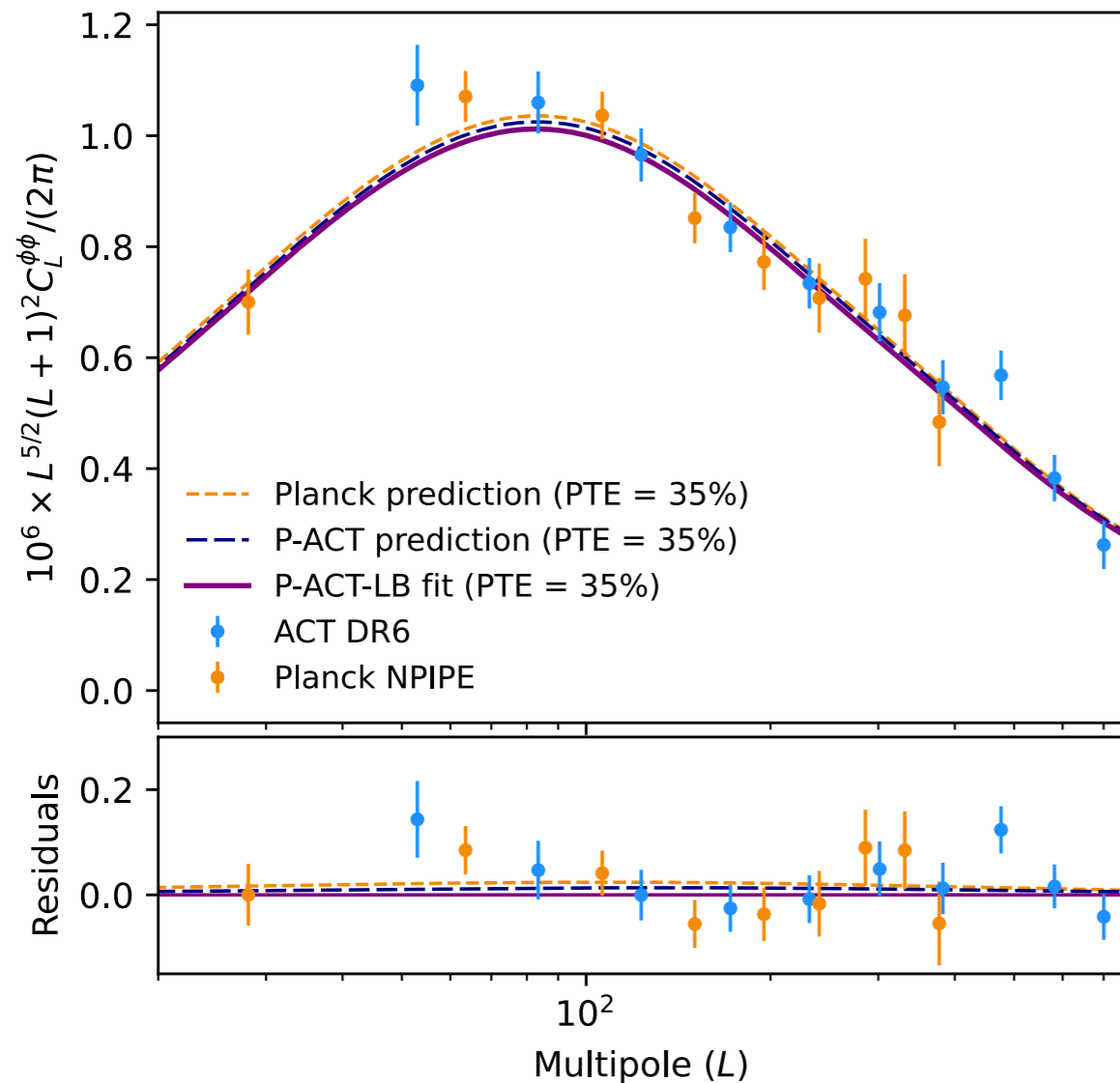
Hubble  
constant

# Cosmological Constraints

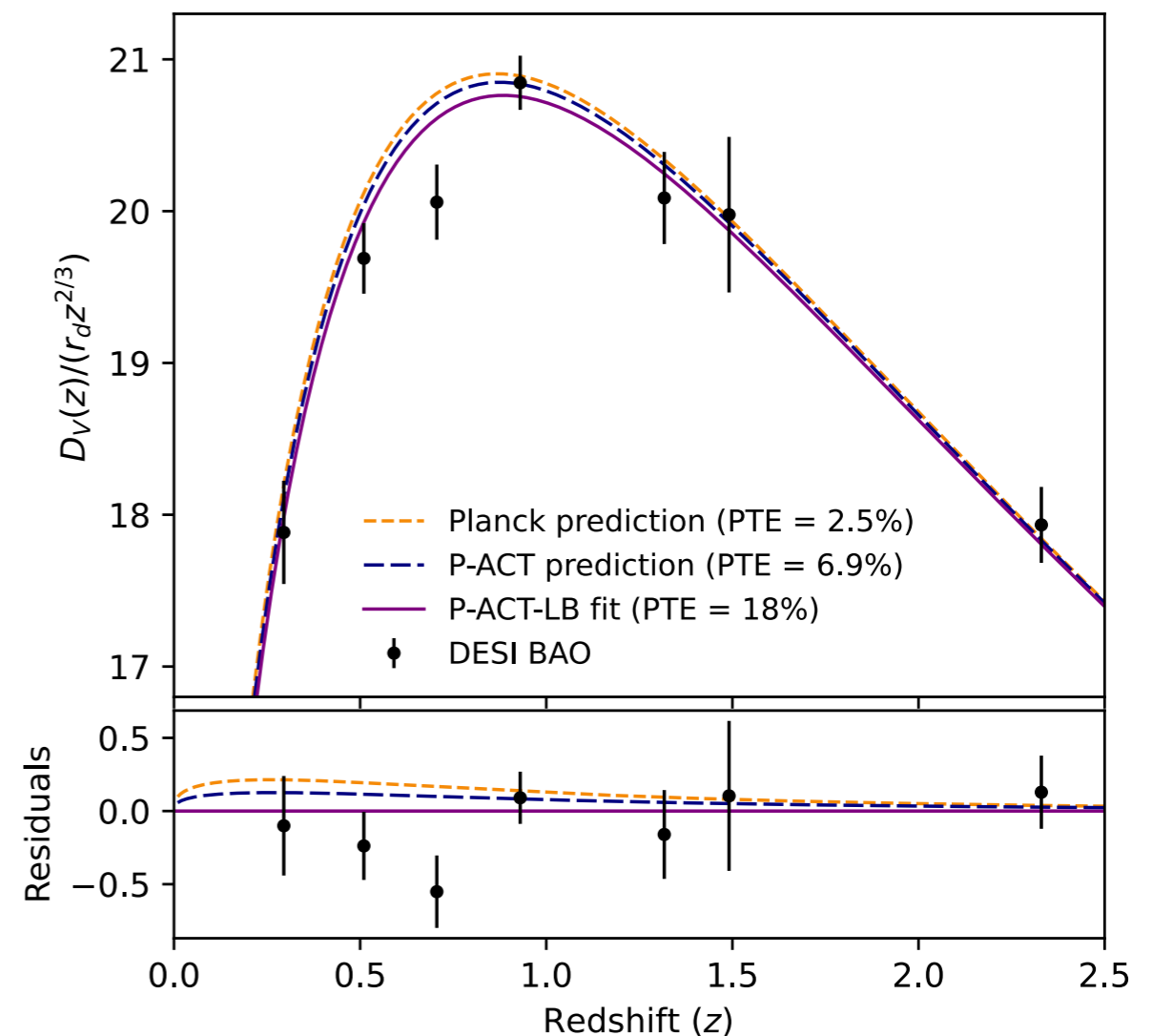
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- Predictions of the best-fit P-ACT  $\Lambda$ CDM model agree well with direct low-redshift measurements
- $\Lambda$ CDM gives an excellent joint fit to these datasets

### CMB lensing power spectrum



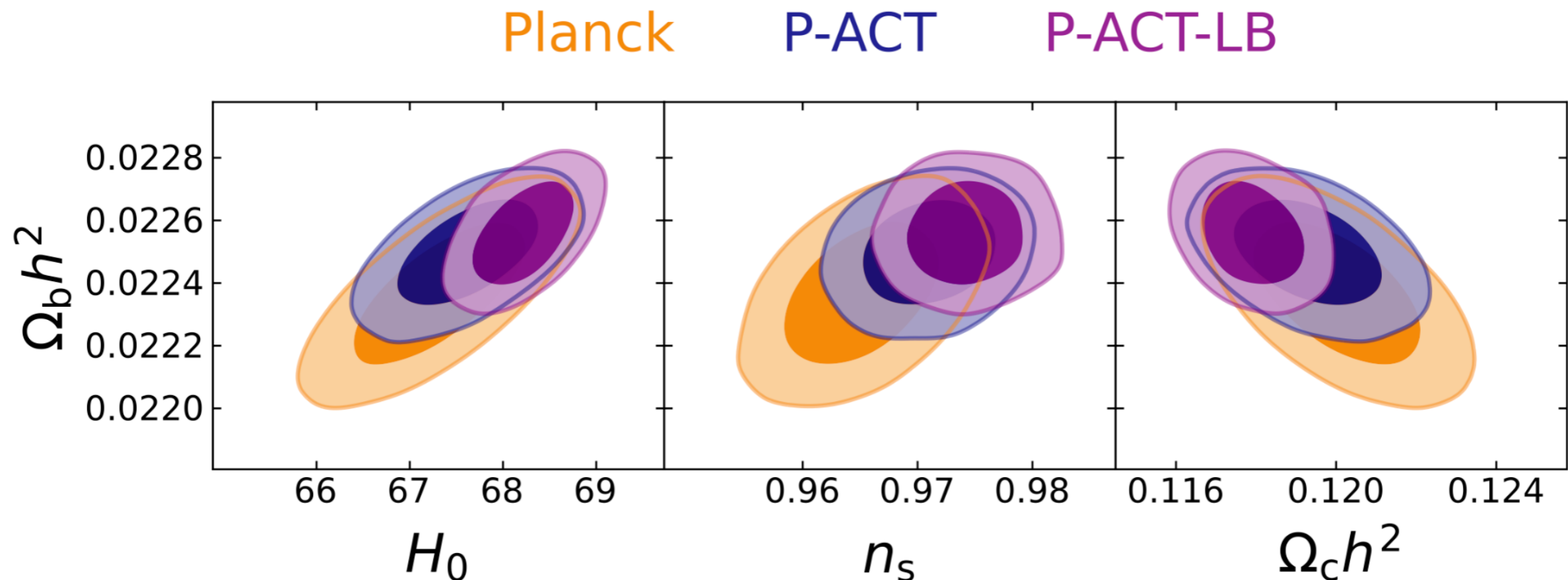
### BAO distance-redshift relation [DESI DR1]



# Cosmological Constraints

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Combining ACT and Planck primary CMB data with CMB lensing (“L”) and DESI-Y1 BAO (“B”) data gives state-of-the-art constraints on cosmological parameters



0.5% constraint on the (predicted) present-day expansion rate:  
 $H_0 = 68.22 \pm 0.36 \text{ km/s/Mpc}$

>130 $\sigma$  detection of dark matter:

$$\Omega_c h^2 = 0.1179 \pm 0.0009$$

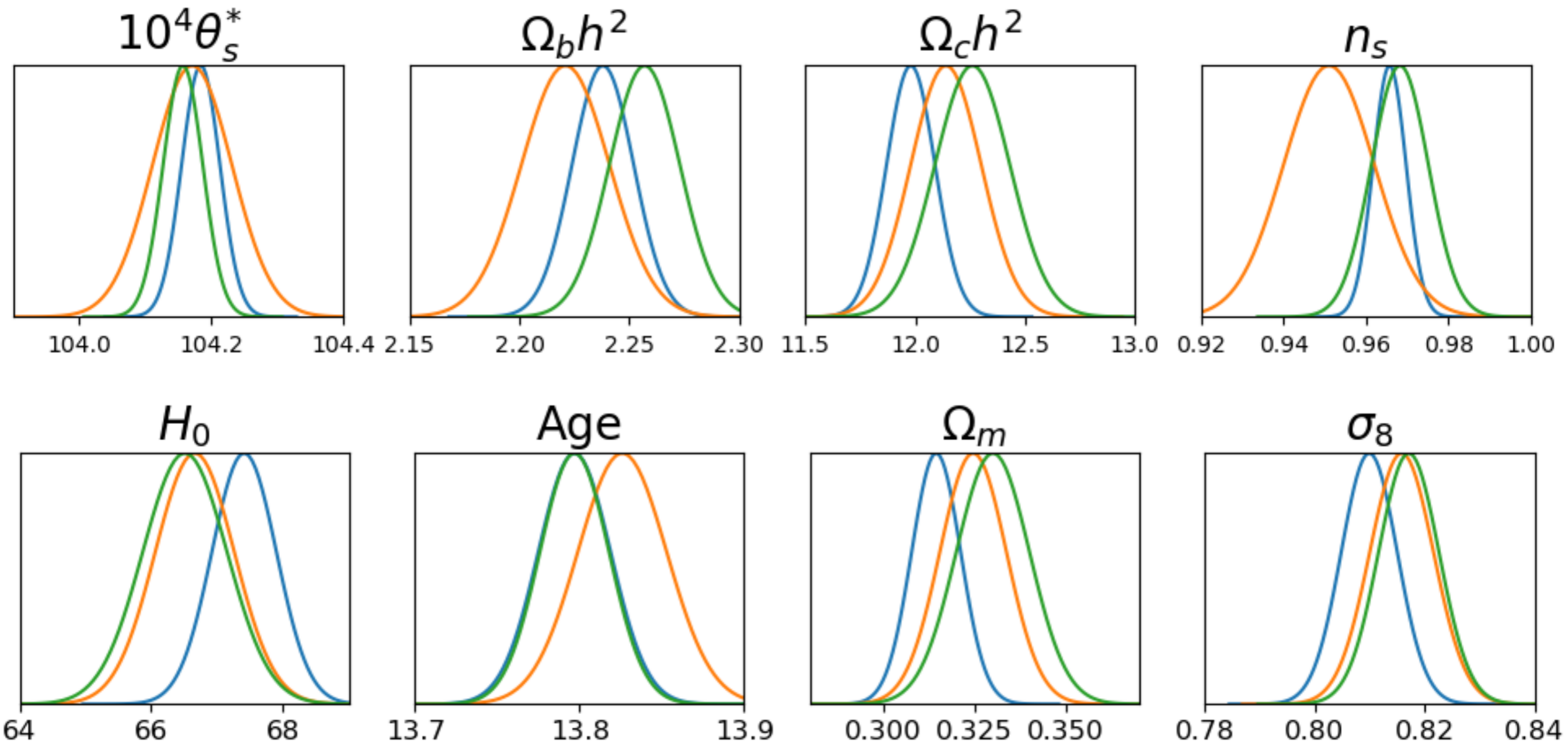
# CMB State of the Art

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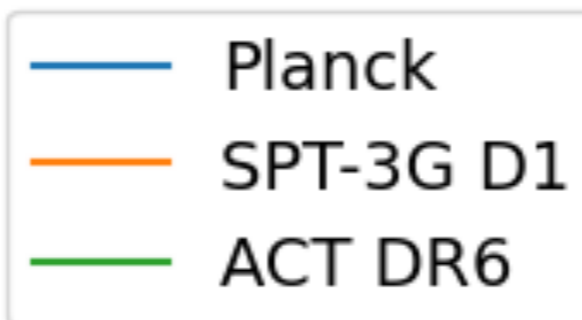
Planck

ACT DR6

SPT-3G D1



$\text{TT}+\text{TE}+\text{EE}+\phi\phi$



Good agreement in  $\Lambda$ CDM; constraints dominated by P+ACT

# Beyond $\Lambda$ CDM

(just a small sampling — see the paper!)

## Notation:

P = Planck

ACT = ACT

L = ACT+Planck CMB lensing

B = BAO [DESI DR1, or DR2 where indicated]

# Primordial Power Spectrum

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Constraints on scale dependence of primordial curvature perturbation power spectrum

$$\begin{aligned}n_s &= 0.9660 \pm 0.0046 \text{ (W-ACT)} \\ &= 0.9651 \pm 0.0044 \text{ (Planck),}\end{aligned}$$

Independent confirmation  
of  $n_s < 1$  at  $7\sigma$

# Primordial Power Spectrum

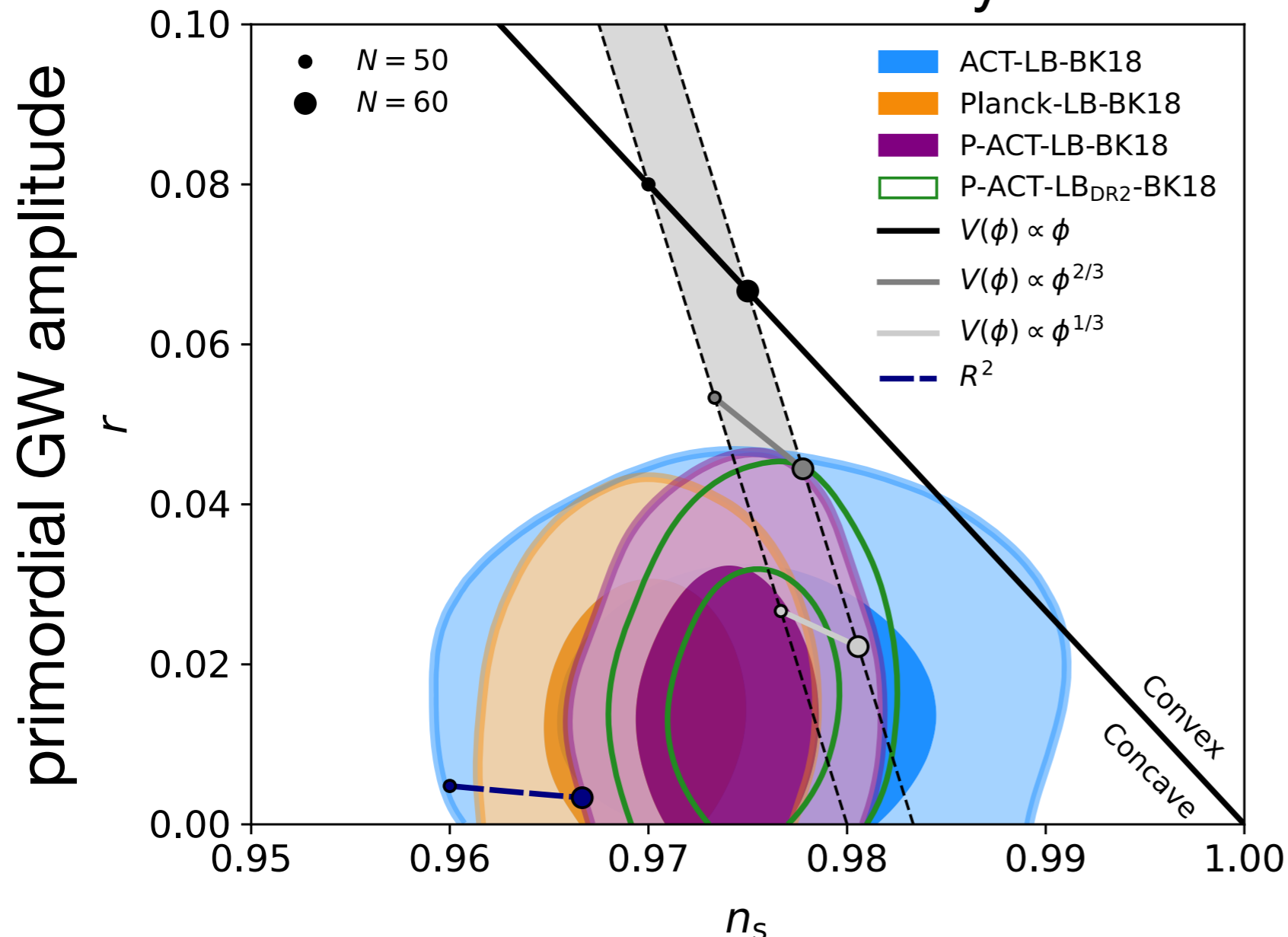
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Constraints on scale dependence of primordial curvature perturbation power spectrum

$$n_s = 0.9660 \pm 0.0046 \text{ (W-ACT)}$$
$$= 0.9651 \pm 0.0044 \text{ (Planck),}$$

Independent confirmation  
of  $n_s < 1$  at  $7\sigma$

## constraints on inflationary models



# Primordial Power Spectrum

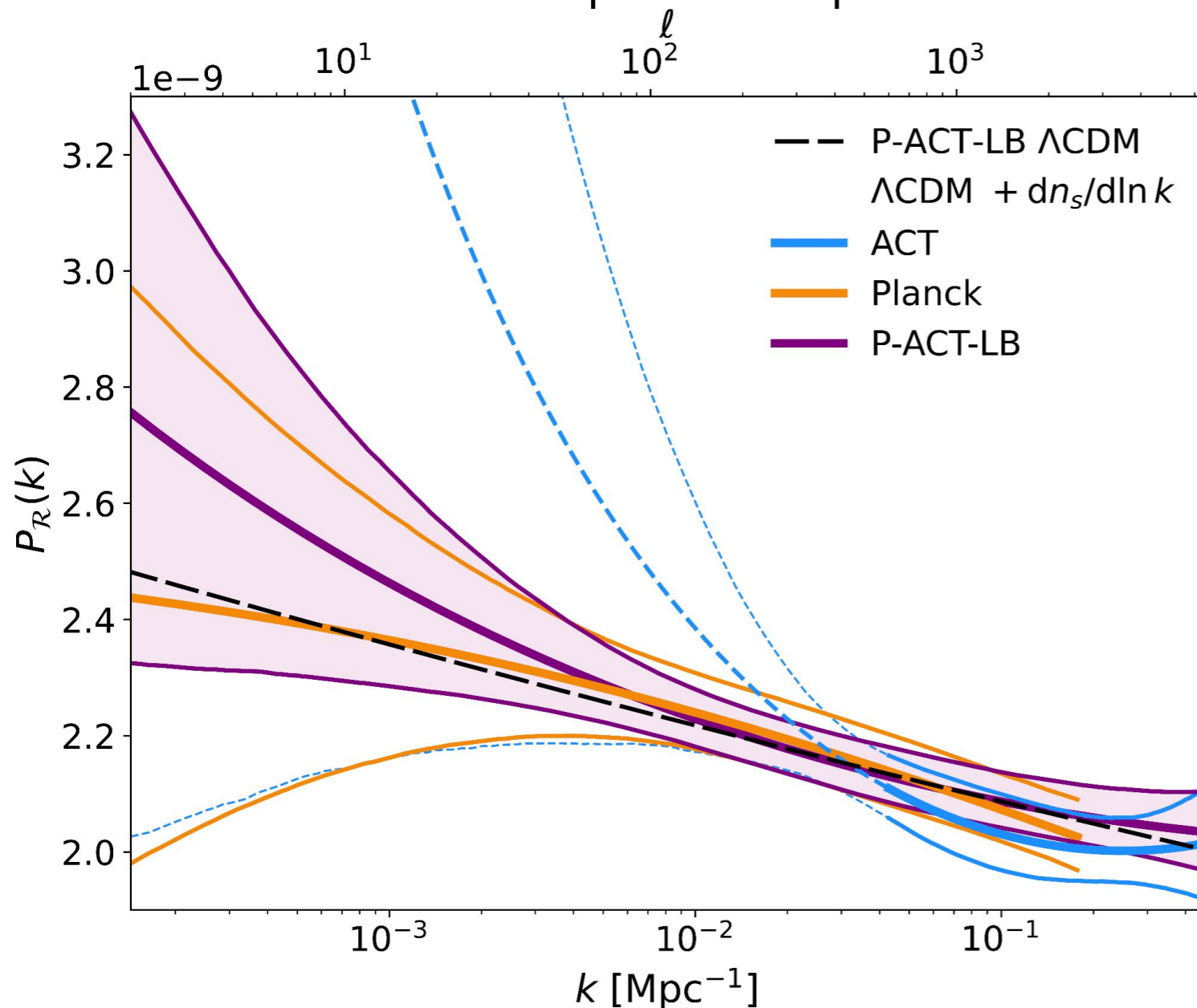
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Constraints on scale dependence of primordial curvature perturbation power spectrum

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Independent confirmation  
of  $n_s < 1$  at  $7\sigma$

Primordial power spectrum



**+ No evidence of departure from simple power-law**

$$dn_s/d \ln k = 0.0062 \pm 0.0052 \text{ (P-ACT-LB)}$$

(30% tighter than previous CMB+LSS constraints)

+ tightened constraints on primordial isocurvature perturbations — no deviation from adiabaticity detected

# New Light, Relativistic Particles

- CMB power spectra are sensitive to any light particles (mass  $< eV$ ) that were *ever* in thermal contact with the primordial plasma (“dark radiation”, e.g., neutrinos)

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- CMB power spectra are sensitive to any light particles (mass  $< eV$ ) that were *ever* in thermal contact with the primordial plasma (“dark radiation”, e.g., neutrinos)
- $N_{\text{eff}}$ : “effective number of light, relativistic species” — simple parameterization that captures a wide range of BSM theories, with SM value = 3.044 (neutrinos):

$$N_{\text{eff}} = \frac{8}{7} \left( \frac{11}{4} \right)^{4/3} \frac{\rho_{\nu}}{\rho_{\gamma}}$$

neutrino energy density (+dark radiation)  
photon energy density

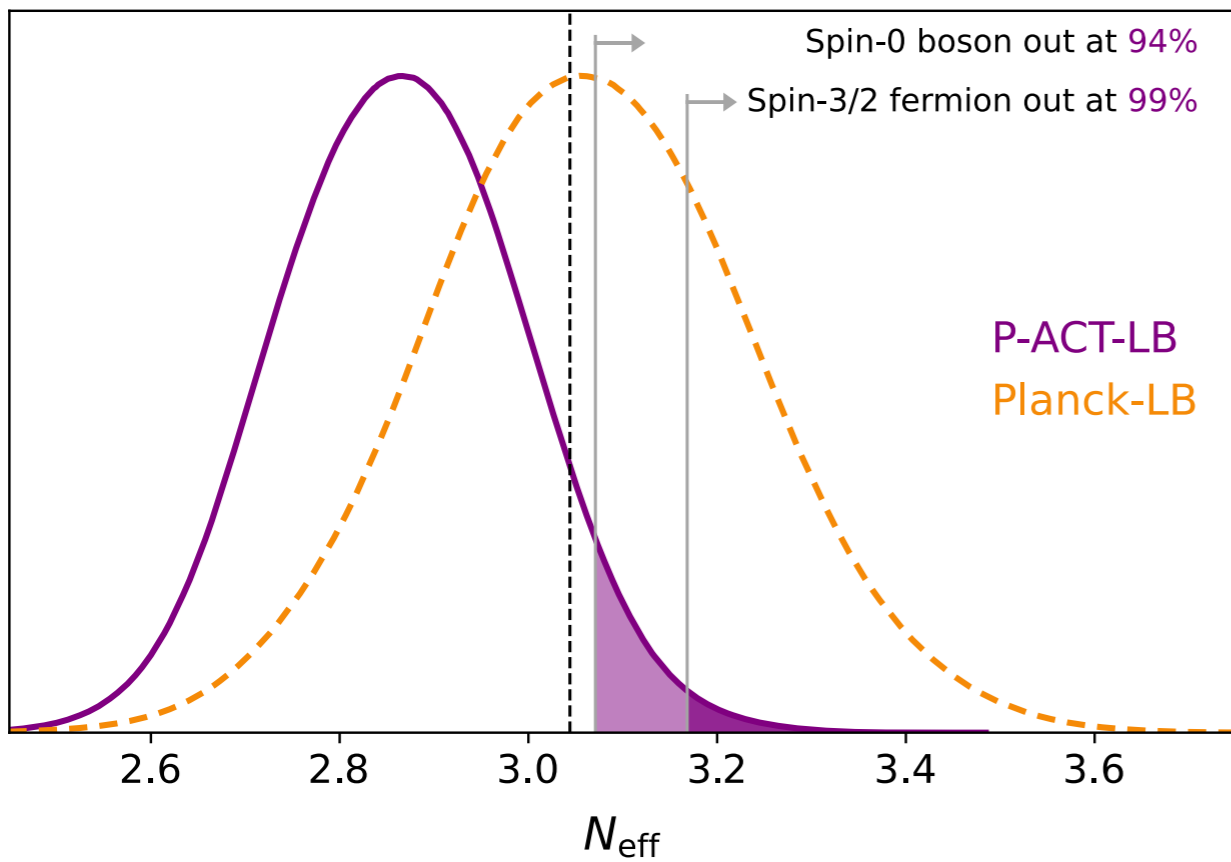
- Detection would be the first direct cosmic signal from the epoch before neutrino decoupling ( $t \sim 1$  sec)

# New Light, Relativistic Particles

Free-streaming relativistic particles:

$$N_{\text{eff}} = 2.86 \pm 0.13 \text{ (68\%, P-ACT-LB)}$$

$$N_{\text{eff}} = 2.89 \pm 0.11 \text{ (68\%, P-ACT-LB-BBN)}$$



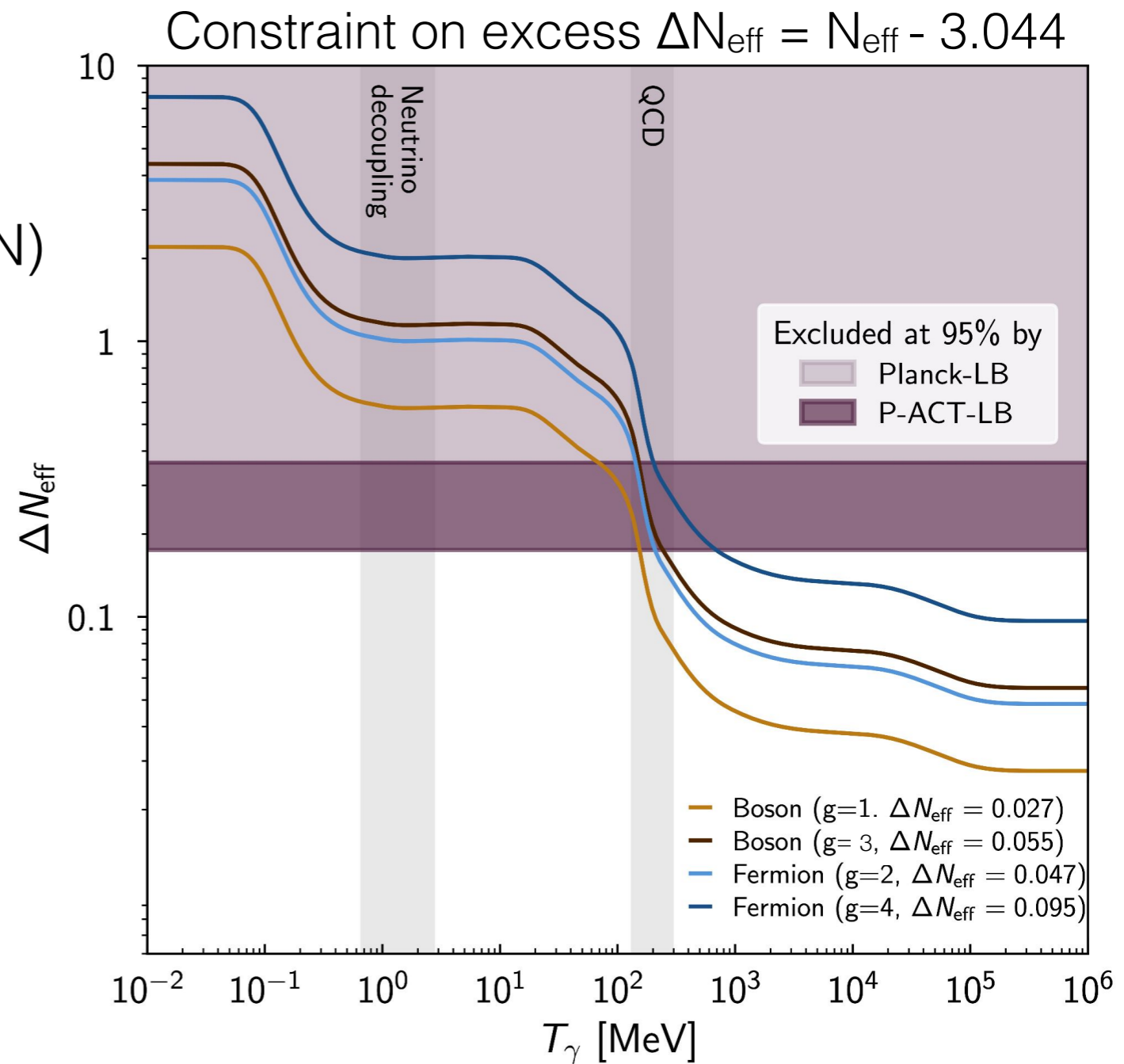
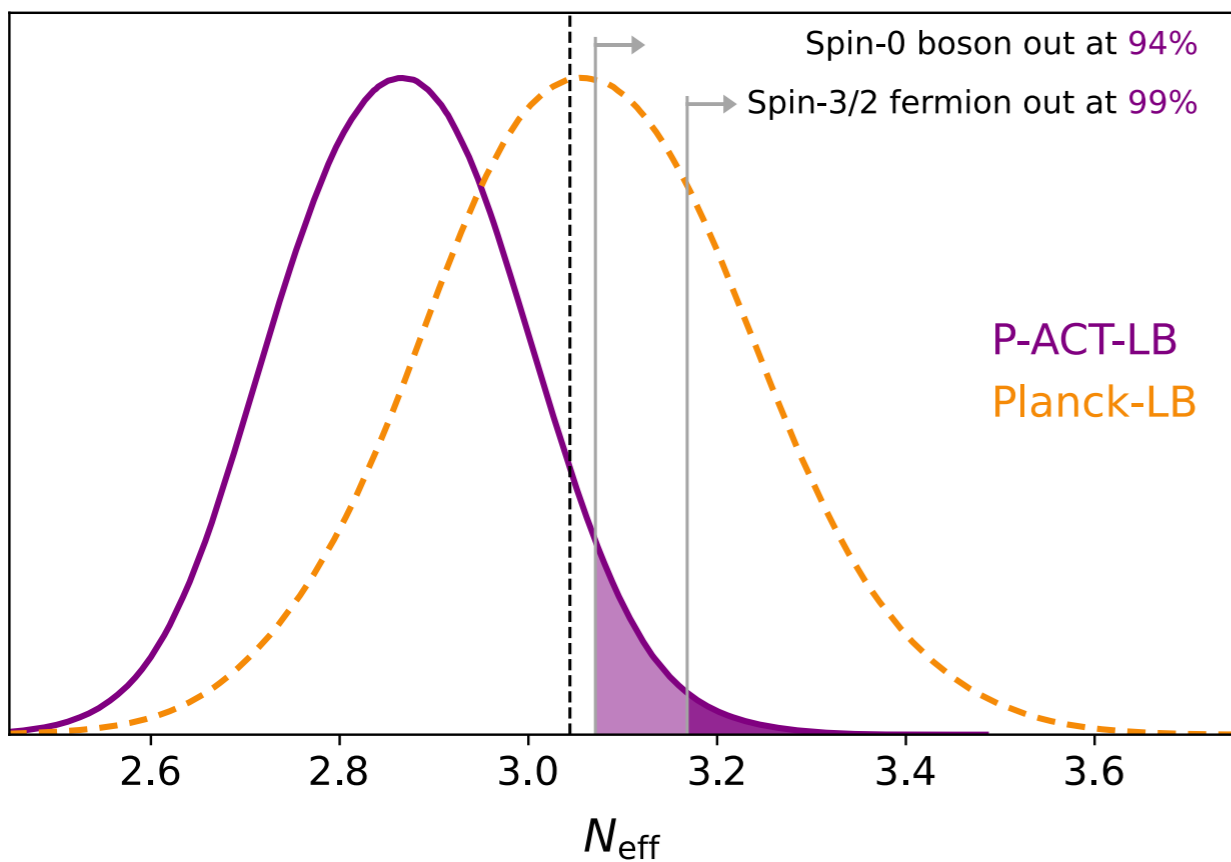
~1.6x tighter than *Planck* limit

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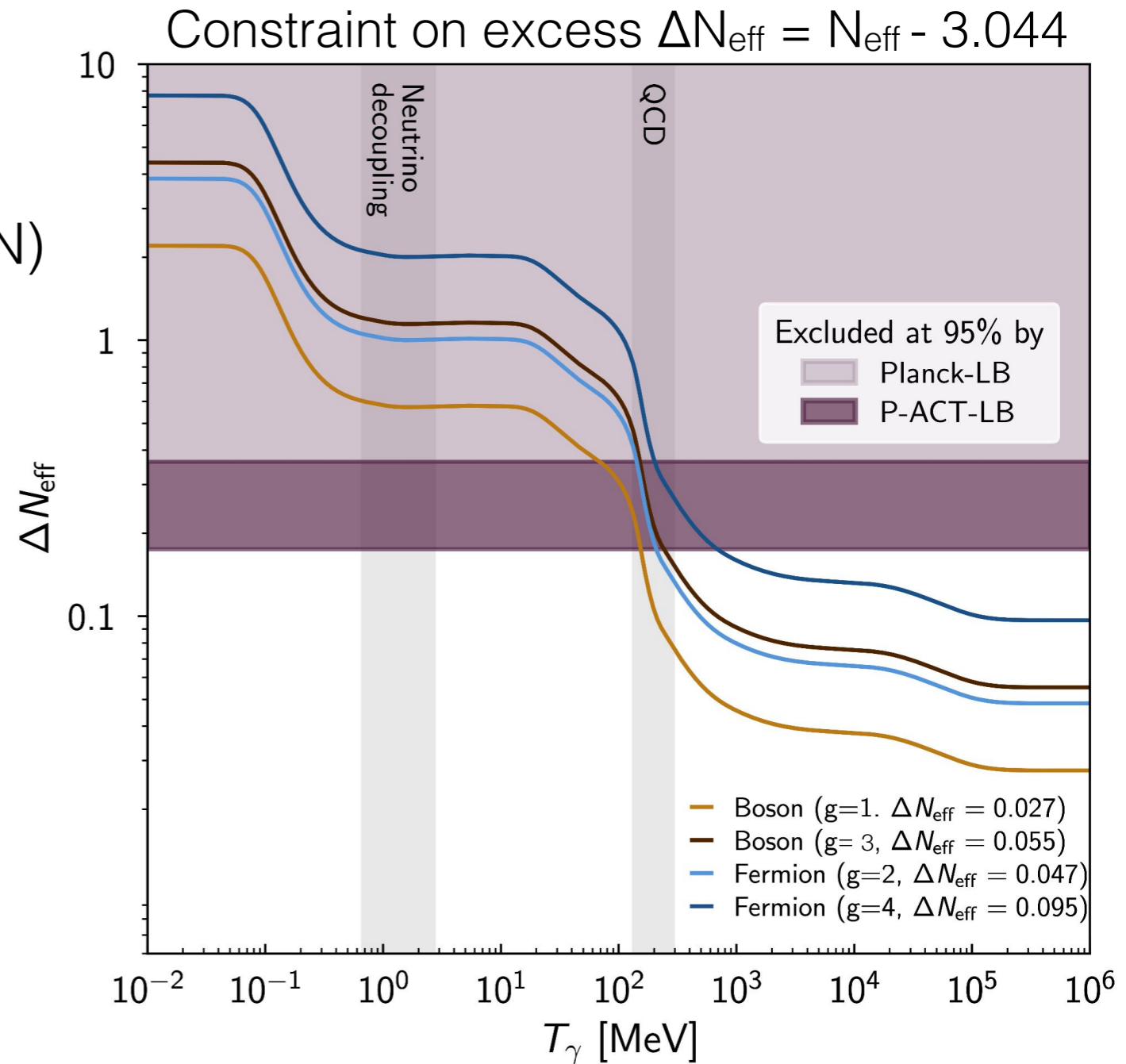
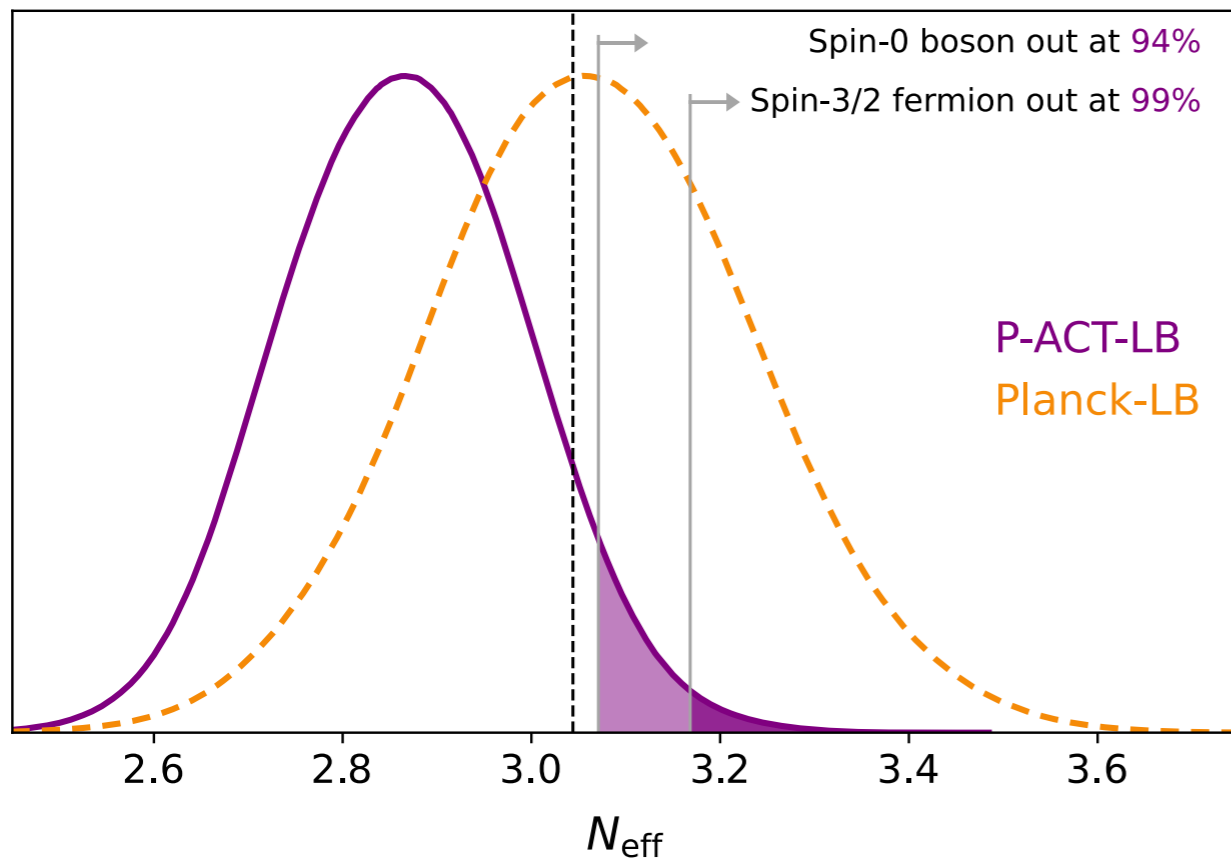
Any light, spin-3/2 particle must have decoupled from the plasma at  $T > 1 \text{ GeV}$

# New Light, Relativistic Particles

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$$N_{\text{eff}} = 2.89 \pm 0.11 \text{ (68\%, P-ACT-LB-BBN)}$$



Also: no evidence for non-zero neutrino mass:  
 $\Sigma m_\nu < 0.082 \text{ eV}$  (95%, P-ACT-LB)

# New Light, Relativistic Particles

Post-DR6 updates

Primordial helium abundance is highly sensitive to expansion rate during Big Bang nucleosynthesis (BBN)  $\longrightarrow$  sensitive to  $N_{\text{eff}}$  (at BBN)

January 2026 [LBT  $Y_p$  Project]:  $Y_P^{\text{LBT}26} = 0.2458 \pm 0.0013$

2x improvement upon previous state-of-the-art!

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January 2026 [LBT  $Y_p$  Project]:  $Y_P^{\text{LBT}26} = 0.2458 \pm 0.0013$

2x improvement upon previous state-of-the-art!

$$\longrightarrow N_{\text{eff}} = 2.976 \pm 0.093 \quad [\text{BBN}]$$

This is consistent with  $N_{\text{eff}} = 2.86 \pm 0.13$  (68%, P-ACT-LB) [CMB]

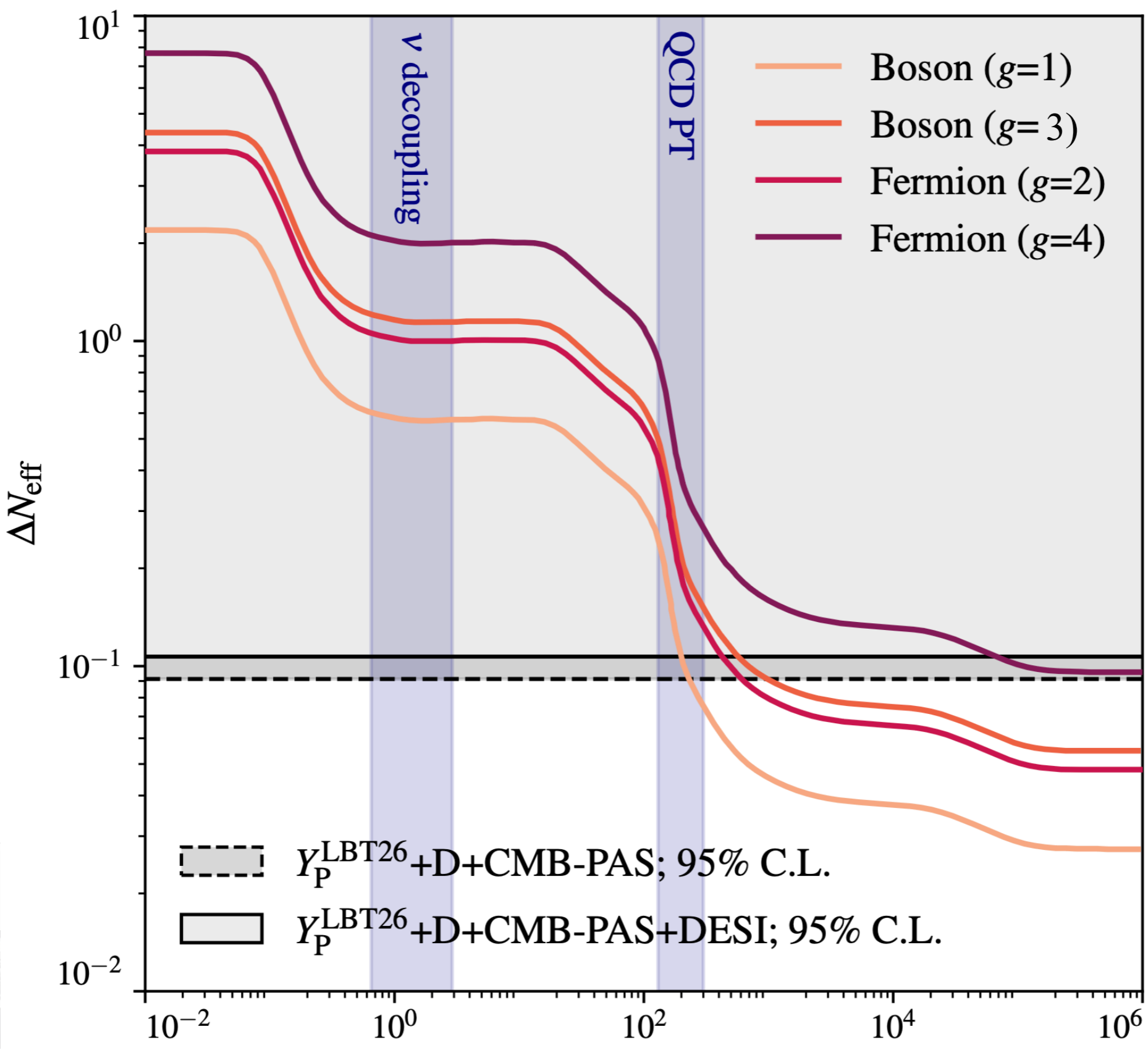
$\longrightarrow$  Joint analysis yields state-of-the-art, 2% constraint:

$$N_{\text{eff}} = 2.990 \pm 0.070$$

# New Light, Relativistic Particles

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excess  
 $N_{\text{eff}}$



light, spin-3/2 particles in equilibrium with SM at any time back to reheating are excluded at ~95% CL

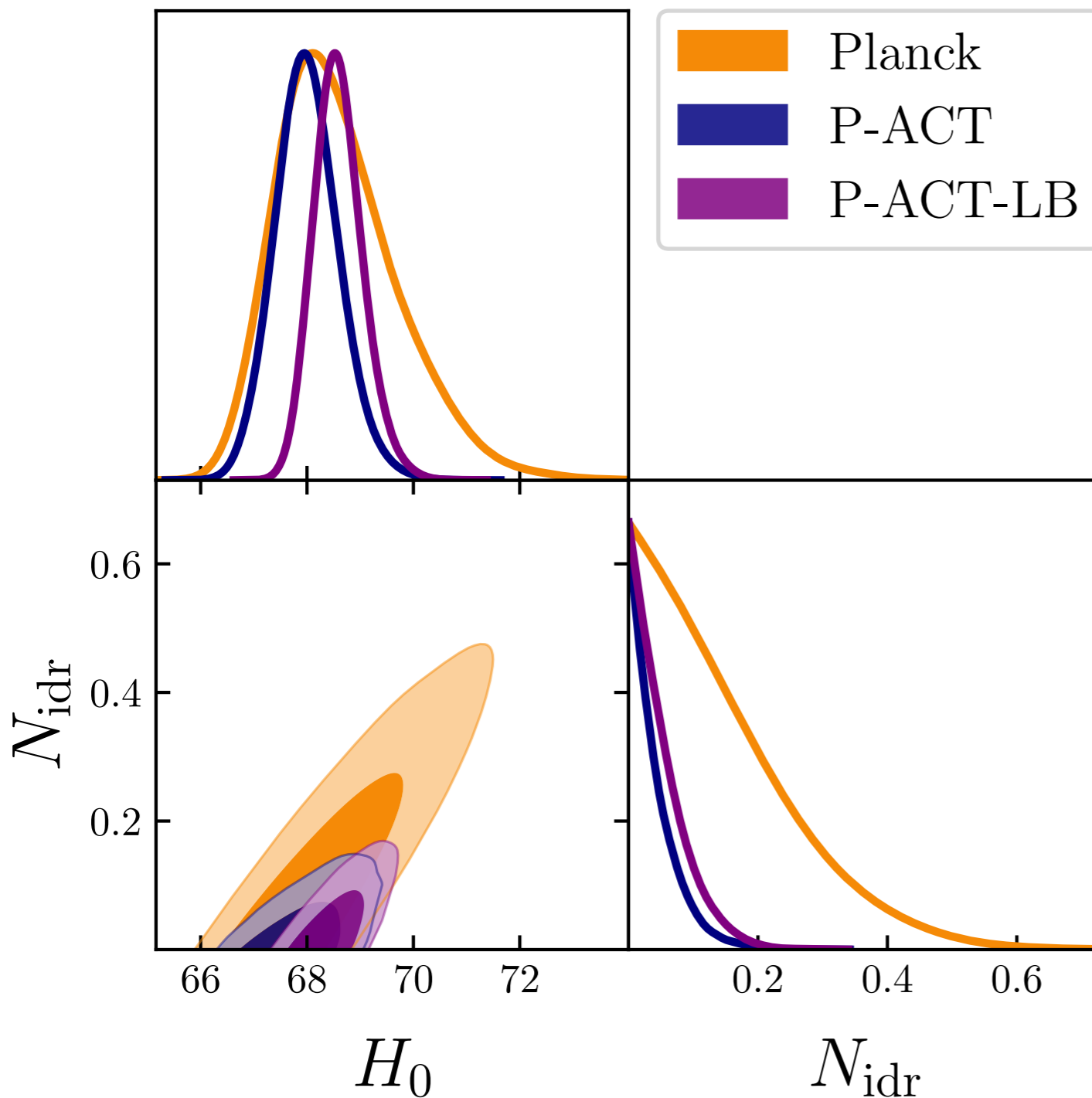


# New Light, Relativistic Particles

Search for new light, relativistic particles that are strongly self-interacting

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Search for new light, relativistic particles that are strongly self-interacting



Self-interacting  
relativistic particles:  
 $N_{\text{idr}} < 0.134$  (95%, P-ACT-LB)

~3x tighter than *Planck* limit

We exclude this scenario as a  
resolution of the  $H_0$  tension

Also: no evidence of neutrino self-  
interactions or interactions  
between dark matter and dark  
radiation

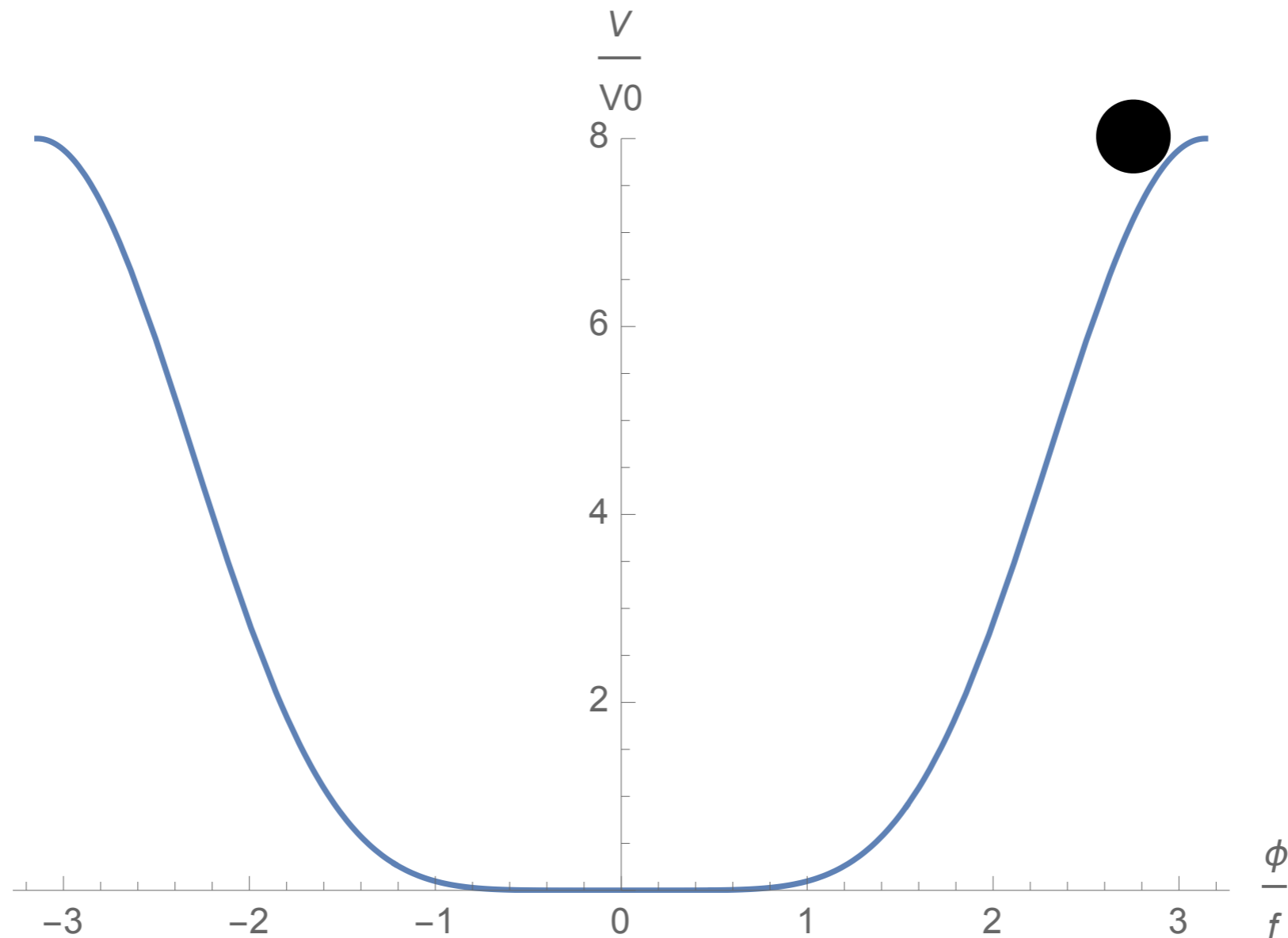
# Early Dark Energy

New pseudo-scalar field that becomes dynamical around recombination

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New pseudo-scalar field that becomes dynamical around recombination

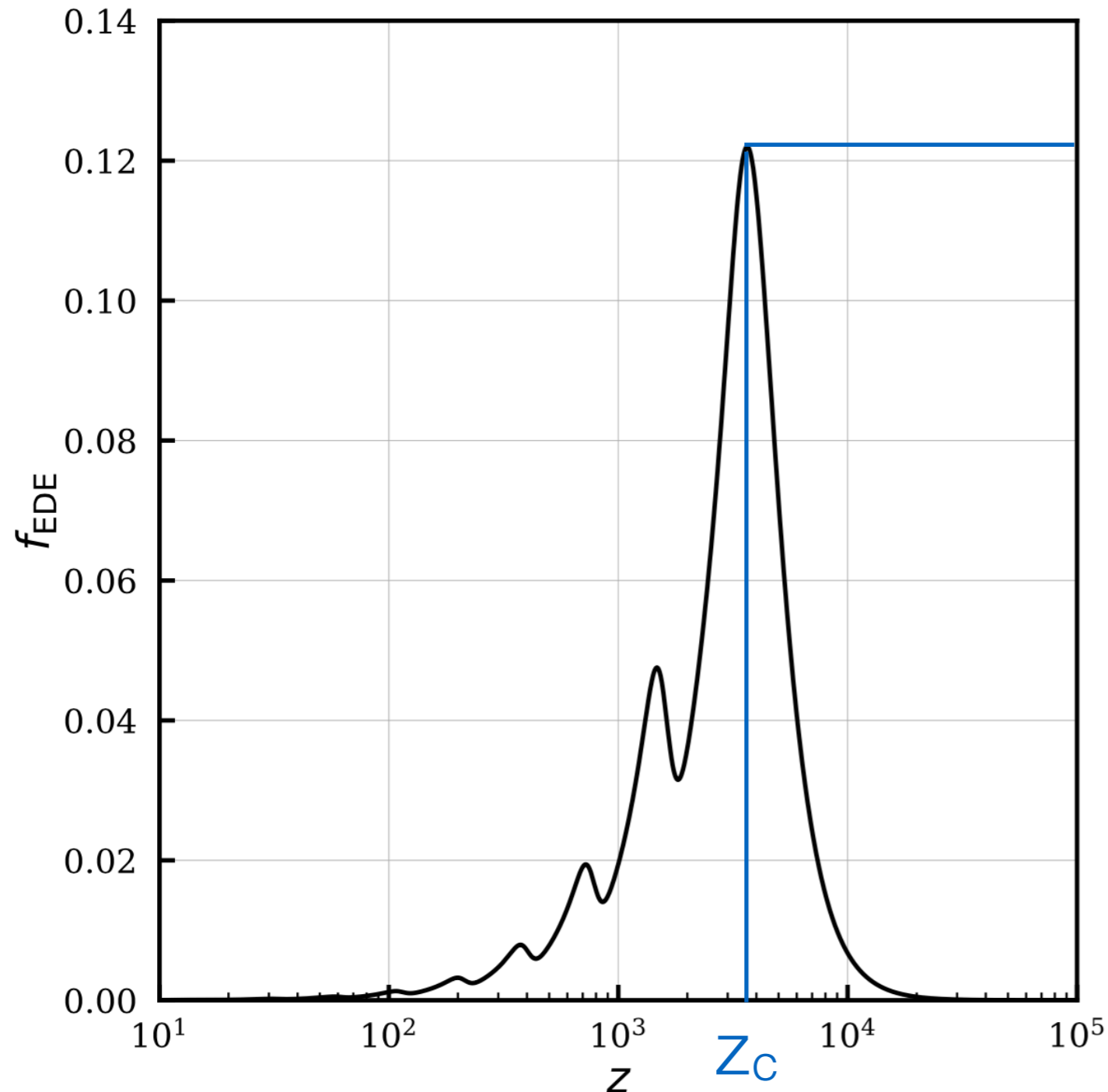
$$V(\phi) = m^2 f^2 (1 - \cos(\phi/f))^n$$



# Early Dark Energy

New pseudo-scalar field that becomes dynamical around recombination

Fractional contribution of EDE  
to cosmic energy budget



Maximal contribution:  
 $f_{\text{EDE}}(z_c) \equiv (\rho_{\text{EDE}}/3M_{pl}^2 H^2)|_{z_c}$   
 which occurs at redshift  $z_c$

Final parameter:  $\theta_i = \phi_i/f$   
 (initial field displacement)

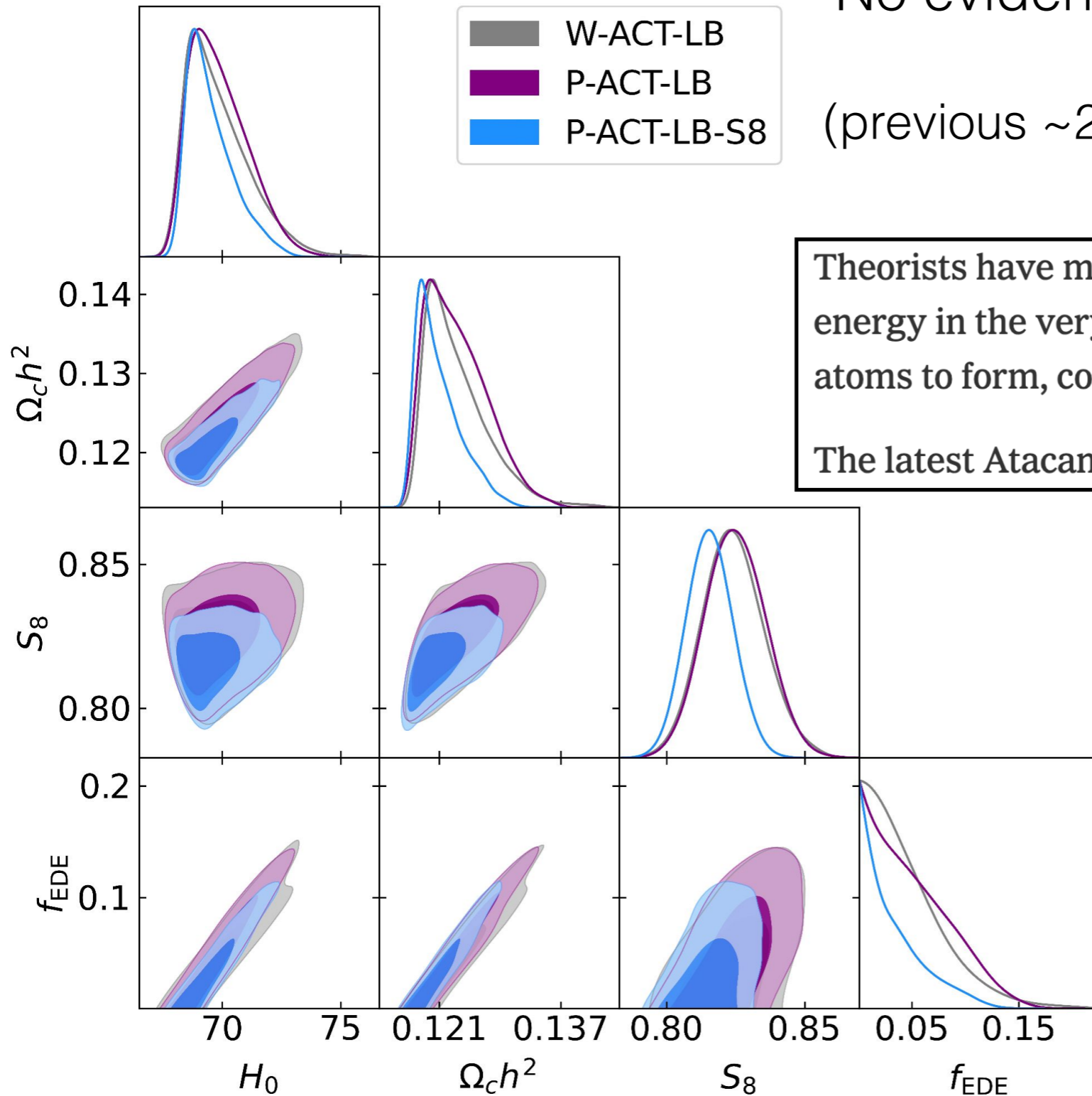
→  $\{f_{\text{EDE}}, z_c, \theta_i\}$

3-parameter extension of  
 $\Lambda$ CDM

# Early Dark Energy

New pseudo-scalar field that becomes dynamical around recombination

No evidence seen for EDE component in ACT DR6  
(previous  $\sim 2.5\sigma$  hint had been seen in ACT DR4 data [JCH+22])



Theorists have mused that perhaps an additional spurt of dark energy in the very early universe, when conditions were too hot for atoms to form, could resolve this so-called Hubble tension.  
The latest Atacama results seem to rule out this idea. **-NYT**

Frequentist: max. preference:  
 $\Delta\chi^2 = 6.6 (1.7\sigma)$



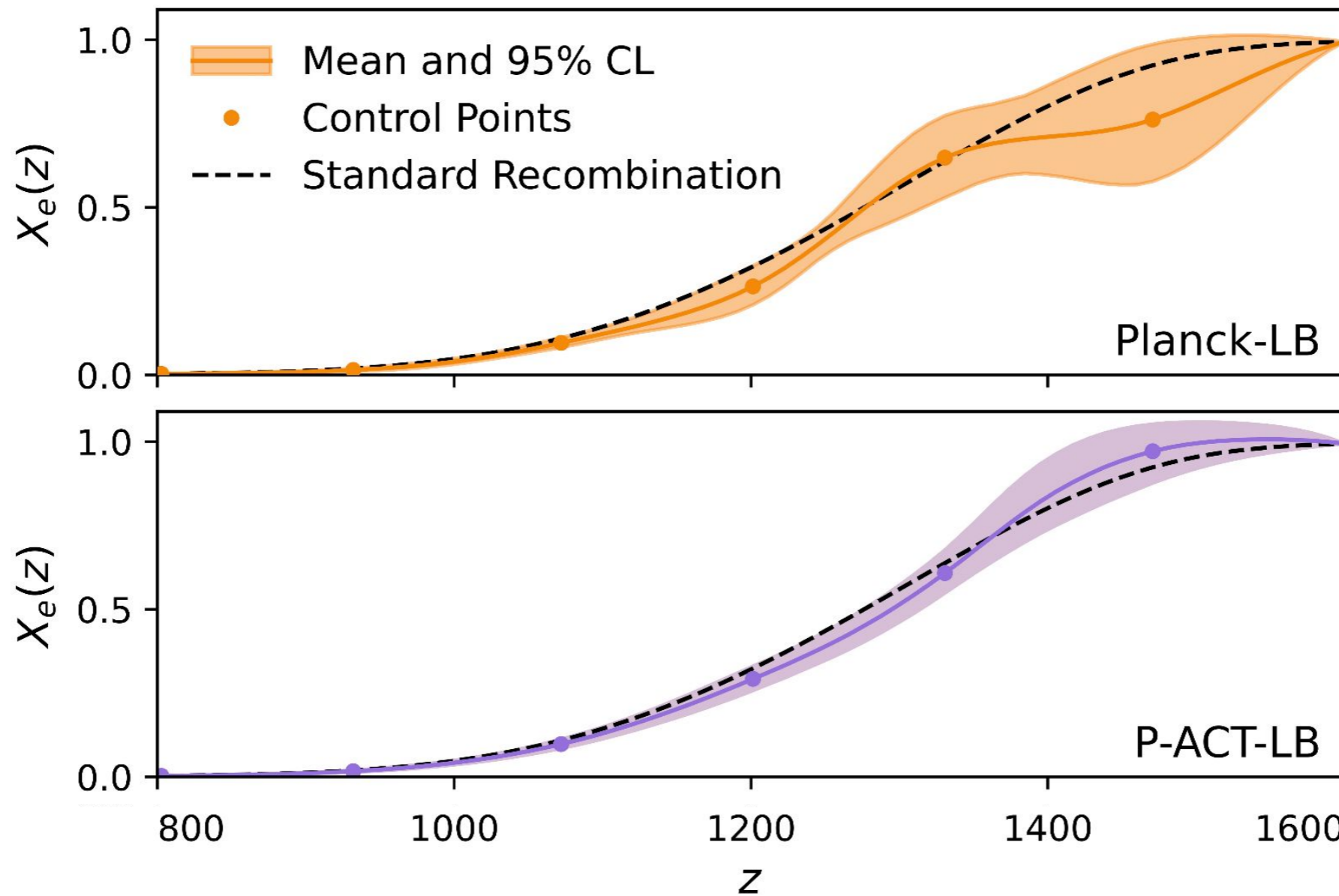
# Modified Recombination

Ex.: primordial magnetic fields; variations of fundamental constants; change to CMB monopole temperature or distribution function

# Modified Recombination

We perform a non-parametric reconstruction of the recombination history

We obtain the tightest limits to date and find no evidence of deviations from the standard history



Planck

+ACT



ionization  
fraction

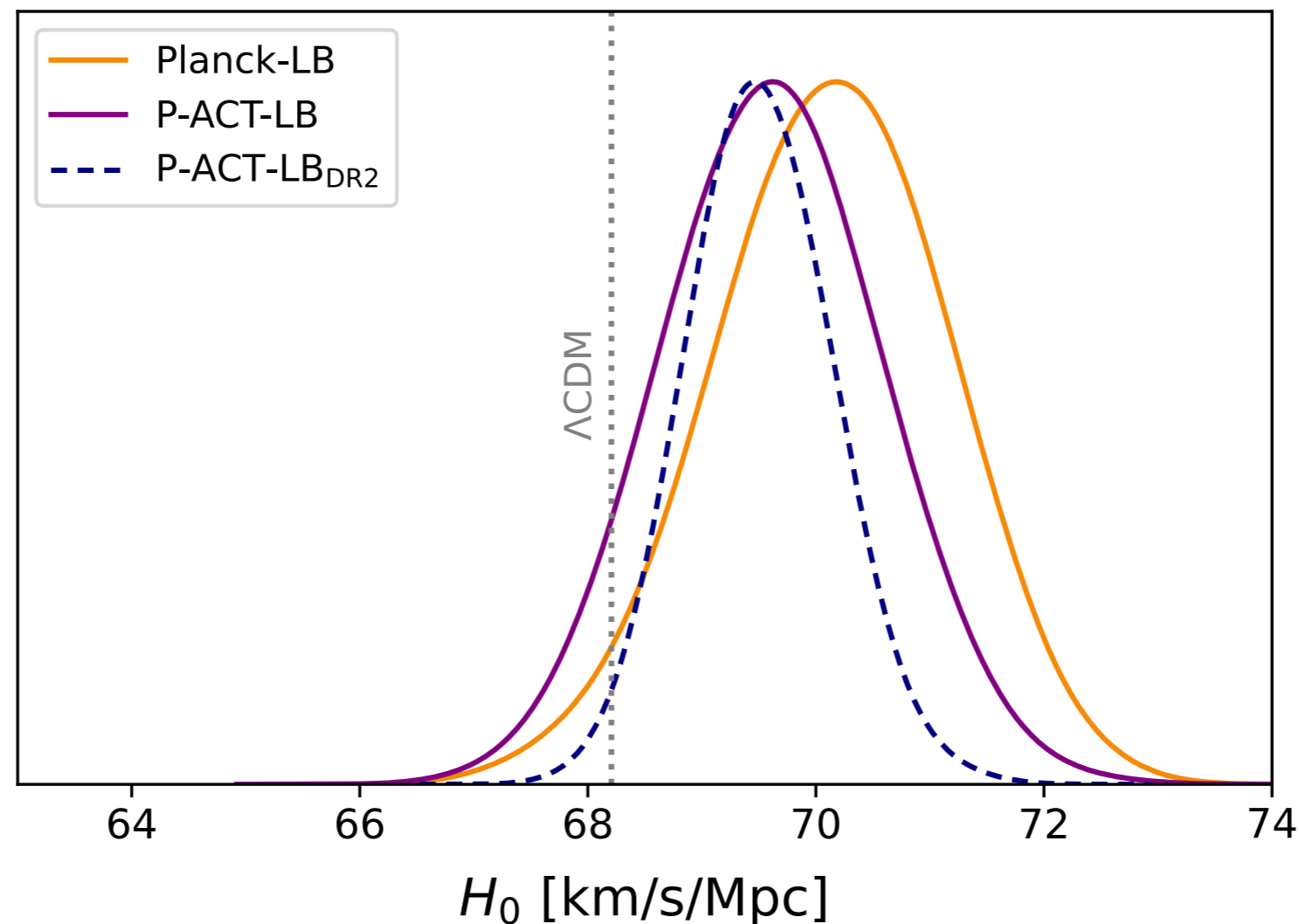
redshift

# Modified Recombination

We perform a non-parametric reconstruction of the recombination history

We obtain the tightest limits to date and find no evidence of deviations from the standard history

This result restricts the ability of such scenarios to increase  $H_0$



**P-ACT-LB<sub>DR2</sub>**:  $H_0 = 69.5 \pm 0.7$  km/s/Mpc

+ SPT-D1:  $H_0 = 69.5 \pm 0.7$  km/s/Mpc



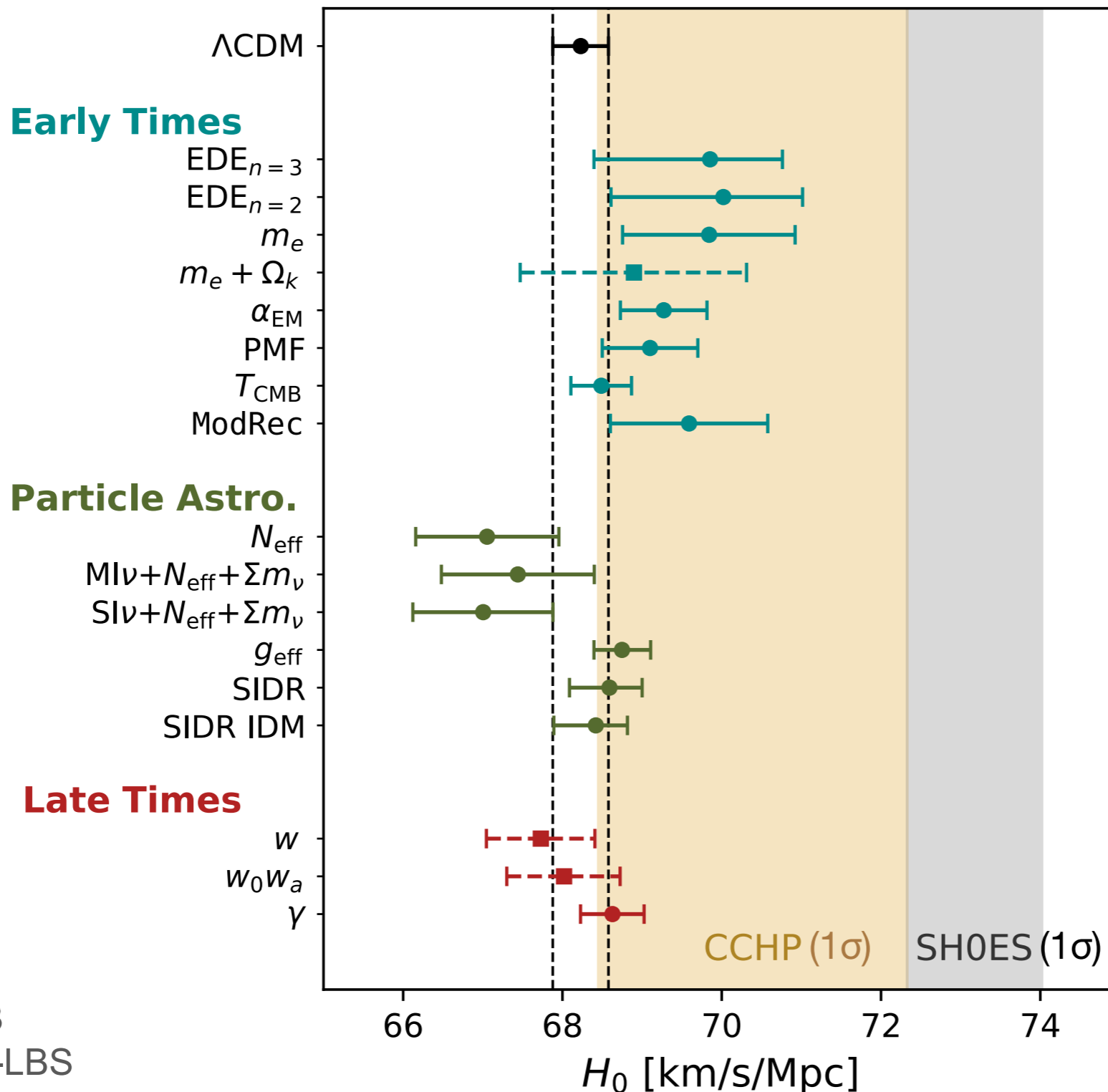
# Cosmological Concordance

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No evidence for new-physics models aiming to increase CMB-inferred  $H_0$

Tightest limits to date on wide ranges of new-physics scenarios

new-physics  
models



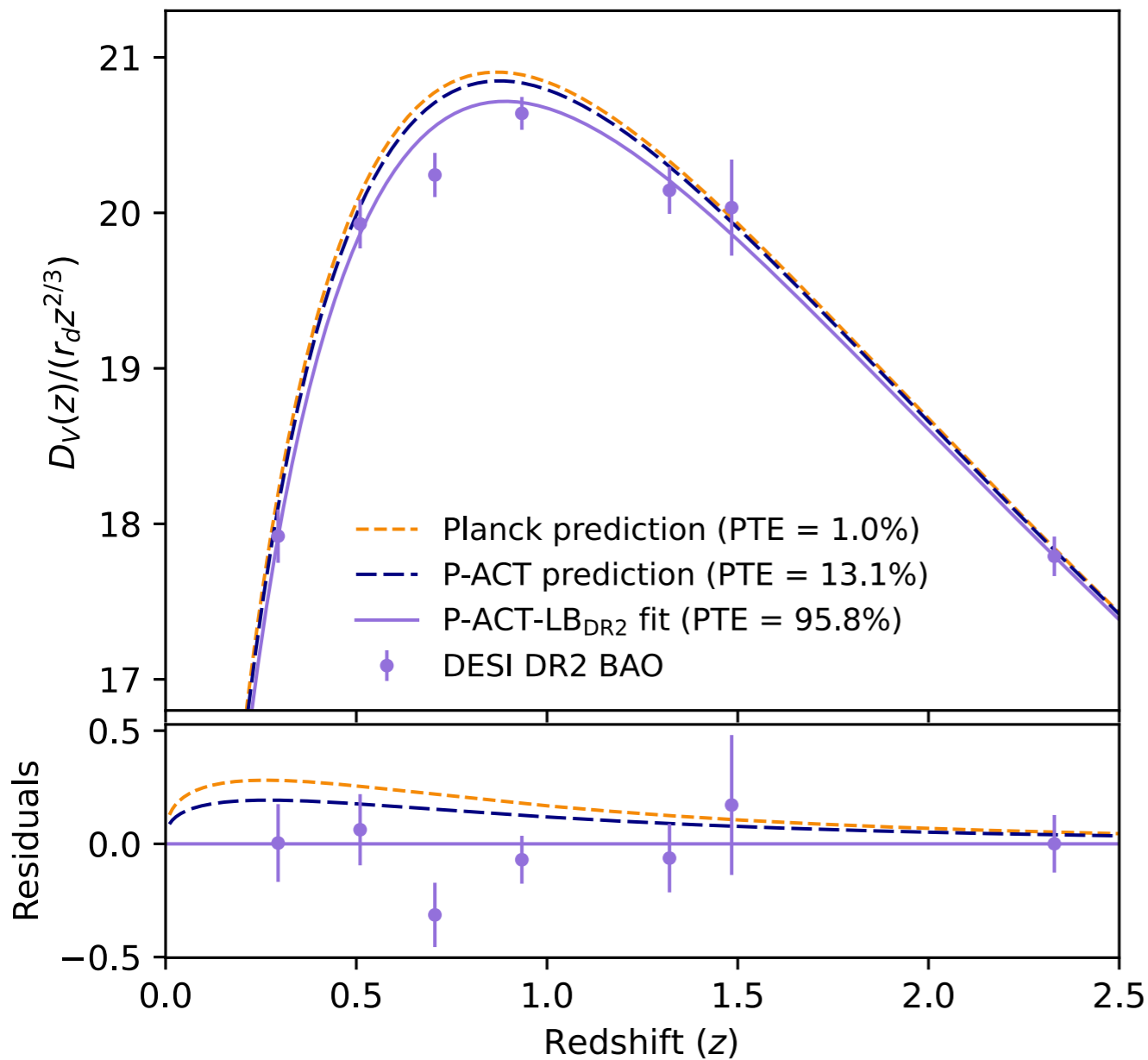
$H_0$  “tension”  
persists

Back to the  
theory  
drawing  
board...

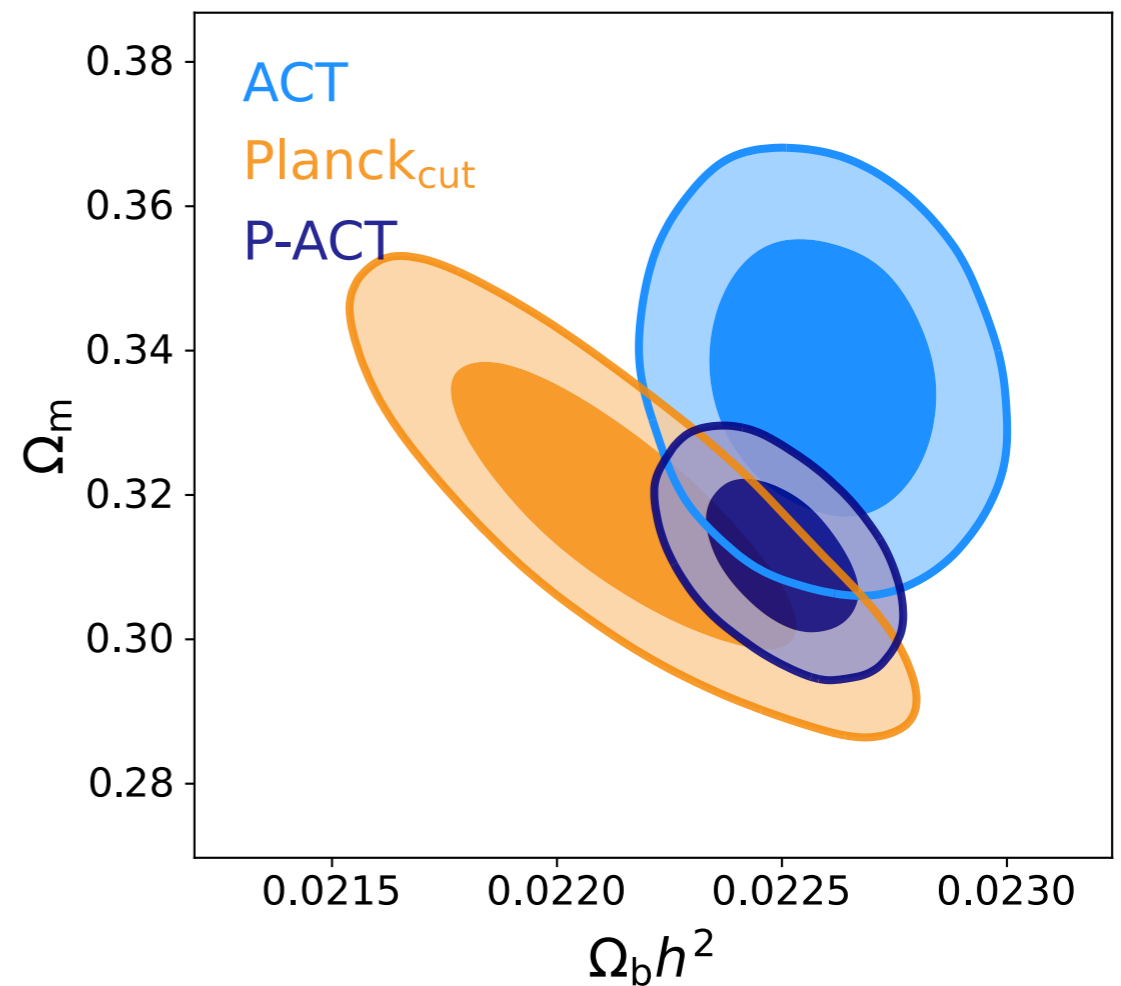
solid = P-ACT-LB  
dashed = P-ACT-LBS

# DESI and Dark Energy

P-ACT  $\Lambda$ CDM agrees well with  
DESI DR2



Why? P-ACT  $\Omega_m$  slightly  
lower than Planck, hence in  
better agreement with DESI



# Aside: $\Omega_m$

Could foregrounds be responsible for a CMB bias toward high  $\Omega_m$ ? (No)

---

---

	<b>TT</b>	<b>TE</b>	<b>EE</b>
	high- $l$ foregrounds	~foreground-free	
<b><math>H_0</math></b>	$68.47 \pm 0.91$	$66.92 \pm 0.76$	$67.6 \pm 1.2$
<b><math>10^2 \Omega_m</math></b>	$30.0 \pm 1.2$	$32.1 \pm 1.2$	$31.6 \pm 1.6$

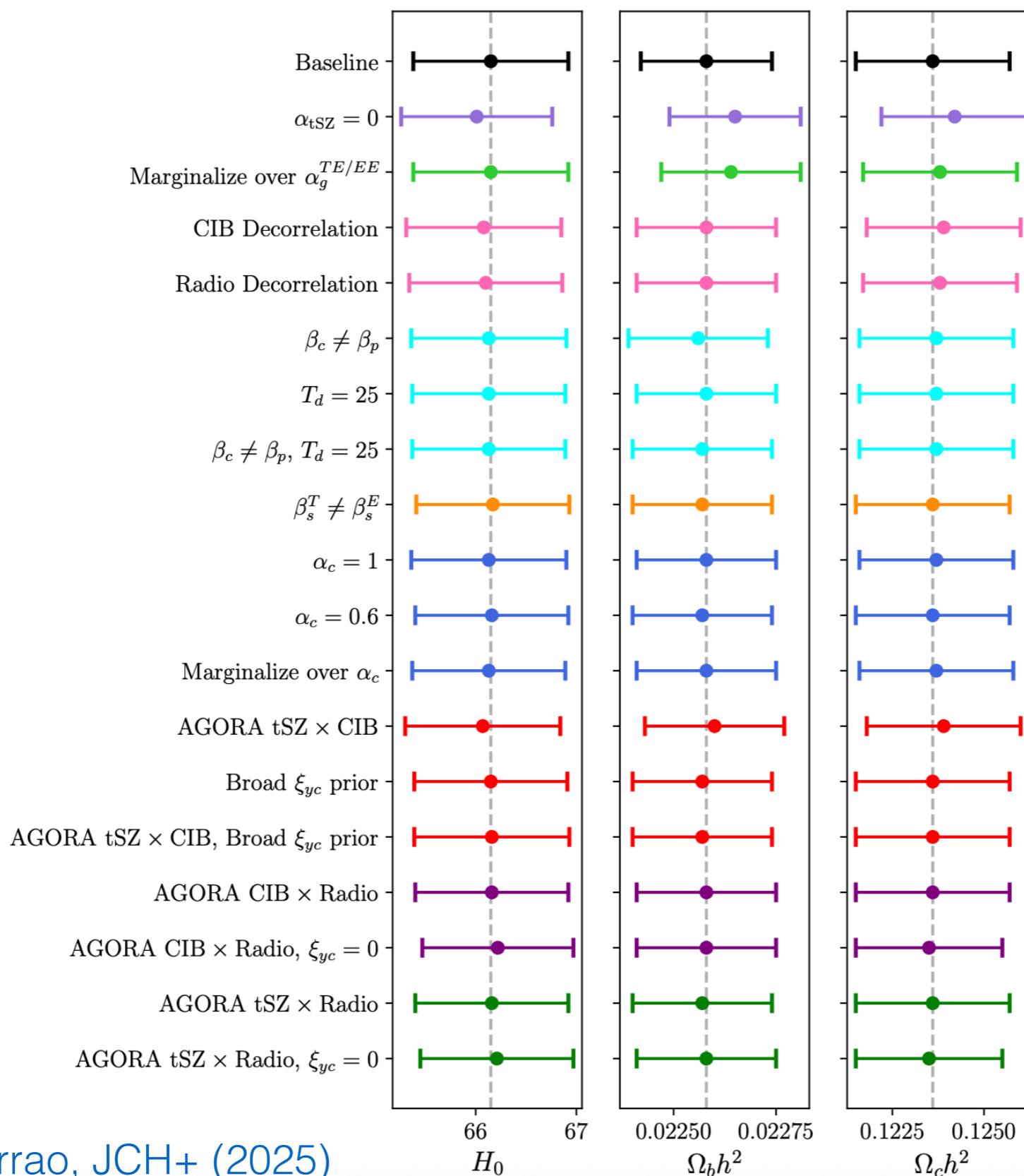
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Could foregrounds be responsible for a CMB bias toward high  $\Omega_m$ ? (No)

Foreground model variations

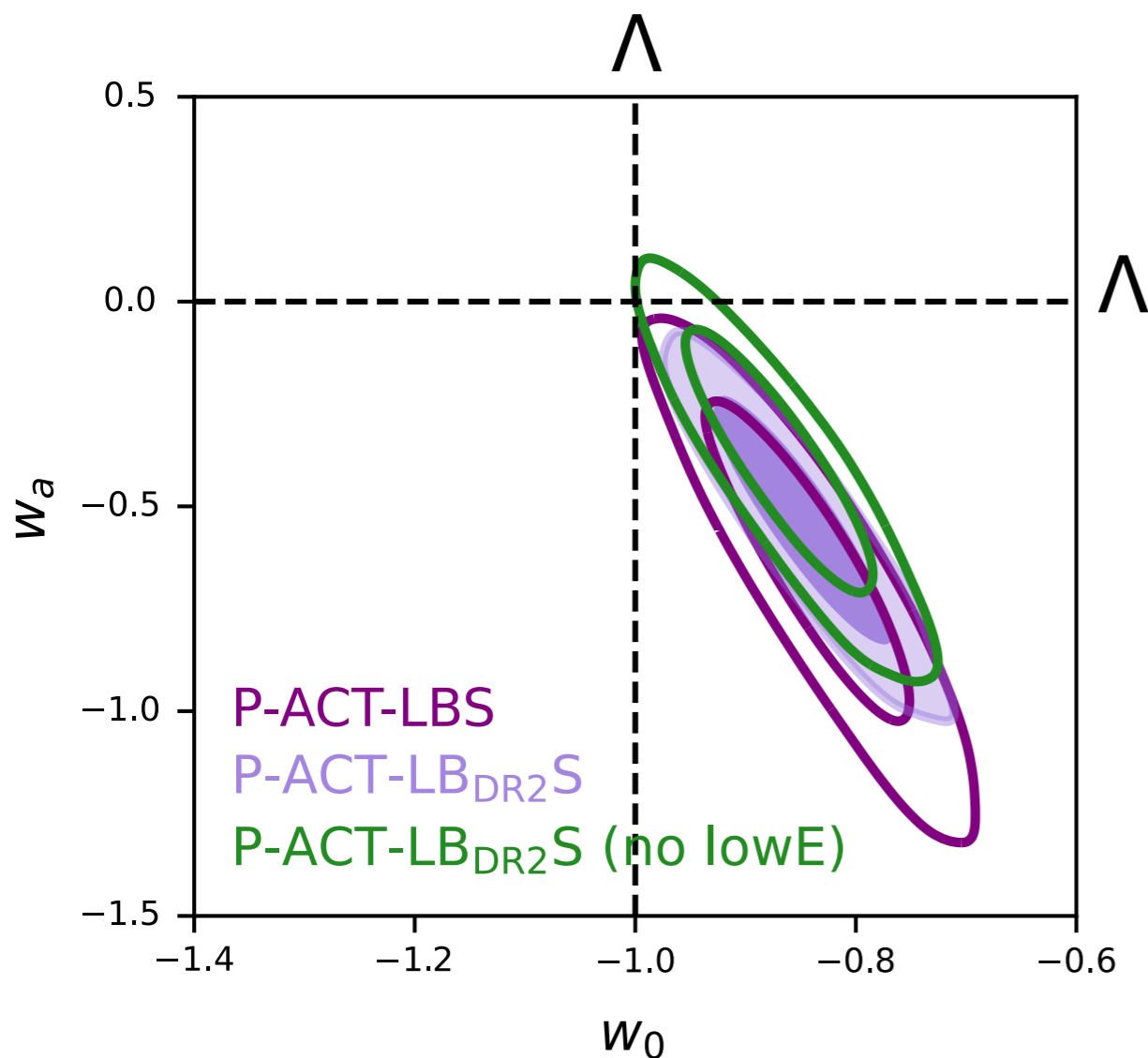


Cosmological parameters are extremely stable under foreground model variations

# DESI and Dark Energy

From P-ACT primary CMB data, we find no evidence for non-standard dark energy; hints of non-standard evolution are driven by low-redshift data

$$w(a) = w_0 + w_a(1 - a)$$



$$\left. \begin{aligned} w_0 &= -0.837 \pm 0.061 \\ w_a &= -0.66^{+0.27}_{-0.24} \end{aligned} \right\} (68\%, \text{ P-ACT-LBS})$$

P-ACT-LBS consistent with  $\Lambda$  at  $2.2\sigma$   
P-ACT-LB<sub>DR2S</sub> consistent with  $\Lambda$  at  $2.4\sigma$

Discarding Planck low- $l$  EE data:  
 $\tau = 0.081 \pm 0.016$   
consistent with  $\Lambda$  at  $\sim 2\sigma$

# Outlook

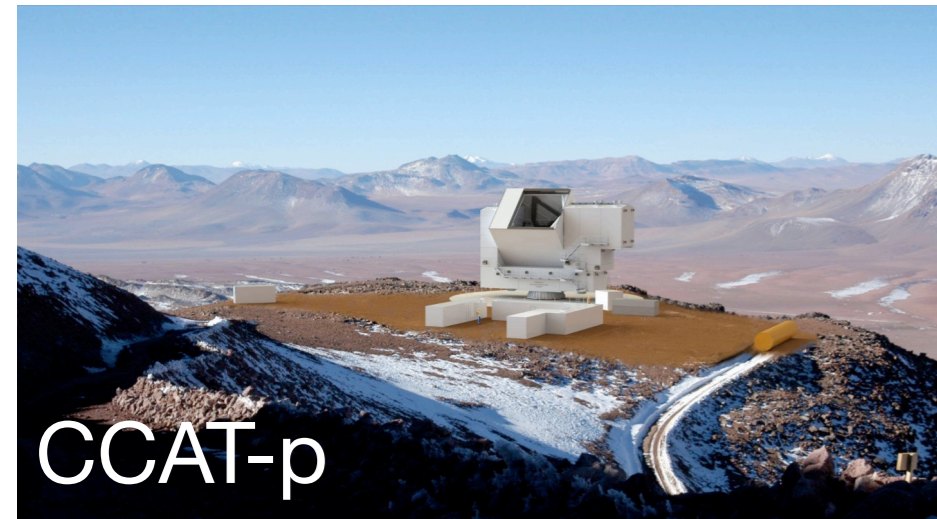


End of ACT

# Landscape



Atacama Cosmology  
Telescope (obs:  
2007-2022)



CCAT-p



South Pole Telescope

Photo Credit: Daniel Luong-Van



Simons Observatory  
Large Aperture  
Telescope



SO obs: **now-2034**

Simons Observatory  
Small Aperture  
Telescopes

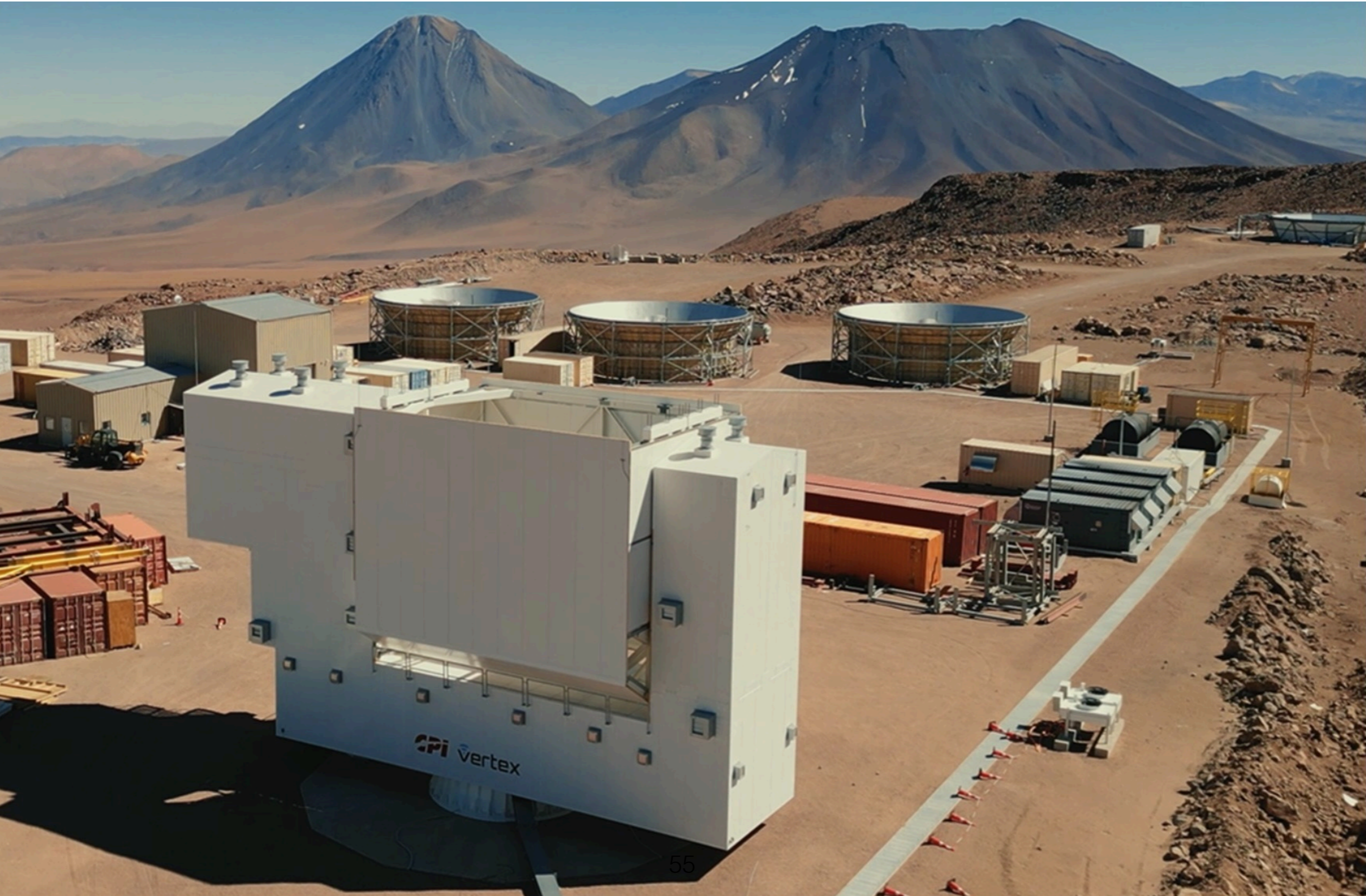


BICEP/Keck

*P5 Report: "A transformative **next-generation CMB experiment** [...] will plumb the secrets of the primordial universe during and immediately after a period of rapid expansion; it should reveal signatures of new physics at energies far beyond the reach of colliders."*

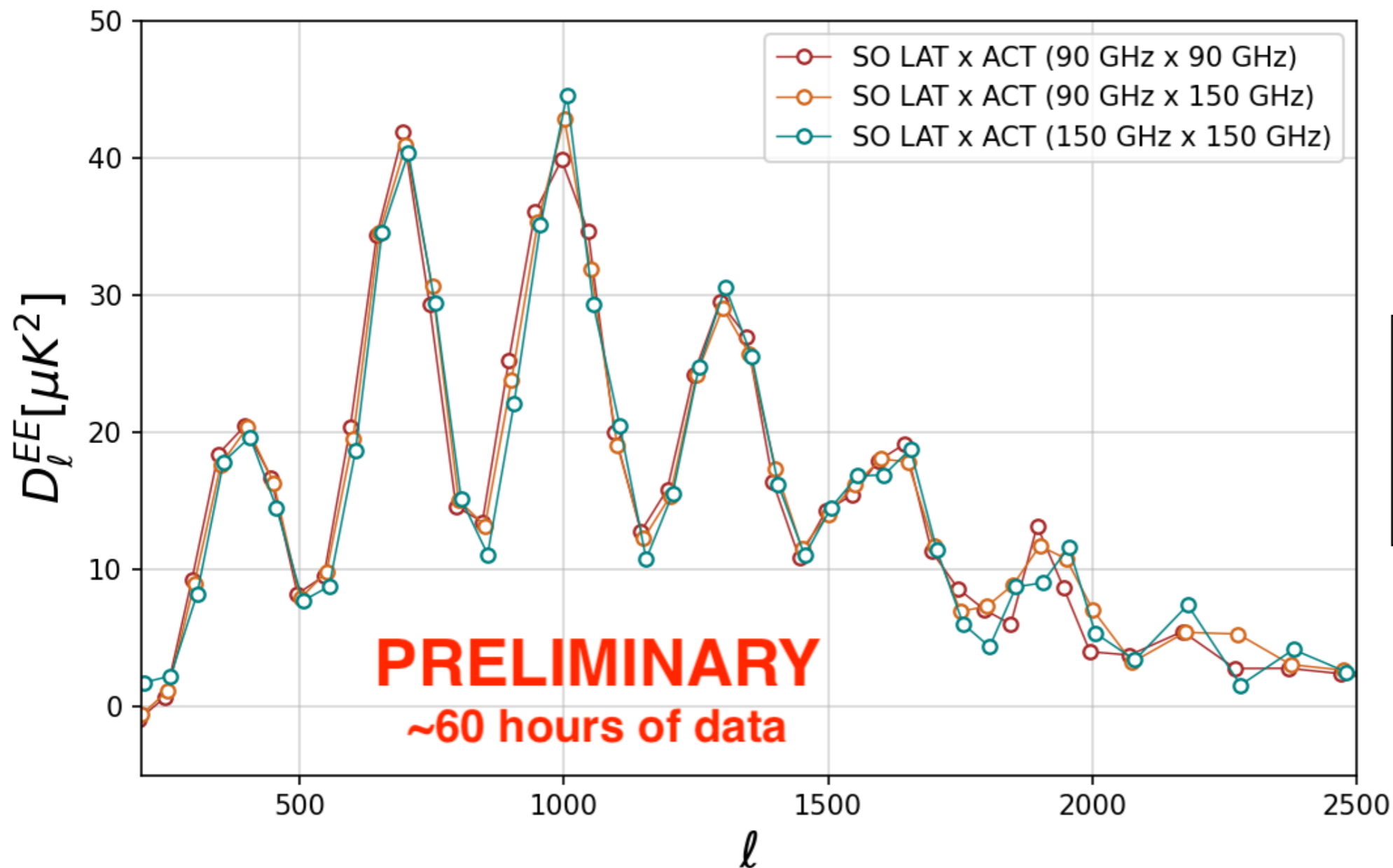
# Simons Observatory: Now

Colin Hill  
Columbia



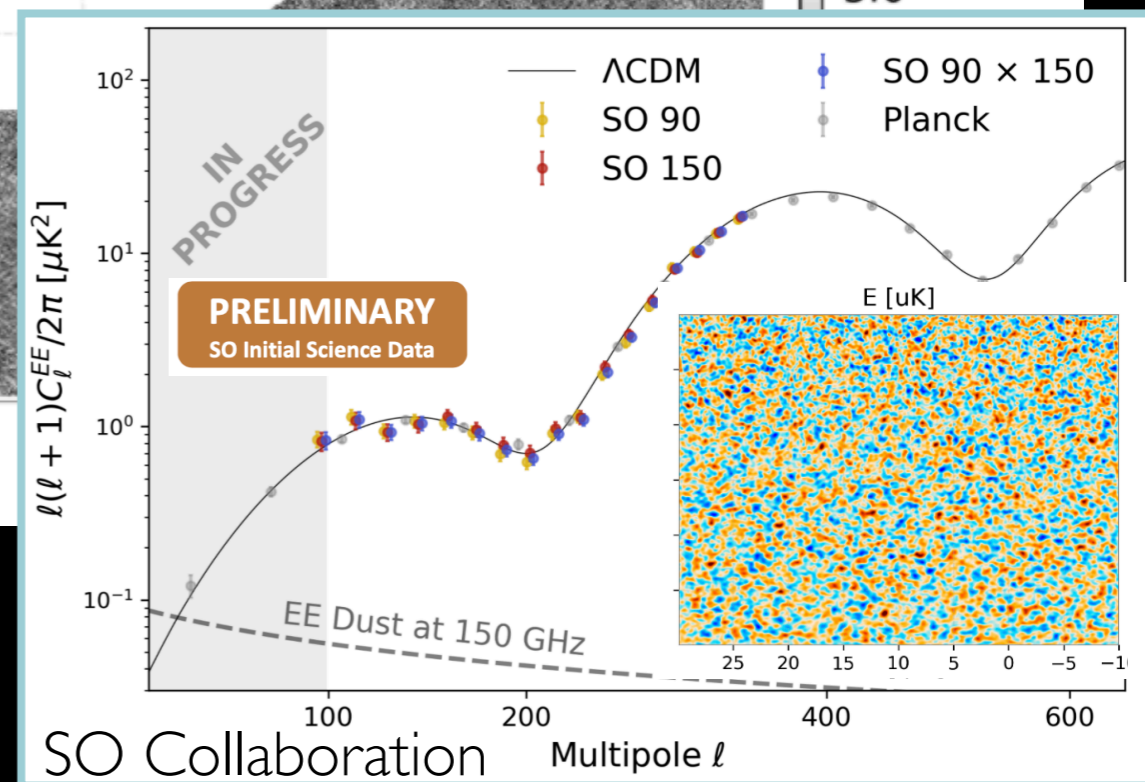
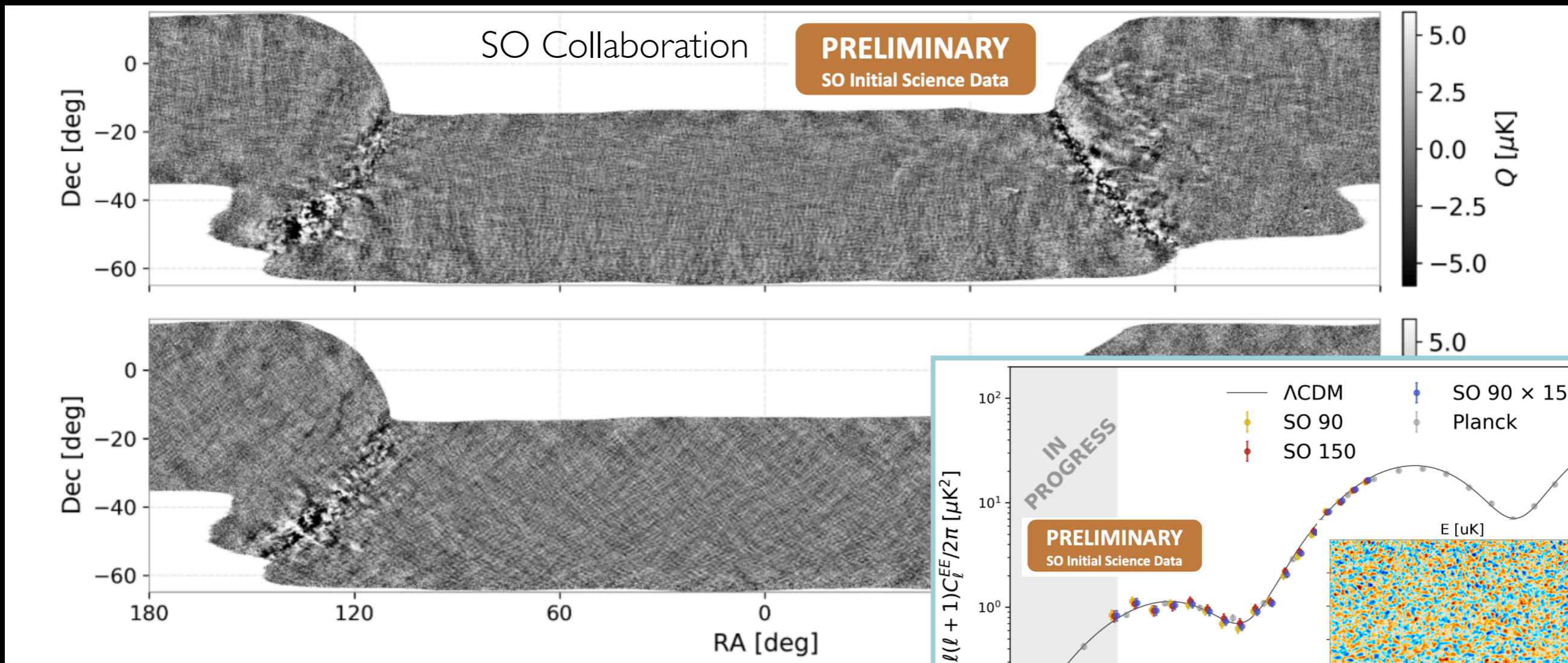
# Simons Observatory: Now

Colin Hill  
Columbia



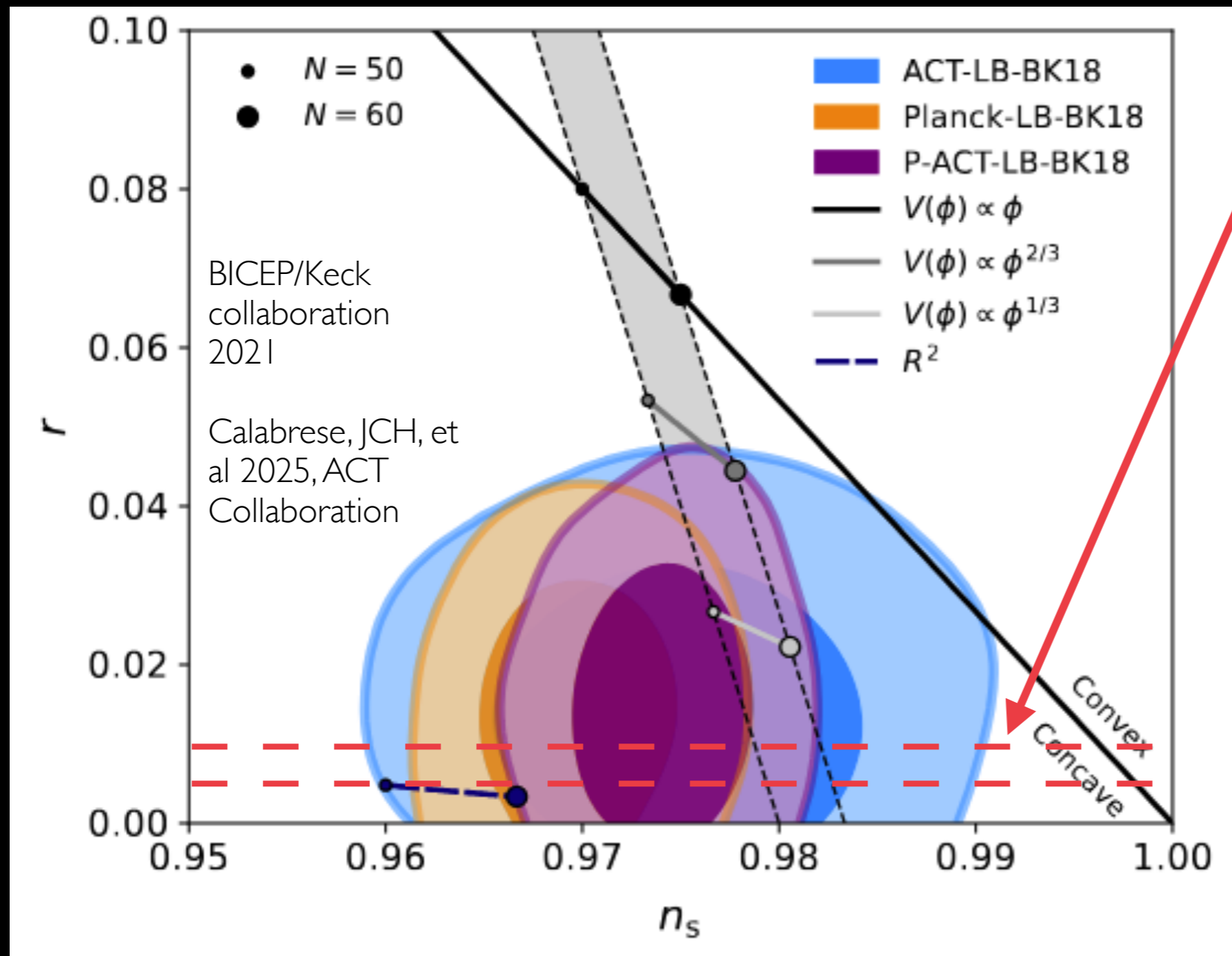
SO projection  
[~2034]:  
 $\sigma(N_{\text{eff}}) \sim 0.045$

# Simons Observatory: Small Aperture Telescopes (SATs)



SO detectors are exceeding baseline specifications  
A key enabling technology: rotating half-wave plates  
Target depth is  $\sim 1 \mu\text{K-arcmin}$  for  $f_{\text{sky}} \sim 0.1$

# Seeking a detection of the inflationary energy scale



SO's goal detection levels:  
 $r=0.01$  in 4 yrs w 3 SATs ( $\sigma(r) = 0.002-3$ )  
 $r=0.005$  in 10 yrs w 6 SATs ( $\sigma(r) = 0.001$ )

Similar progress on  $r$  is anticipated from South Pole

*If we detect something, we will want to map out as much of the B-mode field as possible, and check that it behaves as expected.*

# Outlook

- 1) ACT DR6 provides a stringent new test of the cosmological model:  $\Lambda$ CDM continues to succeed
- 2) P-ACT yields the tightest constraints on a wide range of BSM scenarios in cosmology. Many previously-viable new-physics scenarios (e.g., those aiming to resolve the  $H_0$  tension) are now severely constrained
- 3) The next decade will bring a torrent of incredible CMB data (SO++), with even higher sensitivity to new physics — stay tuned!

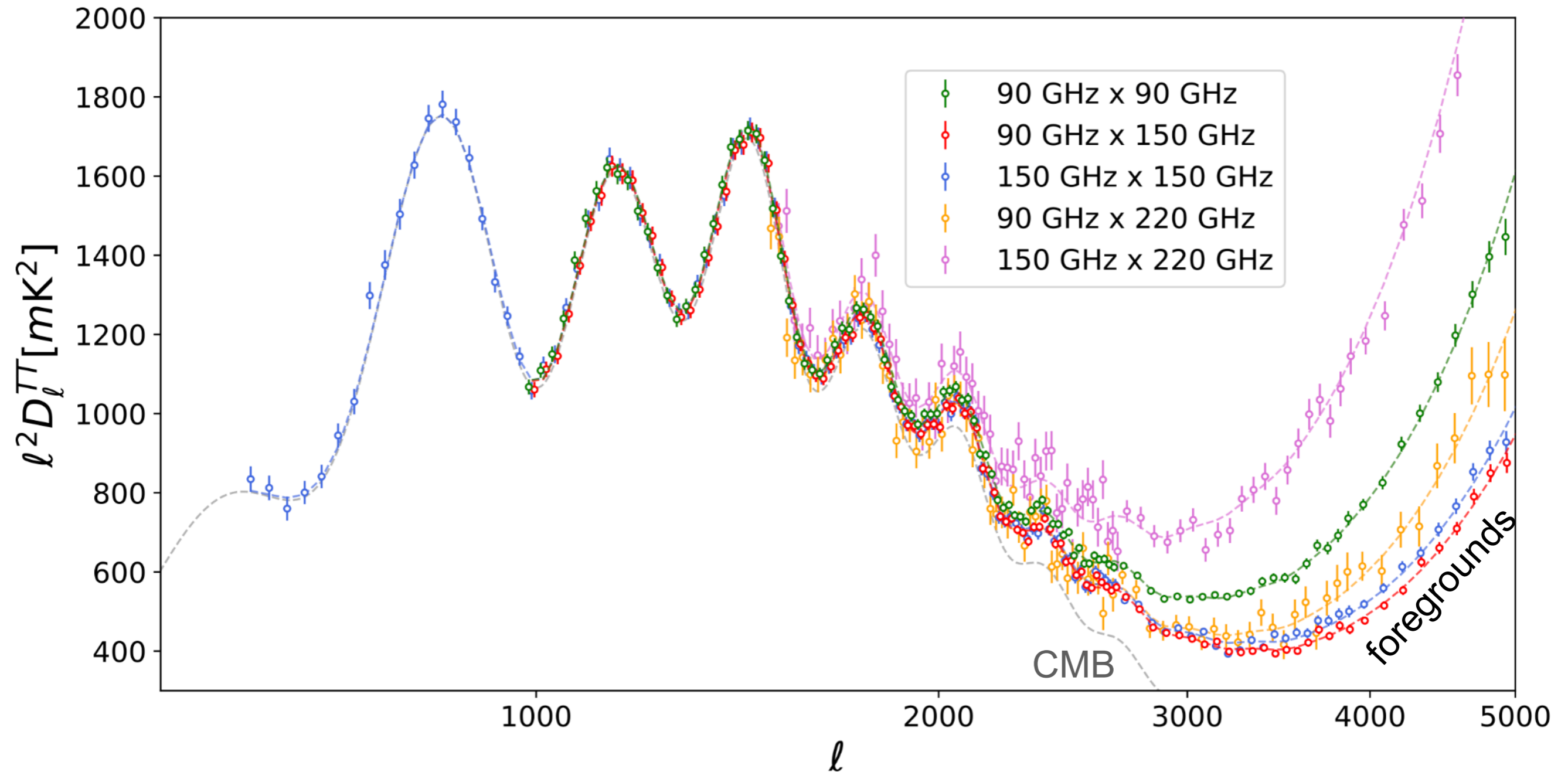
# Bonus

# Multifrequency Power Spectra

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Columbia

The CMB is not the only astrophysical signal that we observe

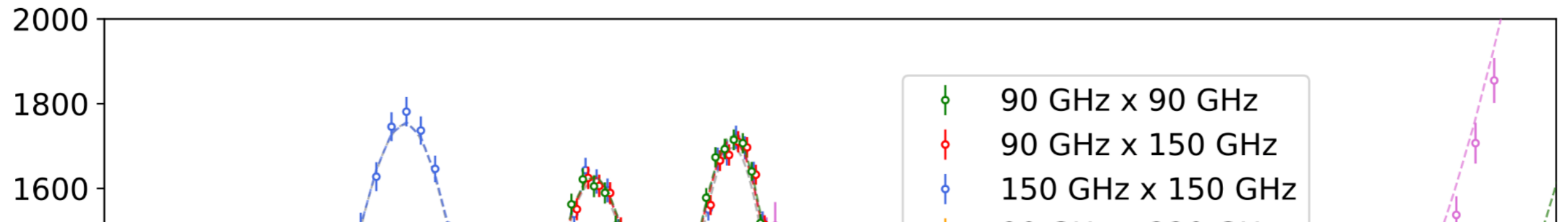
Foregrounds distinguished by non-blackbody frequency dependence



# Multifrequency Power Spectra

The CMB is not the only astrophysical signal that we observe

Foregrounds distinguished by non-blackbody frequency dependence



Foregrounds are fit with a multi-component model comprising 14 free parameters (10 in TT, 2 each in TE/EE)

One new parameter w.r.t. previous work: shape of the thermal SZ power spectrum (constrained at  $3\sigma$ )



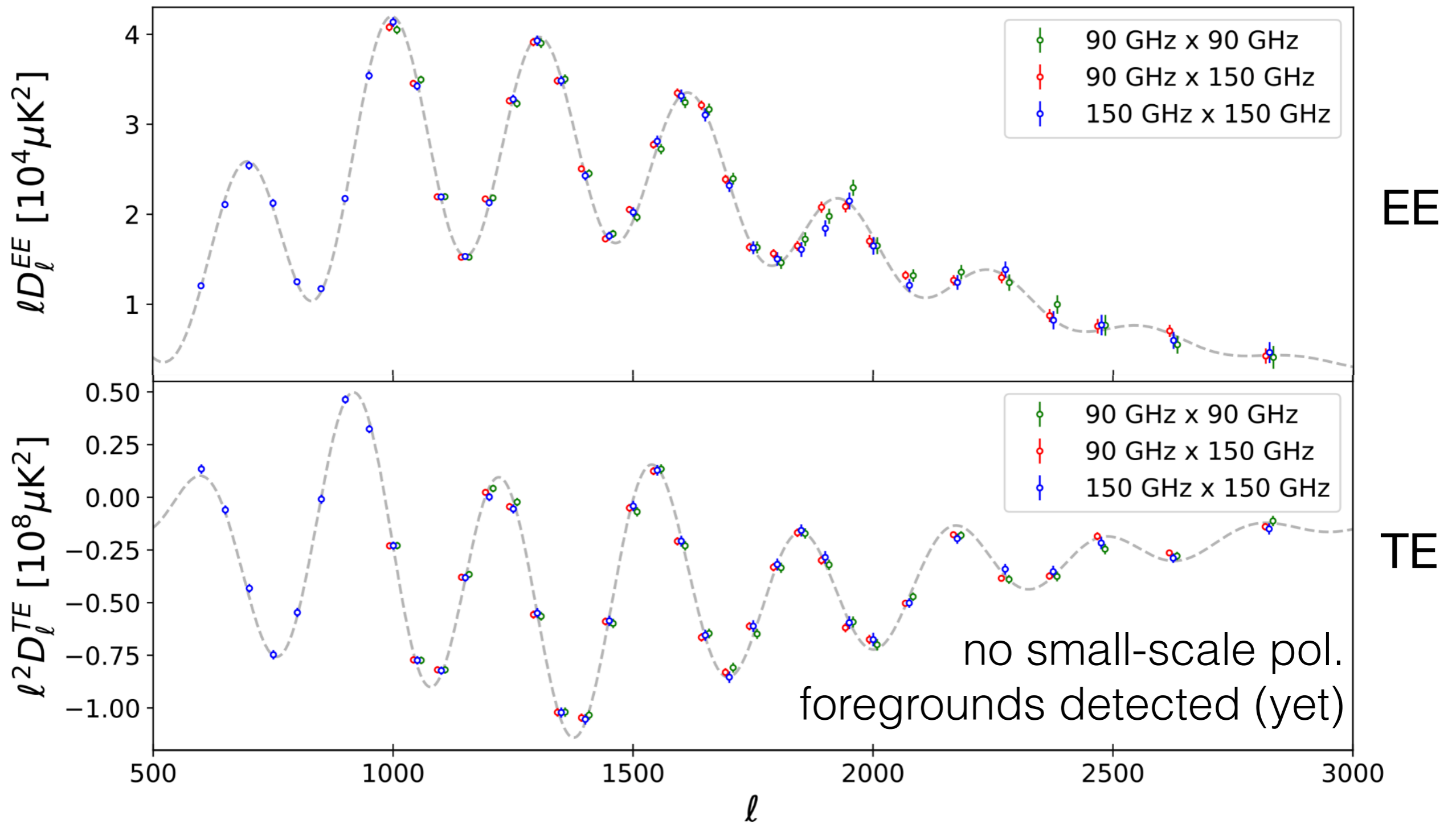
Louis, La Posta, Atkins, Jense, et al. (2025), 2503.14452

Beringue, Surrao, JCH, et al. (2025), 2506.06274

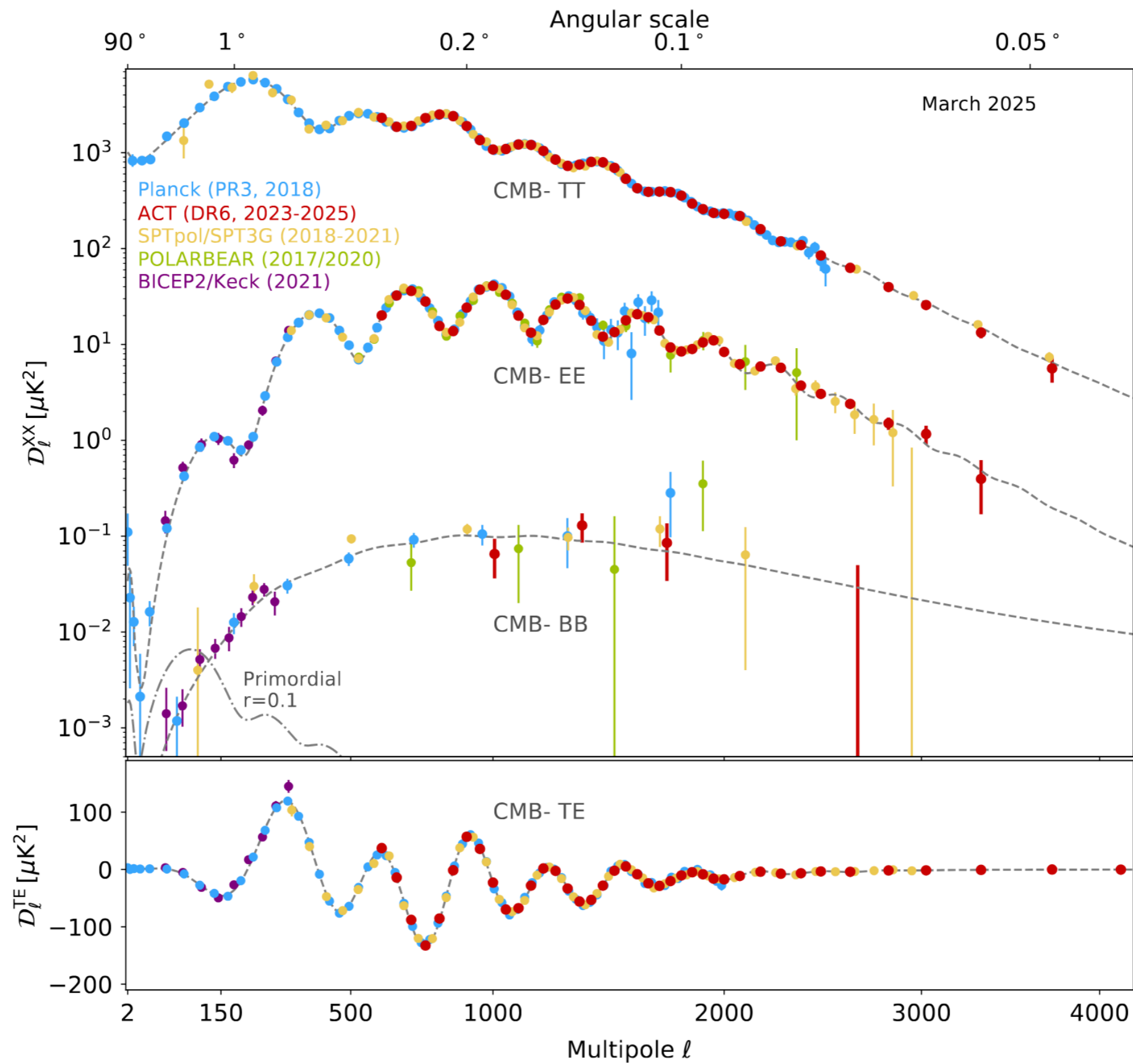
# Multifrequency Power Spectra

Colin Hill  
Columbia

Foregrounds are significantly smaller in TE and EE power spectra



# CMB: State of the Art

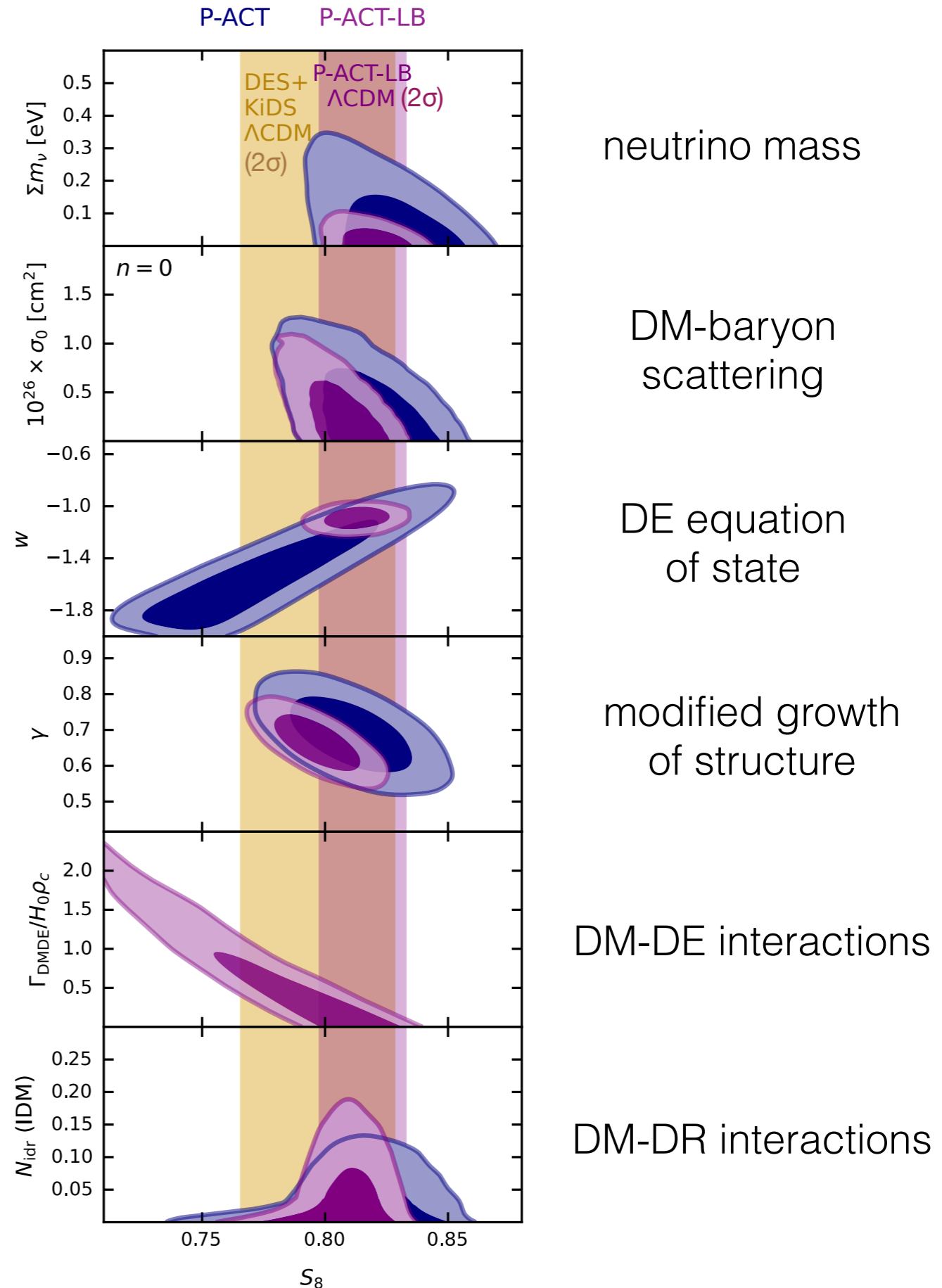


# Cosmological Concordance

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Columbia

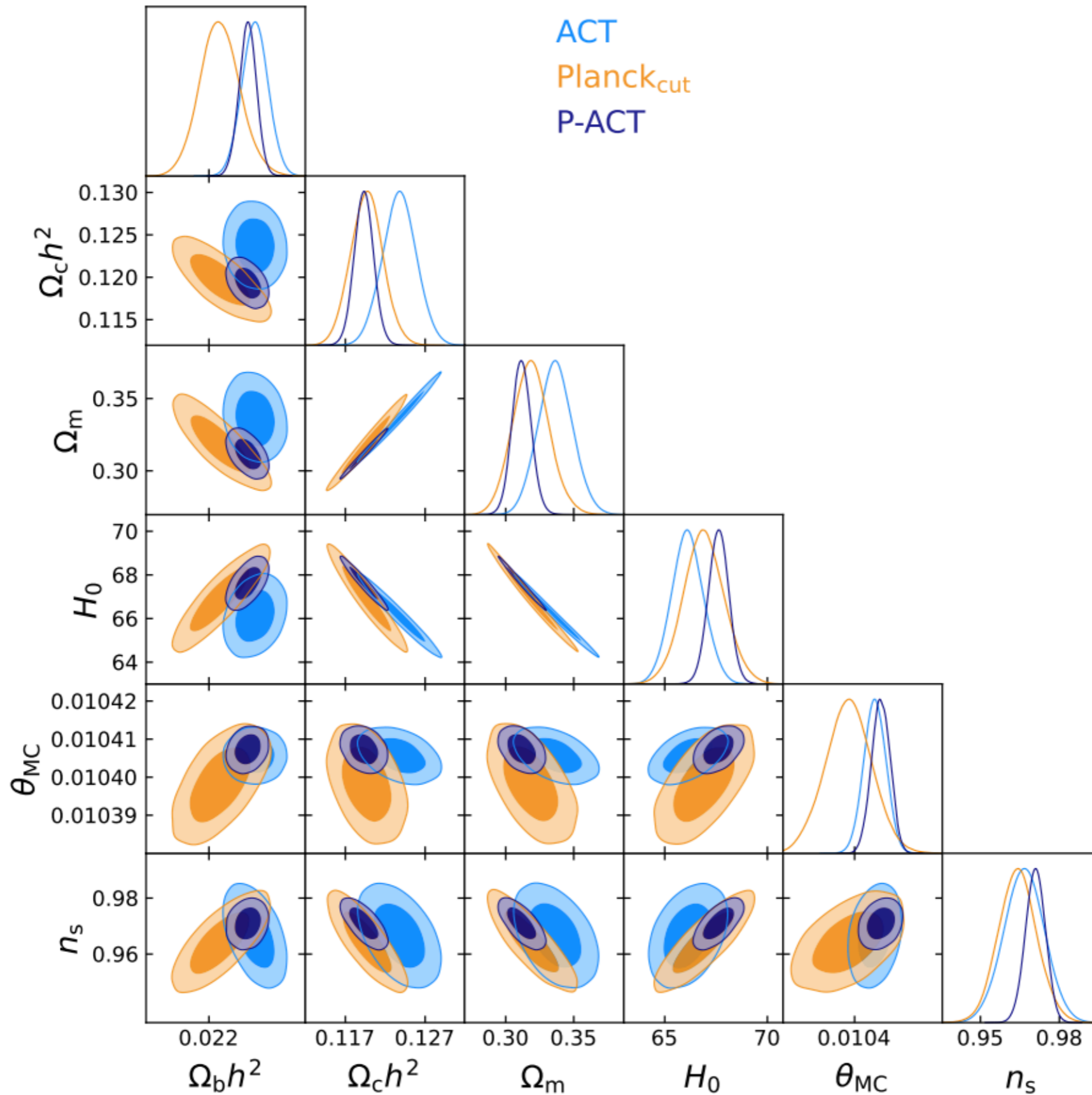
Also no evidence for models aiming to decrease  $S_8$  (late-time fluctuation amplitude)

— but no significant tension is seen in  $\Lambda$ CDM for this parameter between our CMB-driven constraints and those from the DES+KiDS weak lensing surveys



# P-ACT vs. ACT, Planck

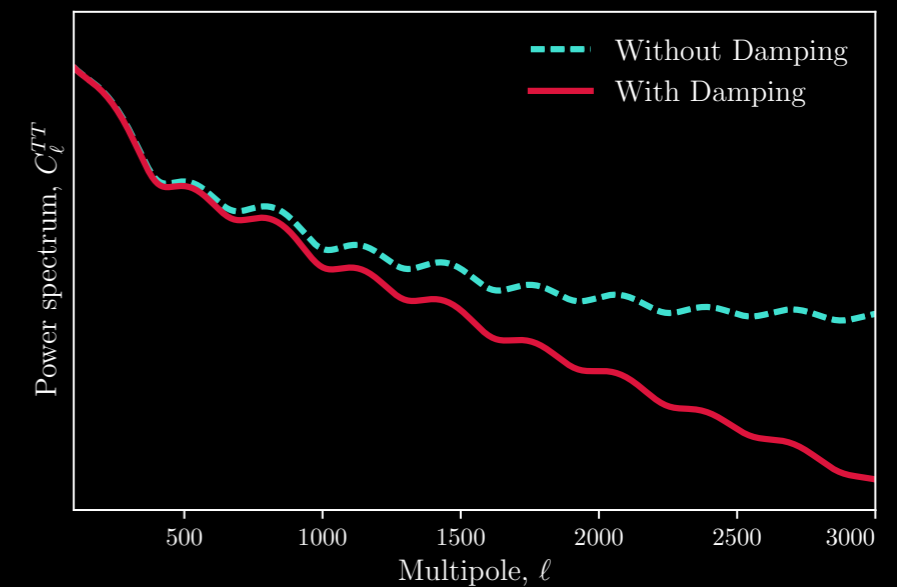
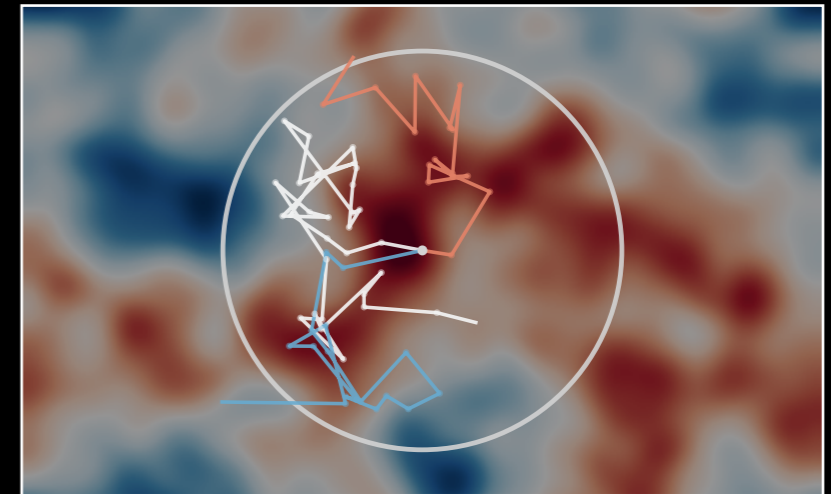
Colin Hill  
Columbia



# Imprints of $N_{\text{eff}}$ on the CMB

- Small-scale CMB is damped by photon diffusion
  - Scale is set by photon diffusion length

$$D \sim 1/\sqrt{n_e \sigma_T H}$$



**Qualitative** illustration of diffusion damping

# Imprints of $N_{\text{eff}}$ on the CMB

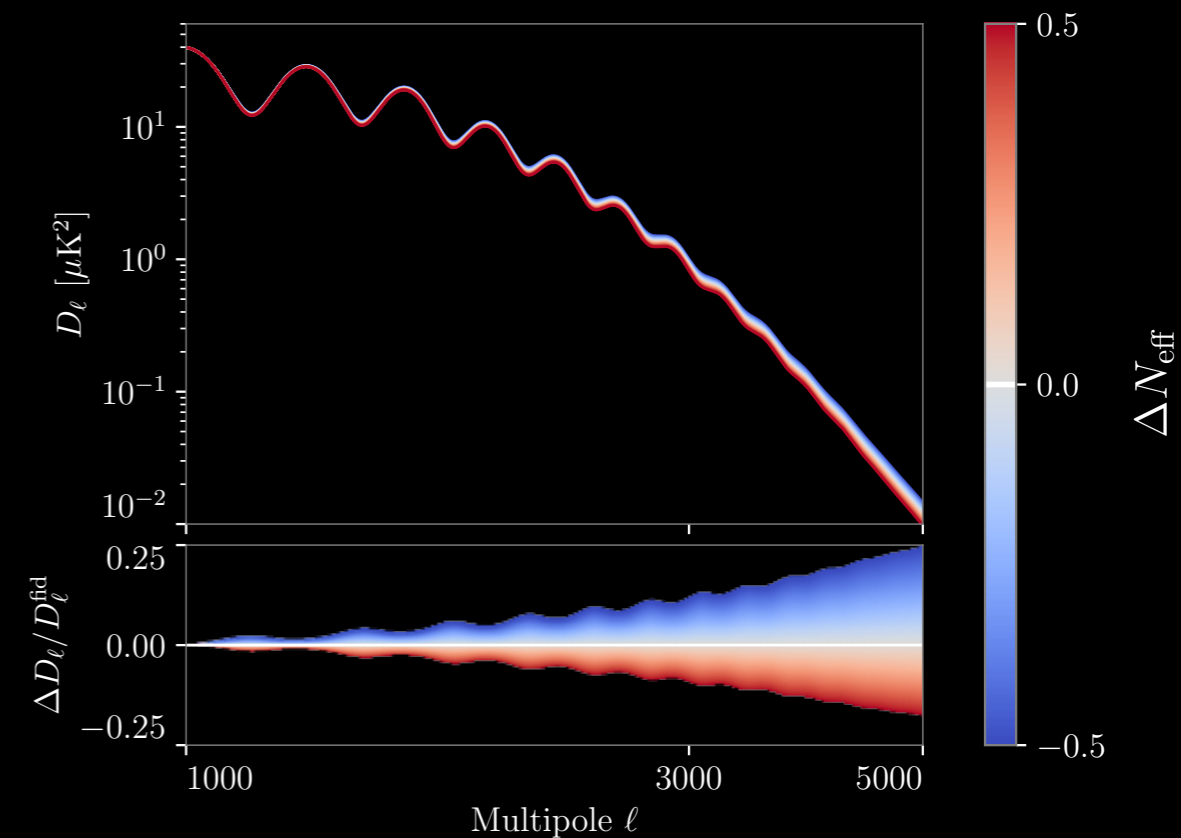
- Small-scale CMB is damped by photon diffusion
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$$D \sim 1/\sqrt{n_e \sigma_T H}$$

- Hubble param. depends on radiation density:

$$H \sim \sqrt{\rho_{\text{rad}}}$$

- $N_{\text{eff}}$  impacts damping tail of the CMB\*



Impact of  $N_{\text{eff}}$  on  $C_\ell^{EE}$

\*  $N_{\text{eff}}$  also introduces a phase shift in the BAO (see, e.g., [Bashinsky & Seljak 04](#), [Baumann++17](#))

# Imprints of $N_{\text{eff}}$ on the CMB

- Small-scale CMB is damped by photon diffusion
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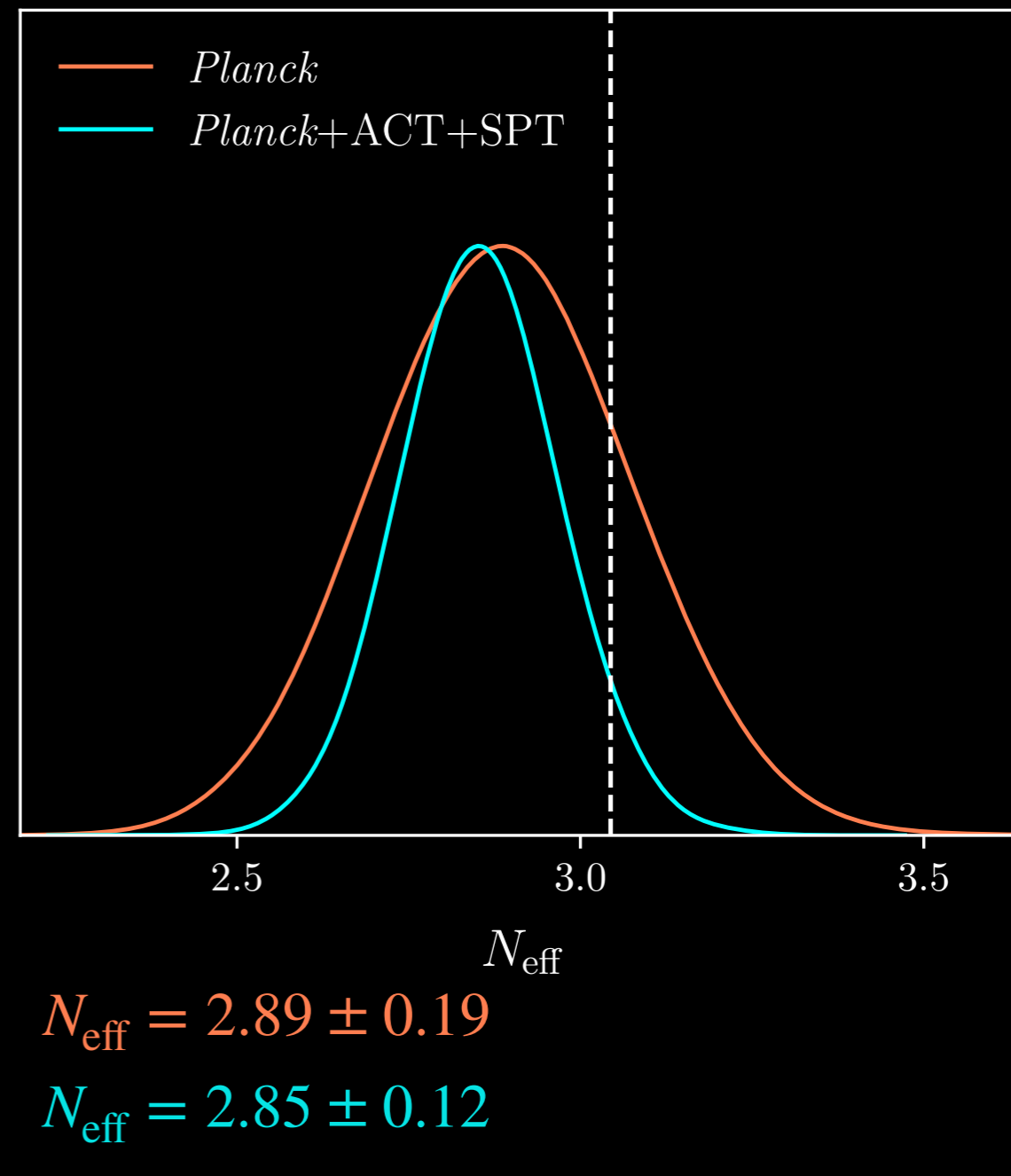
$$H \sim \sqrt{\rho_{\text{rad}}}$$

- $N_{\text{eff}}$  impacts damping tail of the CMB\*

- **ACT DR6 significantly improved  $N_{\text{eff}}$  bounds**

\*

$N_{\text{eff}}$  also introduces a phase shift in the BAO (see, e.g., [Bashinsky & Seljak 04](#), [Baumann++17](#))



# Astrophysical determinations of $N_{\text{eff}}$

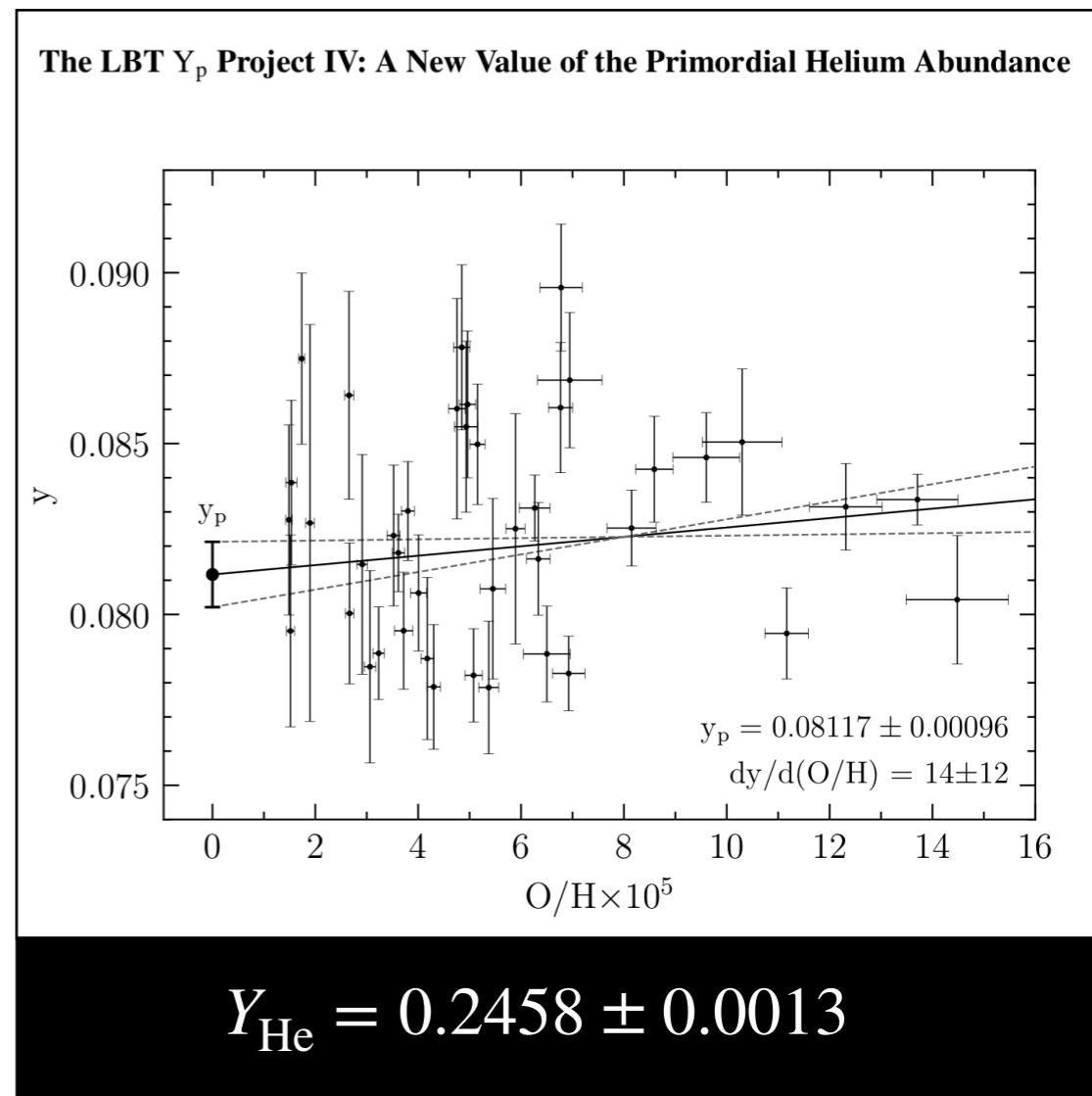
- Primordial helium fraction ( $Y_{\text{He}} \equiv \rho_{\text{He}}/\rho_b$ ) is sensitive to  $N_{\text{eff}}$
- LBT Yp Project: new measurement this year

- YHe+D+BBN:  $N_{\text{eff}} \approx 3.000 \pm 0.092$

- Including *Planck* CMB:

$$N_{\text{eff}} \approx 2.965 \pm 0.082$$

- Leading constraint at the time
  - Did not include small-scale CMB data



[Skillman++26](#), [Rogers++26](#), [Weller++26](#), [Aver++26](#), [Yeh++26](#)

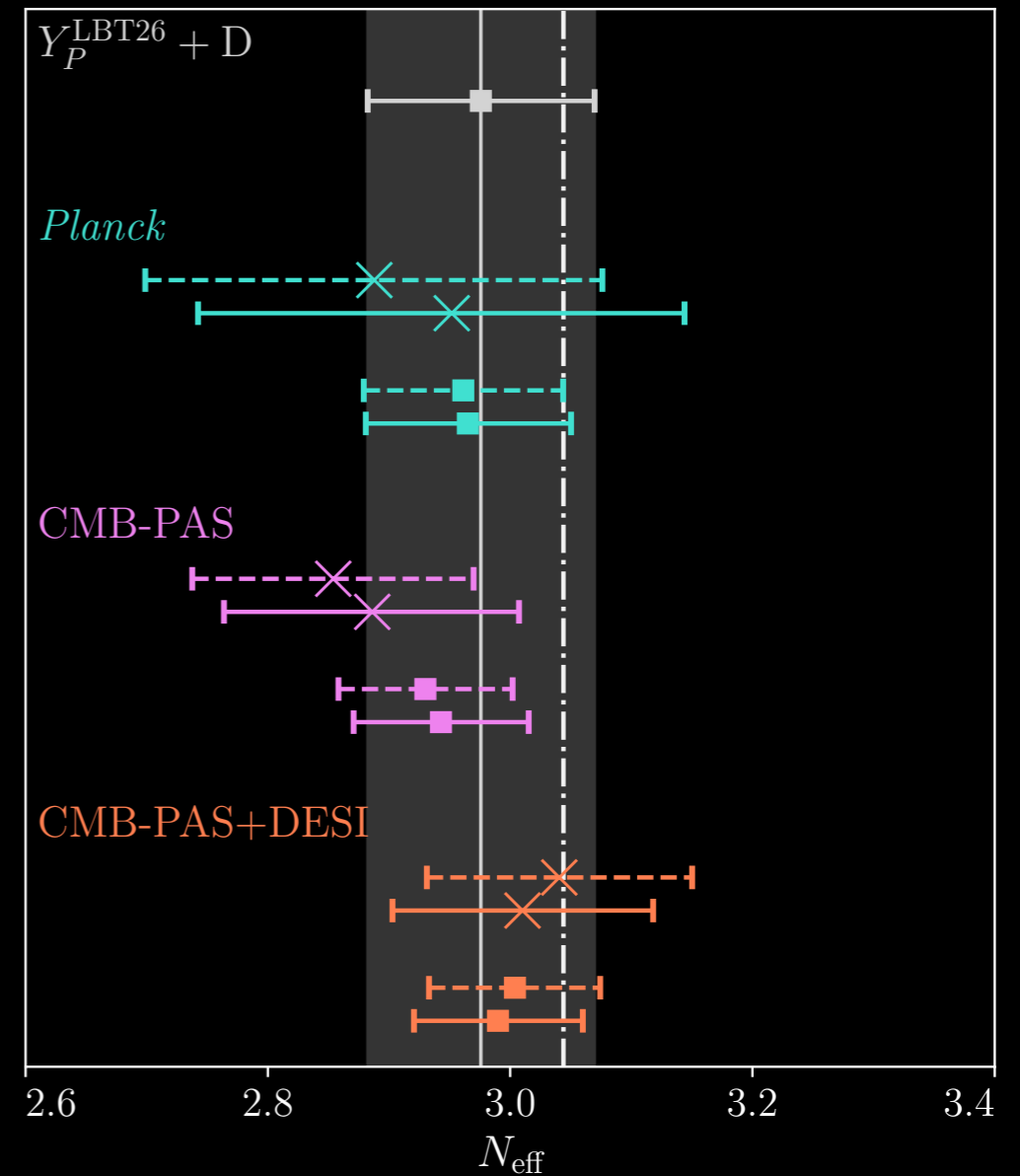
# A 2% constraint on $\Delta N_{\text{eff}}$

- Combining with CMB and BAO

$$N_{\text{eff}} = 2.990 \pm 0.070$$

- Tightest constraint to date by 15%
- Consistent with standard model
$$H_0 = 68.16 \pm 0.50 \text{ km/s/Mpc}$$
- Consistency across different probes

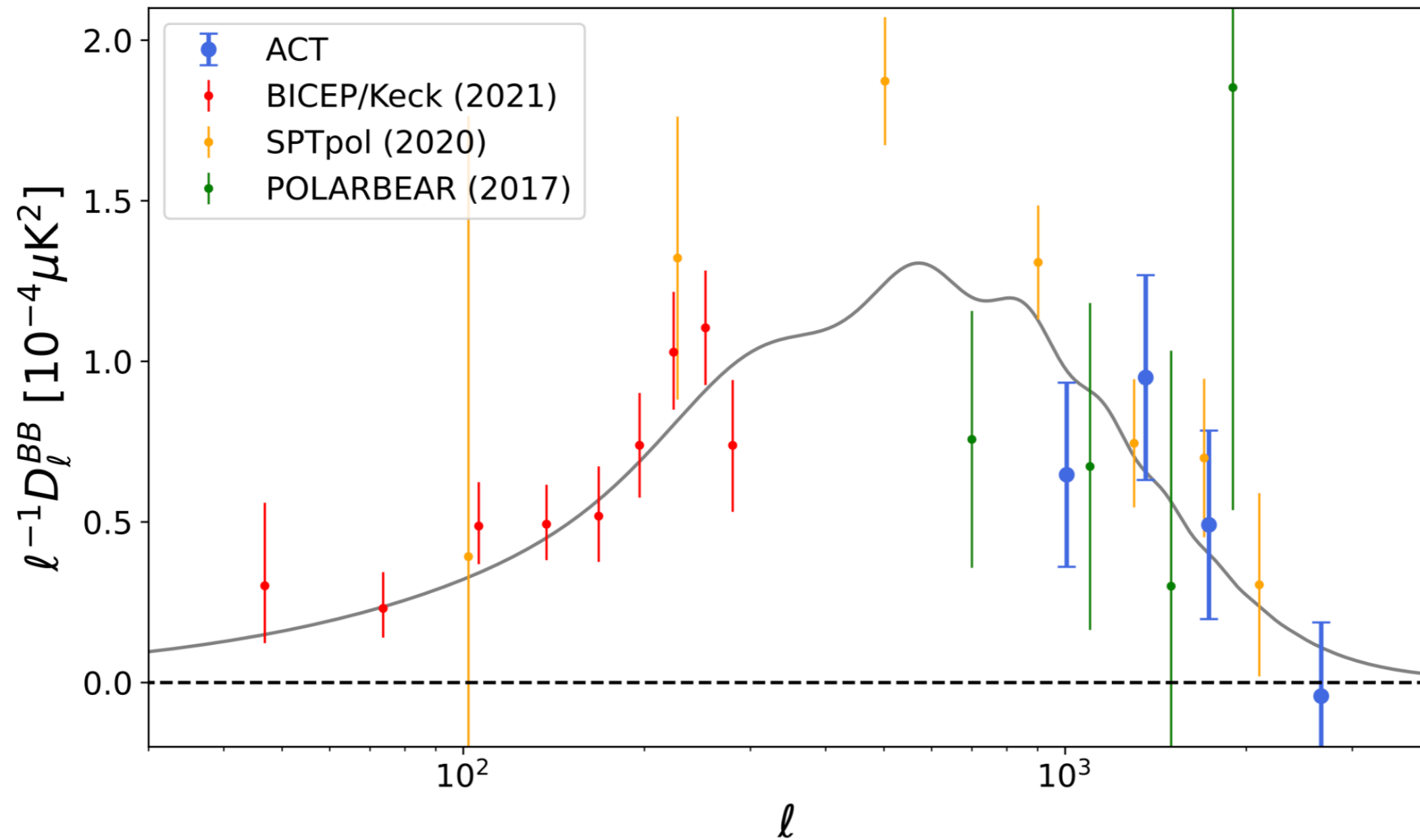
Legend:  
|-----| With low- $\ell$  EE      |-----| Without low- $\ell$  EE  
|-----■-----| With  $Y_P^{\text{LBT}26} + \text{D}$       |-----X-----| Without  $Y_P^{\text{LBT}26} + \text{D}$



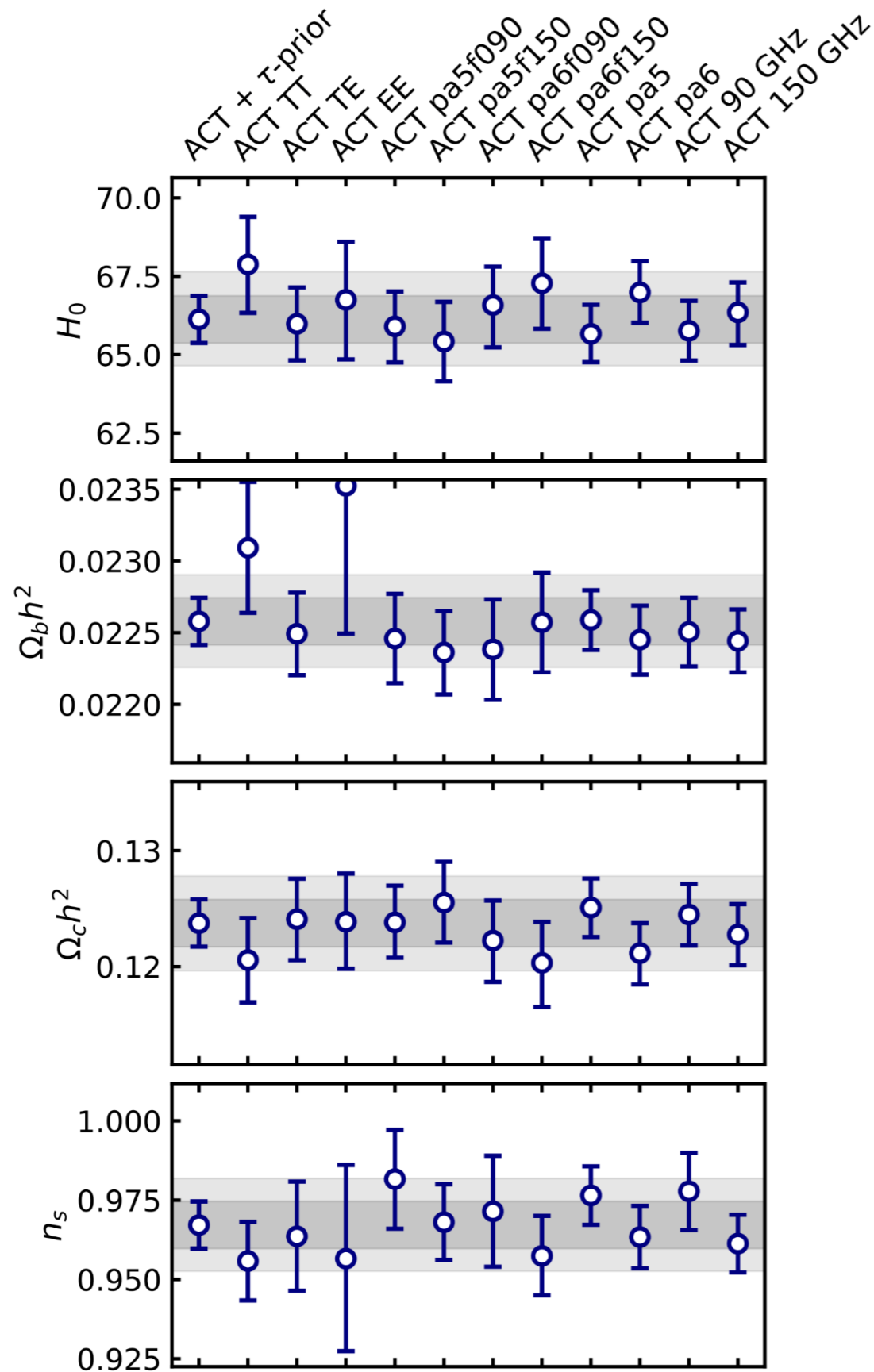
Goldstein & Hill, 2026  
Submitted to PRD

# B-Mode Power Spectrum

$\sim 4\sigma$  evidence for BB power sourced by gravitational lensing



# Parameter Stability



Breakdown of  $\chi^2$  for P-ACT fit in  $\Lambda$ CDM:

TT:

- ACT: 566.05/601
- Planck: 89.05/114

TE:

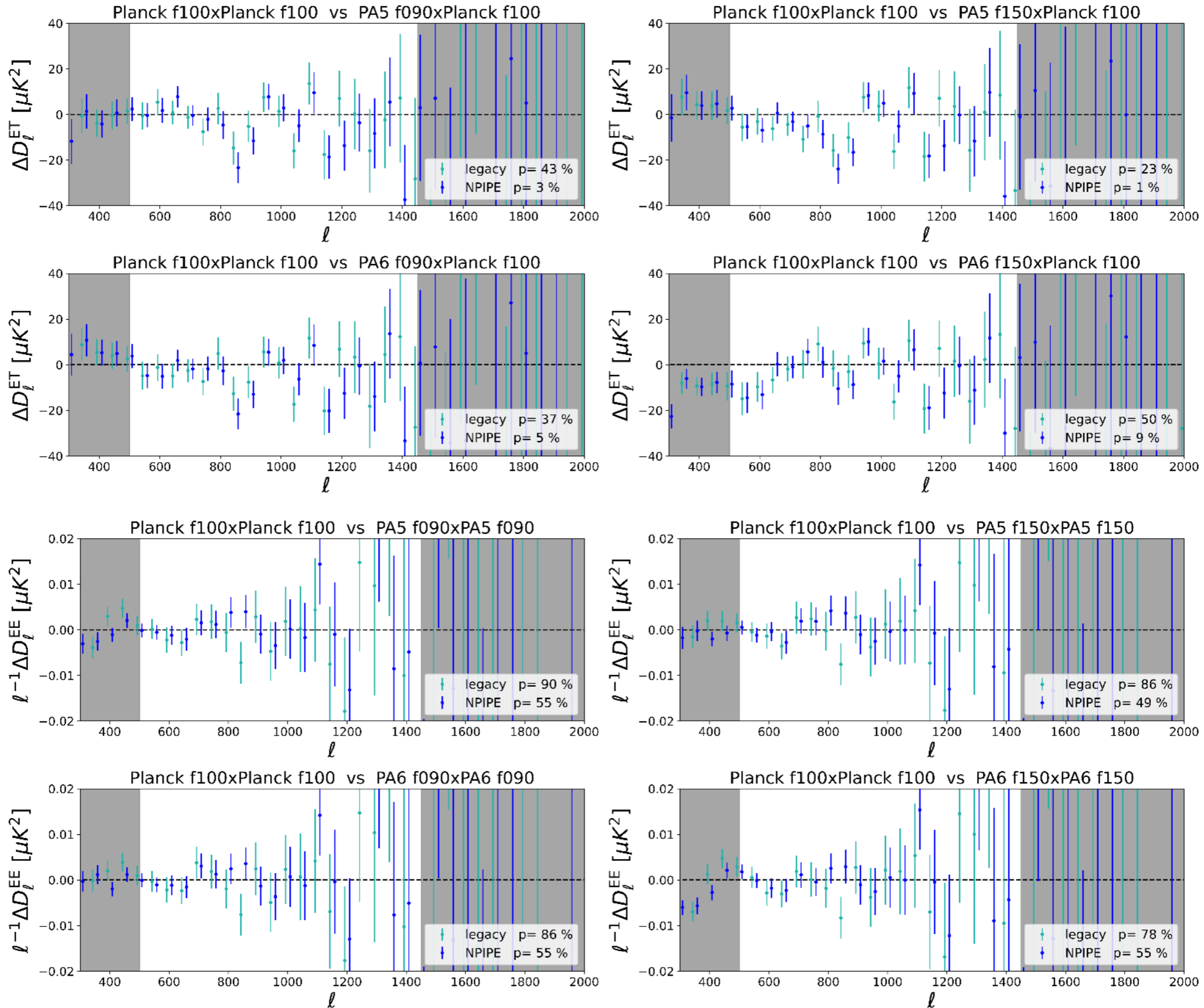
- ACT: 651.77/644
- Planck: 67.82/69

EE:

- ACT: 392.19/406
- Planck: 68.93/69

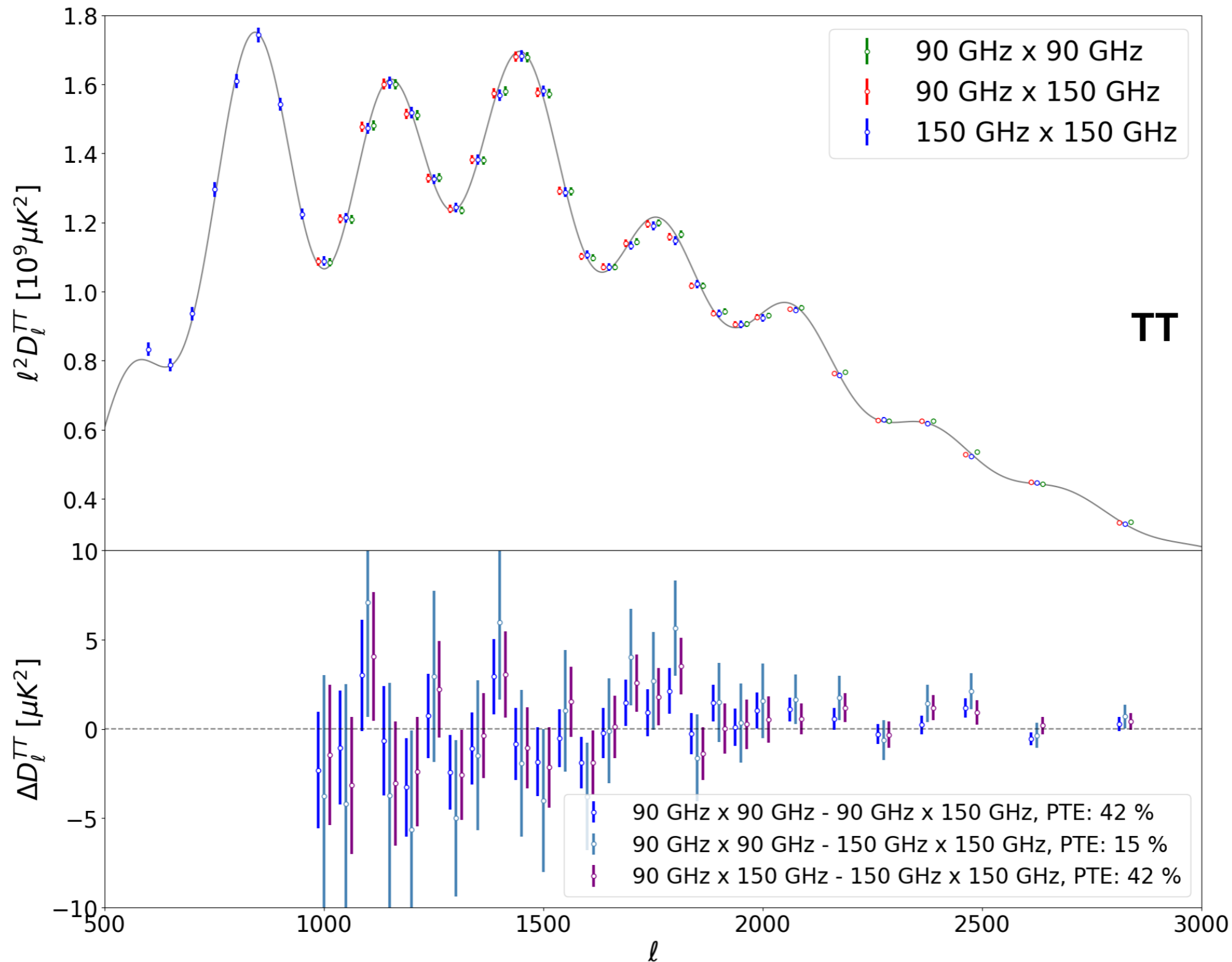
# ACT and Planck on same patch of sky

Colin Hill  
Columbia



# Foreground Model Robustness

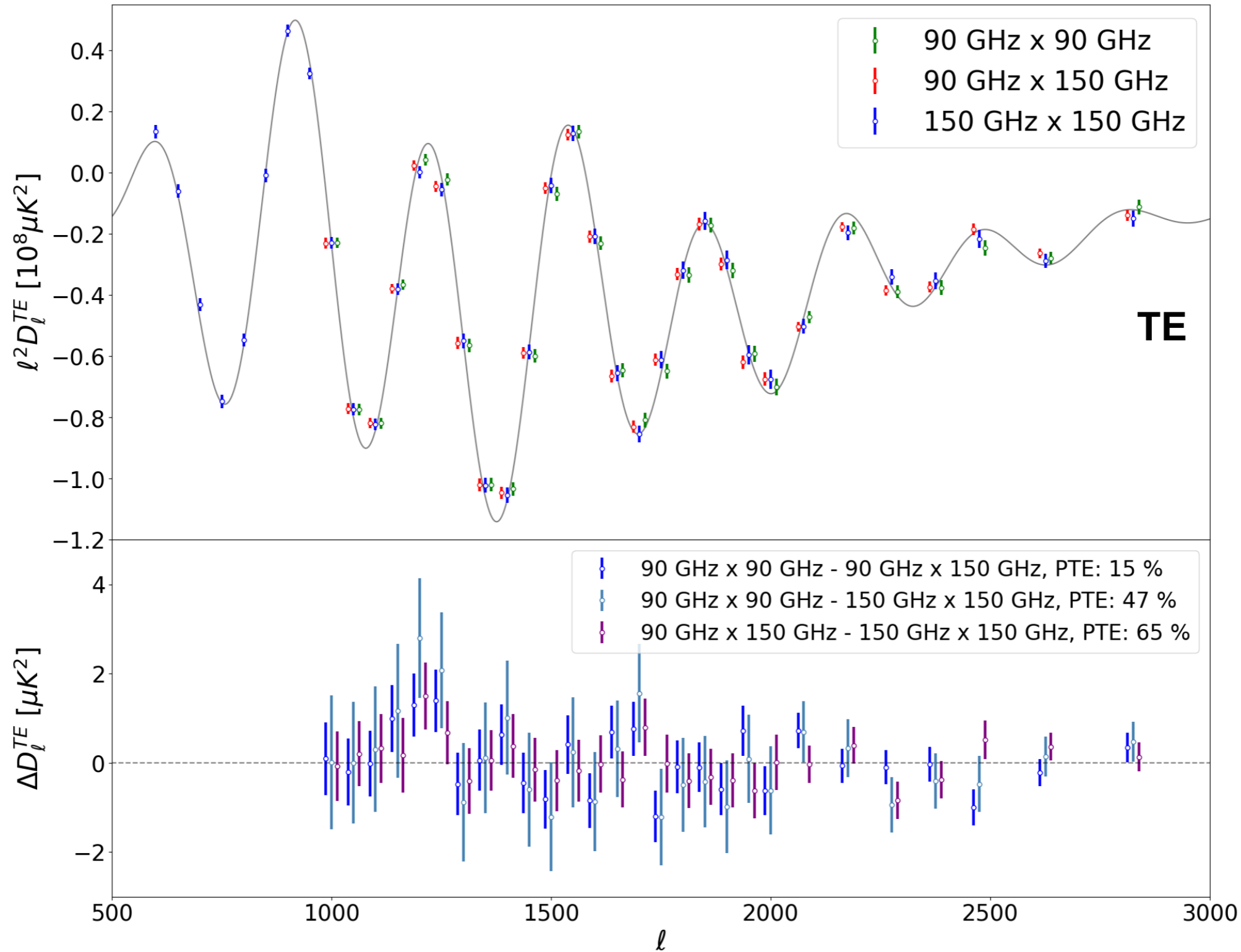
Important null test: after subtracting the best-fit foreground model, do the different frequency auto- and cross-power spectra agree with one another? Yes



# Foreground Model Robustness

Colin Hill  
Columbia

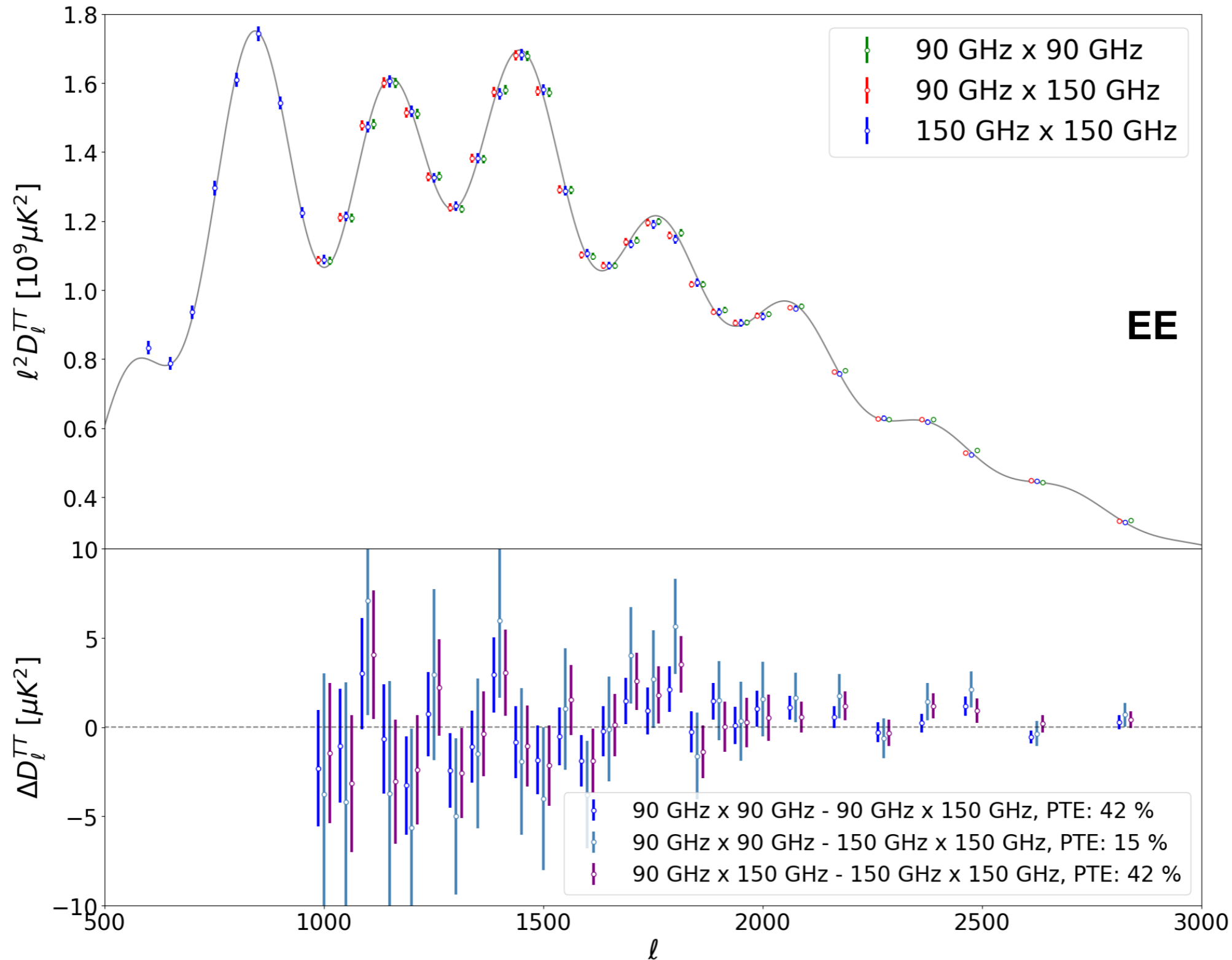
Important null test: after subtracting the best-fit foreground model, do the different frequency auto- and cross-power spectra agree with one another? Yes



# Foreground Model Robustness

Colin Hill  
Columbia

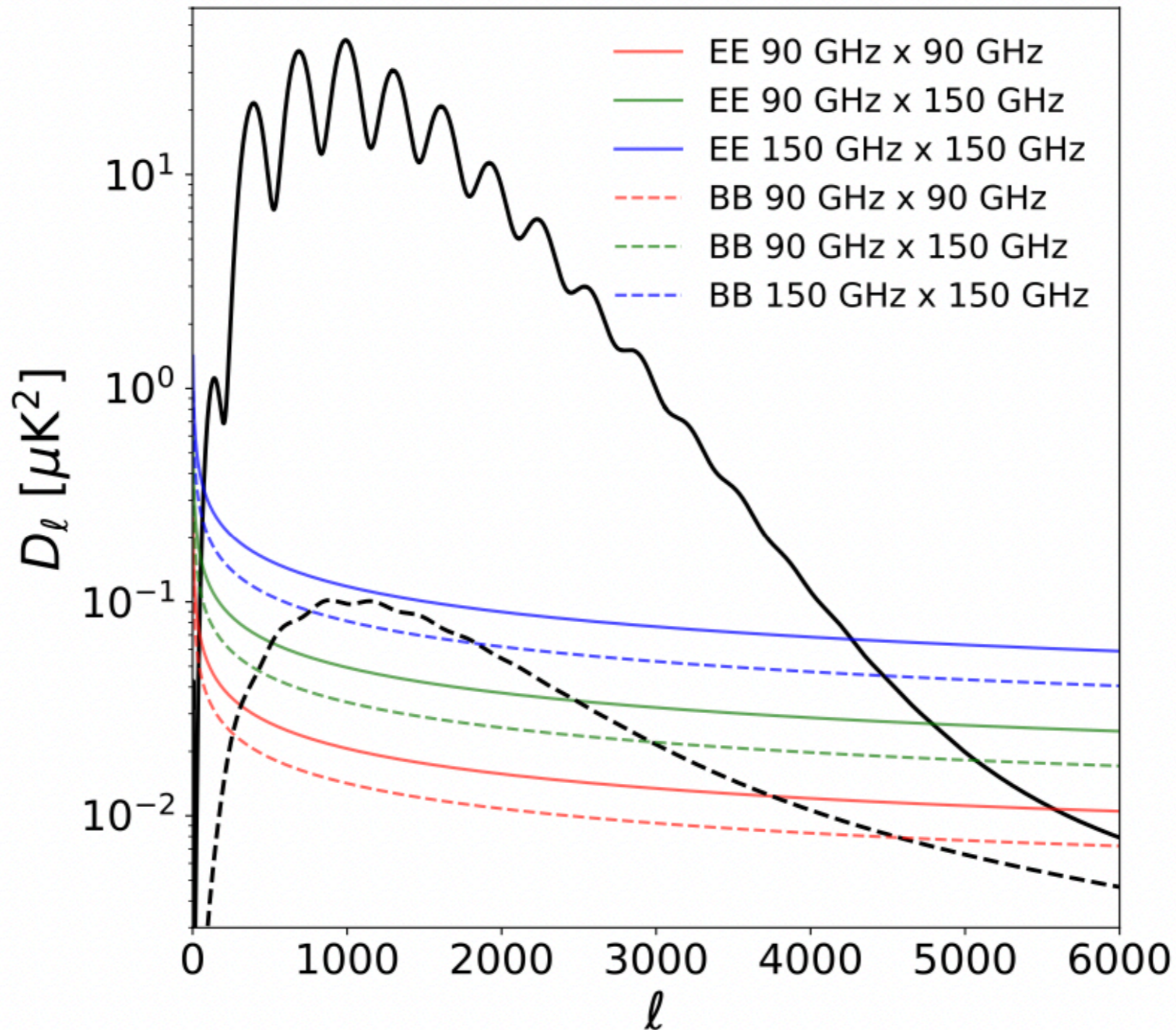
Important null test: after subtracting the best-fit foreground model, do the different frequency auto- and cross-power spectra agree with one another? Yes



# Galactic Dust on DR6 Footprint

Colin Hill  
Columbia

Measured from Planck 353 GHz and extrapolated using modified blackbody SED



# Foreground Model

Colin Hill  
Columbia

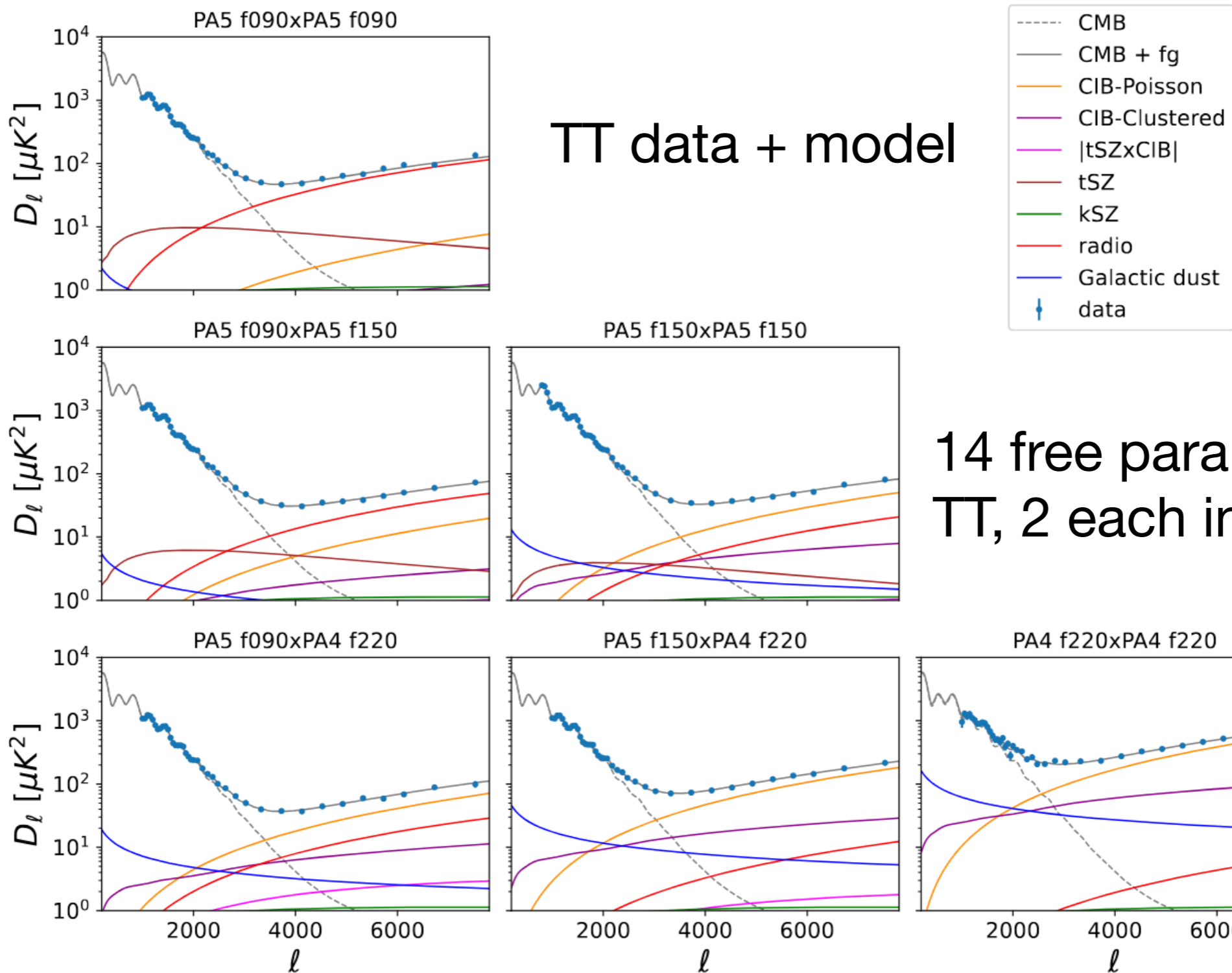
Baseline model

Extensions

	Description	Default Prior	Extension
$a_{\text{tSZ}}$	Thermal SZ amplitude at $\ell = 3000$ at 150 GHz	$\geq 0$	—
$\alpha_{\text{tSZ}}$	Thermal SZ template spectral index	$-5 \leq \alpha_{\text{tSZ}} \leq 5$	—
$a_{\text{kSZ}}$	Kinematic SZ amplitude at $\ell = 3000$	$\geq 0$	—
$a_c$	Clustered CIB amplitude at $\ell = 3000$ at 150 GHz	$\geq 0$	—
$a_p$	Poisson CIB amplitude at $\ell = 3000$ at 150 GHz	$\geq 0$	—
$\beta_c$	Clustered CIB spectral index	$0 \leq \beta_c \leq 5$	—
$\xi_{yc}$	tSZ–CIB correlation coefficient at $\ell = 3000$ at 150 GHz	$0 \leq \xi_{yc} \leq 0.2$	$0 \leq \xi_{yc} \leq 1$
$a_s^{\text{TT}}$	Poisson radio source amplitude in TT at $\ell = 3000$ at 150 GHz	$\geq 0$	—
$\beta_s$	Radio source spectral index	$-3.5 \leq \beta_s \leq -1.5$	—
$a_g^{\text{TT}}$	Galactic dust amplitude in TT at $\ell = 500$ at 150 GHz	$(7.95 \pm 0.32) \mu\text{K}^2$	—
$a_s^{\text{TE}}$	Poisson radio source amplitude in TE at $\ell = 3000$ at 150 GHz	$-1 \leq a_s^{\text{TE}} \leq 1$	—
$a_g^{\text{TE}}$	Galactic dust amplitude in TE at $\ell = 500$ at 150 GHz	$(0.42 \pm 0.03) \mu\text{K}^2$	—
$a_s^{\text{EE}}$	Poisson radio source amplitude in EE at $\ell = 3000$ at 150 GHz	$0 \leq a_s^{\text{EE}} \leq 1$	—
$a_g^{\text{EE}}$	Galactic dust amplitude in EE at $\ell = 500$ at 150 GHz	$(0.168 \pm 0.017) \mu\text{K}^2$	—
$\alpha_g^{\text{TE/EE}}$	Galactic dust $C_\ell$ power-law index in TE/EE for $\ell > 500$	$\alpha_g^{\text{TE/EE}} = -0.4$	$\alpha_g^{\text{TE/EE}} \in [-2, 1]$
$\alpha_c$	Clustered CIB $C_\ell$ power-law index for $\ell > 3000$	$\alpha_c = 0.8$	$\alpha_c = 0.6, \alpha_c = 1, \alpha_c \in [0.5, 1]$
$\beta_p$	Poisson CIB spectral index	$\beta_p = \beta_c$	$0 \leq \beta_p \leq 5$
$\beta_s^E$	Radio source spectral index in polarization	$\beta_s^E = \beta_s$	$-3.5 \leq \beta_s^E \leq -1.5$
$\xi_{ys}$	tSZ–radio correlation coefficient at $\ell = 3000$ at 150 GHz	$\xi_{ys} = 0$	$0 \leq \xi_{ys} \leq 0.2$
$\xi_{cs}$	CIB–radio correlation coefficient at $\ell = 3000$ at 150 GHz	$\xi_{cs} = 0$	$0 \leq \xi_{cs} \leq 0.2$
$r_{\nu_i \times \nu_j}^{\text{CIB}}$	CIB decorrelation between $\nu_i$ and $\nu_j$	$r_{\nu_i \times \nu_j}^{\text{CIB}} = 1$	$0.8 \leq r_{\nu_i \times \nu_j}^{\text{CIB}} \leq 1.0, (\text{for } \nu_i \neq \nu_j)$
$r_{\nu_i \times \nu_j}^{\text{radio}}$	Radio decorrelation between $\nu_i$ and $\nu_j$	$r_{\nu_i \times \nu_j}^{\text{radio}} = 1$	$0.8 \leq r_{\nu_i \times \nu_j}^{\text{radio}} \leq 1.0, (\text{for } \nu_i \neq \nu_j)$

# Multi-Component Model

We fit a multi-component sky model to the multi-frequency auto- and cross-power spectra



14 free parameters (10 in TT, 2 each in TE/EE)

# Foreground Constraints

	<b>Nominal P-ACT</b>	Nominal ACT	$\beta_c \neq \beta_p$ ACT
<b>SZ</b>			
$a_{\text{tSZ}}$	$3.3 \pm 0.4$	$3.4 \pm 0.4$	$3.0 \pm 0.4$
$\alpha_{\text{tSZ}}$	$-0.6 \pm 0.2$	$-0.5 \pm 0.2$	$-0.7^{+0.3}_{-0.2}$
$a_{\text{kSZ}}$	$2.0 \pm 0.9$	$1.5^{+0.7}_{-1.1}$	$2.4^{+0.9}_{-0.8}$
<b>CIB</b>			
$a_c$	$3.6 \pm 0.5$	$3.7 \pm 0.5$	$2.4^{+0.4}_{-0.8}$
$a_p$	$7.7 \pm 0.3$	$7.7 \pm 0.3$	$8.2 \pm 0.4$
$\beta_p$	$1.9 \pm 0.1$	$1.9 \pm 0.1$	$1.8 \pm 0.1$
$\beta_c$			$2.6^{+0.4}_{-0.3}$
<b>SZ-CIB</b>			
$\xi$	$0.09^{+0.05}_{-0.07}$	$0.09^{+0.04}_{-0.08}$	$< 0.15$
<b>Radio</b>			
$a_s^{TT}$	$2.8 \pm 0.2$	$2.9 \pm 0.2$	$2.7 \pm 0.2$
$\beta_s$	$-2.8 \pm 0.1$	$-2.8 \pm 0.1$	$-2.8 \pm 0.1$
$a_s^{TE}$	$-0.026 \pm 0.012$	$-0.025 \pm 0.012$	$-0.024 \pm 0.012$
$a_s^{EE}$	$< 0.04$	$< 0.04$	$< 0.04$

# Foregrounds and Systematics

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Columbia

Unblinding

+  $\alpha_{\text{tSZ}}$  marginalization

+  $\alpha_{\text{tSZ}}$  + beam chromaticity

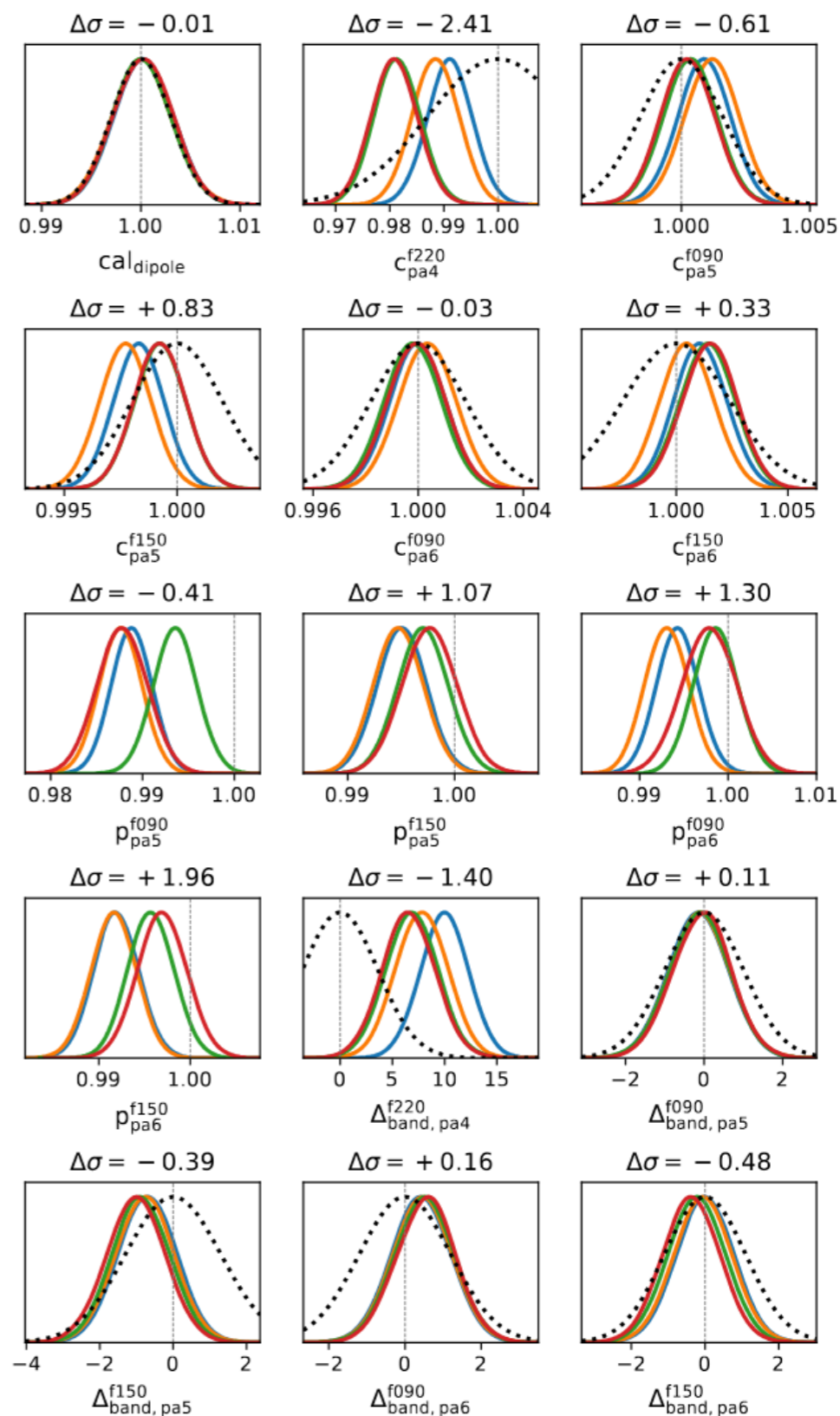
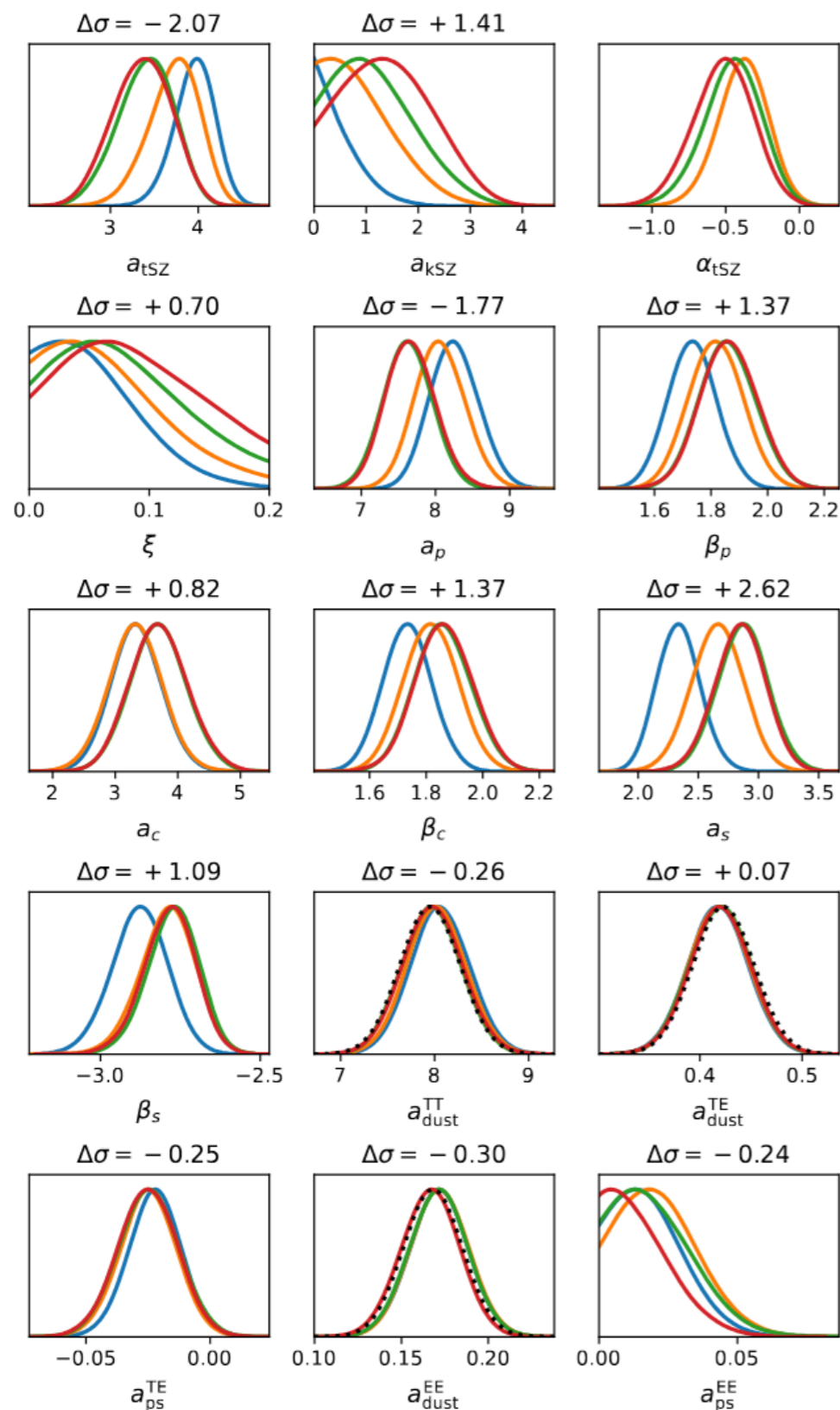
Baseline ( $\alpha_{\text{tSZ}}$  + chromatic beams + polarization cuts)

Unblinding

+  $\alpha_{\text{tSZ}}$  marginalization

+  $\alpha_{\text{tSZ}}$  + beam chromaticity

Baseline ( $\alpha_{\text{tSZ}}$  + chromatic beams + polarization cuts)



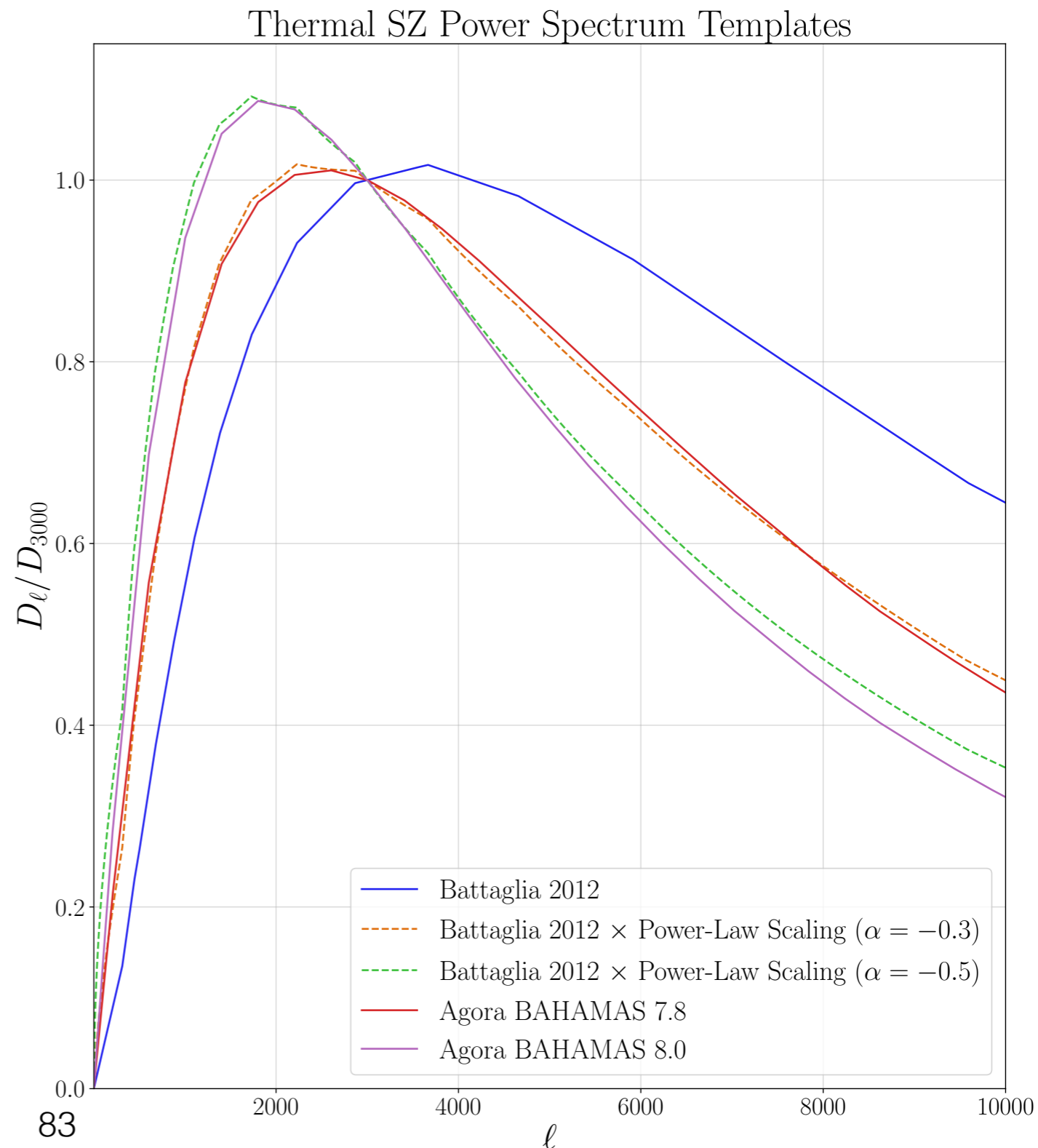
# Foreground Robustness

## New developments in foreground modeling

- Simulation-based tests indicated that DR6 parameter inference is now sensitive to the shape of the thermal SZ power spectrum template used in the TT modeling

- Efficiently captured by a single new free parameter: power-law index  $\alpha_{\text{SZ}}$

$$D_{\ell}^{\text{tSZ}} = D_{\ell}^{\text{tSZ,Batt.}} \left( \frac{\ell}{3000} \right)^{\alpha}$$

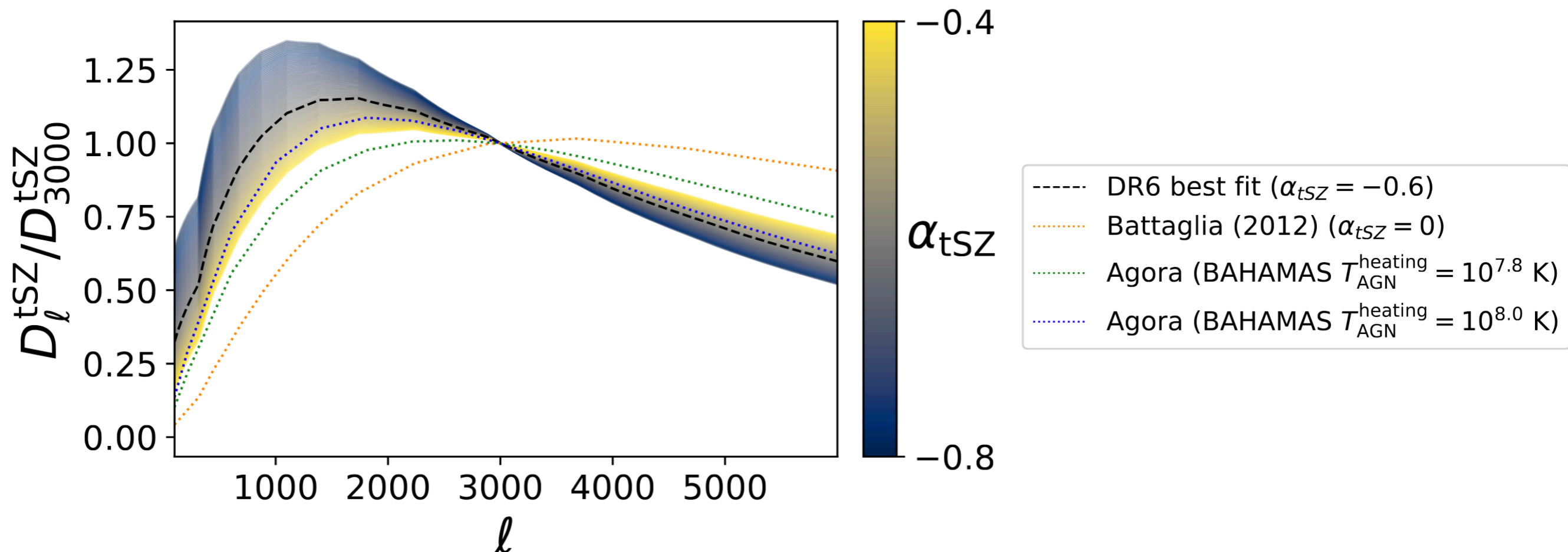


# Thermal SZ Constraints

For the first time, our data are sufficiently sensitive to require the introduction of a new foreground parameter describing the scale dependence of the tSZ power spectrum

$$D_{\ell, \text{tSZ}}^{T_i T_j} = a_{\text{tSZ}} D_{\ell, \ell_0}^{\text{tSZ}} \left[ \frac{\ell}{\ell_0} \right]^{\alpha_{\text{tSZ}}} \frac{f_{\text{tSZ}}(\nu_i) f_{\text{tSZ}}(\nu_j)}{f_{\text{tSZ}}^2(\nu_0)}$$

We find  $\sim 3\sigma$  evidence for a steeper tSZ power spectrum than modeled in our fiducial template, consistent with hydro simulations invoking strong baryonic feedback



# Foreground Model Robustness

End-to-end validation from simulated sky maps to parameters

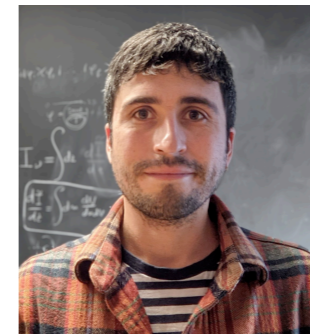
- Standard in previous CMB power spectrum analyses: simulate gaussian random fields and run analysis pipeline with the same sky model
- More stringent test in DR6: infer parameters from ~realistic, non-gaussian sky maps with realistic instrument systematics, using analysis pipeline that does not contain models designed to match these simulations



# Foreground Model Robustness

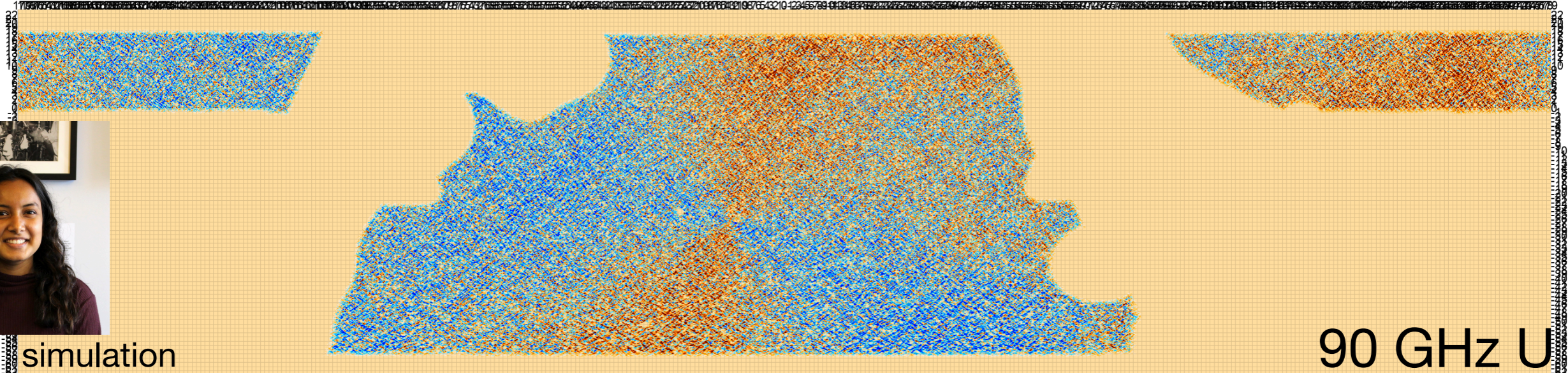
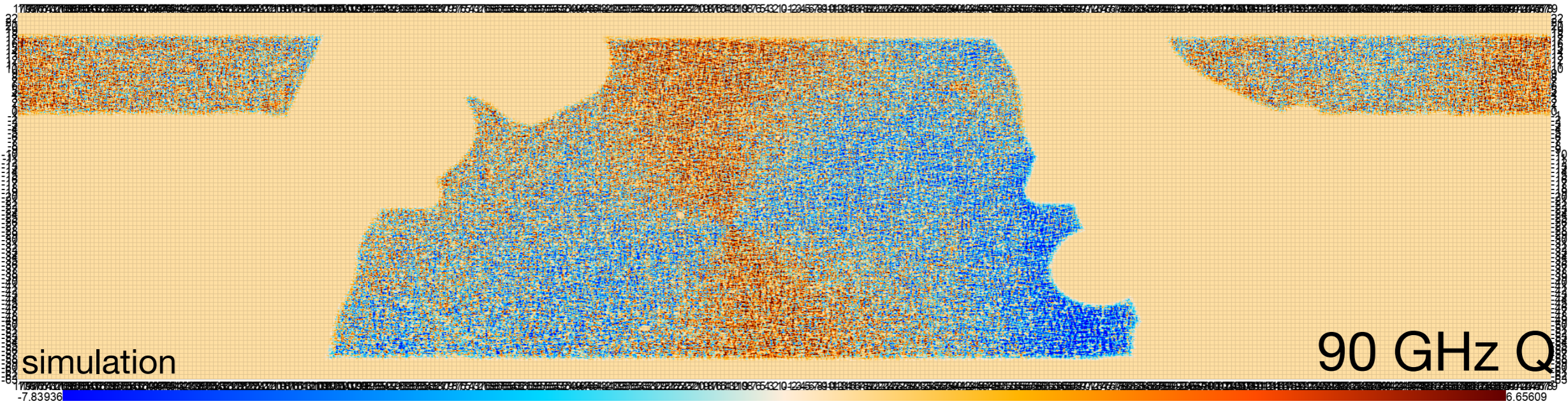
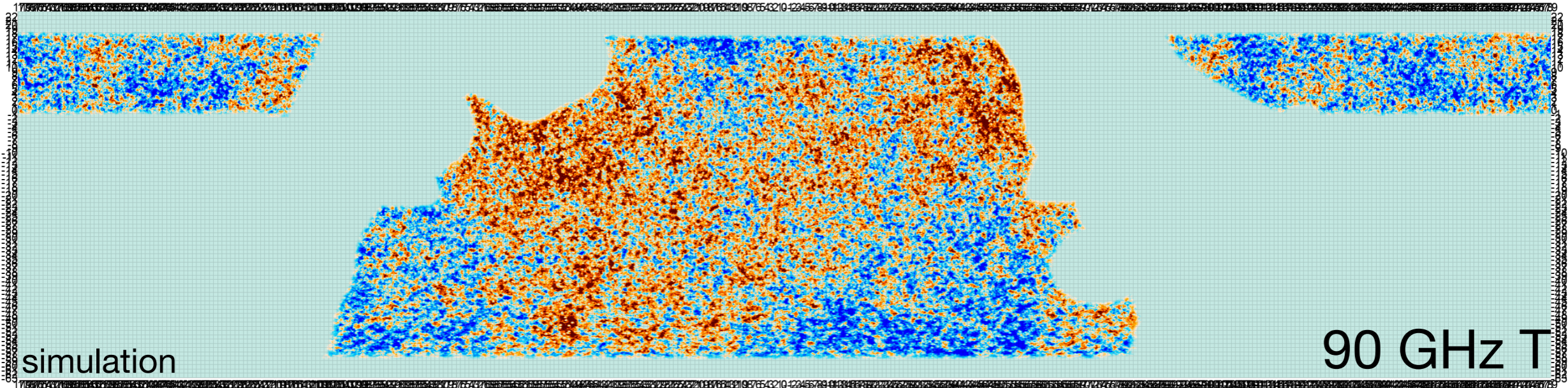
## End-to-end validation from simulated sky maps to parameters

- Standard in previous CMB power spectrum analyses: simulate gaussian random fields and run analysis pipeline with the same sky model
- More stringent test in DR6: infer parameters from ~realistic, non-gaussian sky maps with realistic instrument systematics, using analysis pipeline that does not contain models designed to match these simulations
- Extragalactic fields = *Agora* (Omori 2022): N-body simulation post-processed with detailed models for tSZ, kSZ, CIB, sources
- Galactic fields = *PySM3* (Thorne+2017, Zonca+2021)
- Maps for each ACT detector array are generated and processed with beams, passbands, and noise model built from data (Atkins+ 2023)
- Pipeline accelerated by  $>100x$  using neural-network-based Boltzmann code emulators (Bolliet, JCH,+ 2023)



# ACT DR6: Robustness

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Columbia

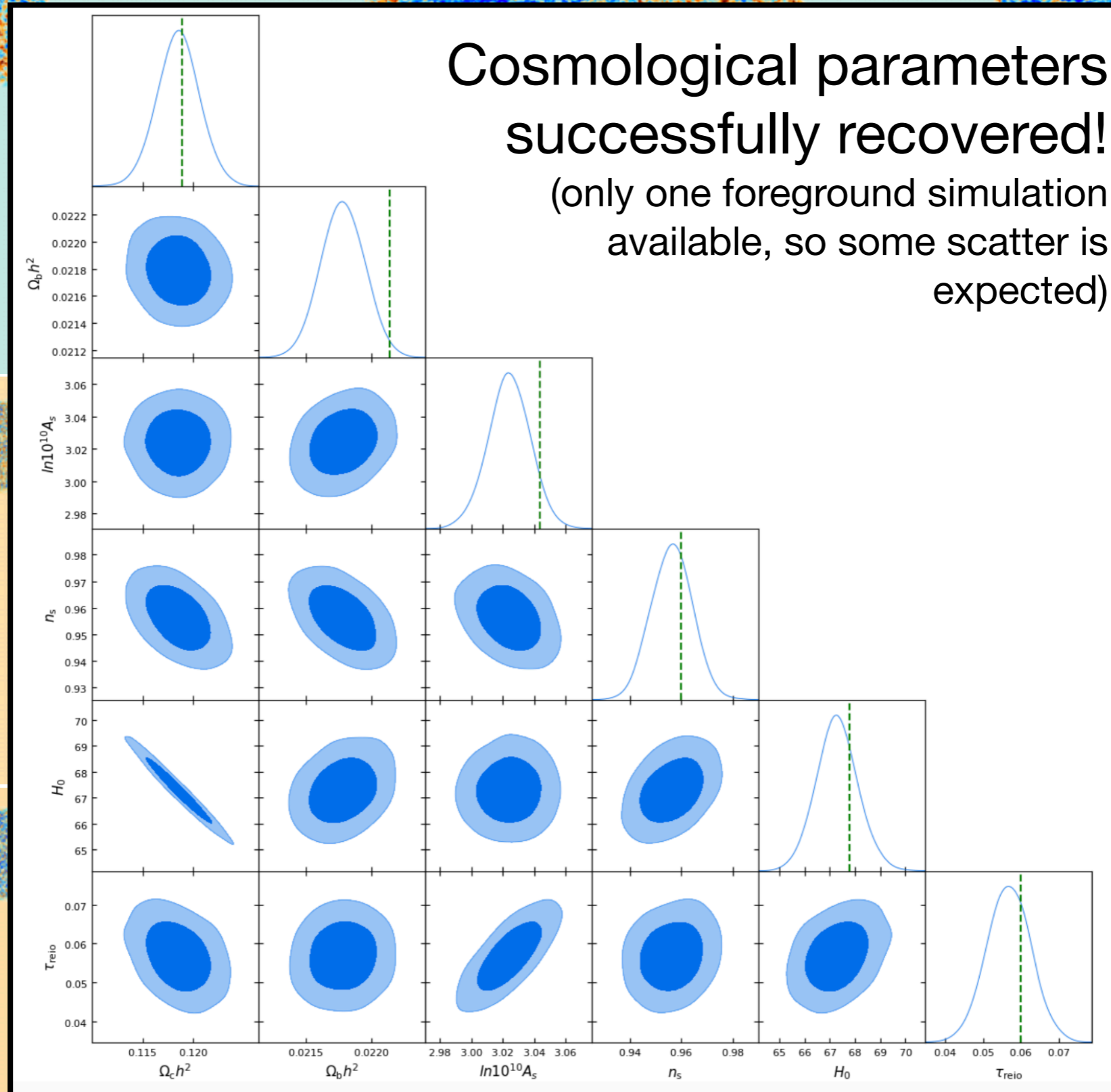


# ACT DR6: Robustness

Colin Hill  
Columbia

simulation

simulation



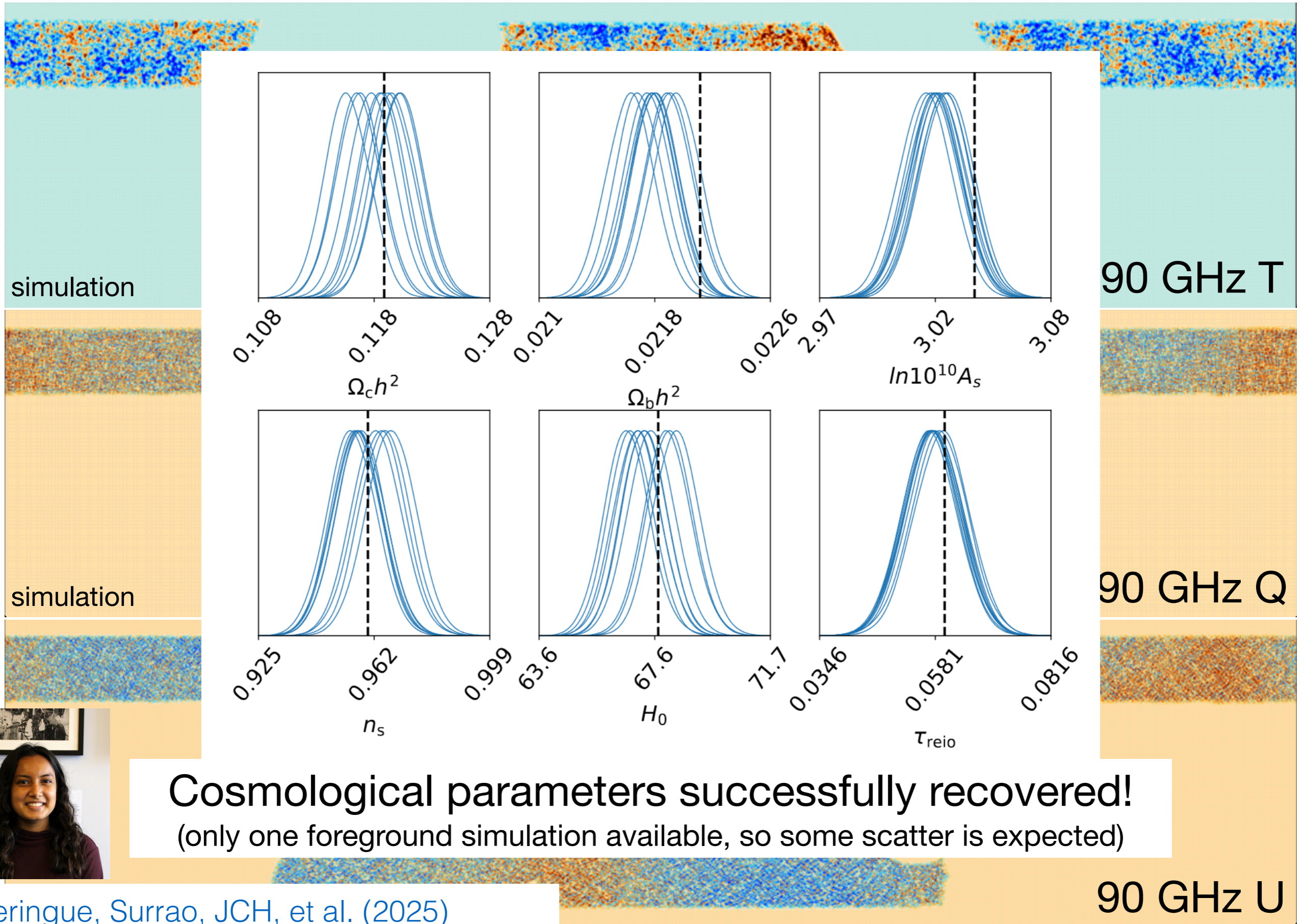
90 GHz T

90 GHz Q

90 GHz U



# ACT DR6: Robustness



**Cosmological parameters successfully recovered!**  
(only one foreground simulation available, so some scatter is expected)



# Reionization kSZ

Colin Hill  
Columbia

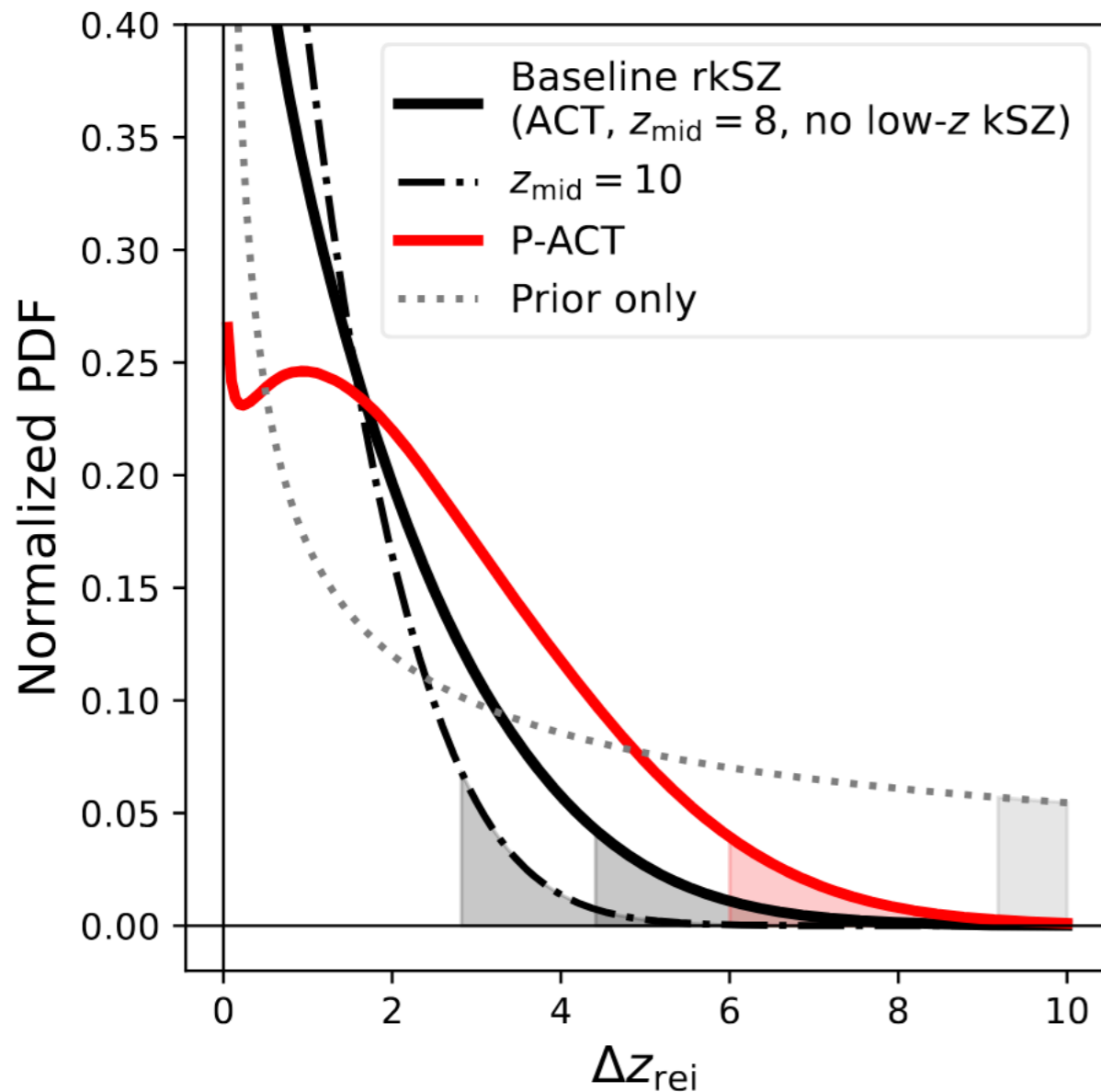
		<b>P-ACT</b>	<b>ACT</b>	
Louis et al.:	$a_{\text{kSZ}}$	$2.0 \pm 0.9$	$1.5^{+0.7}_{-1.1}$	kSZ amplitude at $l=3000$

---

# Reionization kSZ

		<b>P-ACT</b>	<b>ACT</b>	kSZ amplitude at $l=3000$
Louis et al.:	$a_{\text{kSZ}}$	$2.0 \pm 0.9$	$1.5^{+0.7}_{-1.1}$	

Convert into constraint on duration of reionization using Battaglia+13 model:

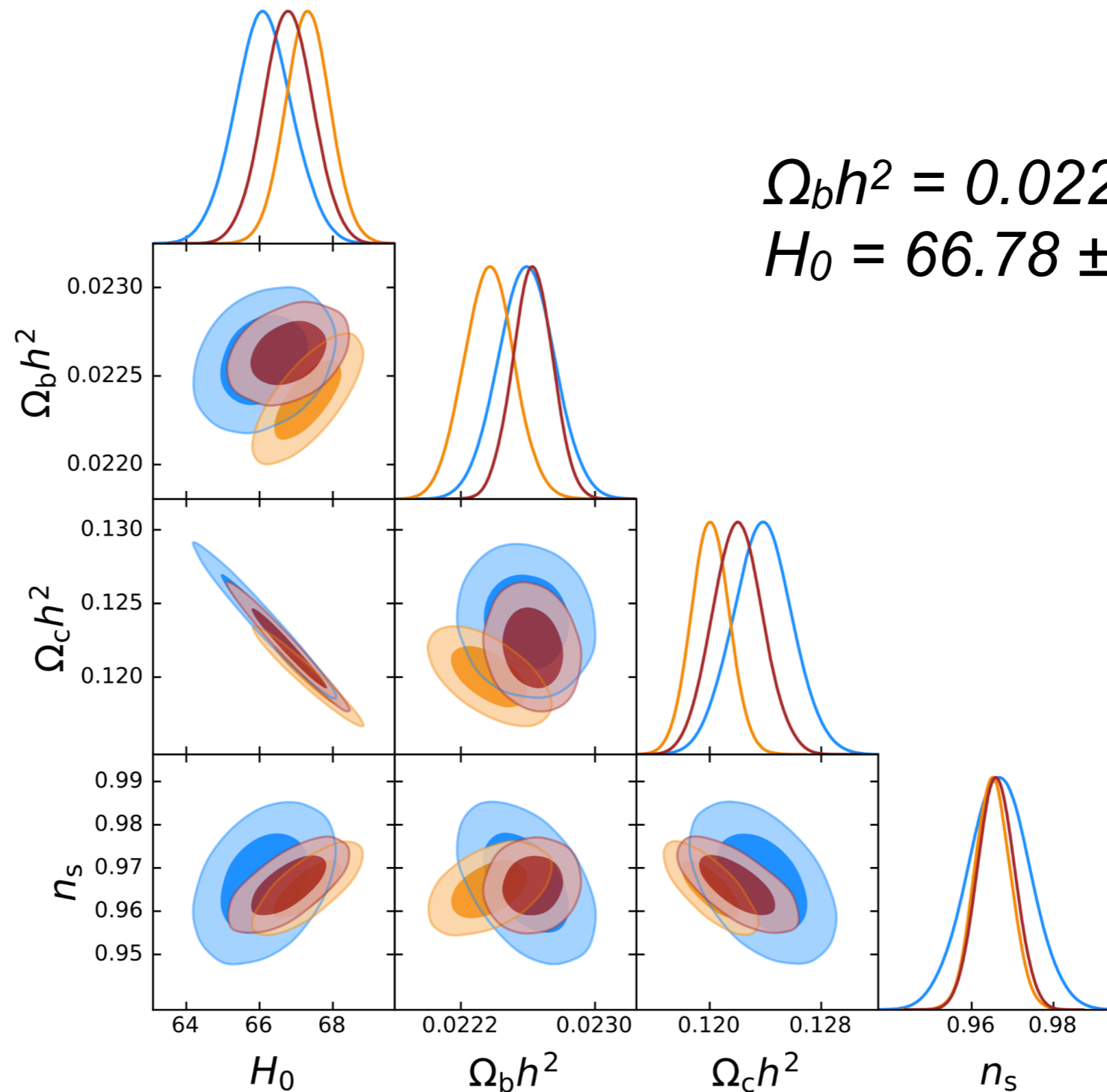


Model	95% Upper Limit
Baseline rkSZ (ACT, B13 param., $z_{\text{mid}} = 8$ , no low- $z$ kSZ)	$\Delta z_{\text{rei}} < 4.4$
$z_{\text{mid}} = 10$	$\Delta z_{\text{rei}} < 2.9$
P-ACT	$\Delta z_{\text{rei}} < 6.0$
low- $z$ kSZ: $\log(T_{\text{AGN}}) = 8.0$	$\Delta z_{\text{rei}} < 2.5$
low- $z$ kSZ: $\log(T_{\text{AGN}}) = 7.6$	$\Delta z_{\text{rei}} < 0.7$



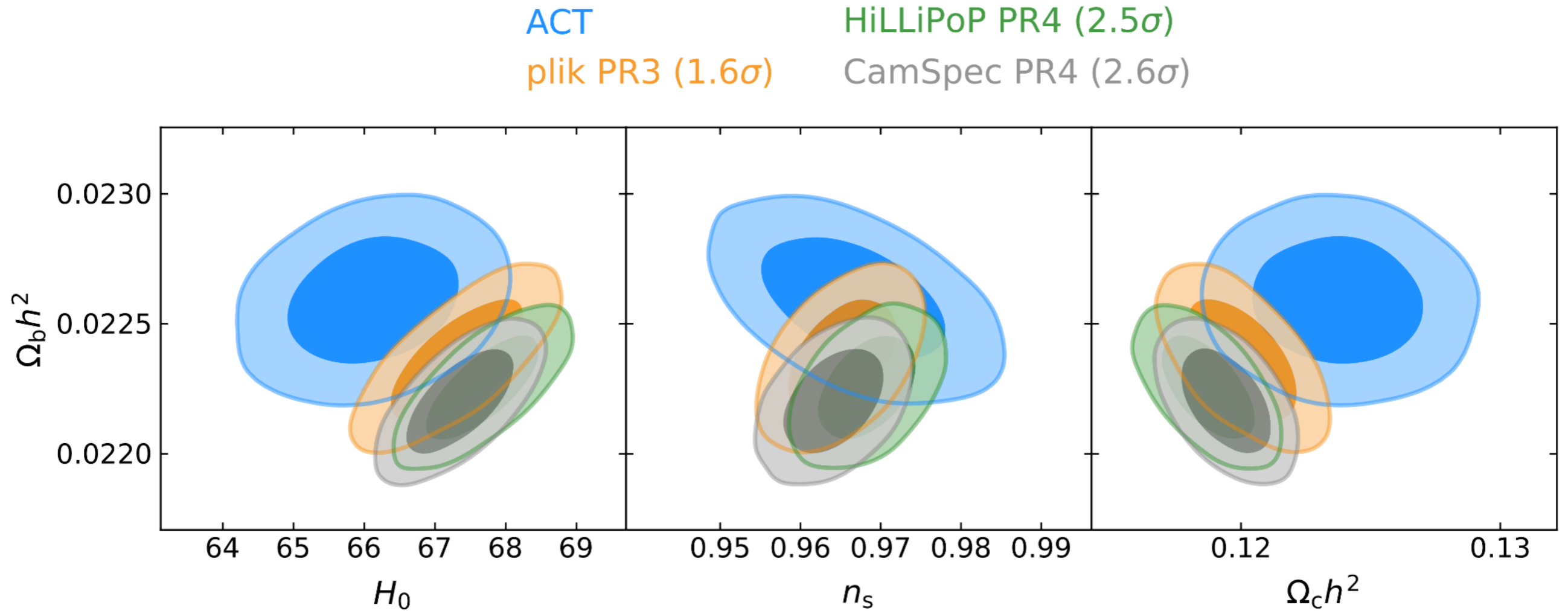
# ACT+WMAP

Comparable constraining power to Planck; completely independent



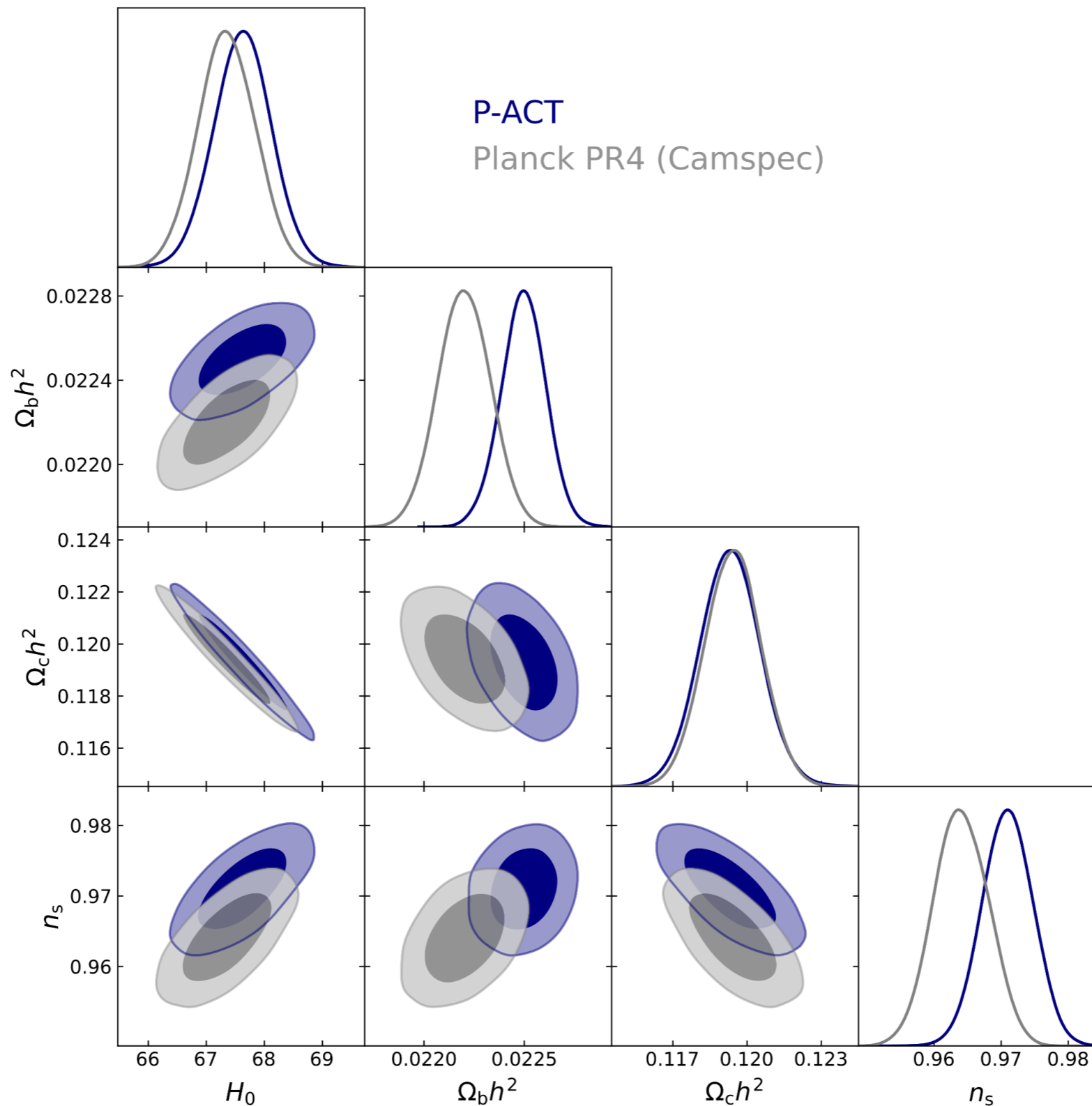
# Comparison with Planck

ACT slightly more consistent with PR3 than PR4/NPIPE



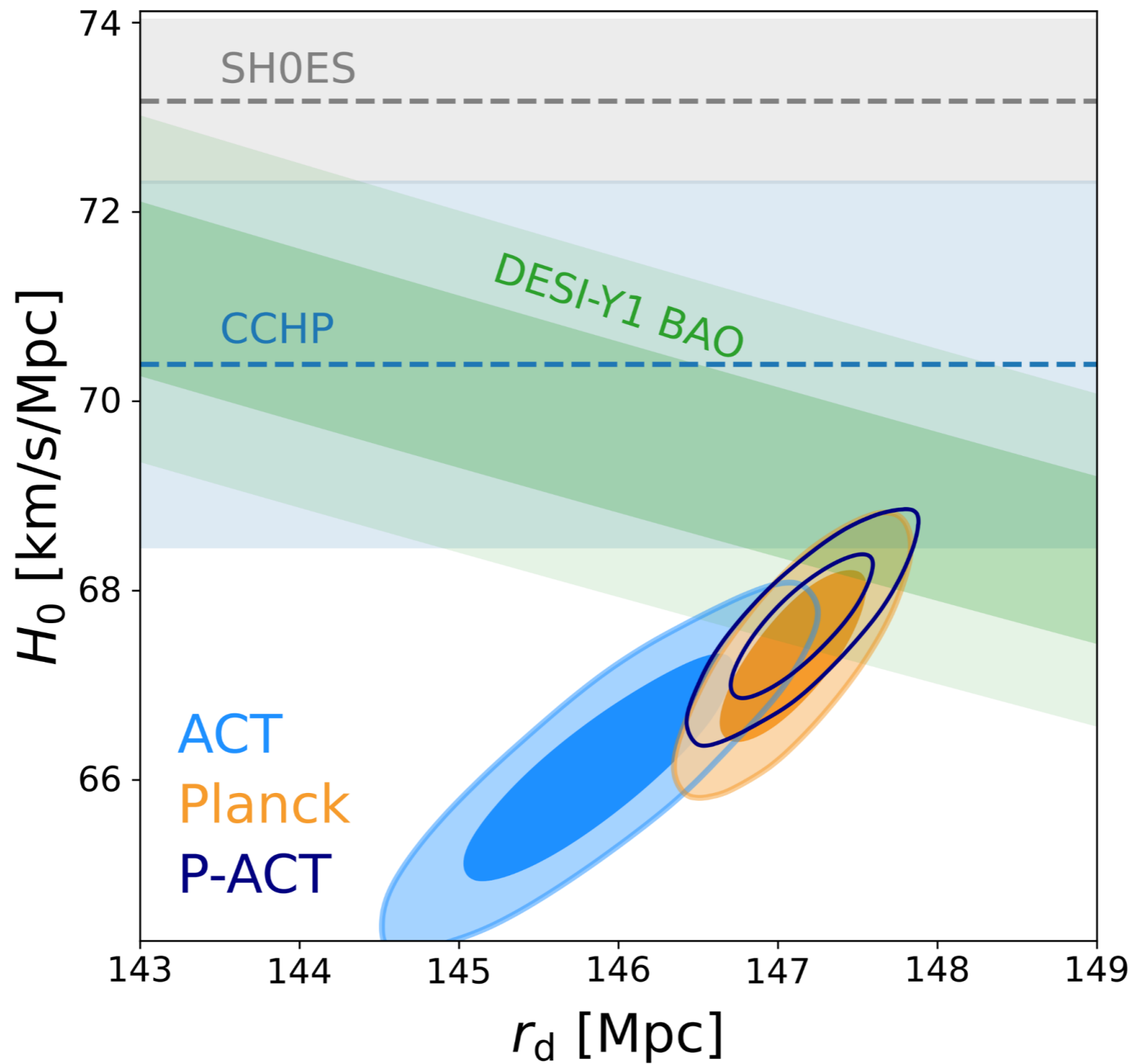
# Comparison with Planck

Nevertheless, P-ACT is consistent with PR4/NPIPE



# Comparison with BAO and $H_0$

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Columbia



assuming  
 $\Lambda$ CDM

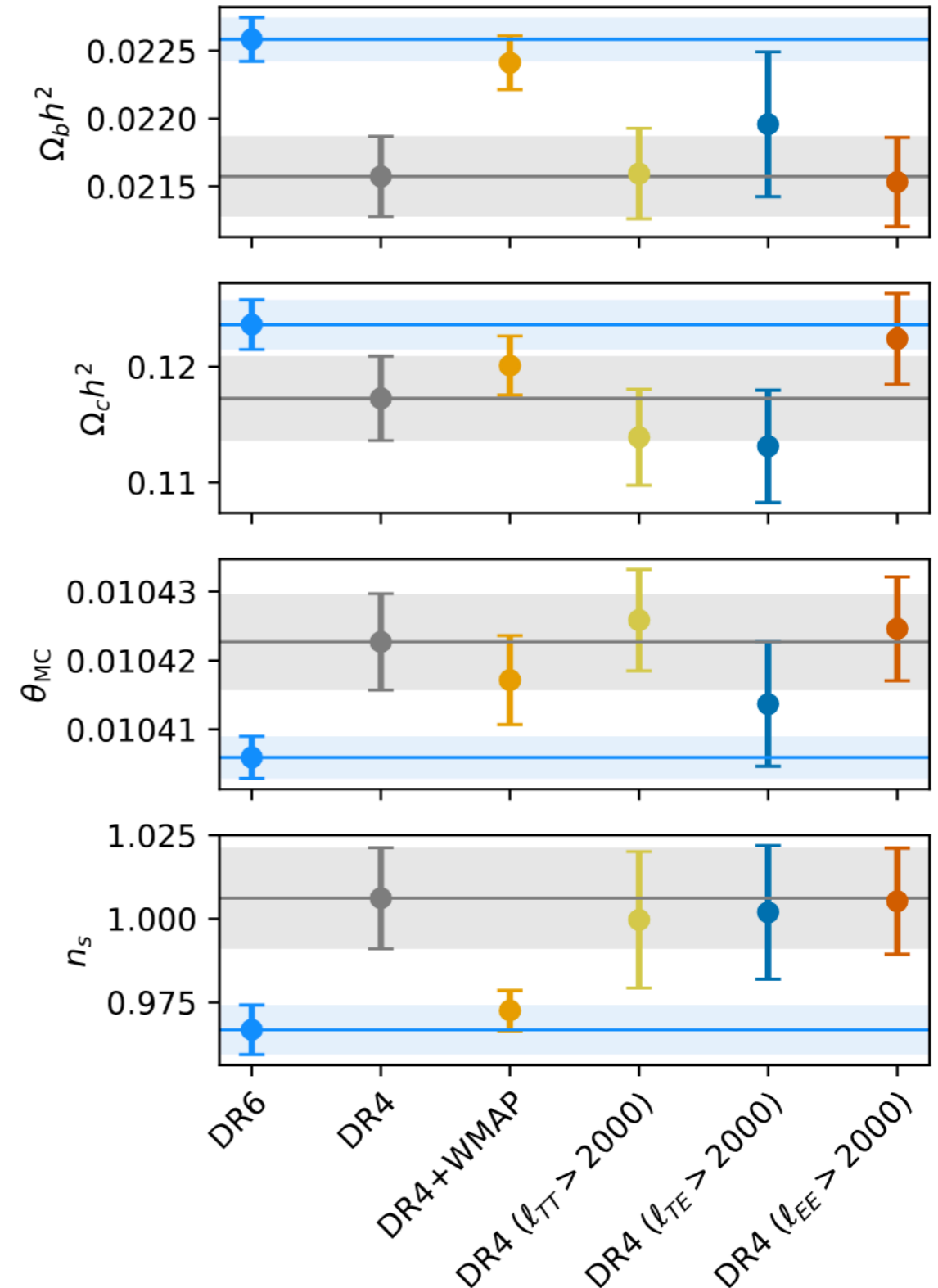
**SH0ES:** *Breuval et al. 2024, Riess et al. 2022*

**CCHP:** *Freedman et al. 2024*

# ACT DR6 vs. DR4

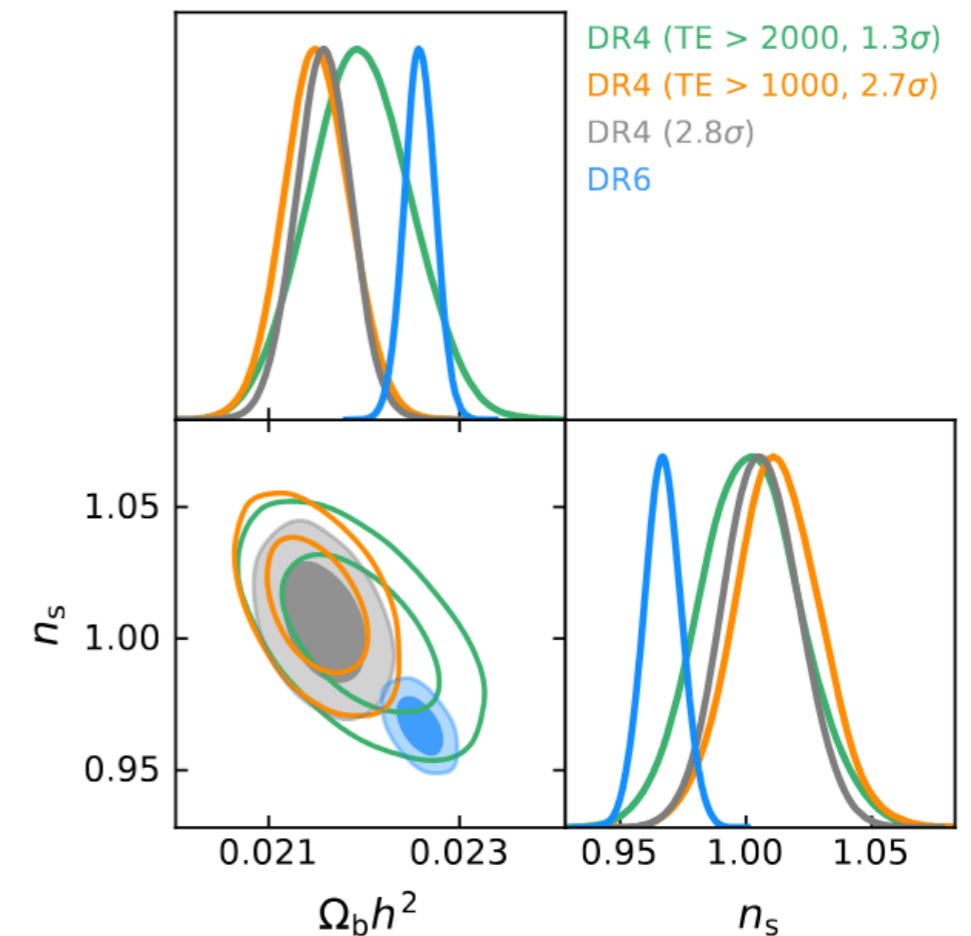
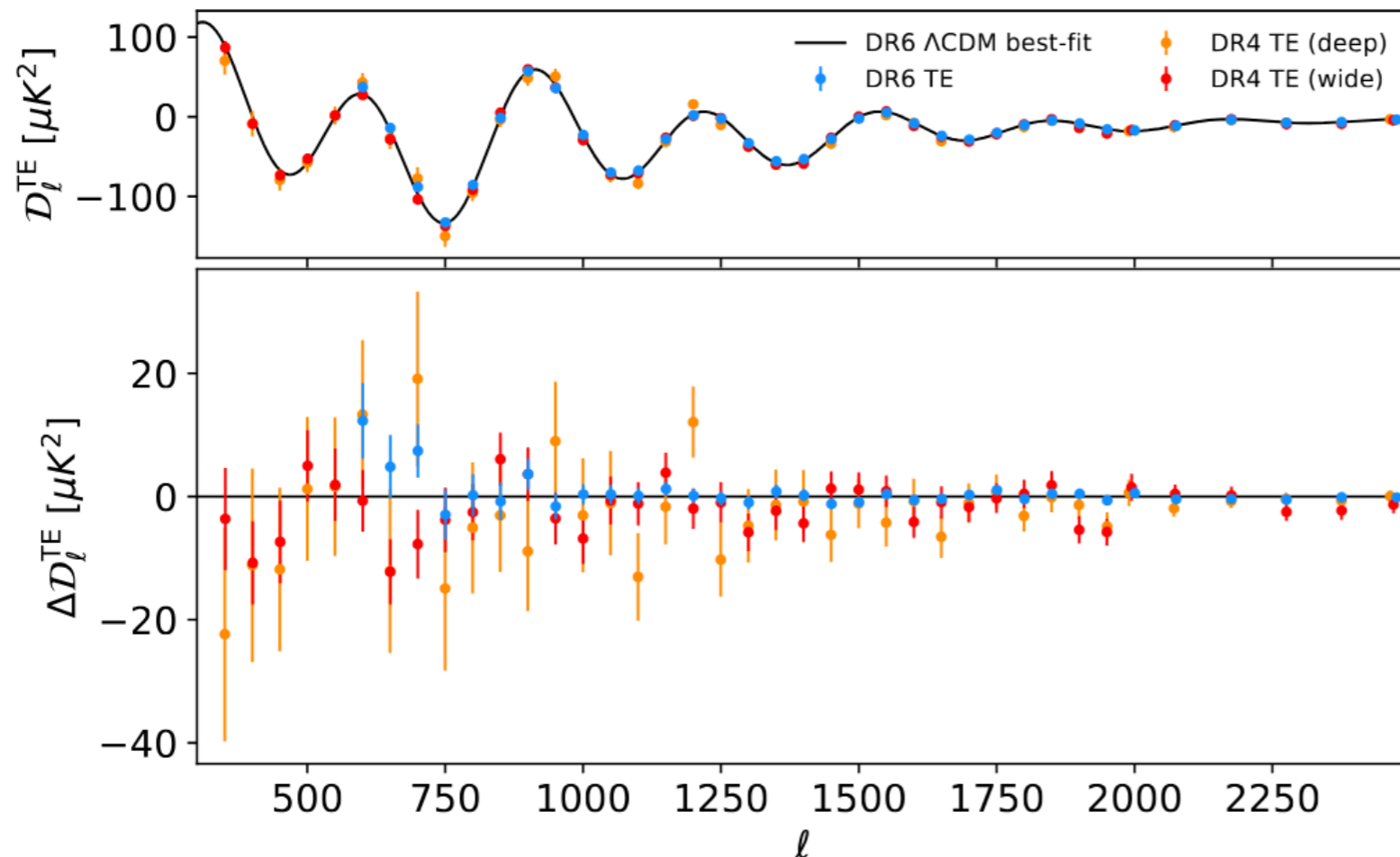
Colin Hill  
Columbia

- Very good agreement between DR6 and DR4 baseline result obtained from ACT+WMAP
- Some differences between DR6 and DR4 ACT-alone cosmology
- Mainly driven by TE data at multipoles  $< 2000$  (where residuals are mostly negative, disfavoring the DR6  $\Lambda$ CDM cosmology)
- We speculate beam leakage modeling may be responsible (significantly improved in DR6)



# ACT DR6 vs. DR4

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- We speculate beam leakage modeling may be responsible (significantly improved in DR6)

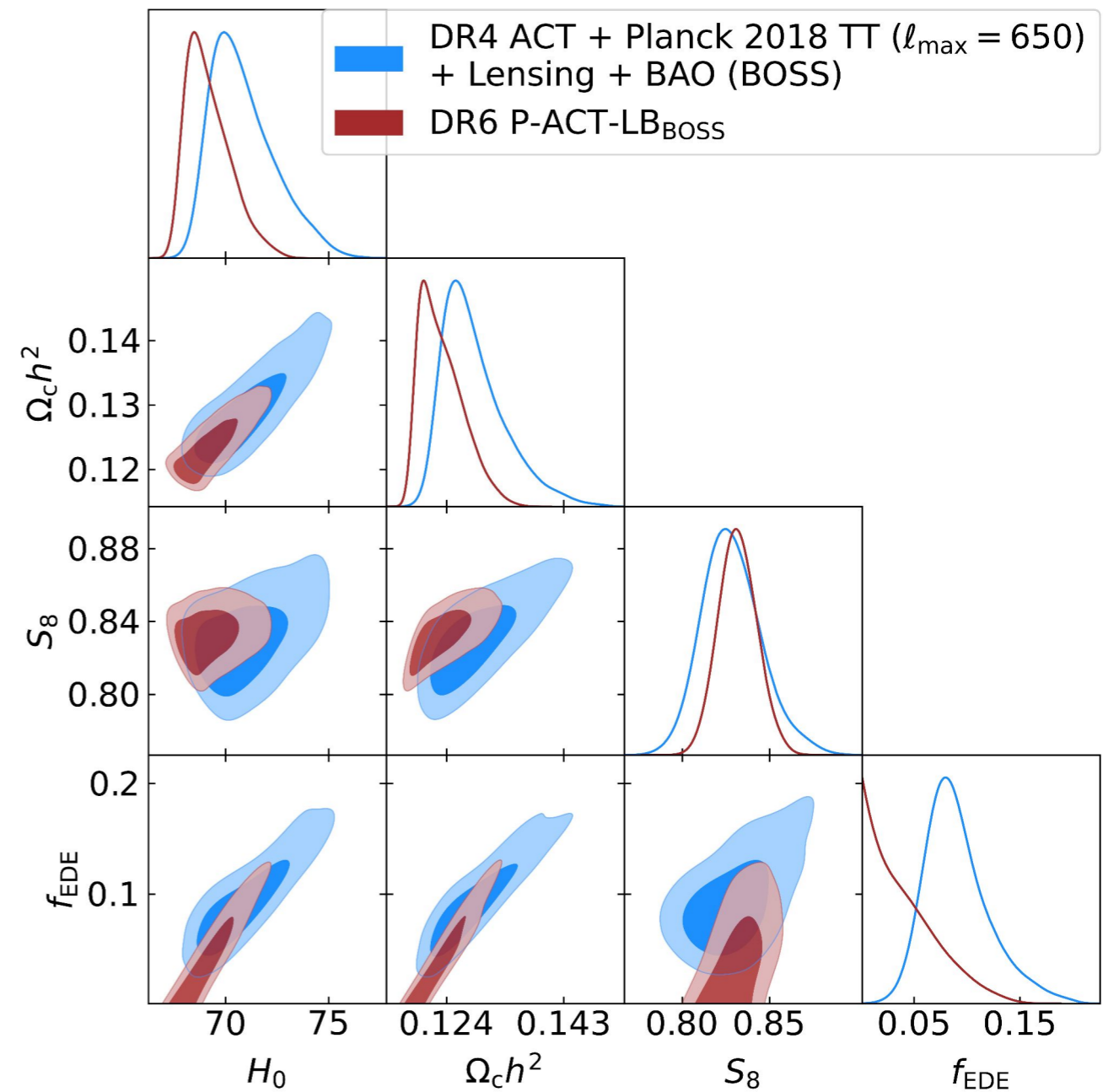
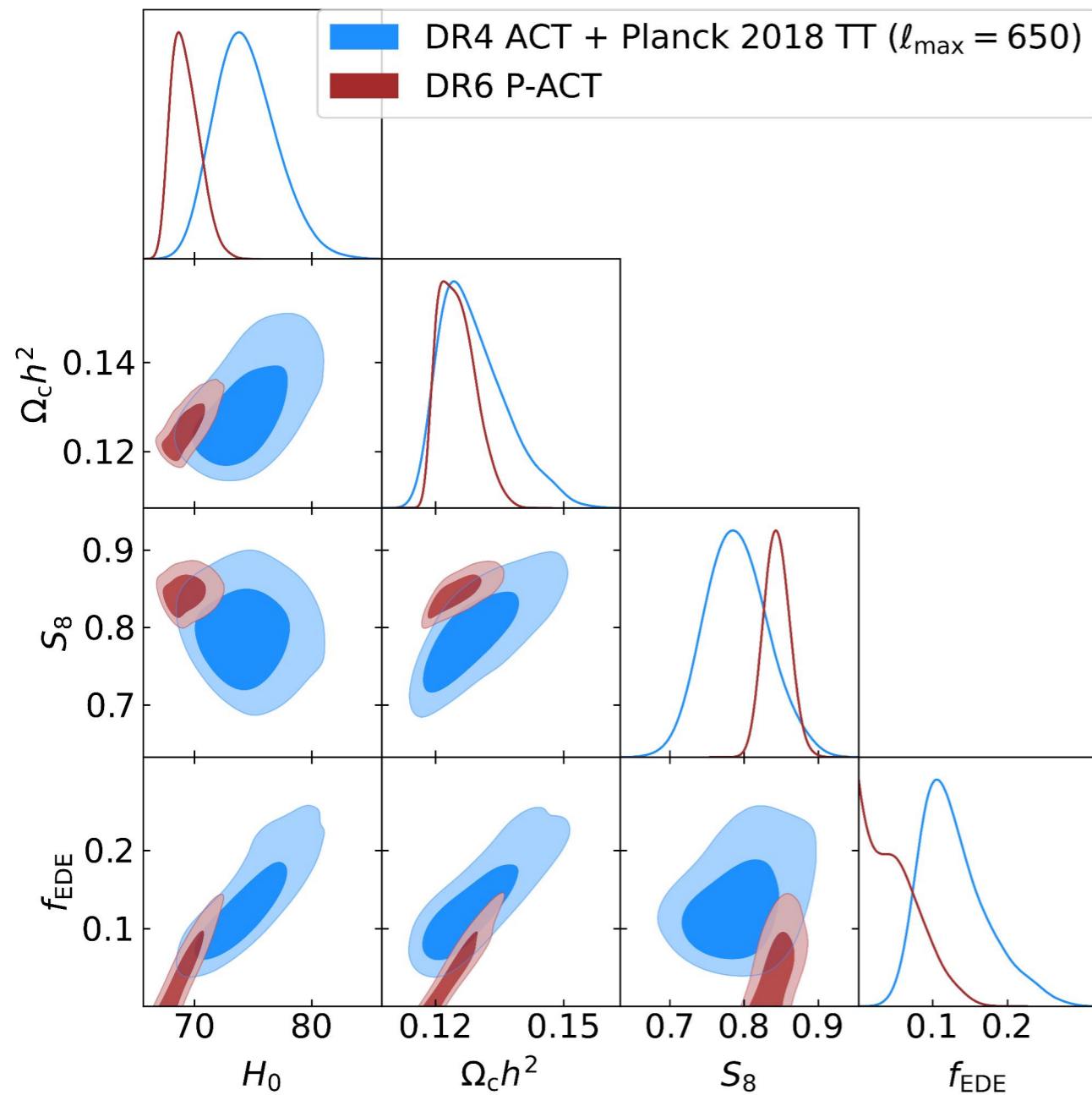


# ACT DR6 vs. DR4

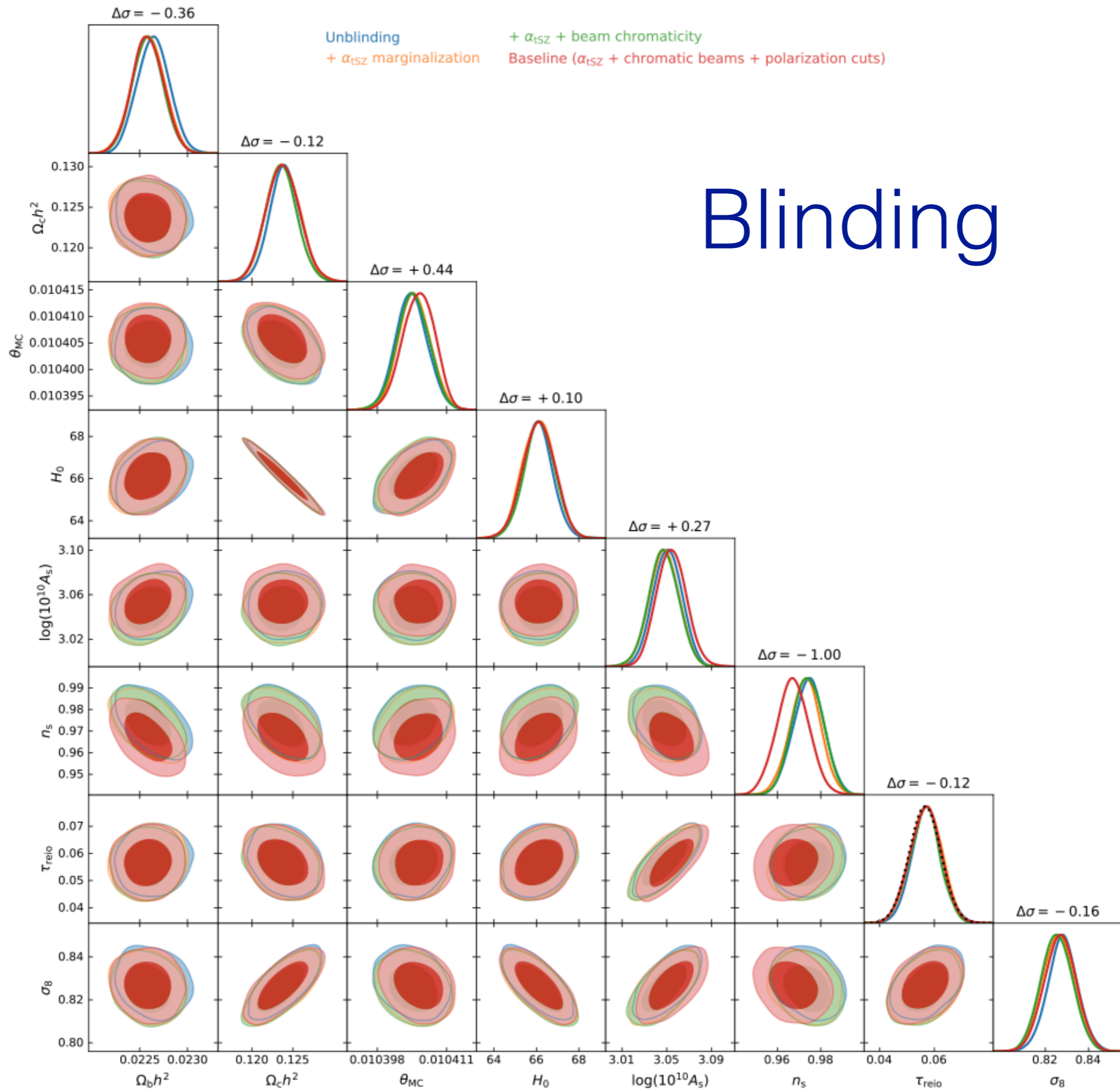
## Comparison of early dark energy constraints

ACT+Planck

ACT+Planck+Lensing+BAO



# Blinding



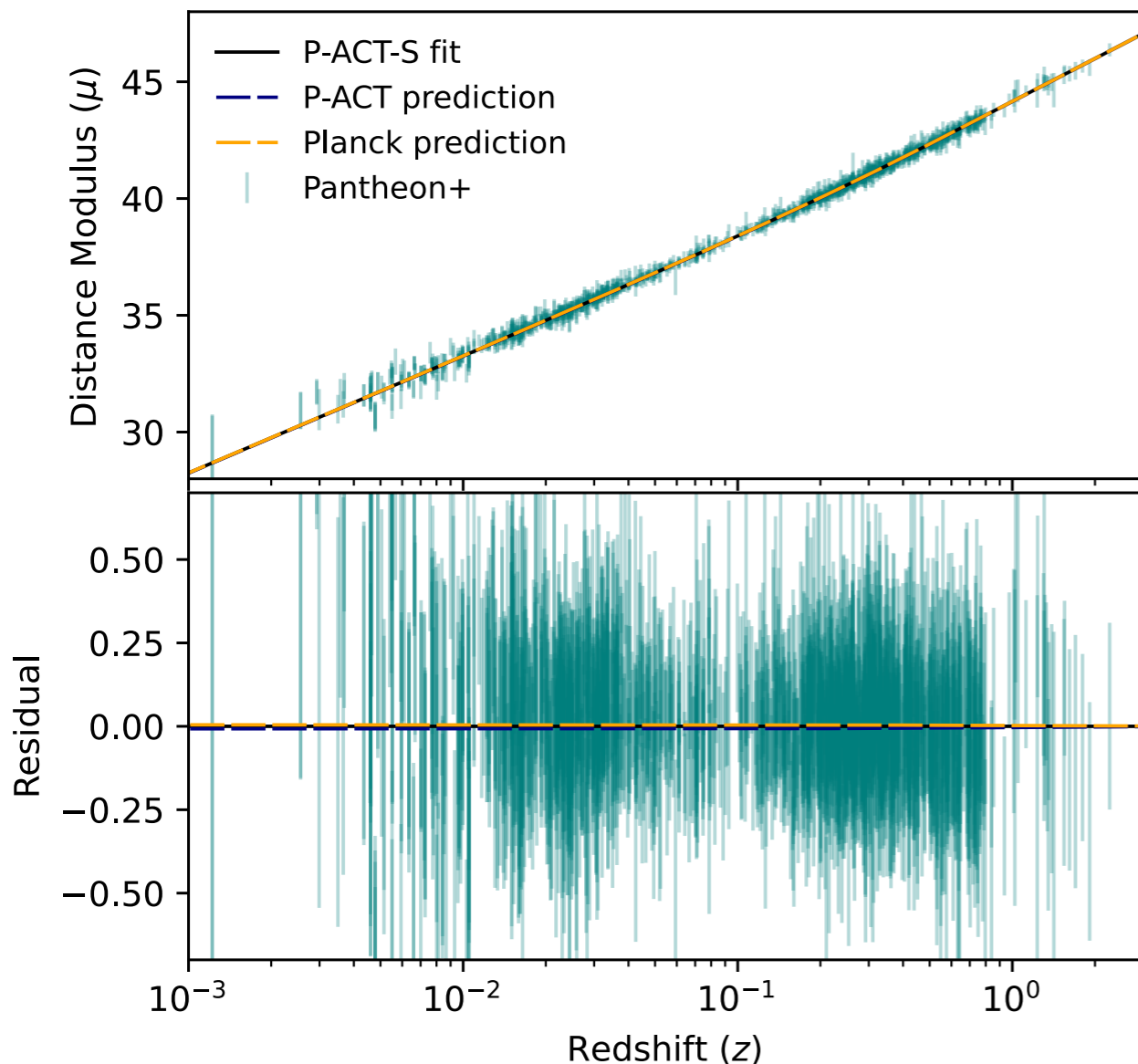
# Cosmological Concordance

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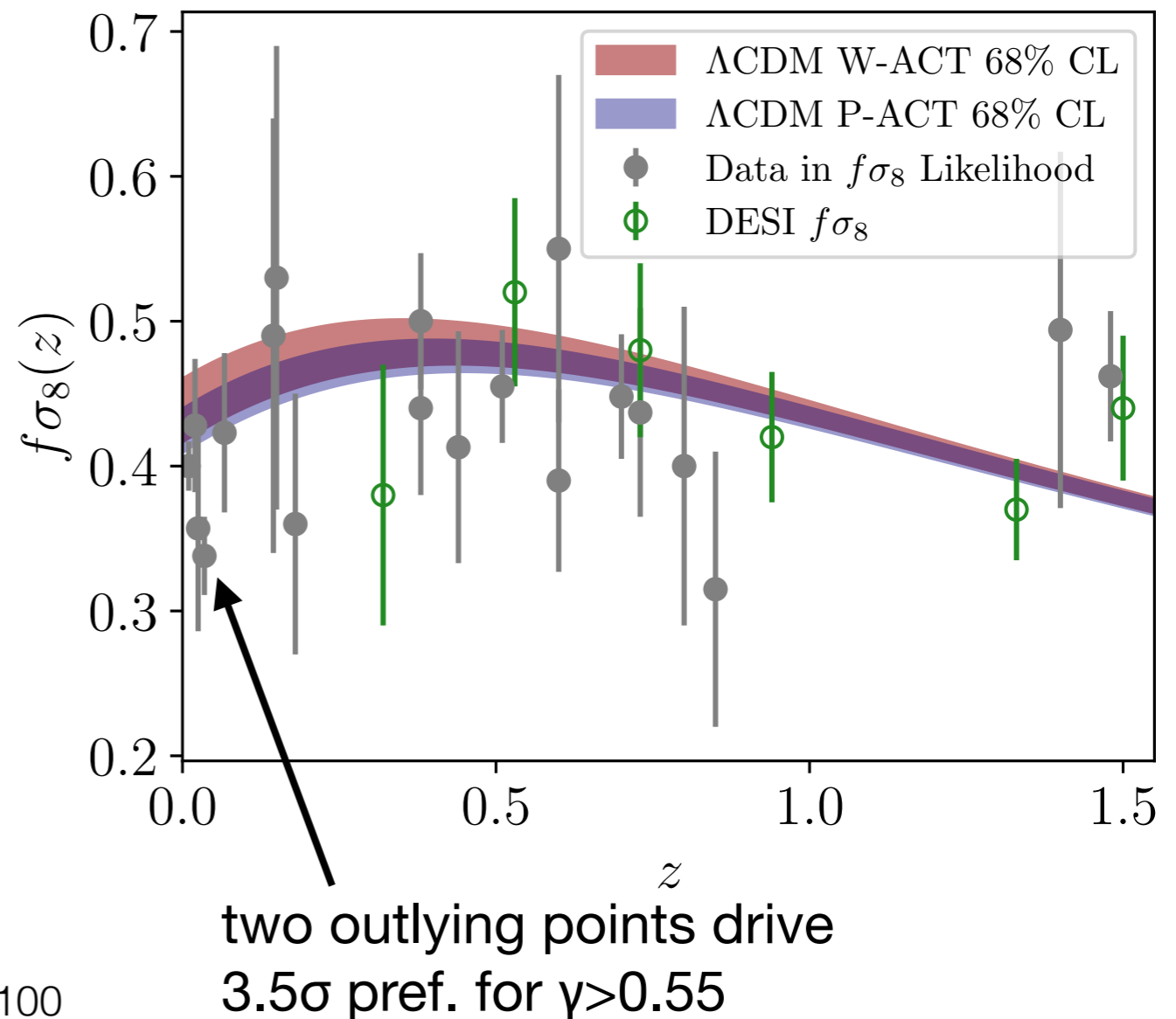
- Predictions of the best-fit P-ACT  $\Lambda$ CDM model agree well with direct low-redshift measurements
- $\Lambda$ CDM gives an excellent joint fit to these datasets

$$f = d \ln D / d \ln a$$

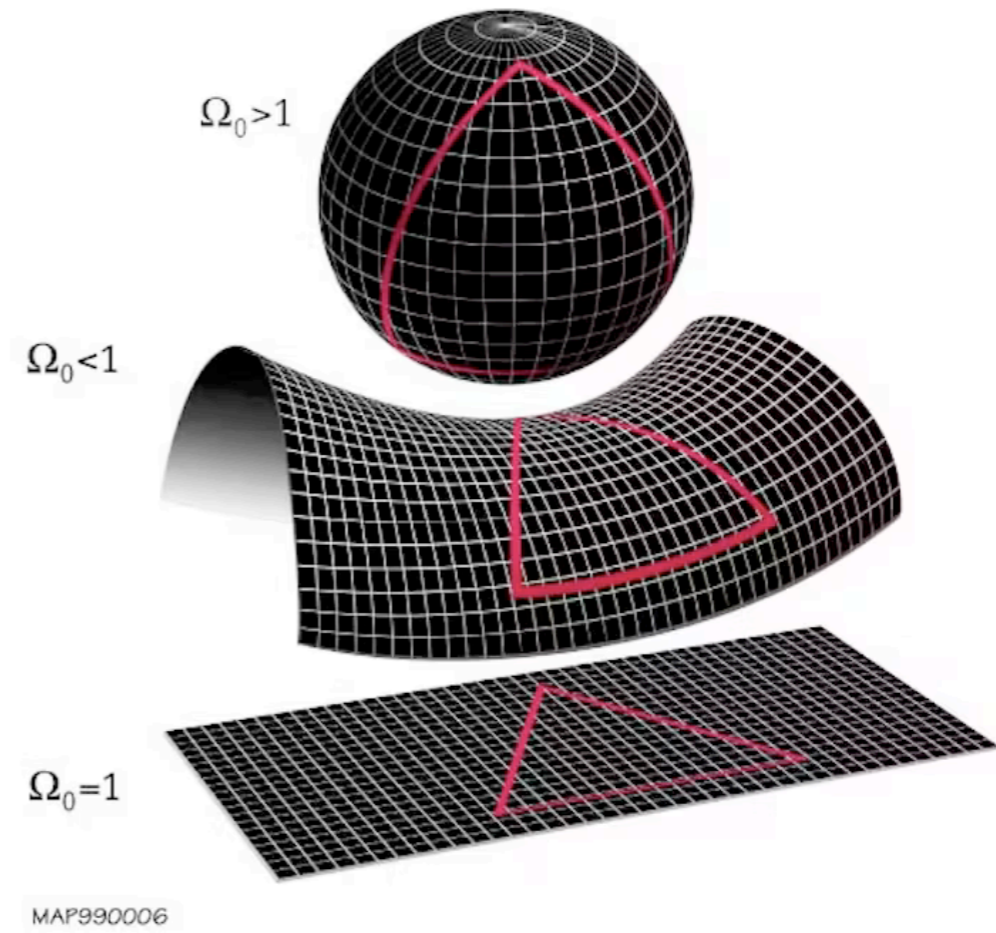
### SN Ia distance modulus



### $f\sigma_8$ from RSD and pec. vel.

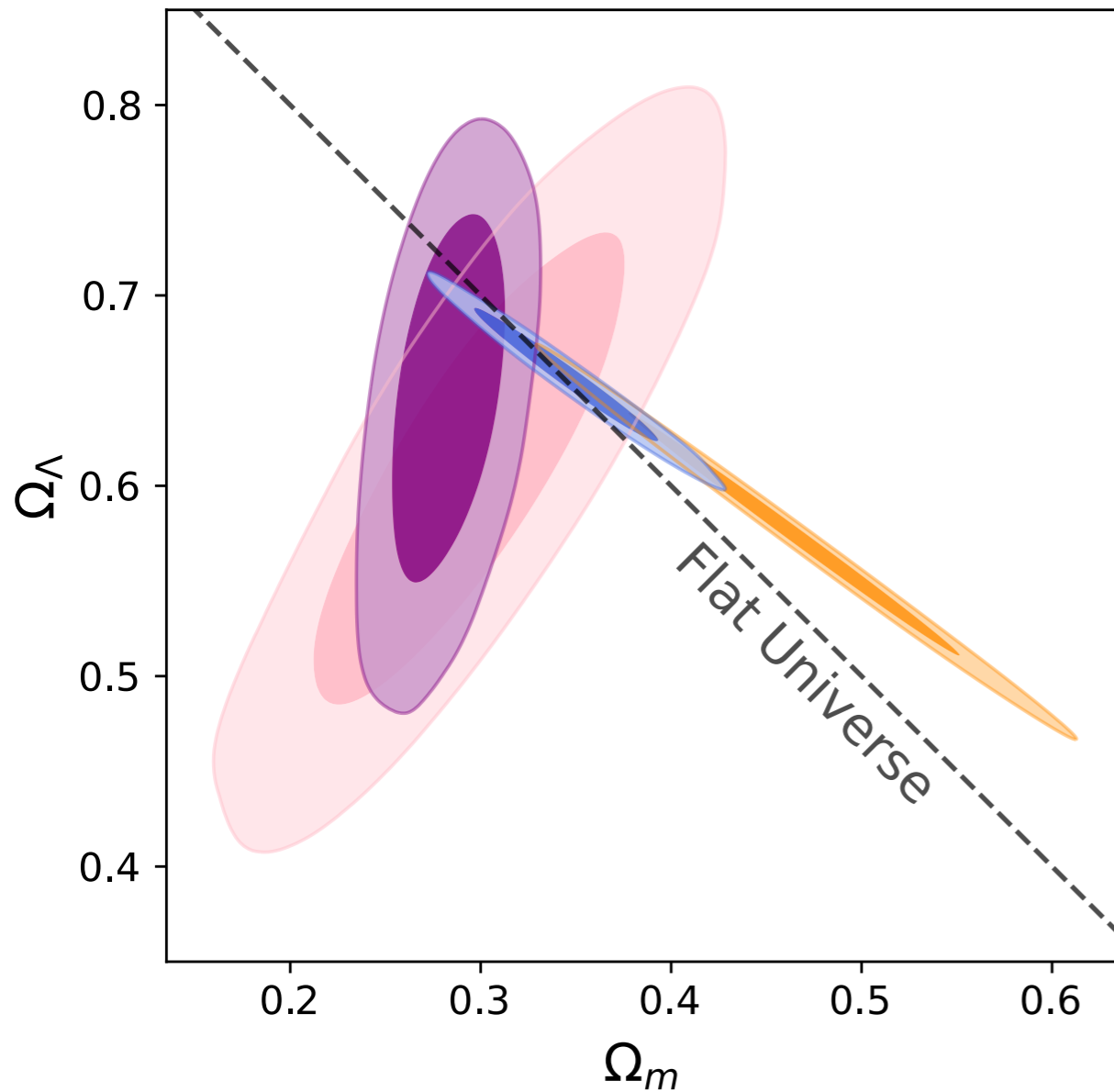


# Spatial Curvature

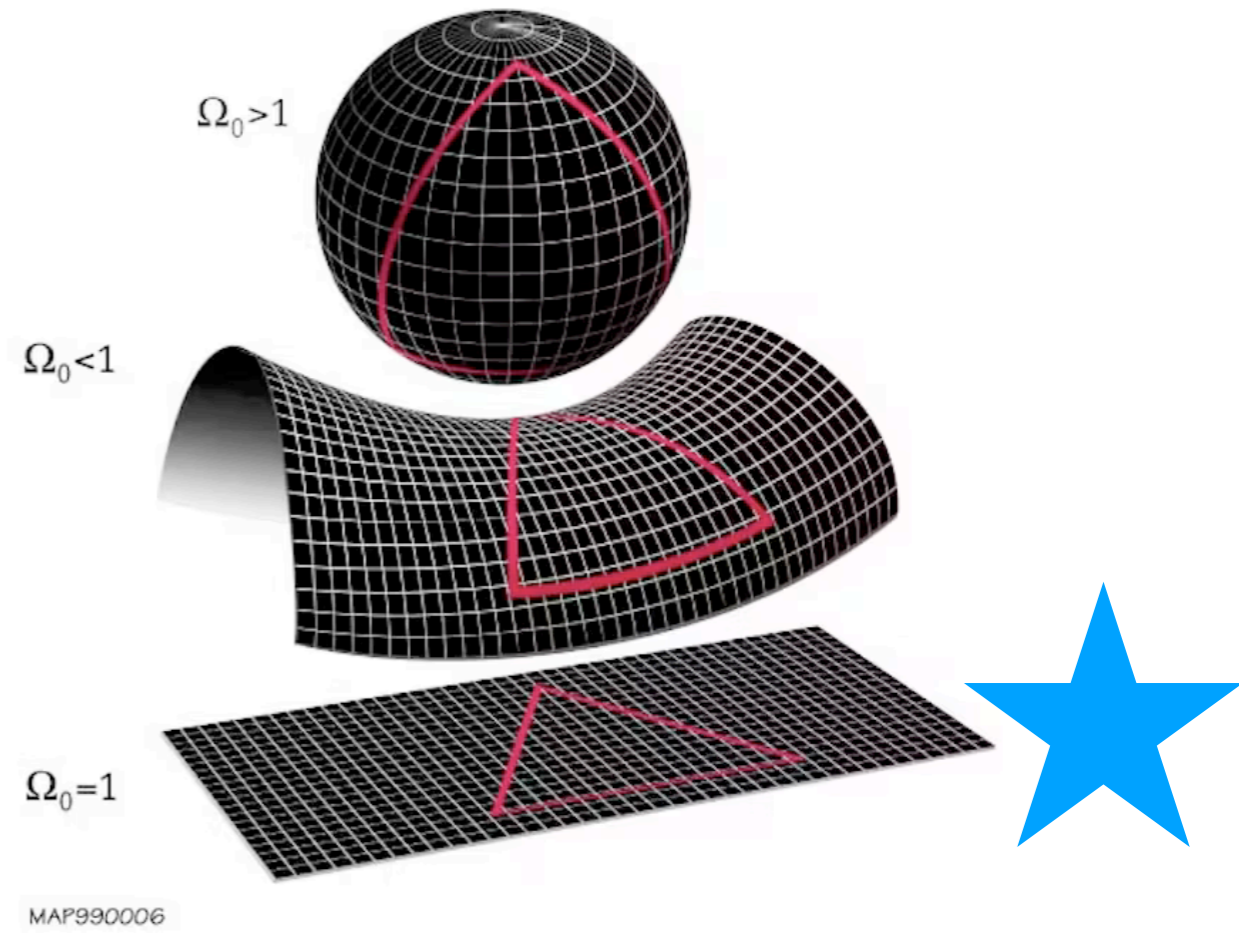


# Spatial Curvature

No evidence of spatial curvature (3-geometry = Euclidean)



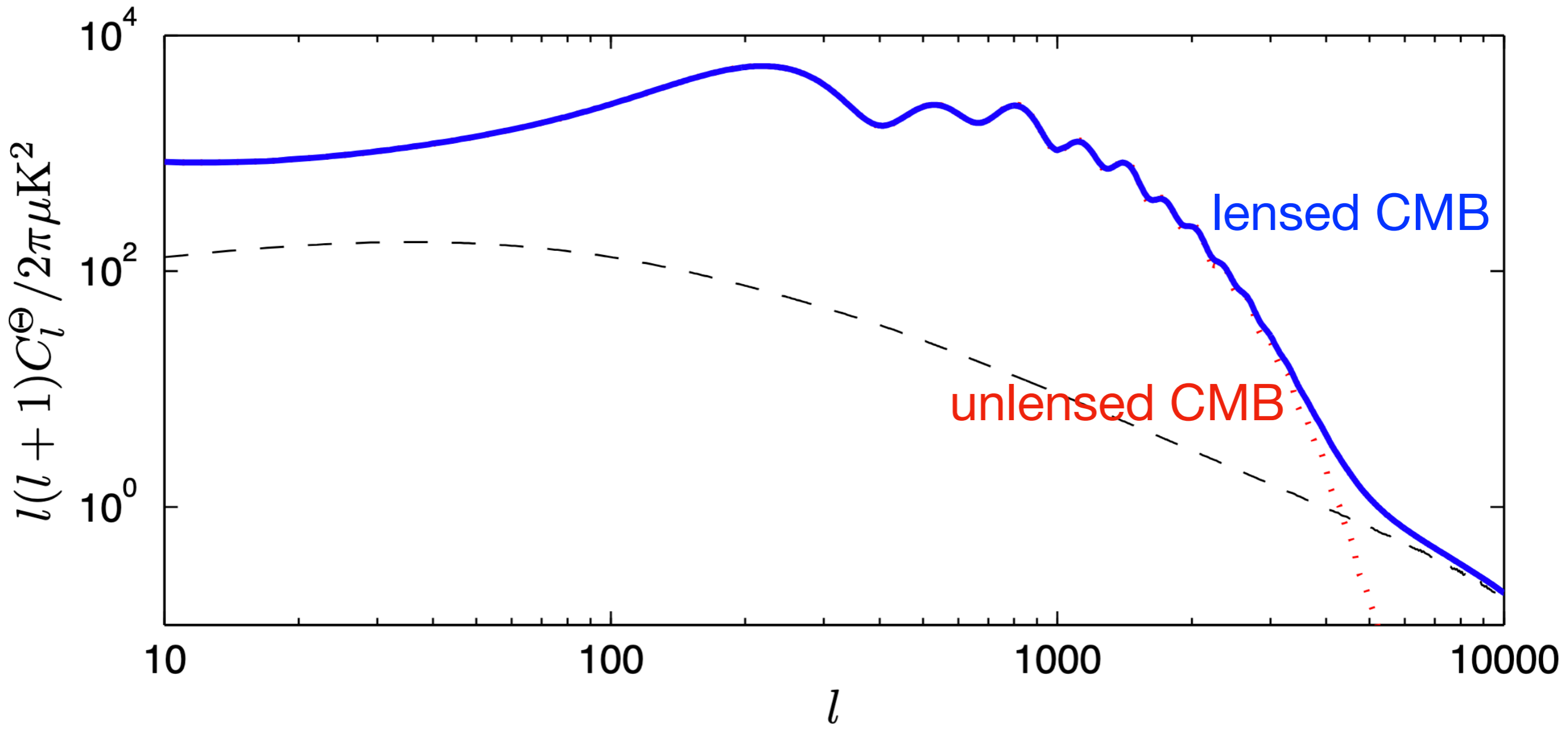
- Pantheon+ SNe (uncalib.)
- DESI Y1 BAO
- ACT
- Planck



$$\Omega_k = 0.0019 \pm 0.0015 \quad (68\%, \text{P-ACT-LB})$$

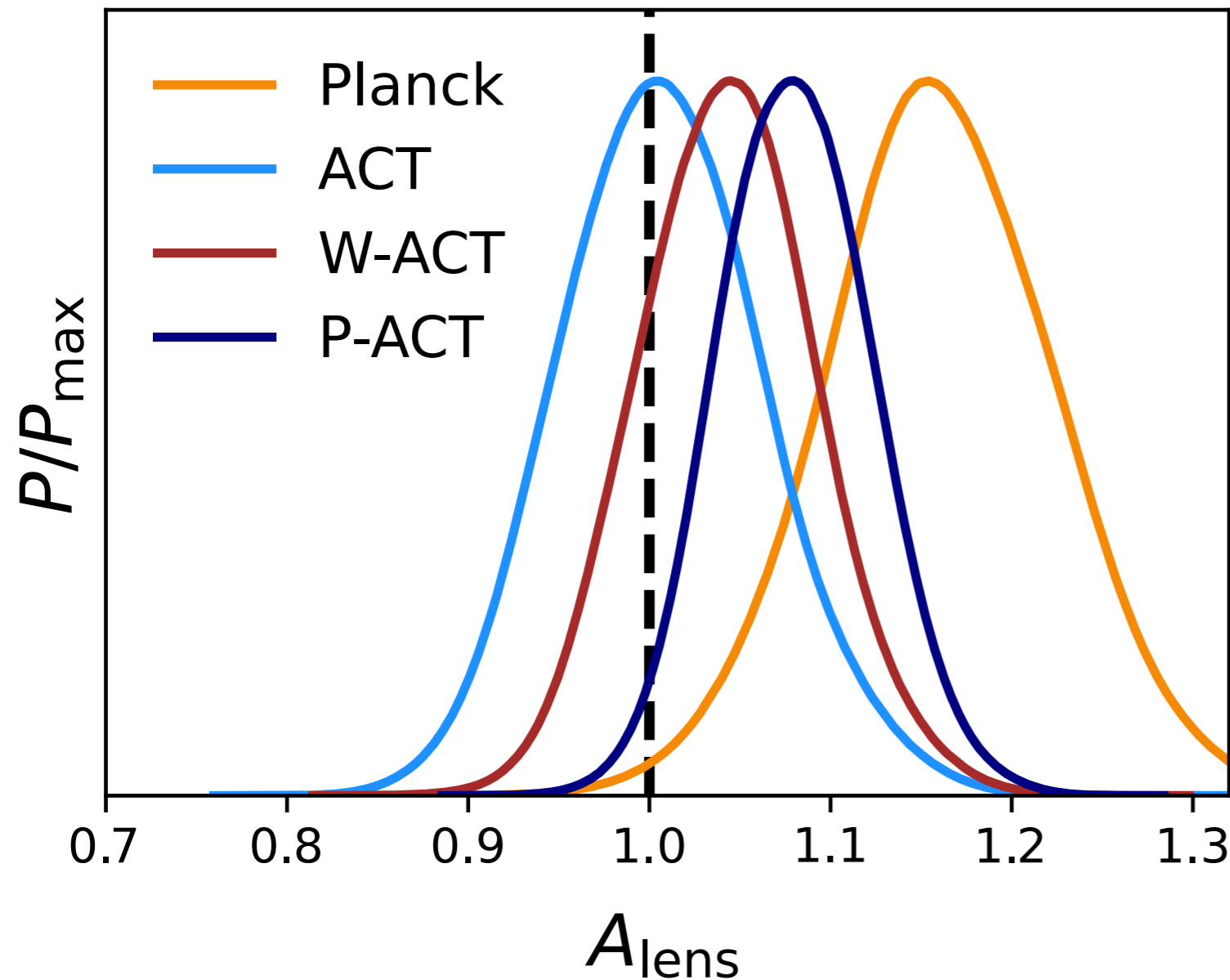
# Lensing Amplitude

Anomalous lensing of the CMB?



# Lensing Amplitude

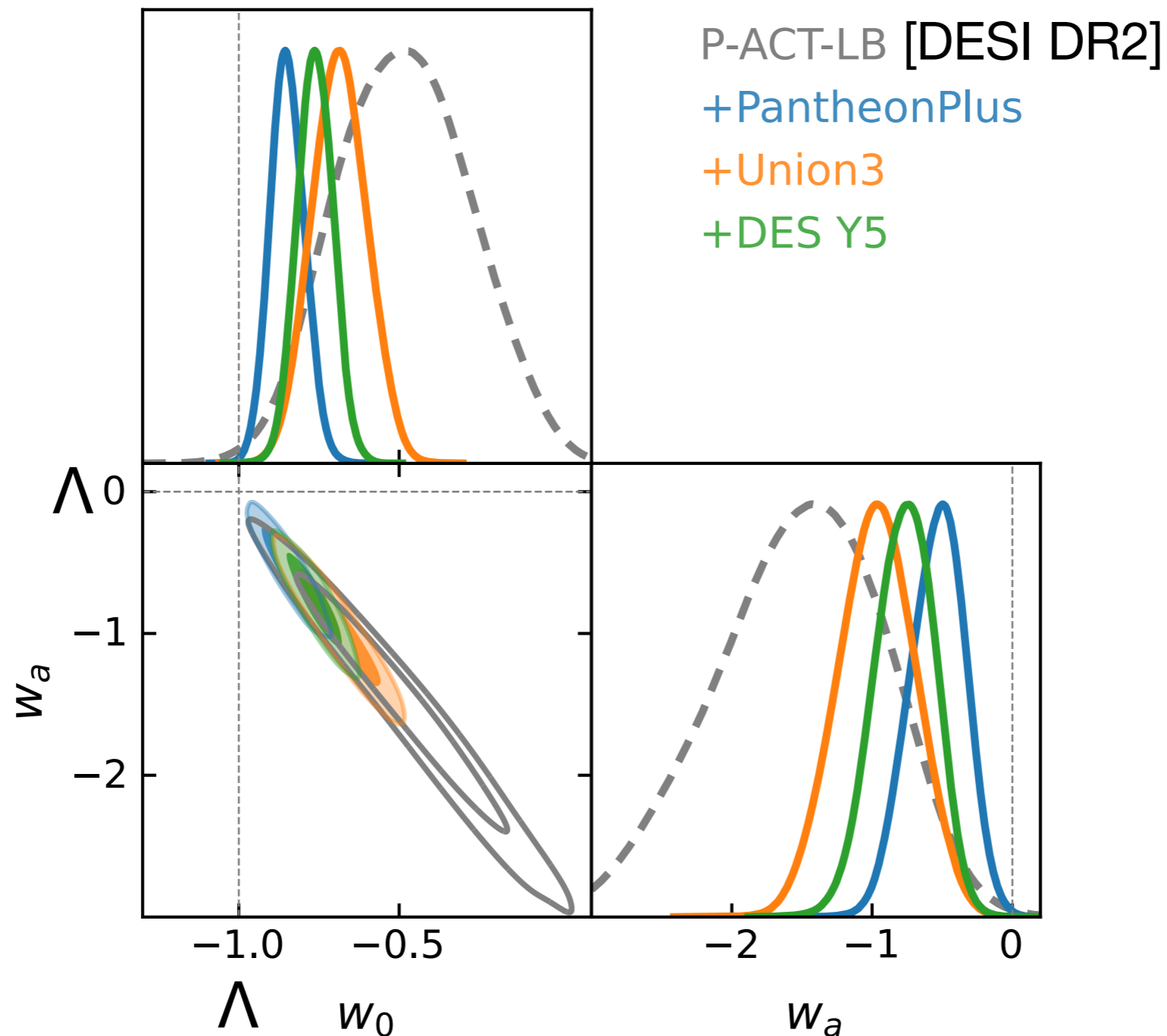
No evidence of excess “peak smearing” or “lensing anomaly” in ACT



$$\begin{aligned}
 A_{\text{lens}} &= 1.007 \pm 0.057 \quad (\text{ACT}) \\
 &= 1.08^{+0.10}_{-0.12} \quad (\text{ACT-TT}) \\
 &= 1.24^{+0.18}_{-0.22} \quad (\text{ACT-TE}) \\
 &= 0.89^{+0.10}_{-0.23} \quad (\text{ACT-EE}) \\
 A_{\text{lens}} &= 1.043 \pm 0.049 \quad (\text{W-ACT}), \\
 A_{\text{lens}} &= 1.081 \pm 0.043 \quad (\text{P-ACT})
 \end{aligned}$$

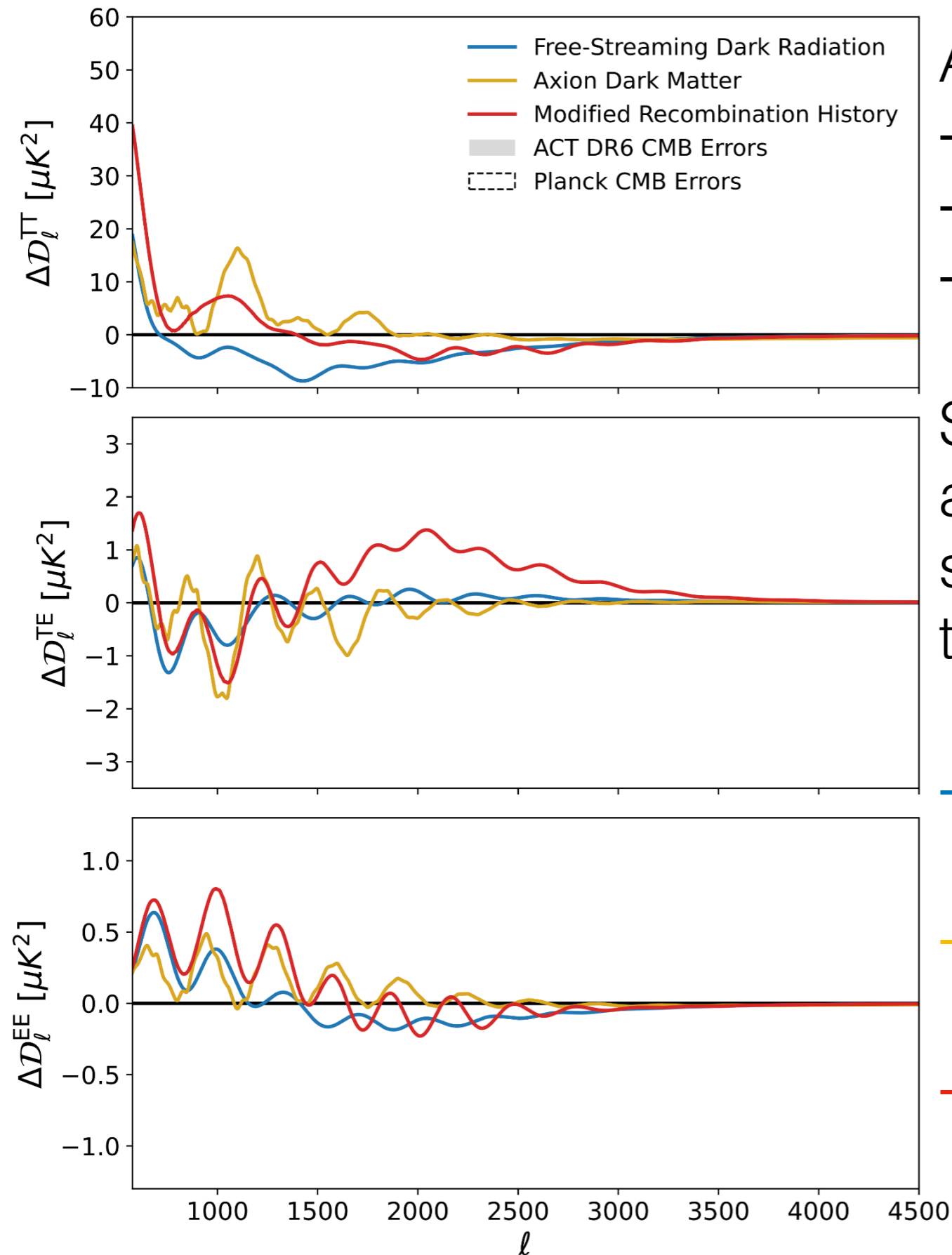
# Dark Energy

Inclusion of ACT DR6 in joint fit with Planck + DESI-DR2 slightly moves best-fit point toward  $\Lambda$  ( $\sim 0.2\sigma$ ) — evidence for evolving DE from CMB+DESI drops below  $3\sigma$



# ACT Constraining Power

Colin Hill  
Columbia



ACT DR6 probes new information:

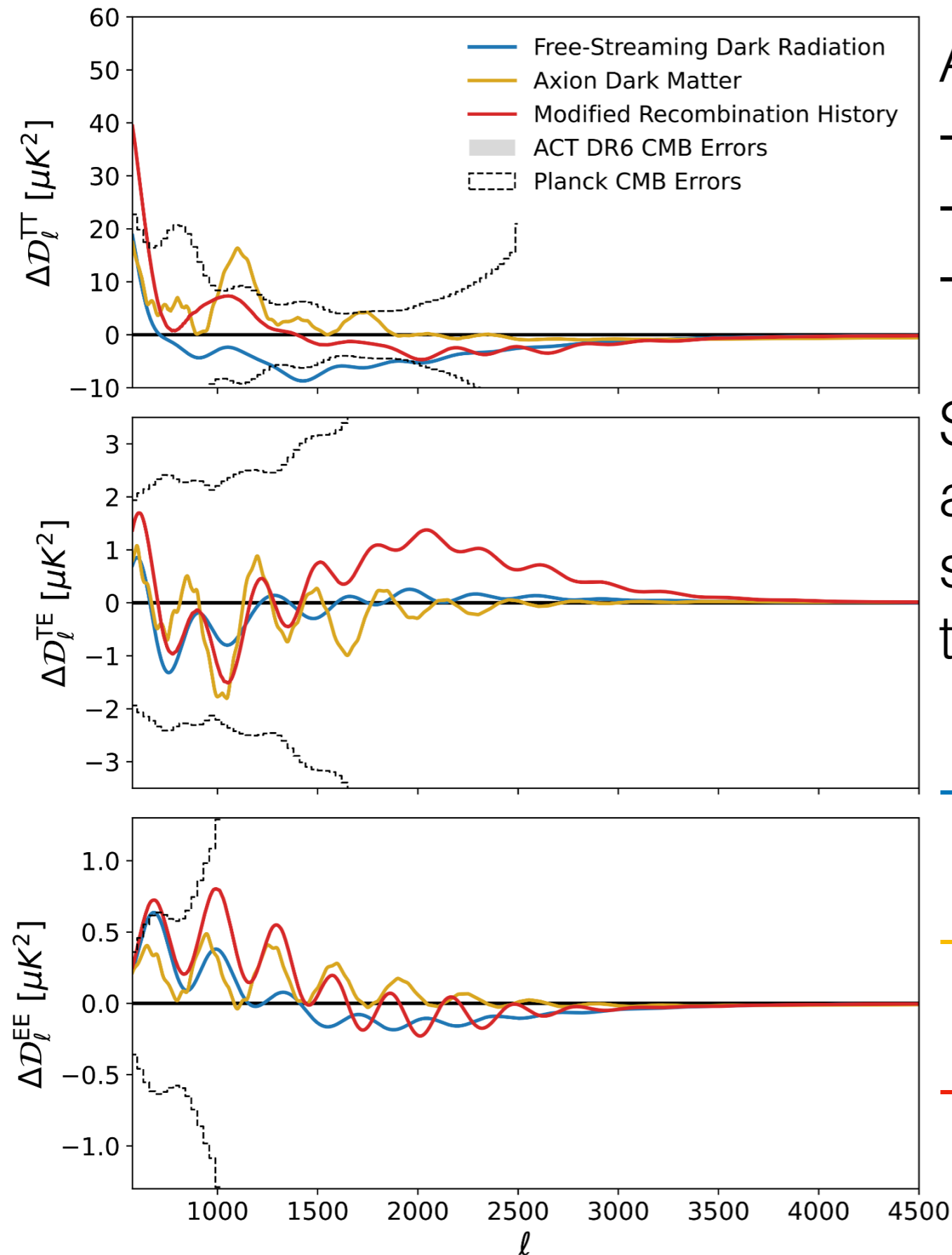
- in TT for multipoles  $> 1700$ ,
- in TE for multipoles  $> 1000$ ,
- in EE for multipoles  $> 600$ .

Select models that are well within allowed Planck bounds, but strongly excluded by the addition of the new ACT DR6 power spectra:

- Free-streaming dark radiation
- Axion-like DM sub-component
- Modified recombination history

# ACT Constraining Power

Colin Hill  
Columbia



ACT DR6 probes new information:

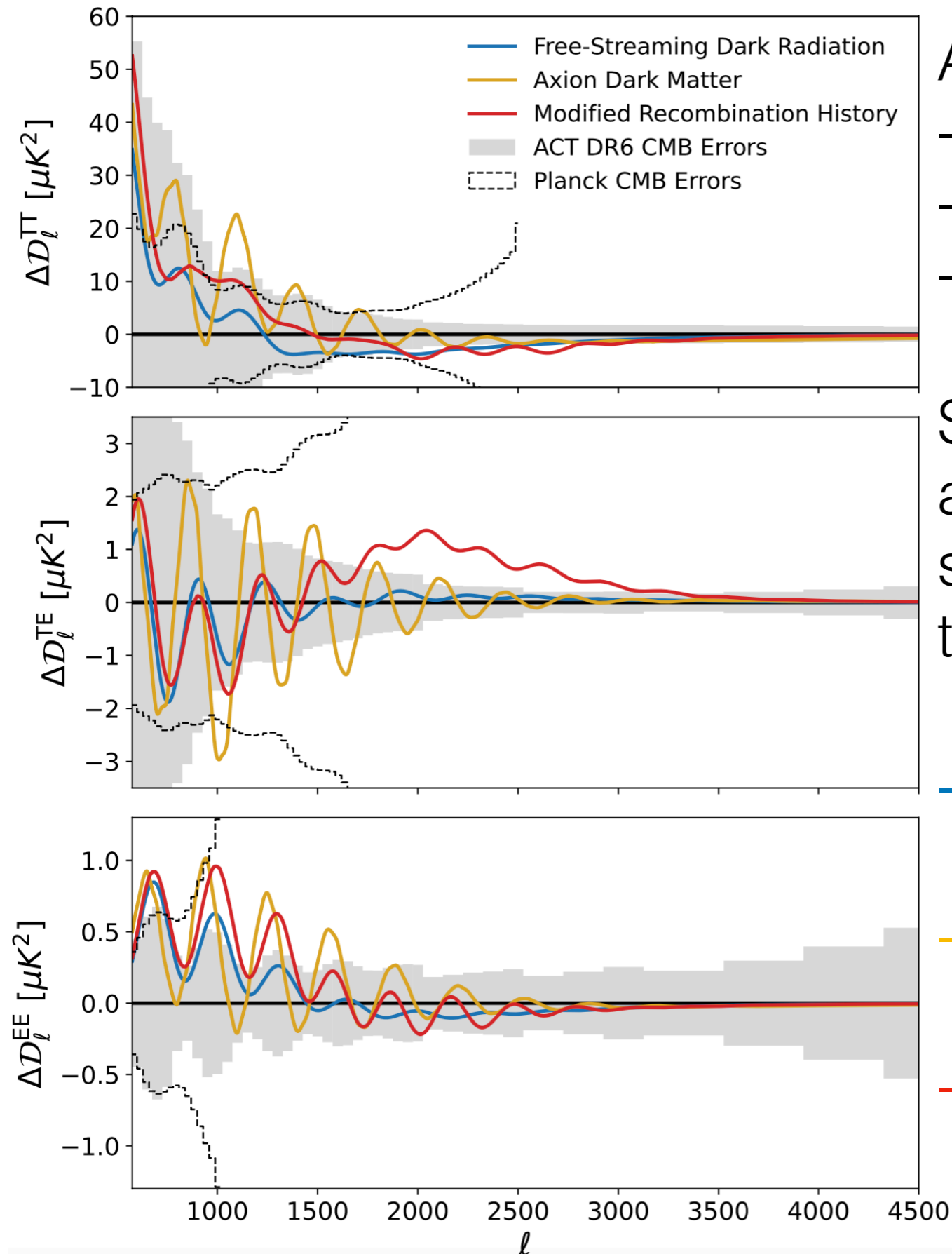
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- in TE for multipoles  $> 1000$ ,
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# ACT Constraining Power

Colin Hill  
Columbia



ACT DR6 probes new information:

- in TT for multipoles  $> 1700$ ,
- in TE for multipoles  $> 1000$ ,
- in EE for multipoles  $> 600$ .

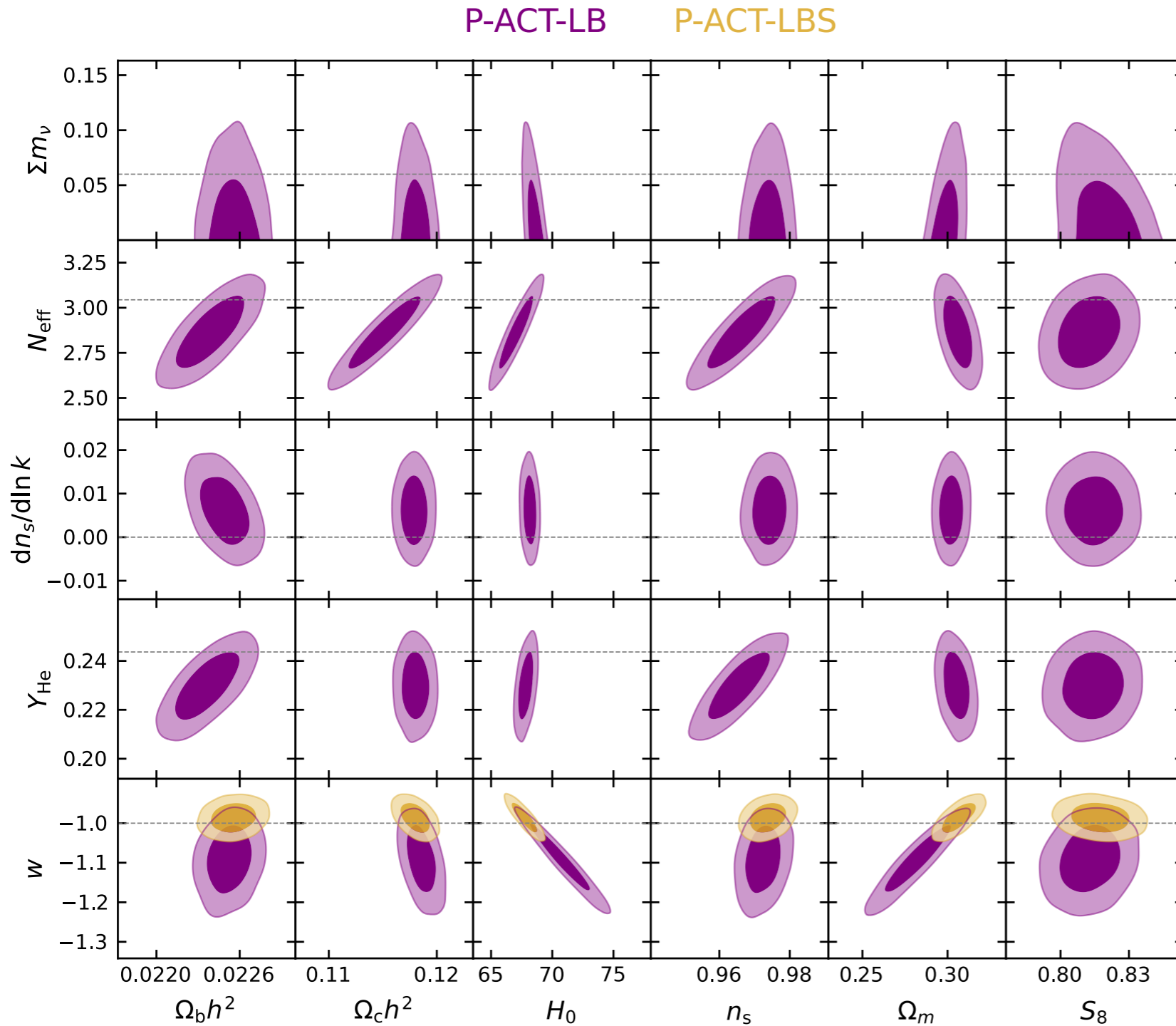
Select models that are well within allowed Planck bounds, but strongly excluded by the addition of the new ACT DR6 power spectra:

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- Axion-like DM sub-component
- Modified recombination history

# Cosmological Constraints

Colin Hill  
Columbia

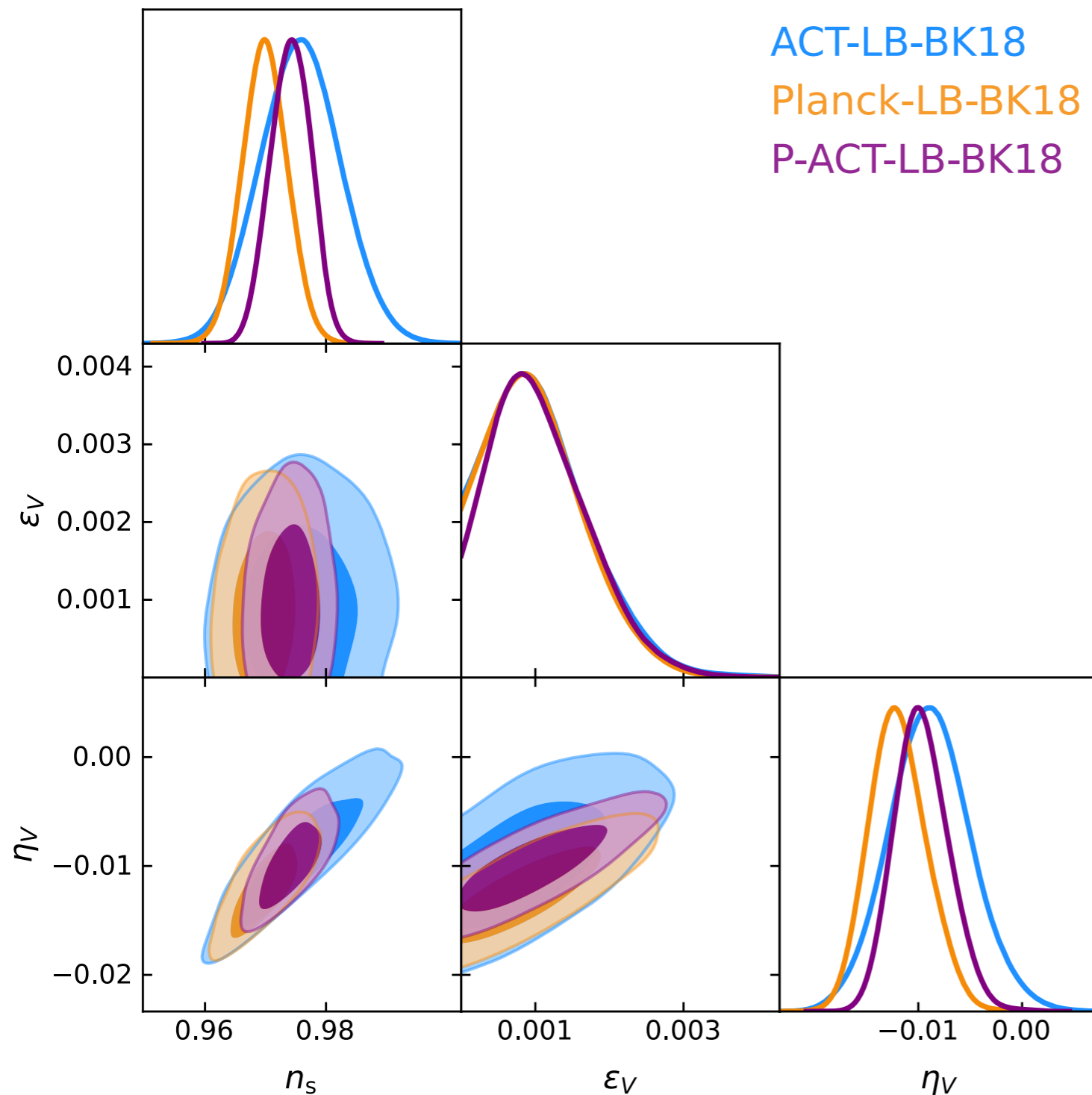
We investigated ~30 beyond-standard-model scenarios:  
no evidence of deviations from  $\Lambda$ CDM found



Model
Running of scalar spectral index
$P_{\mathcal{R}}(k)$
Isocurvature perturbations
Tensor modes
Early dark energy
Varying electron mass
Varying electron mass and curvature
Varying fine-structure constant
Varying fine-structure constant and curvature
Primordial magnetic fields
CMB temperature
Modified recombination history
Neutrino number, $N_{\text{eff}}$
Neutrino mass, $\sum m_{\nu}$
$N_{\text{eff}} + \sum m_{\nu}$
Neutrino self-interactions
Helium and deuterium
Axion-like particles
DM-baryon interactions
DM annihilation
Self-interacting DR
Interacting DR-DM
Spatial curvature
Dark energy equation of state, $w$
Dark energy equation of state, $w_0/w_a$
Interacting DE-DM
Modified gravity

# Cosmological Constraints

Constraints on potential slow-roll parameters (inflation)



$$\epsilon_V \equiv \frac{M_{Pl}^2}{2} \left( \frac{V_{,\phi}}{V} \right)^2$$

$$\eta_V \equiv M_{Pl}^2 \left( \frac{V_{,\phi\phi}}{V} \right)$$

$$r = 16\epsilon_V,$$

$$n_s - 1 = 2\eta_V - 6\epsilon_V$$

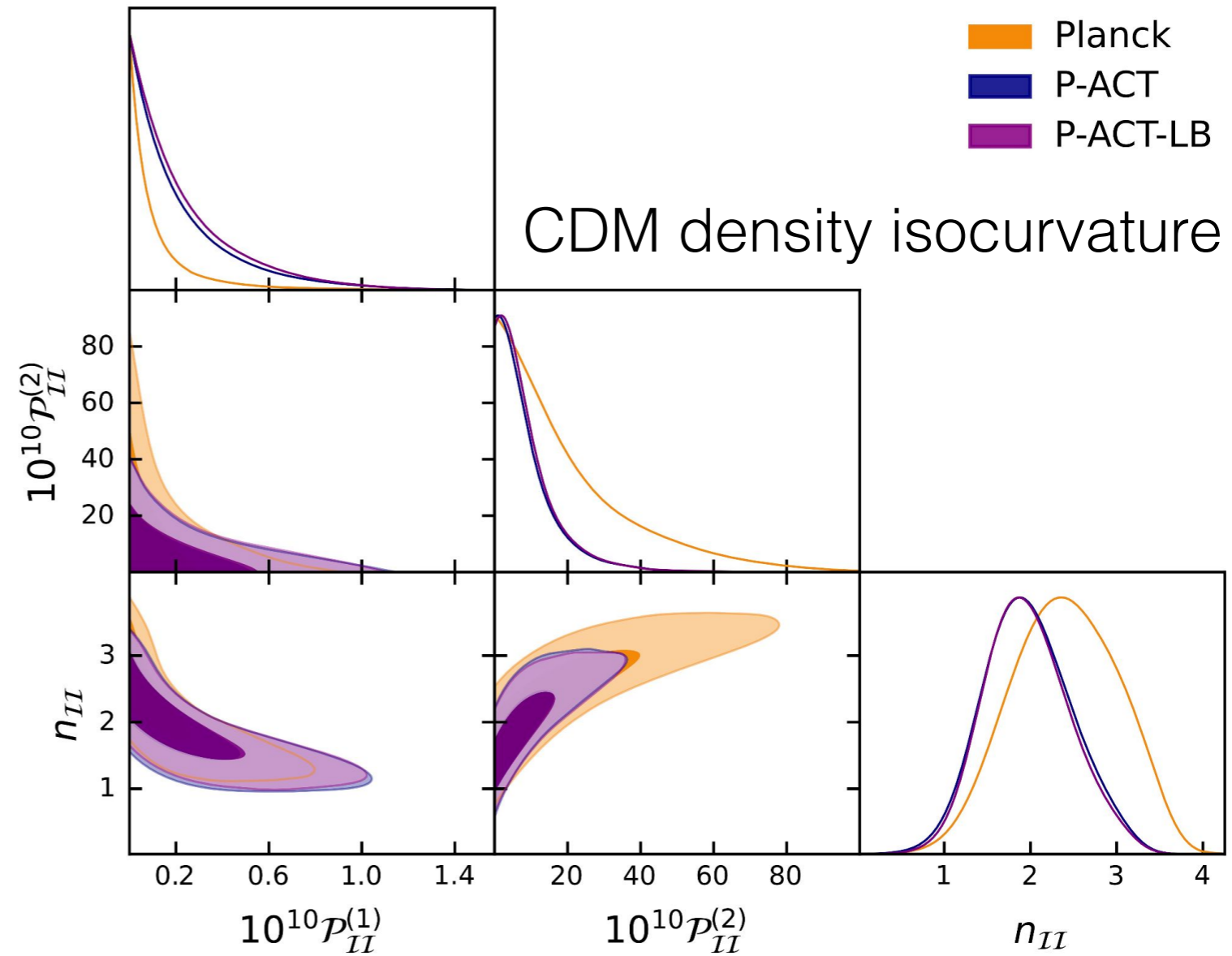
# Cosmological Constraints

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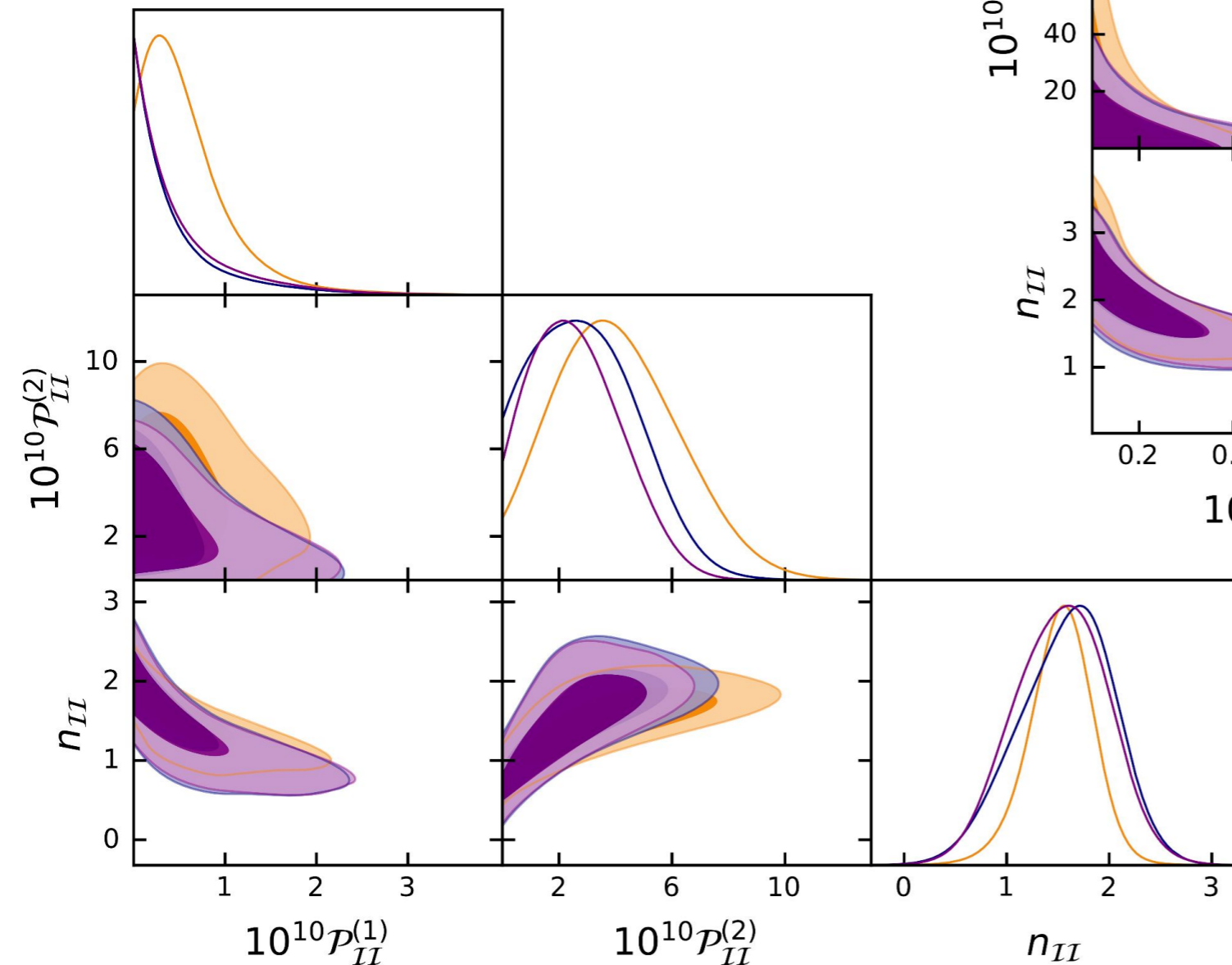
No evidence of primordial  
isocurvature  
perturbations

Planck  
P-ACT  
P-ACT-LB

CDM density isocurvature

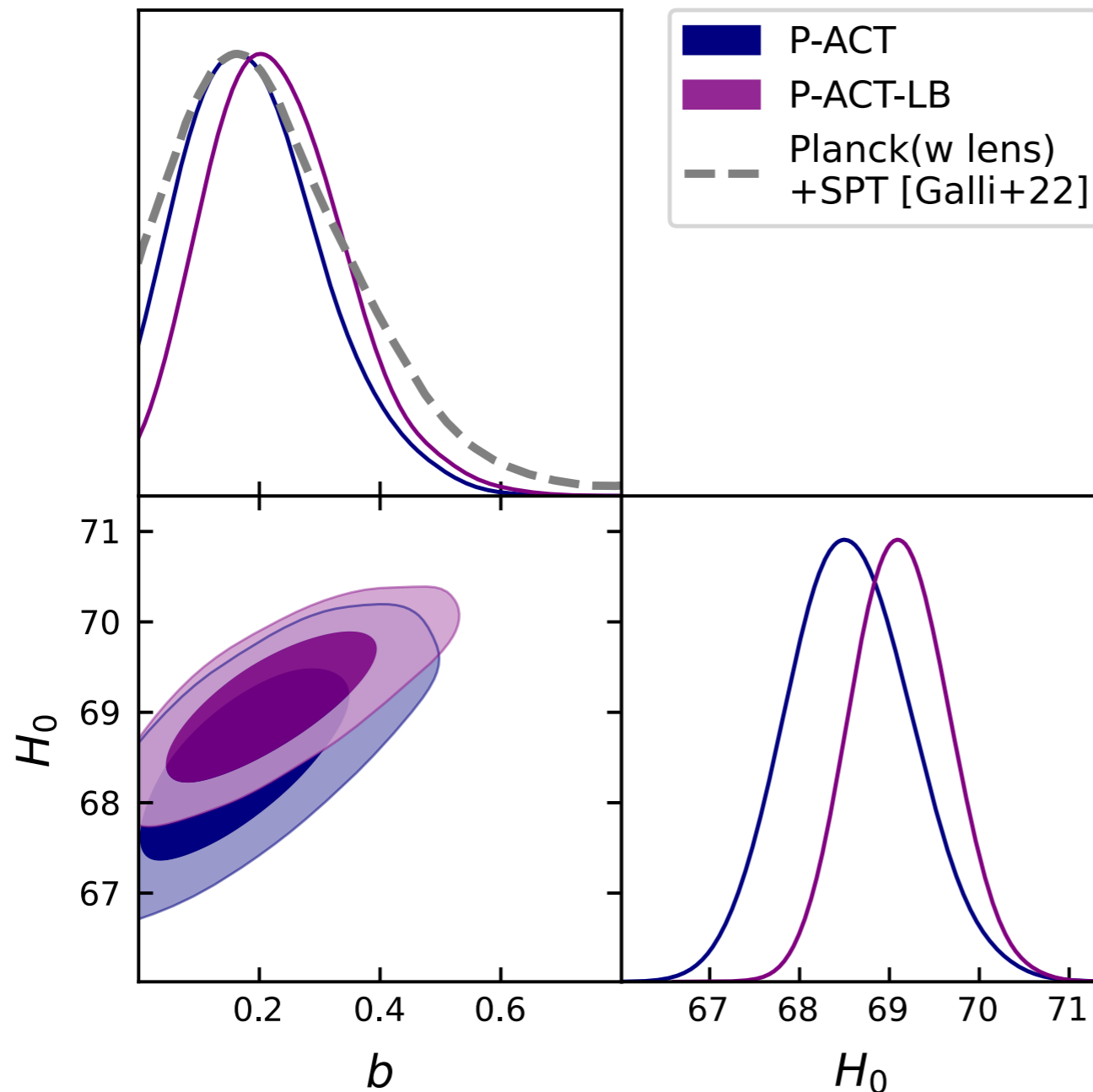


Neutrino density isocurvature



# Modified Recombination

Ex.: **primordial magnetic fields/baryon clumping**; variations of fundamental constants; change to CMB monopole temperature or distribution function



variance of small-scale  
baryon density  
fluctuations:

$$1 + b \equiv \sum_i f_i \Delta_i^2$$

$$\Delta_i \equiv \rho_{b,i} / \langle \rho_b \rangle$$

volume fraction  $f_i$

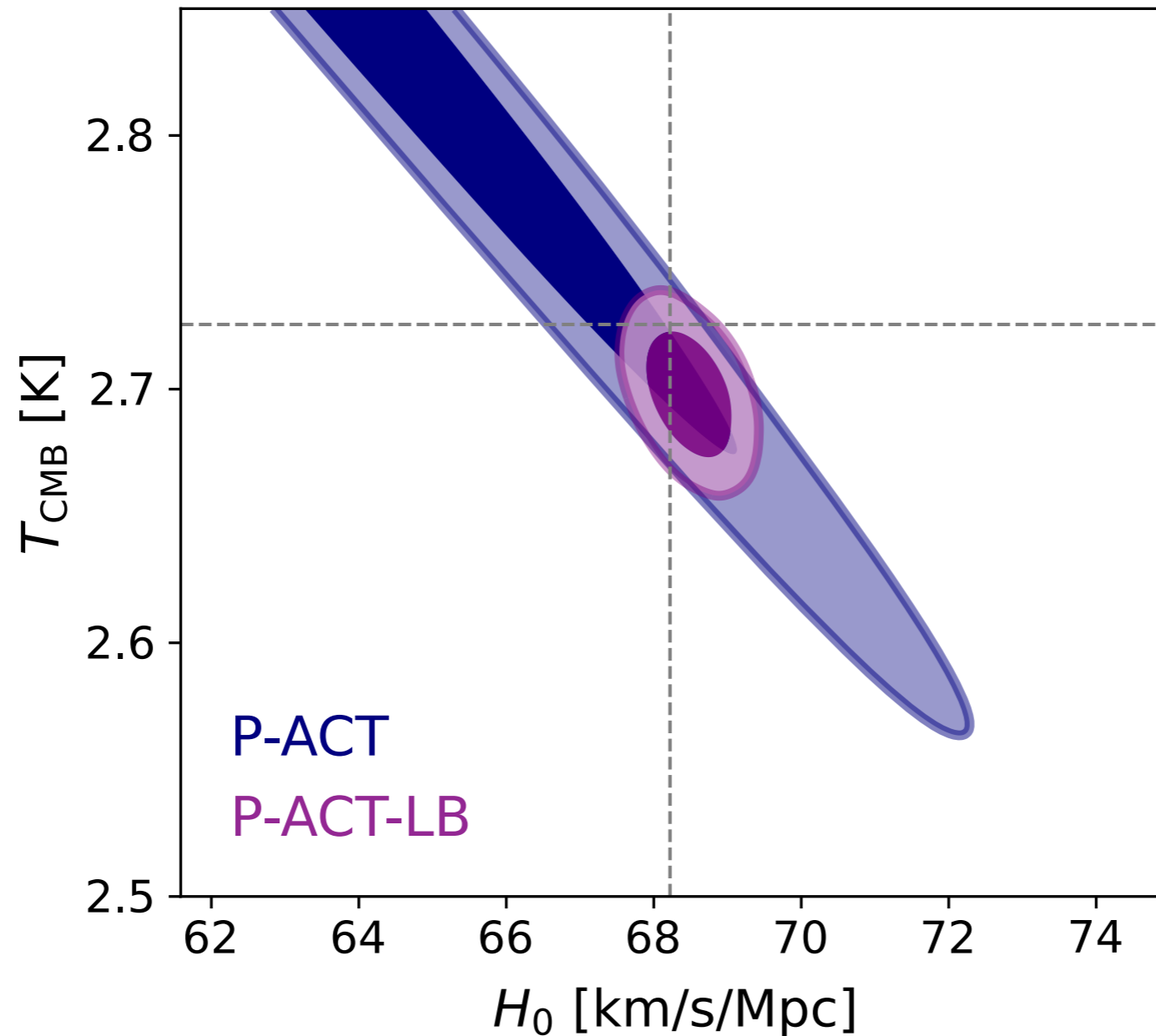
$$i = 1, 2, 3$$

$b < 0.41$  (95%, P-ACT),  
 $< 0.44$  (95%, P-ACT-LB)

~30% improvement in sensitivity over Planck

# Modified Recombination

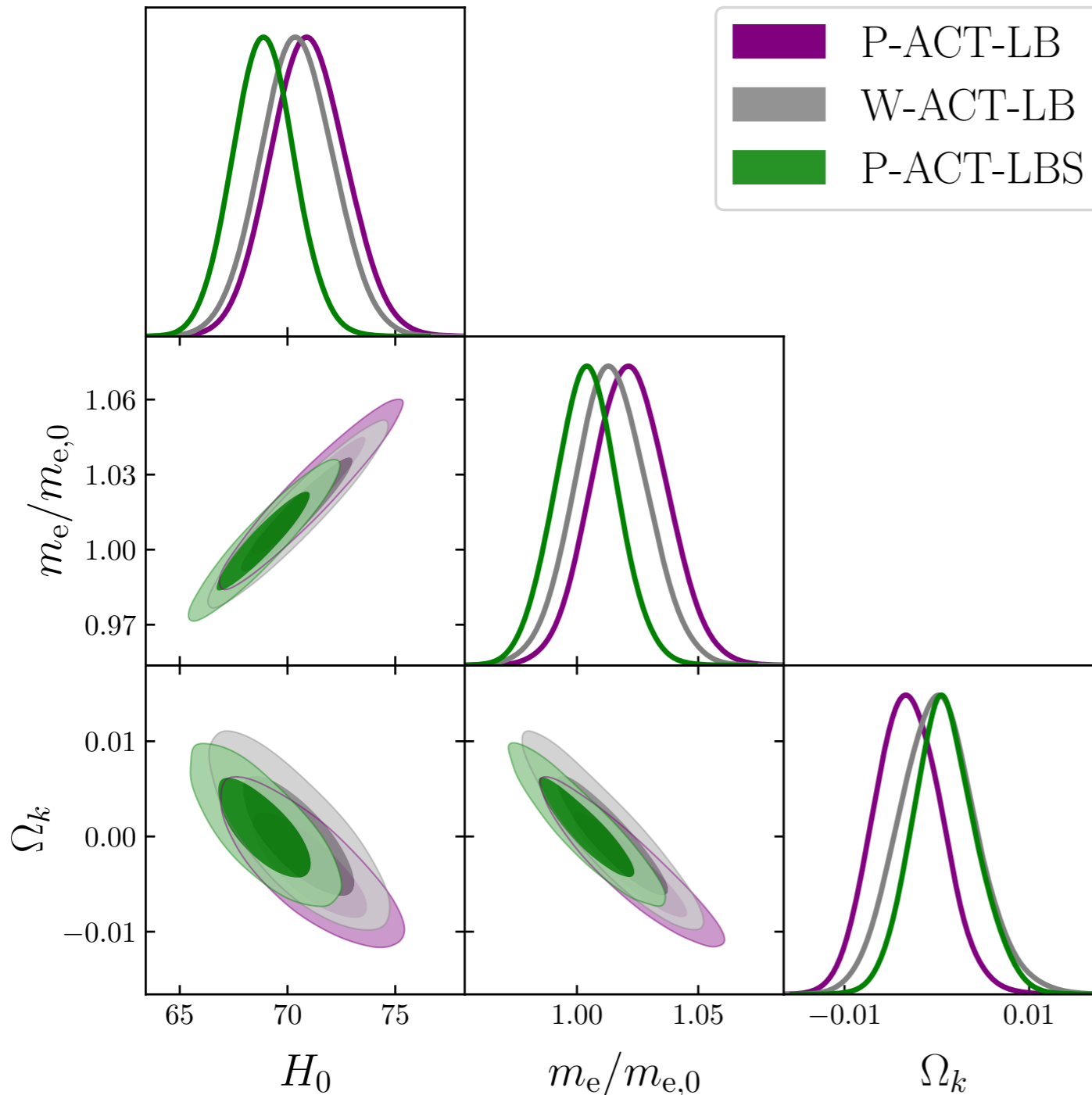
Ex.: primordial magnetic fields; variations of fundamental constants; **change to CMB monopole temperature** or distribution function



$$T_{\text{CMB}} = 2.698 \pm 0.016 \text{ K (68\%, P-ACT-LB)}$$

# Modified Recombination

Ex.: primordial magnetic fields; **variations of fundamental constants**;  
change to CMB monopole temperature or distribution function



Early-universe variation of  $m_e$ :

$$m_e/m_{e,0} = 1.0063 \pm 0.0056$$

$$H_0 = 69.1 \pm 1.0$$

P-ACT-LBS

+ varying spatial curvature:

$$m_e/m_{e,0} = 1.004 \pm 0.013$$

$$\Omega_k = 0.0008^{+0.0032}_{-0.0036}$$

$$H_0 = 68.9 \pm 1.4$$

P-ACT-LBS

Dominant physical effects:

$$\sigma_T \propto \alpha_{\text{EM}}^2 m_e^{-2}$$

$$E \propto \alpha_{\text{EM}}^2 m_e$$

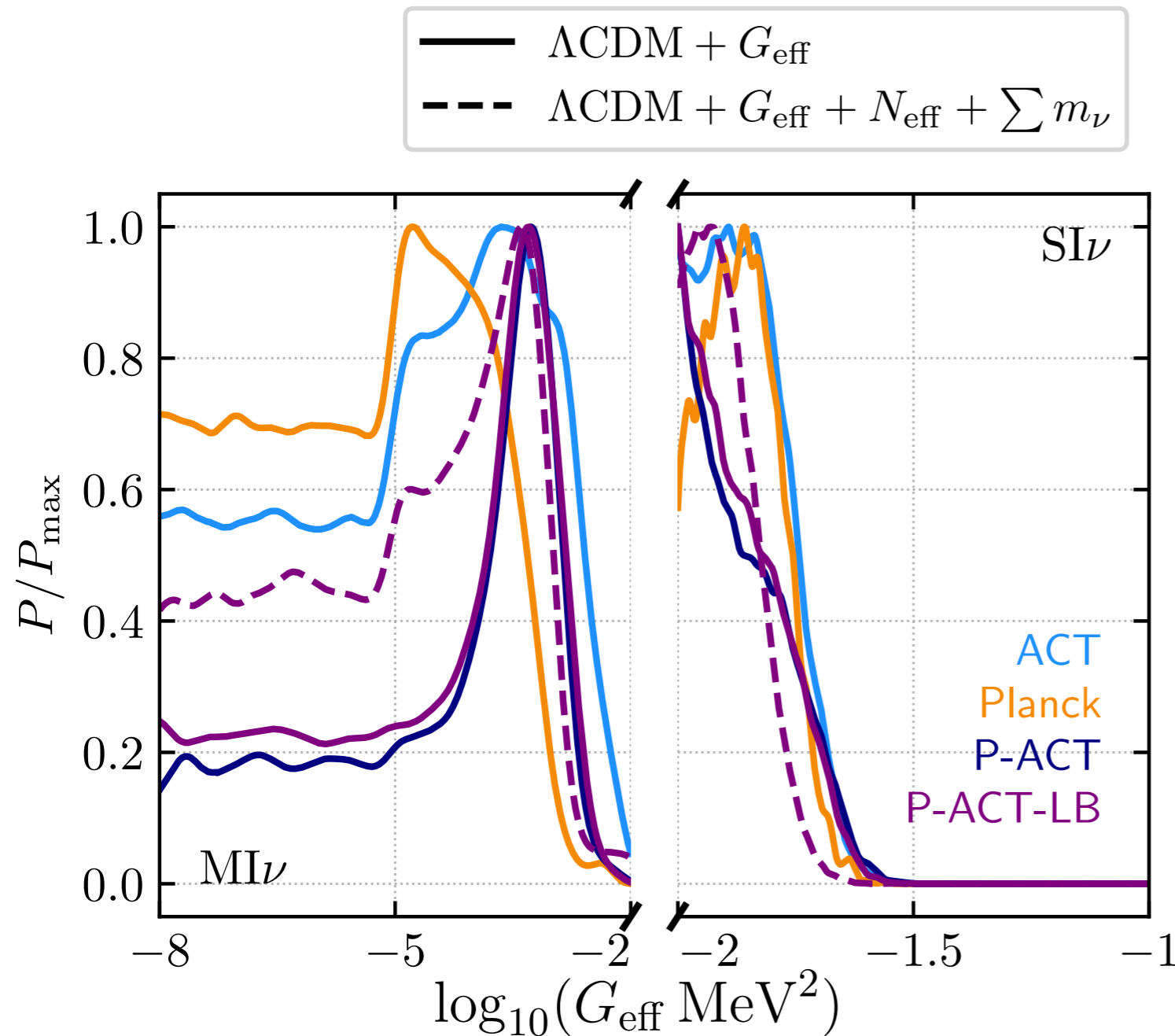
# Self-Interacting Neutrinos

Delay  $\nu$  free-streaming until  $z \sim z^*$        $\mathcal{L}_{\text{eff}} = G_{\text{eff}} \bar{\nu} \nu \bar{\nu} \nu$

$$\dot{\tau}_\nu = -a G_{\text{eff}}^2 T_\nu^5 \qquad g_\nu(\tau) \equiv -\dot{\tau}_\nu e^{-\tau_\nu}$$

# Self-Interacting Neutrinos

No evidence seen for self-interacting  $\nu$  component in ACT DR6  
(previous  $\sim 2.5\sigma$  hint had been seen in ACT DR4 data [Kreisch+24])



Frequentist: max. preference:  
 $\Delta\chi^2 = 3.1$  ( $1.8\sigma$ ) for  $MI\nu$   
 $\Delta\chi^2 \sim 0$  for  $SI\nu$

$MI\nu$ :  $H_0 = 68.2 \pm 0.4$  ( $G_{\text{eff}}$ )

$MI\nu$ :  $H_0 = 67.5 \pm 1.0$  ( $G_{\text{eff}} + N_{\text{eff}} + M_\nu$ )

# Curiosities / Hints?

If we looked at  $\sim 30$  models, there should be at least one  $\sim 2.5\sigma$  hint...

Louis, La Posta, Atkins, Jense, et al. (2025), 2503.14452

Calabrese & JCH, Jense, La Posta, et al. (2025), 2503.14454

# Modified Recombination

Ex.: primordial magnetic fields; **variations of fundamental constants**;  
change to CMB monopole temperature or distribution function

Early-universe variation of fine-structure constant  $\alpha_{\text{EM}}$ :

$$\alpha_{\text{EM}}/\alpha_{\text{EM},0} = 1.0043 \pm 0.0017 \text{ (68\%, P-ACT-LB)}$$

$$H_0 = 69.27 \pm 0.54 \text{ km/s/Mpc}$$

$\sim 2.5\sigma$  fluctuation away from unity

But parameter degeneracies are far smaller than in varying electron mass scenario — thus no significant increase in  $H_0$

Dominant physical effects:

$$\sigma_{\text{T}} \propto \alpha_{\text{EM}}^2 m_e^{-2} \quad E \propto \alpha_{\text{EM}}^2 m_e$$

cf. earlier work from Hart & Chluba, Sekiguchi & Takahashi, ++

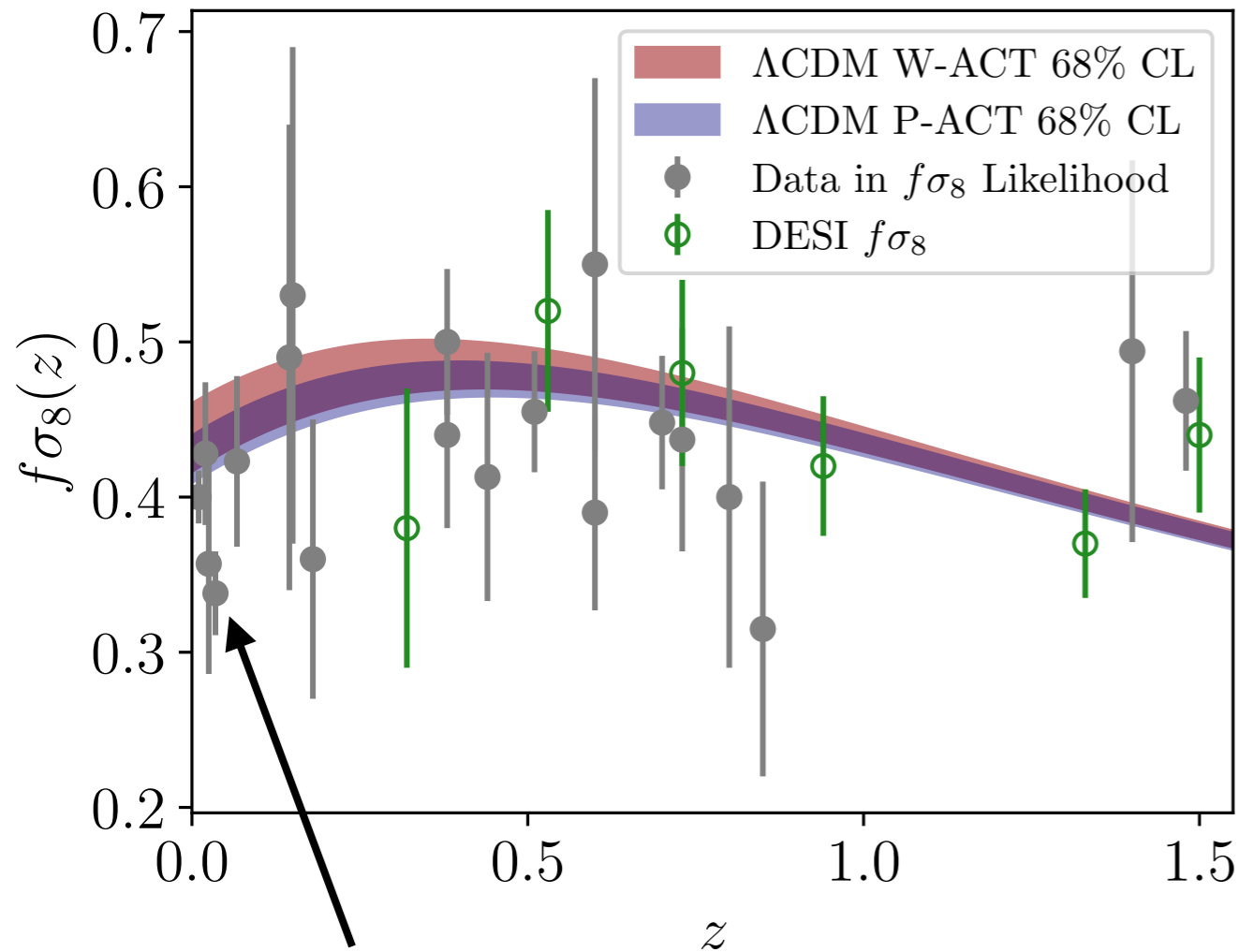
# Modified Growth

$$f = d \ln D / d \ln a$$

$$f(a) = \Omega_m^\gamma(a)$$

$$\text{GR: } \gamma = 0.55$$

$f\sigma_8$  from RSD and pec. vel.



two outlying points drive  
3.5 $\sigma$  pref. for  $\gamma > 0.55$

$$\left. \begin{aligned} \gamma &= 0.630 \pm 0.023 \\ S_8 &= 0.8050 \pm 0.0081 \end{aligned} \right\} (68\%, \text{P-ACT-LB-}f\sigma_8)$$

cf. earlier work from Nguyen, Huterer, +

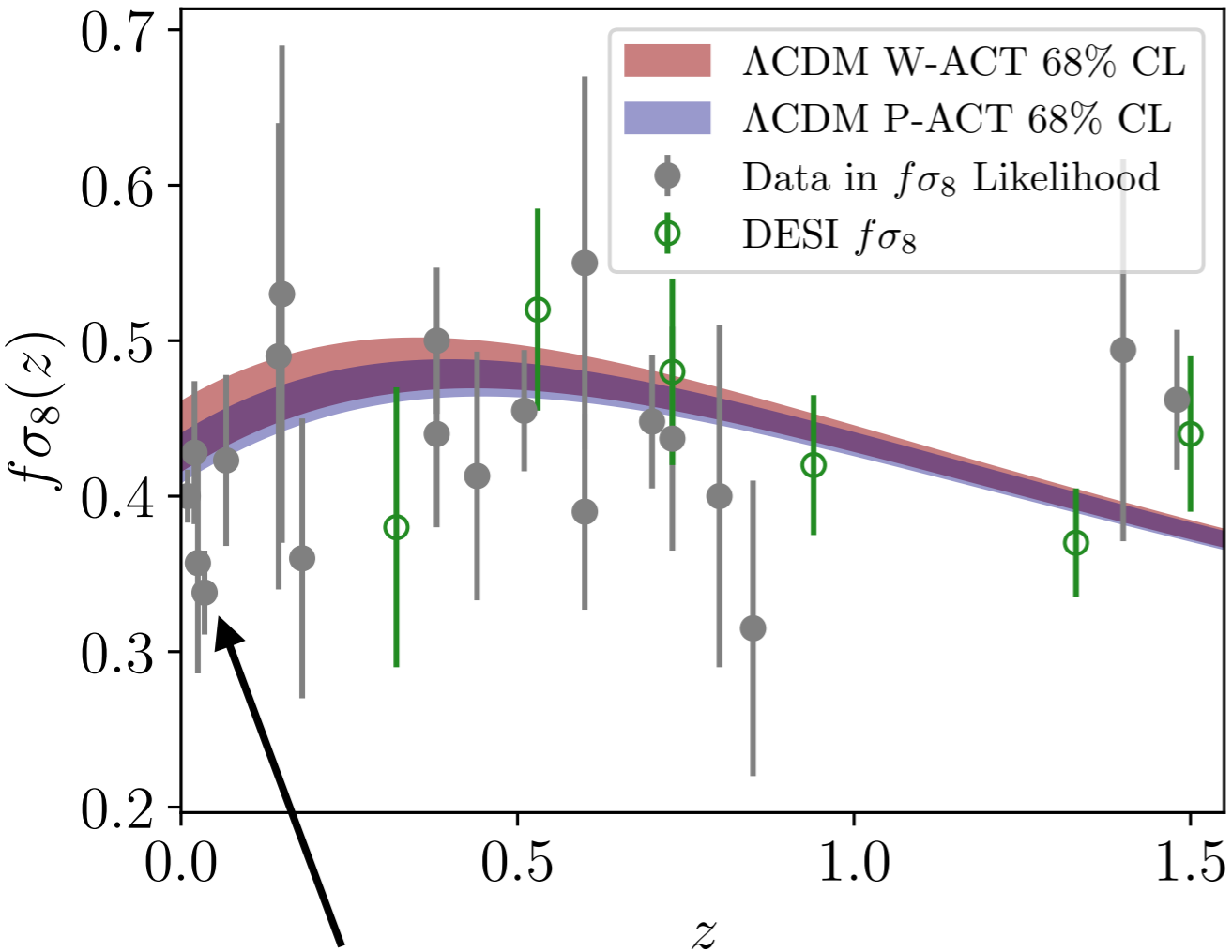
# Modified Growth

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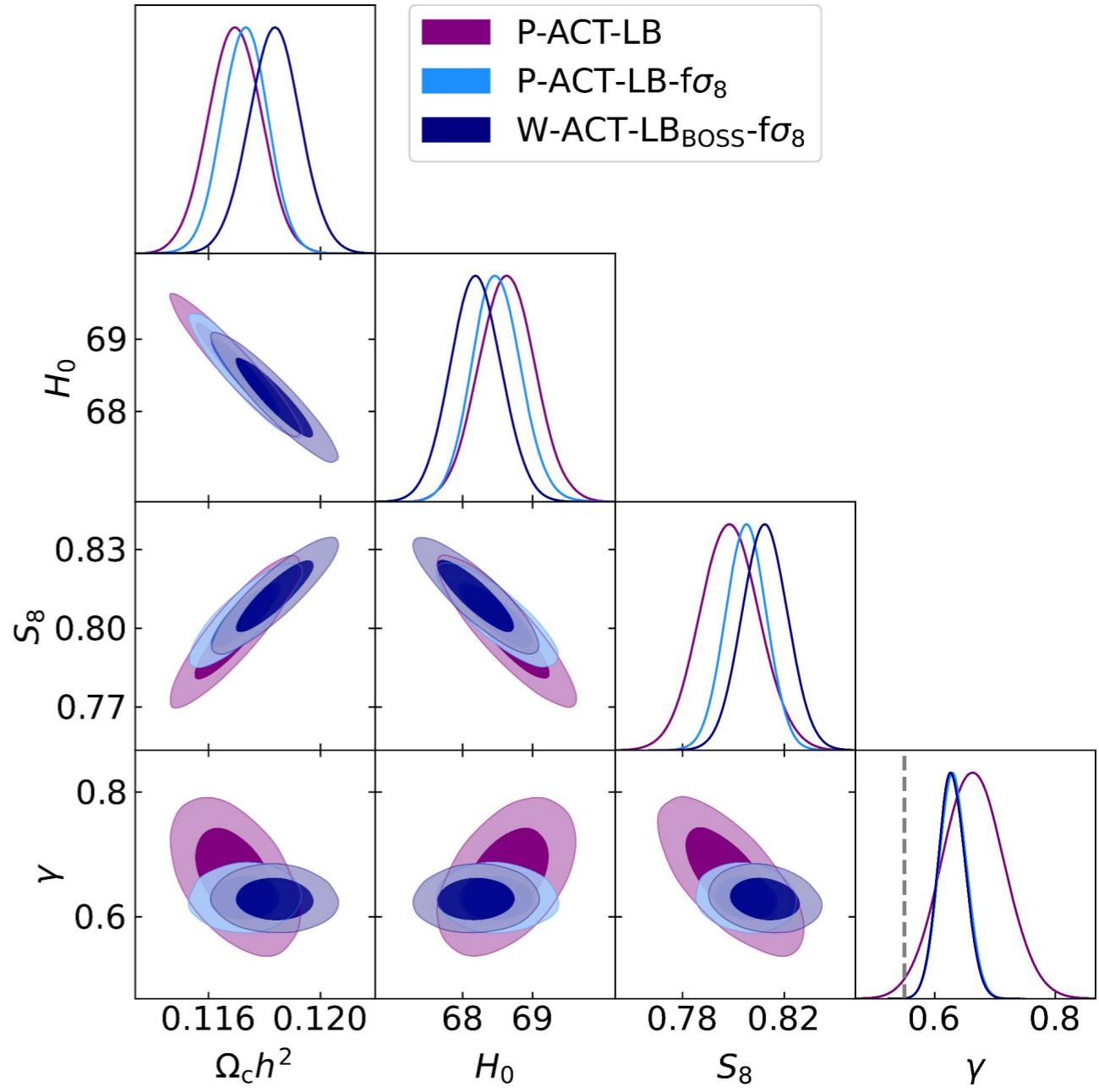
$f(a) = \Omega_m^\gamma(a)$

GR:  $\gamma = 0.55$

$f\sigma_8$  from RSD and pec. vel.



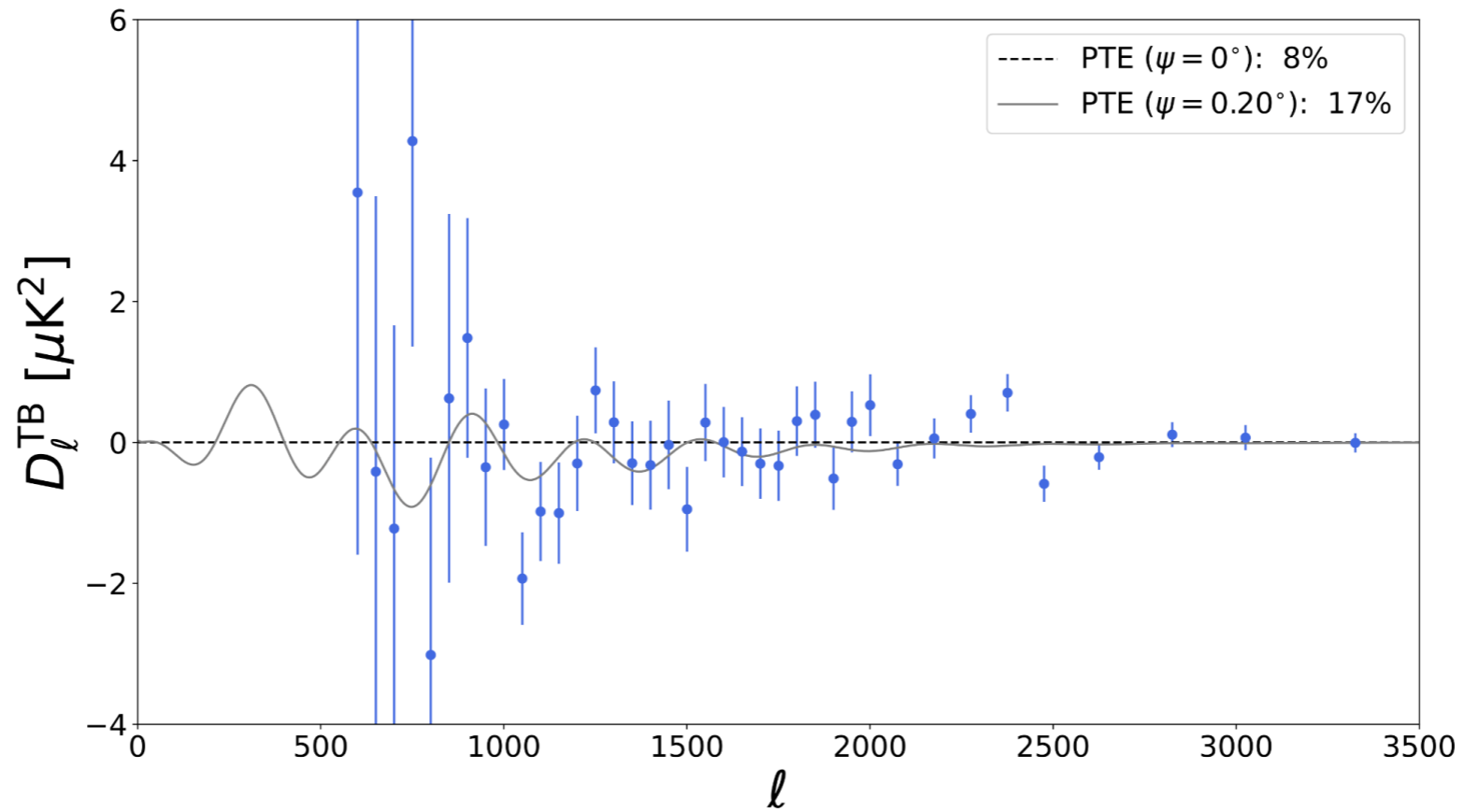
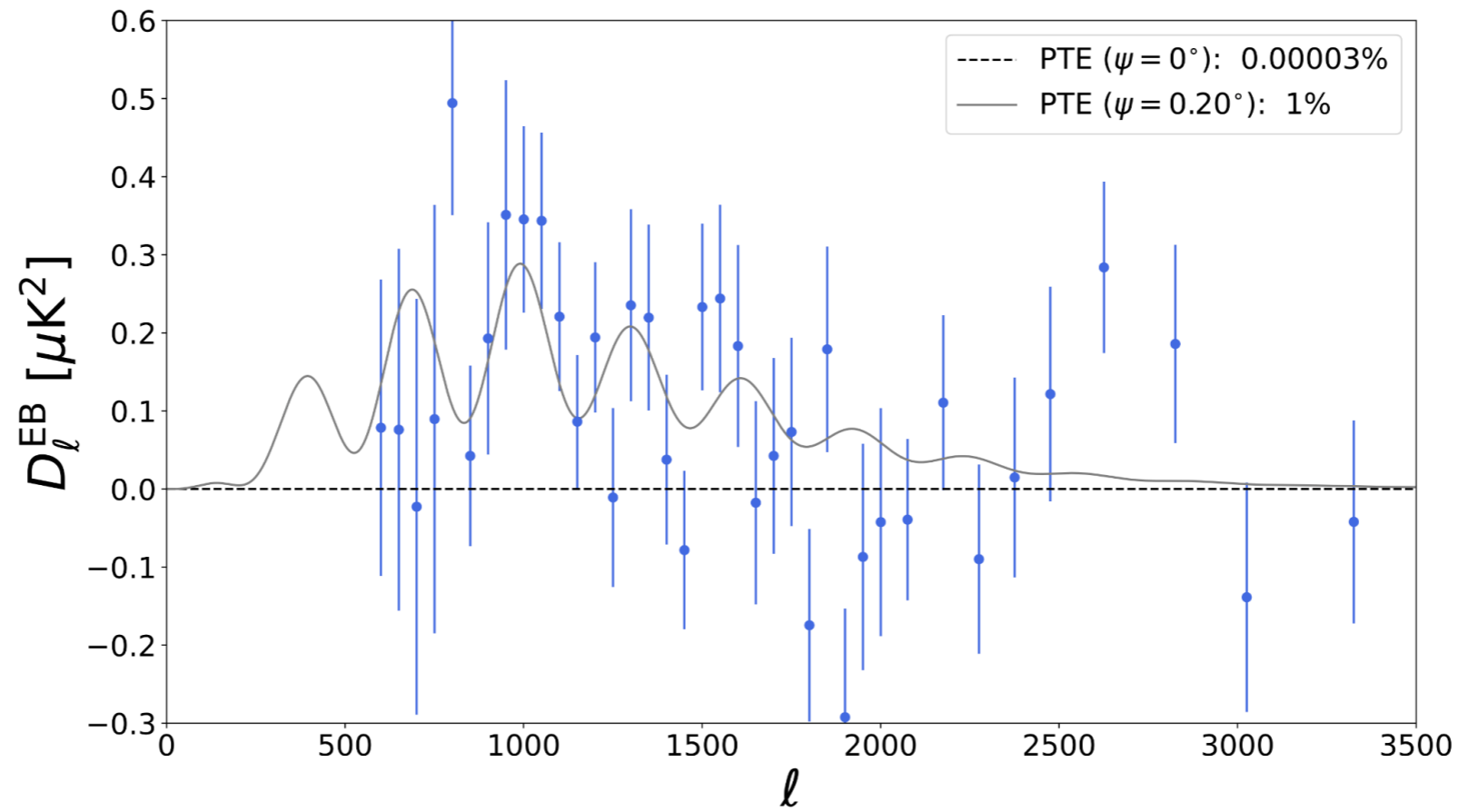
two outlying points drive  $3.5\sigma$  pref. for  $\gamma > 0.55$



$$\left. \begin{aligned} \gamma &= 0.630 \pm 0.023 \\ S_8 &= 0.8050 \pm 0.0081 \end{aligned} \right\} (68\%, \text{P-ACT-LB-}f\sigma_8)$$

$$\left. \begin{aligned} \gamma &= 0.663 \pm 0.052 \\ S_8 &= 0.799 \pm 0.012 \end{aligned} \right\} (68\%, \text{P-ACT-LB})$$

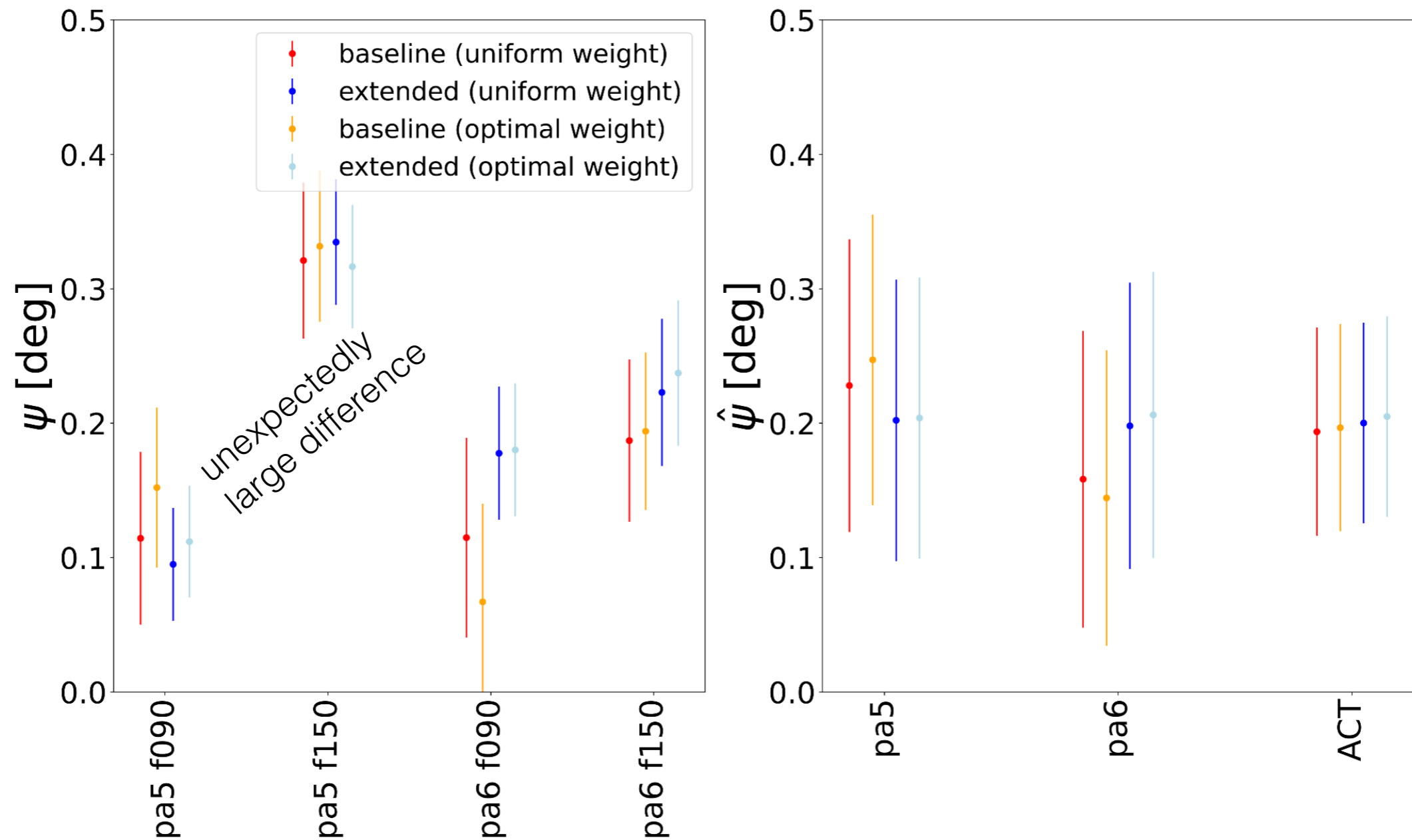
# EB and TB Power Spectra



# EB and TB Power Spectra

Combined best estimate of overall angle:  $0.20^\circ \pm 0.08^\circ$

Error bar dominated by systematic uncertainty from optics modeling

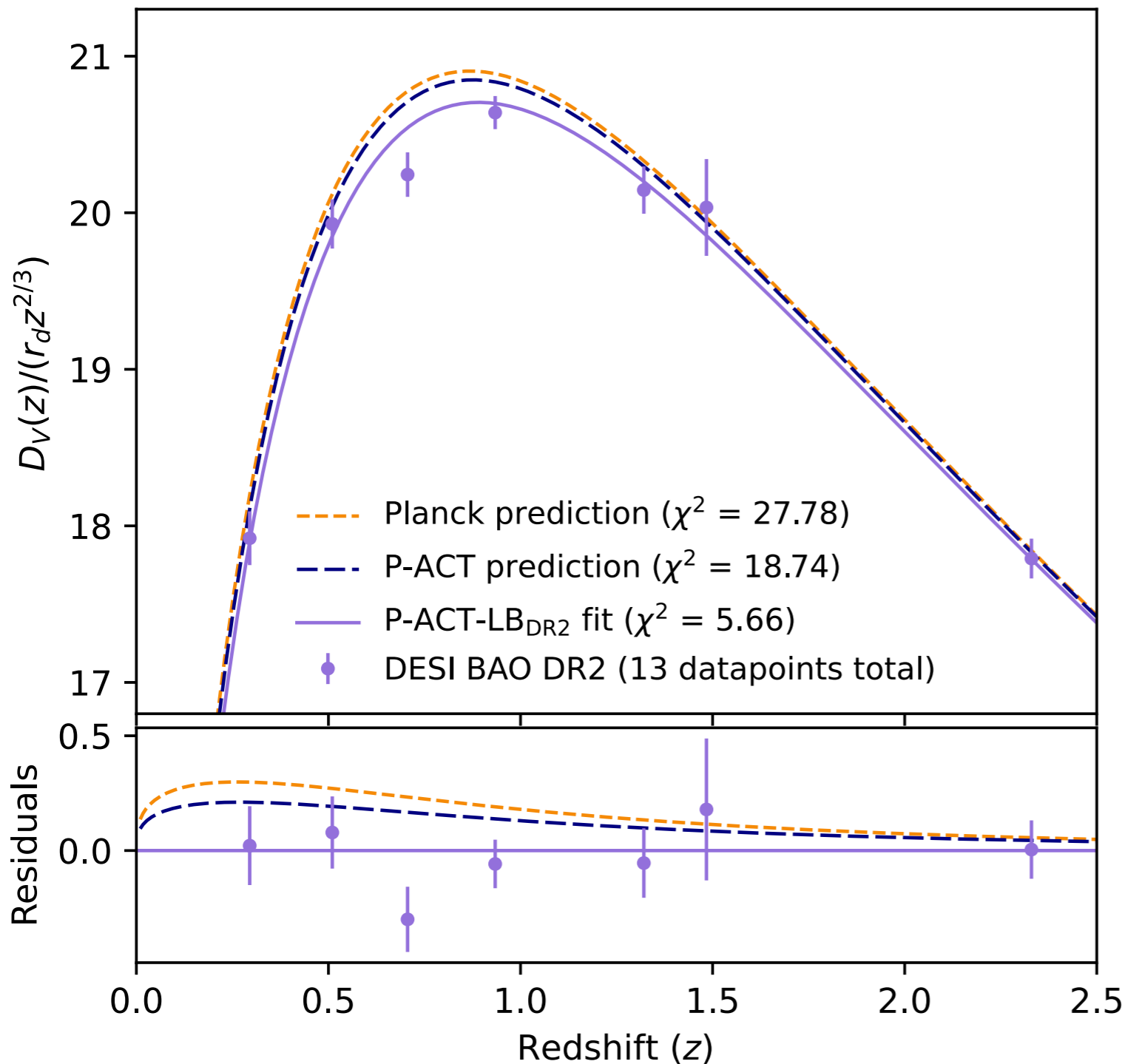


Planck (Eskilt & Komatsu 2022):  $0.34^\circ \pm 0.09^\circ$

# Cosmological Concordance

Colin Hill  
Columbia

- Predictions of the best-fit P-ACT  $\Lambda$ CDM model agree well with direct low-redshift measurements, including DESI DR2 (released March 19, post-DR6)



**DESI DR2 PTE  
w.r.t. P-ACT  
 $\Lambda$ CDM = 0.13 —  
good agreement**

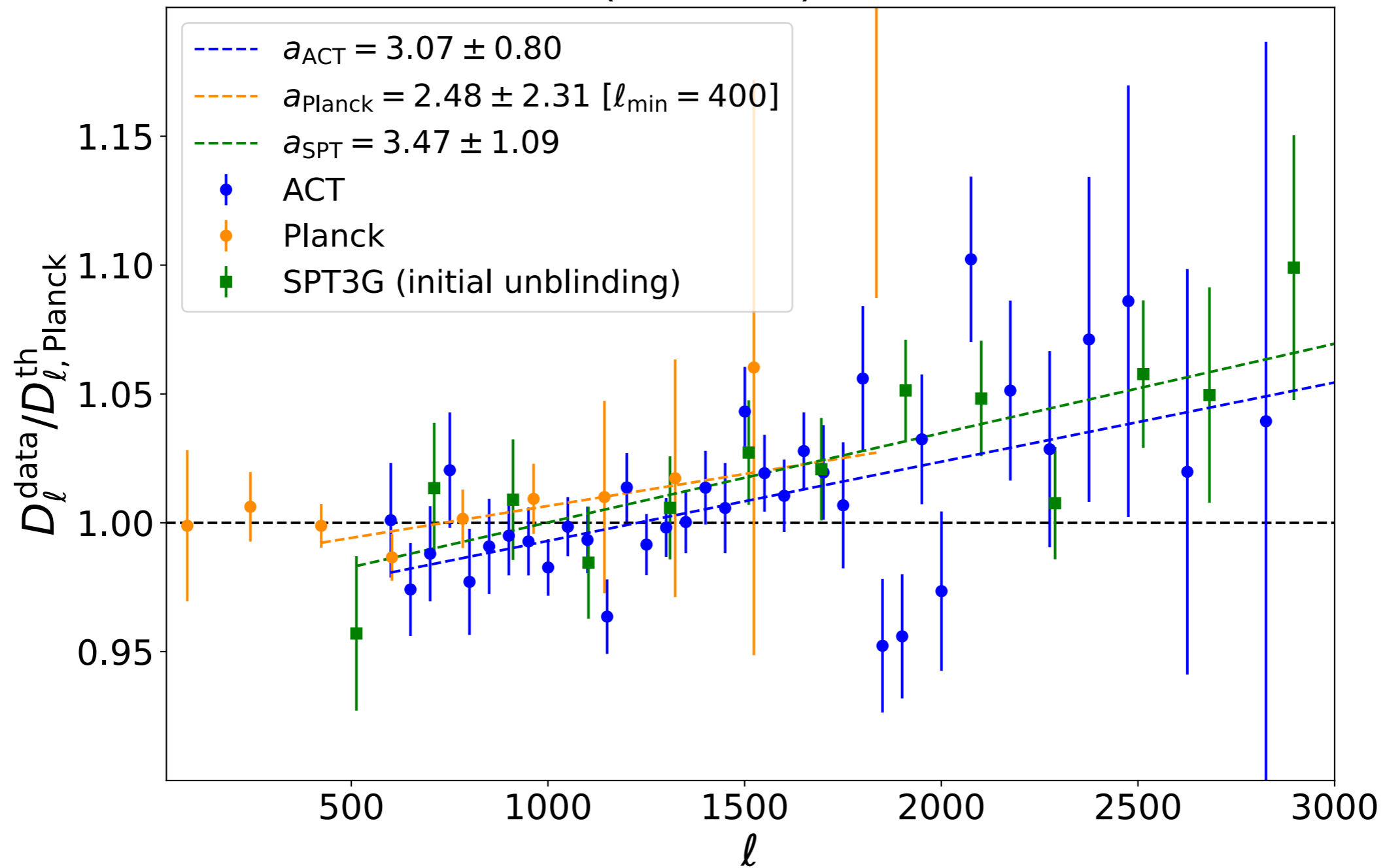
DESI DR2 PTE  
w.r.t. Planck PR3  
 $\Lambda$ CDM = 0.0097

DESI+P-ACT fit yields only  
2.4 $\sigma$  preference for  
 $w_0 w_a$ CDM over  $\Lambda$ CDM  
(DESI+2025, 2504.18464)

# EE Slope at High $\ell$

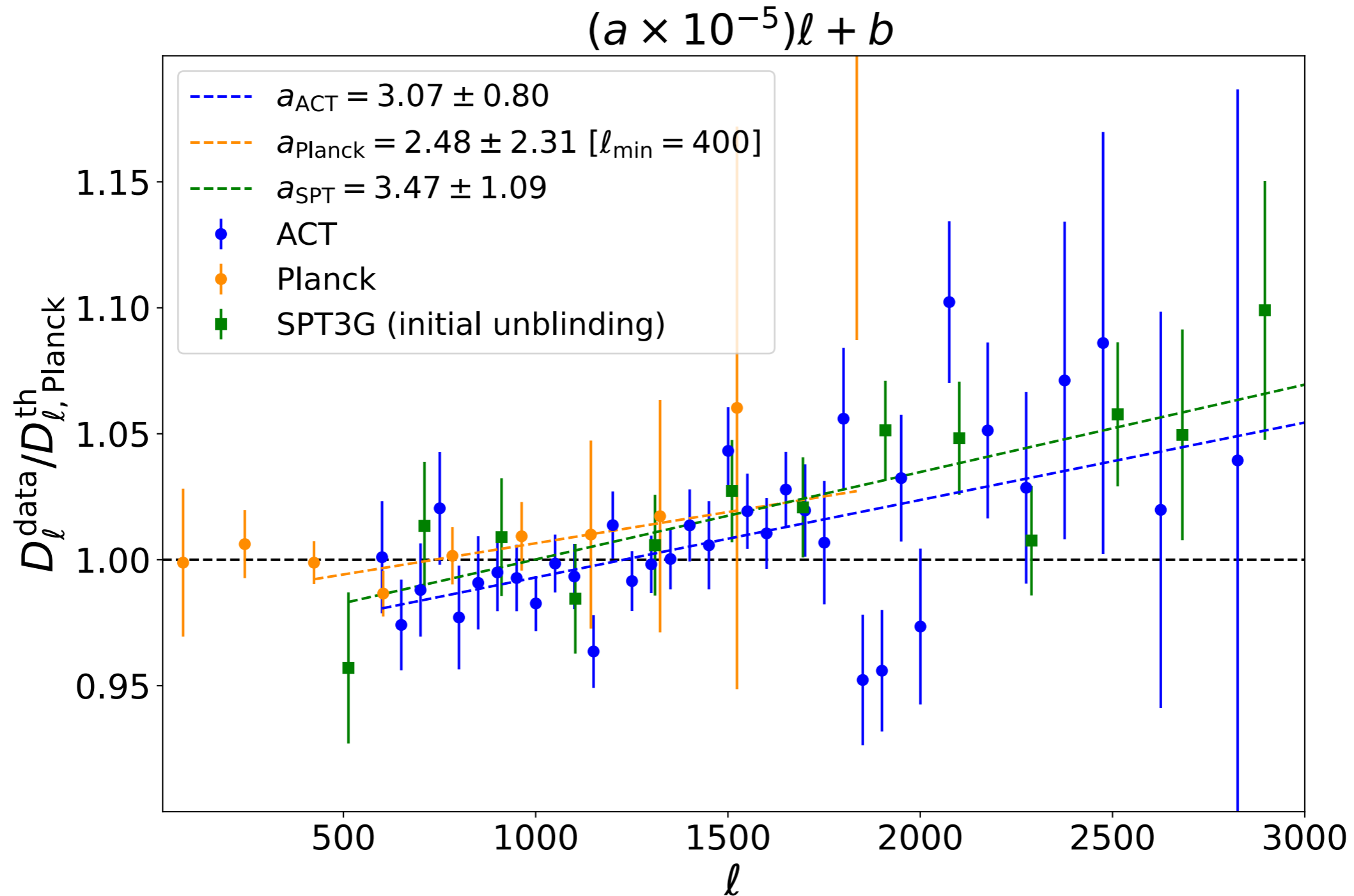
Ratio of EE data to *Planck* best-fit TT+TE+EE  $\Lambda$ CDM model

$$(a \times 10^{-5})\ell + b$$



# EE Slope at High $\ell$

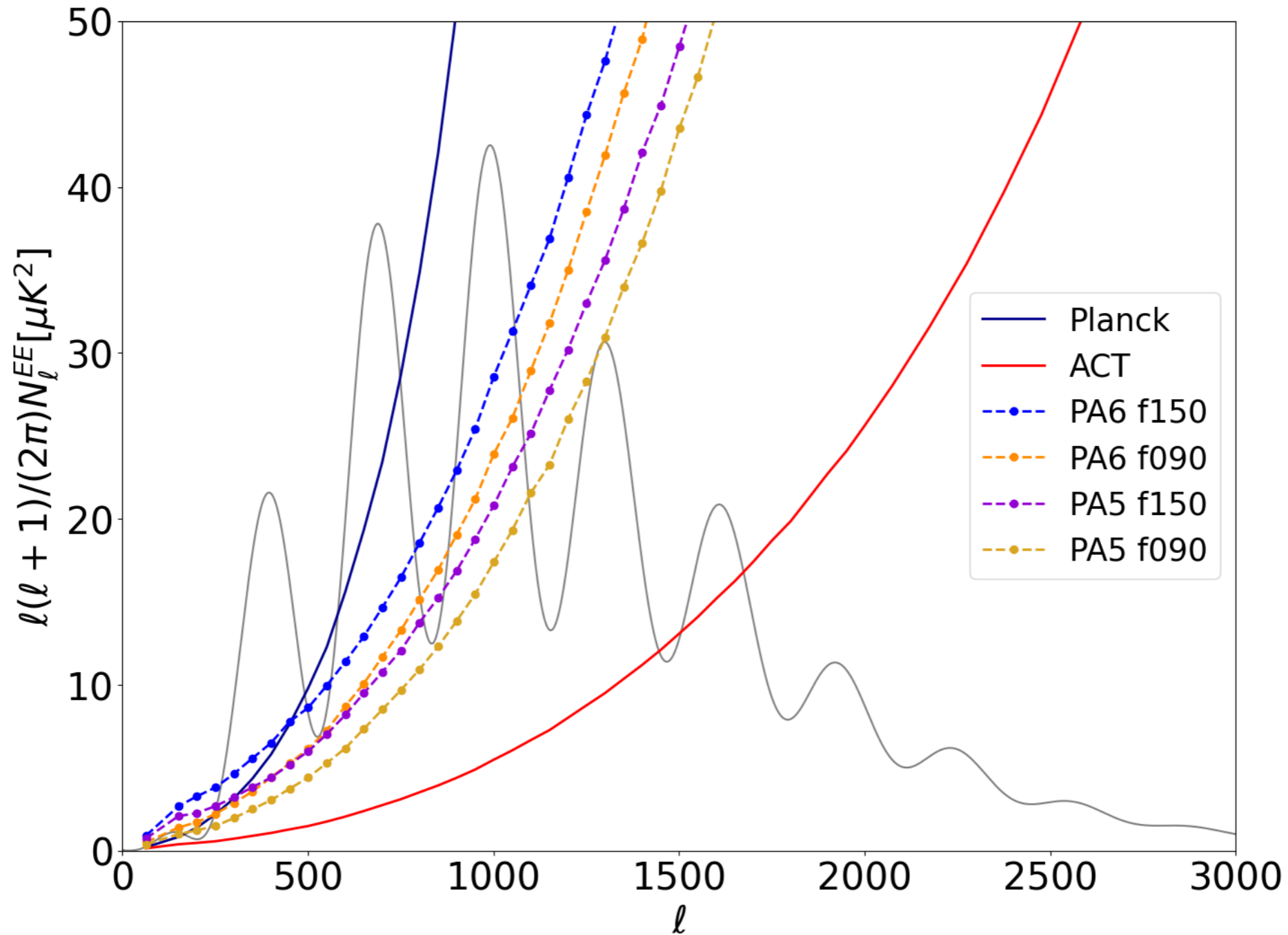
Ratio of EE data to *Planck* best-fit TT+TE+EE  $\Lambda$ CDM model



Not significant enough to affect parameters: ACT EE-only  $\Lambda$ CDM matches *Planck* TT+TE+EE at  $2.3\sigma$

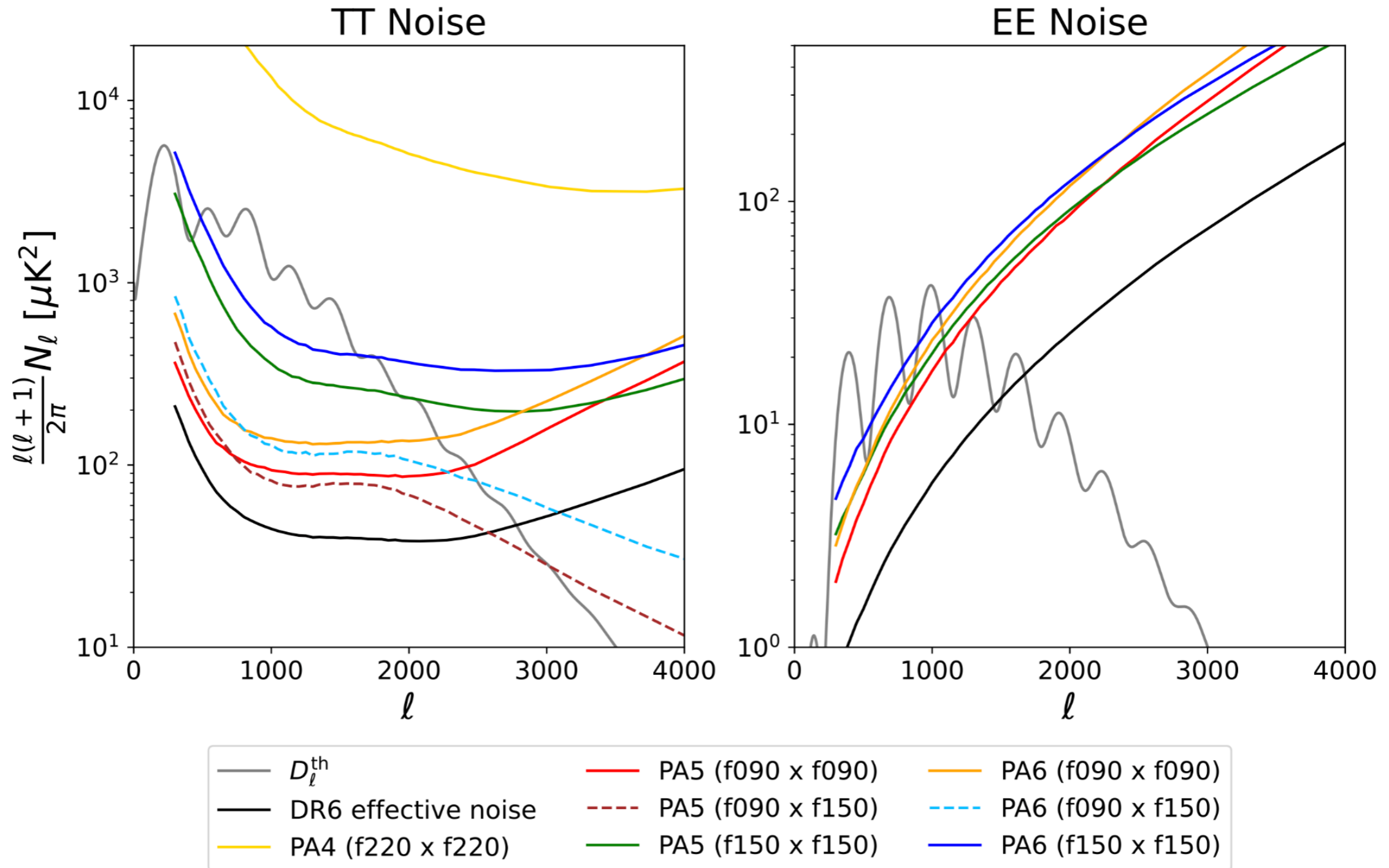
# Noise Properties

EE power spectrum is signal-dominated up to  $\ell \sim 1700$  ( $\theta \sim 0.1$  deg)  
Comparable SNR from each array-band allows stringent null tests



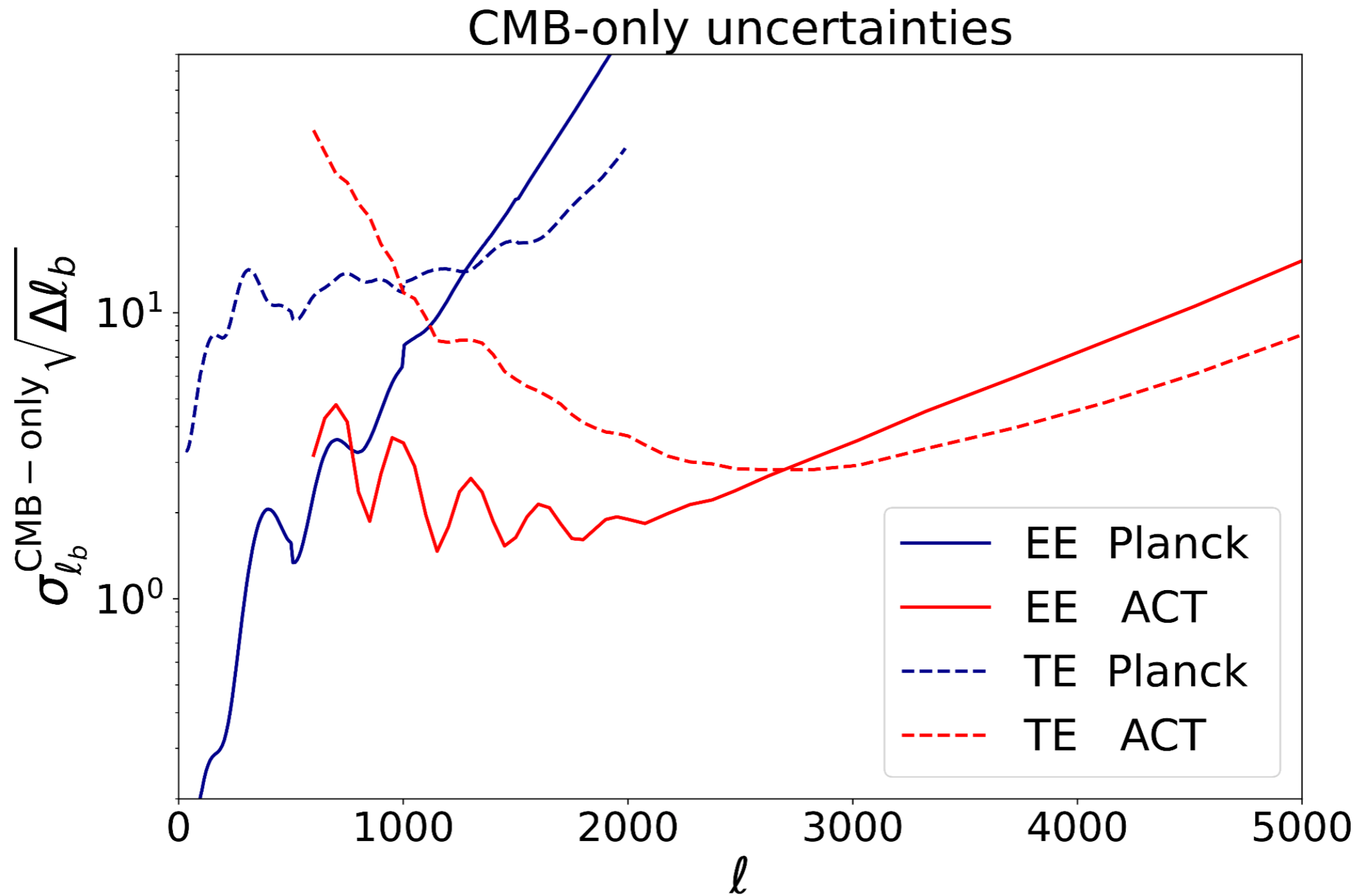
# Noise Properties

Multifrequency noise power spectra



# Noise Properties

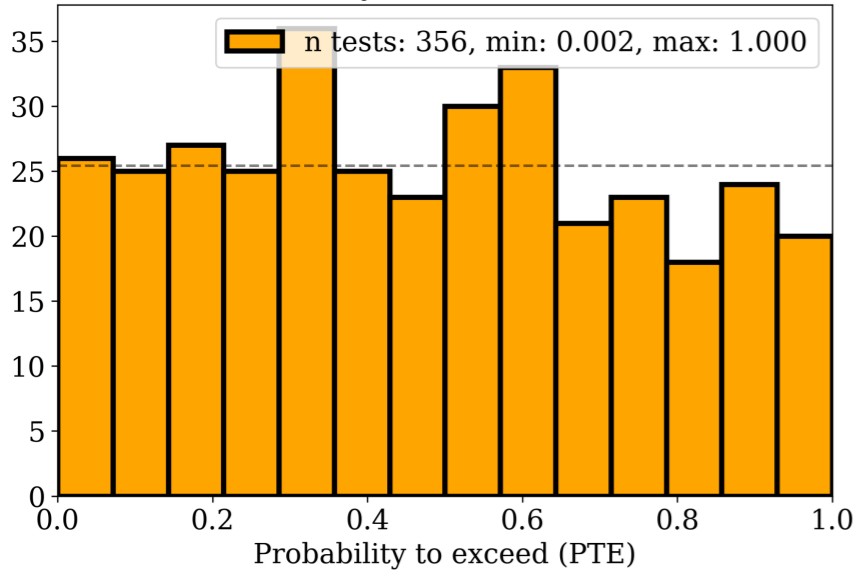
Foreground-marginalized (“CMB-only”) bandpower error bars



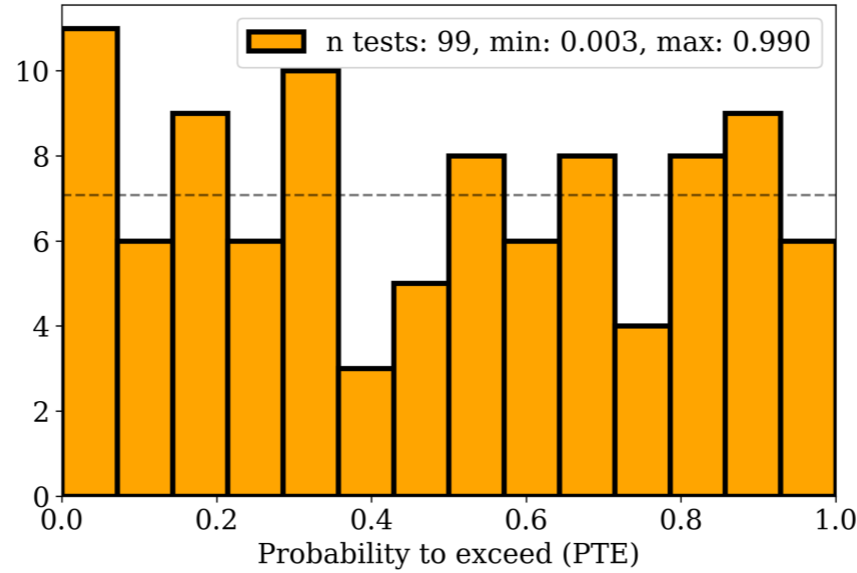
# Null Tests

~2000 null tests passed before unblinding; PTE distributions are uniform

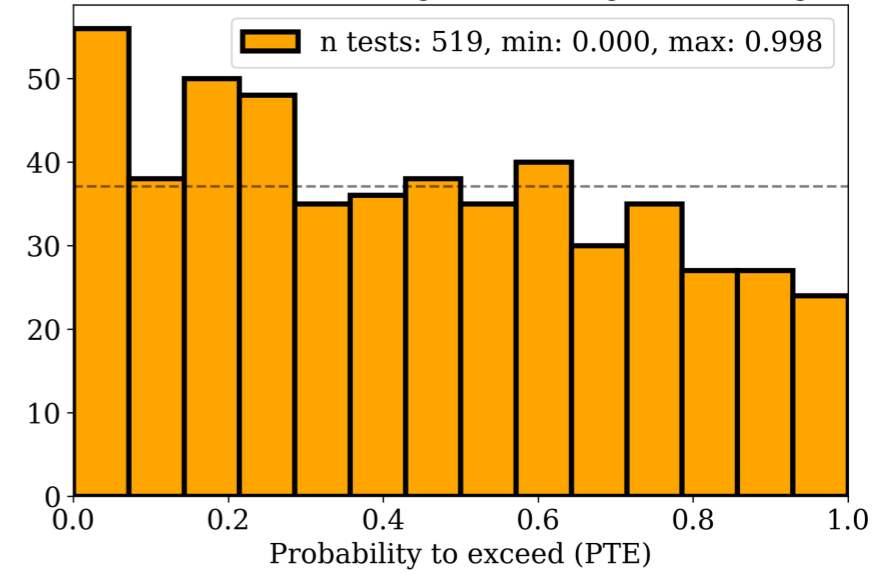
Array-bands null test



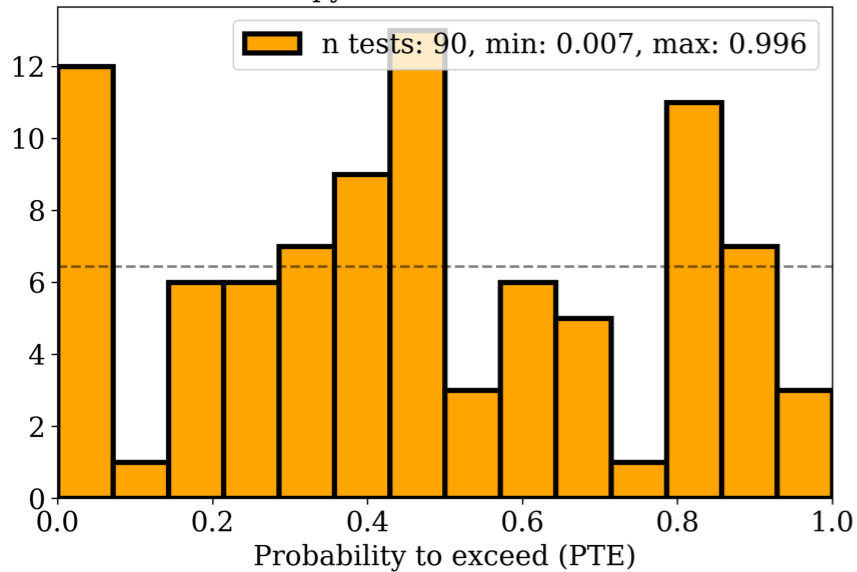
PWV null test: <0.7 mm vs >0.7 mm



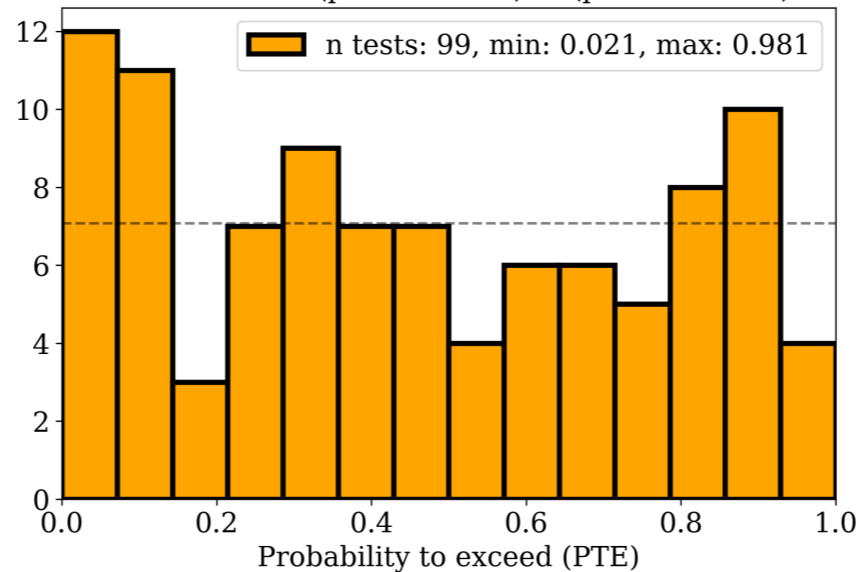
Elevation null test: 40 degree vs 45 degree vs 47 degree



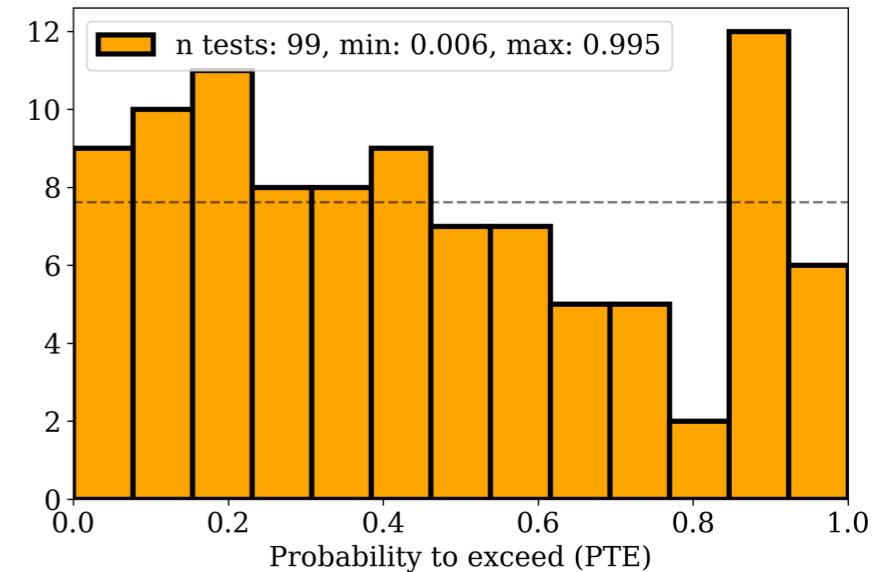
Isotropy null test: North/South



Time null test: (pre Feb 2019) vs (post Feb 2019)



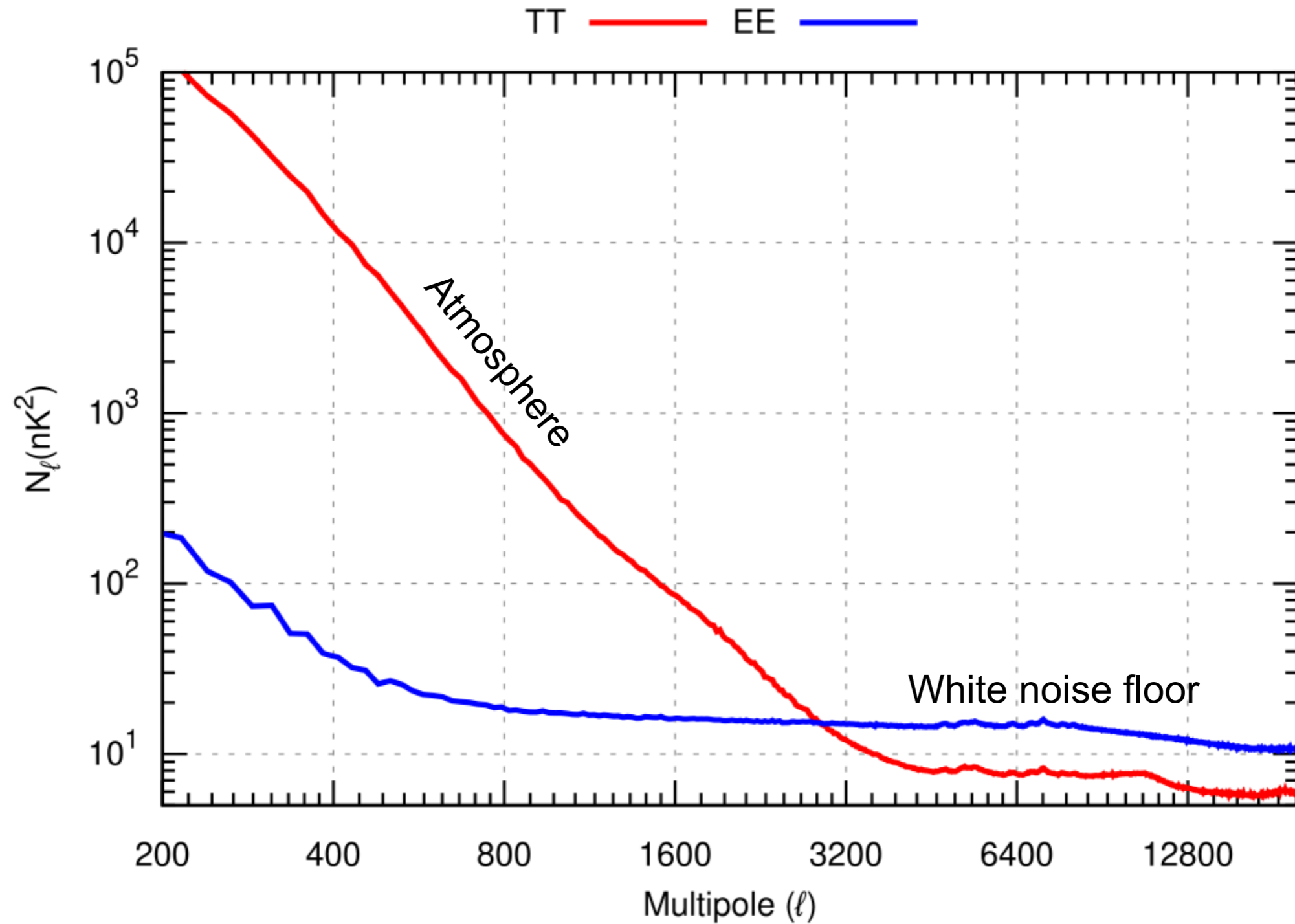
Detectors null test: In vs Out



# Complexities

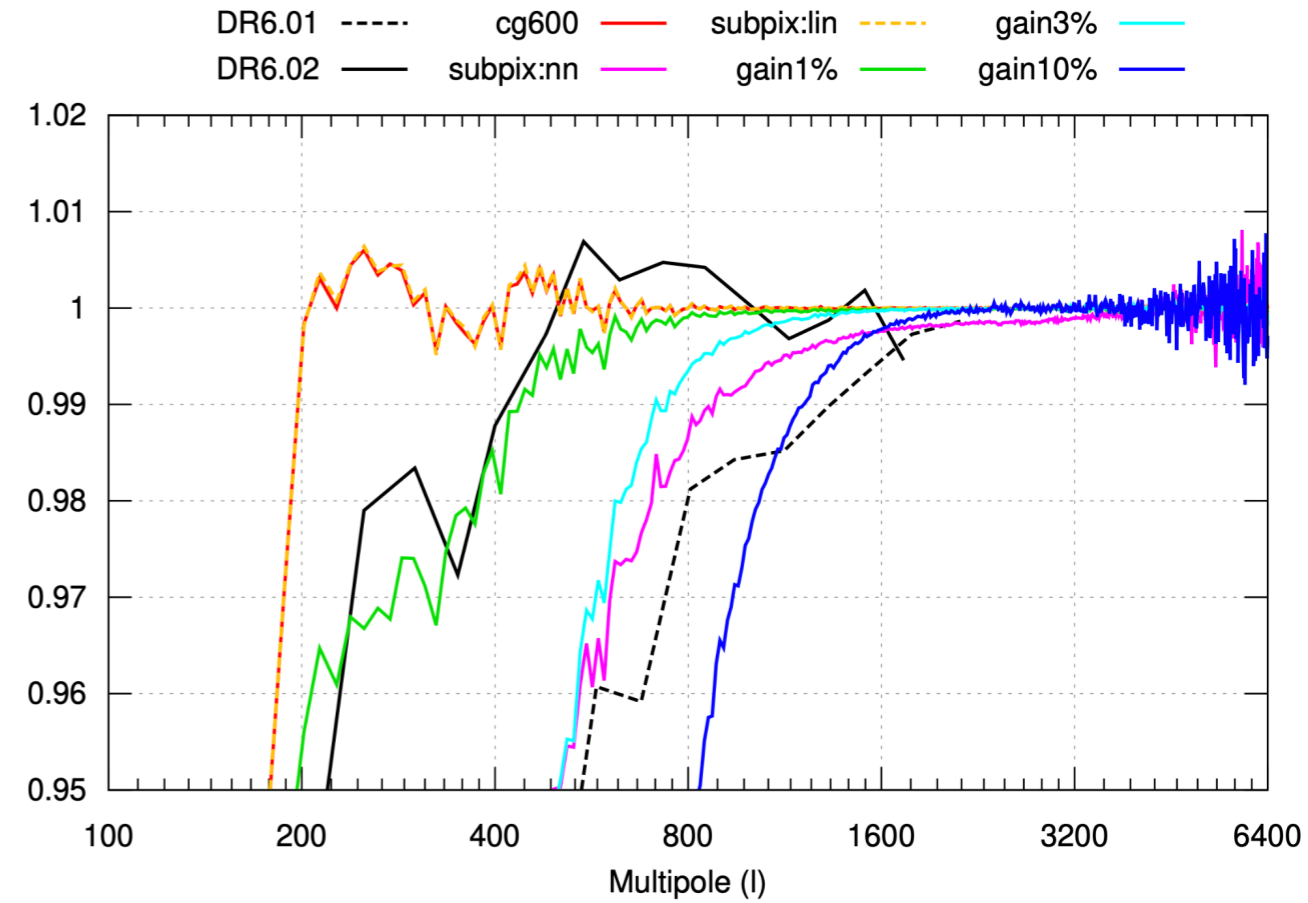
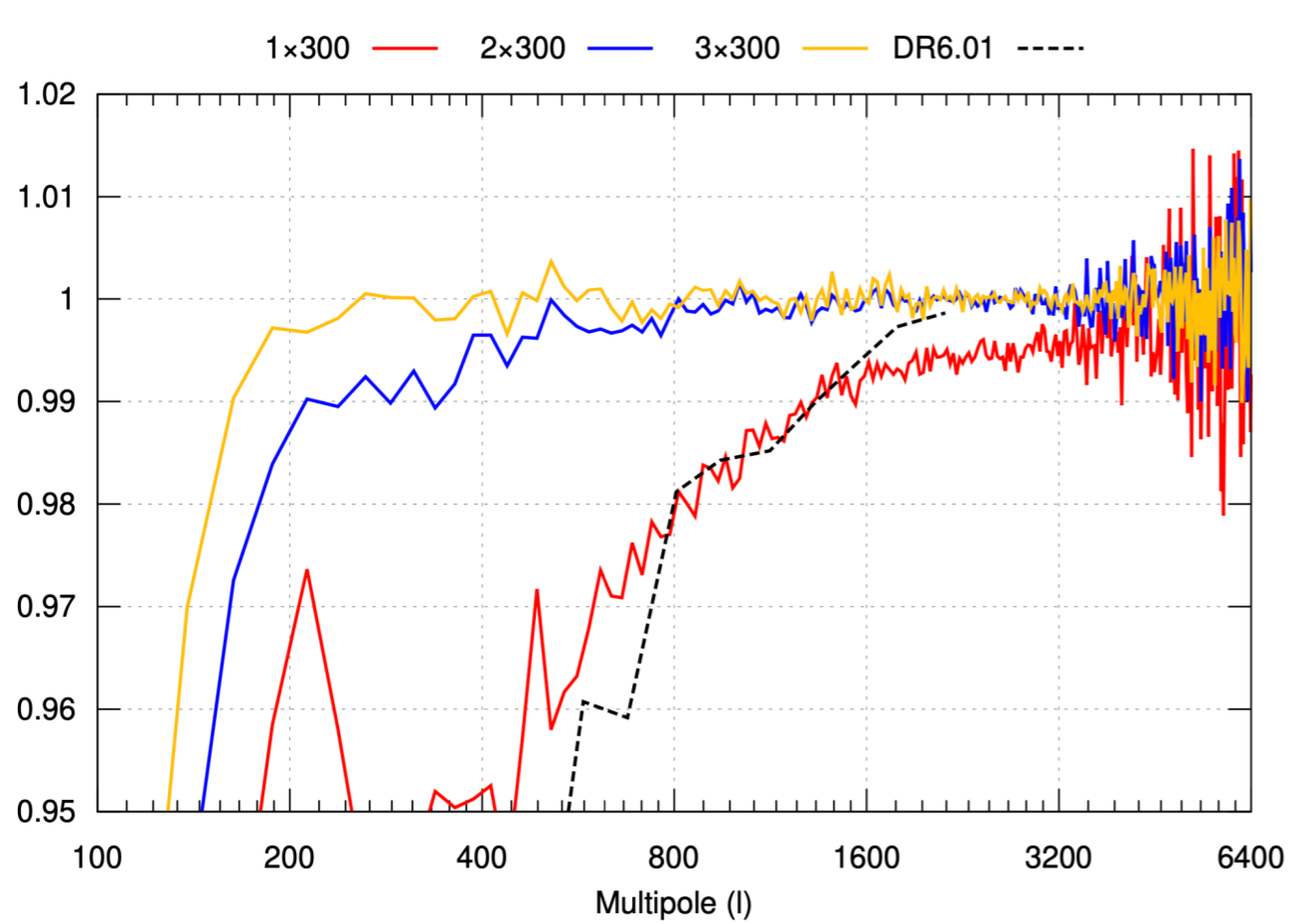
## Atmospheric Noise

Full sensitivity is only reached on small angular scales



# Complexities

## Transfer Function in Temperature Maps

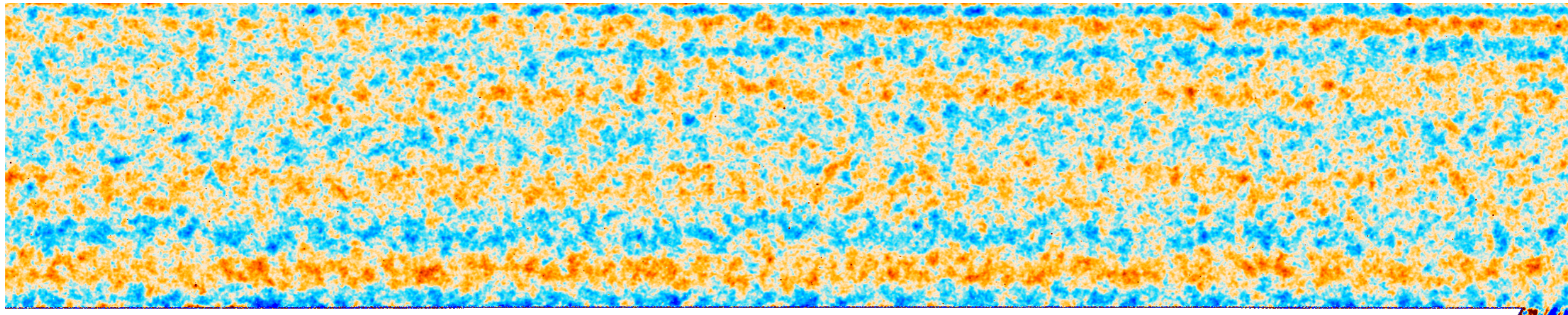


# Complexities

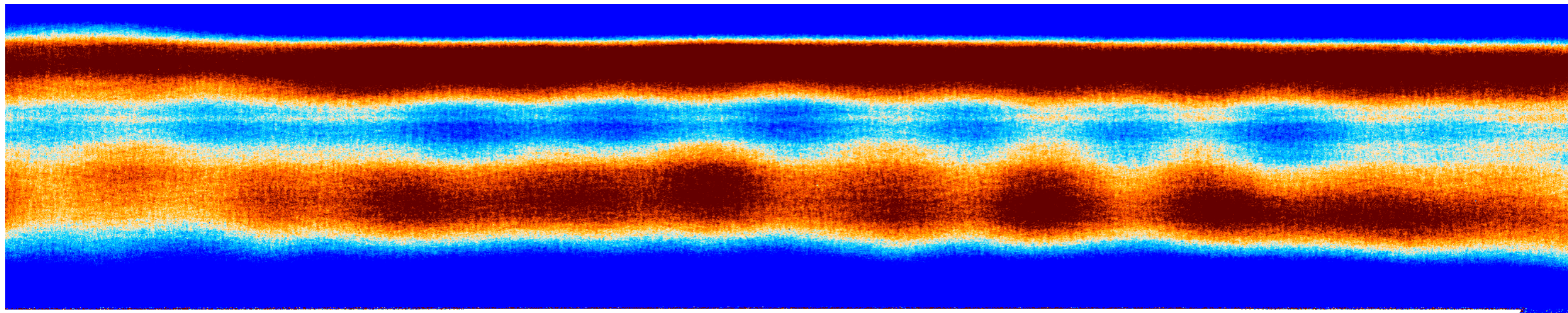
Scan-synchronous “pickup”

Manifests as horizontal stripes in maps

T



Q

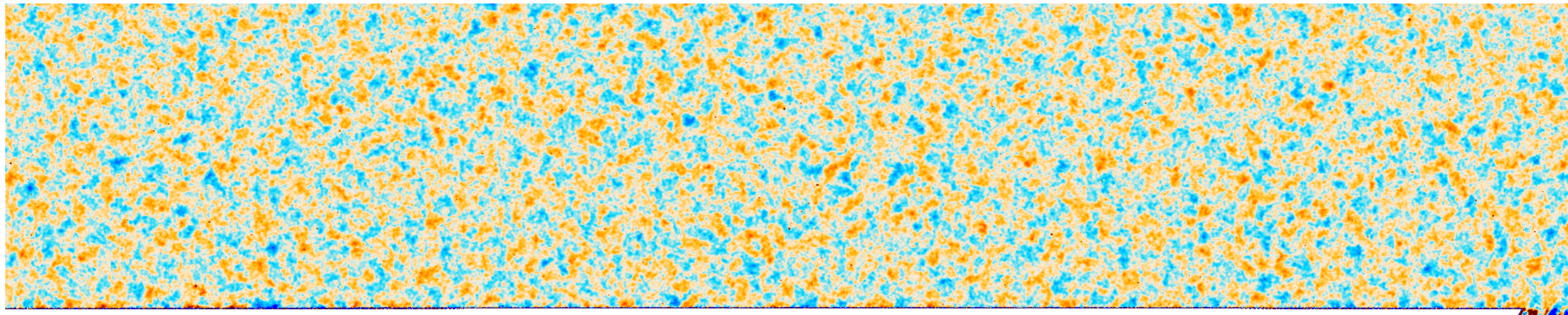


# Complexities

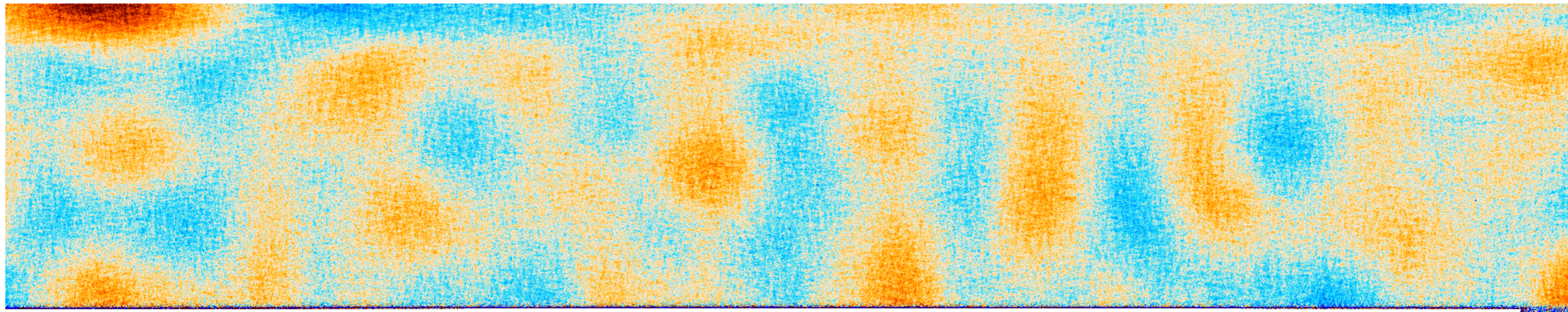
Scan-synchronous “pickup”

Heavily suppressed by removing  $|m| < 5$  modes

T



Q

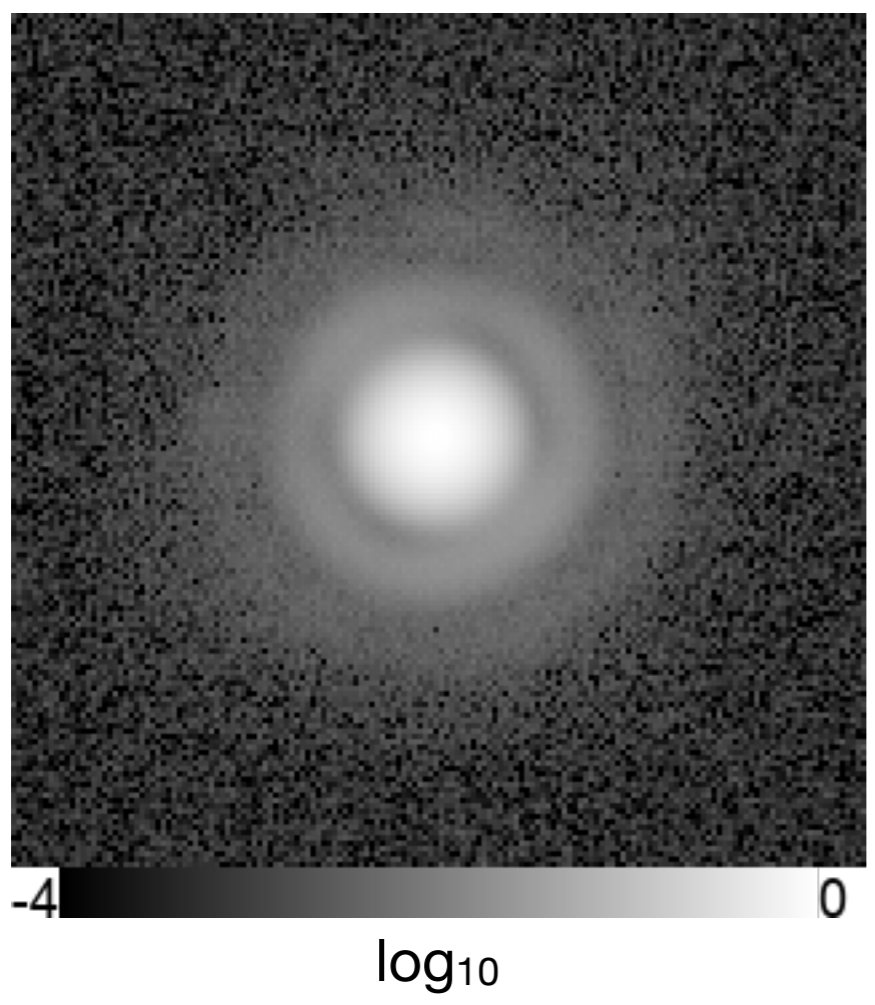


Remaining large-scale features in Q are correlated noise at  $ell < 100$

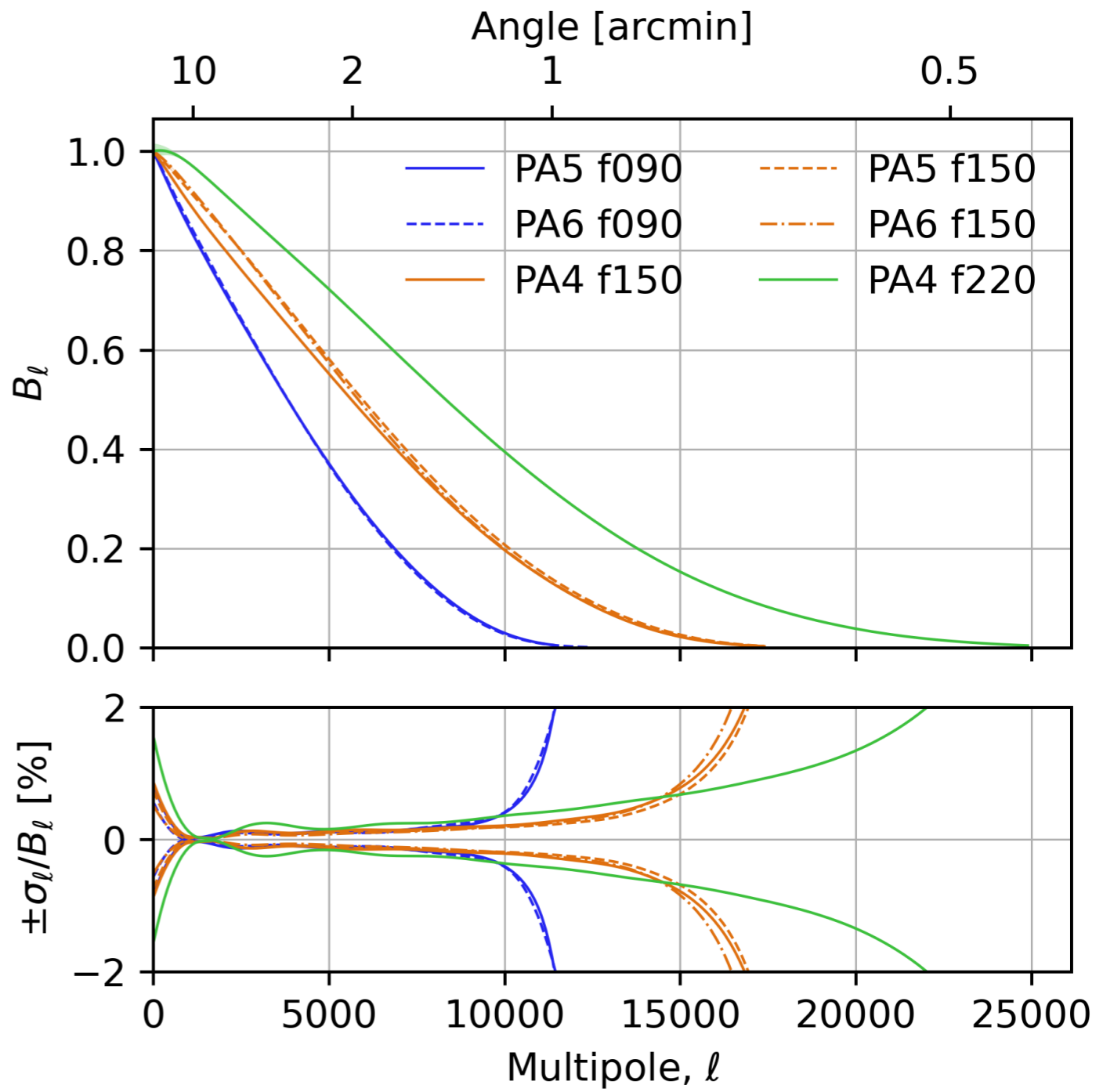
# Beams

Beam (point spread function) calibration based on observations of Uranus, Saturn, and quasars

Effective resolution: 1-2 arcmin



Co-added Uranus obs. (PA5 f090, 2017-2022, 10'x10', normalized)

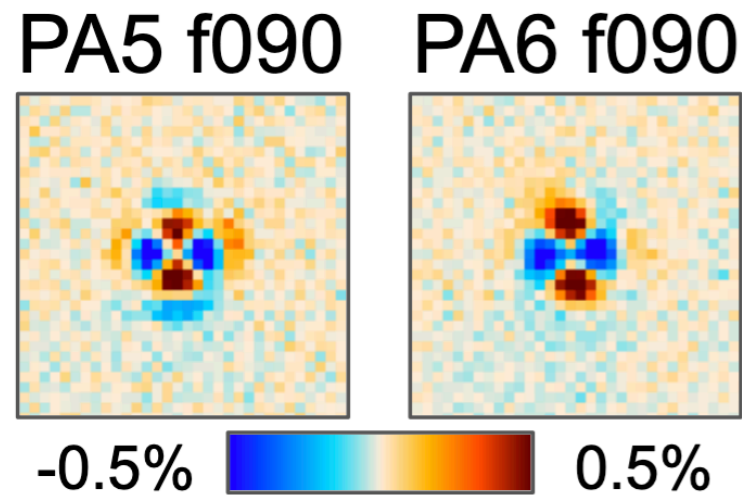


# Temp.-to-Pol. Leakage

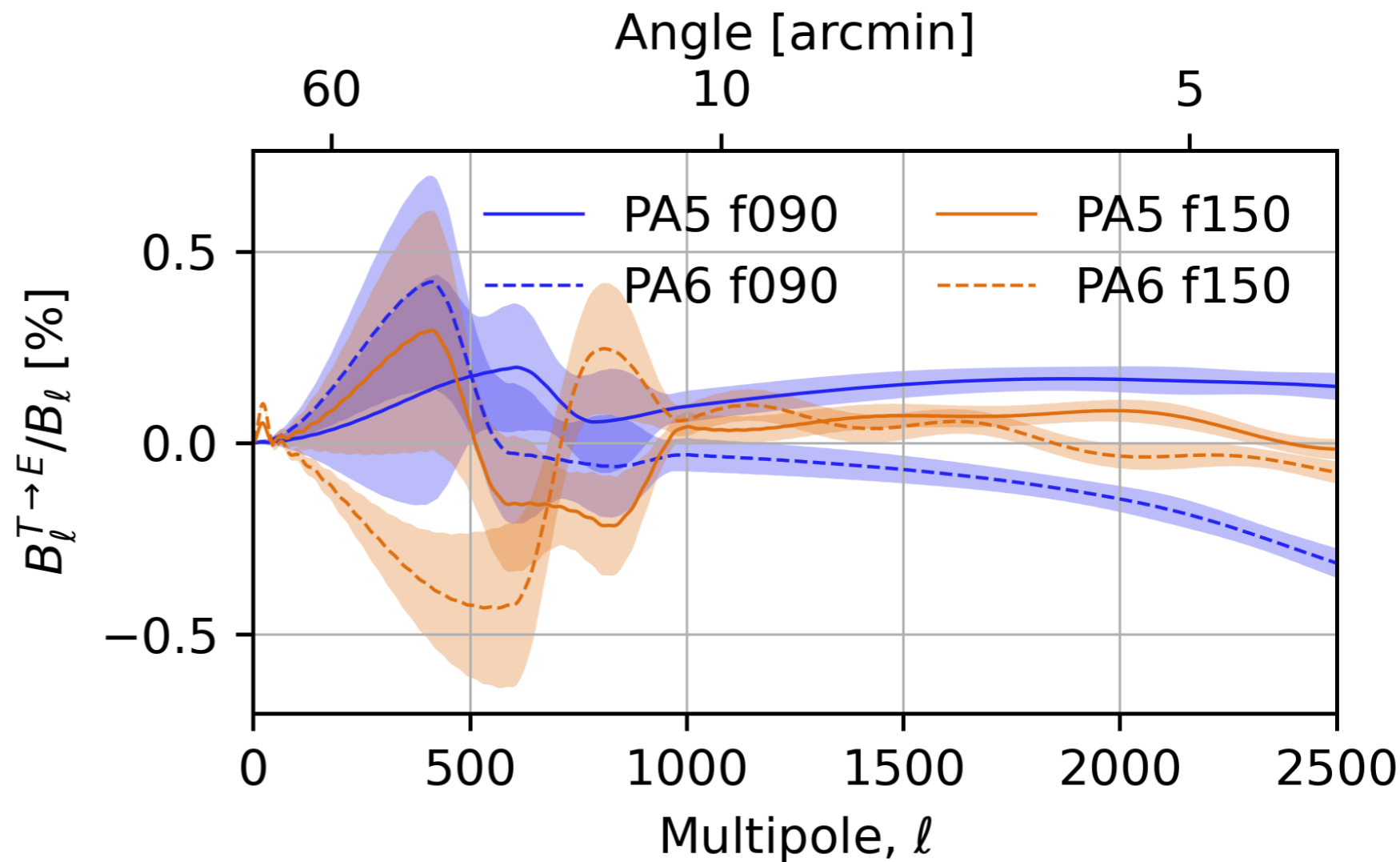
Spurious temperature-to-polarization seen in planet observations

Leakage corrections to the TE power spectra are clearly detectable in null tests

Redundancy from several arrays has been crucial for validation



Spurious polarization in co-added Uranus obs. (Stokes Q, 8'x8')



# Beam Chromaticity

For the first time, the ACT power spectrum analysis properly takes into account the frequency dependence of the beam (previously considered in ACT DR4 component separation: Madhavacheril, JCH, et al. (2020))

~1 - 10% effect depending on angular scale

Very little impact on cosmological parameters

Significant impact on foreground parameters, such as the thermal Sunyaev-Zel'dovich effect

$$B_\ell^X \propto \int B_\ell(\nu) I^X(\nu) \tau(\nu) d\nu$$

$X$  : Sky components: CMB, planets, tSZ, etc.  
 $B_\ell(\nu)$  : Beam as function of frequency  
 $I^X(\nu)$  : Spectral energy distribution of sky signal  
 $\tau(\nu)$  : Instrumental frequency passband