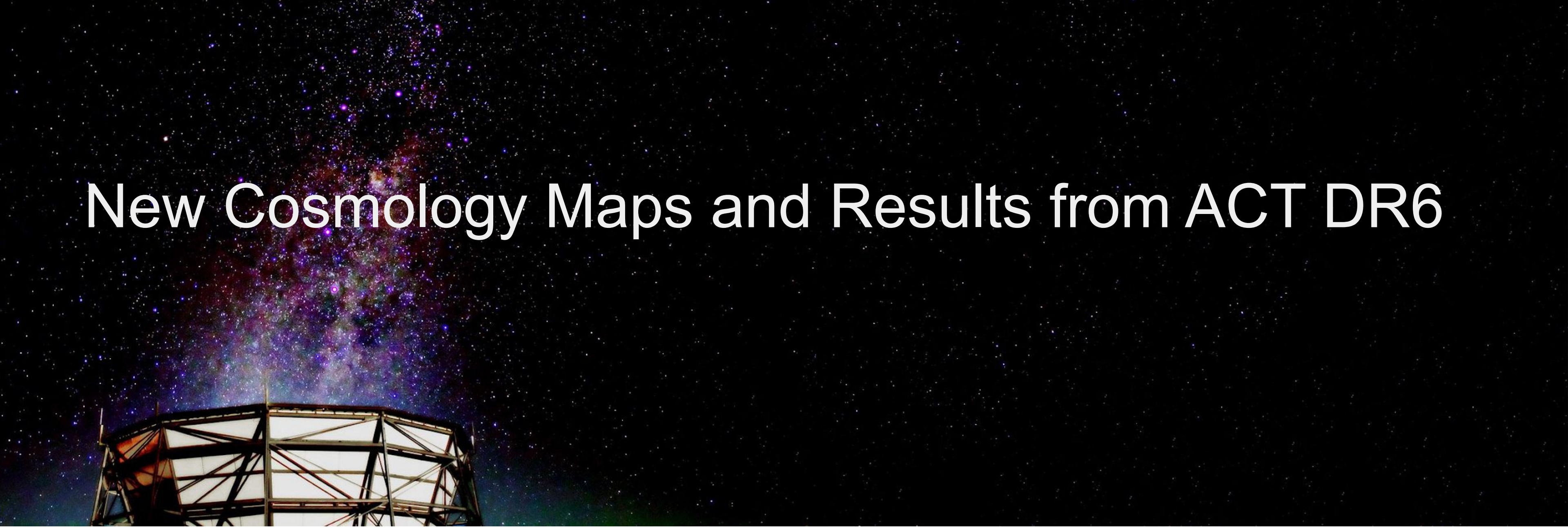
New Cosmology Maps and Results from ACT DR6



Agencia Nacional de Investigación y Desarrollo
Ministerio de Ciencia, Tecnología, Conocimiento e Innovación
Gobierno de Chile

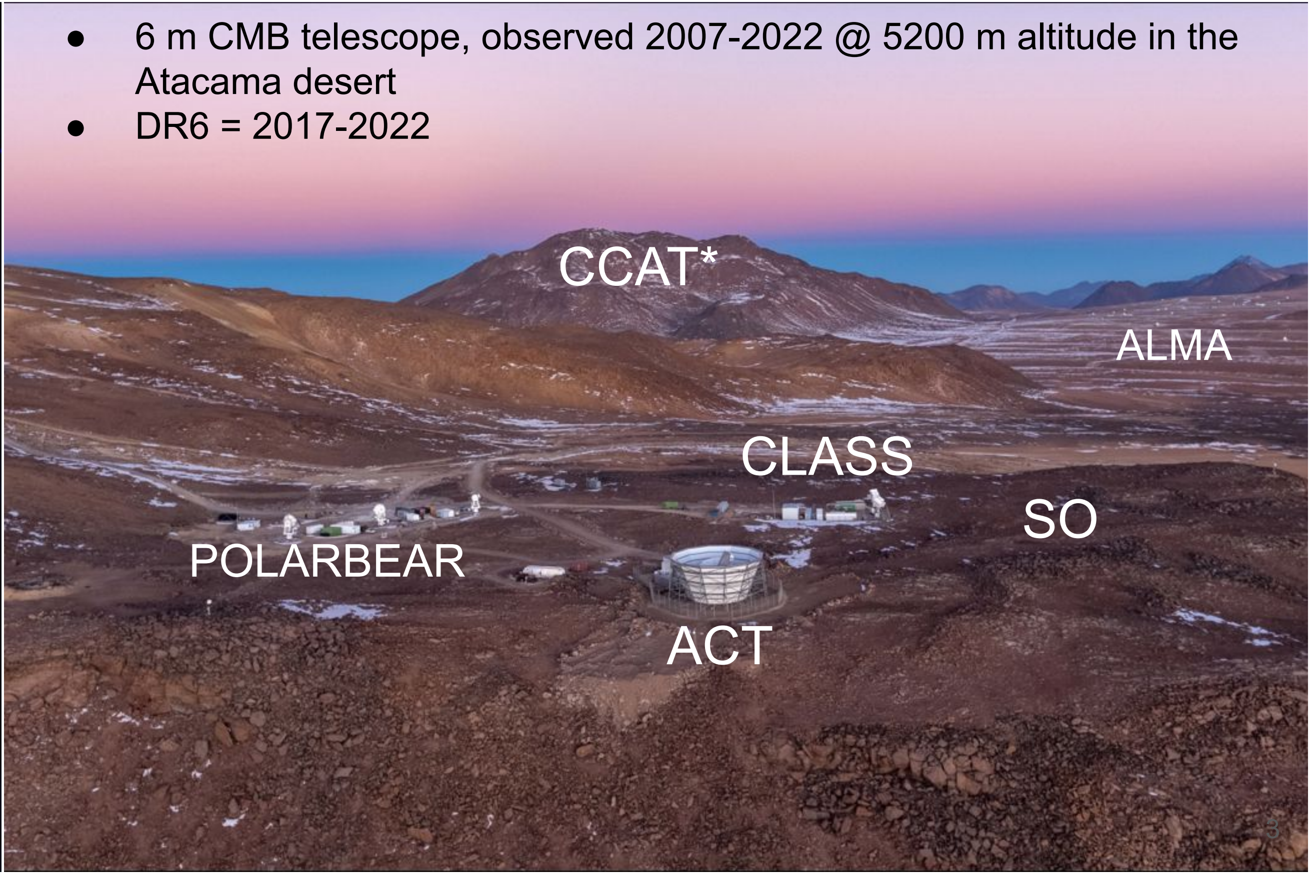
Zach Atkins (GS, Princeton)
on behalf of the ACT Collaboration

The ACT Collaboration

160 collaborators at 60 institutions

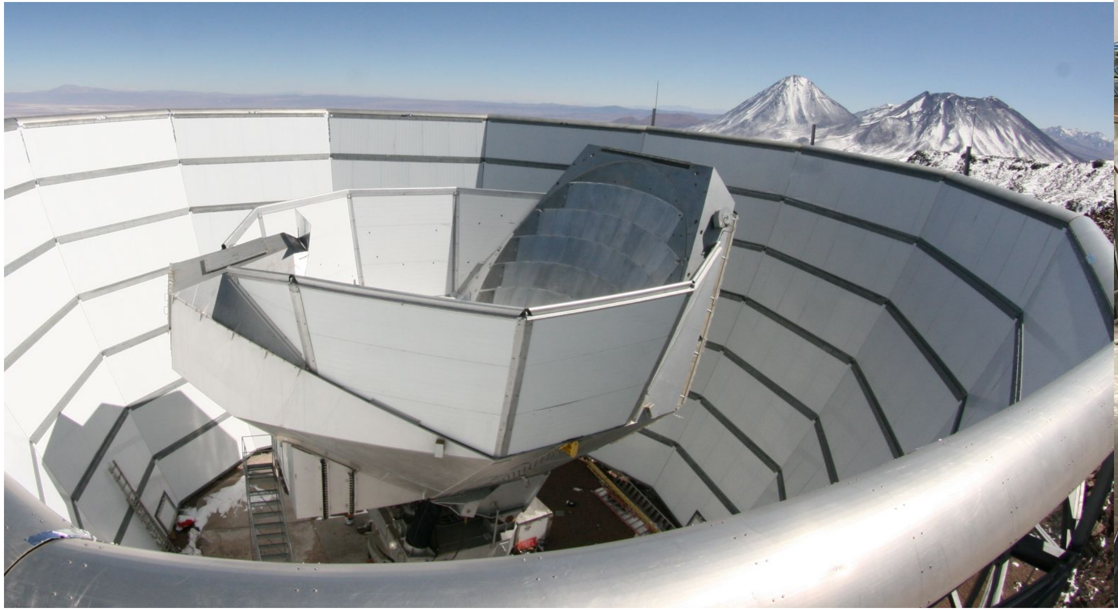
The Atacama Cosmology Telescope

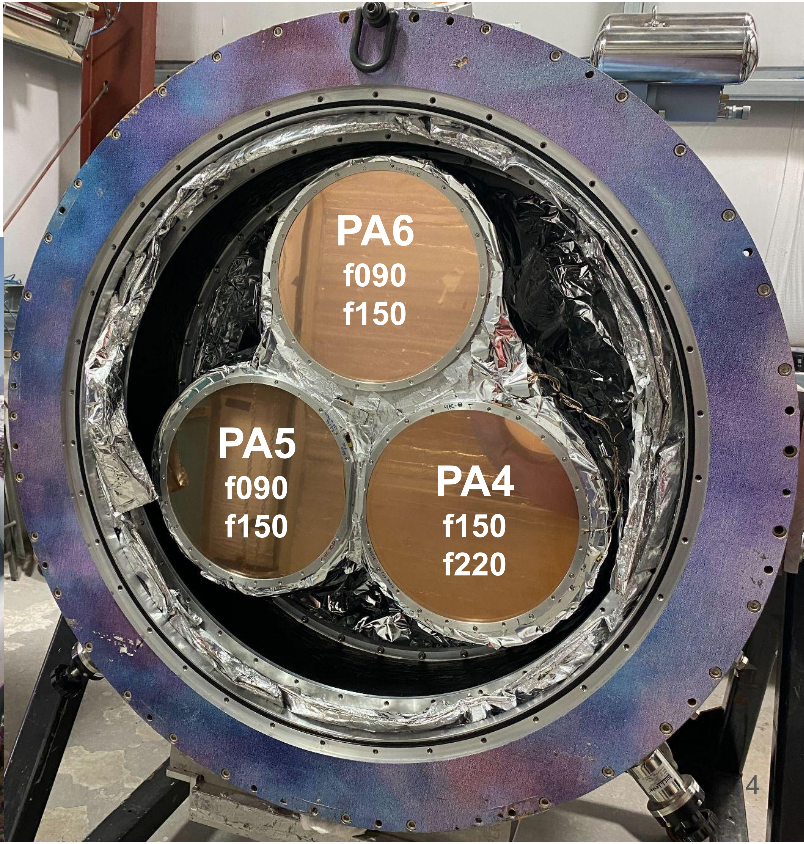
- 6 m CMB telescope, observed 2007-2022 @ 5200 m altitude in the Atacama desert
- DR6 = 2017-2022



Closer look

- 3 dichroic detector arrays: PA4, PA5 and PA6
- 3 broad bands: f090 (77 – 112 GHz),
  f150 (124 – 172 GHz)
  f220 (182 – 277 GHz)
- 1.4’ FWHM @ f150



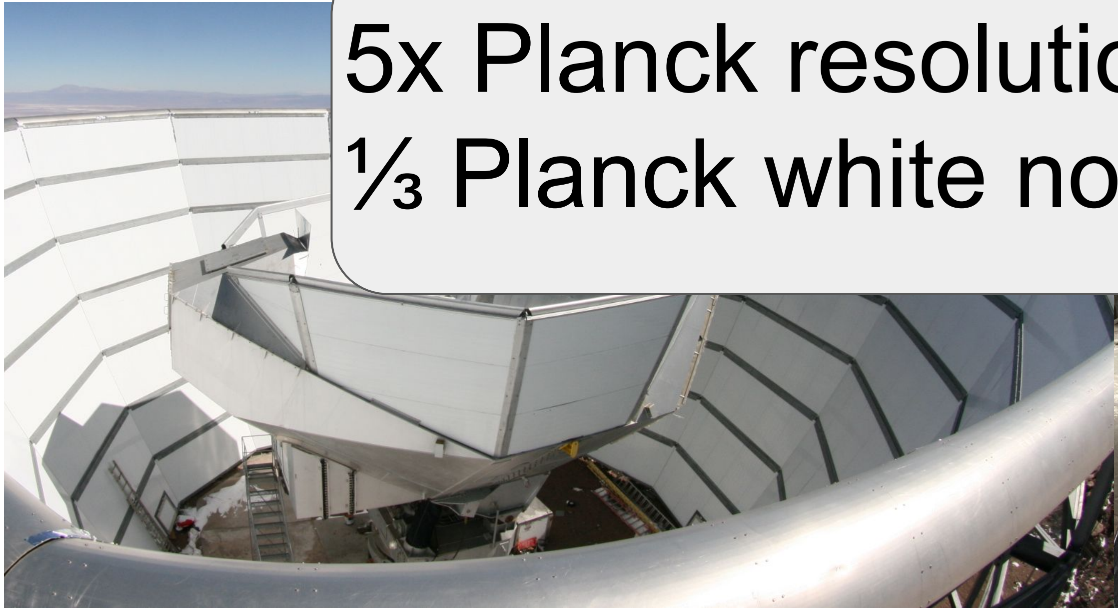


Closer look

- 3 dichroic detector arrays: PA4, PA5 and PA6
- 3 broad bands: f090 (77 – 112 GHz),
  f150 (124 – 172 GHz)
  f220 (182 – 277 GHz)
- 1.4’ FWHM @ f150

5x Planck resolution

⅓ Planck white noise RMS



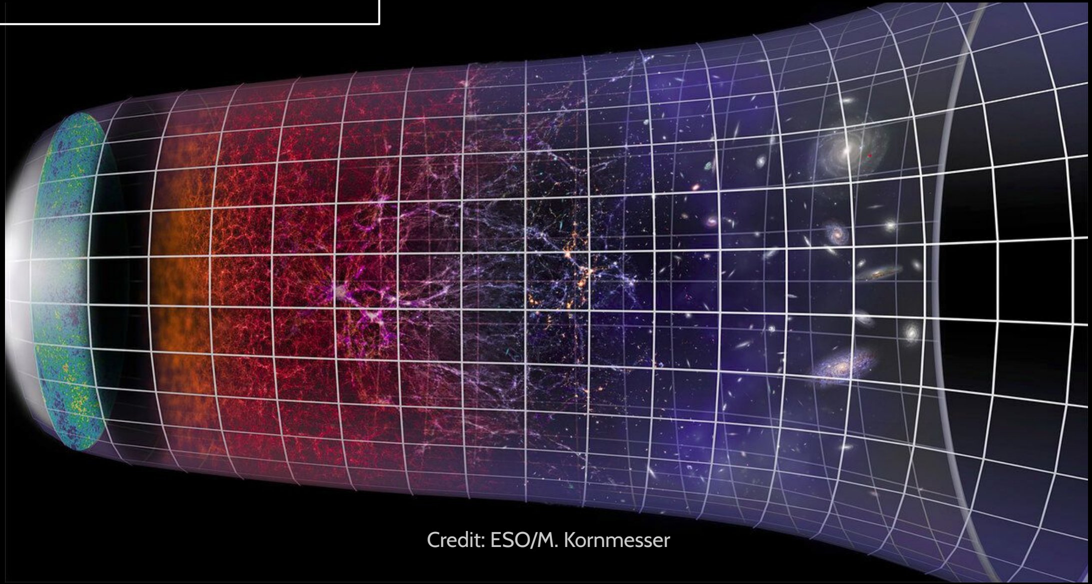
Predictions at low redshift:

- Growth of structure (σ_8)
- Expansion rate (H_0)
- Expansion history (Ω_m)

Measurements at low redshift:

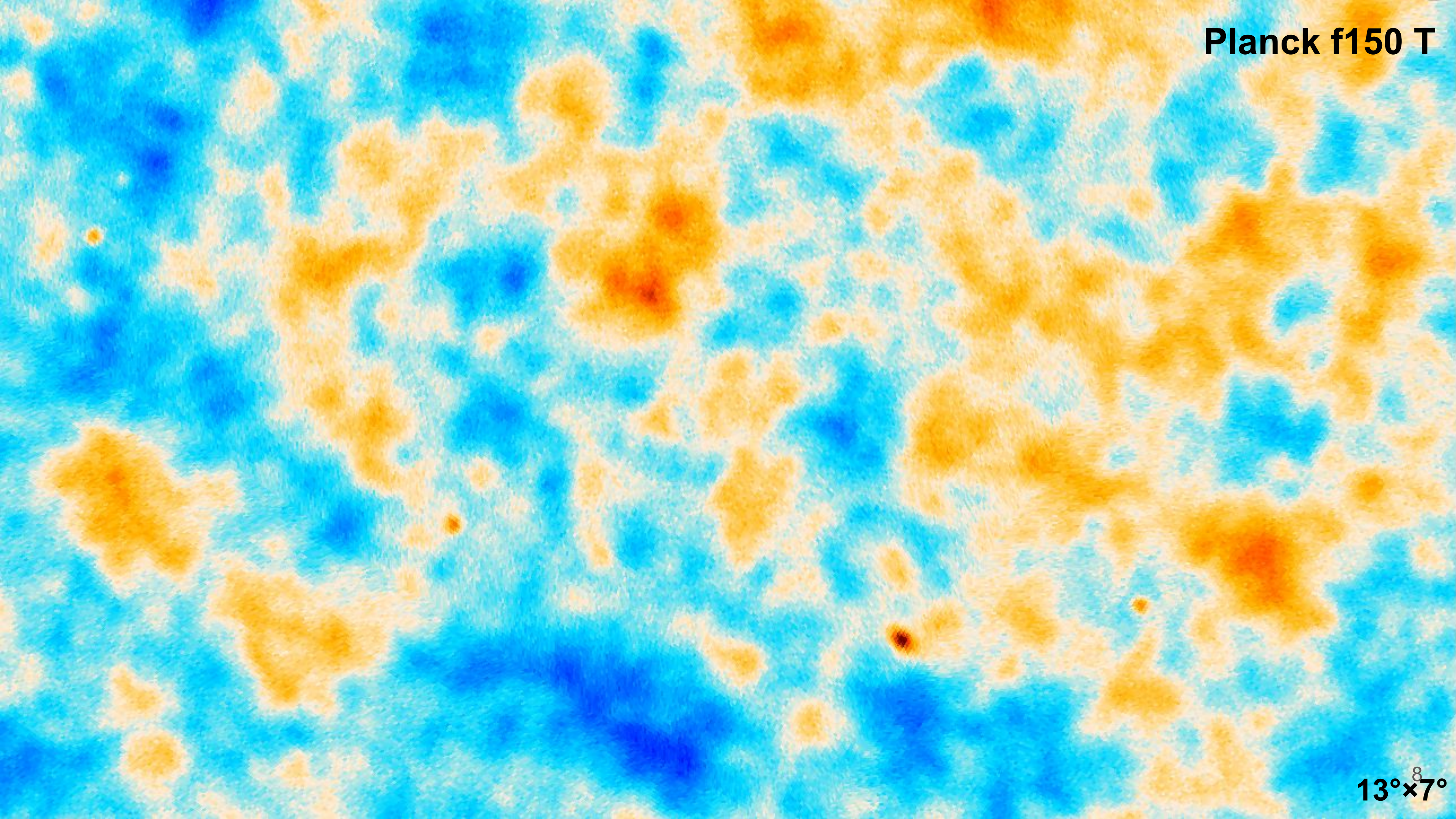
- CMB/galaxy weak lensing
- Galaxy density
- BAO
- Type 1a Supernovae (SNe)

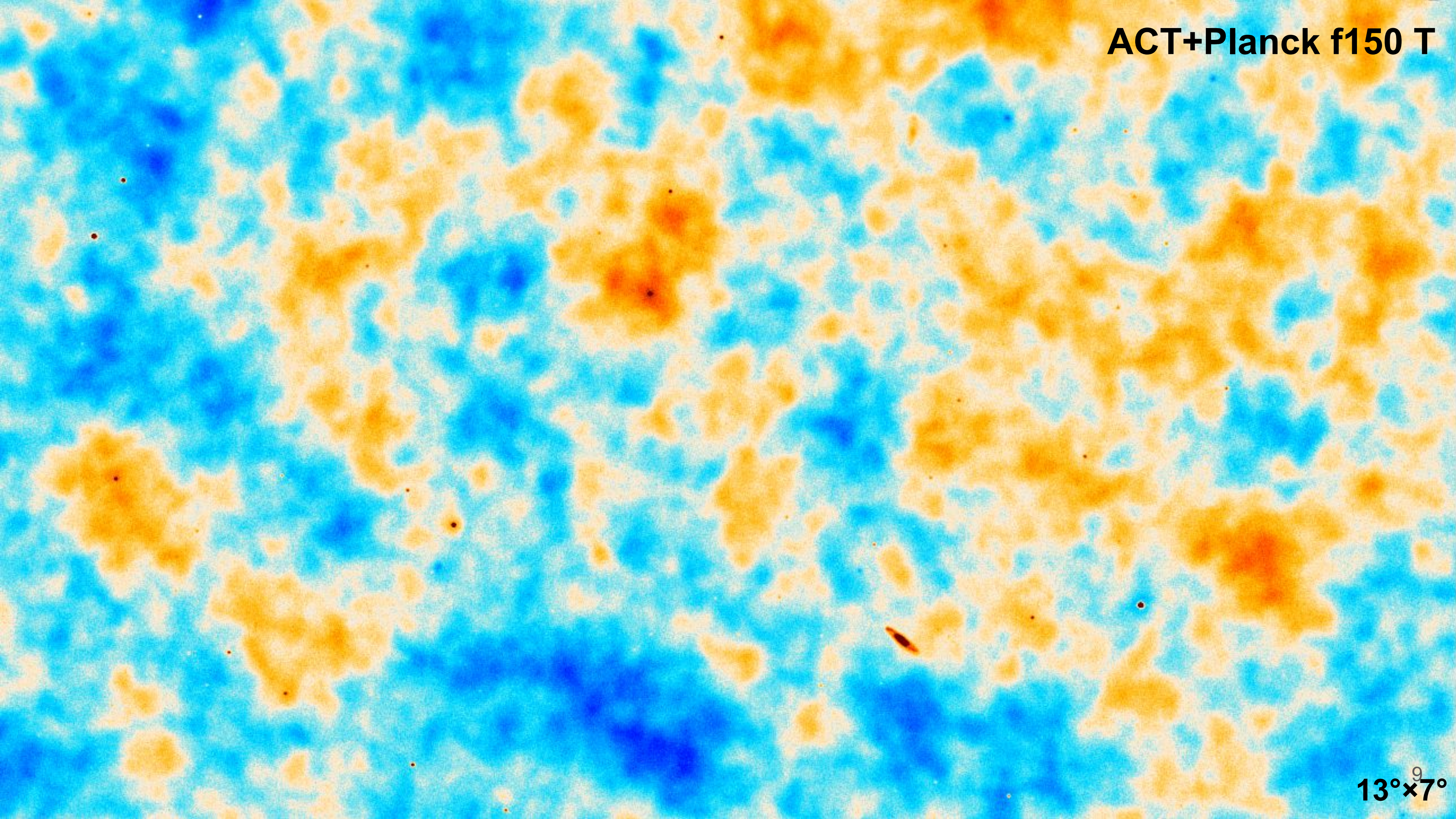
Fit cosmology at z~1100 (ΛCDM)

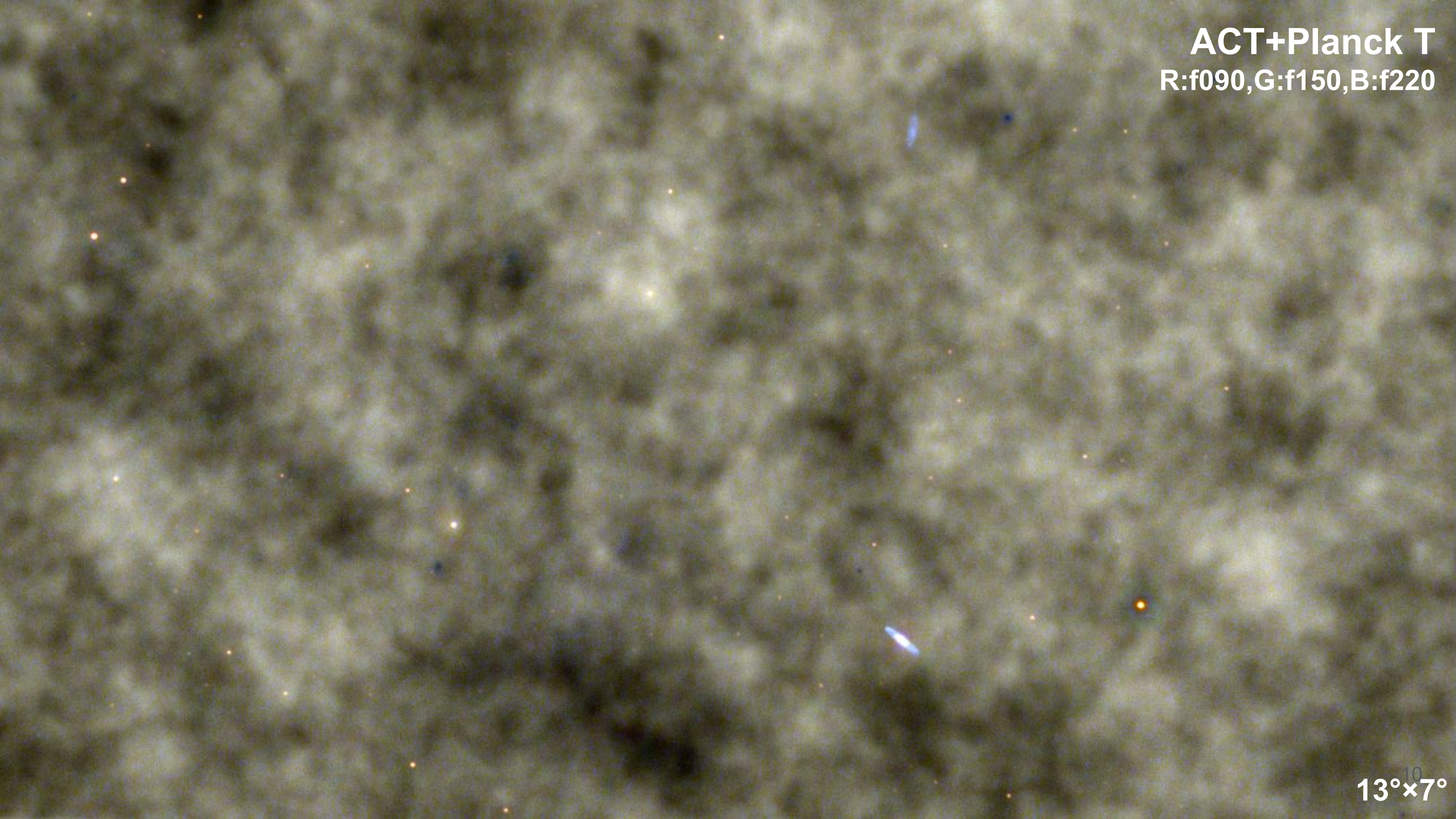


Credit: ESO/M. Kornmesser

What do the maps look like?


Planck f150 T
13°×7°

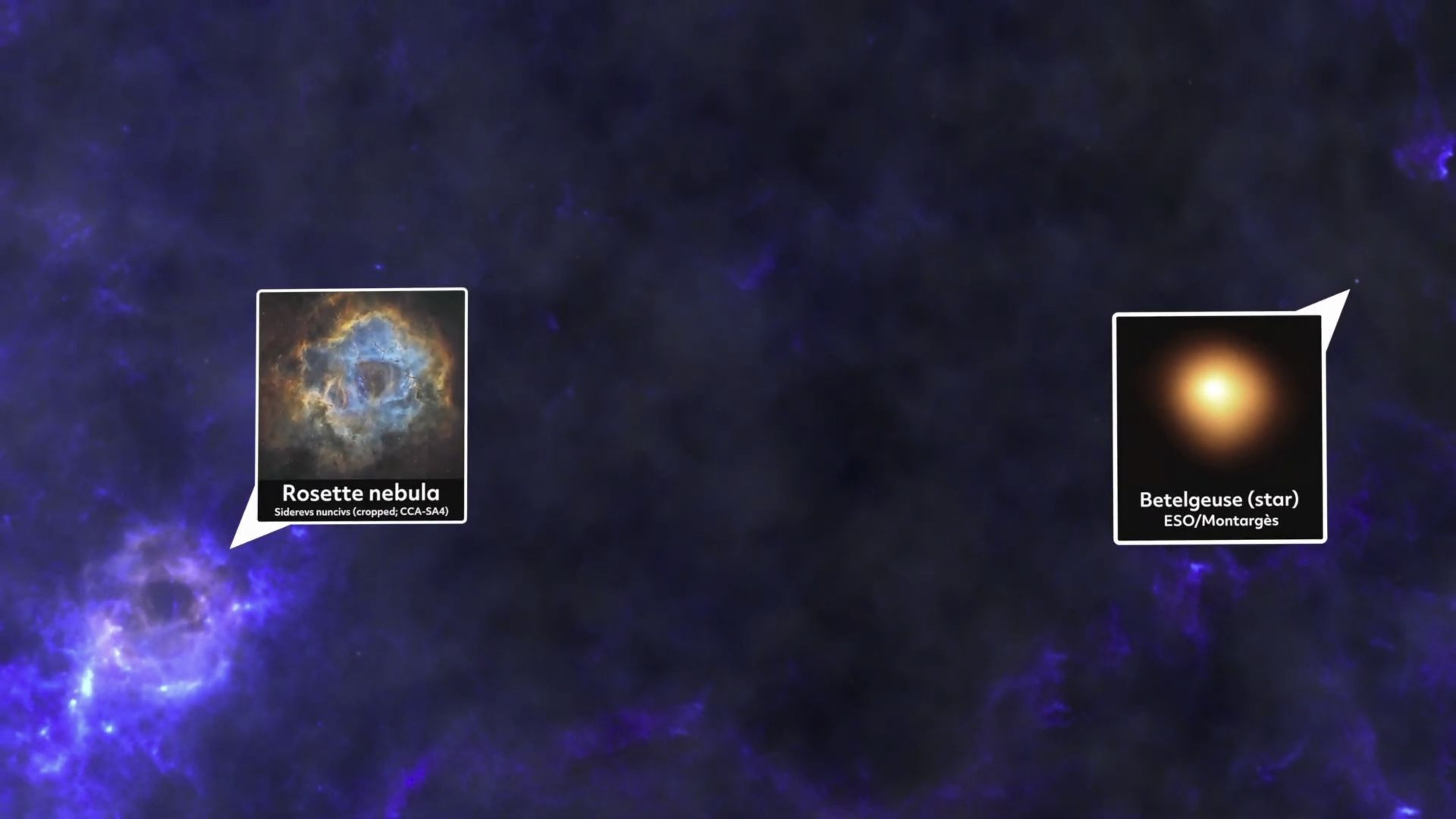

ACT+Planck f150 T
13°×7°


ACT+Planck T
R:f090,G:f150,B:f220
13°×7°

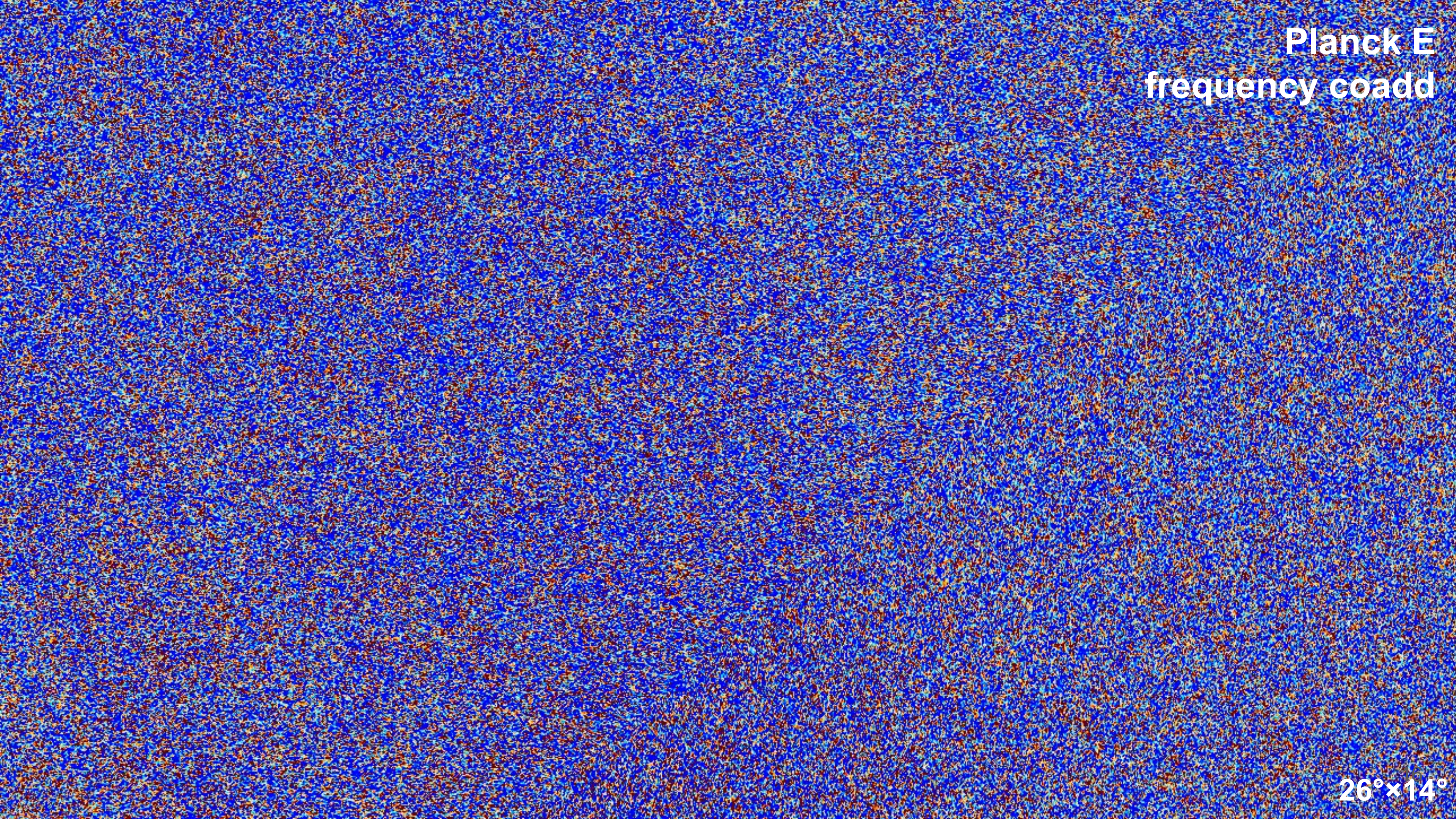

ACT+Planck T
R:f090,G:f150,B:f220
PKS 0102-245 (Artist impression)
NASA, ESA, Joseph Olmsted
Cadwell 62
ESO
Abell 2813 (z=0.29)
Legacy Survey DR9
Sculptor Galaxy
ESO

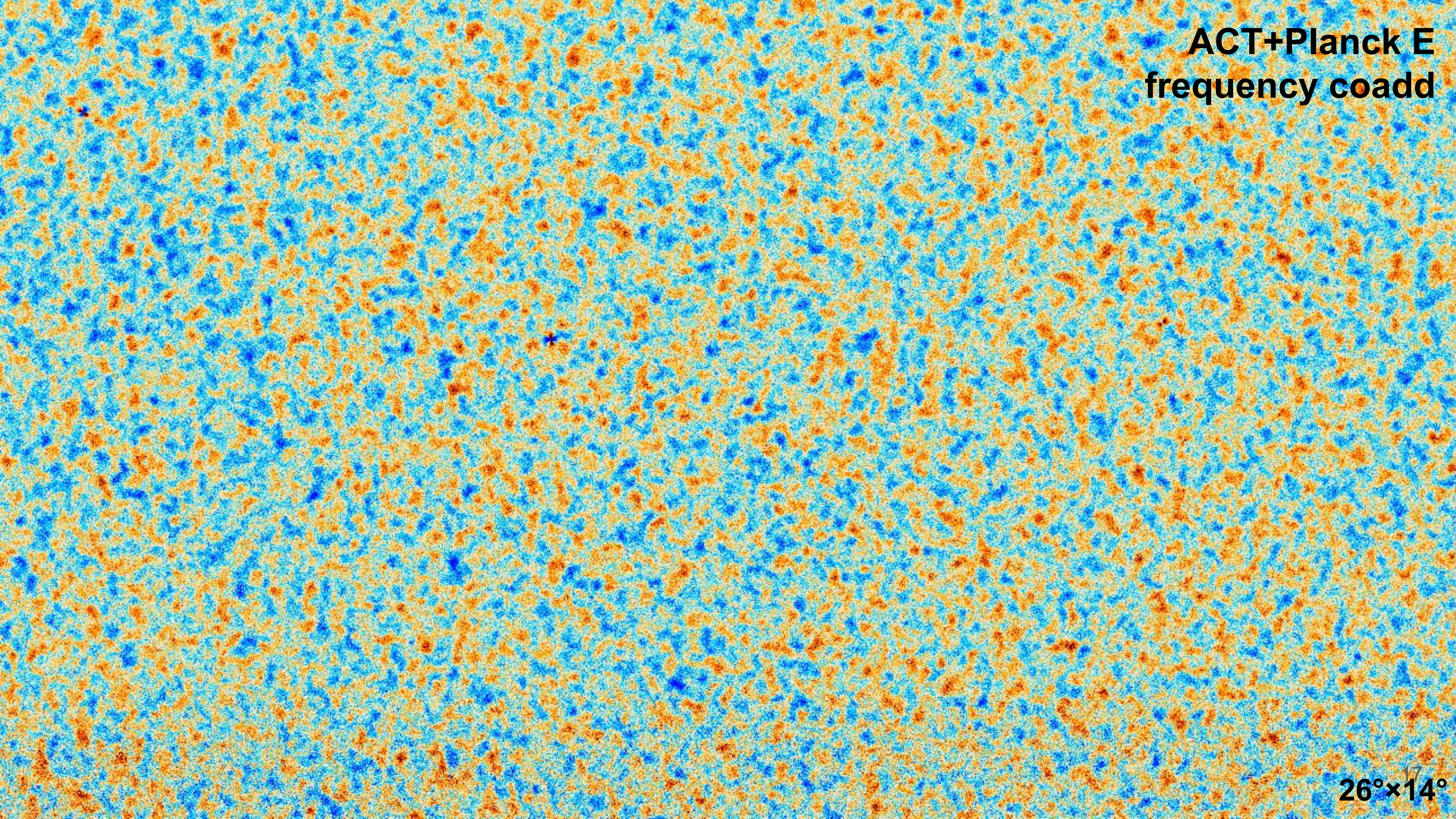

ACT+Planck T
R:f090,G:f150,B:f220
NGC 1399 radio lobes
DSS/Chandra/VLA
Fornax Propeller Galaxy
DES
Fornax A radio lobes
NRAO/AUI/NSF


Orion Nebula
NASA/ESA/HST/Robberto

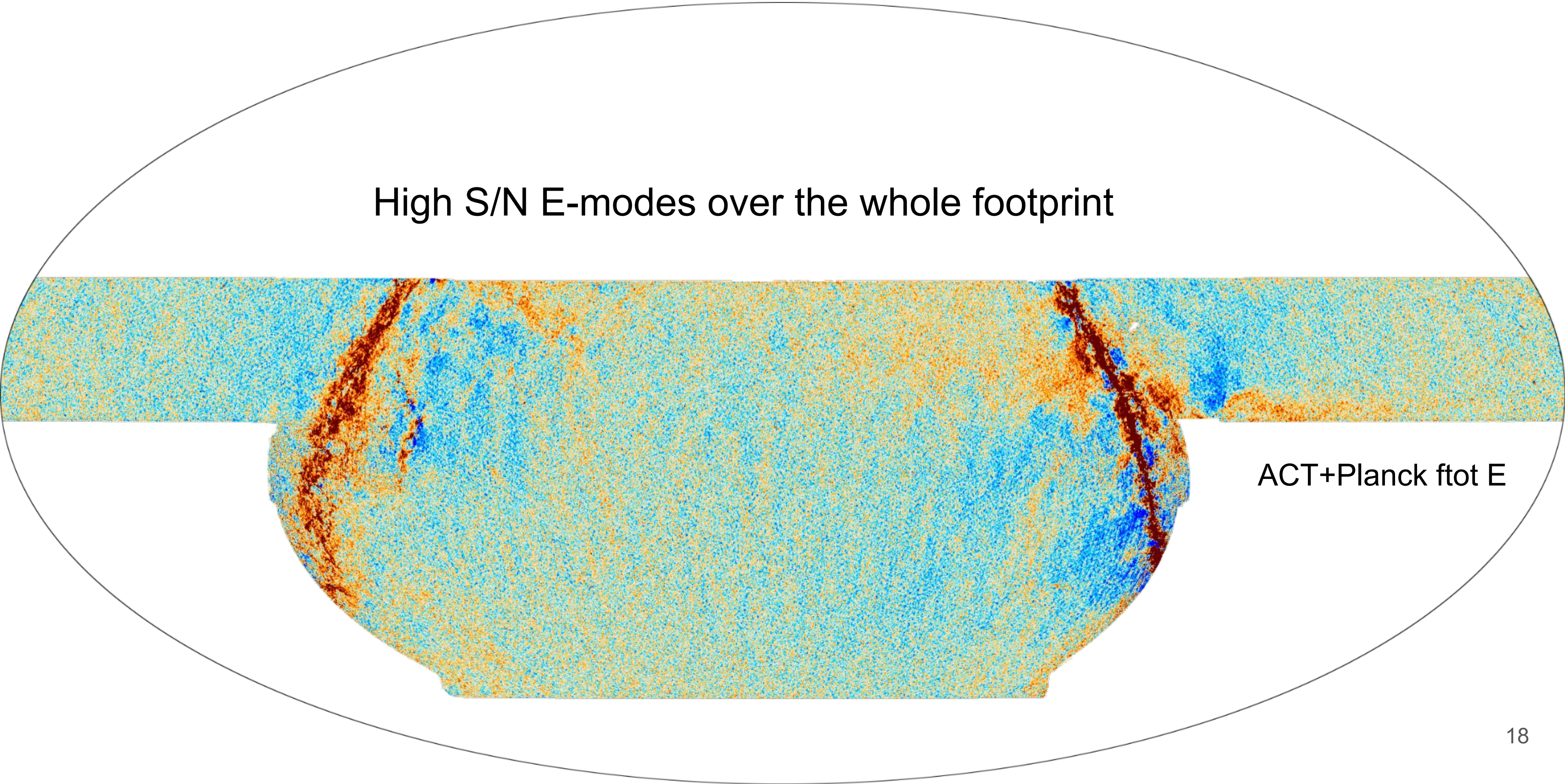

Rosette nebula
Siderevs nuncivs (cropped; CCA-SA4)
Betelgeuse (star)
ESO/Montargès

Polarization

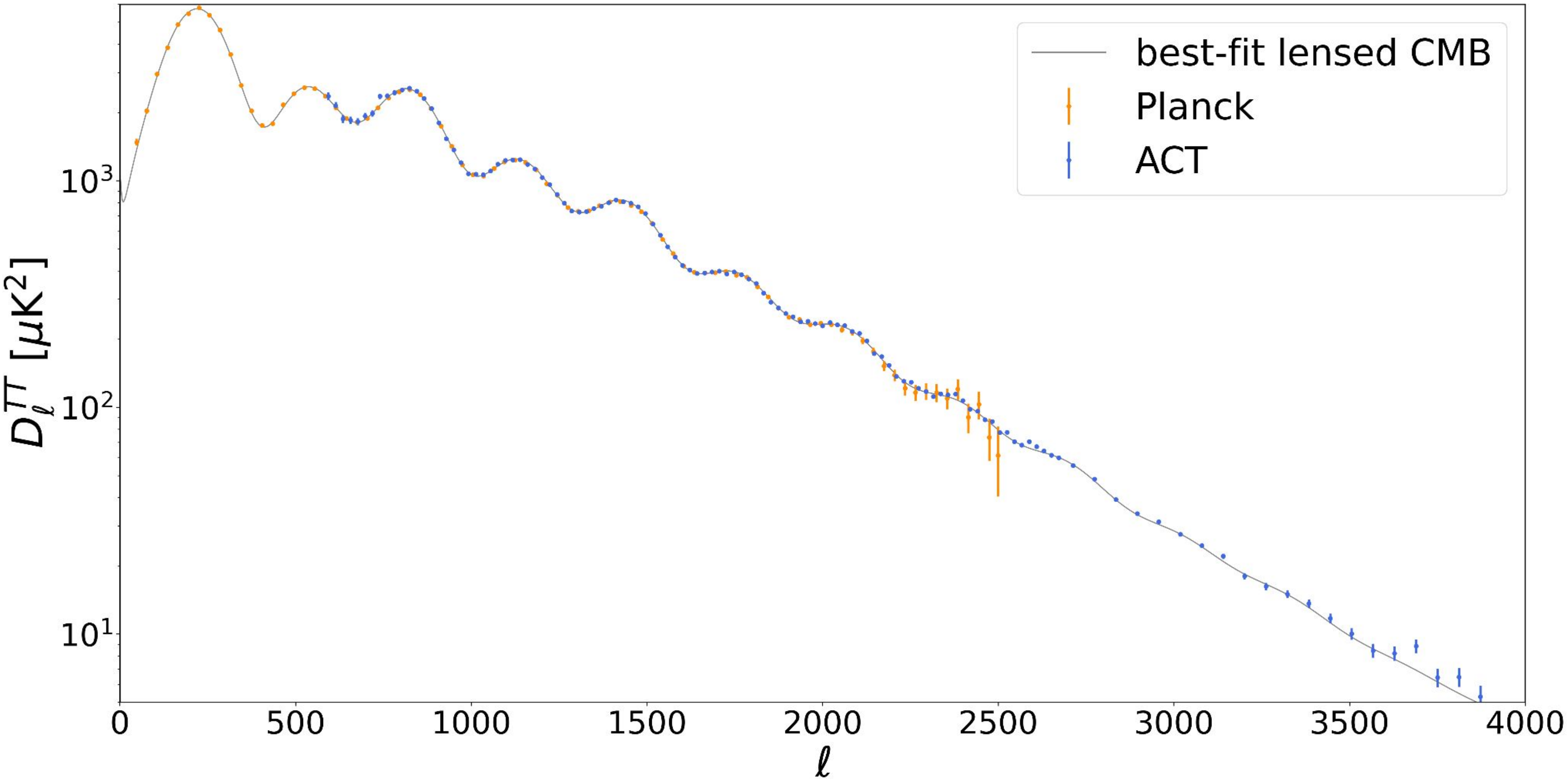

Planck E
frequency coadd
26°×14°


ACT+Planck E
frequency coadd
26°×14°

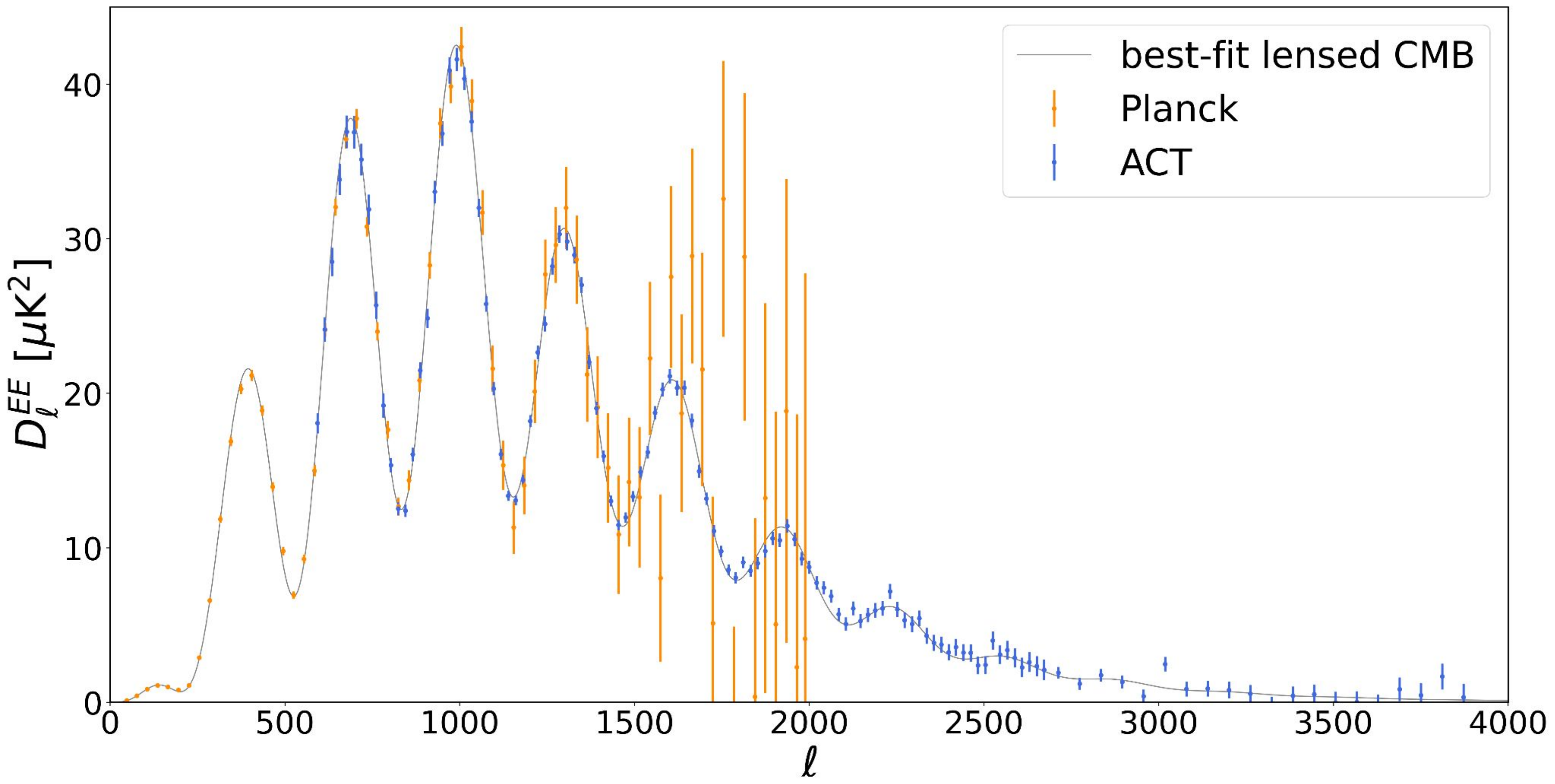
High S/N E-modes over the whole footprint



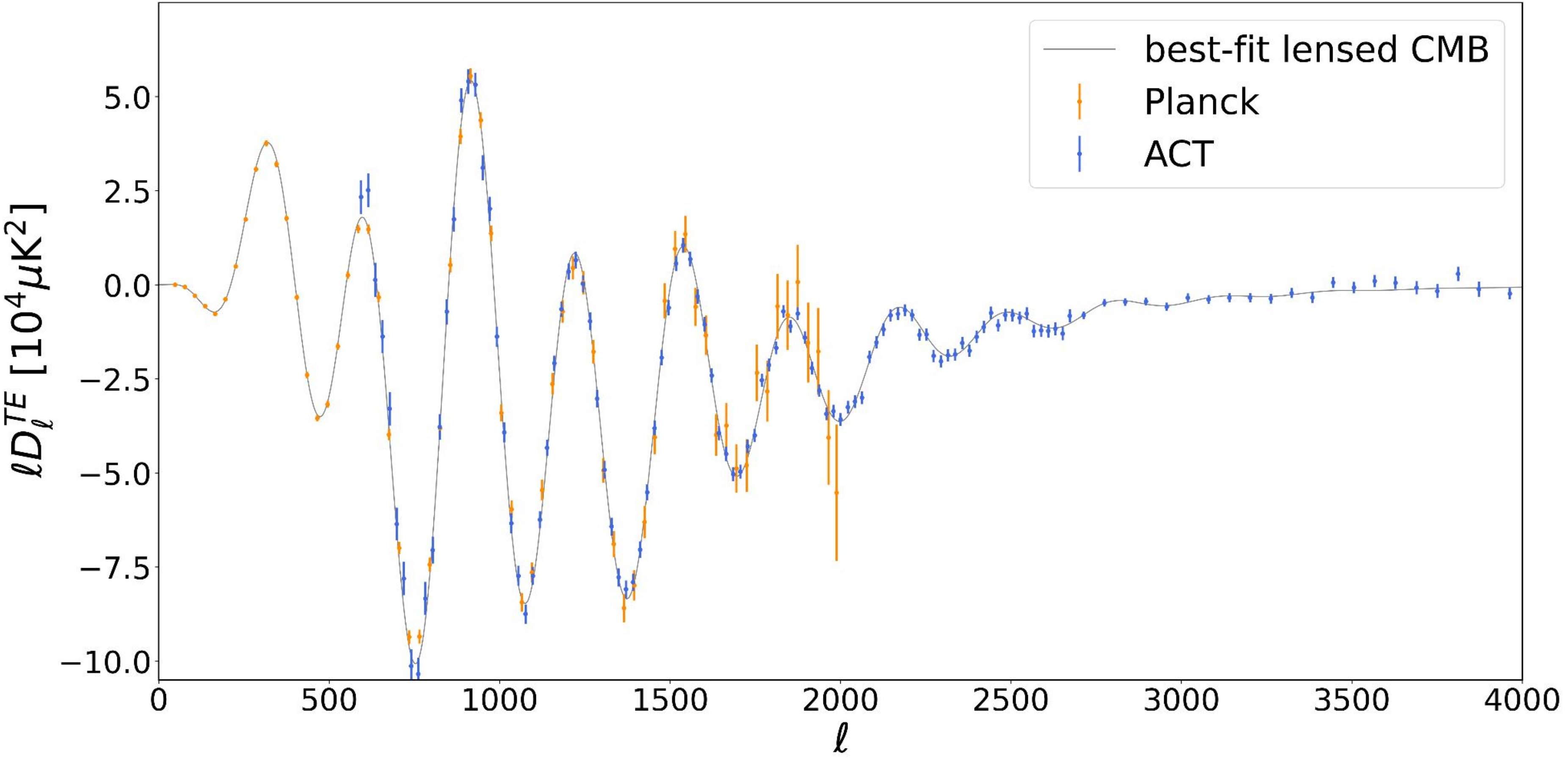
What do we measure?



ACT data 1) Extend Planck measurement to small angular scales.
2) Are very consistent with Planck data on overlapping angular scales.



ACT DR6 EE is more sensitive than Planck for multipoles $\ell > 600$

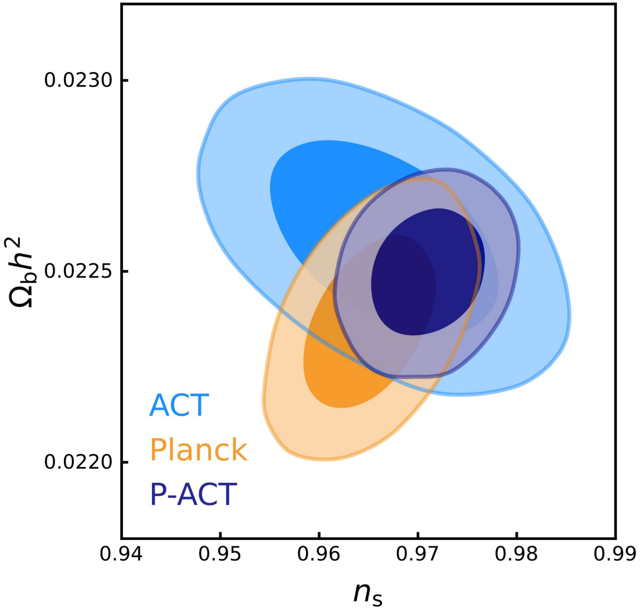


1.1 % constraint on H0 from TE alone
What is the grey line?

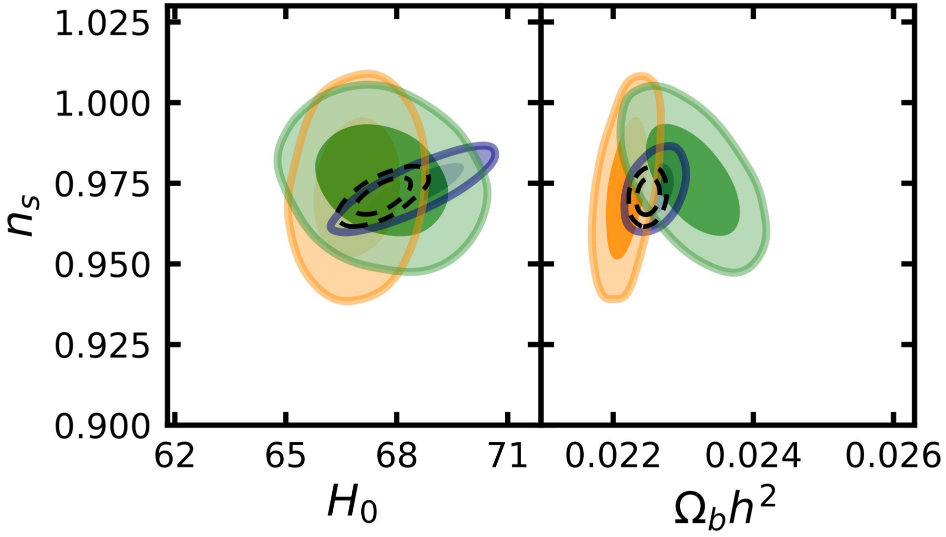
Joint fit of Planck and ACT DR6

ΛCDM provides an excellent fit to both Planck and ACT DR6 (1.6σ agreement)

χ^2(ACT) = 148/128 (11%)
χ^2(P-ACT) = 392/408 (71%)



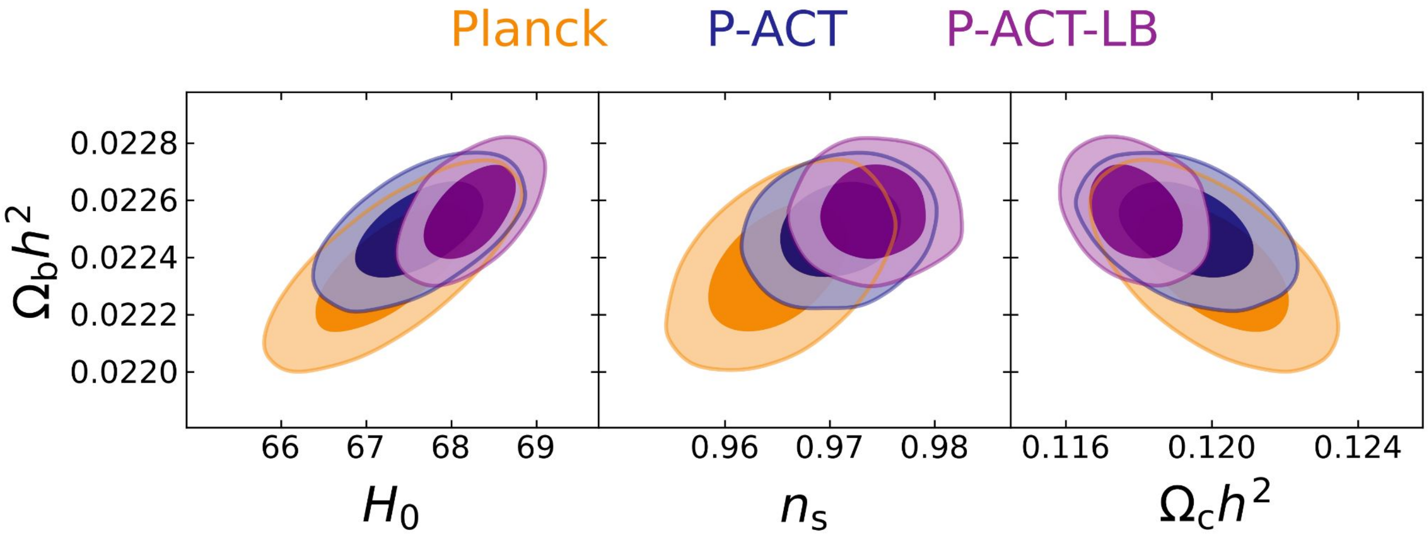
P-ACT TT
P-ACT TE
P-ACT-EE



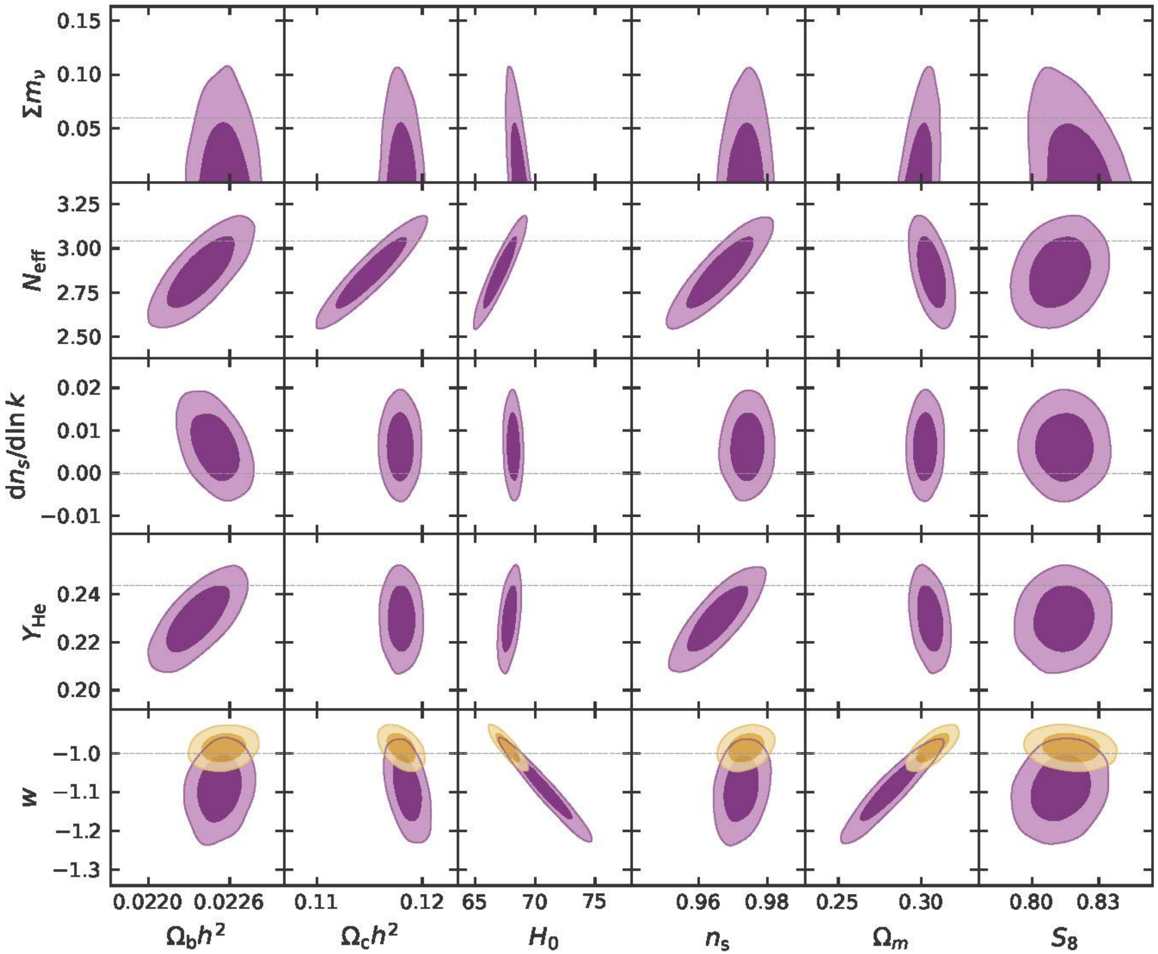
Combinations with the large scale structure

Combining with CMB lensing and DESI-Y1 BAO* gives state-of-the art constraints on the ΛCDM model parameters

0.5% measurement of the expansion rate H_0 = *68.22 ± 0.36 km/s/Mpc*



ACT DR6 – Single-Parameter ΛCDM Extensions



P-ACT-LB

P-ACT-LBS (P-ACT + SN1a)

P-ACT-LB$_{\rm DR2}$

$N_{\rm eff}$ = 2.86 ± 0.13

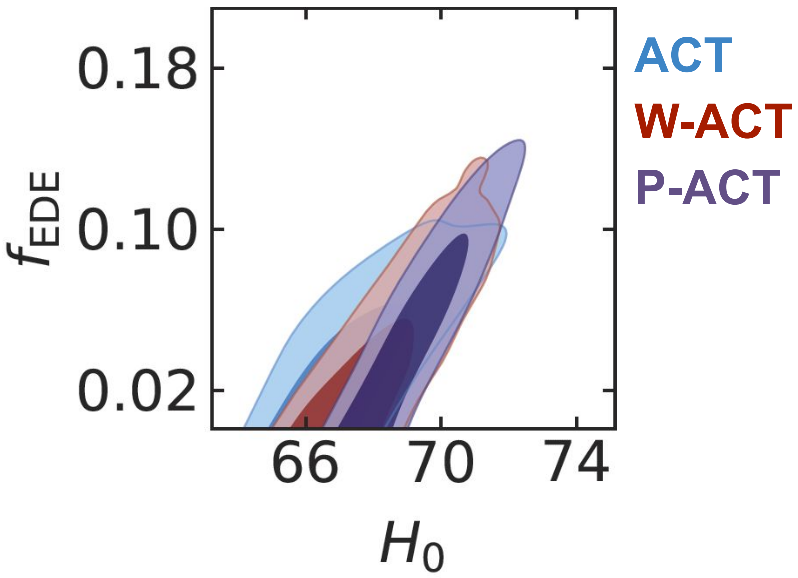
$N_{\rm eff}$ - 3.044 < 0.17 (95% CL)

$N_{\rm eff}$ - 3.044 < 0.36 (Planck + LB)

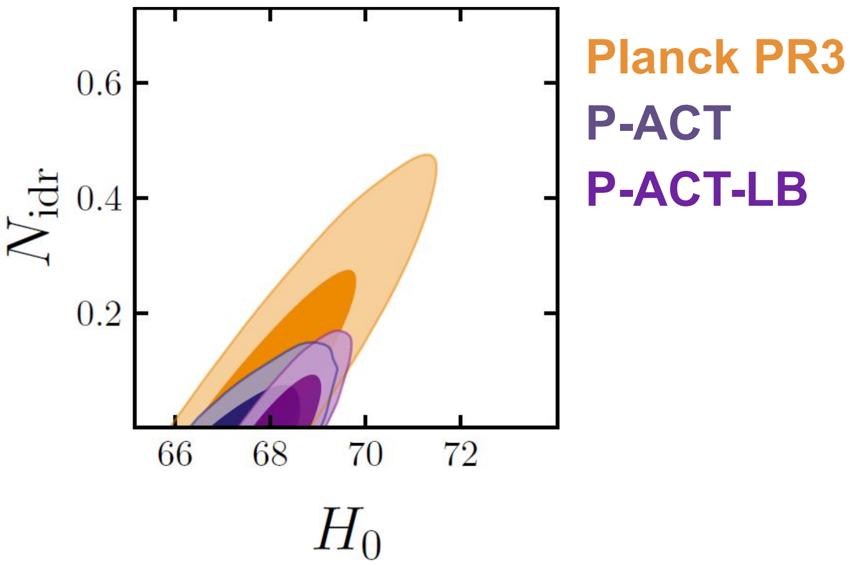
Similar with DESI DR2

ACT DR6 – New Physics

Early Dark Energy



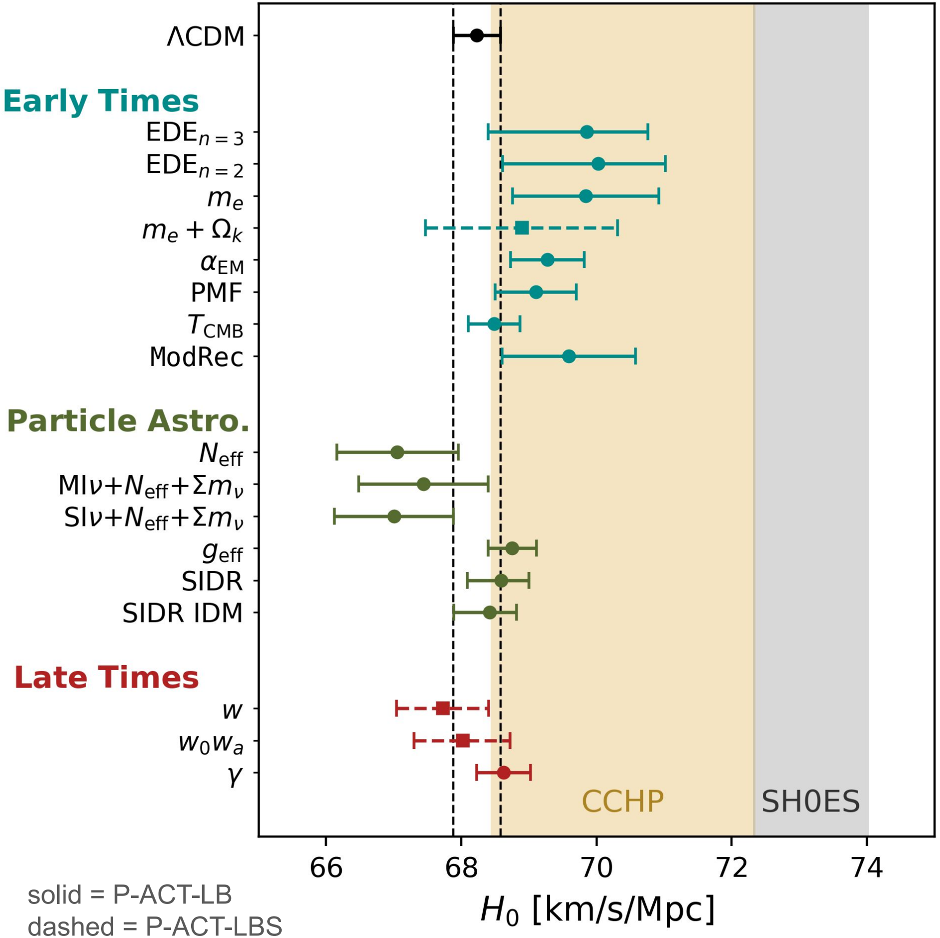
Interacting Dark Radiation



$f_{EDE} < 0.12$ (95% CL)

$N_{IDR} < 0.134$ (95% CL)

ACT DR6 – ΛCDM Extensions and H_0



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

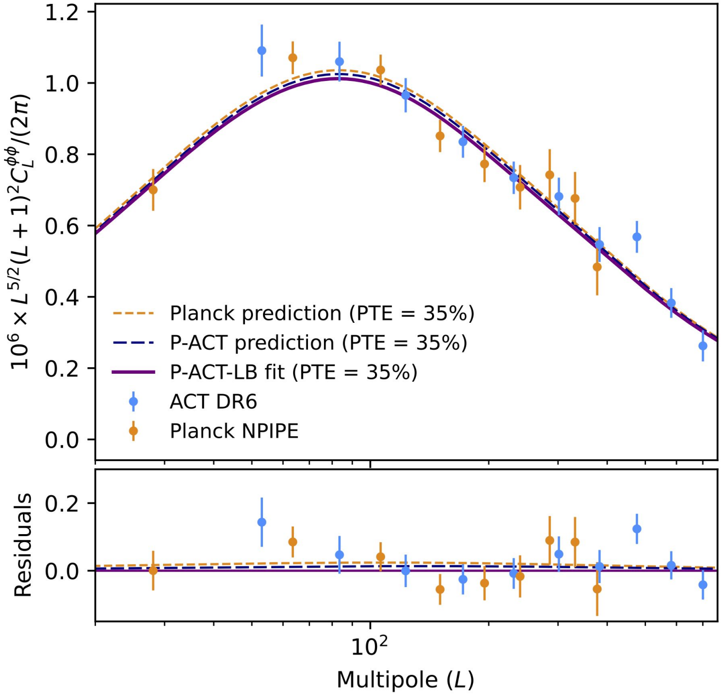
No extensions preferred over ΛCDM

>30 different extensions (not counting different data combos)

Cosmological concordance

- Predictions of the best-fit P-ACT ΛCDM model agree with direct low-redshift measurements
- ΛCDM gives an excellent joint fit to these datasets

CMB Lensing (ACT DR6 + Planck PR4)



BAO (DESI DR2)

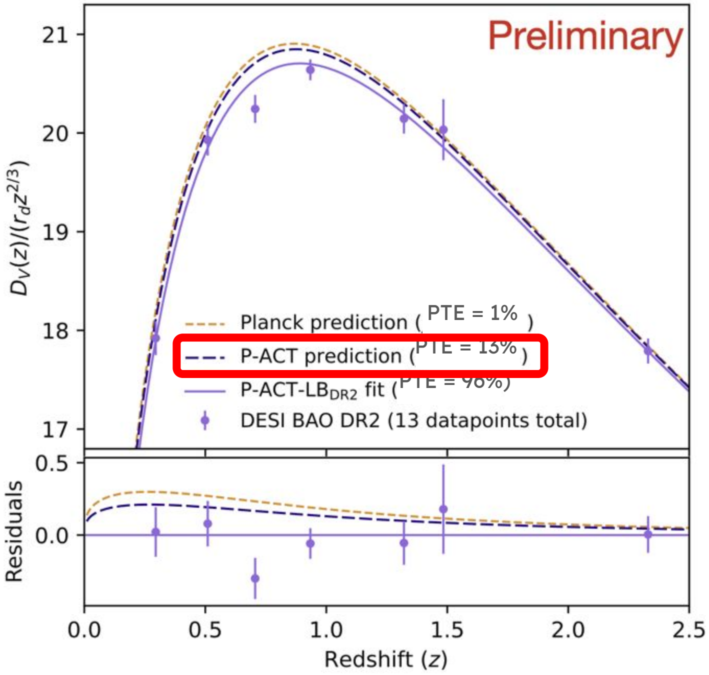
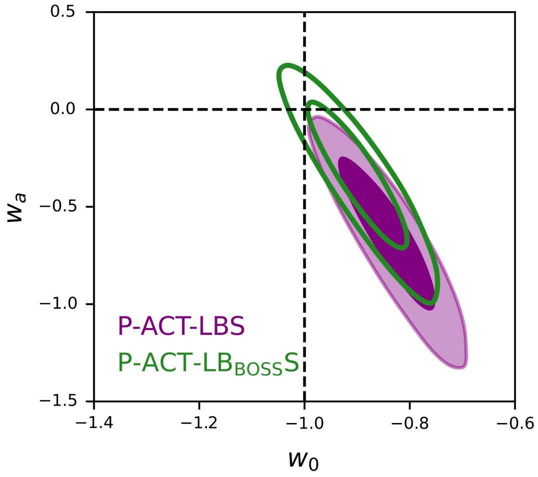


Figure credit: Hidde Jense

Outlook – Challenges to Standard Model?

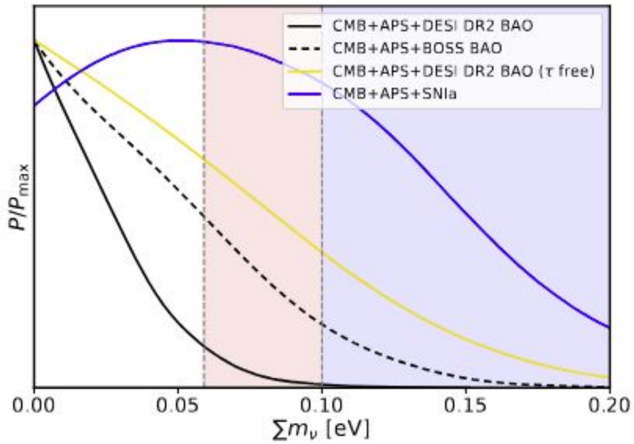
Evolving Dark Energy



- P-ACT-LBS Λ consistency: 2.2σ
- P-ACT-LB$_{DR2}$(S) Λ consistency: 2.4σ
- DESI* finds Planck + ACT: 2.4-3.0σ**

*(Garcia-Quintero et. al. 25)

(Cosmological) Neutrino Mass+

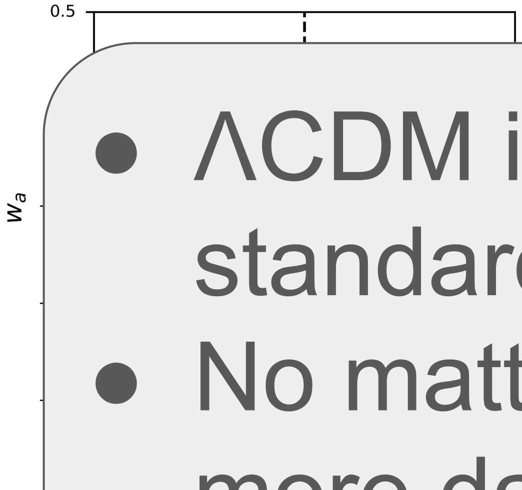


- Σm_ν < 0.061-062eV (95% confidence)**

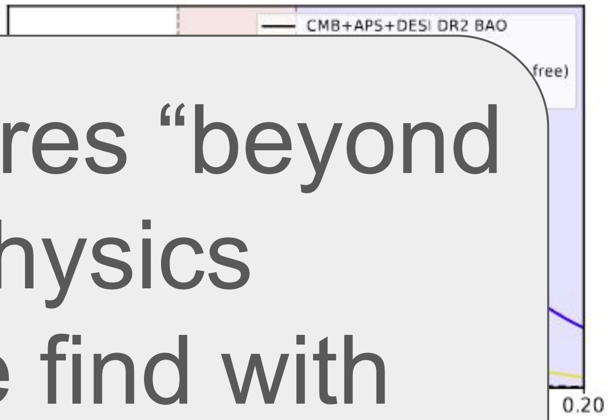
+Figure from Qu et. al. 2025
**Depends on exact choice of likelihoods (Qu et. al. 2025, Garcia-Quintero et. al. 25)

Outlook – Challenges to Standard Model?

Evolving Dark Energy



(Cosmological) Neutrino Mass



- ΛCDM is still requires “beyond standard model” physics
- No matter what we find with more data, it will be exciting

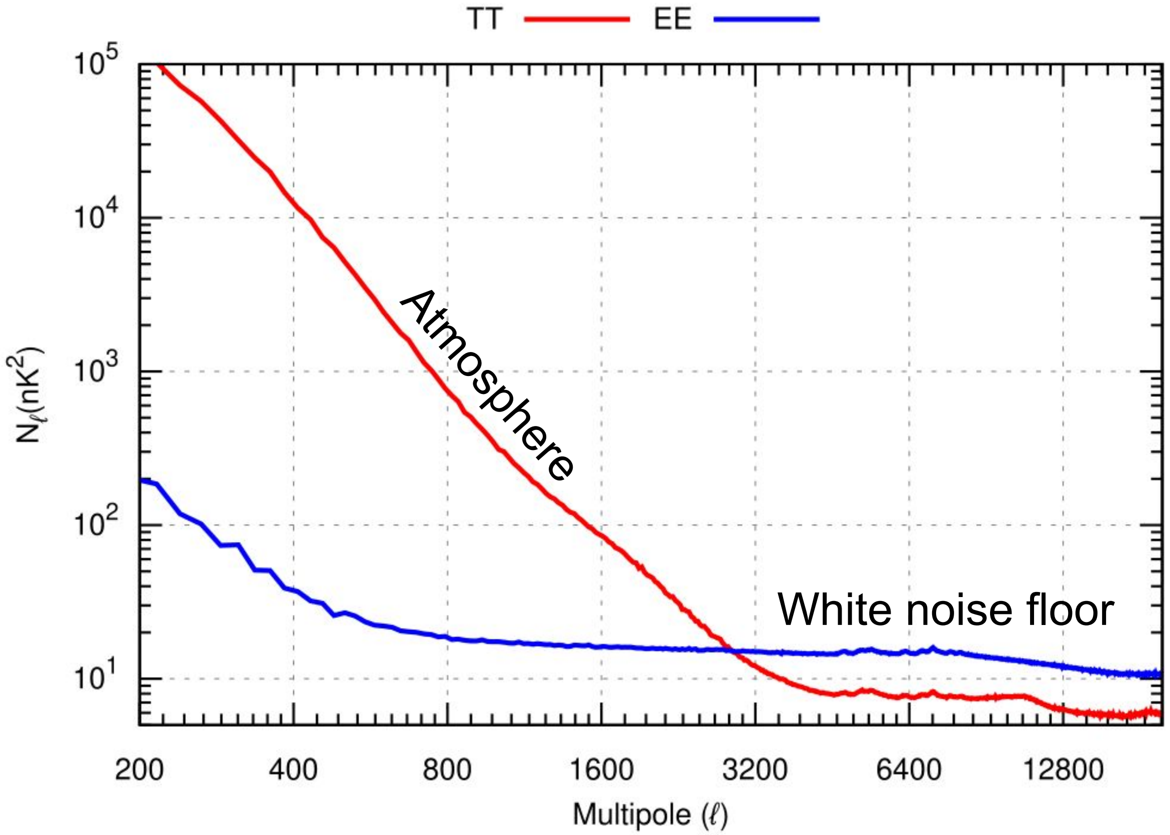
- P-AC … nfidence)*
- P-ACT-LB$_{DR2}$(C) Λ consistency: 2.1σ
- DESI* finds Planck + ACT: 2.4-3.0σ

*(Garcia-Quintero et. al. 25)

*Figure from Qu et. al. 2025
*Depends on exact choice of likelihoods (Qu et. al. 2025, Garcia-Quintero et. al. 25)

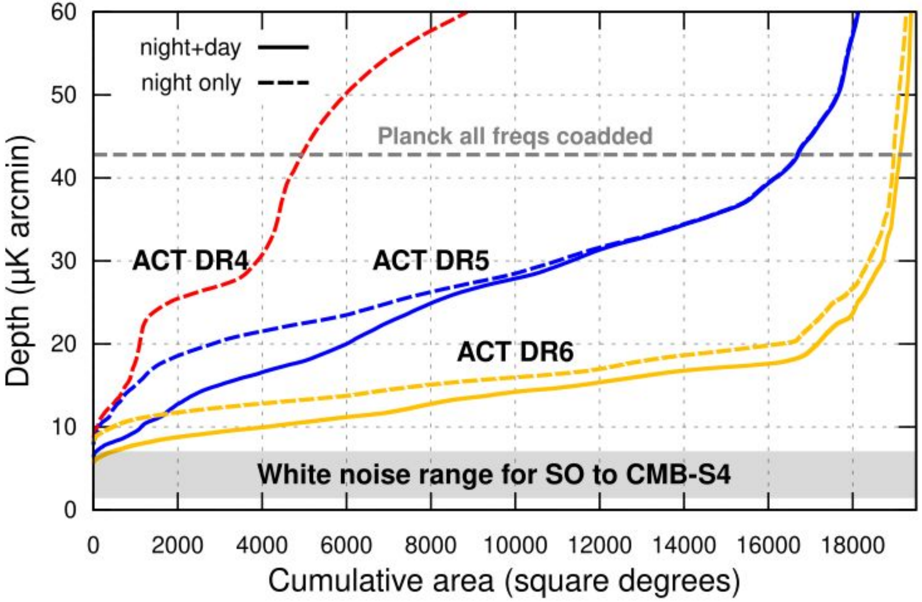
backup

1. Full sensitivity only on small scales

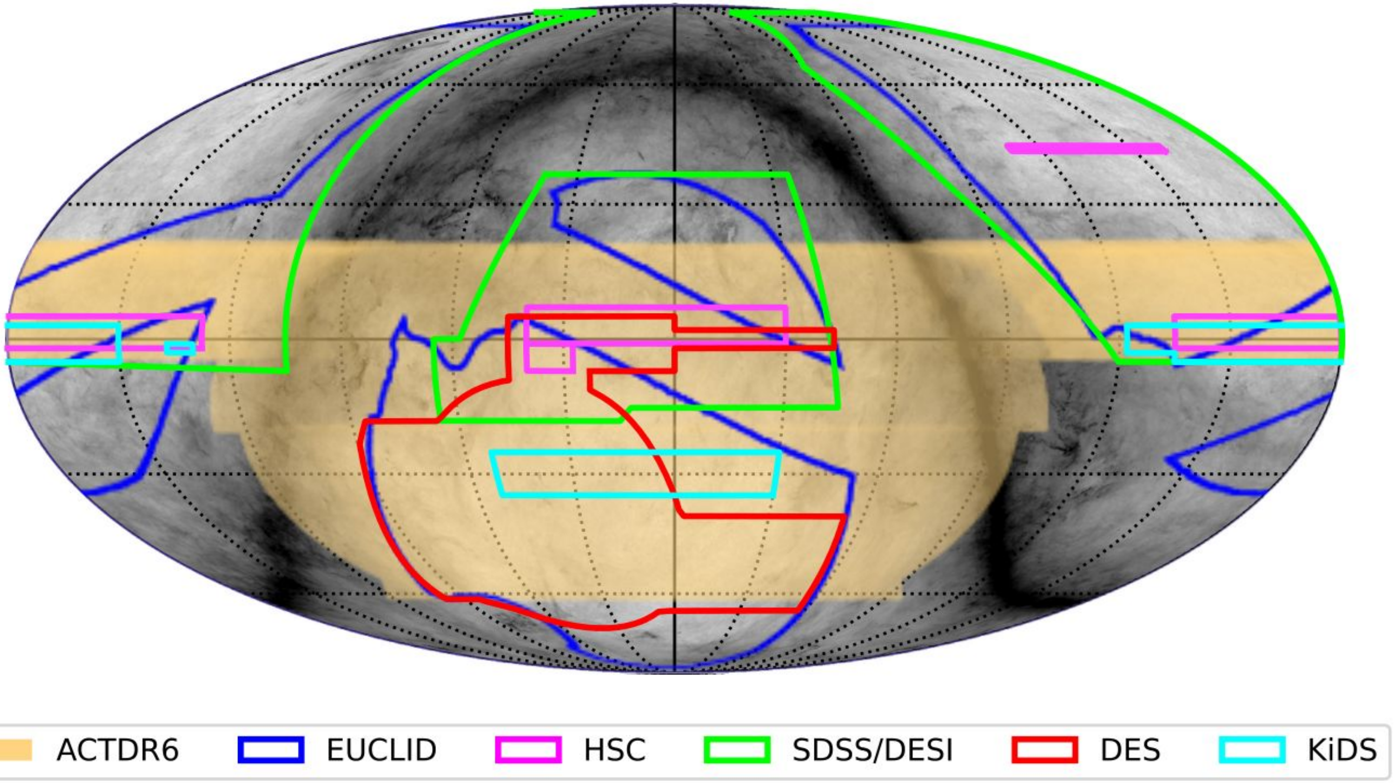


- Large improvement in depth compared to previous full data release (DR4) and interim release (DR5)
- Deeper than Planck over 19000 square degrees (on small scales)
- On average ⅓ the white noise RMS of Planck

Polarization

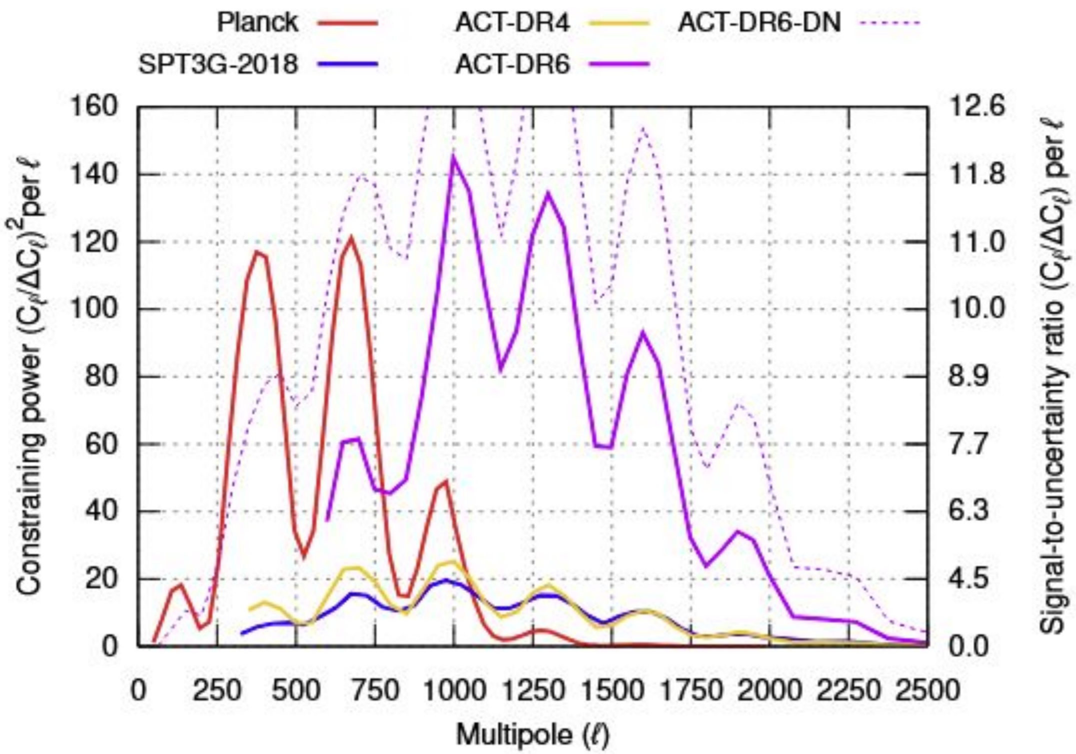


45% sky coverage and large overlap with other surveys



Pushing the data frontier

Constraining power of EE power spectra by experiment



Data release

LAMBDA legacy archive (lambda.gsfc.nasa.gov)

- 600 raw frequency maps including null test maps
- 94 processed maps including Needlet-ILC maps of the CMB blackbody signal and thermal Sunyaev- Zeldovich signal
- MCMC chains, power spectra

NERSC (/global/cfs/cdirs/cmb/data/act_dr6/dr6.02)

In addition to all products on LAMBDA

- 38 TB of short exposure maps used for time-domain analysis
- Noise models and noise simulations of the frequency maps
- All products needed to go from the maps to the power spectrum results

DR6_Notebooks Public

Python notebooks with DR6 tutorials:
github.com/ACTCollaboration/DR6_Notebooks

Code release

https://github.com/simonsobs/PSpipe/project/ACT_DR6

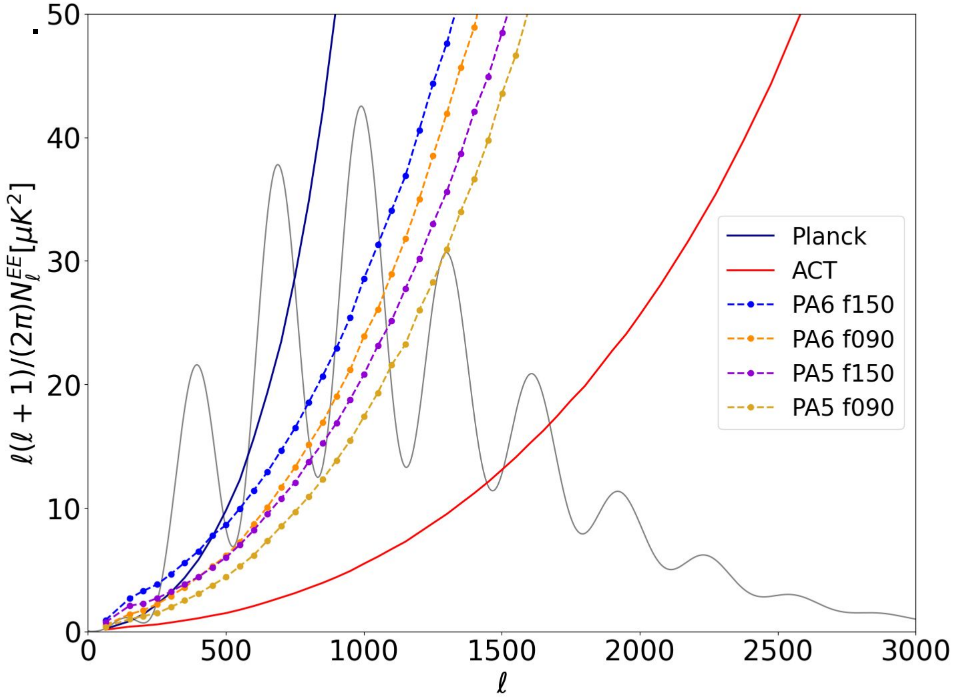
In addition to the data release, we are releasing the entire pipeline that was used to go from maps to cosmological parameters. This includes:

- Power spectra and covariance matrices estimation
- Temperature-to-polarization leakage corrections
- Cross-correlations with Planck data
- Likelihood function for cosmological parameters estimation

Instructions to install and run the code at NERSC are also available.

Noise properties

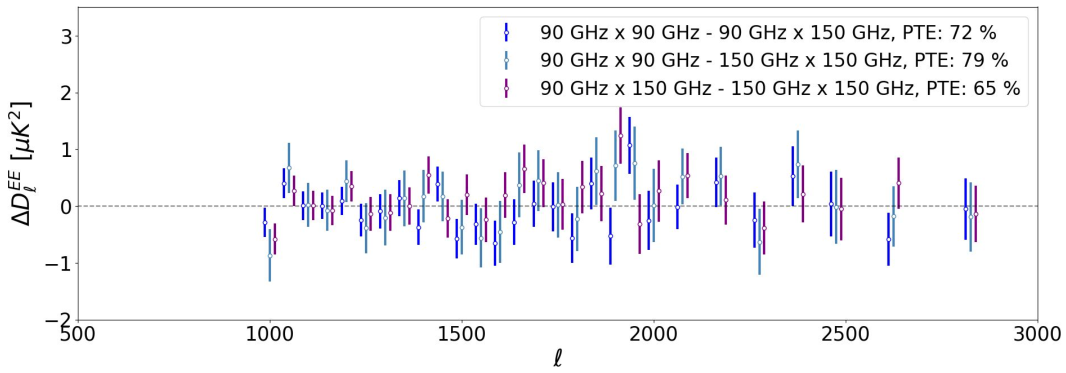
The ACT DR6 polarization data are signal-dominated up to a multipole ℓ=1500, corresponding to an angular scale of ~ 0.1 degrees. The different array-bands have comparable constraining power, providing useful redundancies.

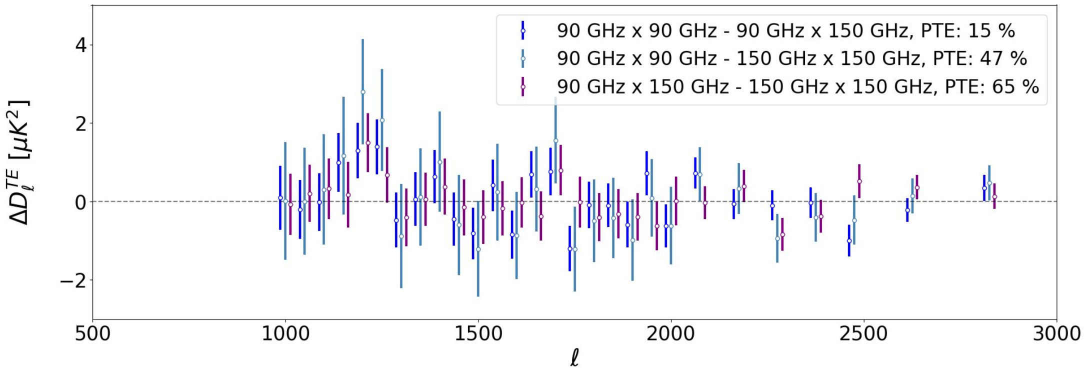


Null tests

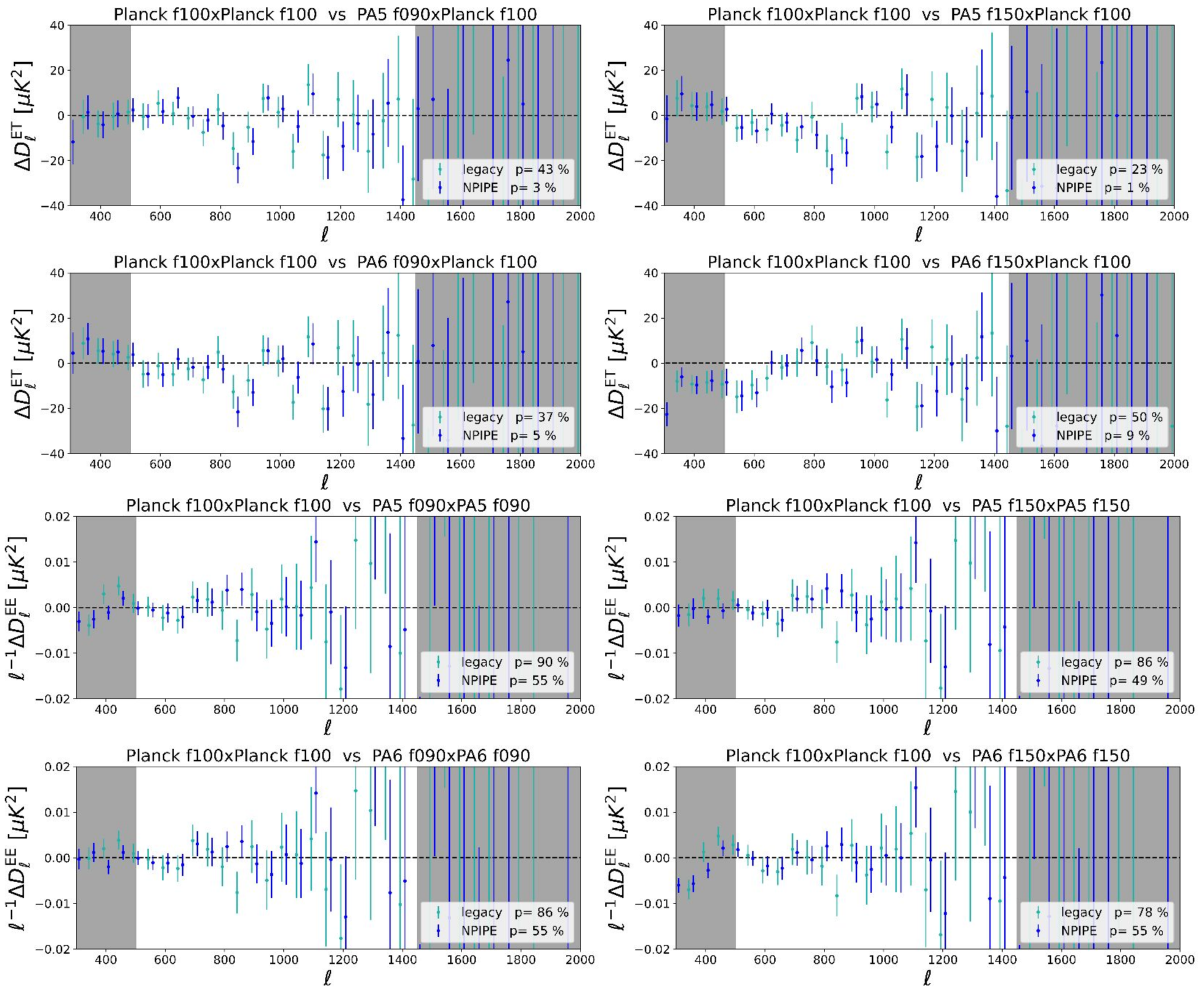
Before unblinding, we have performed around 2000 null tests on the data, we checked that the results do not depend on

- array bands
- weather conditions
- scan elevation
- sky location
- time of observation
- position of the detectors in the focal plane

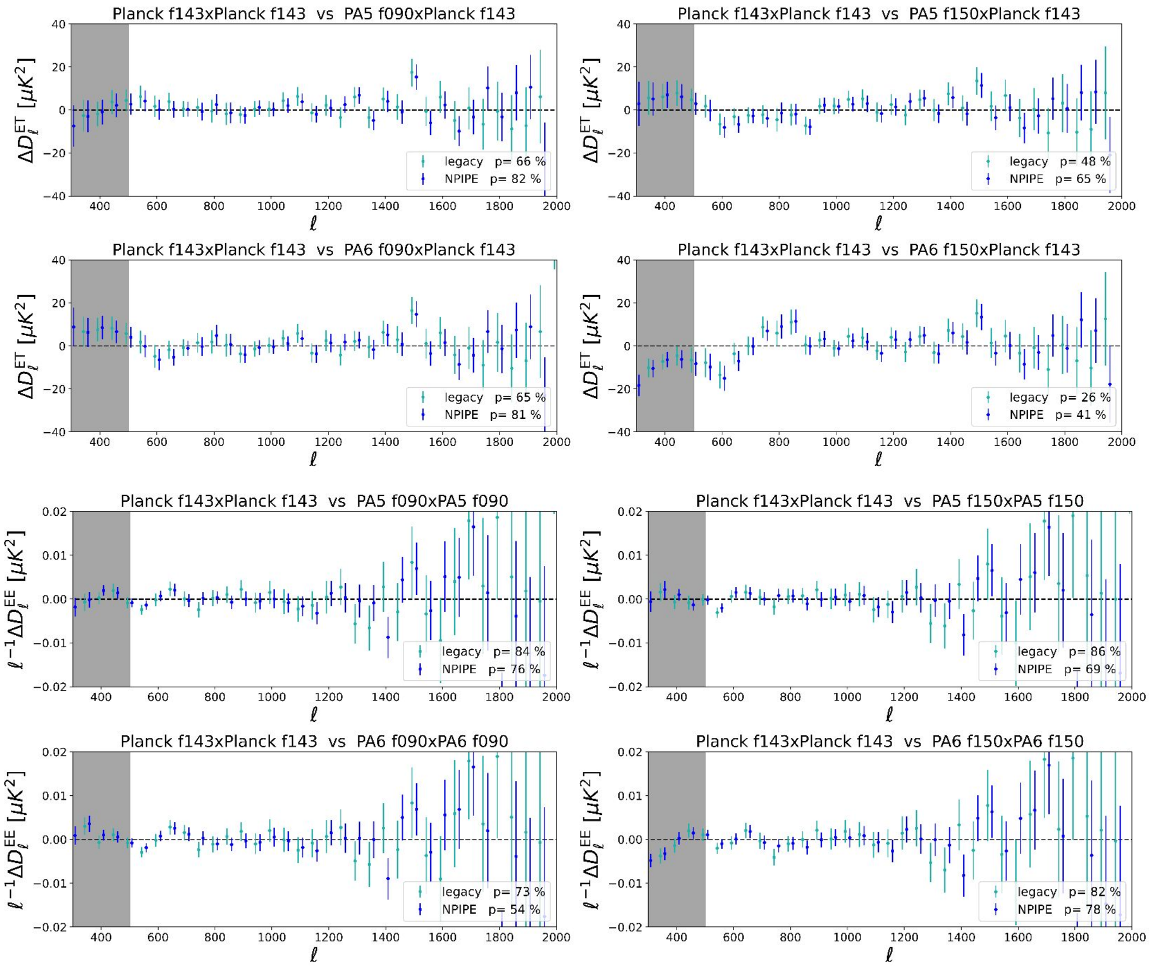




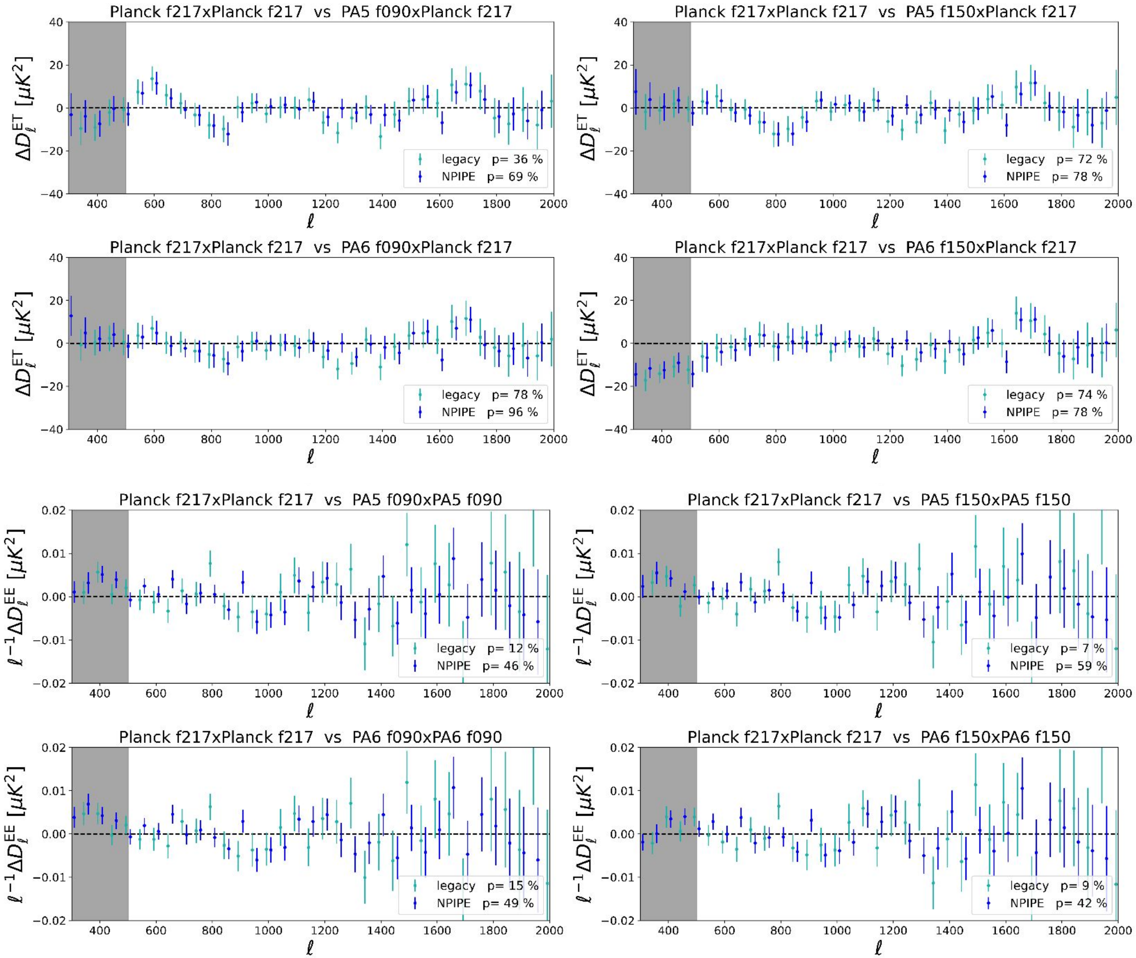
ACT and Planck on the same patch of the sky

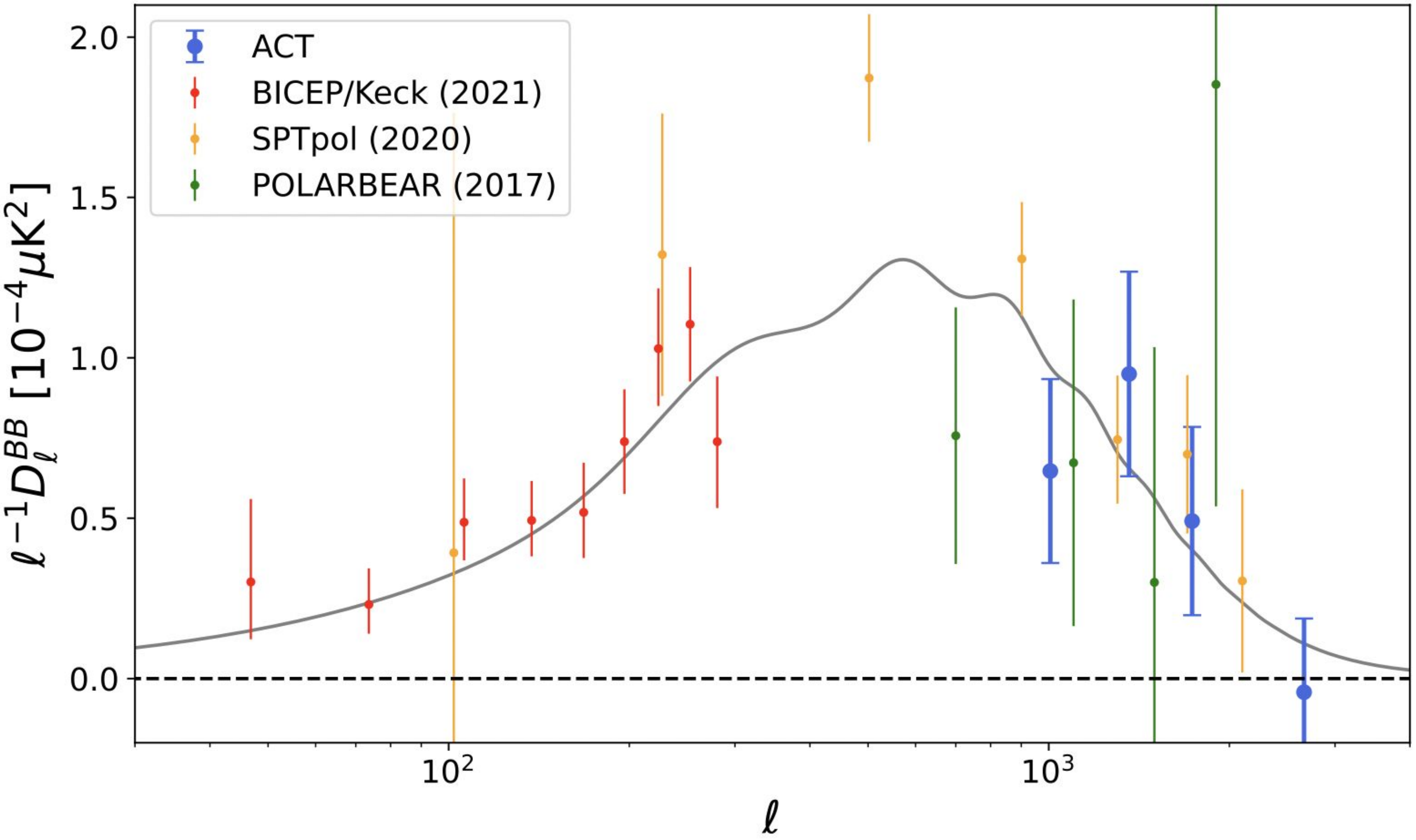


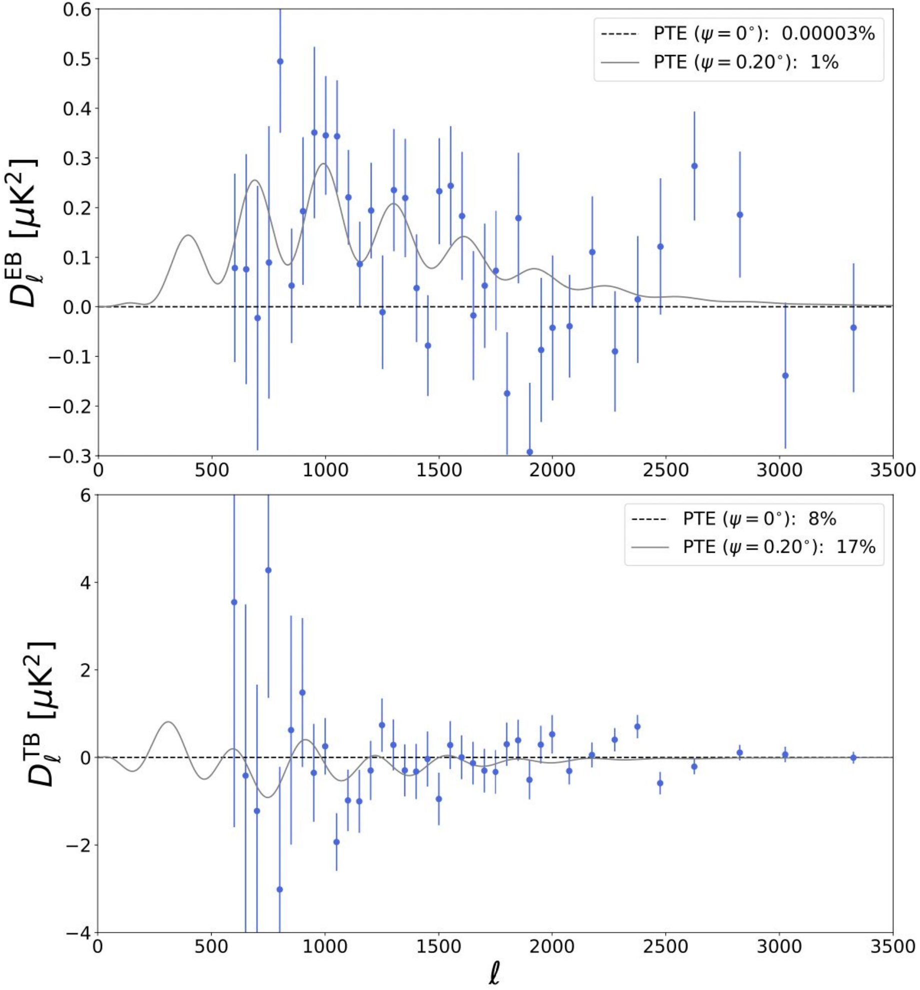
ACT and Planck on the same patch of the sky

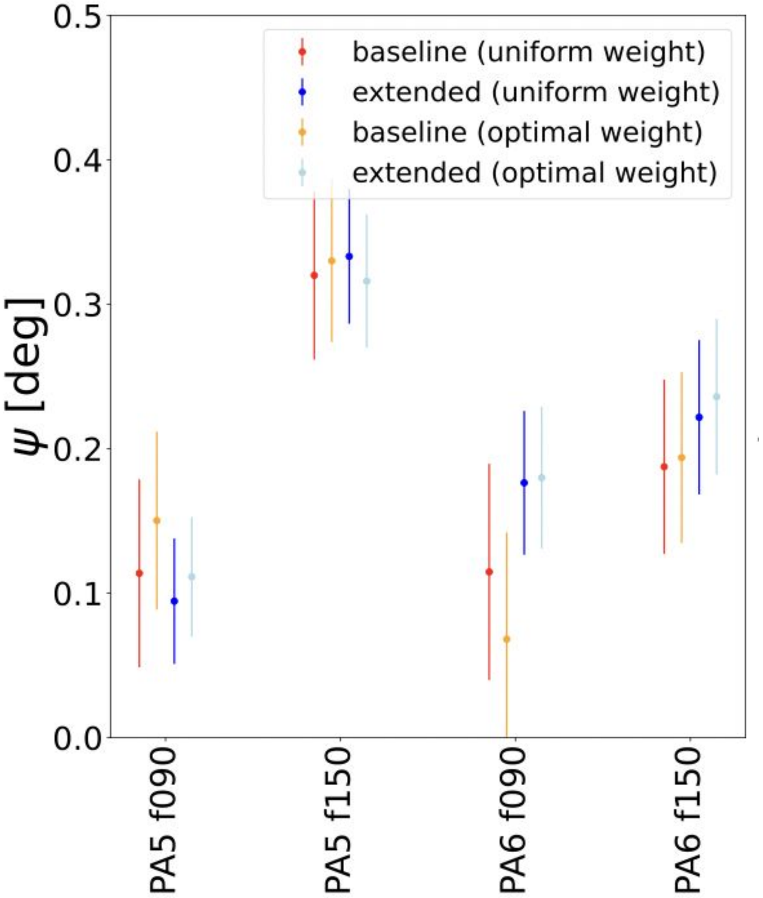


ACT and Planck on the same patch of the sky

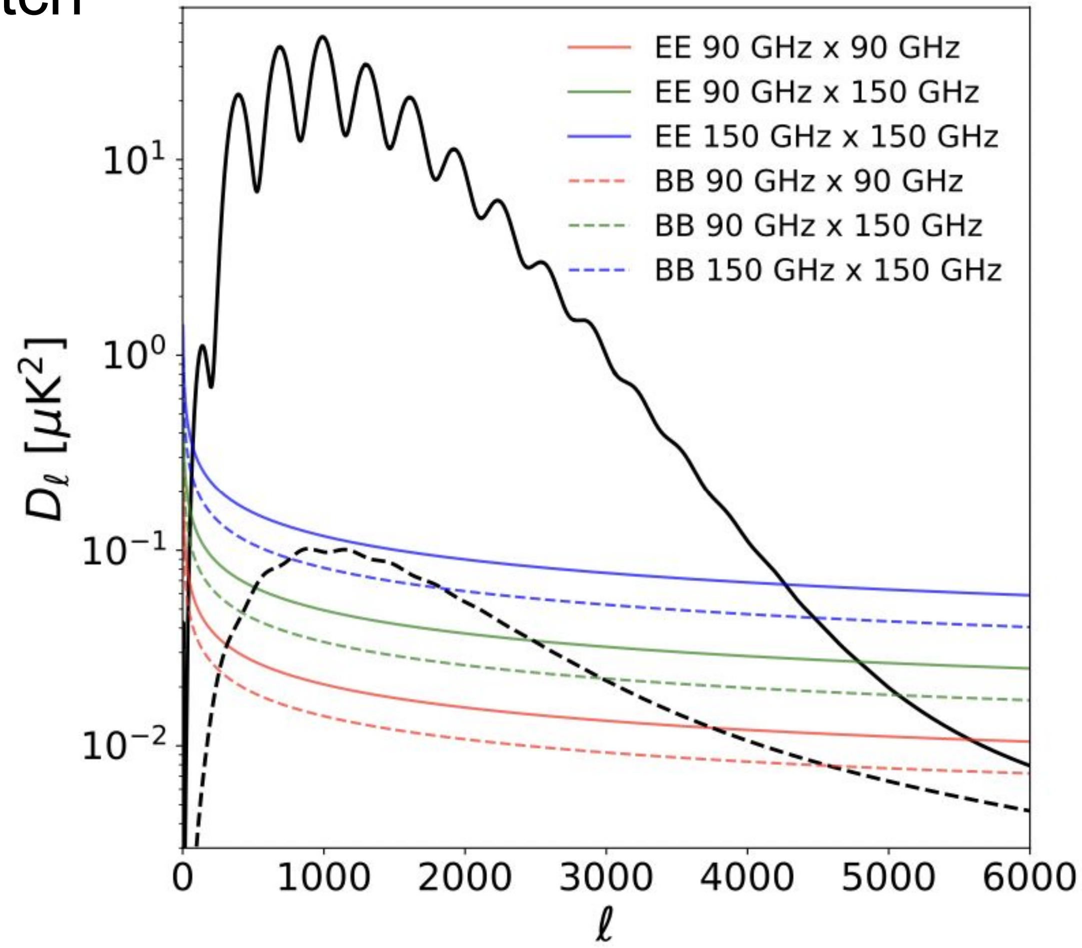



ACT
BICEP/Keck (2021)
SPTpol (2020)
POLARBEAR (2017)
$\ell^{-1} D_\ell^{BB}$ [$10^{-4} \mu K^2$]
2.0
1.5
1.0
0.5
0.0
10^2
10^3
ℓ


PTE ($\psi = 0^\circ$): 0.00003%
PTE ($\psi = 0.20^\circ$): 1%
D_ℓ^{EB} [μK^2]
PTE ($\psi = 0^\circ$): 8%
PTE ($\psi = 0.20^\circ$): 17%
D_ℓ^{TB} [μK^2]
ℓ


baseline (uniform weight)
extended (uniform weight)
baseline (optimal weight)
extended (optimal weight)
ψ [deg]
PA5 f090
PA5 f150
PA6 f090
PA6 f150

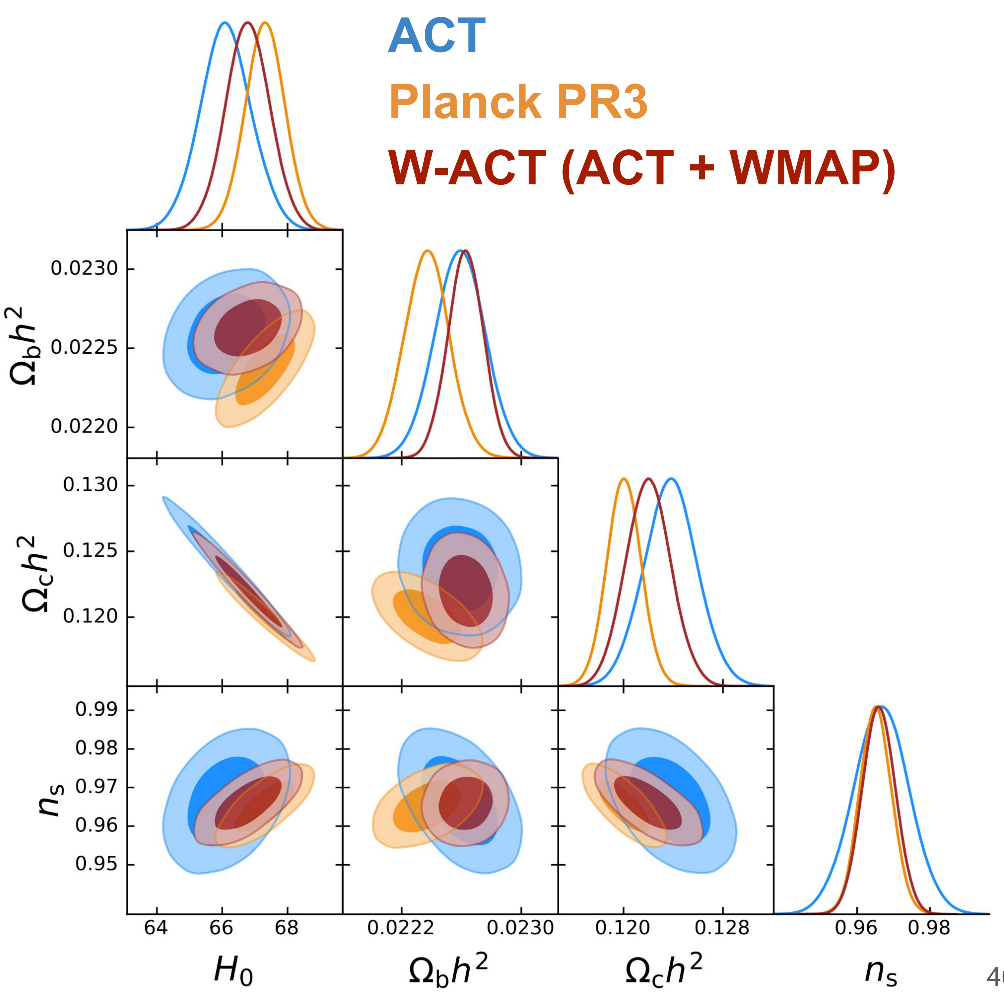
Dust in the DR6 patch



Independent constraints from ACT & WMAP

- Cosmological constraints from ACT DR6 and Planck are consistent (**1.6 σ**)

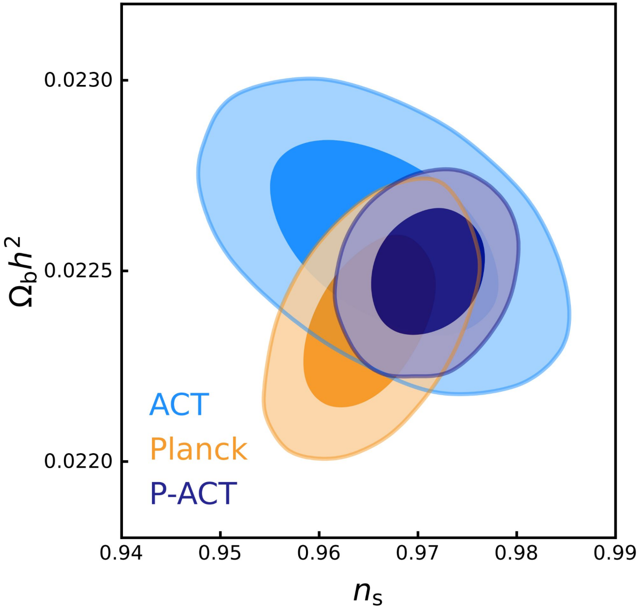
- ACT + WMAP provides an independent and competitive dataset with e.g.
  $\Omega_b h^2 = 0.02263 \pm 0.00012$
  $H_0 = 66.78 \pm 0.68$ *km/s/Mpc*

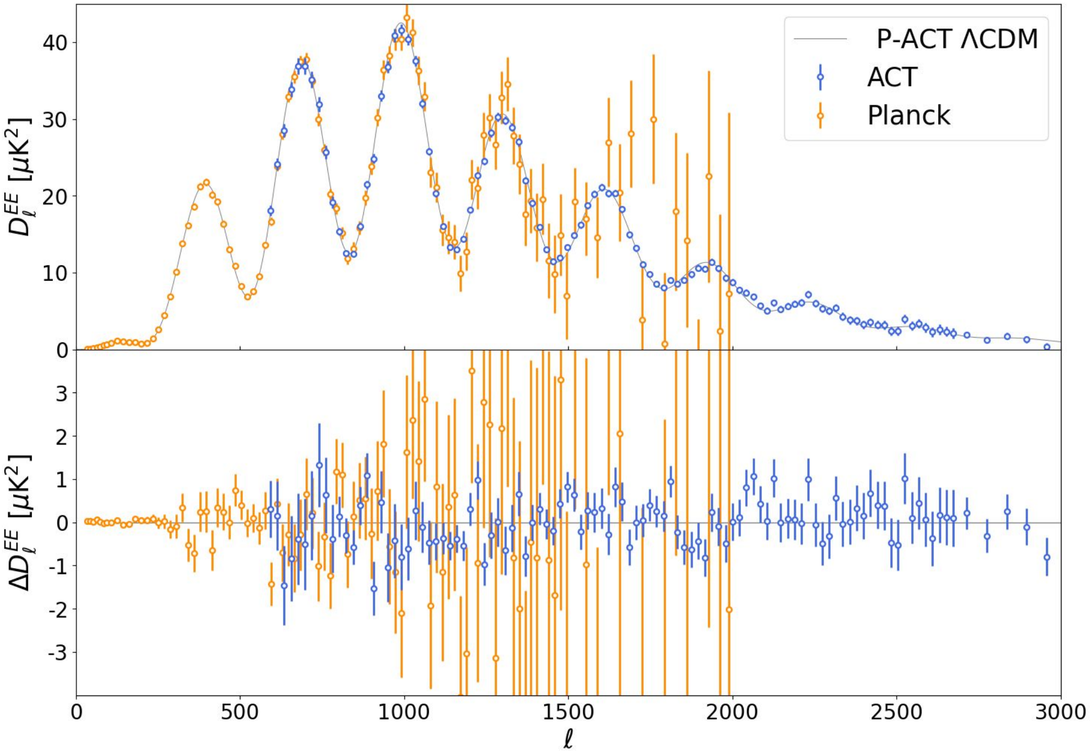


Joint fit of Planck and ACT DR6

ΛCDM provides an excellent fit to both Planck and ACT DR6

χ^2(ACT) = 1598/1617 (63%)
χ^2(P-ACT) = 1842/1897 (81%)

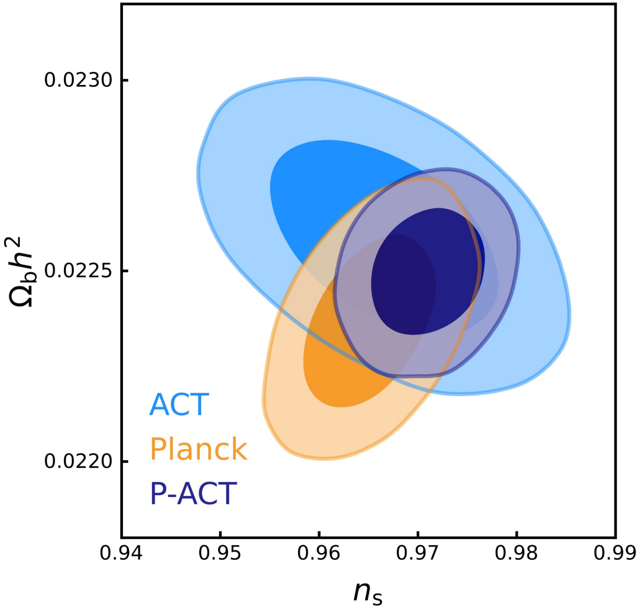


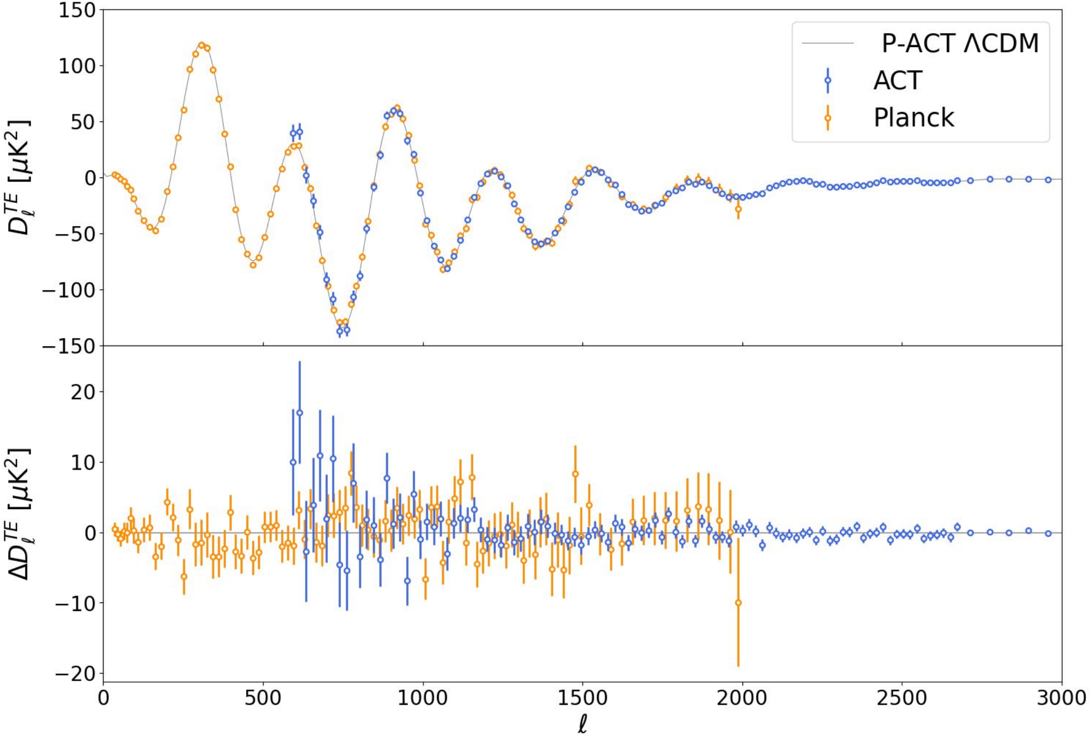


Joint fit of Planck and ACT DR6

ΛCDM provides an excellent fit to both Planck and ACT DR6

χ^2(ACT) = 1598/1617 (63%)
χ^2(P-ACT) = 1842/1897 (81%)

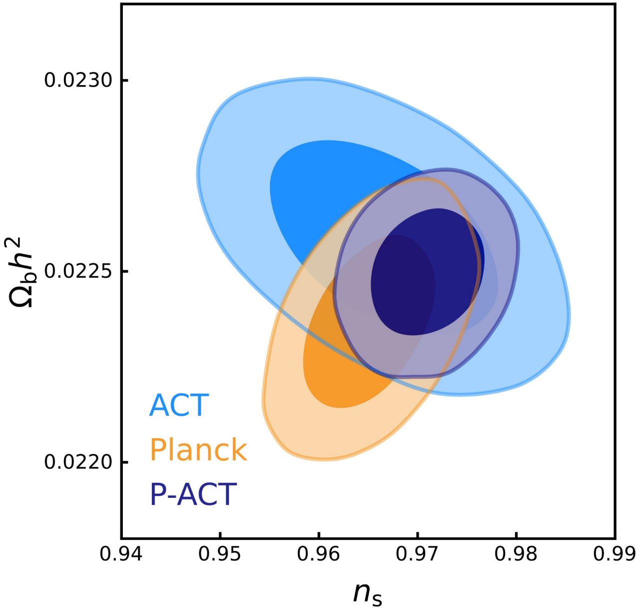


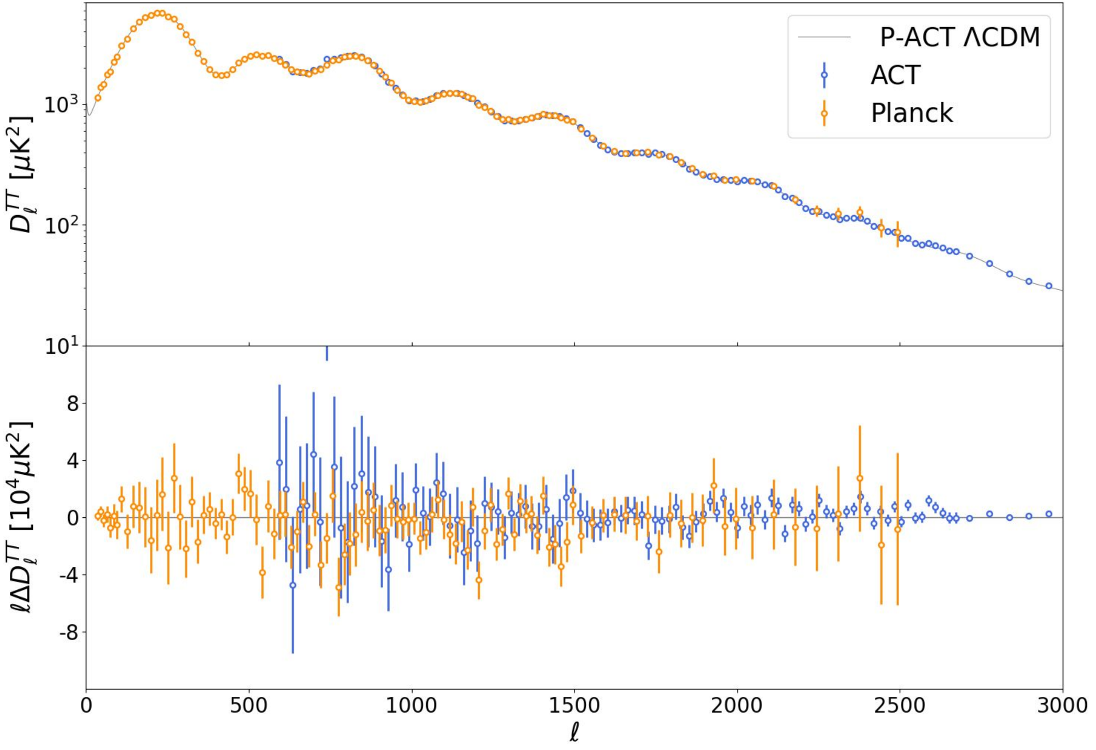


Joint fit of Planck and ACT DR6

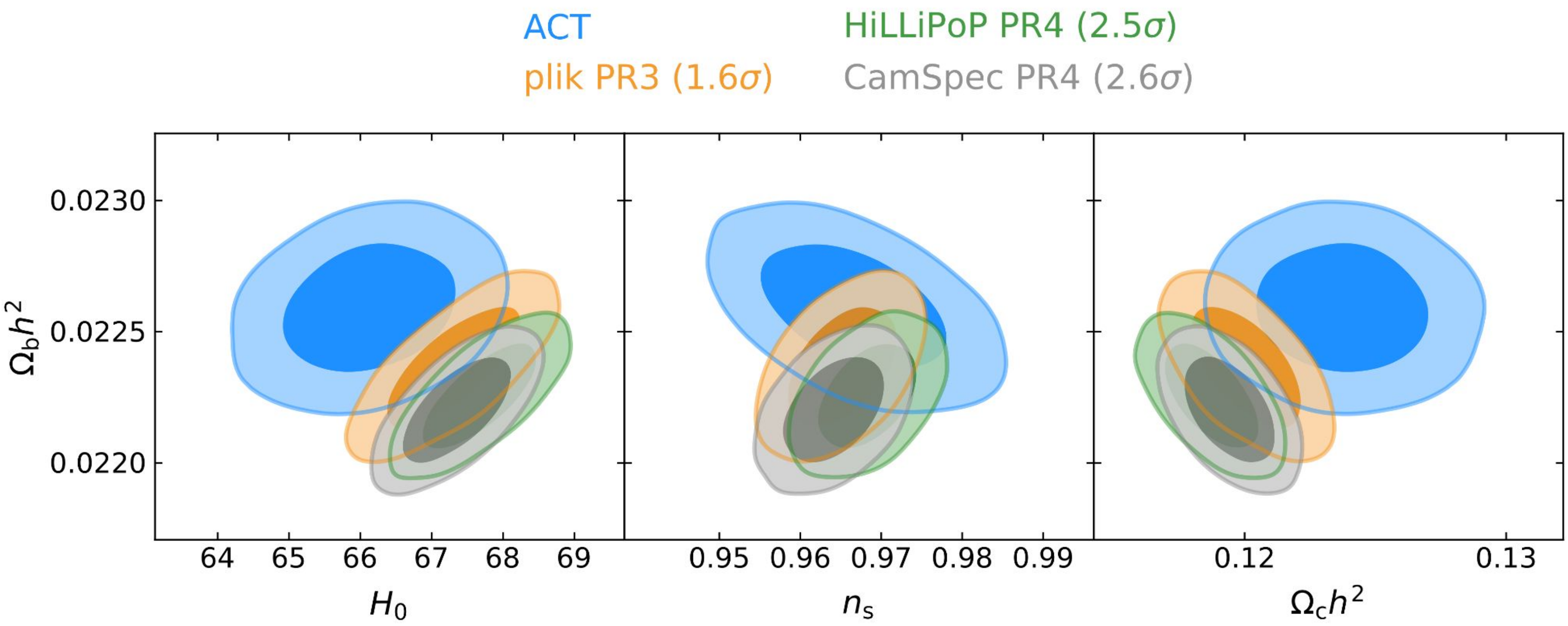
ΛCDM provides an excellent fit to both Planck and ACT DR6

χ^2(ACT) = 1598/1617 (63%)
χ^2(P-ACT) = 1842/1897 (81%)

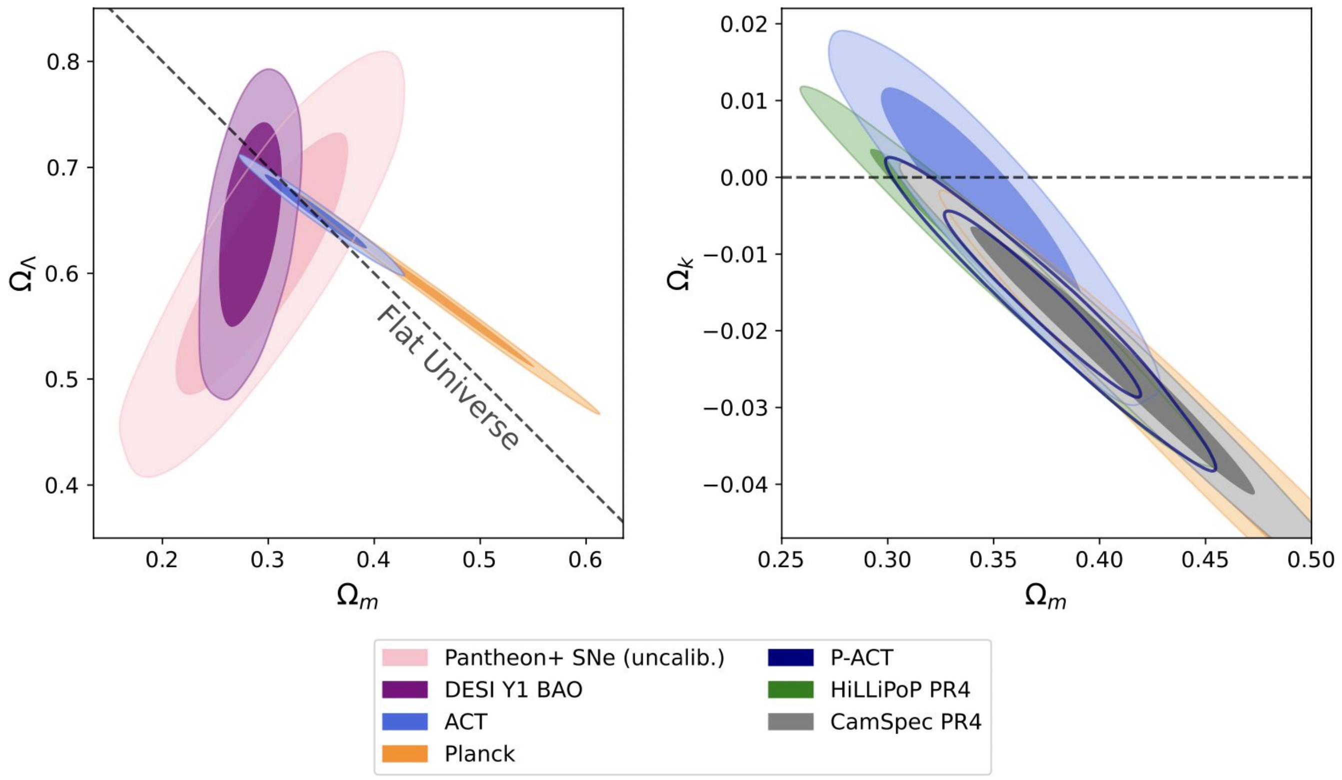




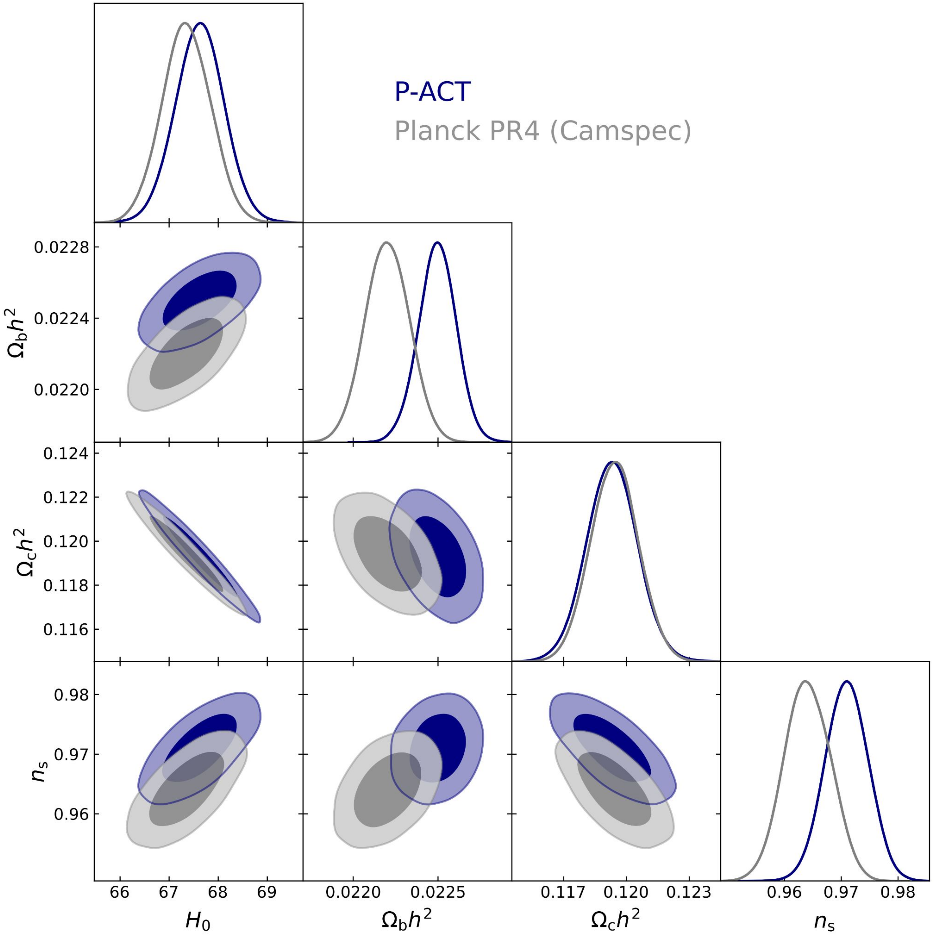
Comparison with Planck PR4 (NPIPE)



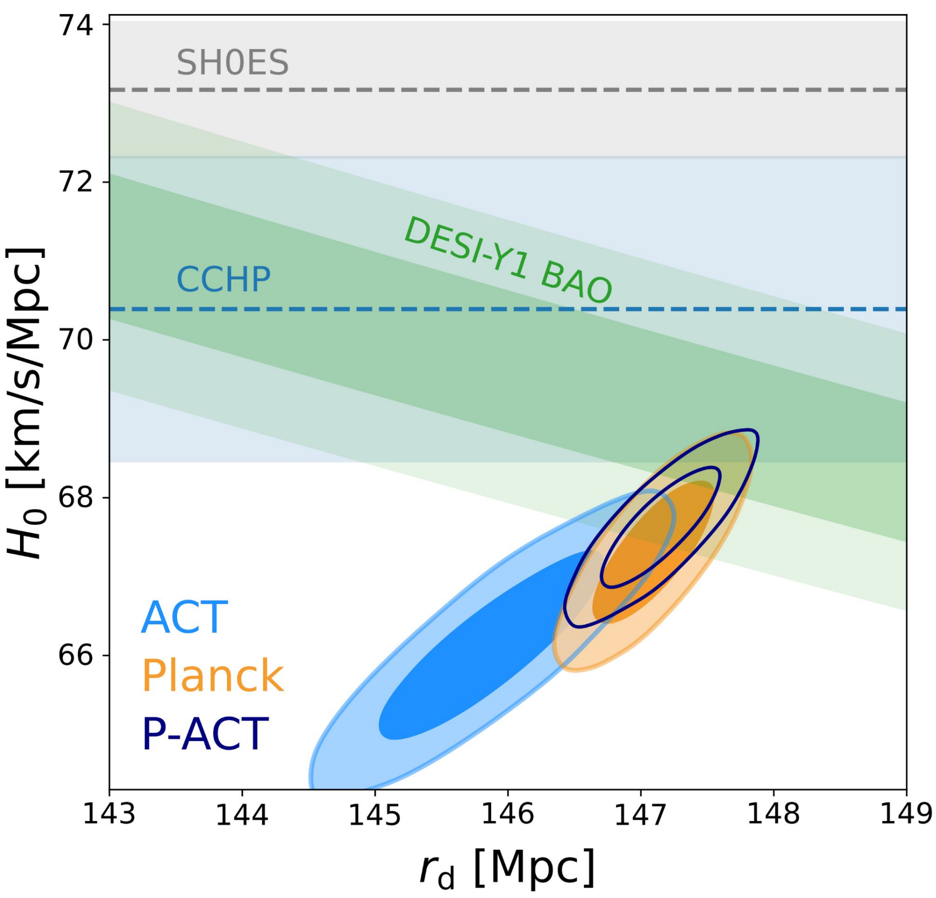
HiLLiPoP/NPIPE, curvature



Comparison with Planck PR4 (NPIPE)



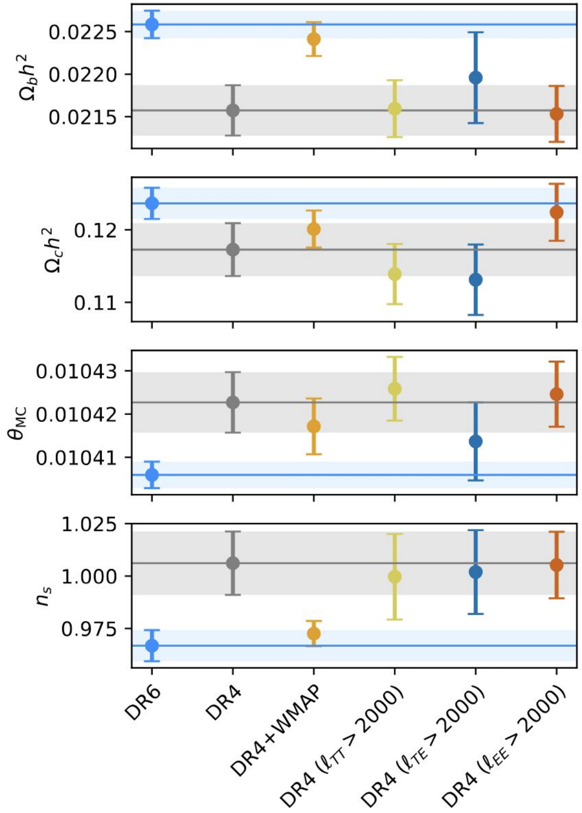
Measuring the expansion rate

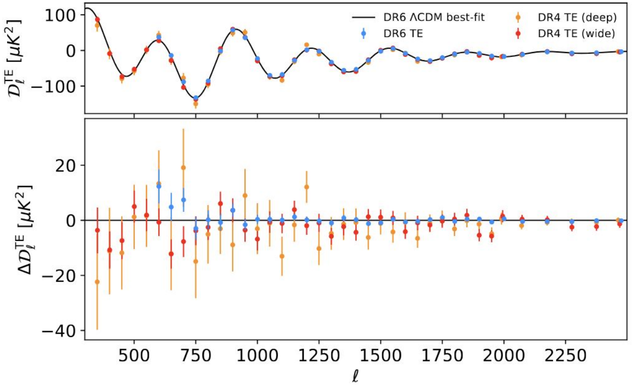


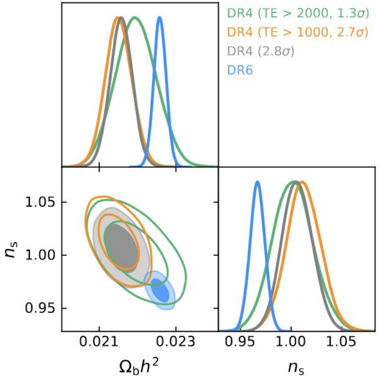
SH0ES: *Breuval et al.* 2024, *Riess et al.* 2022
CCHP: *Freedman et al.* 2024

DR6 vs DR4 cosmology

- very good agreement between DR6 and DR4 baseline result obtained from ACT+WMAP
- some differences with DR4 ACT-alone cosmology
- mainly driven by TE data at multipoles <2000 (where residuals are mostly negative, disfavoring the DR6 LCDM cosmology)
- we speculate beam leakage modelling might be playing a role



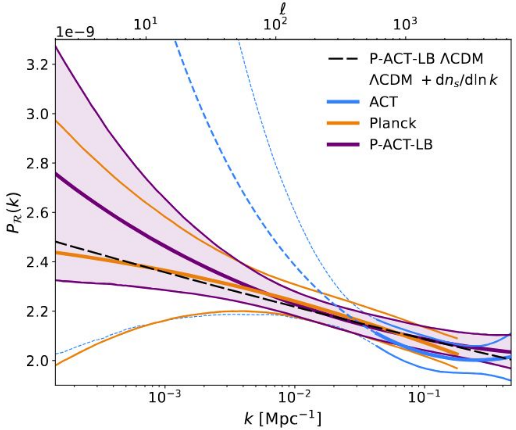




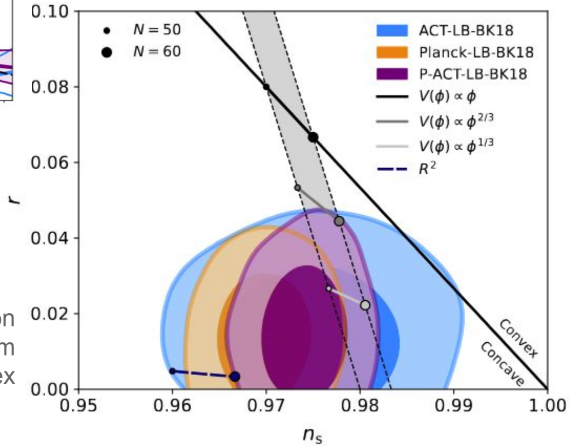
Primordial perturbations and inflation

Consistent with the predictions from simple single-field slow-roll inflation models, finding a vanishing running of the spectral index of scalar perturbations, and limiting the parameter space for inflation models.

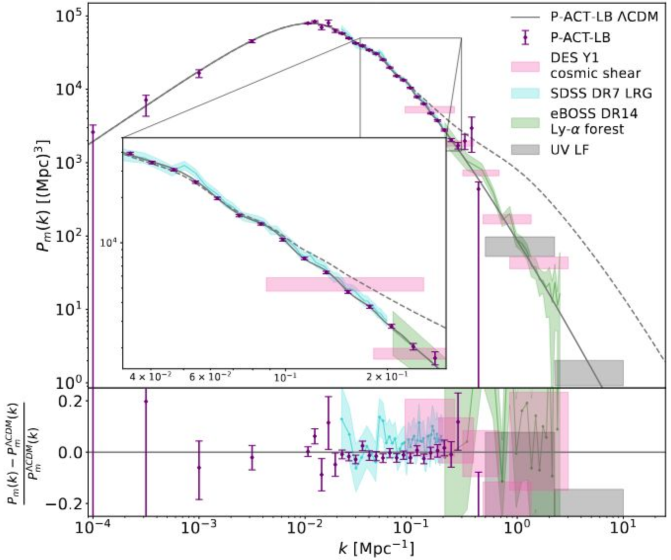
We also find no evidence for isocurvature perturbations, and reconstruct the primordial power spectrum of scalar curvature perturbations expanding by a factor of ~3 the range of wavenumbers measured by Planck.



Primordial power spectrum of scalar curvature perturbations consistent with simple near-scale-invariant power law



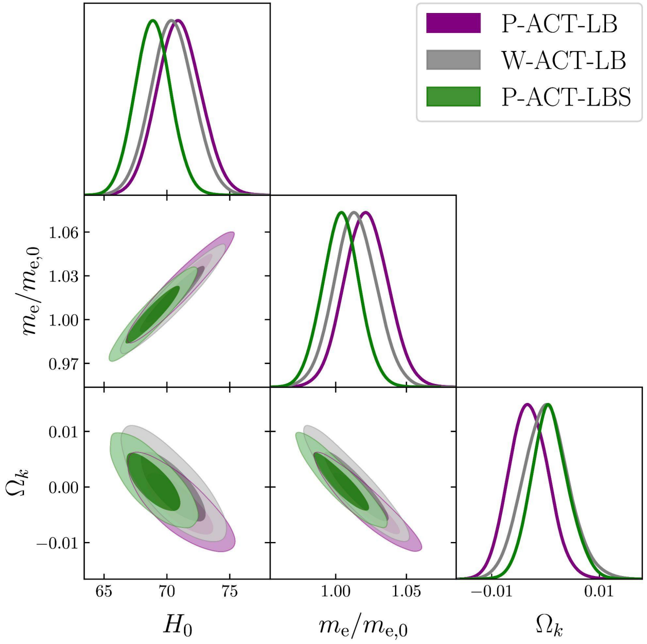
Information on inflation models from scalar spectral index



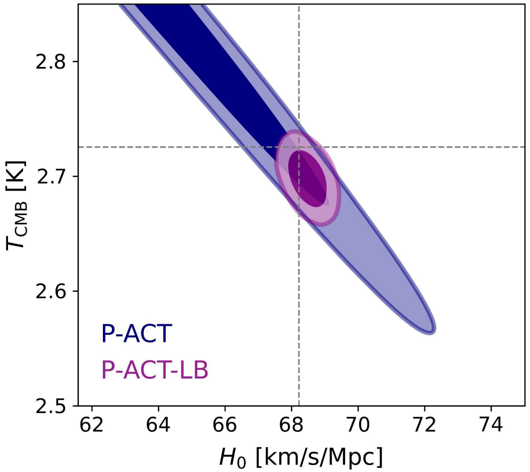
Primordial power spectrum of scalar curvature perturbations mapped onto the linear matter power spectrum

Pre- and modified recombination physics

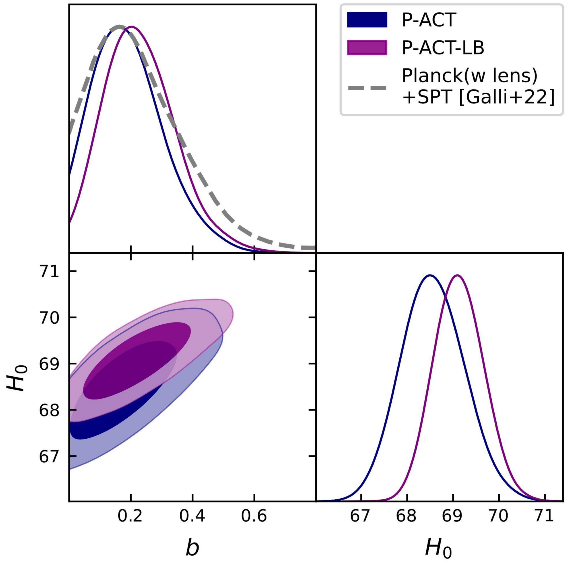
Varying m_e + curvature



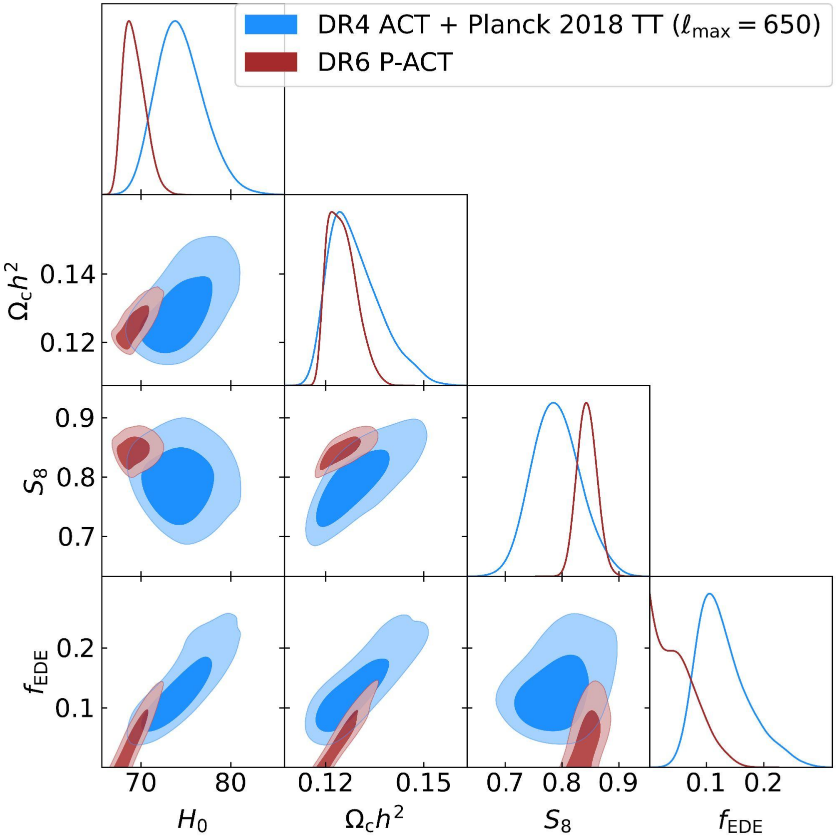
Monopole T_{CMB}

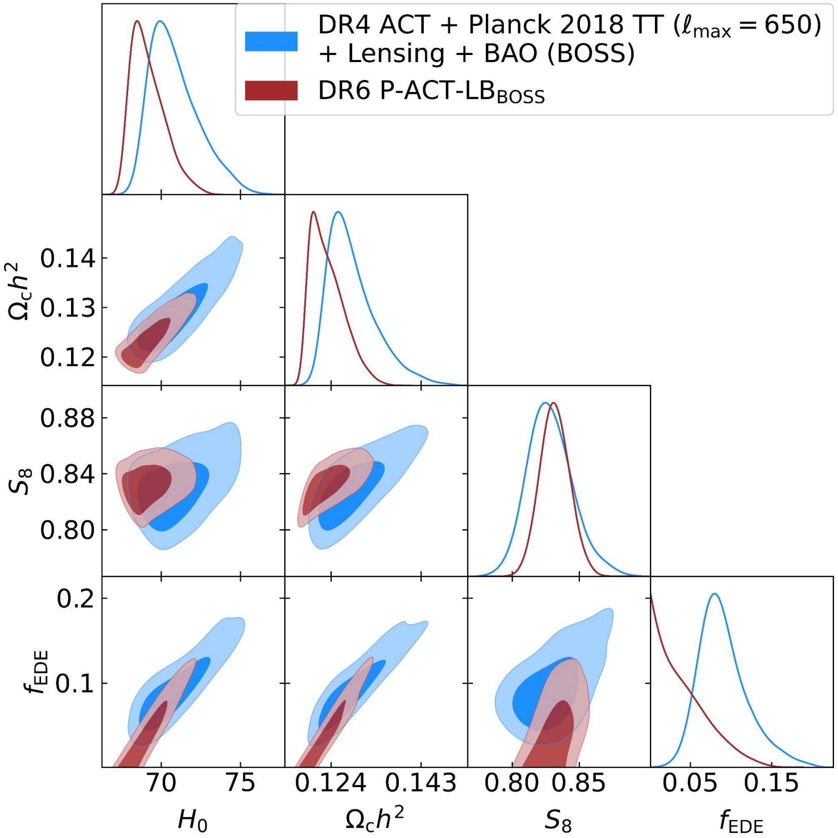


Small-scale baryon clumping



Pre- and modified recombination physics: DR4 vs. DR6 EDE constraints



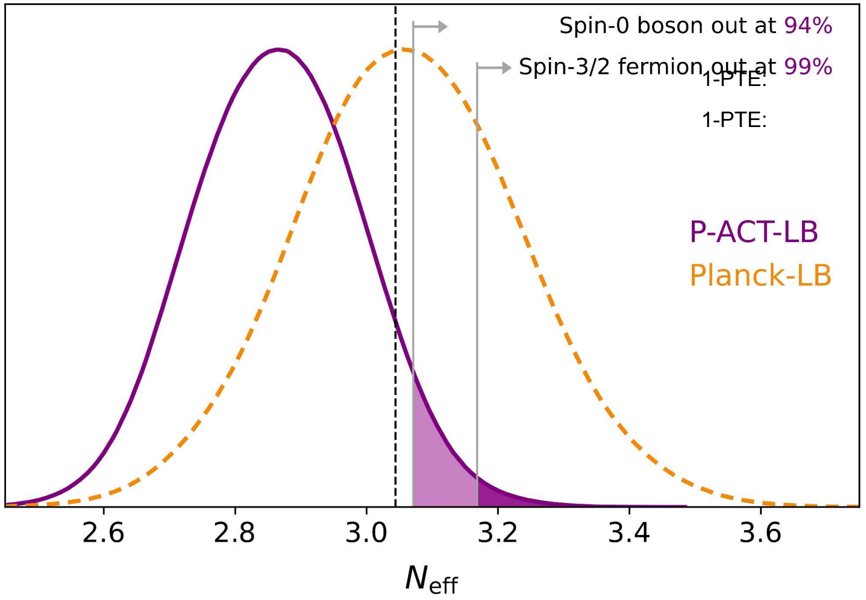


Particle cosmology

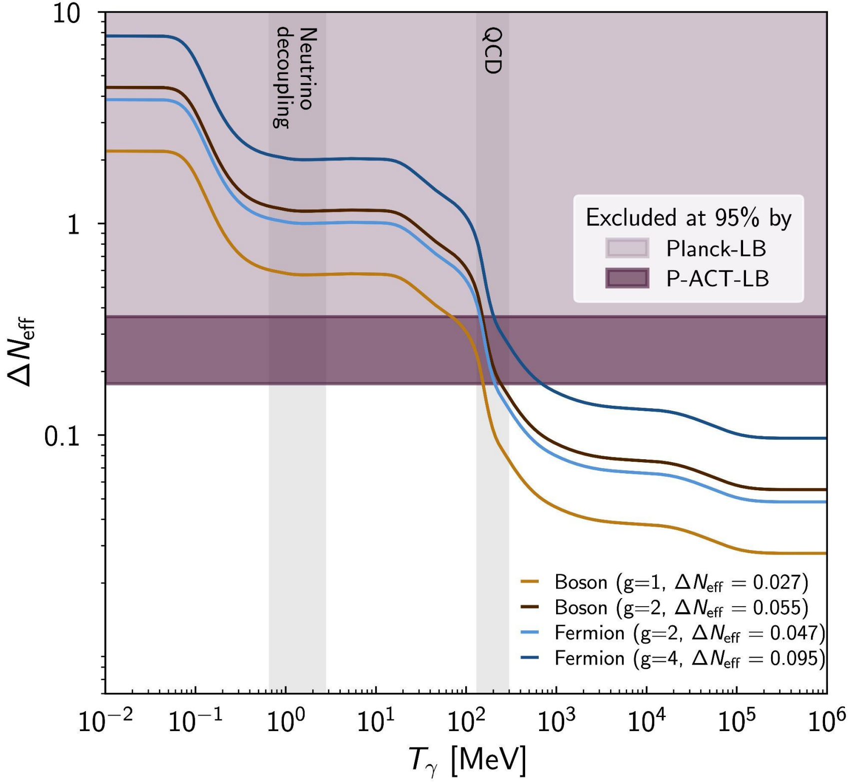
No evidence for new light, relativistic species

Free-streaming:

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



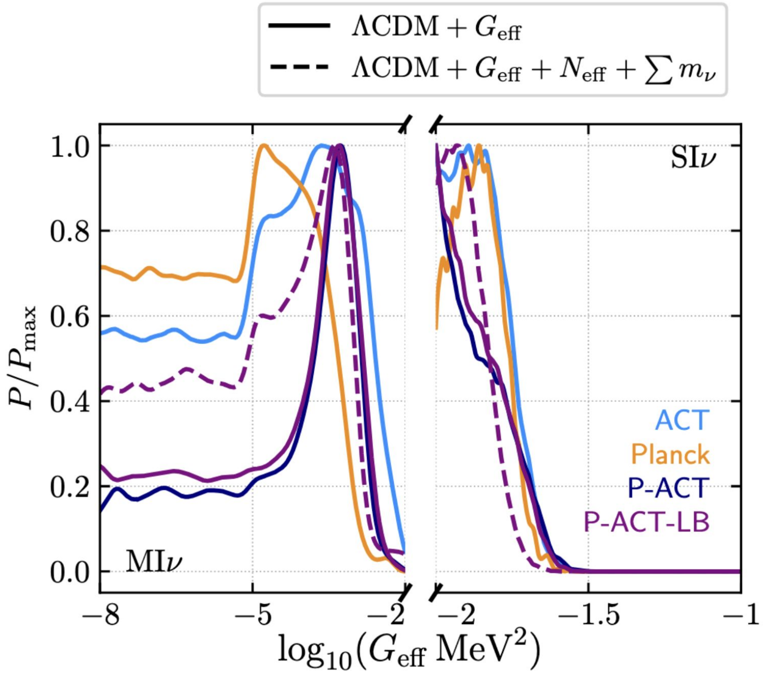
Constraint on excess $\Delta N_{eff} = N_{eff} - 3.044$



Neutrinos

We find no evidence for neutrino self-interactions

MIν only at 1.8σ and no peak for SIν using for P-ACT-LB

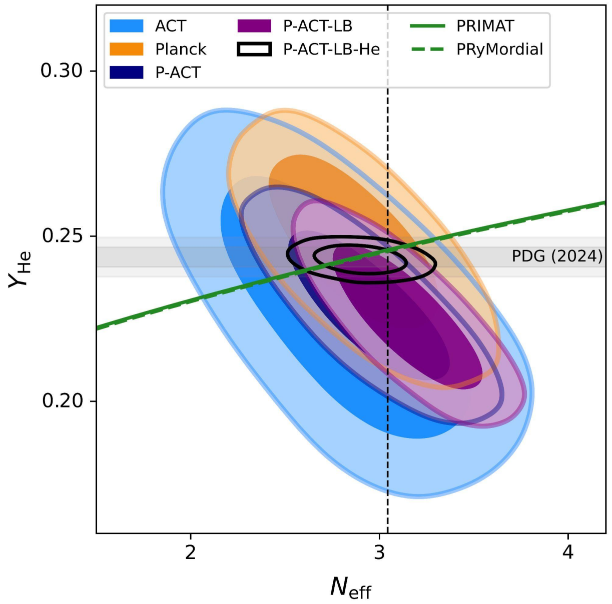


The mild hint of SIν in the DR4 analysis was largely driven by a high fluctuation in the EE power spectrum at intermediate scales, 700 < ℓ < 1000, which is no longer present in the DR6 spectra

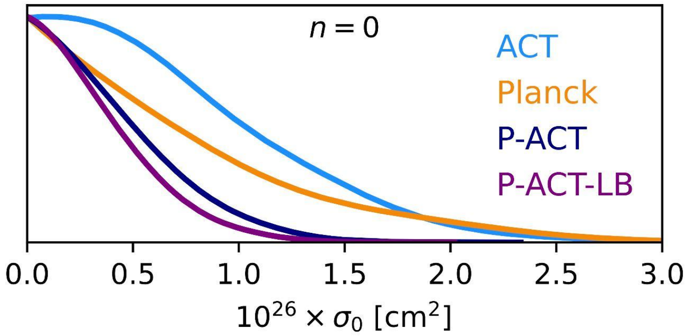
MIν: H_0 = 68.2 ± 0.4 km/s/Mpc (ΛCDM+G_{eff})
MIν: H_0 = 67.5 ± 1.0 km/s/Mpc (ΛCDM+G_{eff}+N_{eff}+M_{v})

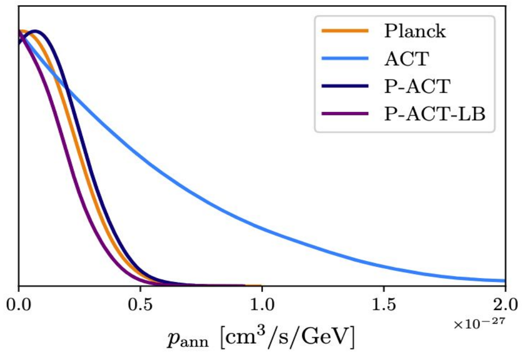
Particle astrophysics

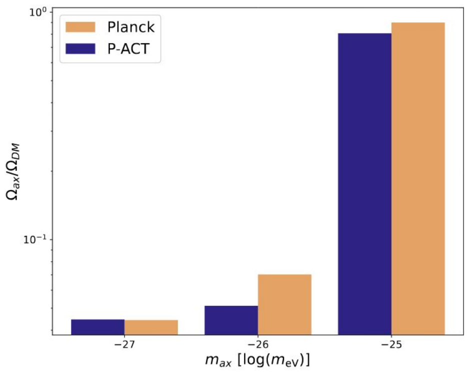
We also find the abundances of primordial elements to be consistent with standard BBN.



We find dark matter to follow the standard CDM paradigm, with no evidence for scattering with baryons, self-annihilation, contribution from axion-like particles, or scattering off a dark radiation component.





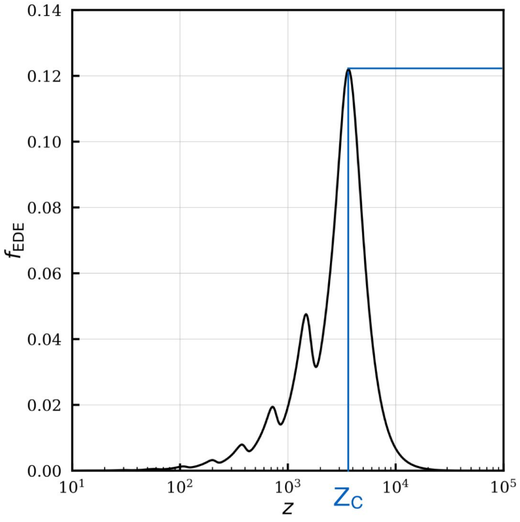


Early Dark Energy

No evidence for an early dark energy (EDE) component:

A mild hint (2-3σ) of EDE was seen in ACT DR4 (Hill+2022); the new ACT DR
spectra show that this was a statistical fluctuation.

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



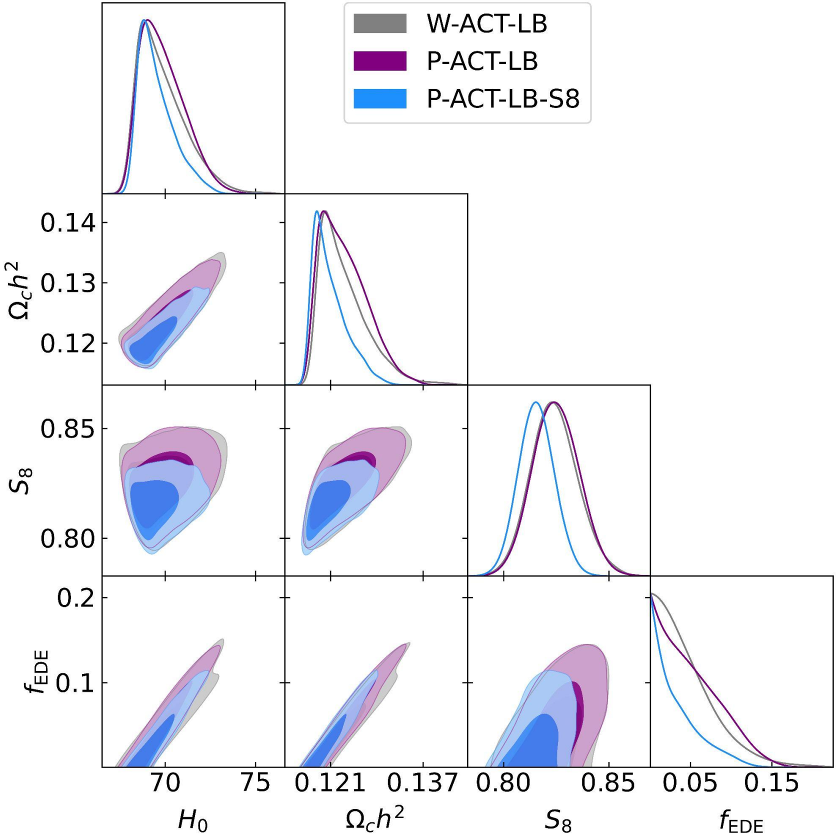
Maximal contribution:

$$f_{\rm EDE}(z_c) \equiv (\rho_{\rm EDE}/3M_{pl}^2 H^2)|_{z_c}$$

which occurs at redshift z_c

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

→ $\{f_{\rm EDE}, z_c, \theta_i\}$



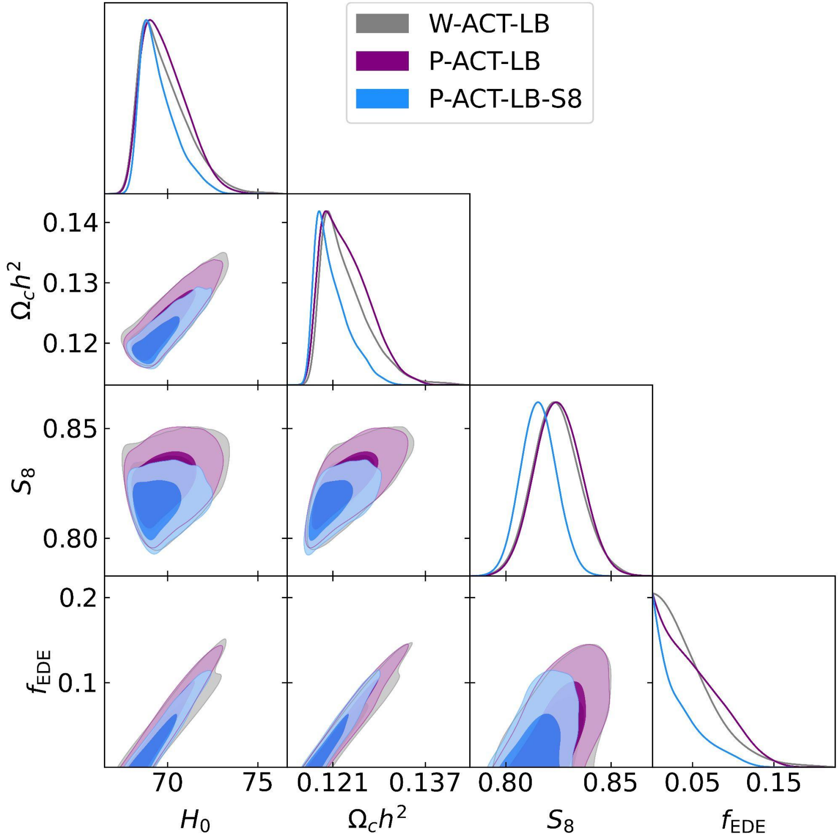
Max. preference: $\Delta\chi^2 = 6.6$ (1.7σ)

Early Dark Energy

No evidence for an early dark energy (EDE) component:

A mild hint (2-3σ) of EDE was seen in ACT DR4 (Hill+2022); the new ACT DR spectra show that this was a statistical fluctuation.

	$\Delta\chi^2$	Pref. in σ	$H_0^{(\mathrm{EDE})}$	f_{EDE}	$\log_{10} z_c$
ACT	≈ 0.0	0.0	66.5	0.012	3.00
W-ACT	1.9	0.5	69.9	0.089	3.55
P-ACT	4.3	1.2	70.4	0.091	3.56
W-ACT-LB	2.9	0.8	70.2	0.070	3.52
P-ACT-LB	6.6	1.7	71.2	0.093	3.56



Max. preference: $\Delta\chi^2 = 6.6$ (1.7σ)

Modified Growth of Structure

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

Nguyen et al. 2023 found evidence of suppression of structure growth from Planck data at 3.7 sigma

Data	γ	S_8	$H_0\ [\mathrm{kms^{-1}Mpc^{-1}}]$	$\lvert \log_{10} \mathrm{BF}_{10} \rvert$	$\Delta\chi^2 \equiv \chi^2_\gamma - \chi^2_{\gamma=0.55}$
PL18 (PL18 includes lensing)	$\mathbf{0.668^{+0.068}_{-0.067}}$	$0.807^{+0.019}_{-0.019}$	$68.1^{+0.7}_{-0.7}$	0.4	-2.8
PL18+$f\sigma_8$	$\mathbf{0.639^{+0.024}_{-0.025}}$	$0.814^{+0.011}_{-0.011}$	$67.9^{+0.5}_{-0.5}$	1.7	-13.6
PL18+$f\sigma_8$+DESY1+BAO	$\mathbf{0.633^{+0.025}_{-0.024}}$	$0.802^{+0.008}_{-0.008}$	$68.4^{+0.4}_{-0.4}$	1.2	-13.2
PL18+$f\sigma_8$+DESY1+BAO (flat ΛCDM+GR)	**0.55**	$0.803^{+0.008}_{-0.008}$	$68.5^{+0.4}_{-0.4}$	-	0

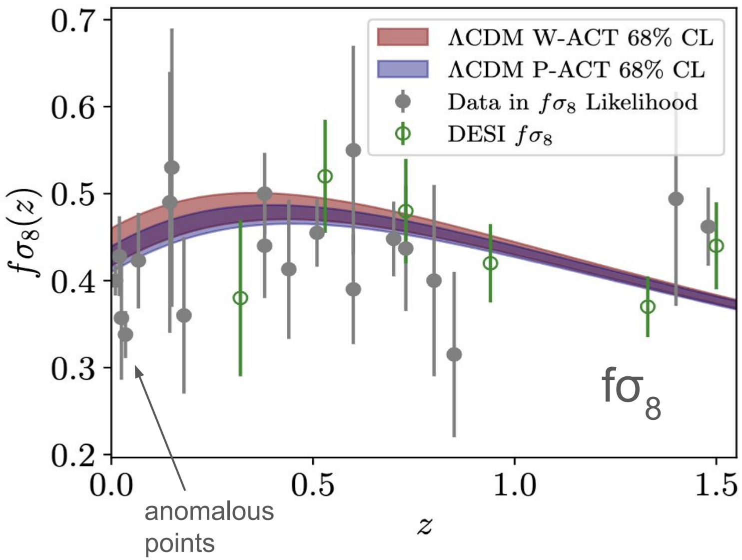
Removes preference for negative curvature found in Planck (negative curvature preference due to A_lens > 1)

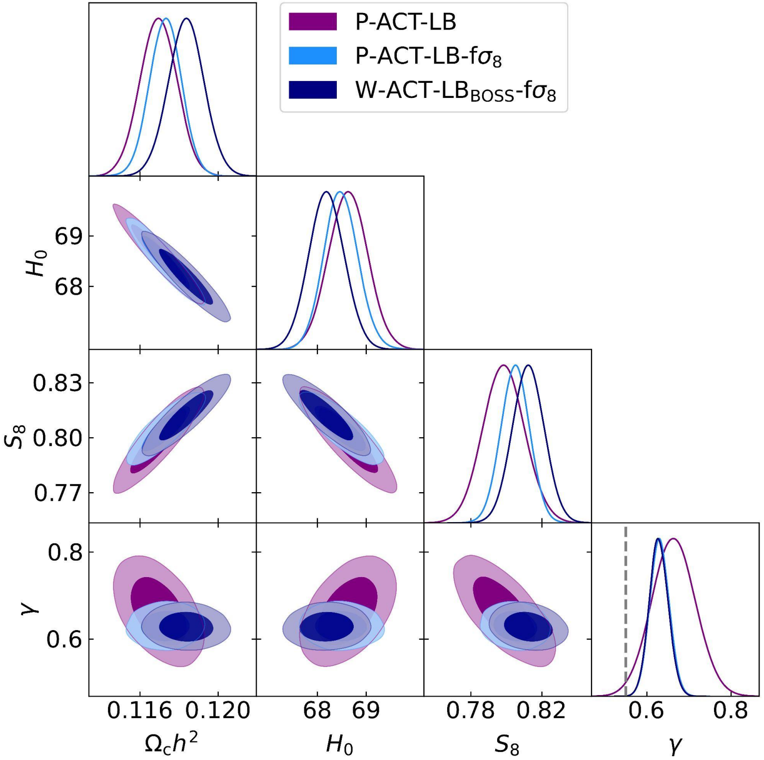
Late-time physics: modified growth

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

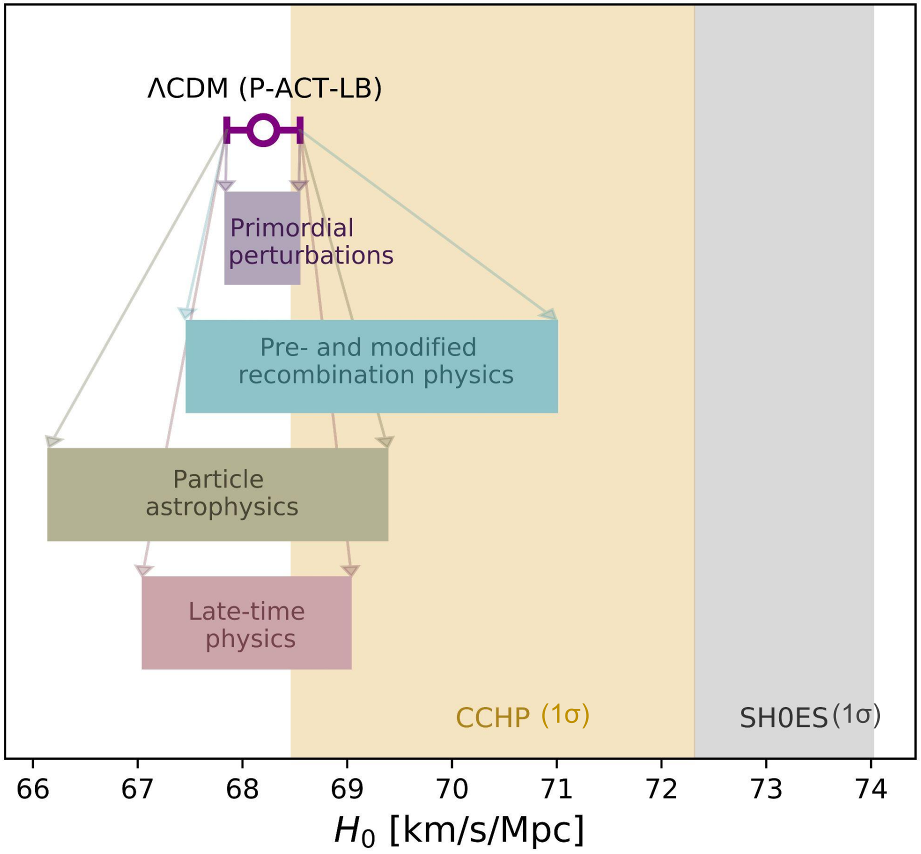
We also see no evidence of modified growth, e.g., due to beyond-GR gravity (modulo two slightly outlying $f\sigma_8$ measurements at very low redshifts).

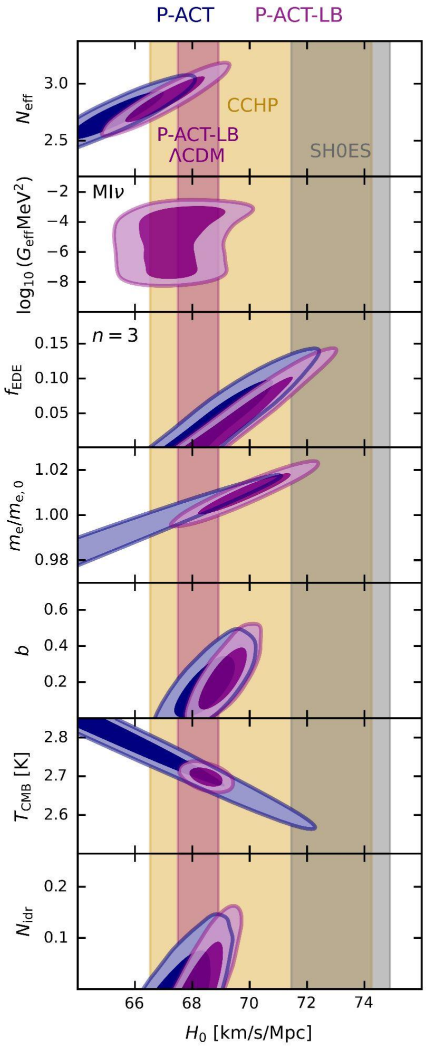
$$\left.\begin{aligned} \gamma &= 0.663 \pm 0.052 \\ S_8 &= 0.799 \pm 0.012 \end{aligned}\right\} \text{(68\%, P-ACT-LB)}$$





Cosmological concordance





$N_{\rm eff}$

Interacting neutrinos

Early dark energy

Varying m_e

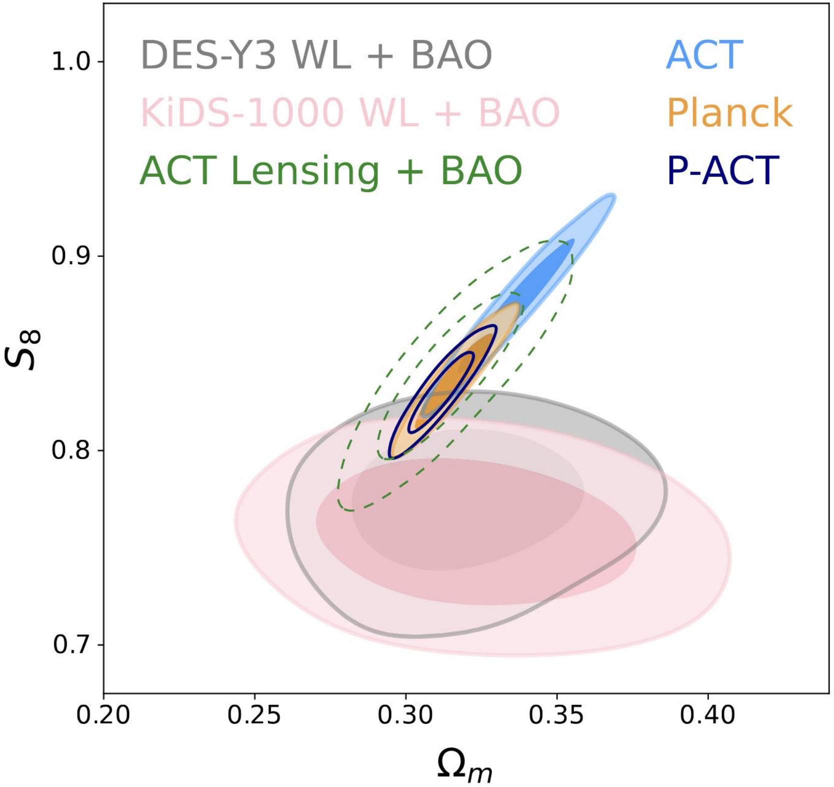
Primordial magnetic fields

CMB monopole temp.

SIDR

Cosmological concordance

P-ACT: $S_8 = 0.830 \pm 0.014$
DES+KiDS: $S_8 = 0.797 +0.017 -0.014$
HSC-Y3 (ξ): $S_8 = 0.769 +0.031-0.034$



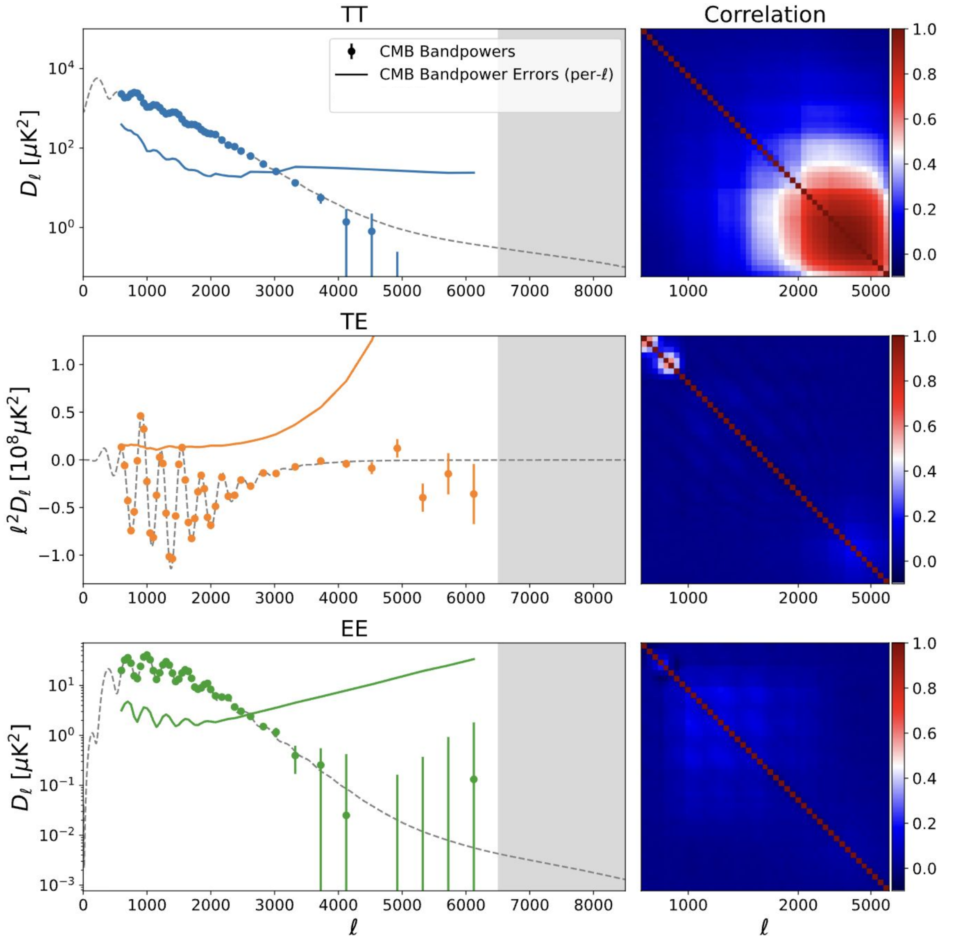
Likelihoods

MFLike

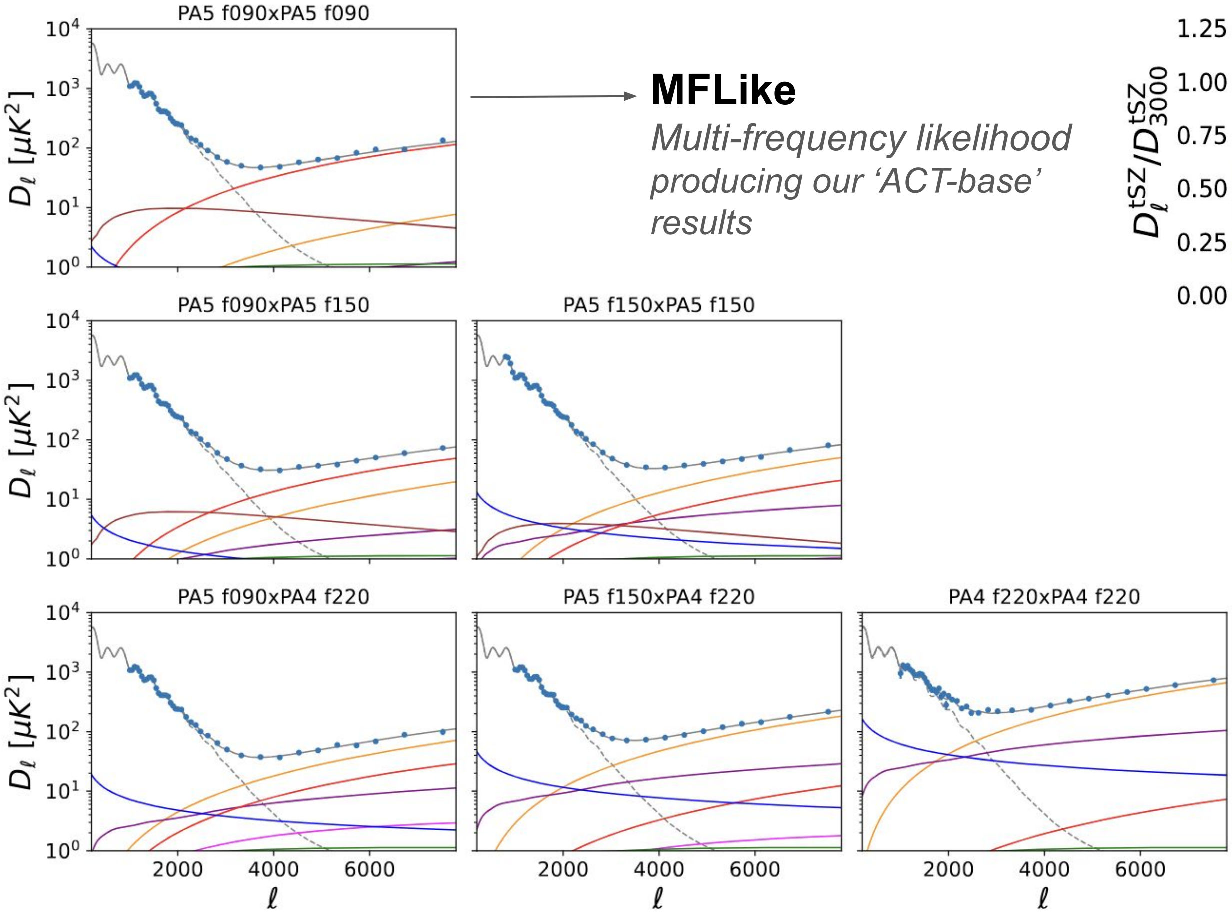
ACT-lite

Compressed likelihood for fast cosmological exploitation

- CMB signal extracted at 600<ell<6500
- Highly-correlated TT tail
- Parameters between the two likelihoods agree, with most estimates at <0.1σ for both ΛCDM and extended models

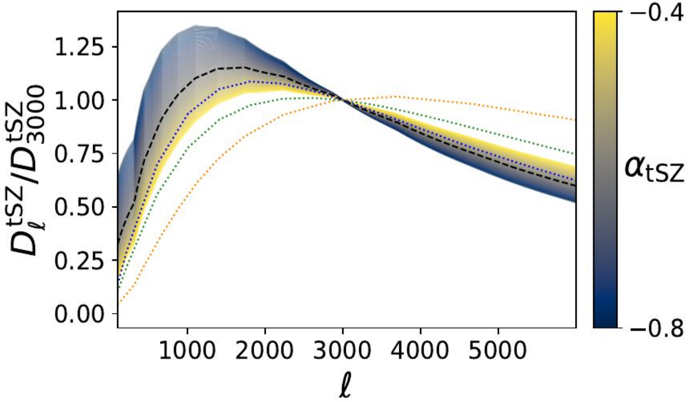


Likelihoods



MFLike

Multi-frequency likelihood producing our 'ACT-base' results



Finding evidence for steeper shape of thermal SZ spectrum