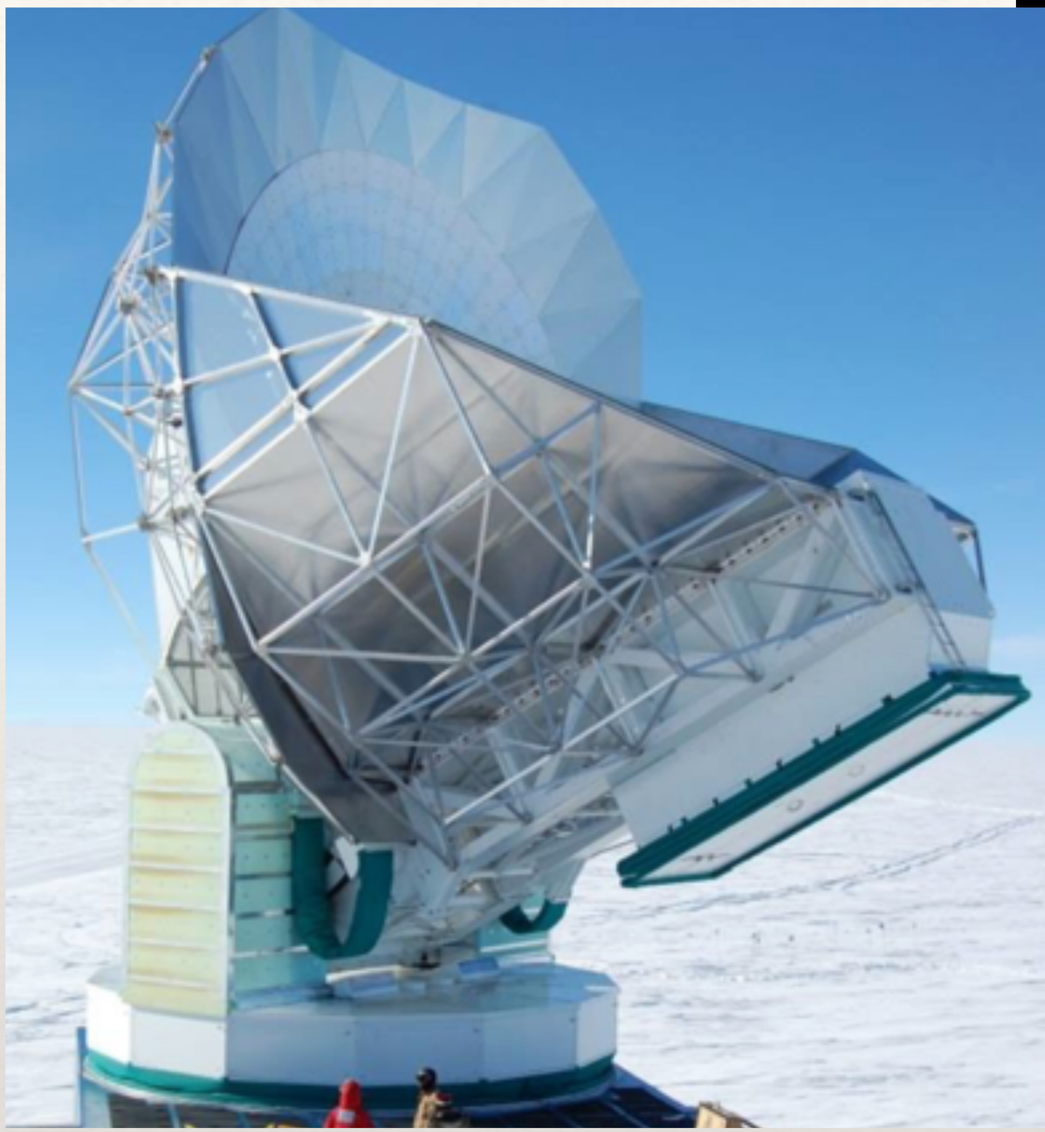
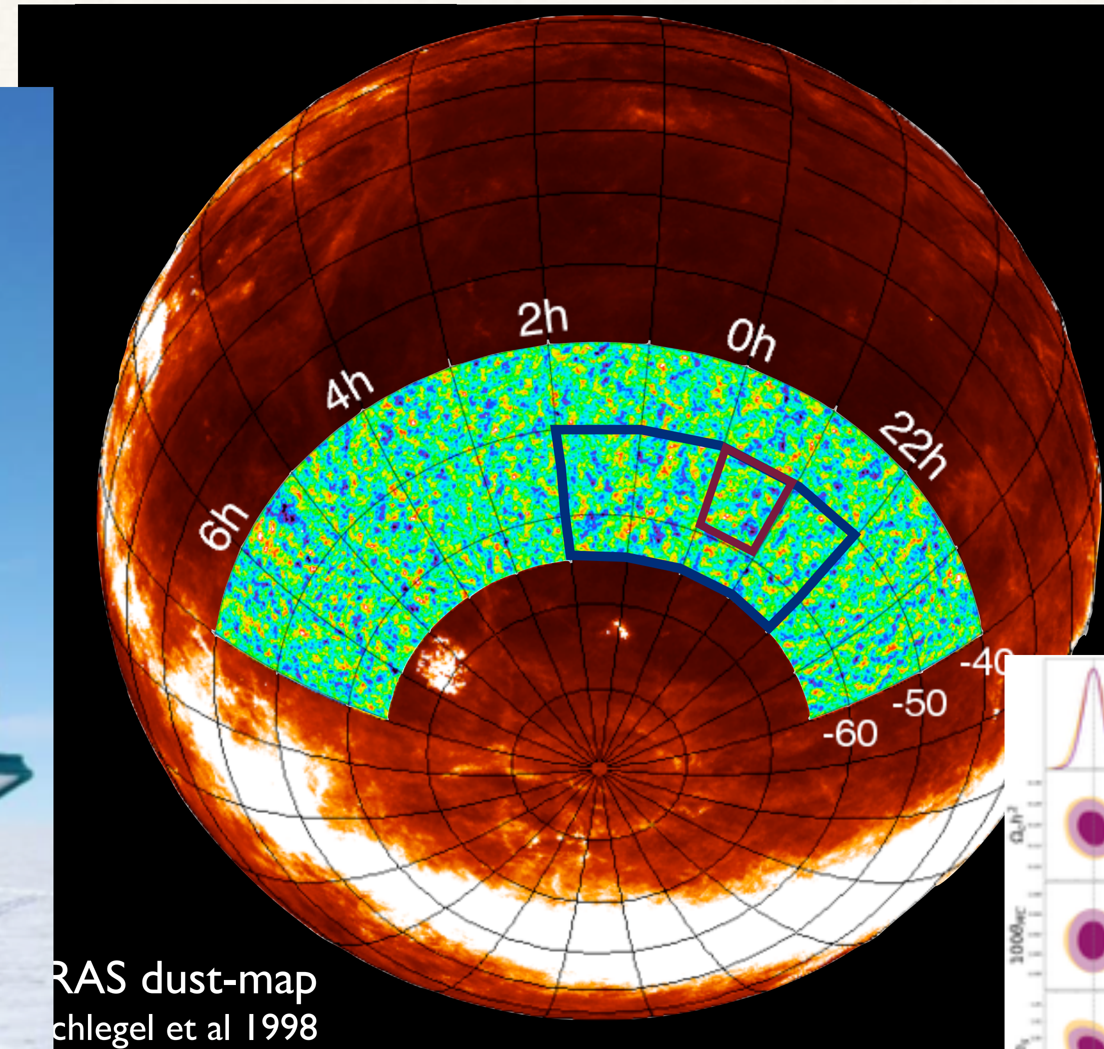
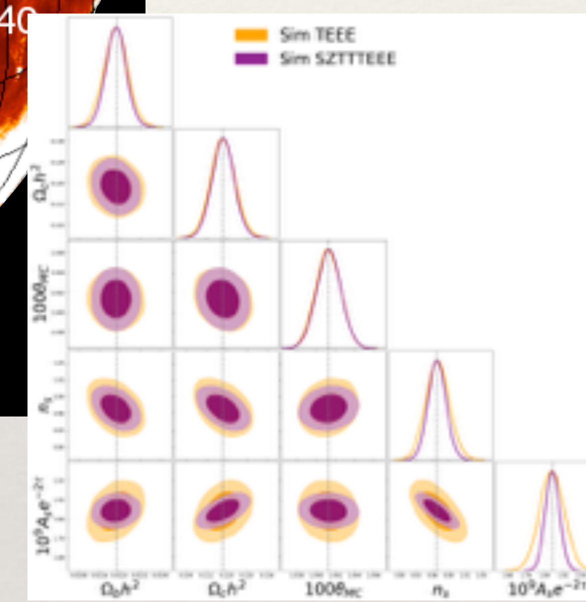






Fitting LCDM to SPT-SZ and SPTpol

Kimmy Wu
KICP Fellow, KICP/UChicago
(for the SPT collaboration)

Tensions in LCDM Workshop
Mainz, Germany
May 14, 2018

Outline

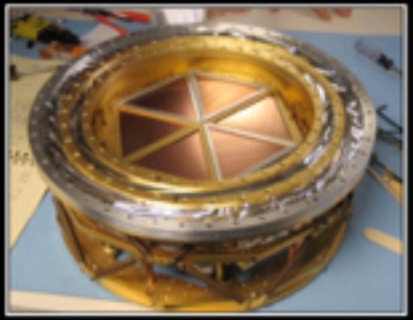
- The South Pole Telescope; SPT-SZ; SPTpol; preliminaries
- SPT-SZ vs Planck (Aylor et al. 2017, Hou et al. 2017)
- SPTpol cosmology from TE/EE spectra (Henning et al. 2017); Current efforts
- How about lensing? (Simard et al. 2017, Omori et al. 2017)
- Summary of SPT's view of LCDM

The South Pole Telescope (SPT)

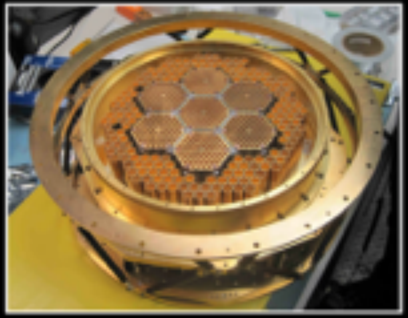
10-meter sub-mm quality wavelength telescope

95, 150, 220 GHz and
1.6, 1.2, 1.0 arcmin resolution

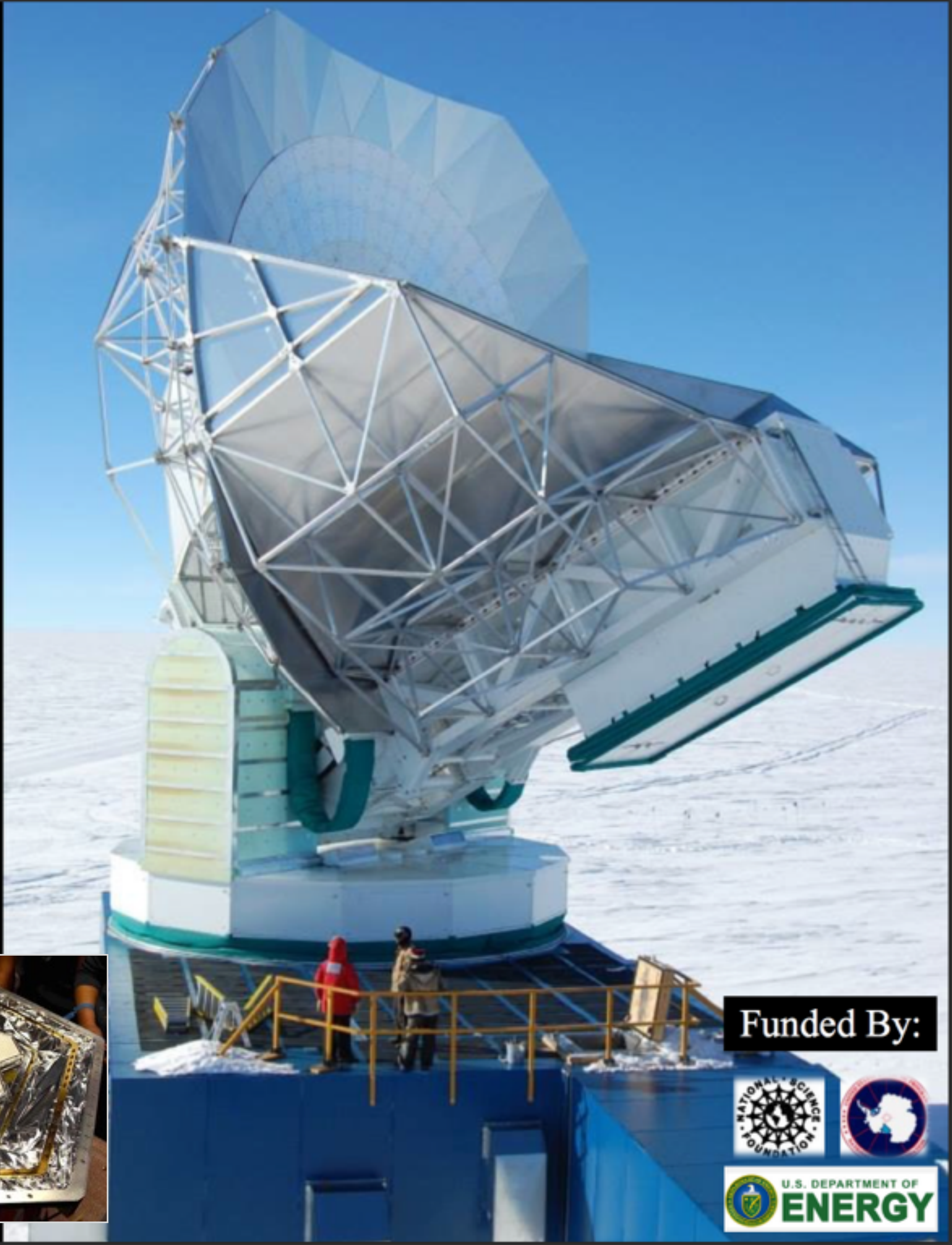
2007: SPT-SZ
960 detectors
95,150,220 GHz



2012: SPTpol
1600 detectors
95,150 GHz
+Polarization

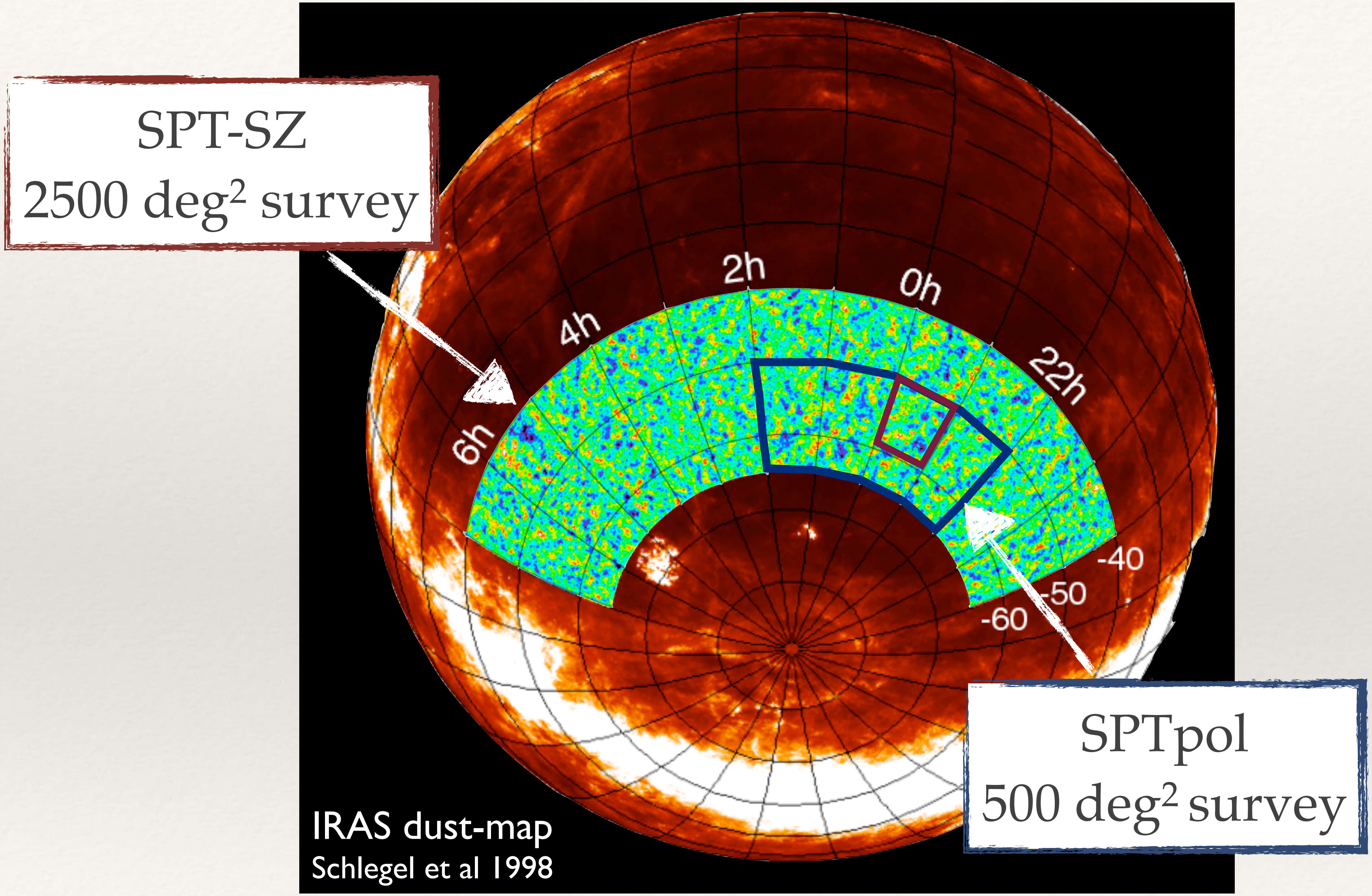


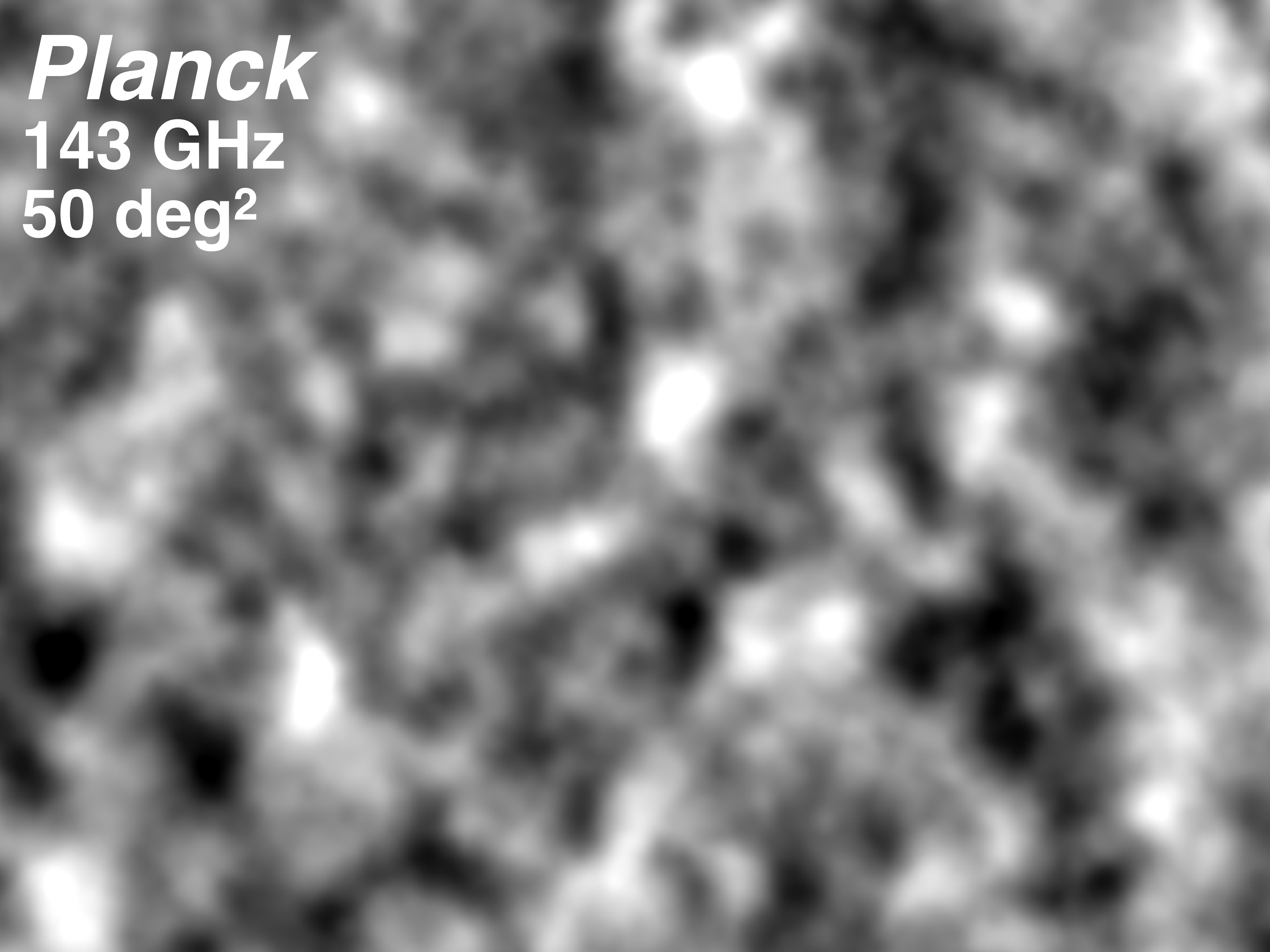
2016: SPT-3G
~16,000 detectors
95,150,220 GHz
+Polarization

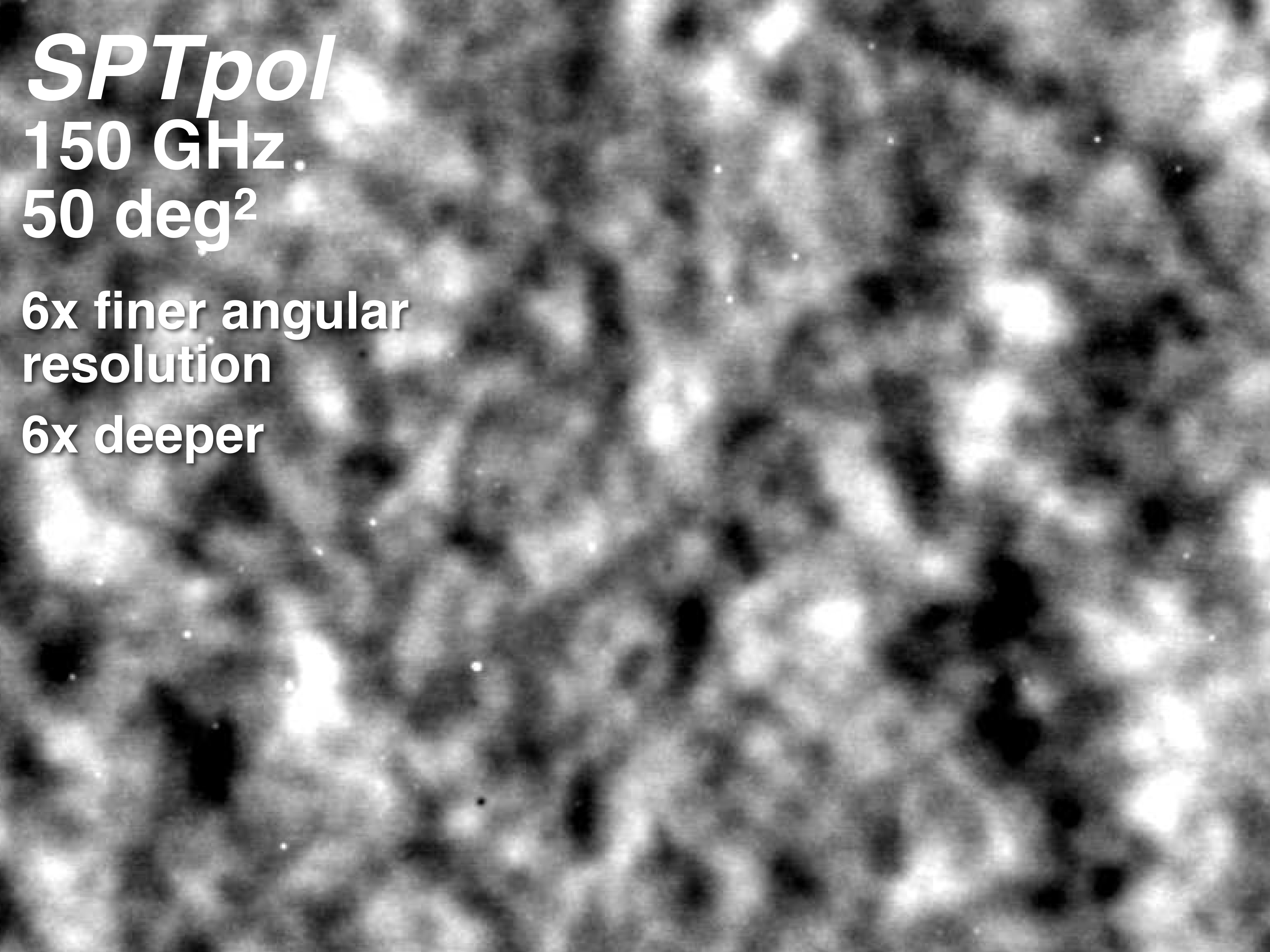


Funded By:
U.S. DEPARTMENT OF ENERGY

SPT-SZ and SPTpol fields




Planck
143 GHz
50 deg²


SPTpol
150 GHz
50 deg²
6x finer angular resolution
6x deeper

CMB temperature anisotropy spectrum

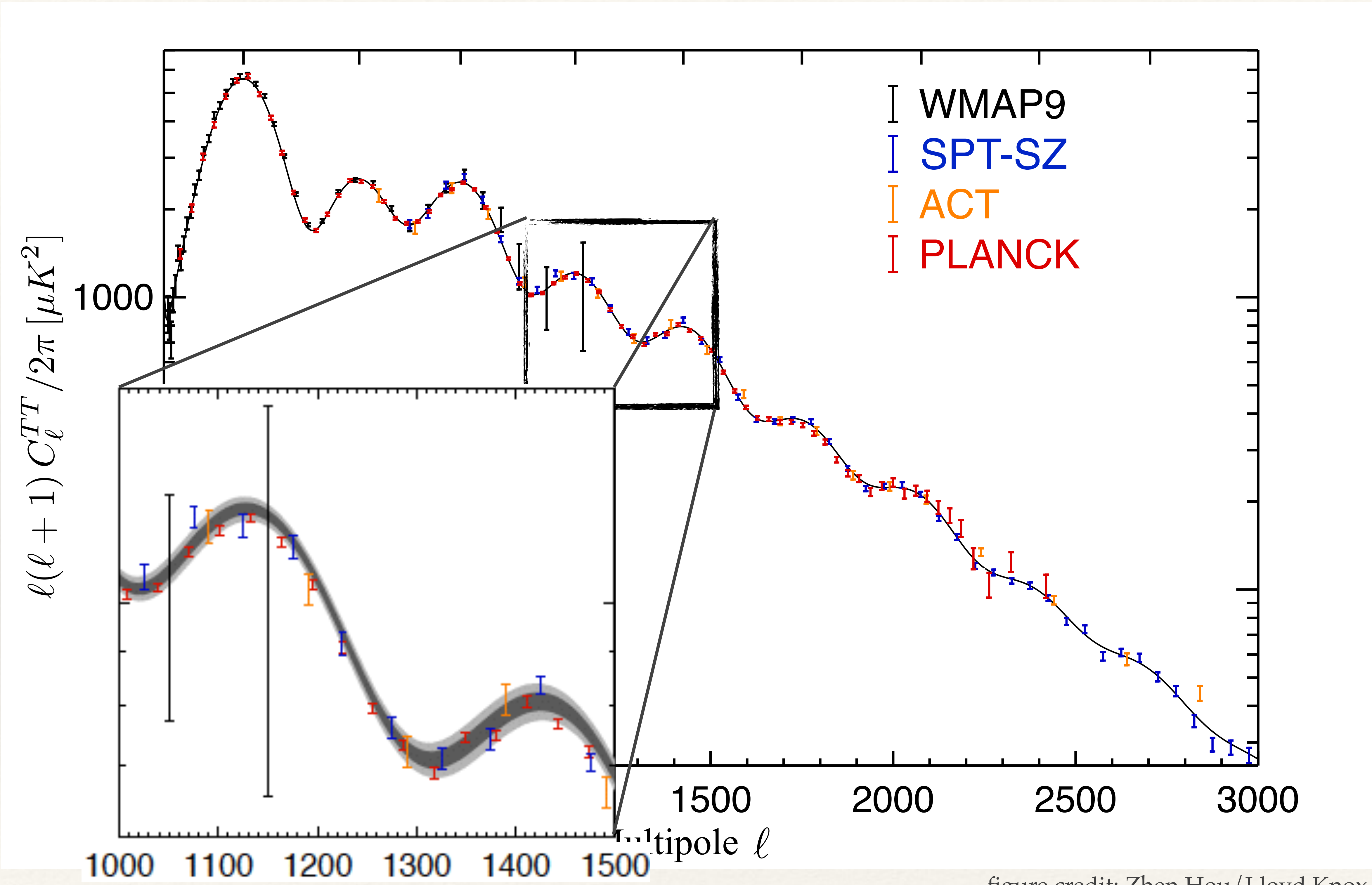
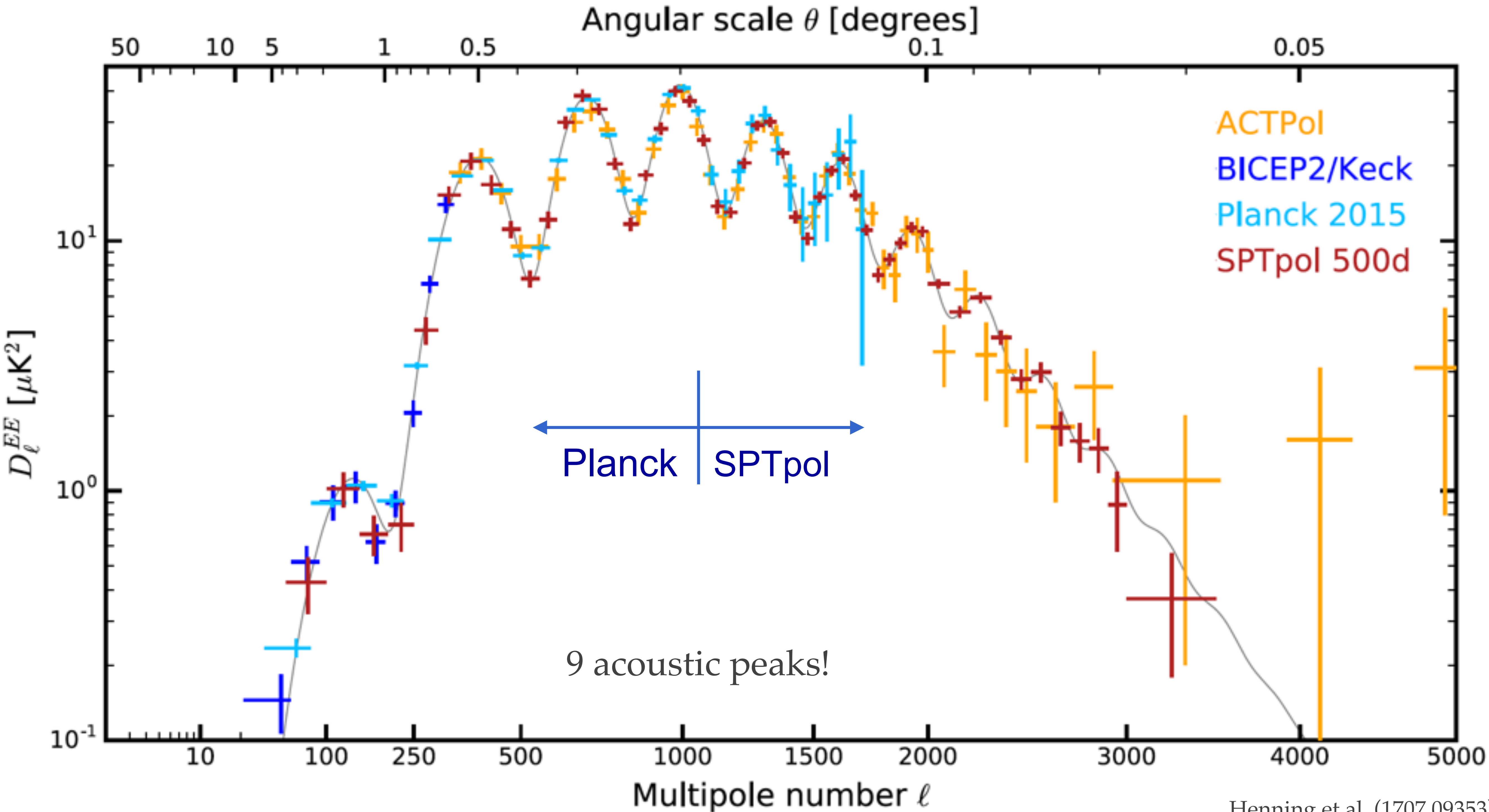


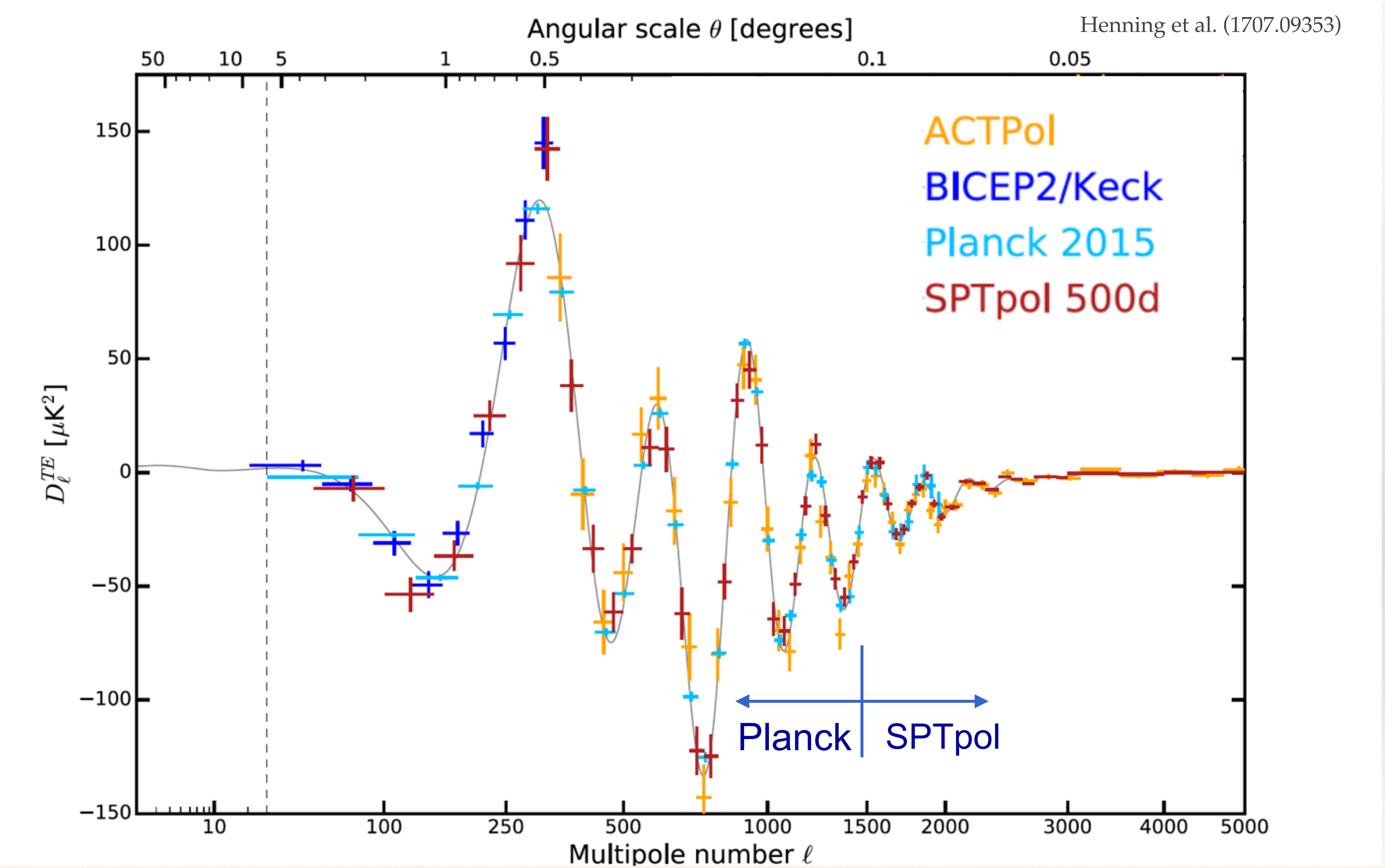
figure credit: Zhen Hou/Lloyd Knox

EE spectra compilation

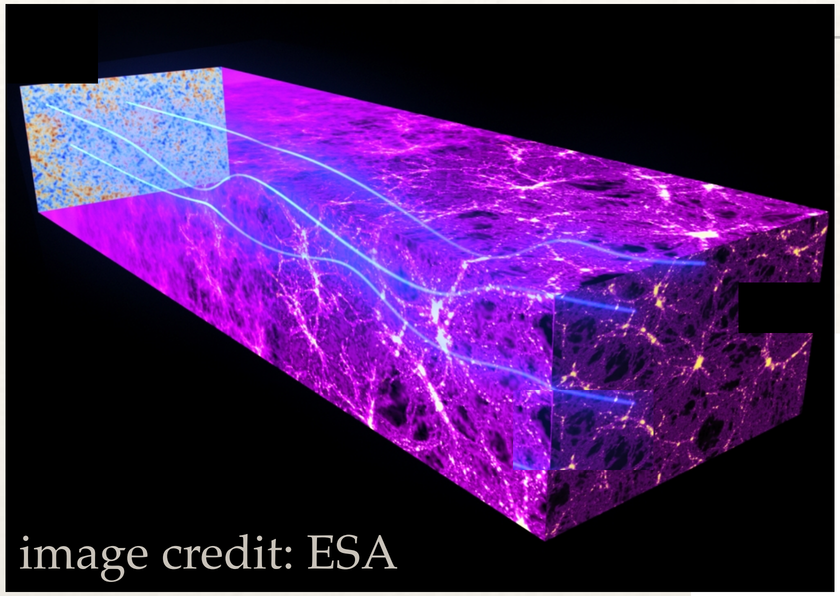


Henning et al. (1707.09353)

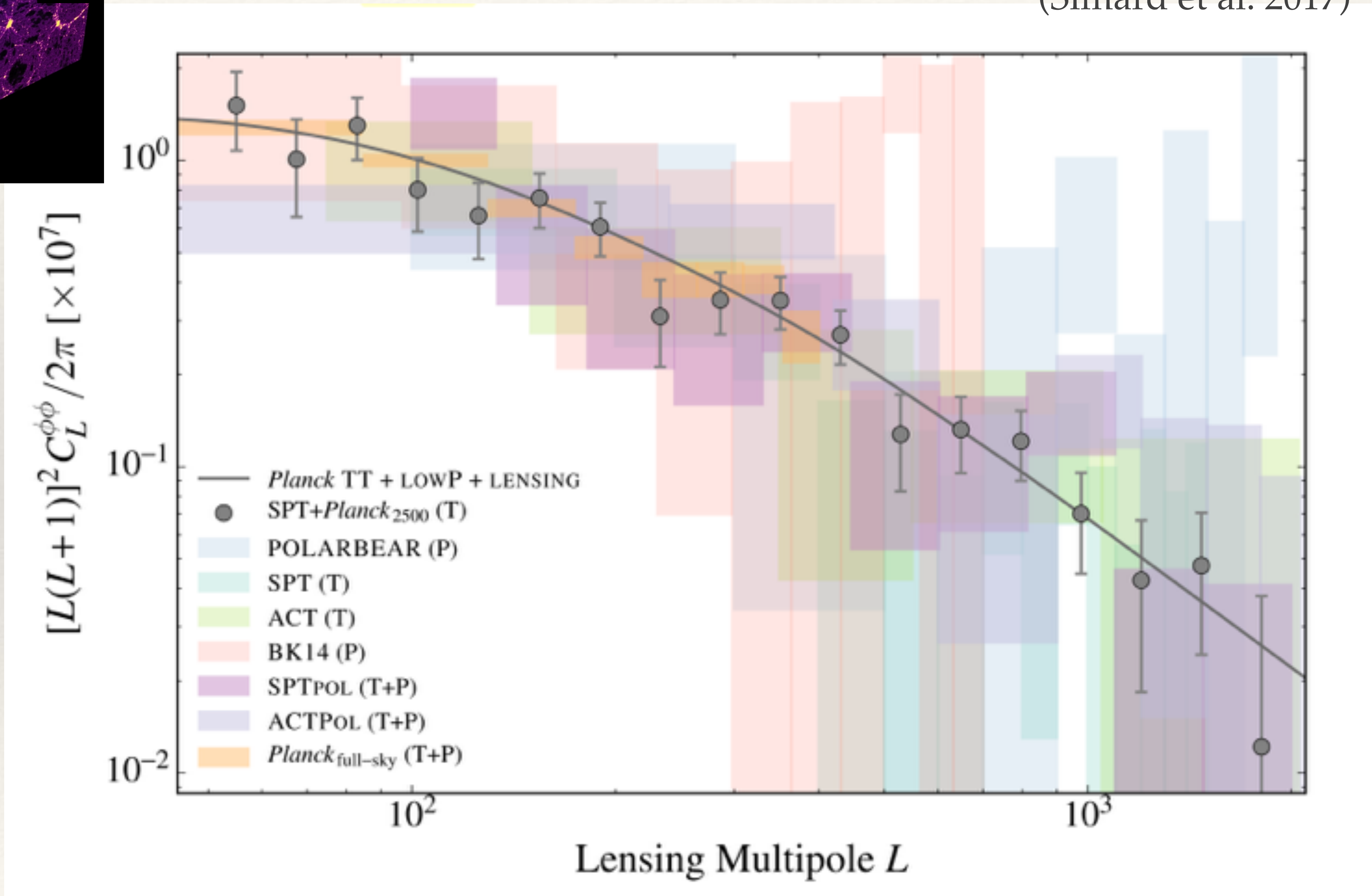
TE spectra compilation



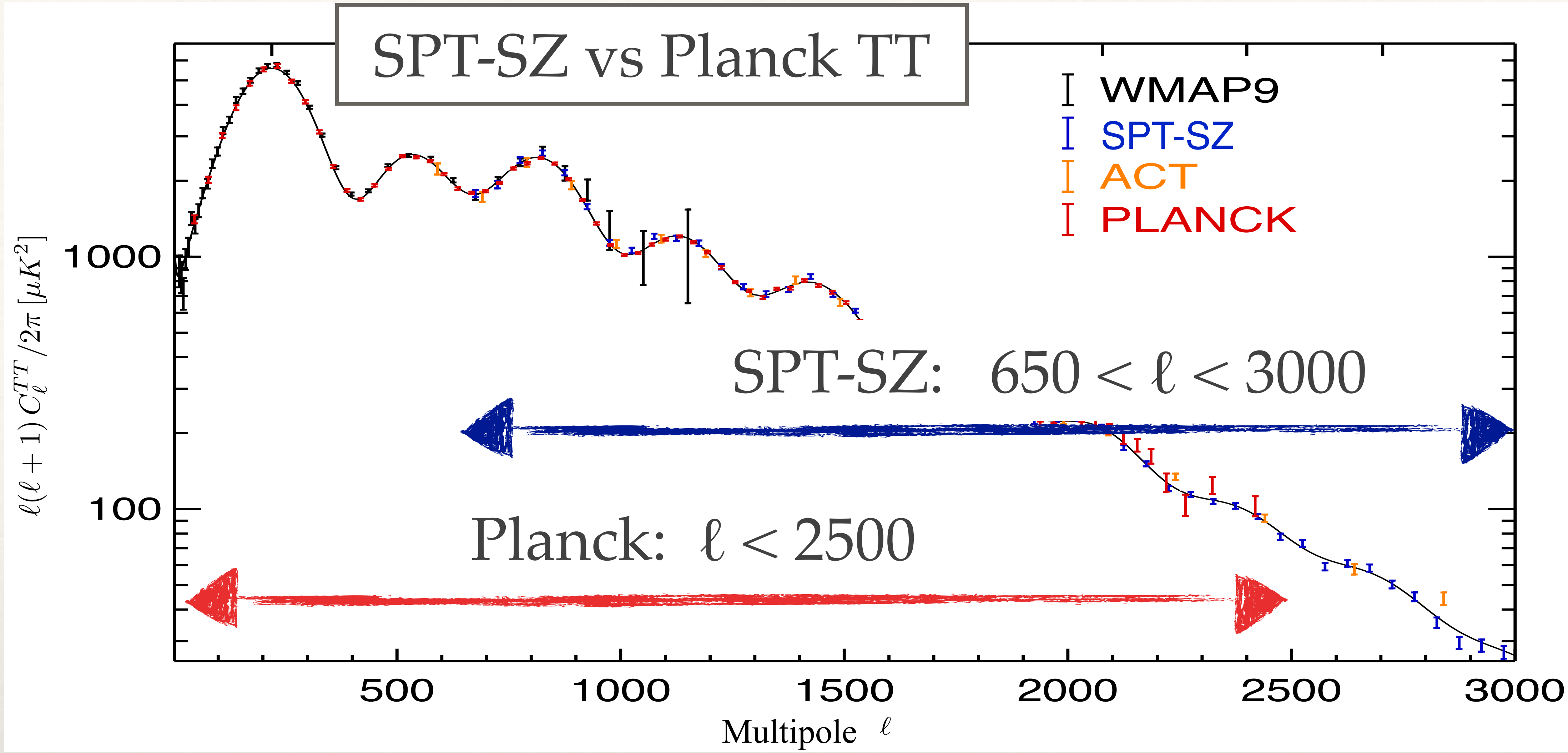
Lensing spectrum



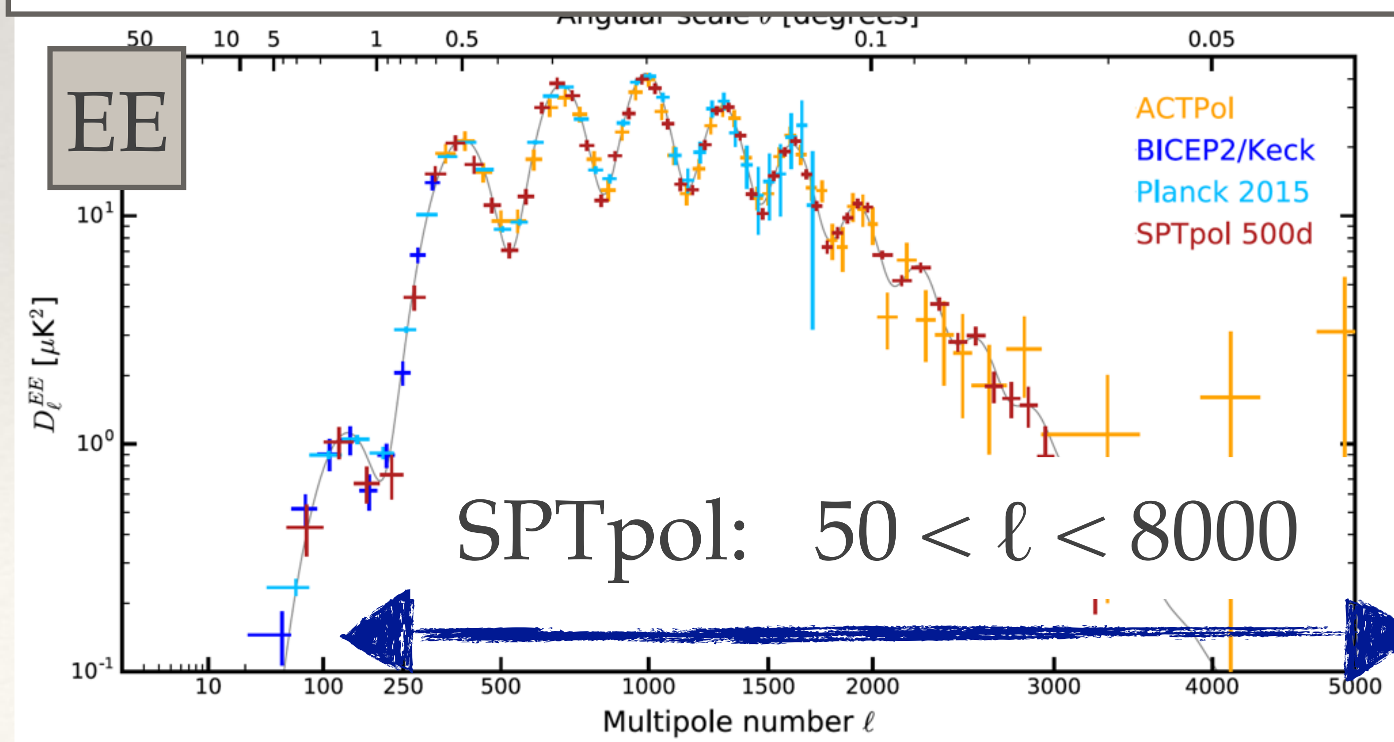
(Simard et al. 2017)

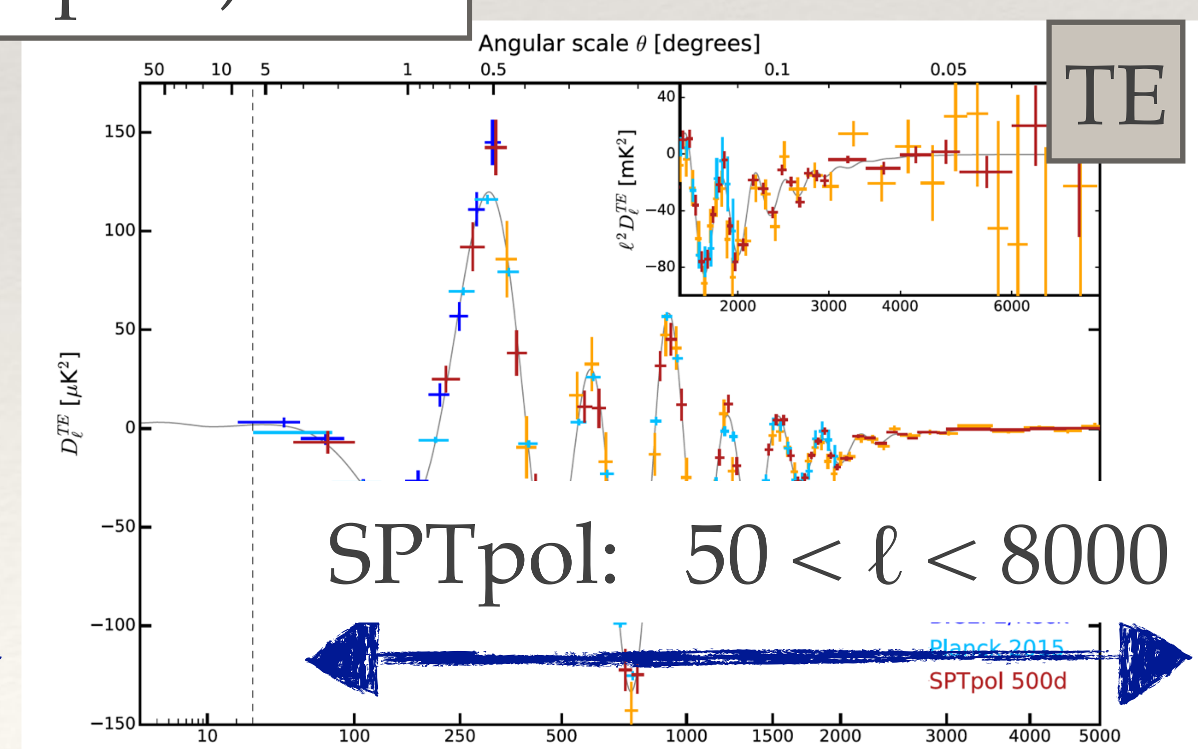


A note on ℓ ranges: relevant for the later parts of the talk

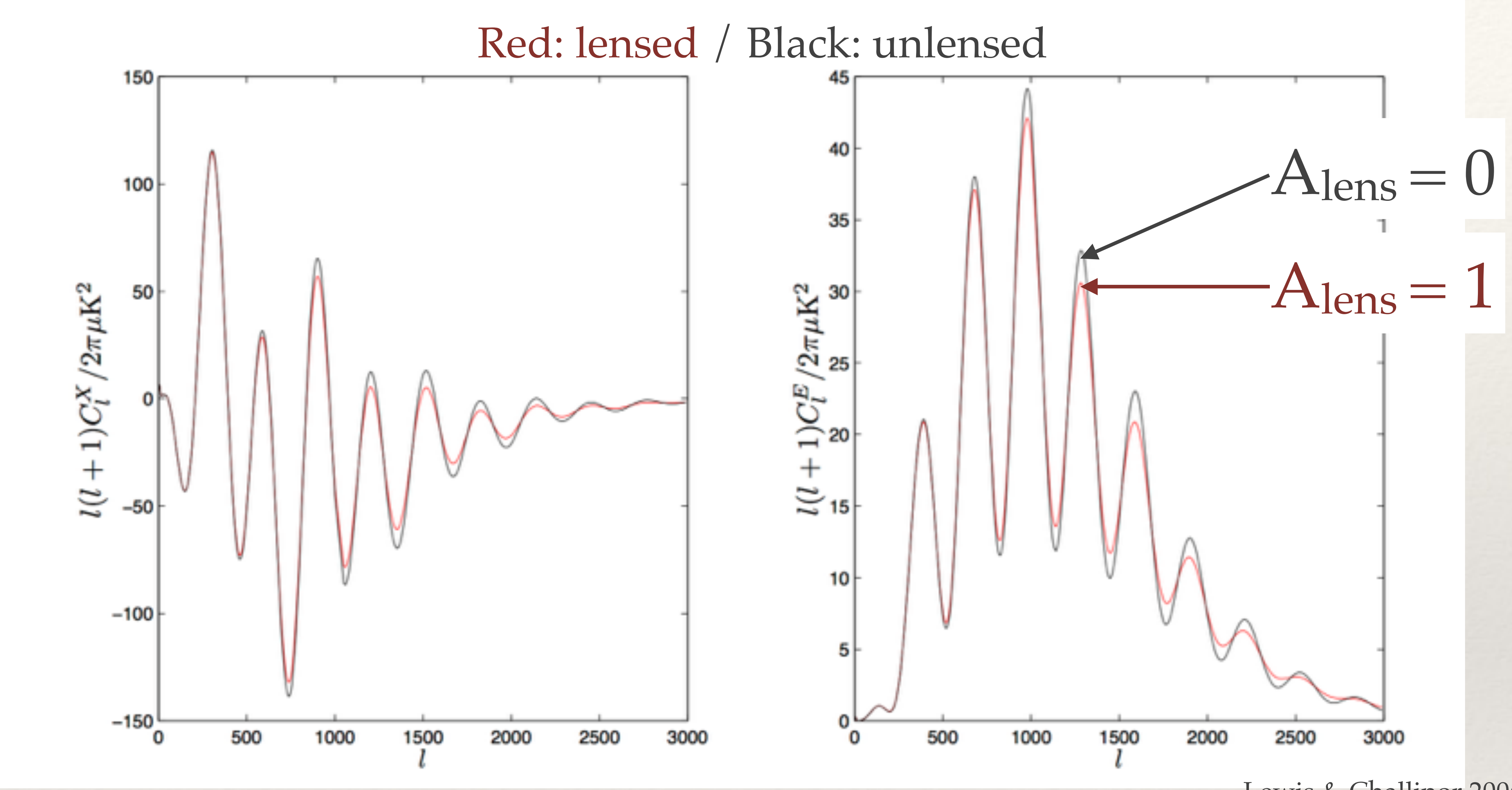


SPTpol cosmology (high / low ℓ splits)





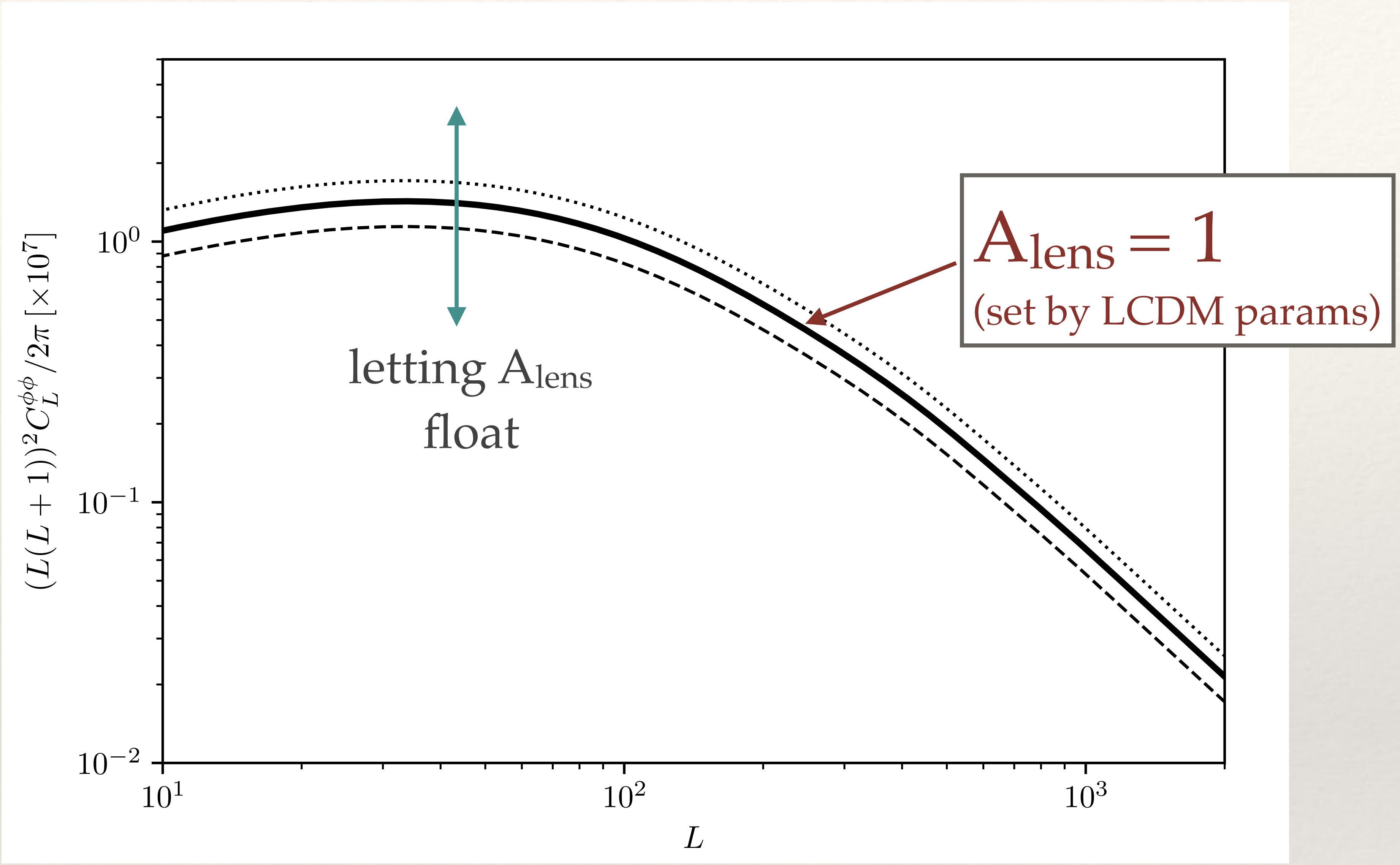
A_{lens} on primary CMB spectrum



Lewis & Challinor 2006

- With A_s and w_m, one fixes the amount of smoothing of the peaks in the CMB spectra
- When we let A_{lens} float , we further tune the amount of lensing manifested on the power spectra relative to the inferred A_s and w_m

A_{lens} on lensing spectrum



- The amplitude and shape of the lensing spectrum is set by LCDM parameters from CMB primary spectra
- When we fit for Alens, we scale the lensing spectrum

Under LCDM, A_{lens} should be consistent with 1

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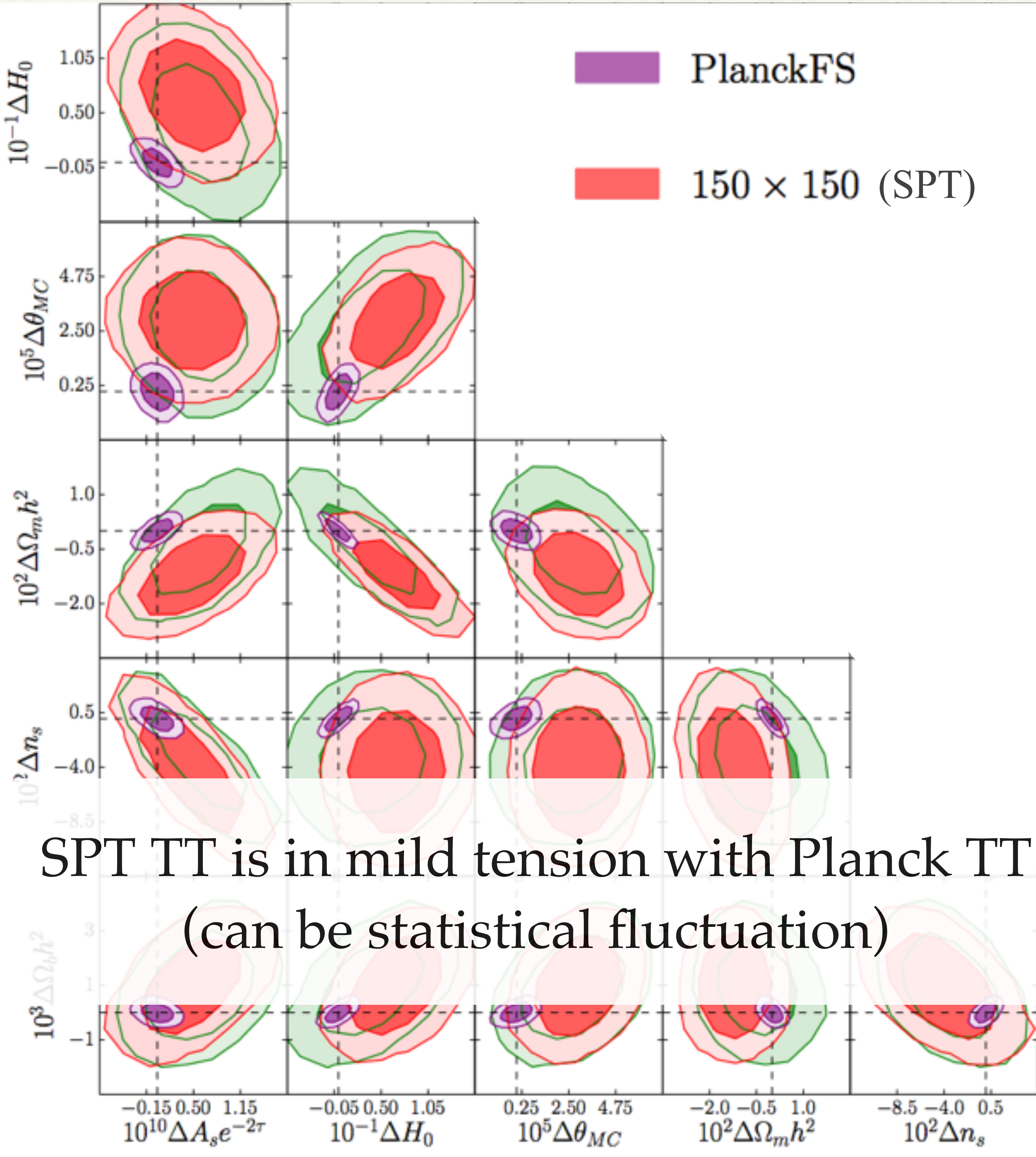
Planck TT and SPT-SZ TT spectra derived parameters



SPT TT is in mild tension with Planck TT
(can be statistical fluctuation)

5 parameter model

$$\Delta\theta_{\rm MC}, \Delta\Omega_m h^2, \Delta\Omega_b h^2,$$
$$\Delta A_s e^{-2\tau}, \Delta n_s$$

chi-square:

$$\chi^2 = \Delta\theta^T \mathbf{C}^{-1} \Delta\theta$$
$$\Delta\theta = \mathbf{p}_1 - \mathbf{p}_2$$

$\mathbf{C}$ = parameter diff. covariance

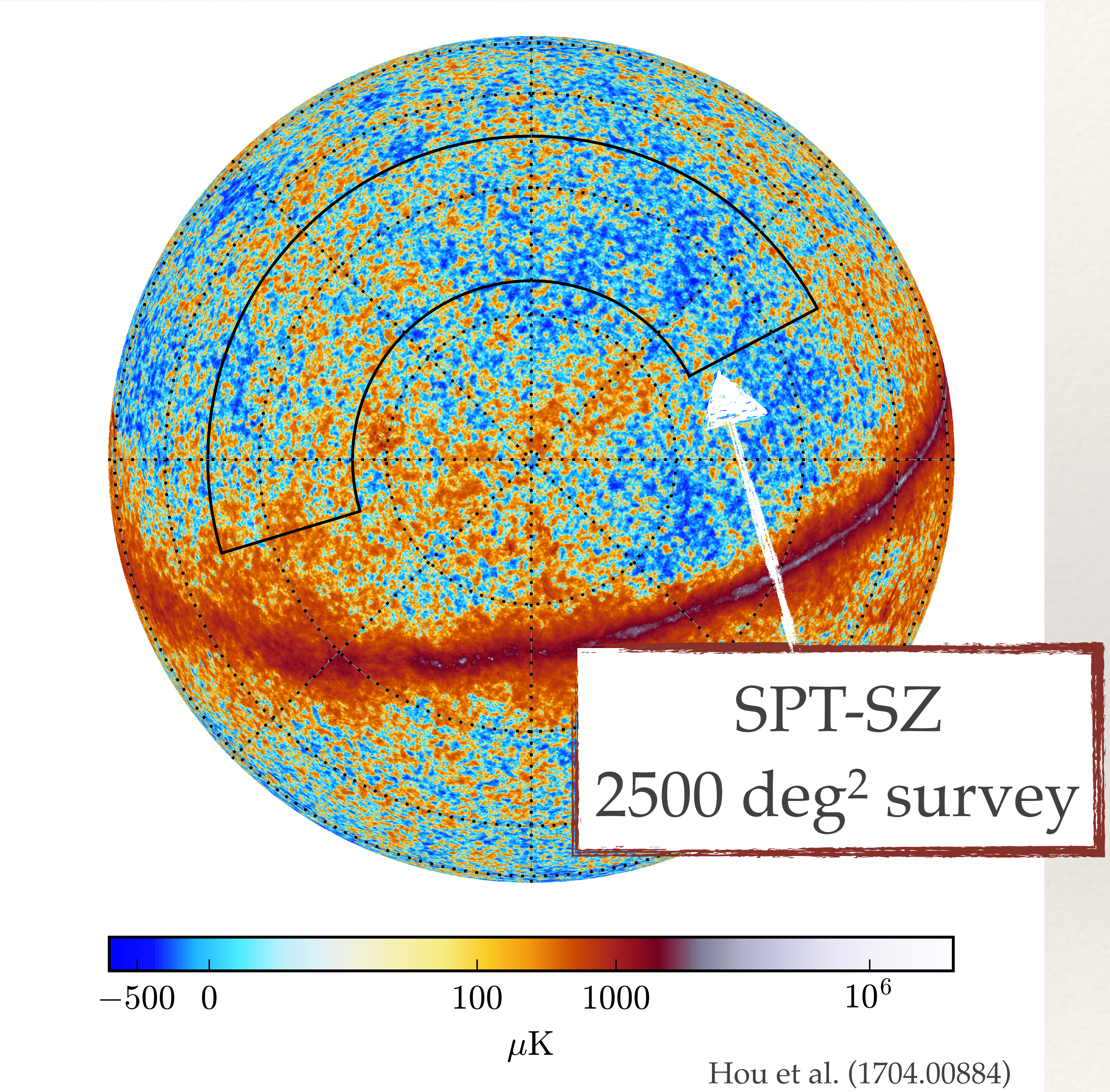
$$\chi^2 = 12.2 \text{ for } 5 \text{ d.o.f.}$$

⟶ PTE = 0.032

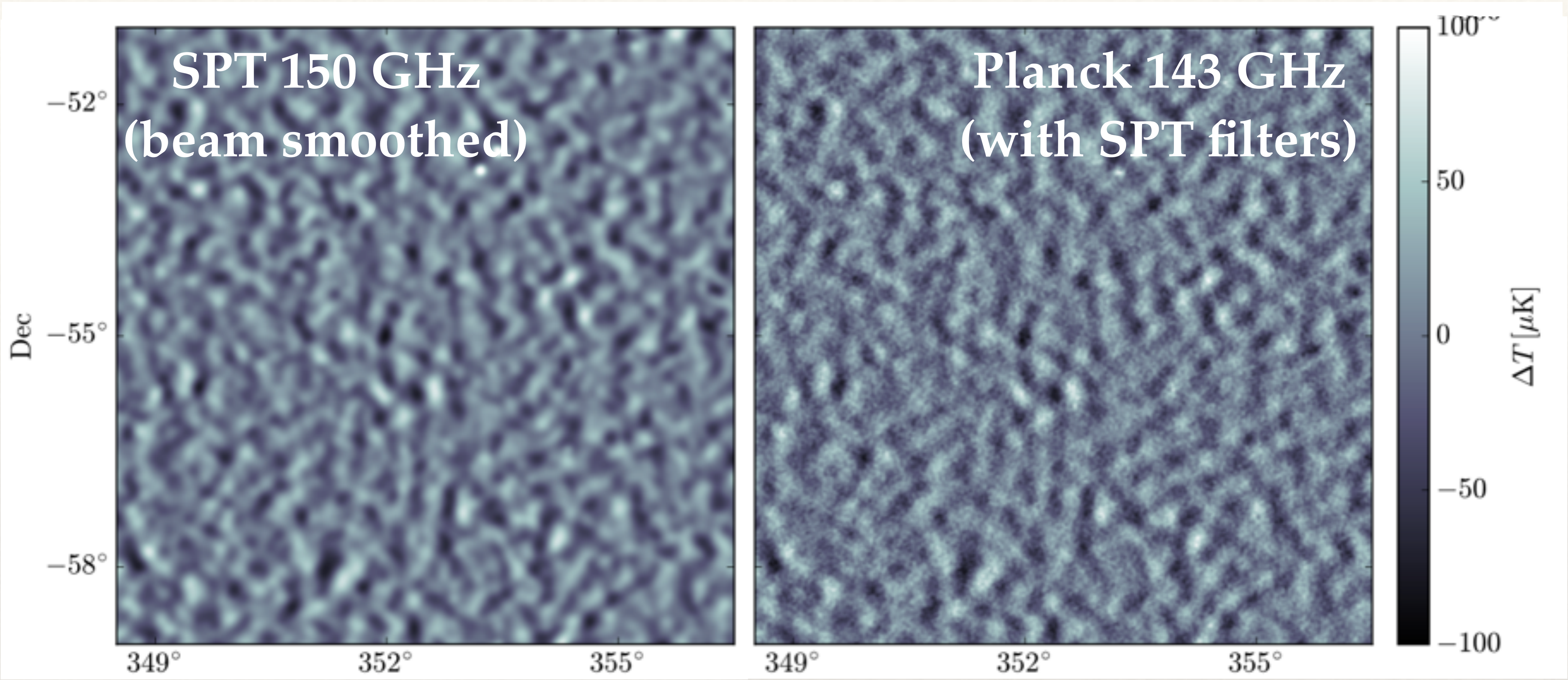
W.L. Kimmy Wu

Not an apples-to-apples comparison

- Planck full-sky vs SPT-SZ 2500 sq. deg (~6% of sky)
- Planck's constraints come from lower ell multipoles than SPT's (ell < 650)
- SPT's constraints contain information from higher ell multipoles than Planck's (ell > 2500)

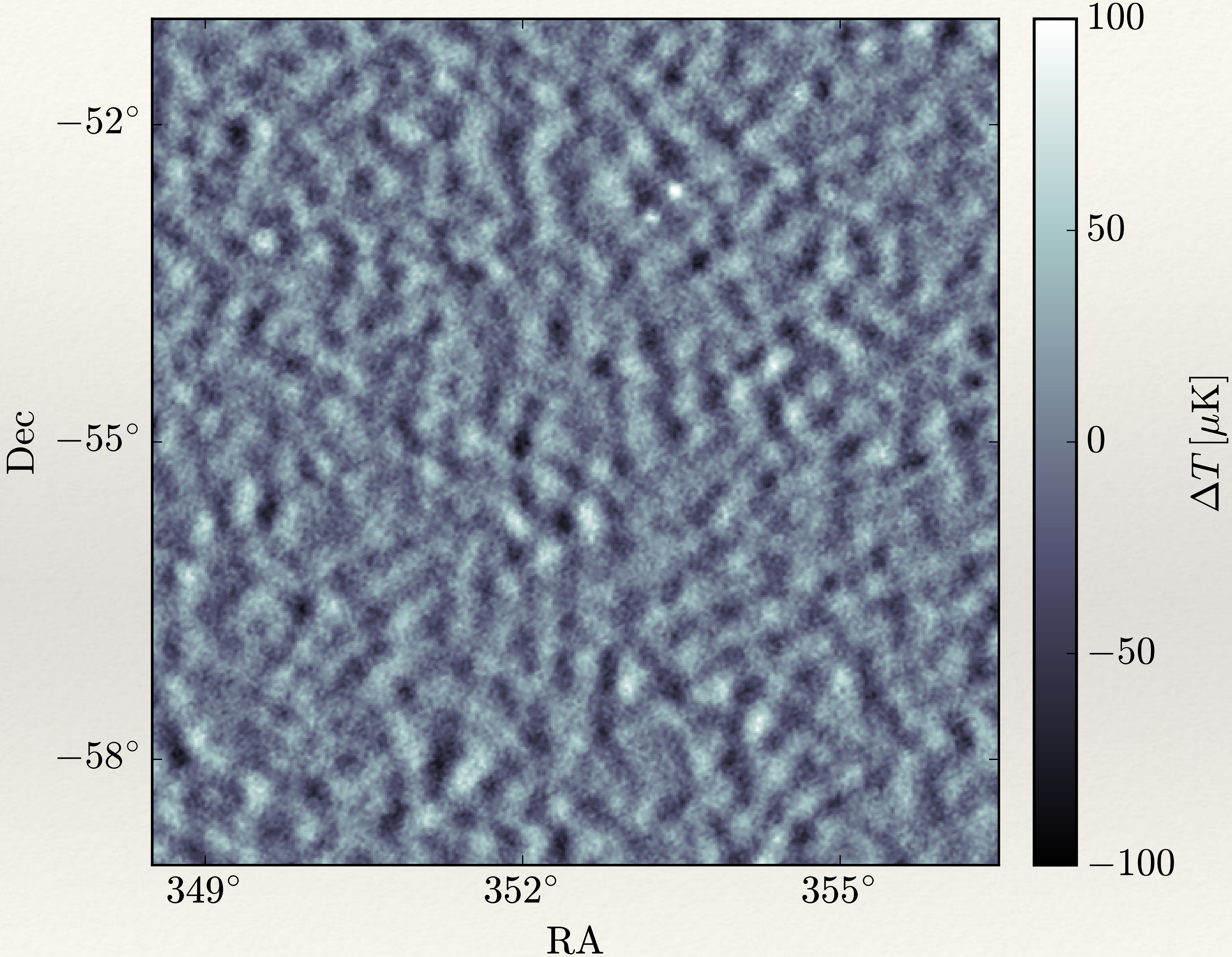


Compare the same modes in-patch

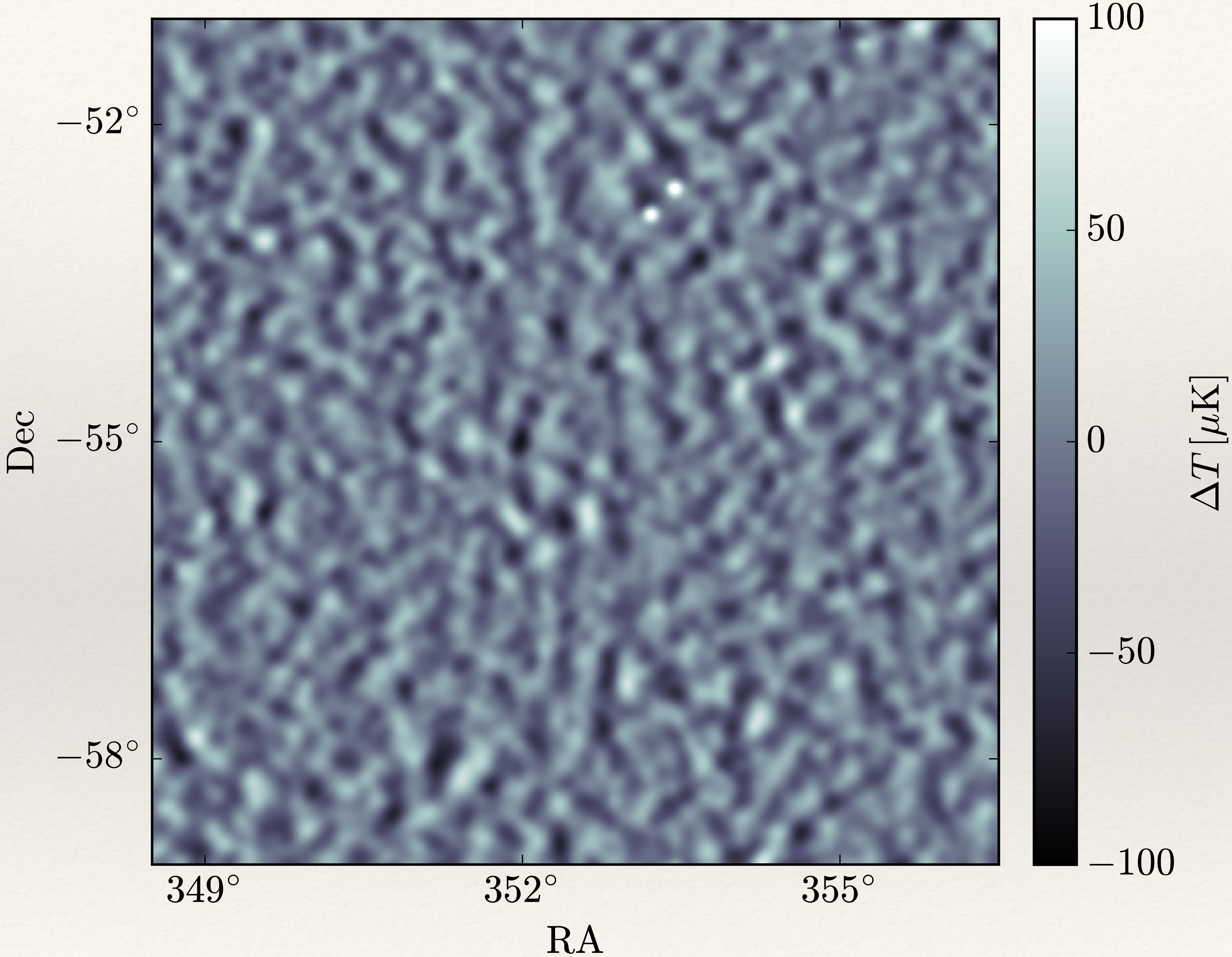


- Mock-observe the Planck map given SPT-SZ's pointing
- Apply same high-pass filter on mock-observed Planck map as on SPT-SZ's

Planck 143 GHz, with SPT Filters

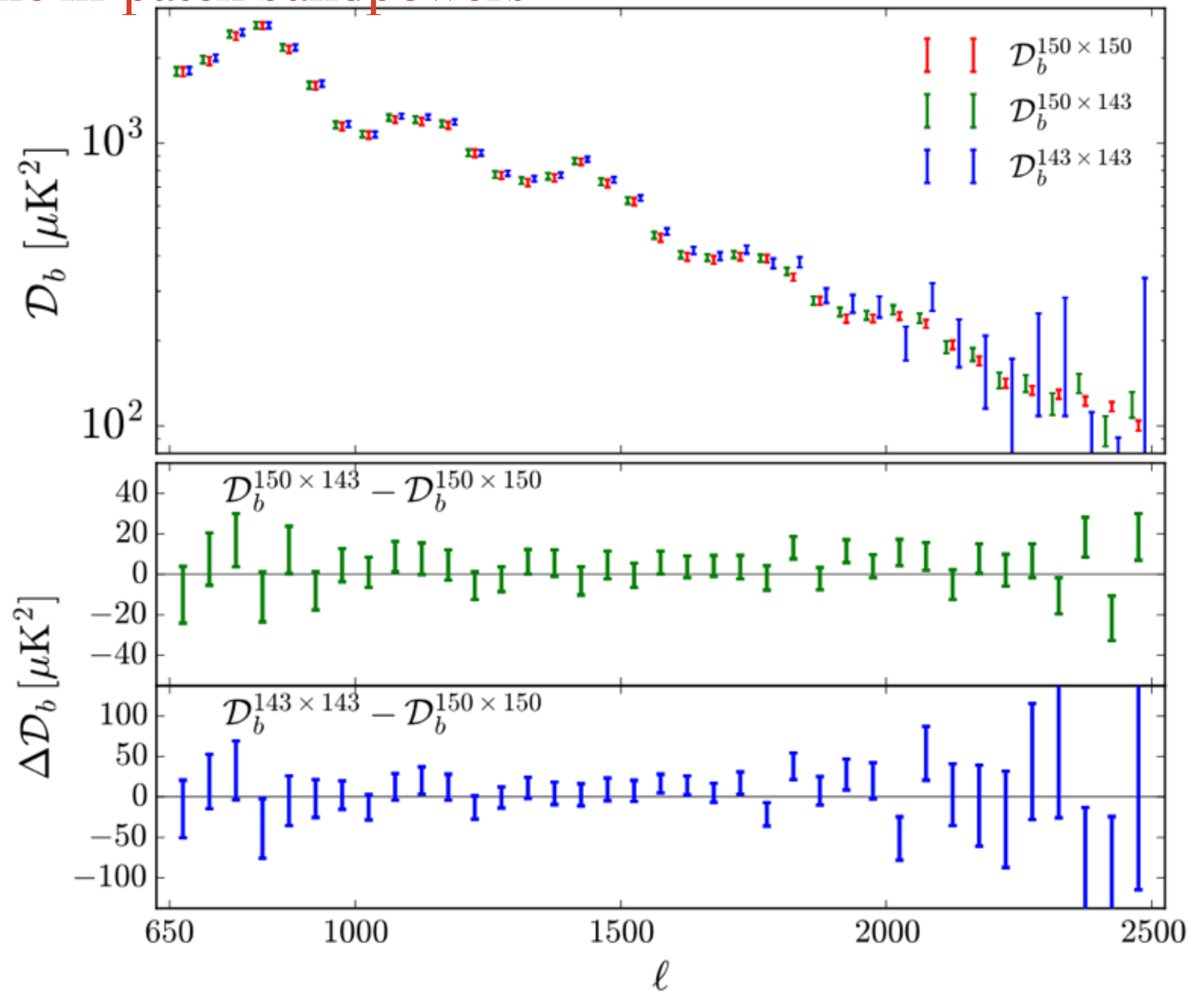


SPT 150 GHz, Planck beam smoothed

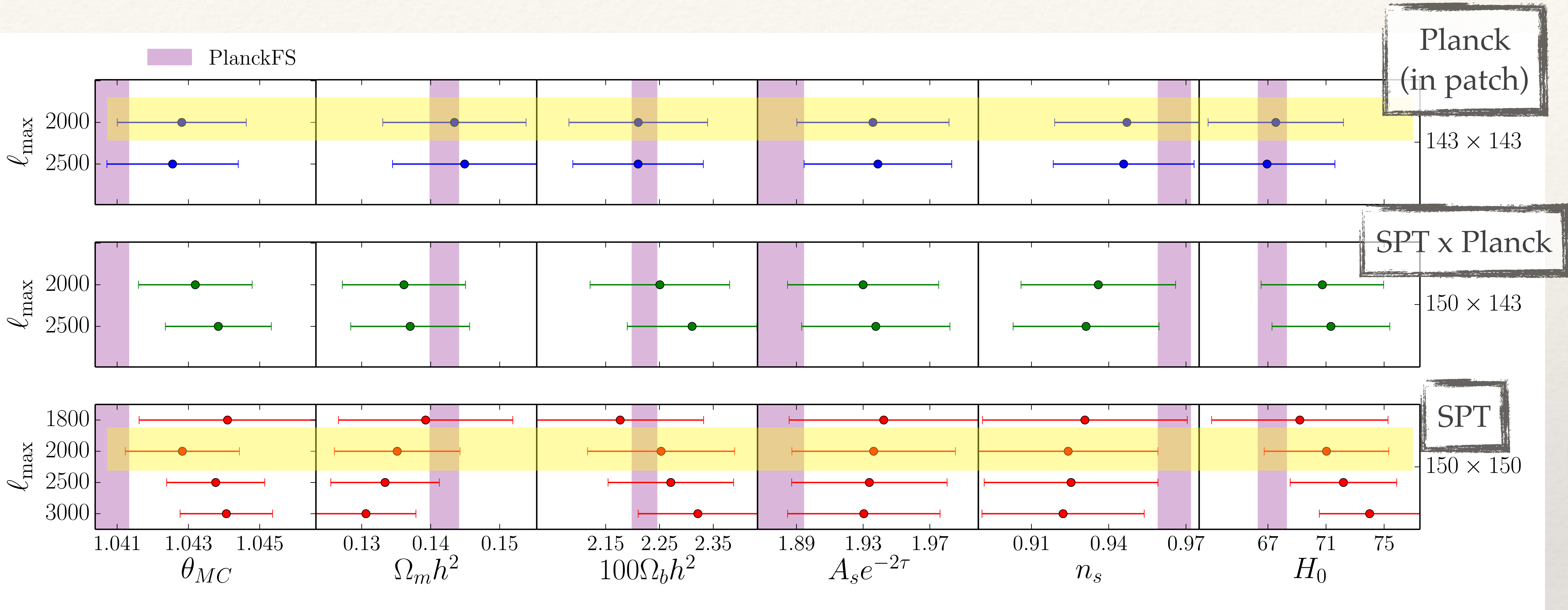


Compare the in-patch bandpowers

(Hou et al. 2017)



Parameters comparison



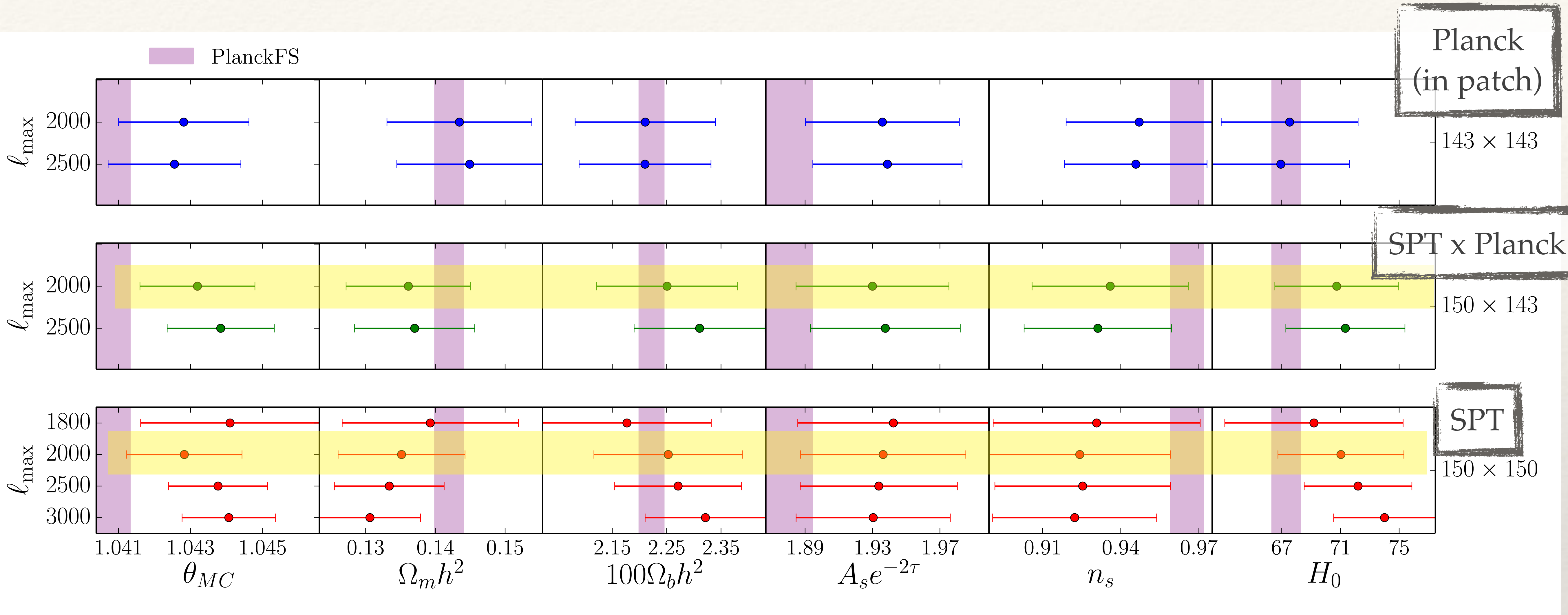
> Planck Full Sky vs Planck in-patch —> consistent with sample variance

> Restricting to modes on the sky that both measure well, the parameters are consistent.

yellow bands:

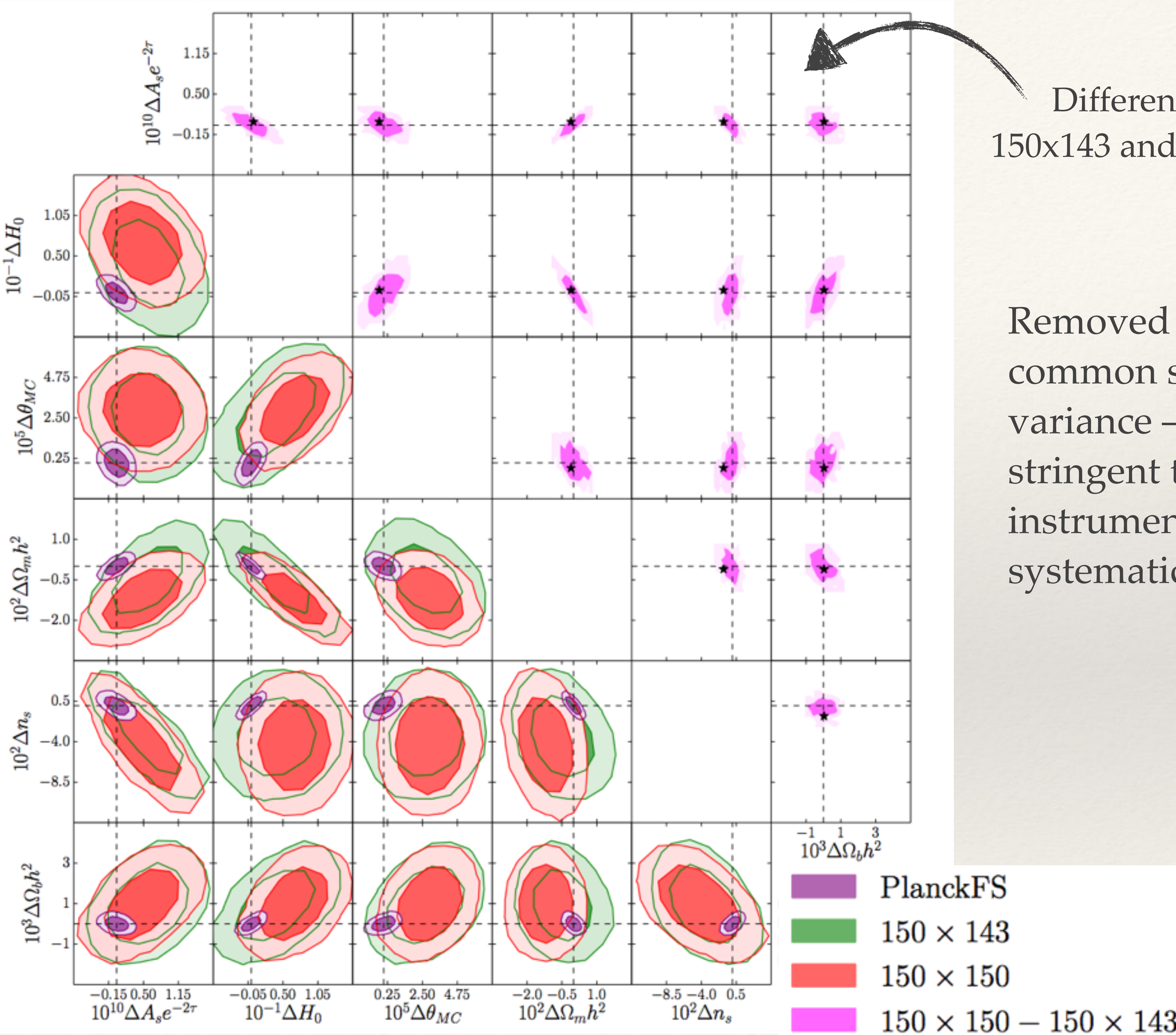
Planck in patch and ell > 650; SPT at ell < 2000 ⟶ PTE = 0.32

Parameters comparison



yellow band:

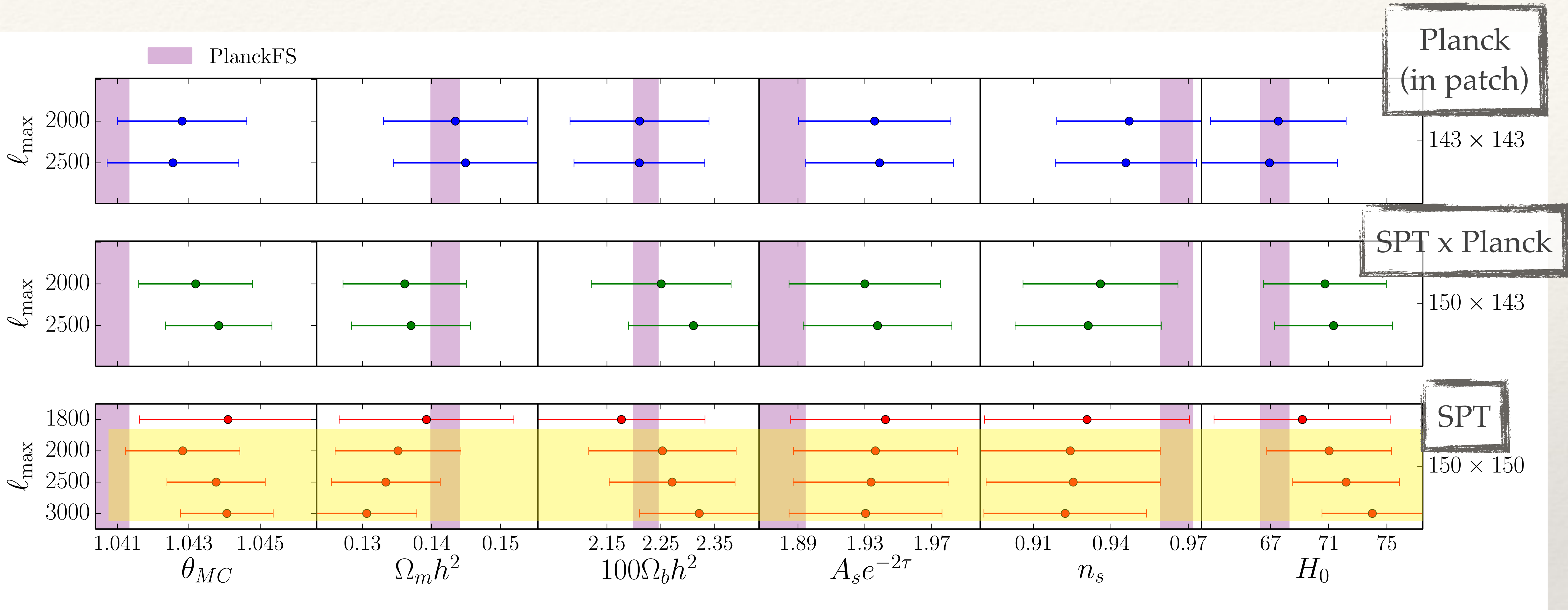
Planck x SPT ell > 650; SPT at ell < 2000 → PTE = 0.74



Difference of 150x143 and 150x150

Removed common sample variance —> stringent test of instrumental systematics

Is SPT consistent with itself when increasing ℓ_{max}?



yellow band:

SPT at ell < 2000 vs SPT at ell < 2500 ⟶ PTE = 0.88

SPT at ell < 2000 vs SPT at ell < 3000 ⟶ PTE = 0.75

Take home 1:

1) Planck Full Sky vs Planck in-patch –> statistical fluctuations consistent with noise+sample variance

2) SPT $\ell < 3000$ vs SPT $\ell < 2000$ –> consistent with expected statistical fluctuations

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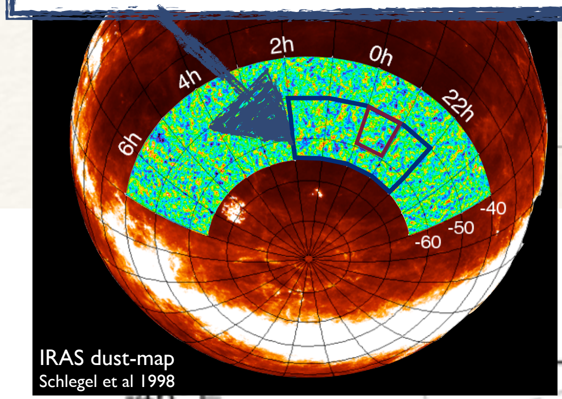
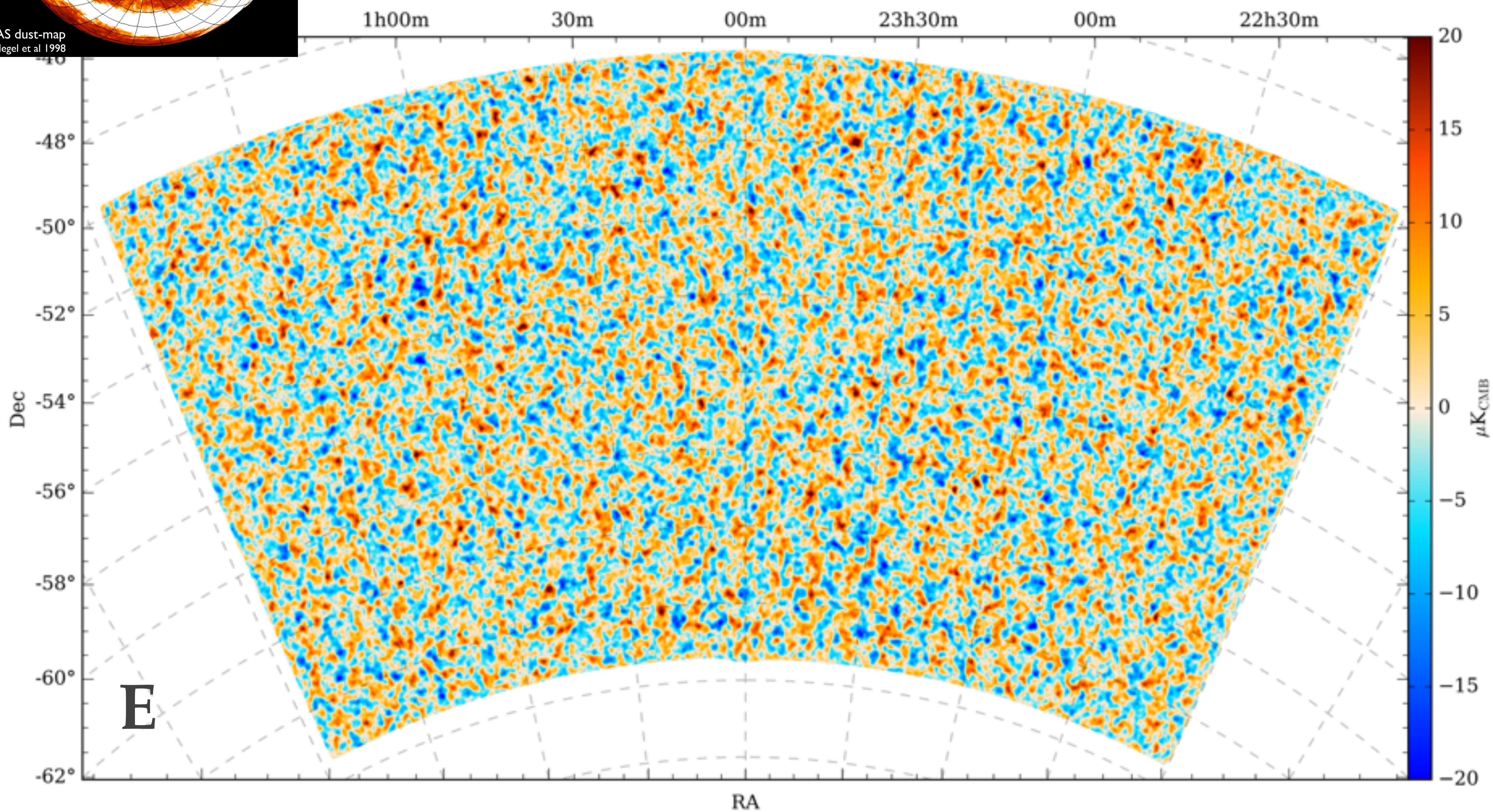
SPTpol 500 deg²

SPTpol measurements

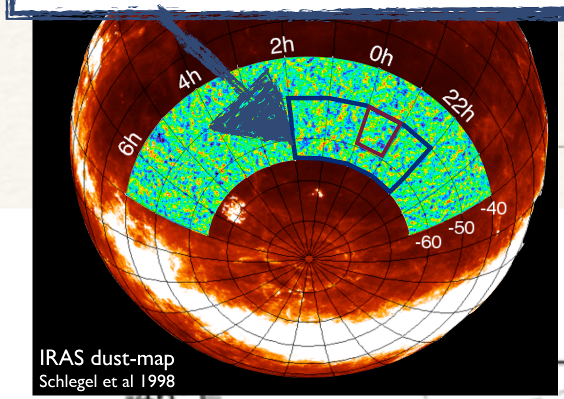


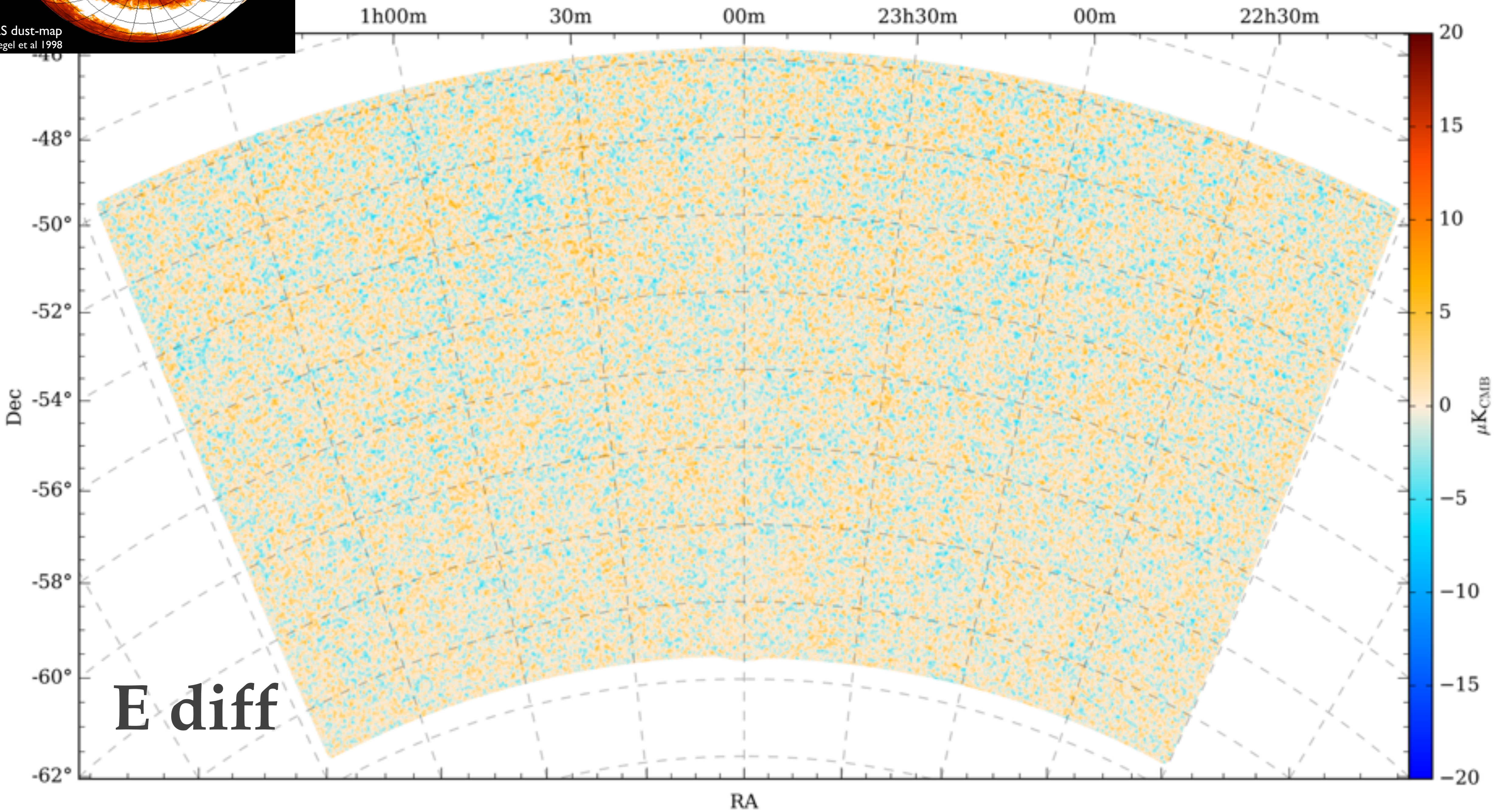


150GHz; 9.4 μK-arcmin between 2000 < ℓ < 4000; Smoothed by 4 arcmin FWHM Gaussian.

SPTpol measurements

SPTpol 500 deg²



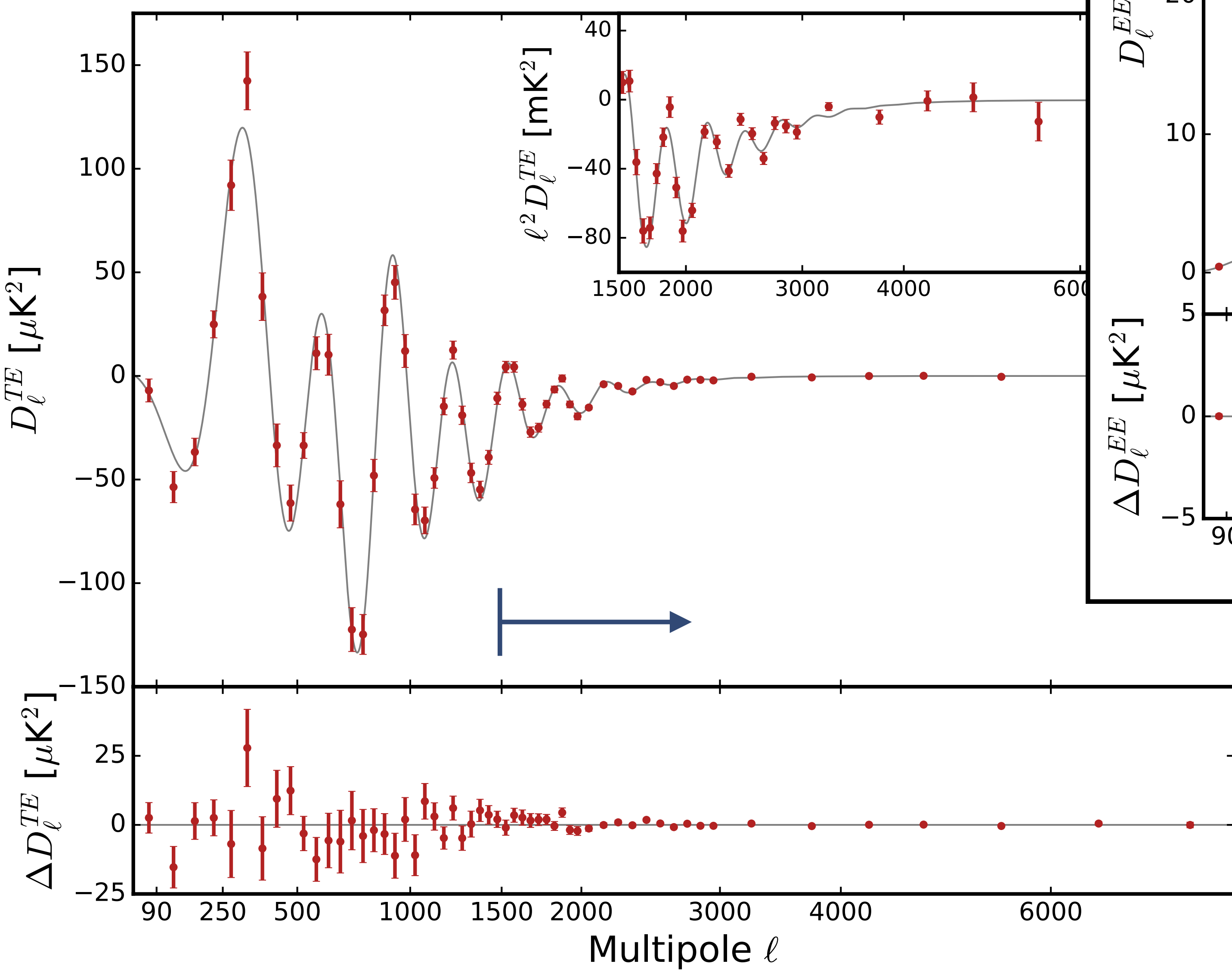


150GHz; First-half map minus second-half map.

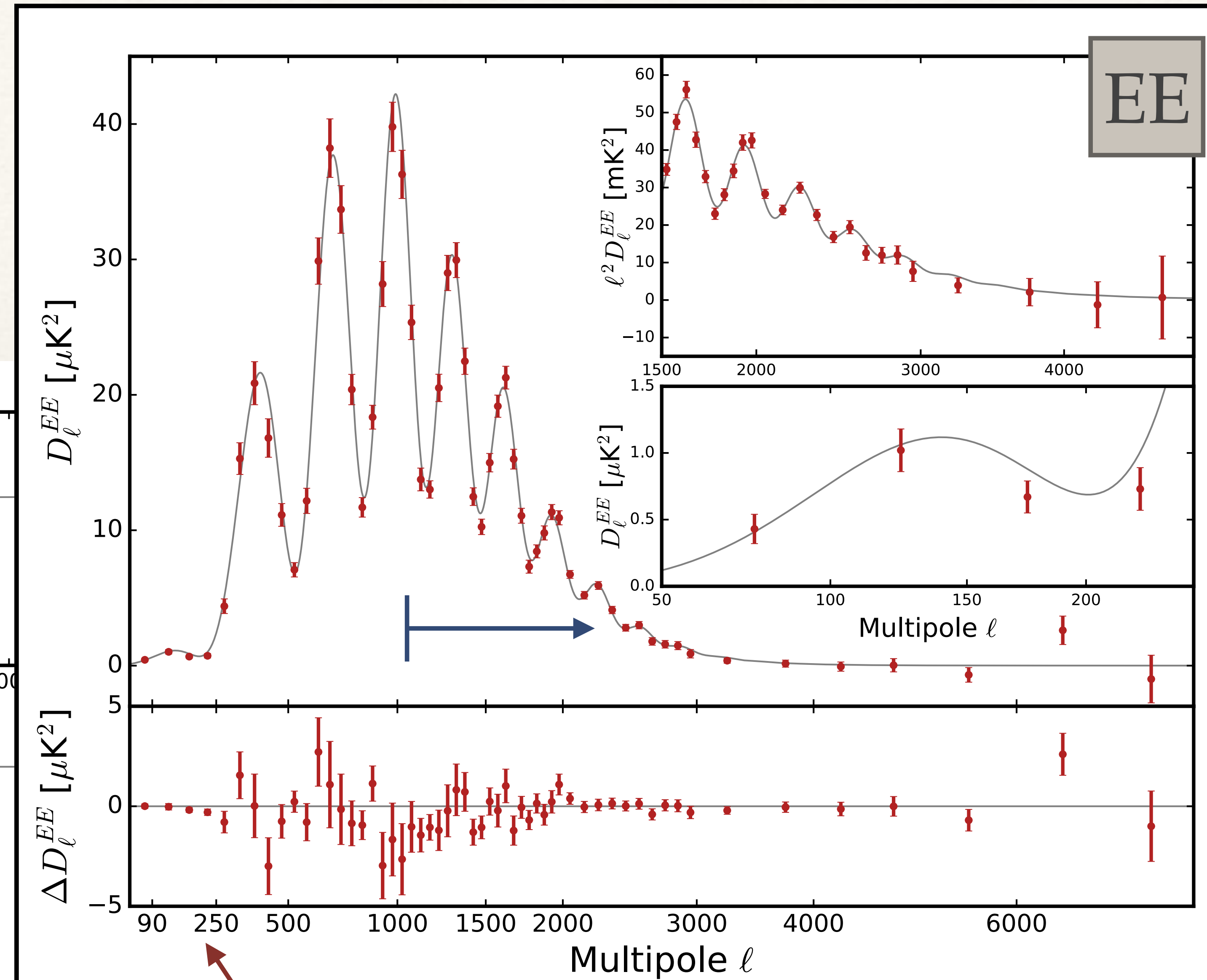
SPTpol TE, EE spectra measurements

most sensitive measurements of TE (EE) power for ℓ > 1475 (ℓ > 1050) to-date

TE



EE



Residuals against best-fit Planck TT

LCDM parameter constraints

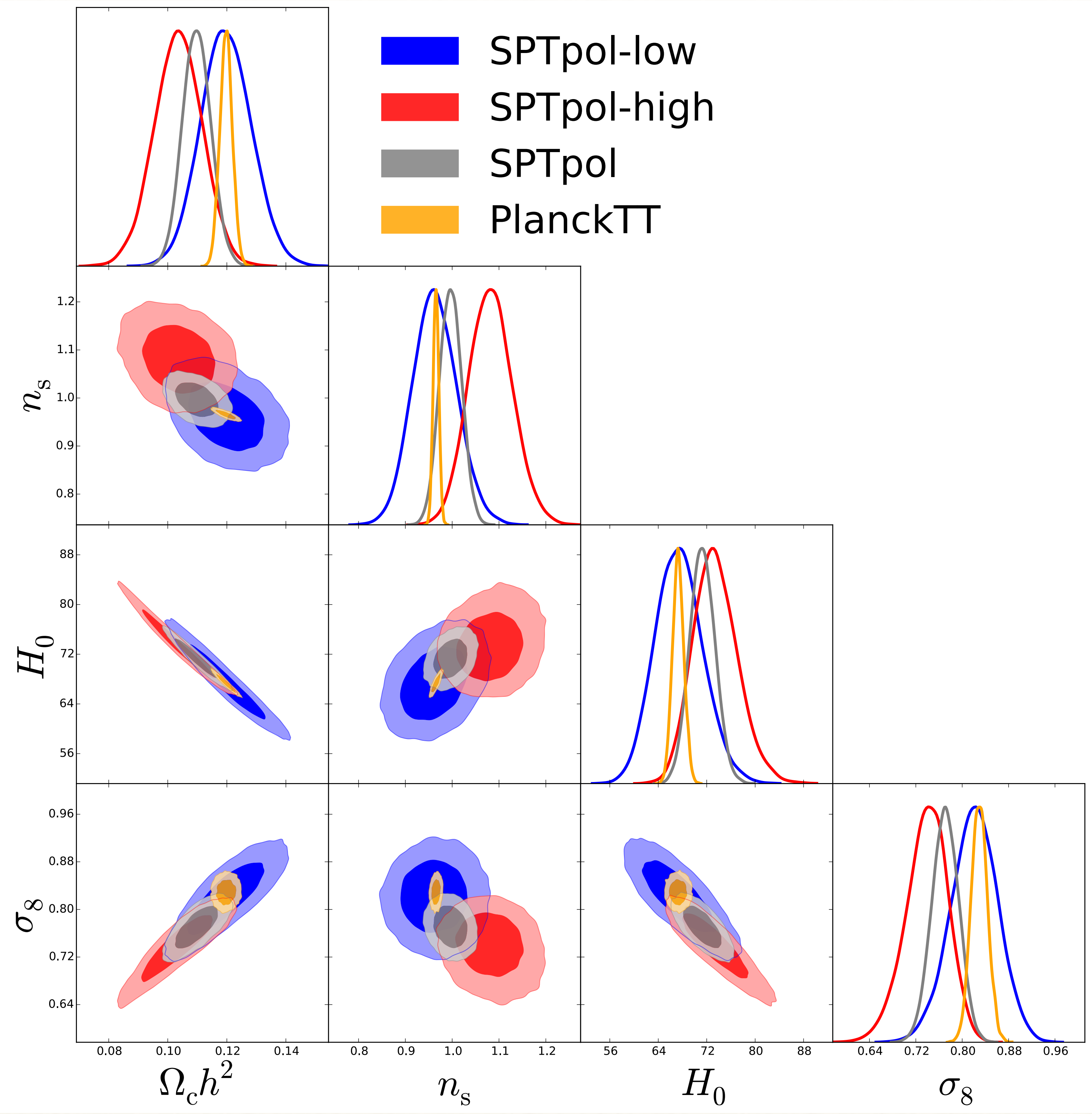
- "Low-ℓ" SPTpol data ($\ell < 1000$) in good agreement with *Planck*TT results.
- Adding "high-ℓ" data ($\ell > 1000$) pushes H_0 1.7σ higher σ_8 2.1σ lower compared to *Planck*TT:

$$H_0 = 71.2 \pm 2.1\,\mathrm{km\,s^{-1}Mpc^{-1}}$$

$$\sigma_8 = 0.770 \pm 0.023$$

(full ℓ range)

- Similar to trends of high H_0 seen in SPT-SZ TT data



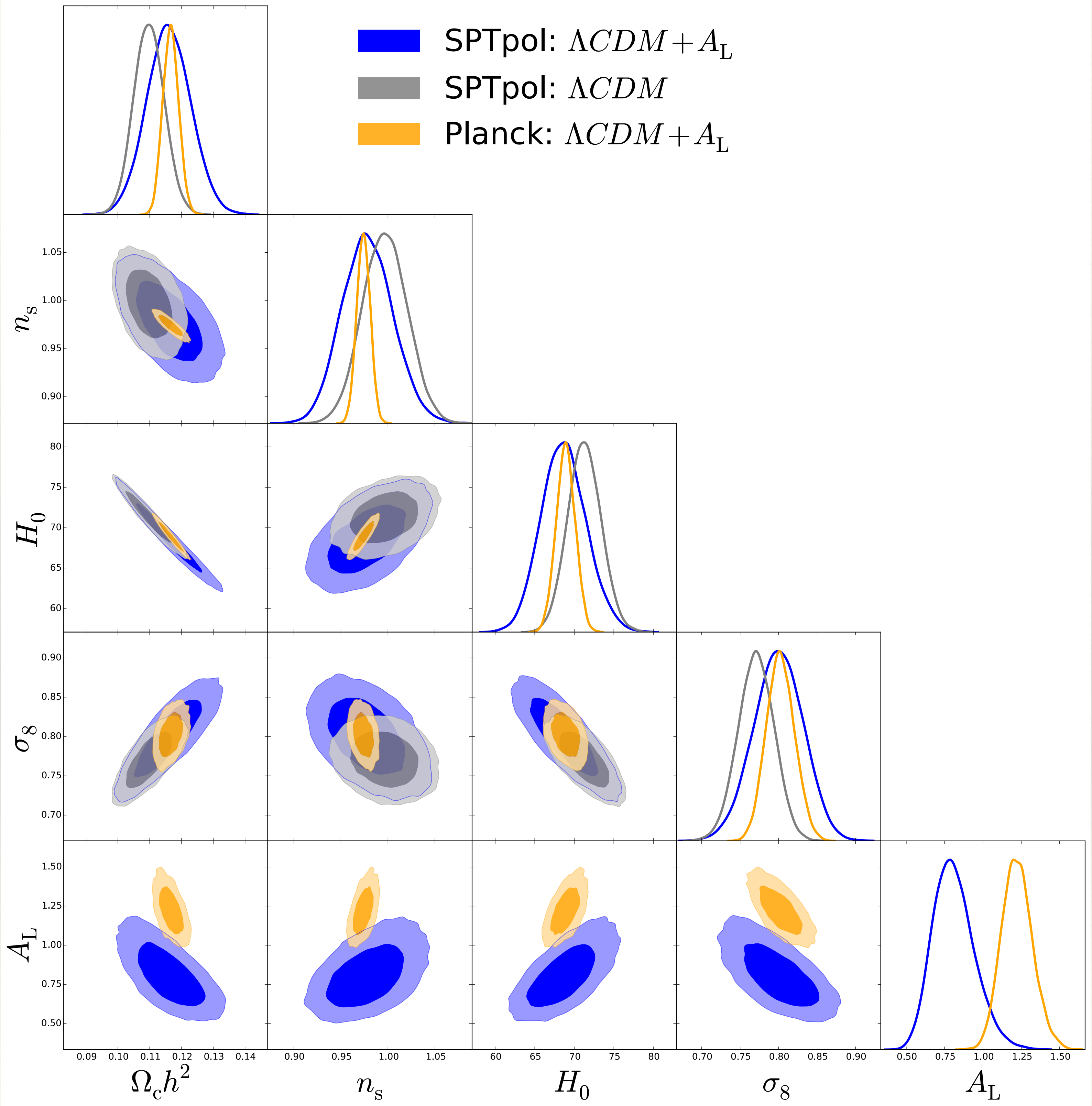
Adding A_{lens} relieves tension

The best-fit A_L are 2.4σ discrepant

$$A_L = 0.81 \pm 0.14\,(\text{SPTpol})$$
$$A_L = 1.22 \pm 0.10\,(\text{PlanckTT})$$

SPTpol's TE/EE spectra prefer **less** smoothing of peaks/troughs than what their best-fit LCDM expects

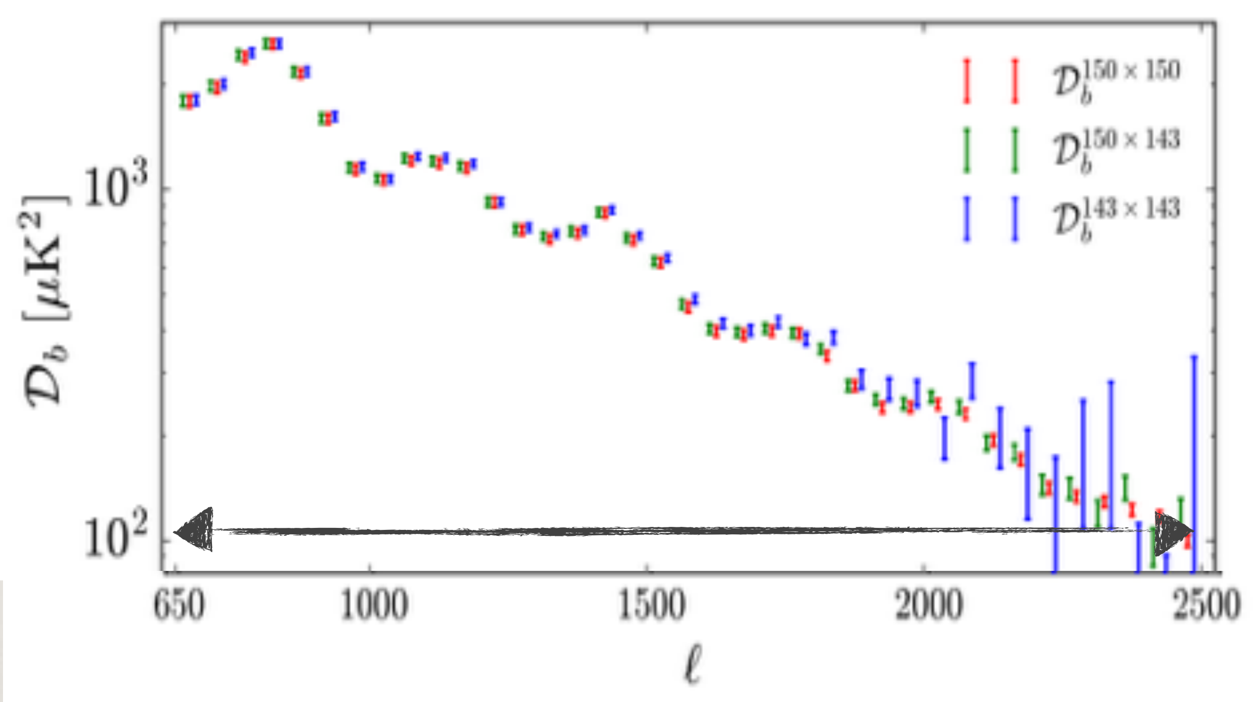
PlanckTT spectrum prefers **more** smoothing of peaks/troughs than what its best-fit LCDM expects



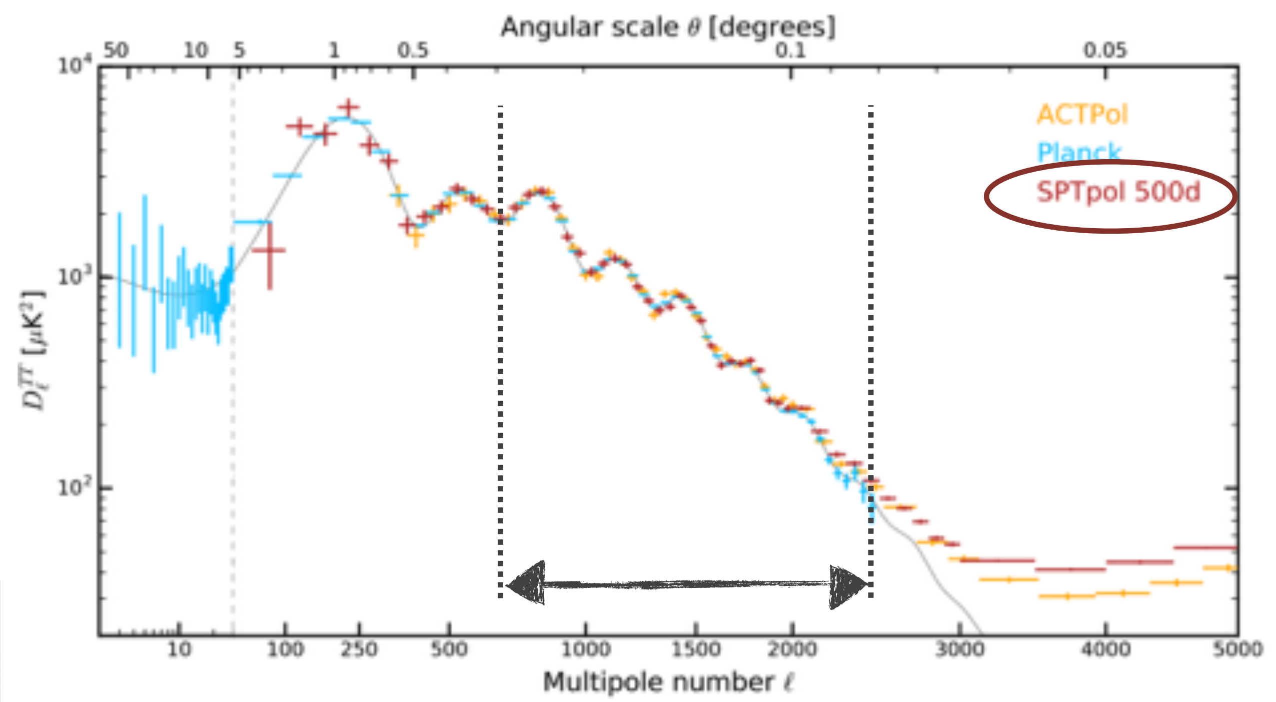
Statistical fluke?
Will they persist?

Consistency tests with SPT-SZ and SPTpol TT

SPT-SZ x Planck TT



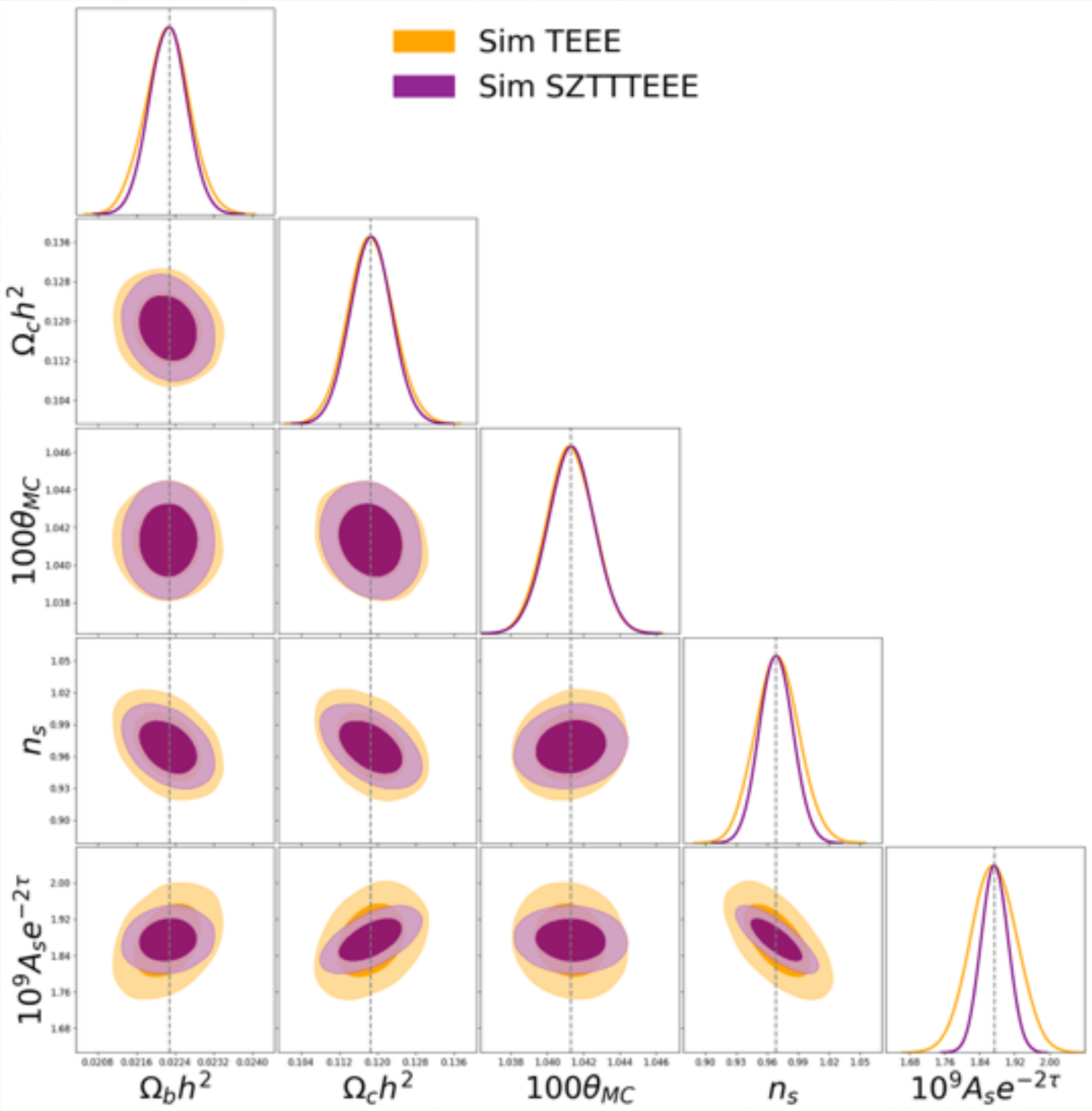
TT



- SPT-SZ TT inferred parameters are completely consistent with PlanckTT when restricted to the same angular multipoles and patch of sky
- SPTpol TT is a subset of SPT-SZ TT. Are the cosmologies they infer consistent with each other?
- Do they infer consistent parameters with SPTpol TE/EE?

Adding SPT-SZ and SPTpol TT information

- Should improve LCDM parameter constraints by 10-15%
- H0 is currently 1.7σ different from from Planck's TT best-fit
- σ_8 is currently 2.1σ different from from Planck's TT best-fit
- Will see what the combined datasets says!



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CMB Lensing: Planck T+ SPT-SZ T

(Omori et al. 2017)

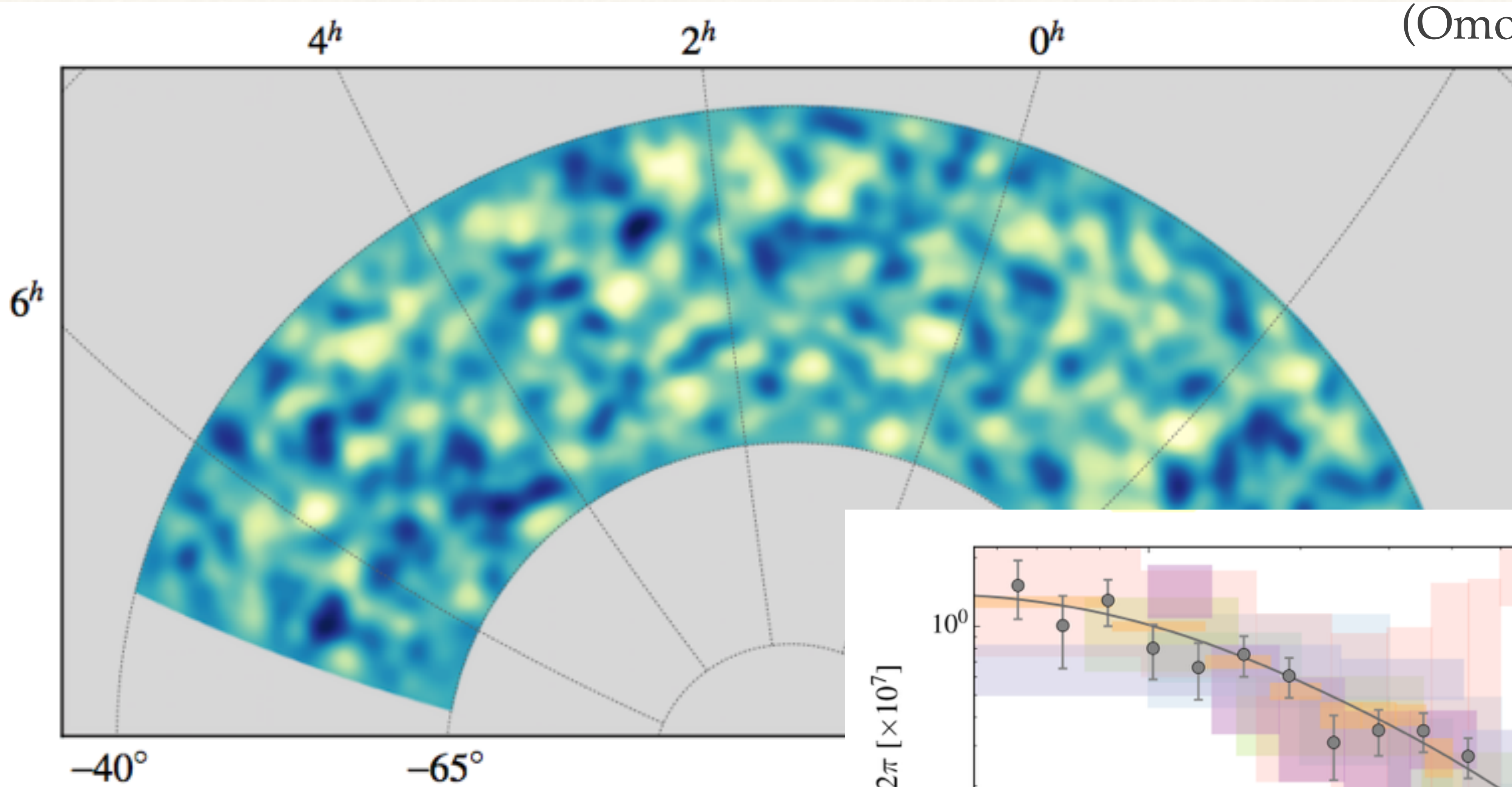
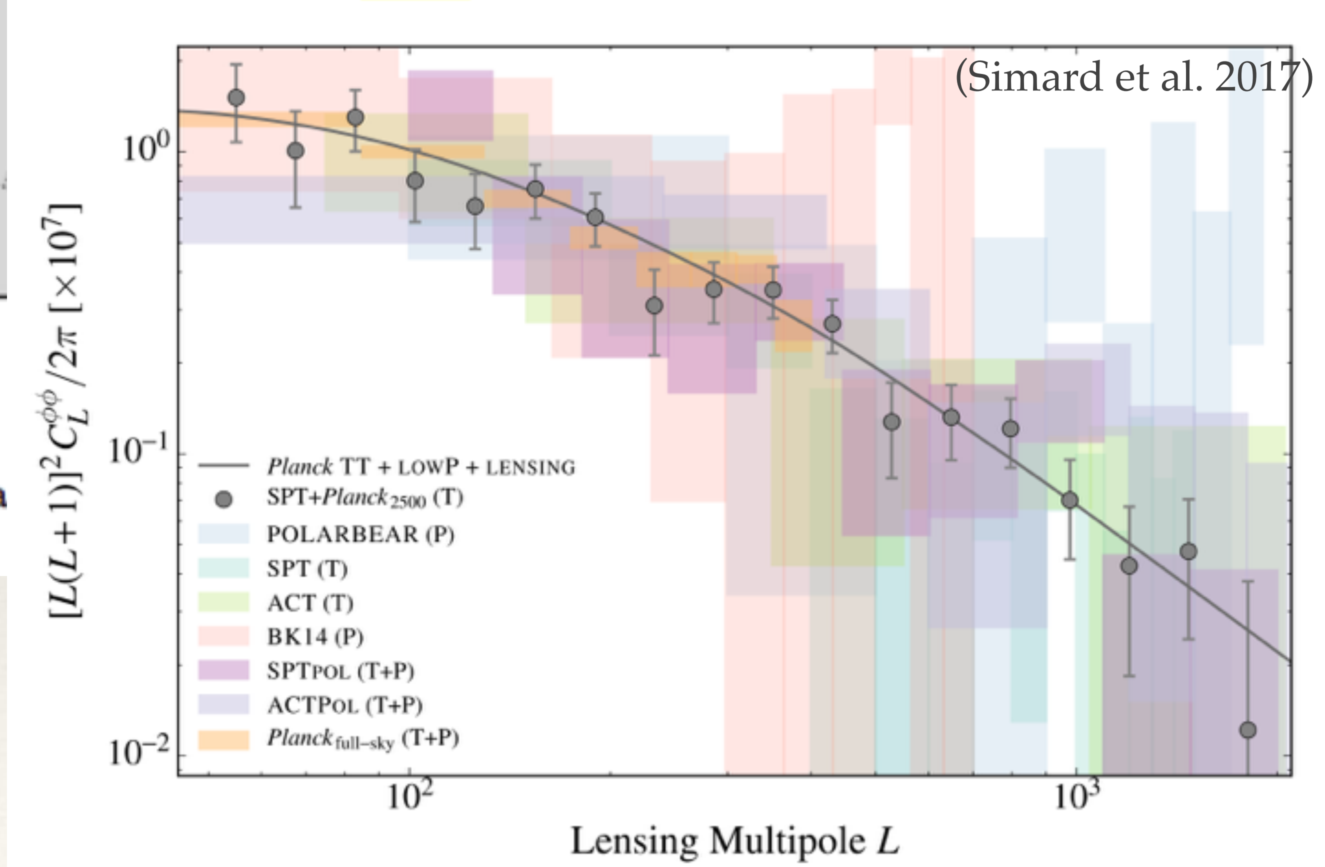
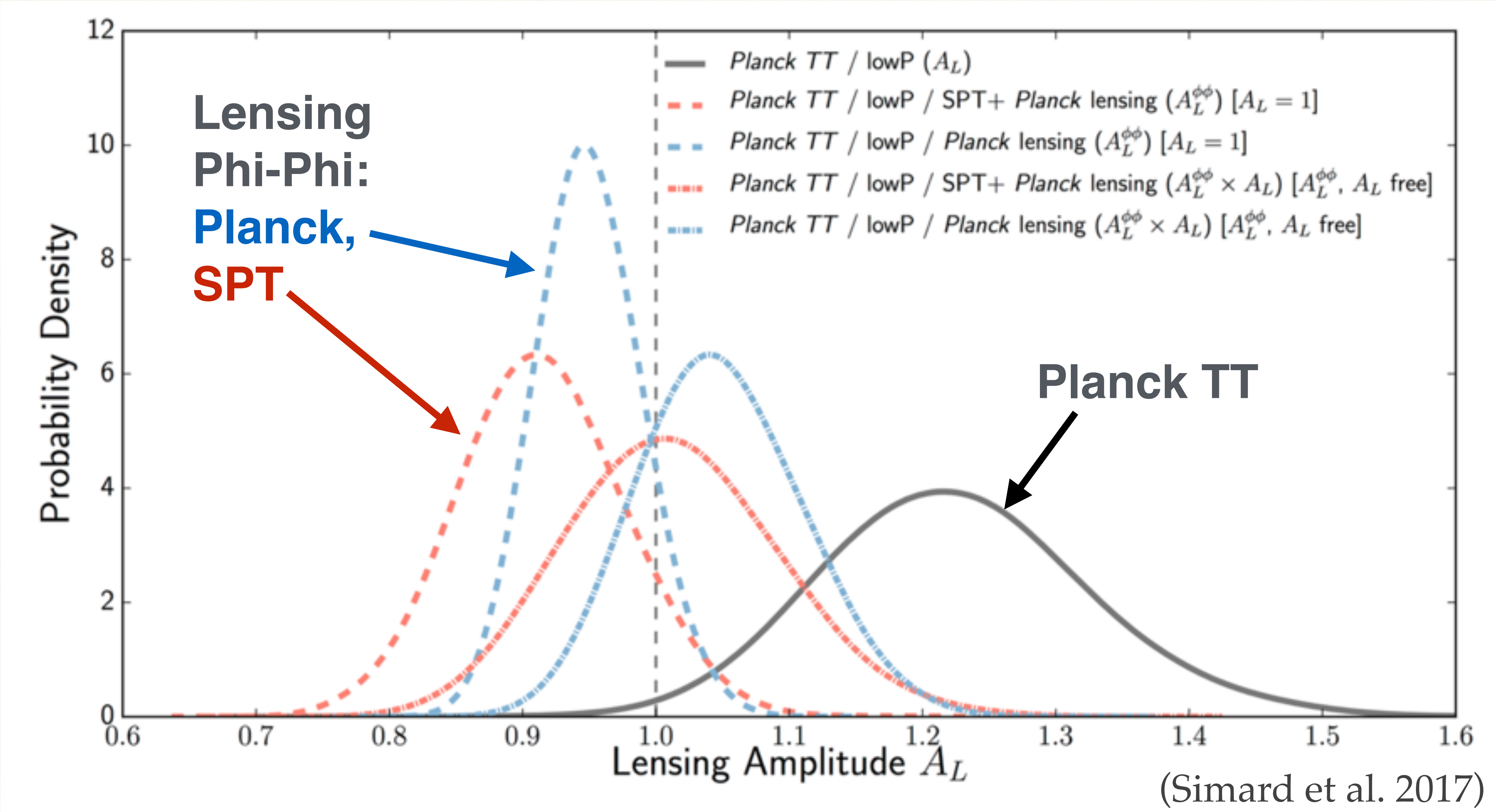


FIG. 4.— The reconstructed lensing map on a zenithal equal-area
FWHM = 2 degrees.



CMB TT Lensing: Planck + SPT



(Simard et al. 2017)

- Lensing power spectrum prefers less structure (or lower $\Omega_m h^2$) than Planck TT

Highlights of SPT's view of LCDM

Planck TT vs. SPT-SZ TT

χ^2_{param} PTE = 0.032

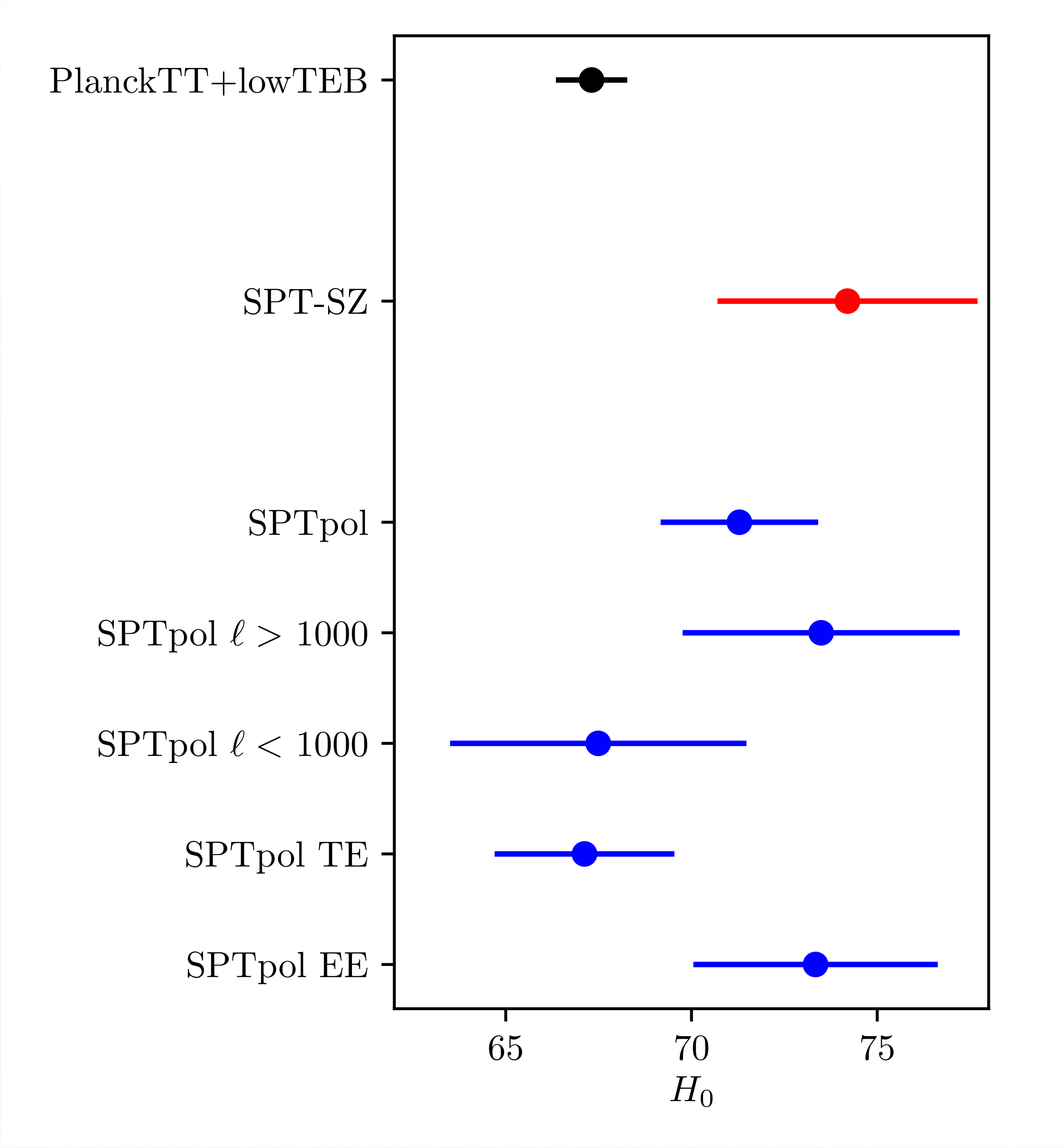
SPTpol params vs. Planck params

$$H_0 = 71.2 \pm 2.1 \,(\mathrm{SPTpol})$$
$$H_0 = 67.31 \pm 0.96 \,(\mathrm{Planck})$$

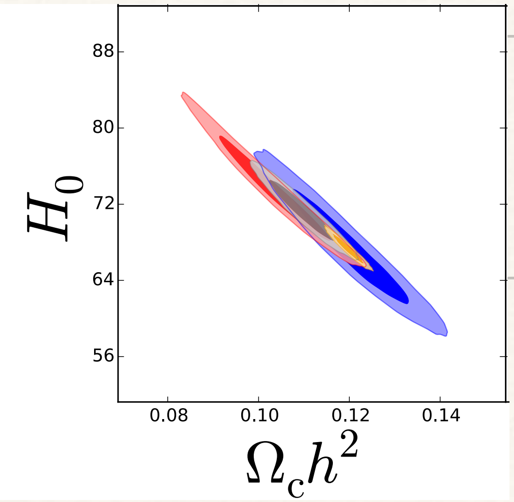
1.7σ

$$A_L = 0.81 \pm 0.14 \,(\mathrm{SPTpol})$$
$$A_L = 1.22 \pm 0.10 \,(\mathrm{PlanckTT})$$

2.4σ



Thanks!



Matter density and H_0

- CMB measures θ_* (acoustic scale) extremely well (better than 0.1%); can think of it as essentially fixed
- increase in w_m -> decrease in sound horizon ($\sim w_m^{-0.25}$);
- increase w_m —> decrease d_A more than it needs to for θ_* to be fixed. So we need to decrease H_0

$$d_A(z_*) \propto \int_0^{z_*} dz/H(z)$$
$$\propto \frac{1}{H_0} \int_0^{z_*} \frac{dz}{\sqrt{\Omega_{m,0}(1+z)^3 + \Omega_\Lambda}}$$

(All assuming flatness)