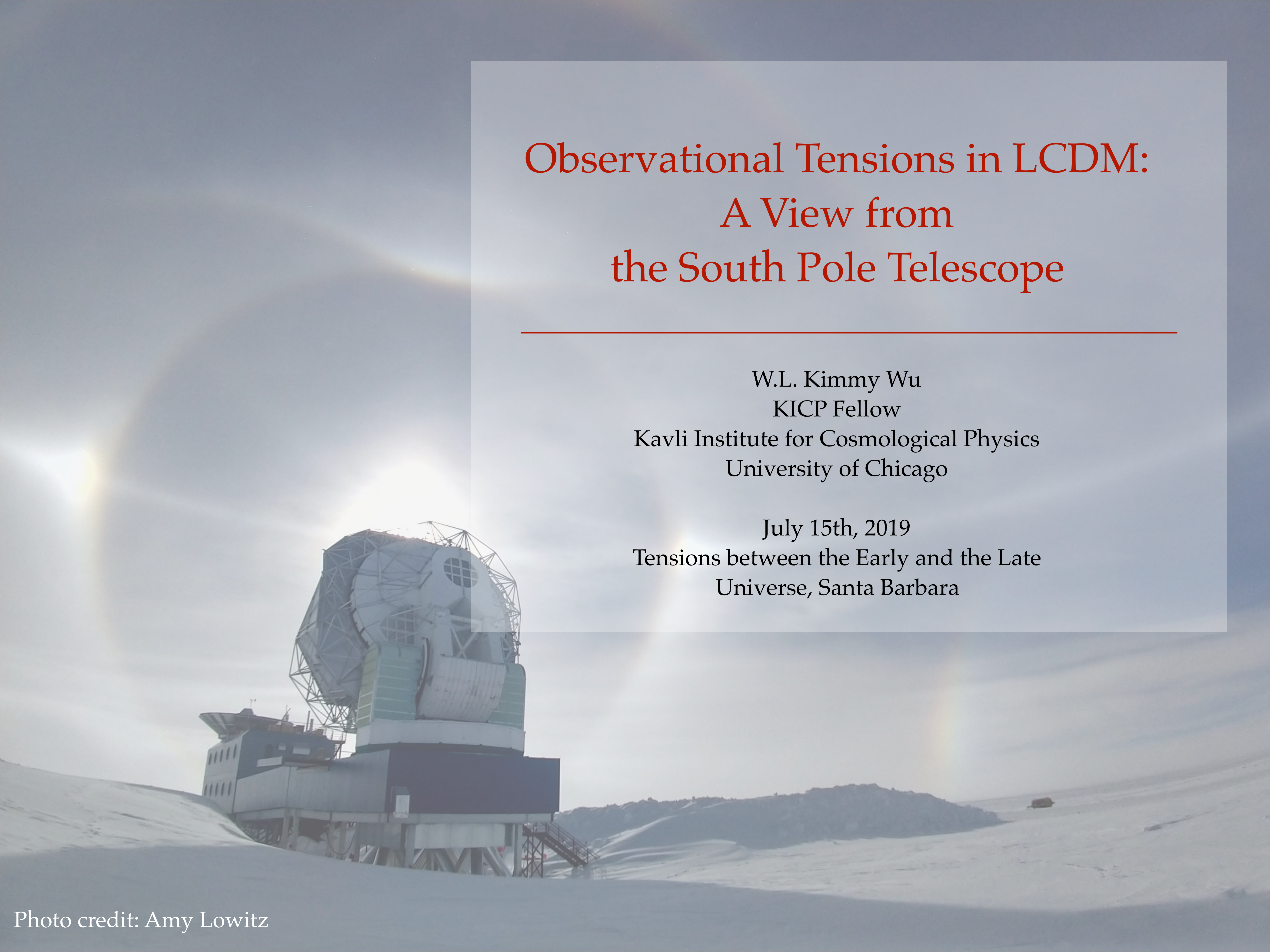

Observational Tensions in LCDM: A View from the South Pole Telescope

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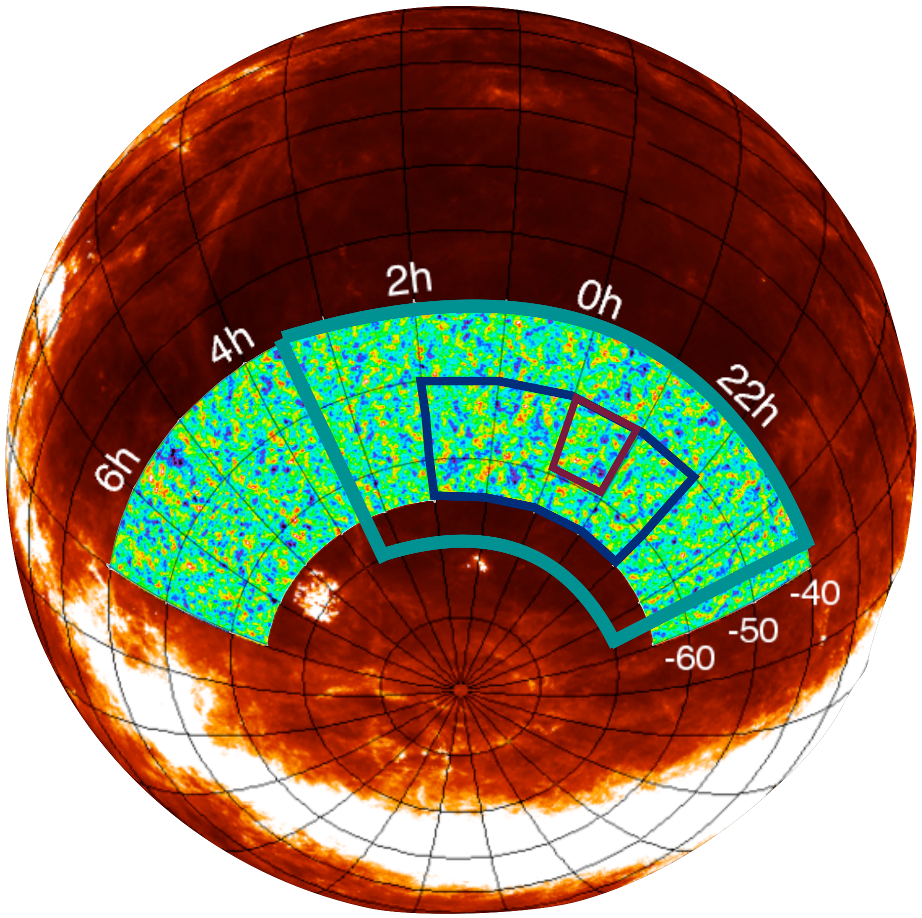
Kavli Institute for Cosmological Physics
University of Chicago

July 15th, 2019
Tensions between the Early and the Late Universe, Santa Barbara

Photo credit: Amy Lowitz

Goal: summarize the state of knowledge of the interpretation of SPT data to inform model building that attempts to resolve tensions in LCDM.

South Pole Telescope

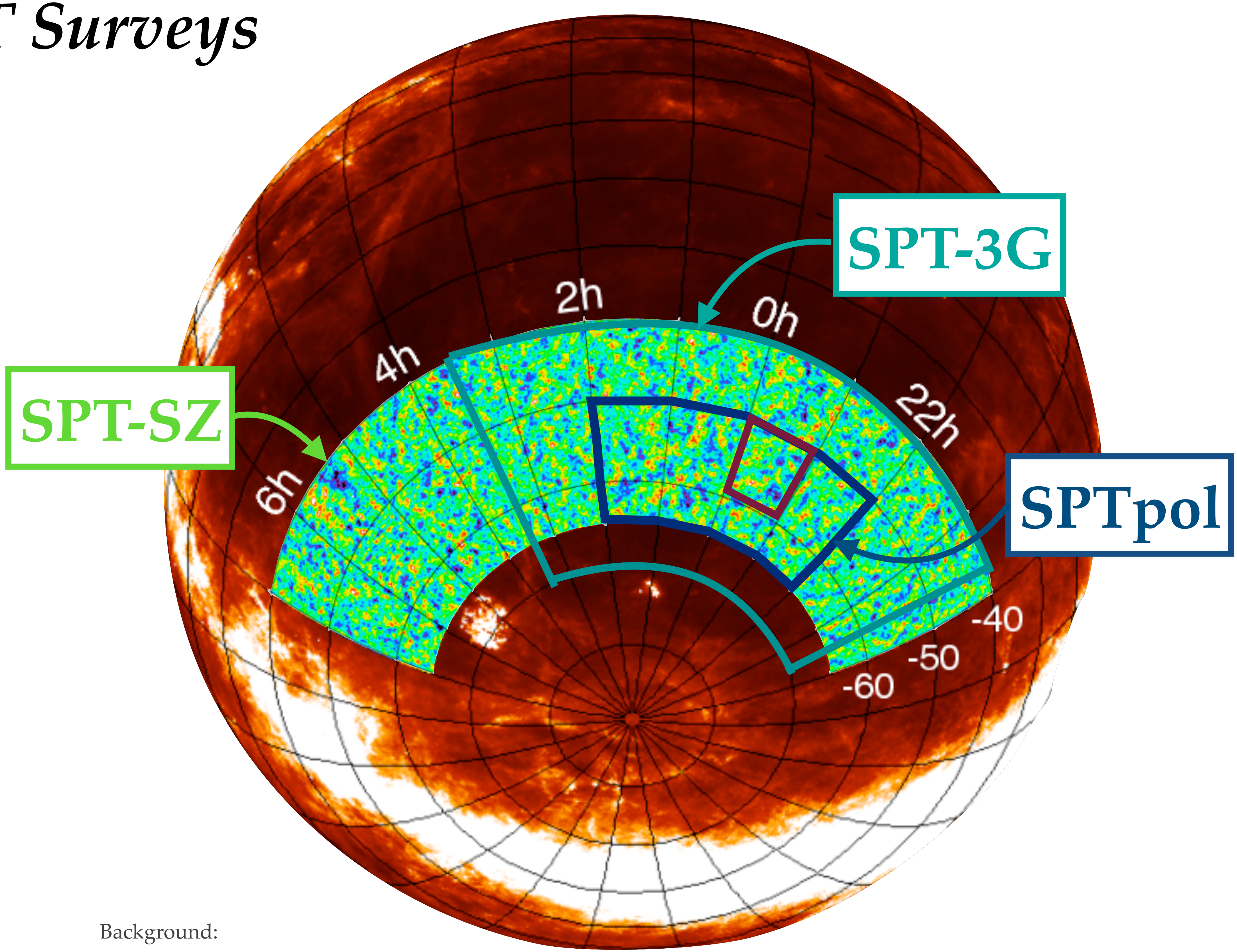


- 10m sub-mm quality dish makes ~1′ resolution at 150GHz;
- Observes in 3 bands (SPT-3G): 90/150/220 GHz;
- Current camera (SPT-3G) has the largest number of detectors (~16000) in a single receiver.

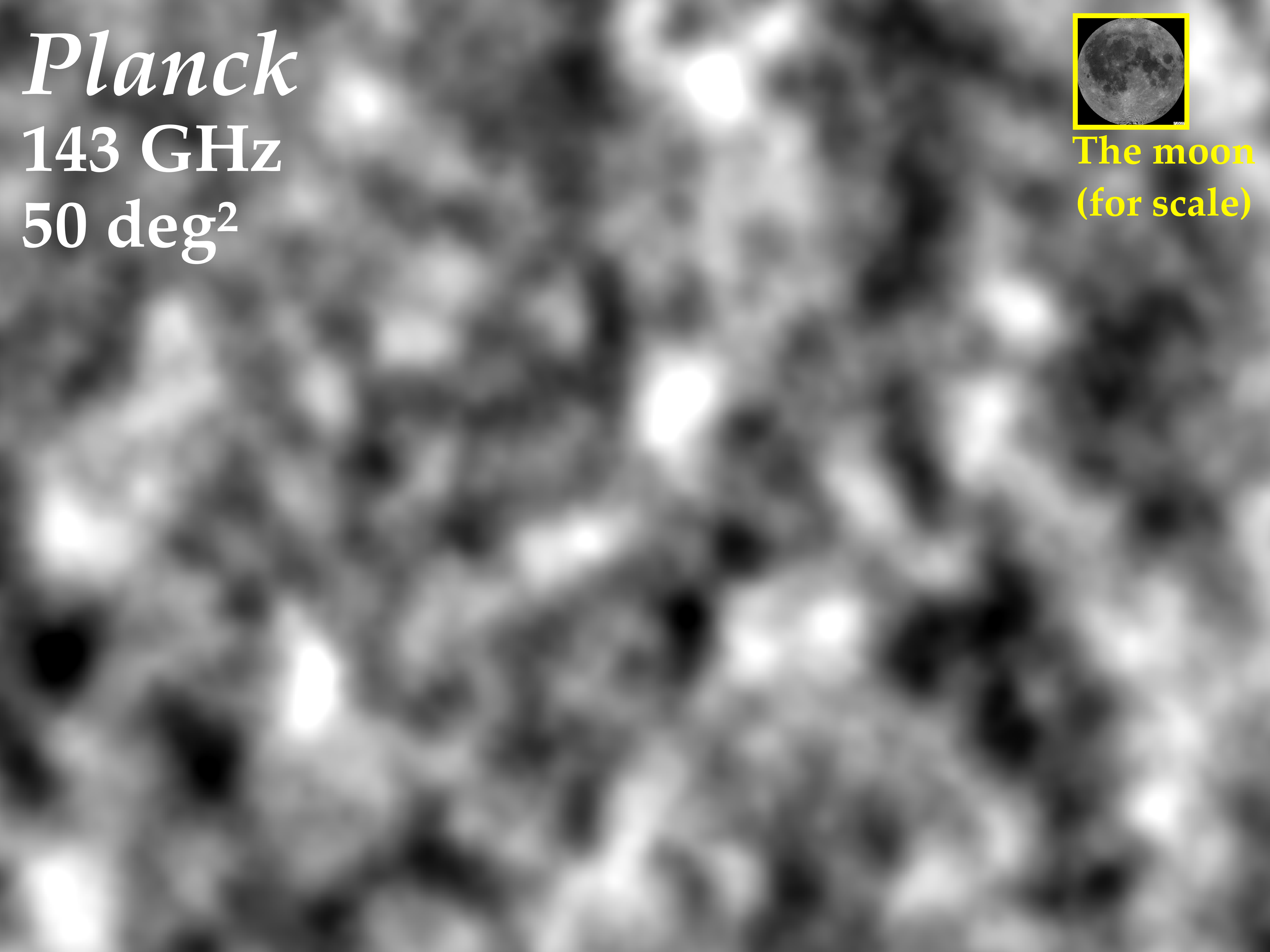
The South Pole has excellent conditions for mm-wave observations

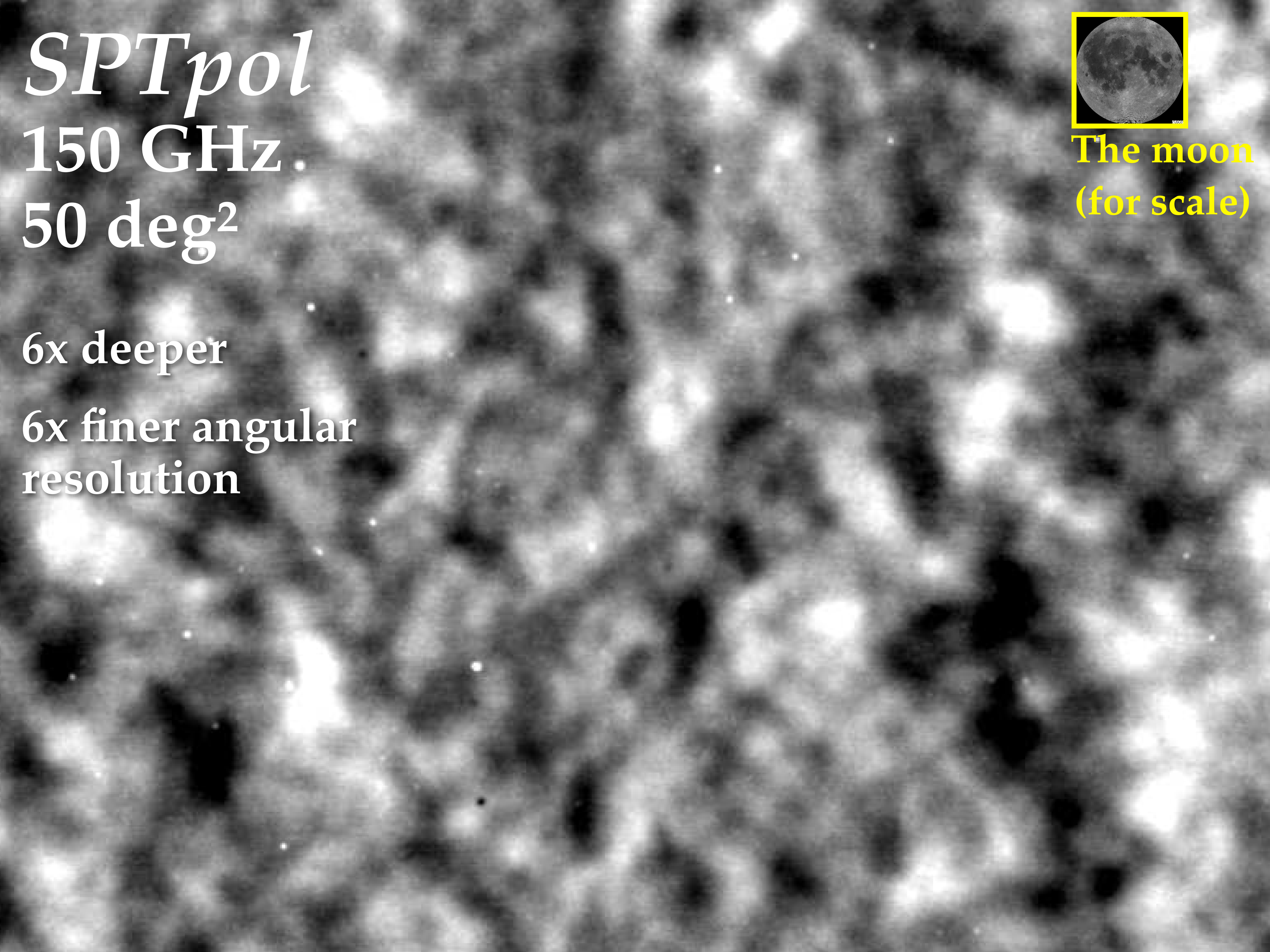
- Extremely dry
- High altitude (10,000 feet)
- Stable atmosphere during its 6-month long night

SPT Surveys

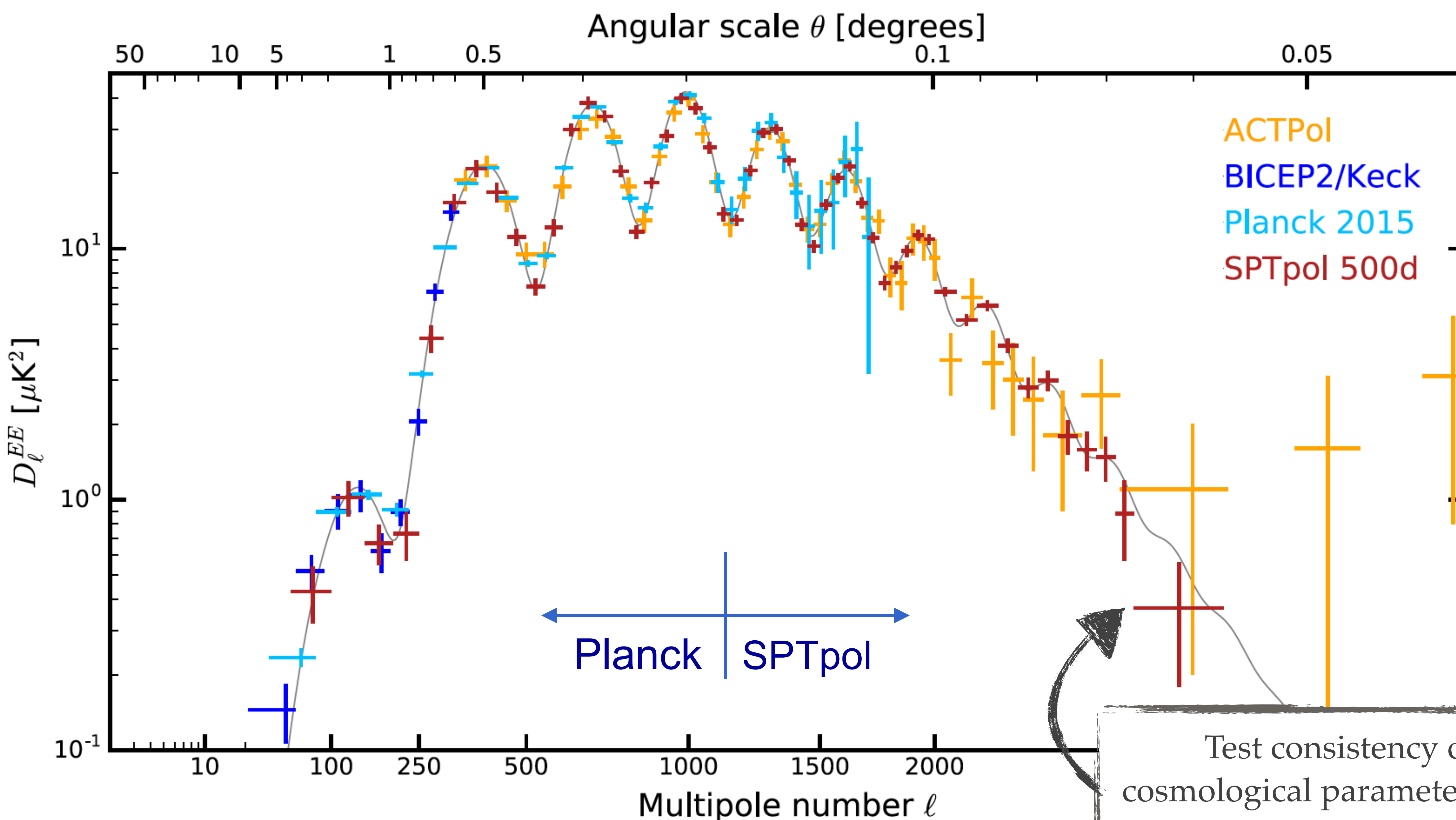


Background:
IRAS dust


Planck
143 GHz
50 deg²
The moon
(for scale)


SPTpol
150 GHz
50 deg²
6x deeper
6x finer angular resolution
The moon (for scale)

Low noise, high resolution: precision measurements of small scale fluctuations



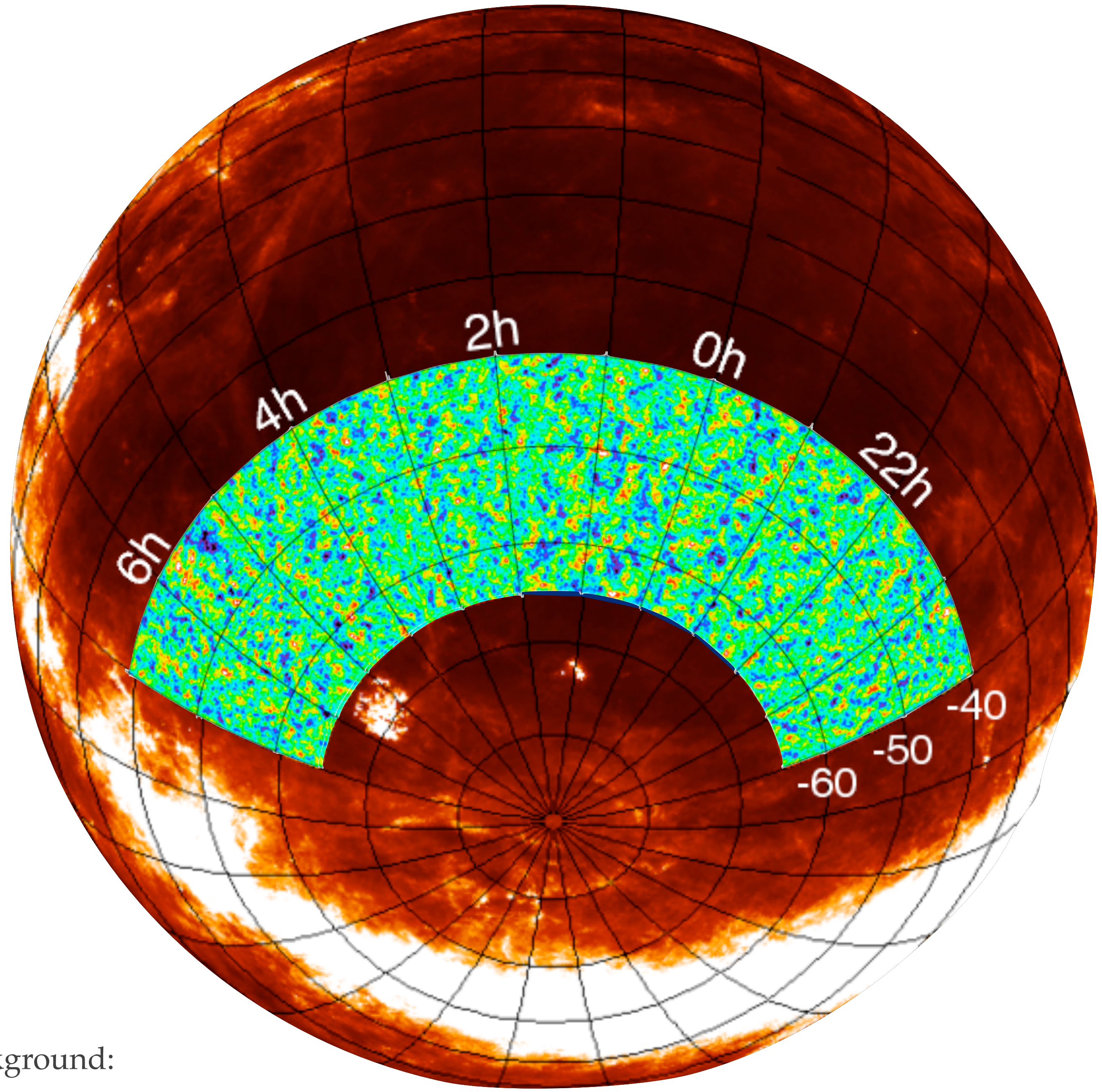
Test consistency of cosmological parameters with scales inaccessible by Planck

Is the H_0 tension due to Planck systematics?
Compare against independent measurements of the CMB.

Compare measurements between SPT-SZ and Planck

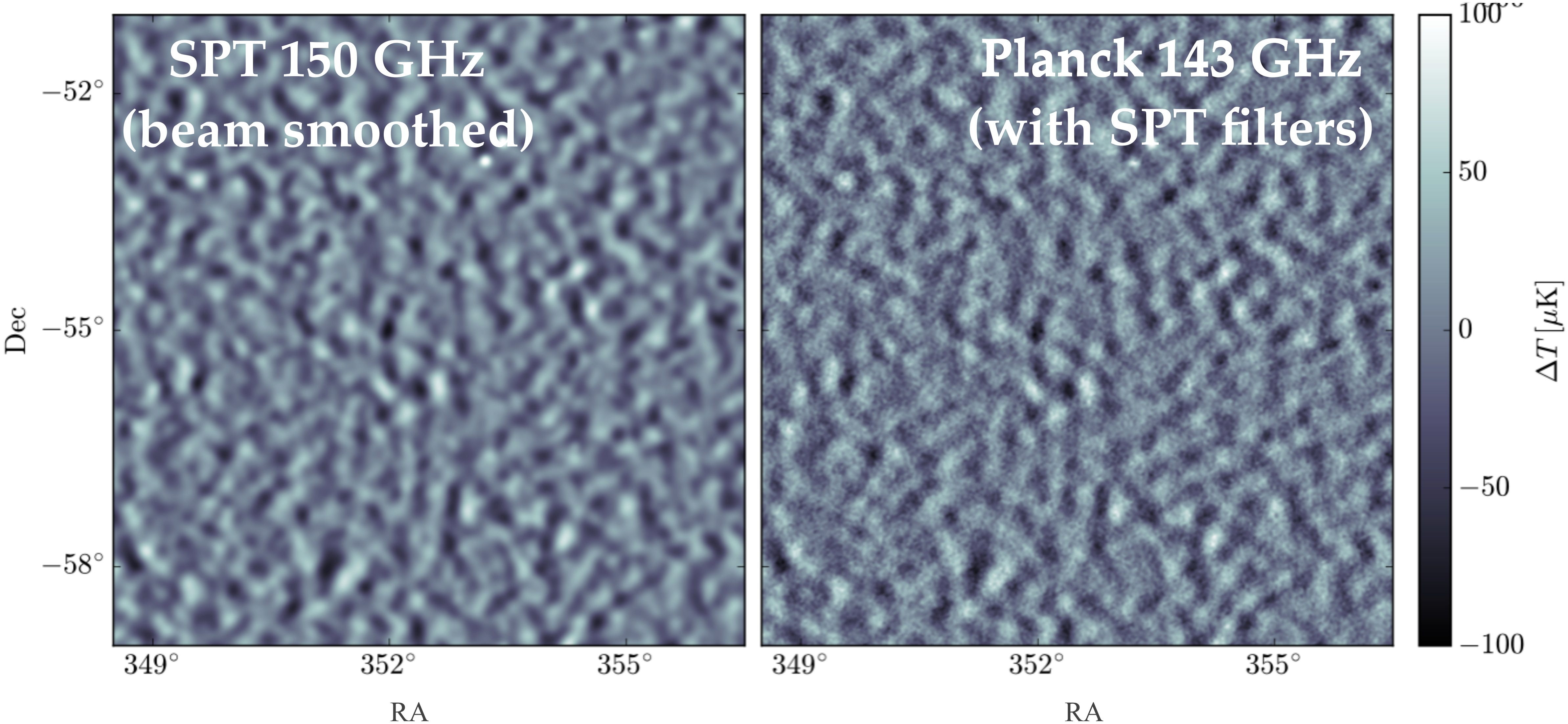
Compare SPT with Planck on the same patch over the same angular scales

- Planck full-sky vs SPT-SZ 2500sq. deg (~6% of sky)

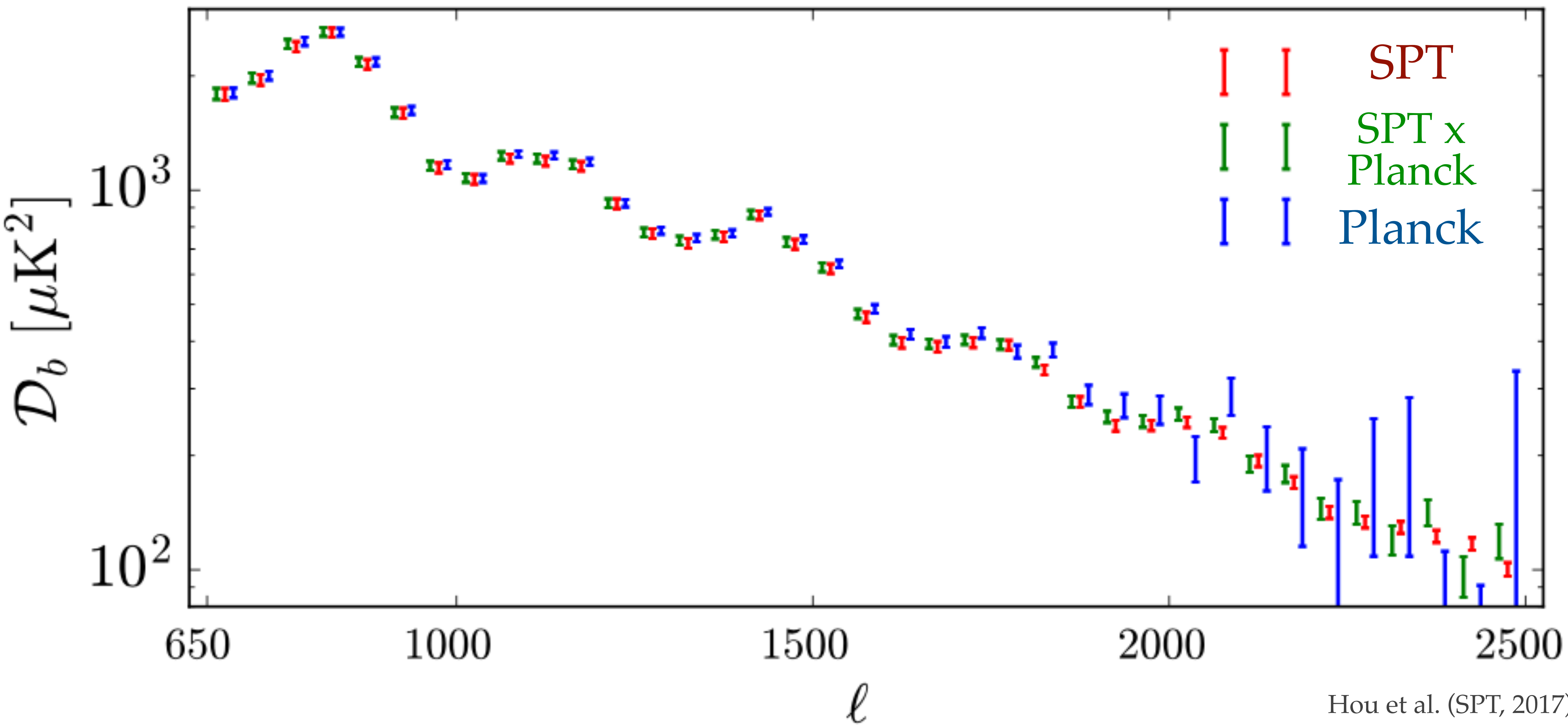


Background:
IRAS dust

Visual comparison of the same modes on sky



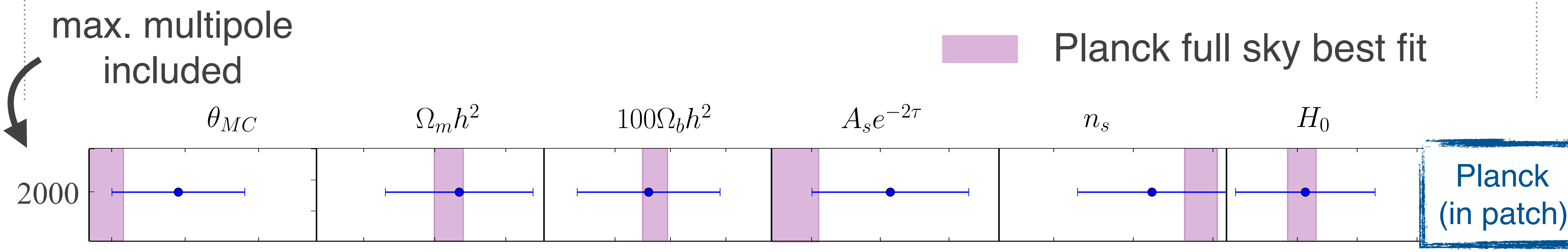
In-patch bandpowers

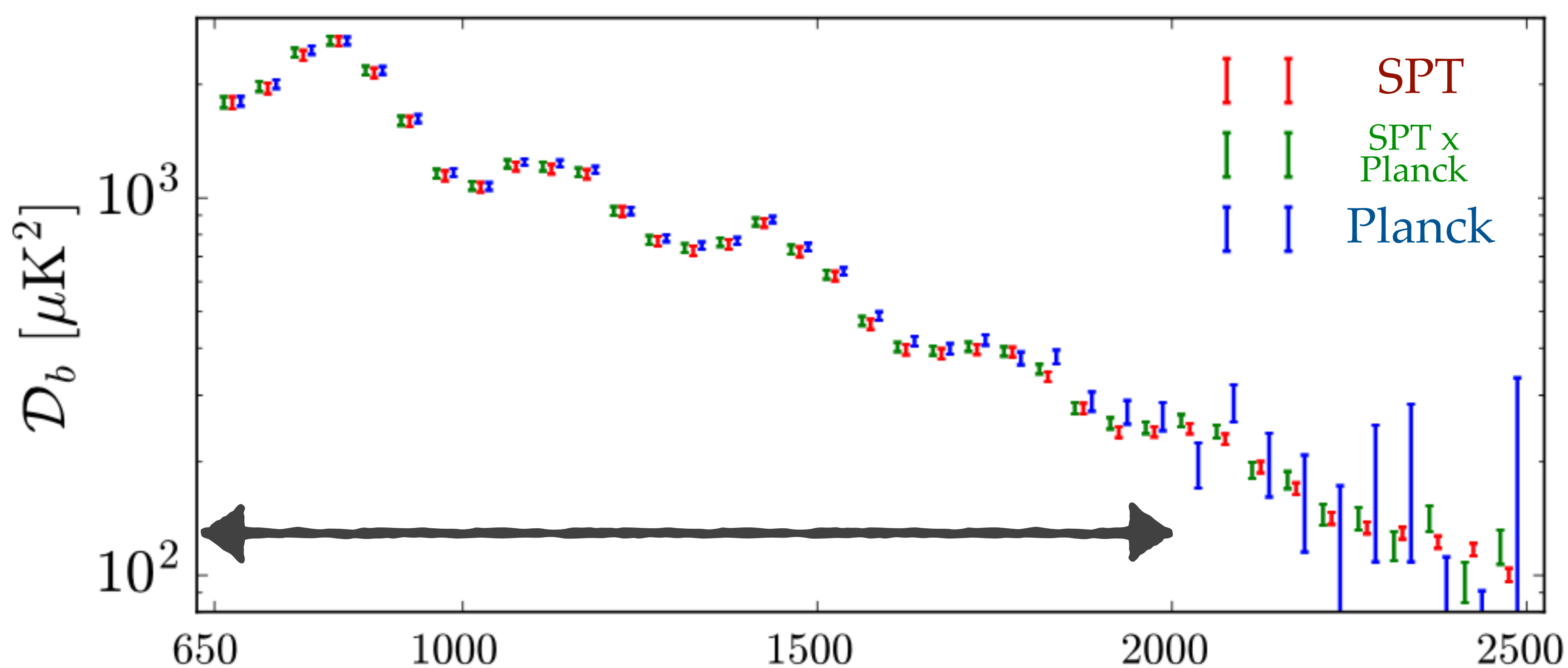


Hou et al. (SPT, 2017)

Bandpowers are statistically consistent amongst SPTxSPT, SPTxPlanck Planck-in-SPT-patch.

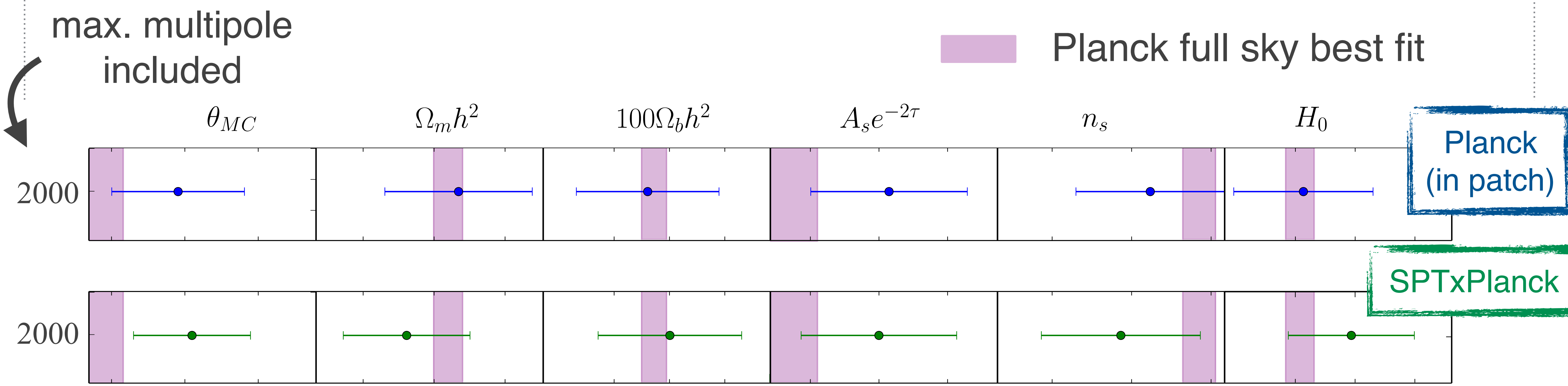
Parameters comparison of Planck vs SPT



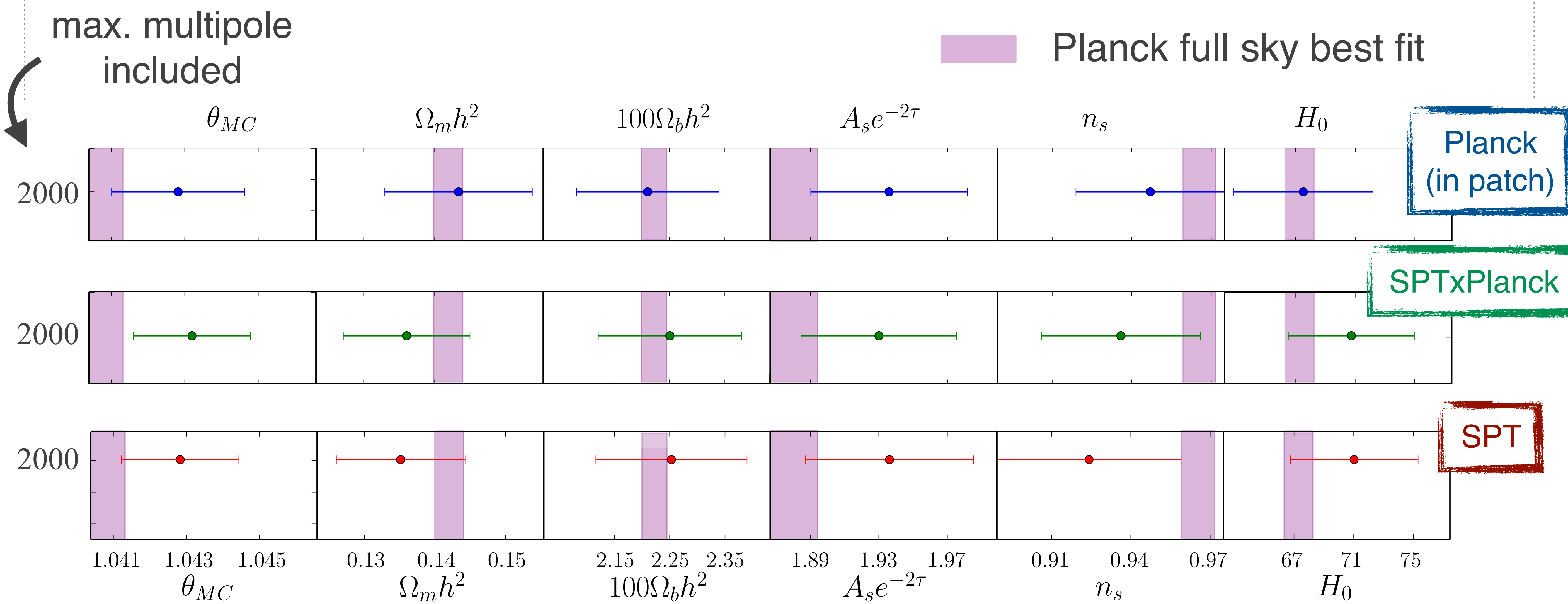


Planck Full Sky vs Planck in-patch —> changes in parameter best fits consistent with sample variance.

Parameters comparison of Planck vs SPT



Parameters comparison of Planck vs SPT



Aylor et al. (SPT, 2017)

Full sky vs individual splits are consistent.

In-patch bandpowers from two experiments are consistent with each other.

Parameter difference test

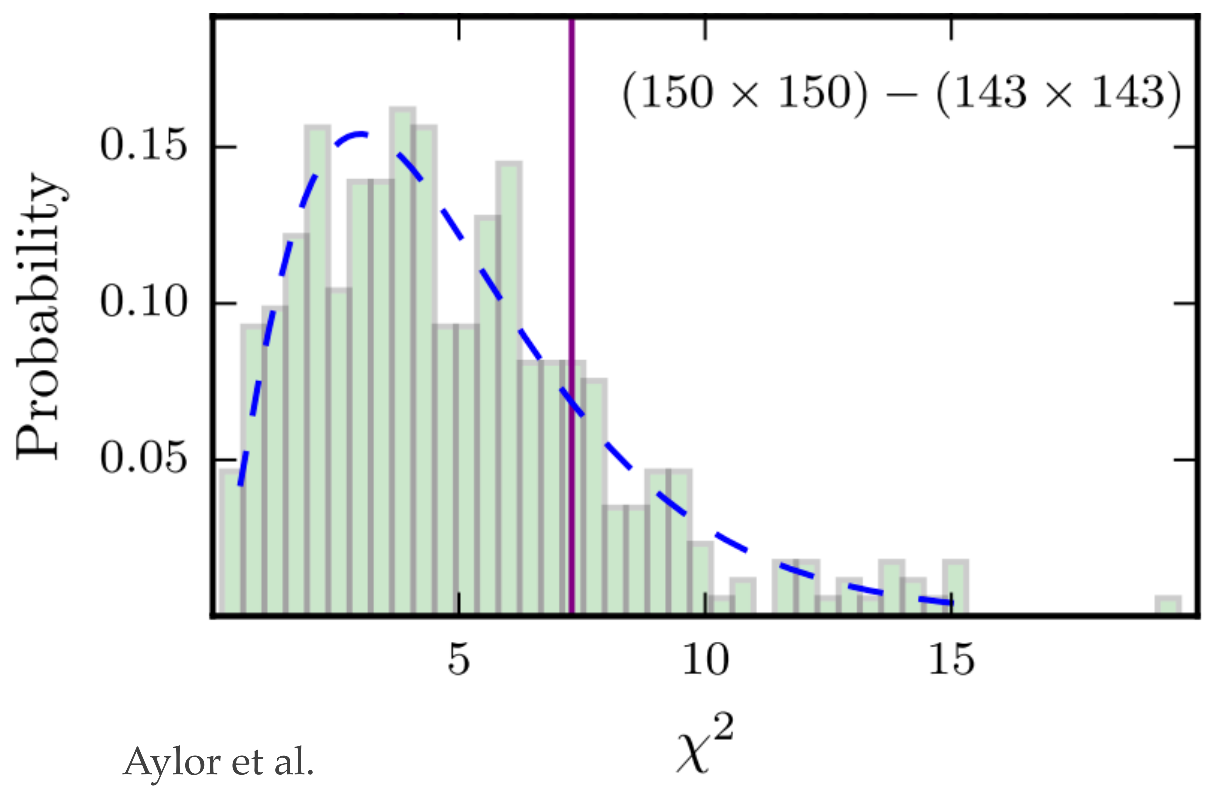
$$\chi^2 = \Delta\theta^T \mathbf{C}^{-1} \Delta\theta$$
$$\Delta\theta = \mathbf{p}_1 - \mathbf{p}_2$$

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

<u>5 parameter model</u>

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

SPT vs Planck-in-patch



Aylor et al.
(SPT, 1706.10286)

- If there are no systematics in either SPT nor Planck, parameter differences would come from noise fluctuations from each set. (*This removes sample variance*.)
- Data differences consistent with sim differences —> evidence against systematics in either Planck-in-patch or SPT and in the common multipole range.

Is it CMB systematics?

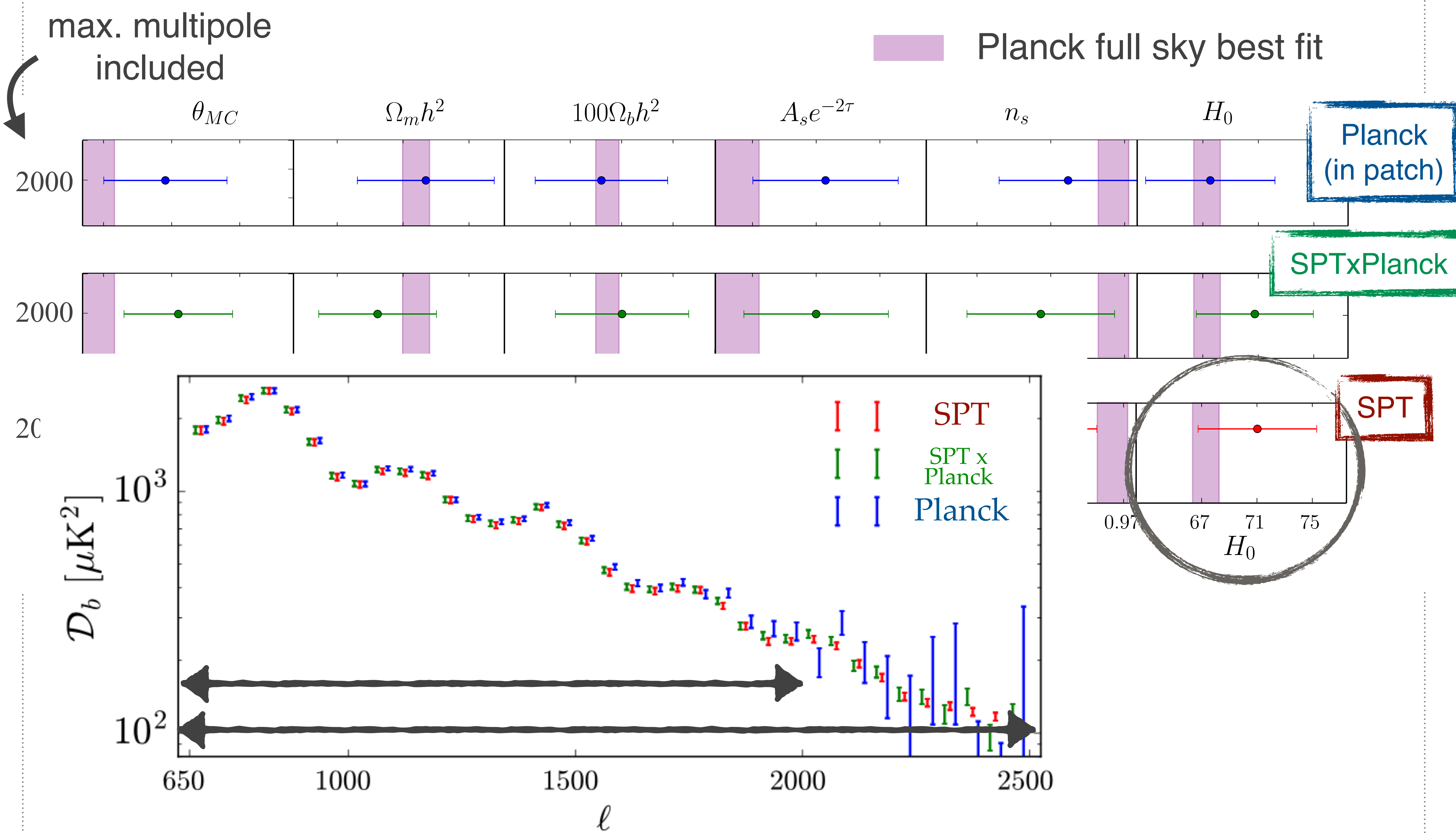
CMB fluctuations seen by both SPT and Planck are consistent with each other.

If there are systematics, they will most likely be

(1) outside the SPT patch,

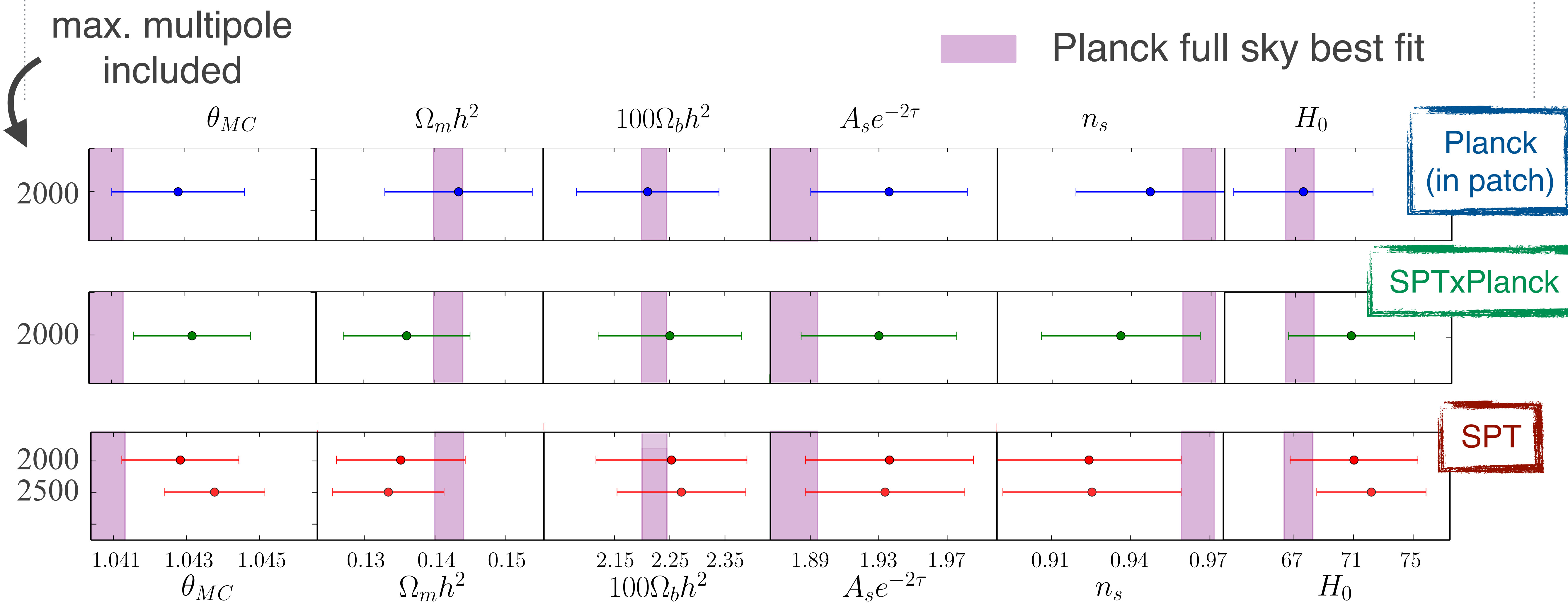
(2) outside the common multipole range of SPT and Planck.

Trends in SPT bandpowers?

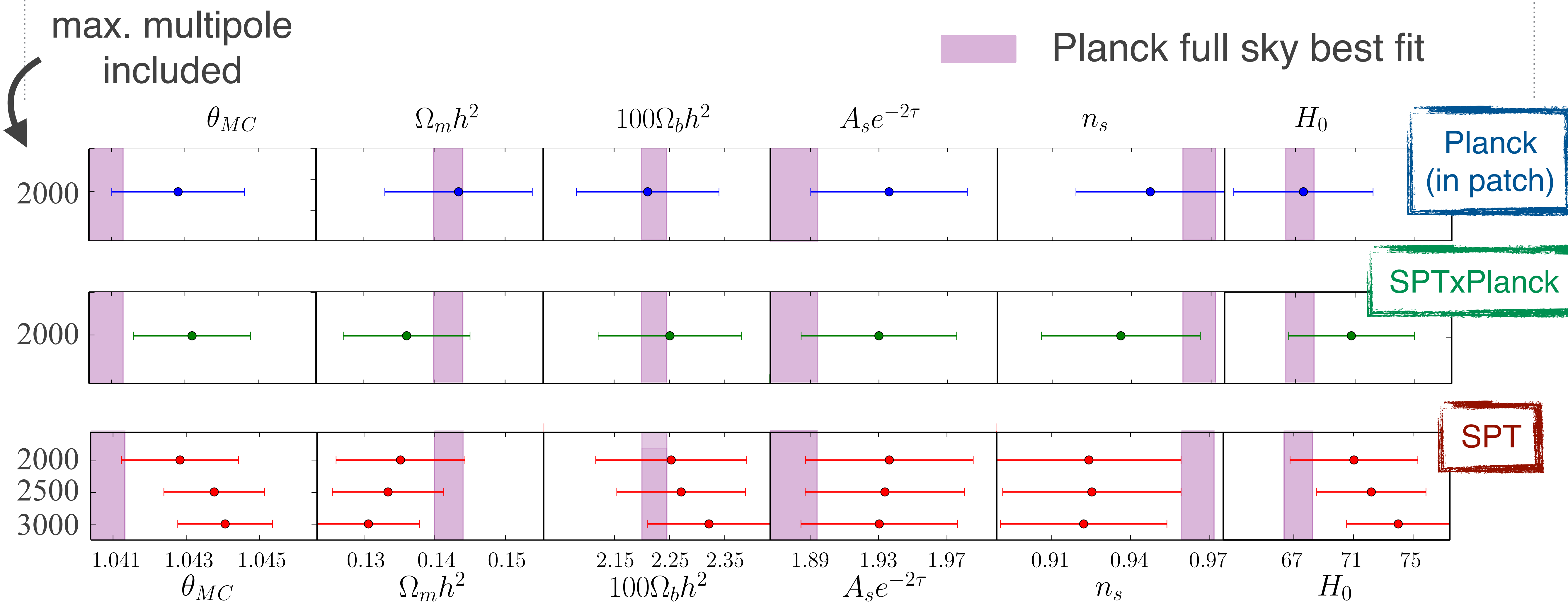


Kimmy Wu, KICP/UChicago

Trends in SPT bandpowers?

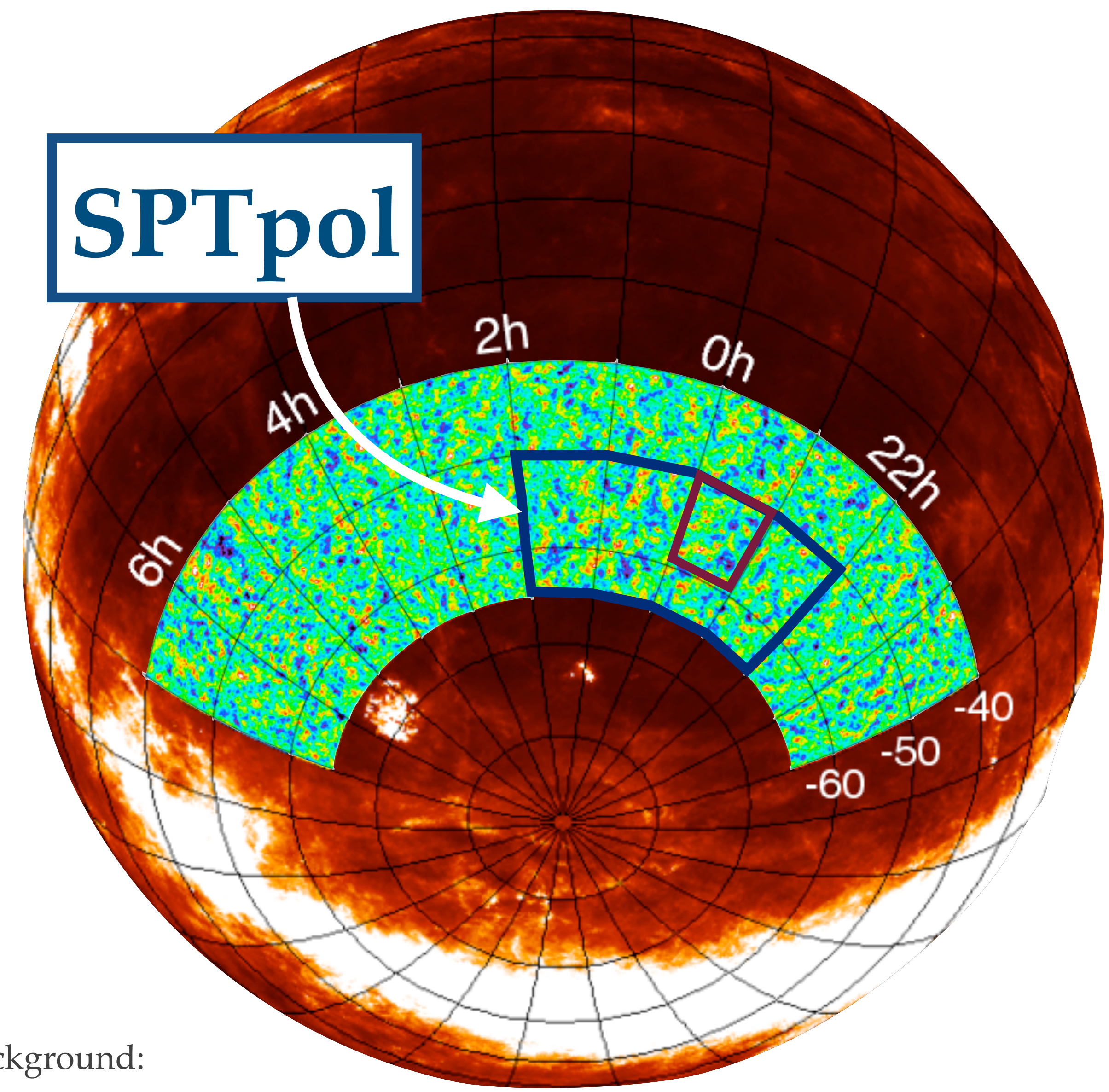


Trends in SPT bandpowers?

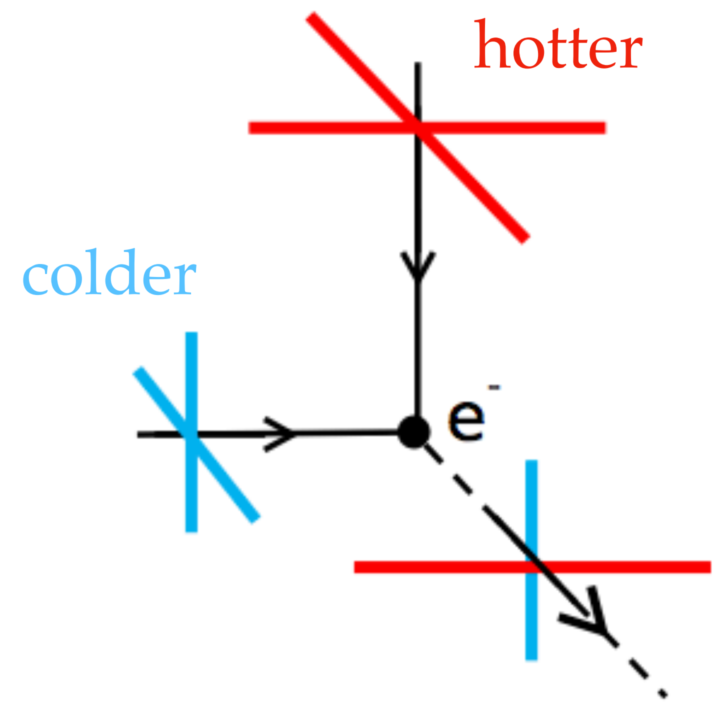


Trend of parameter shifts (e.g. H_0) in SPT as more small scales (higher ell) information are included.

Is it new physics??

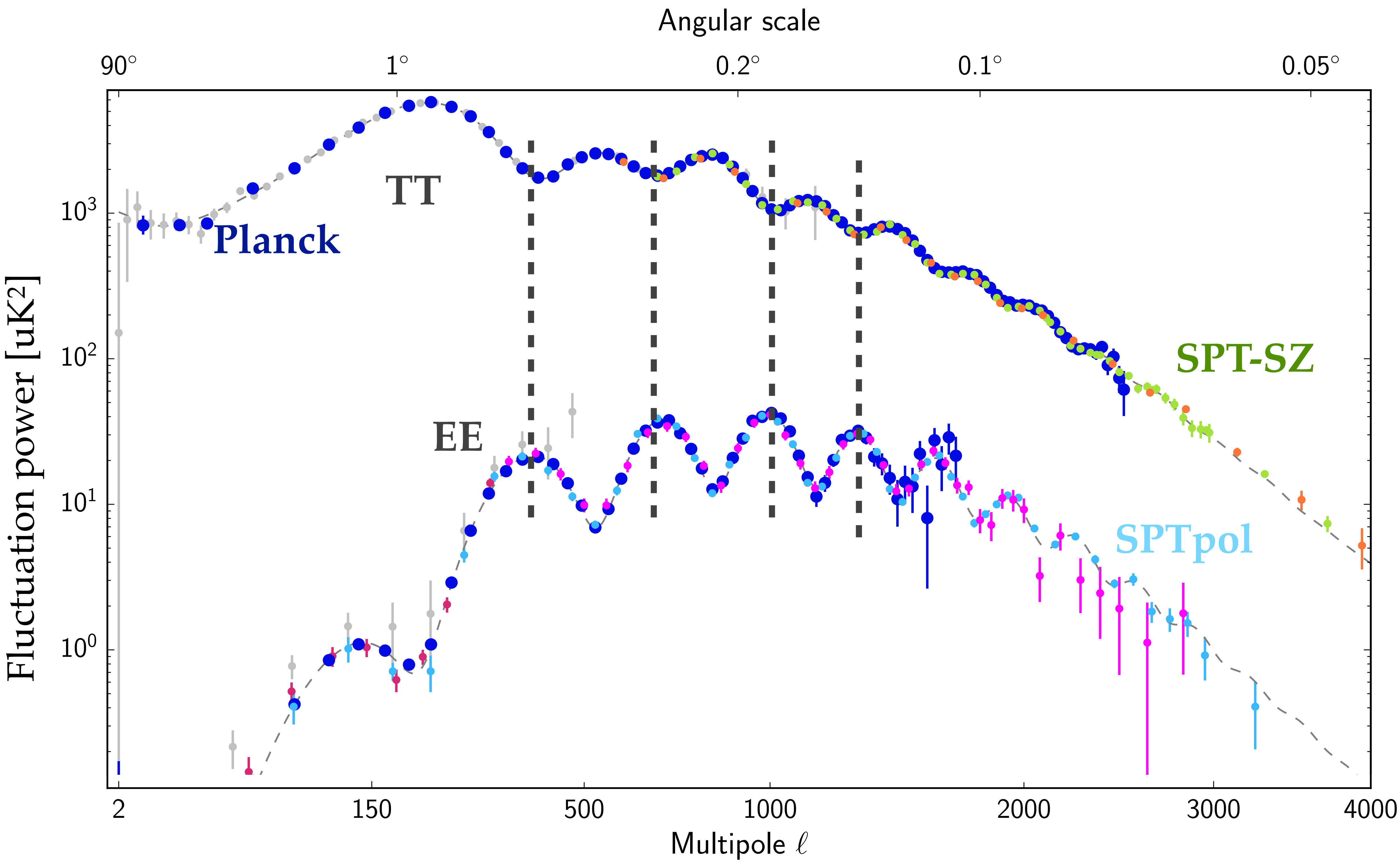


Background:
IRAS dust

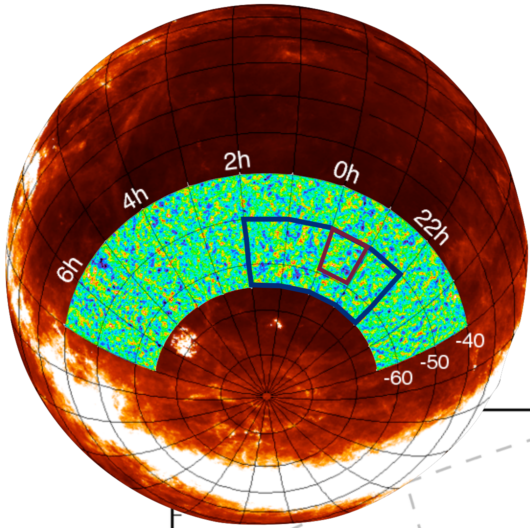


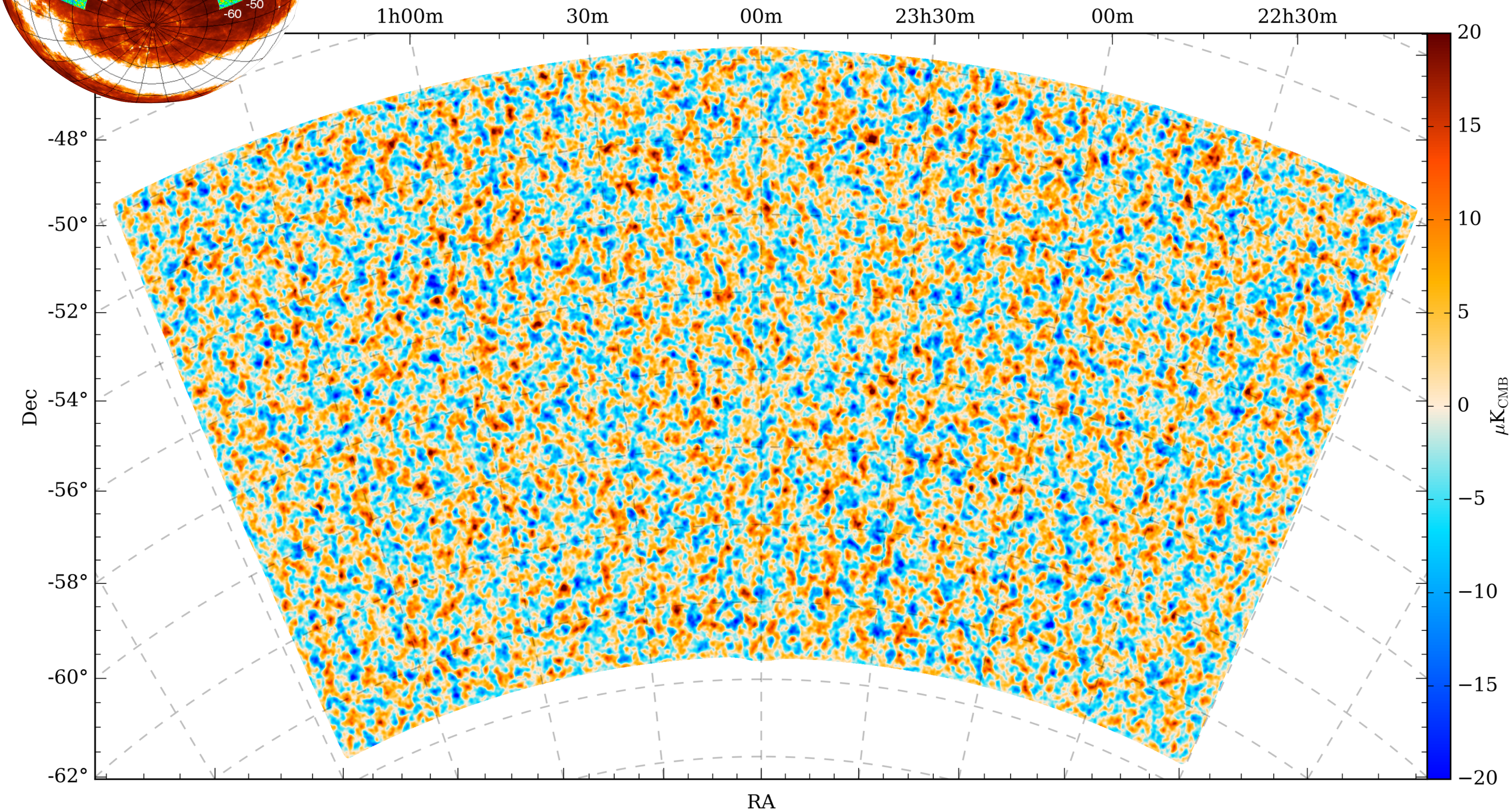
Test with
CMB polarization!

How does having polarization help?



SPTpol E-mode map





150GHz; Smoothed by 4 arcmin FWHM Gaussian; deepest sub-degree polarization map to date.

Henning et. al (SPT, 1707.09353)

Is it new physics??

If we see similar trends in polarization…

it can be new physics,

it can be systematics affecting T/E spectra similarly.

If we don’t see similar trends in polarization…

it can be systematics in either T or E or both,

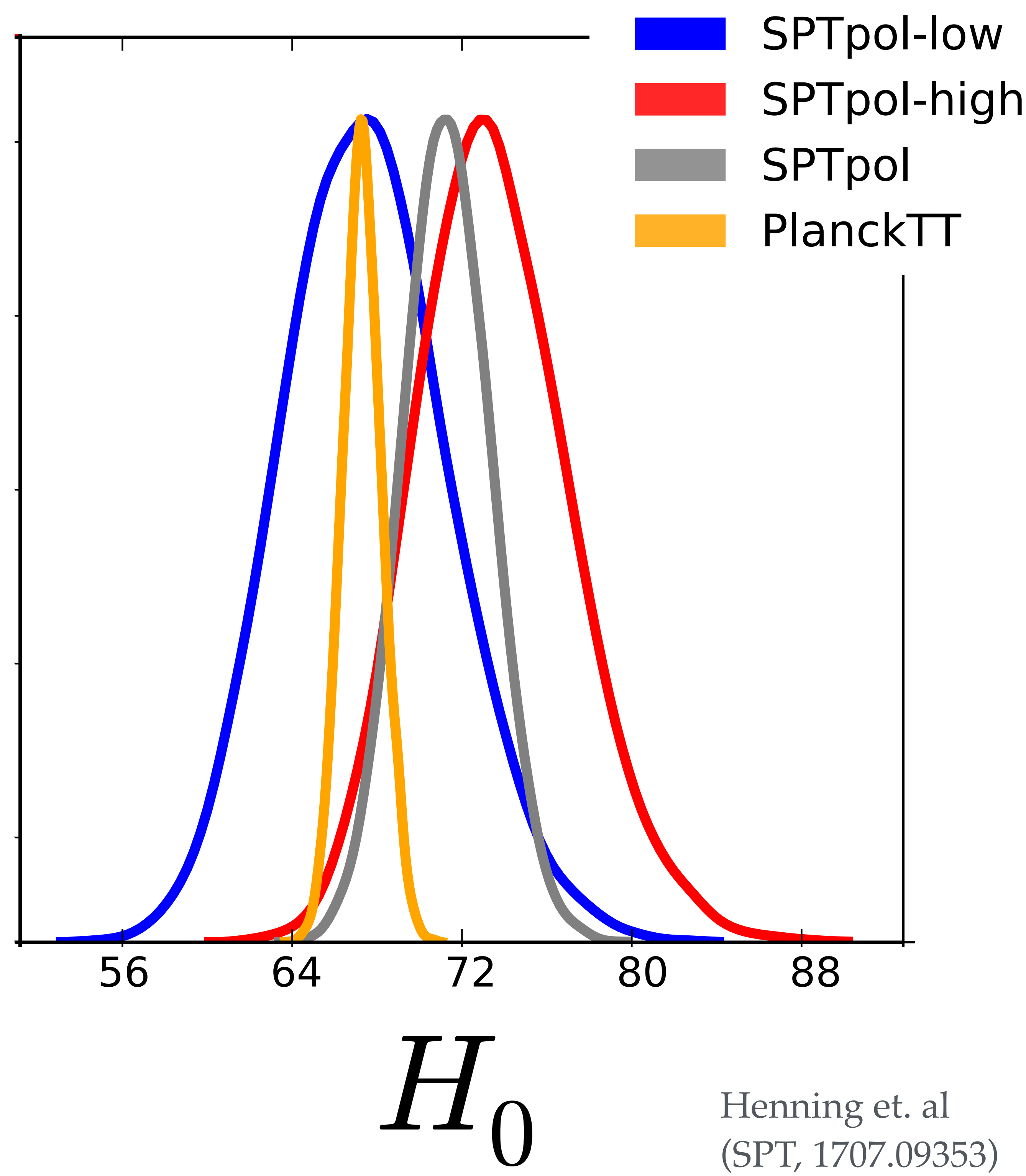
it can be new physics that is observable only in T or E.

SPTpol H_0 Trend

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

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

Like from SPT-SZ, we see a trend of increasing H_0 when including more small scales: need lower noise small scale measurements to further investigate if this is real! (SPT-3G and AdvACT)



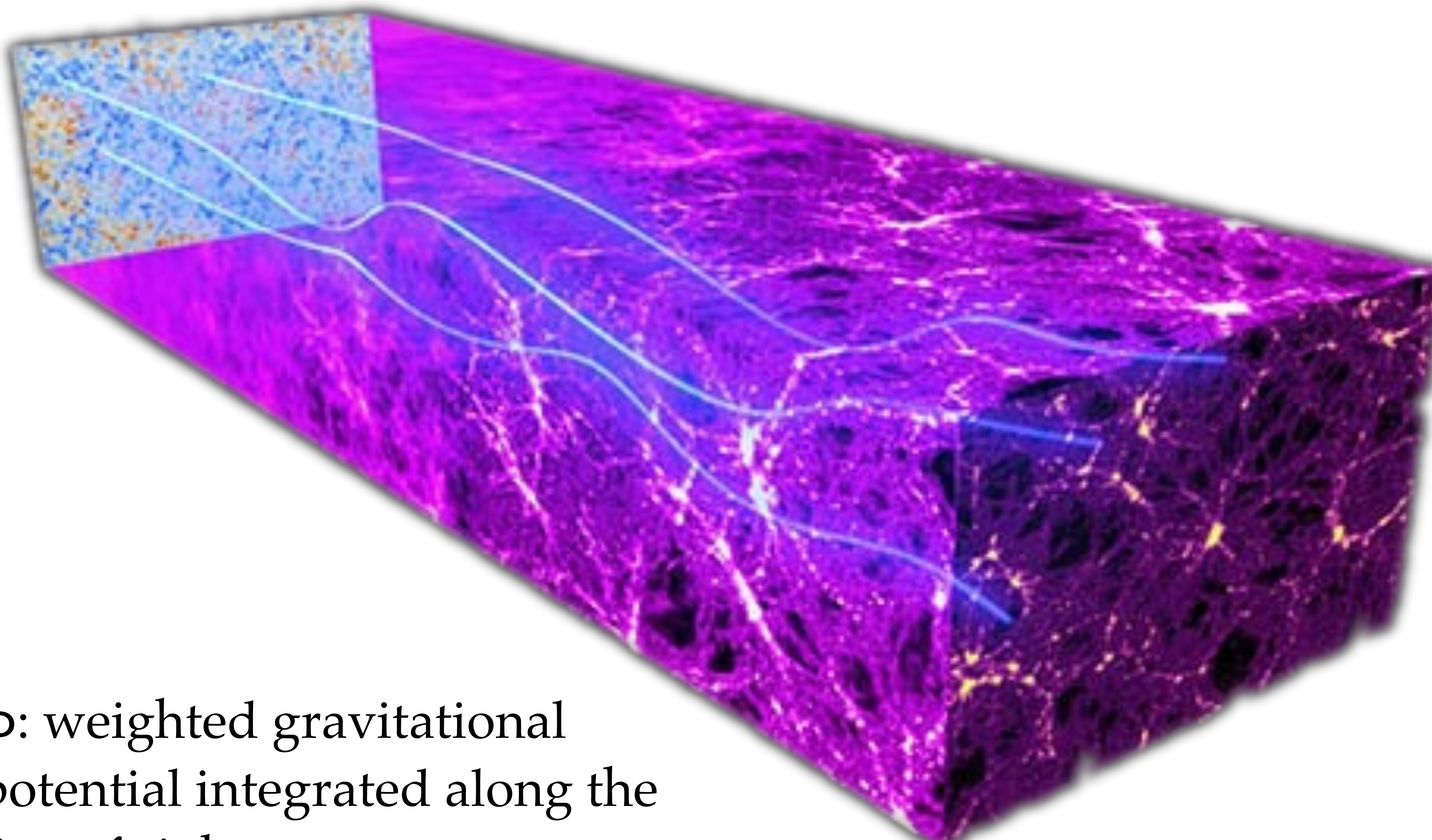
Henning et. al (SPT, 1707.09353)

Late-time* cosmology from gravitational lensing

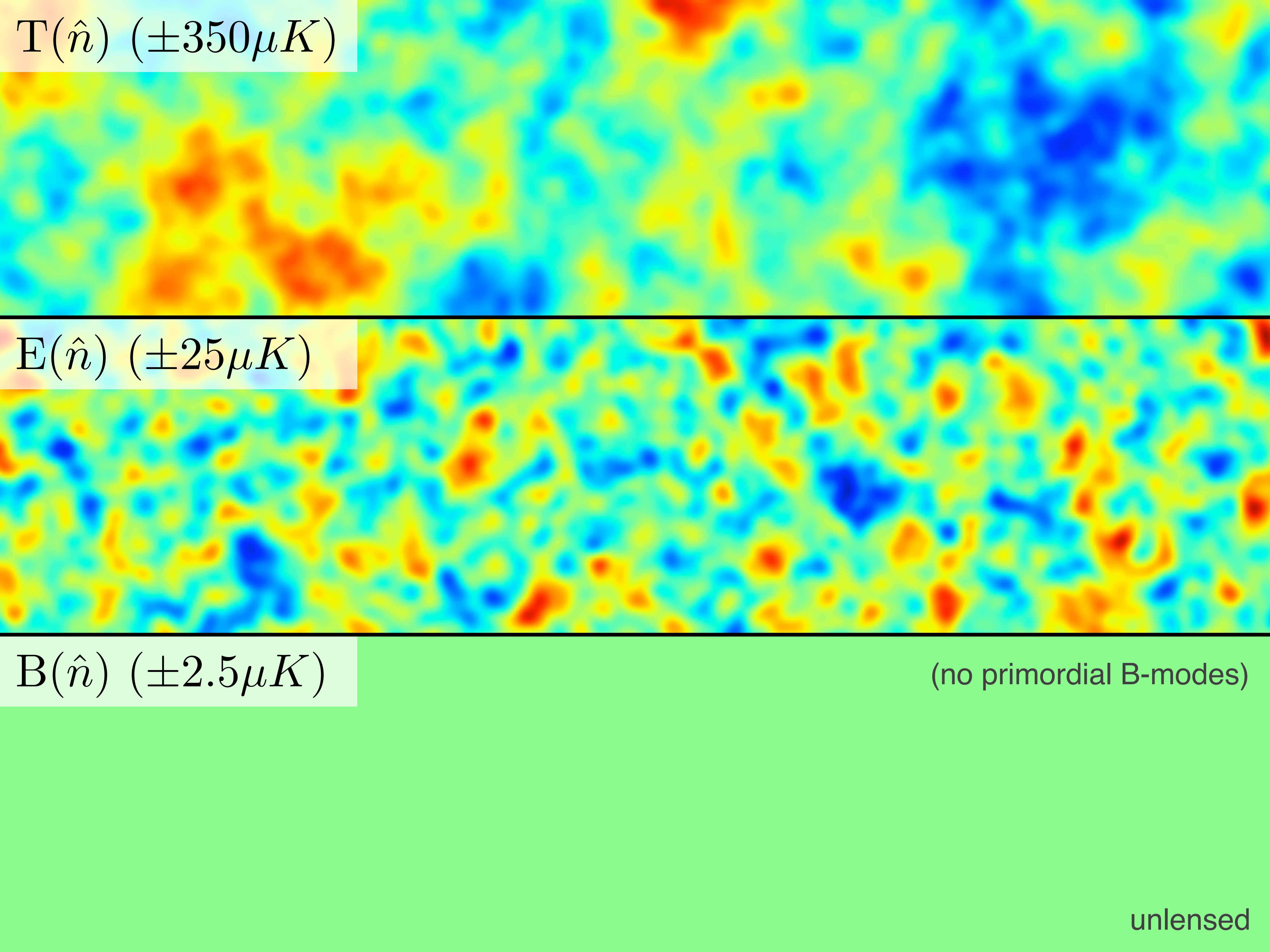
*z~2

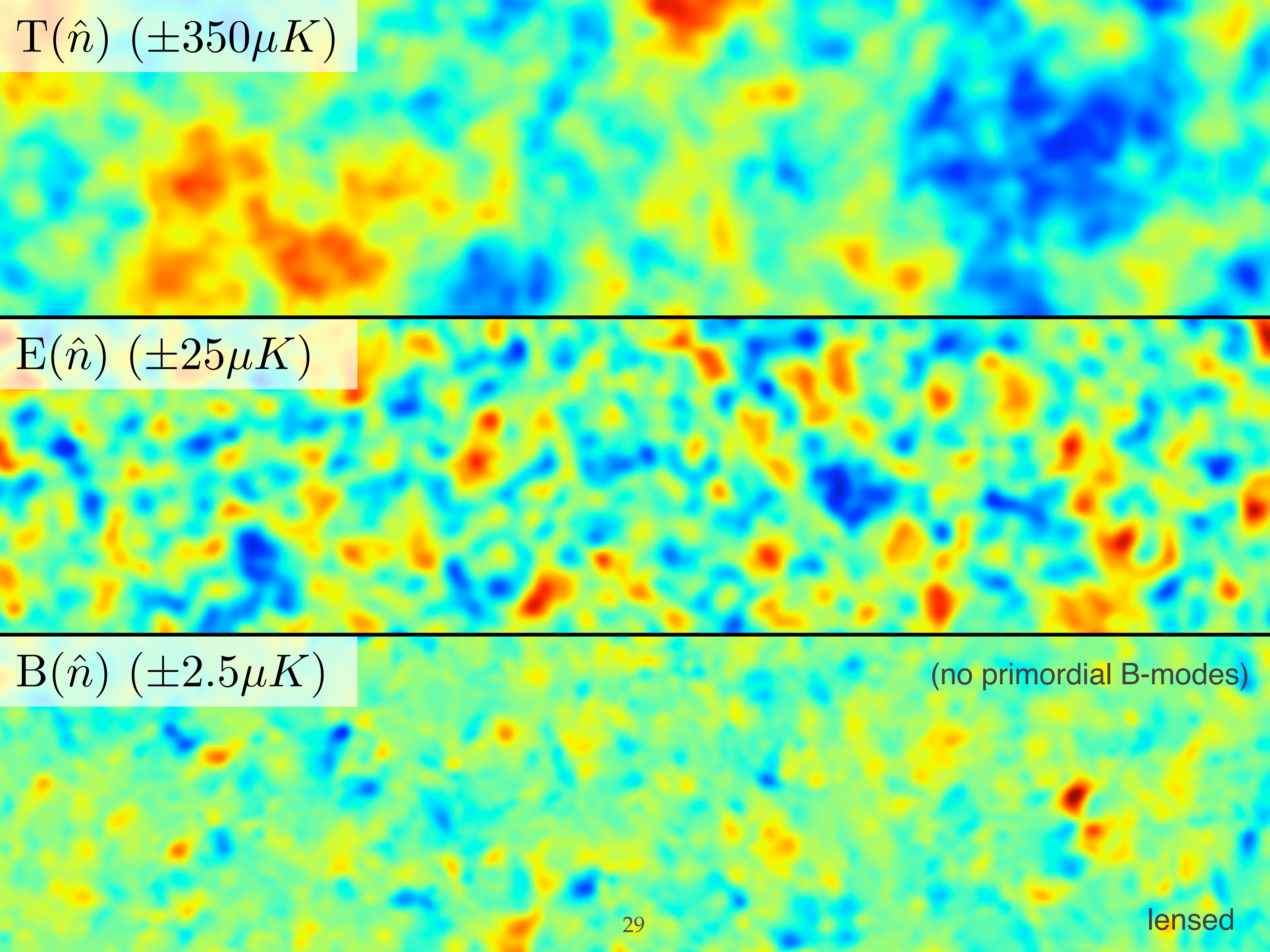
Lensing of the CMB

$$\text{lensed field}(\hat{n}) = \text{unlensed field}(\hat{n} + \nabla\phi)$$

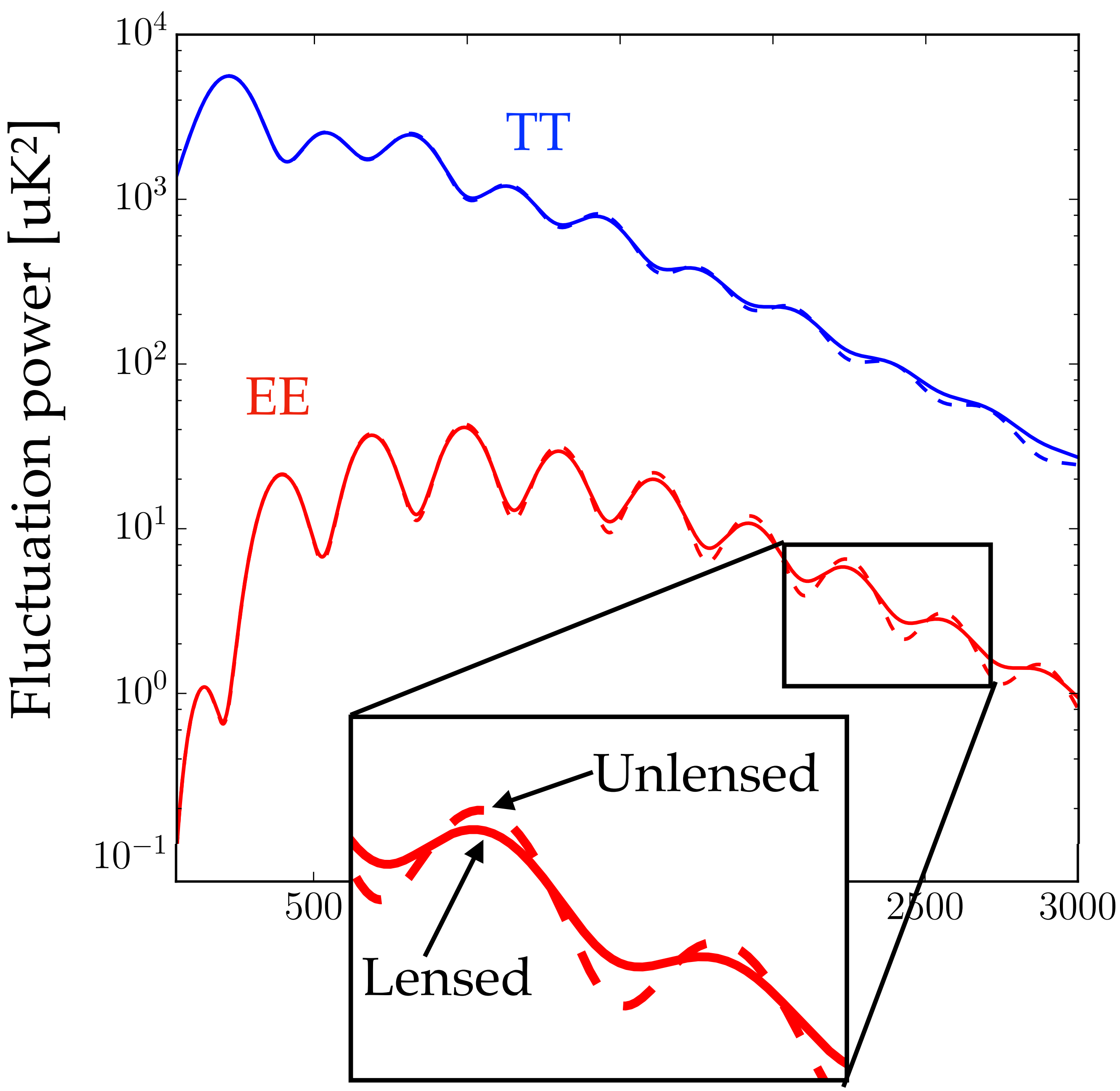


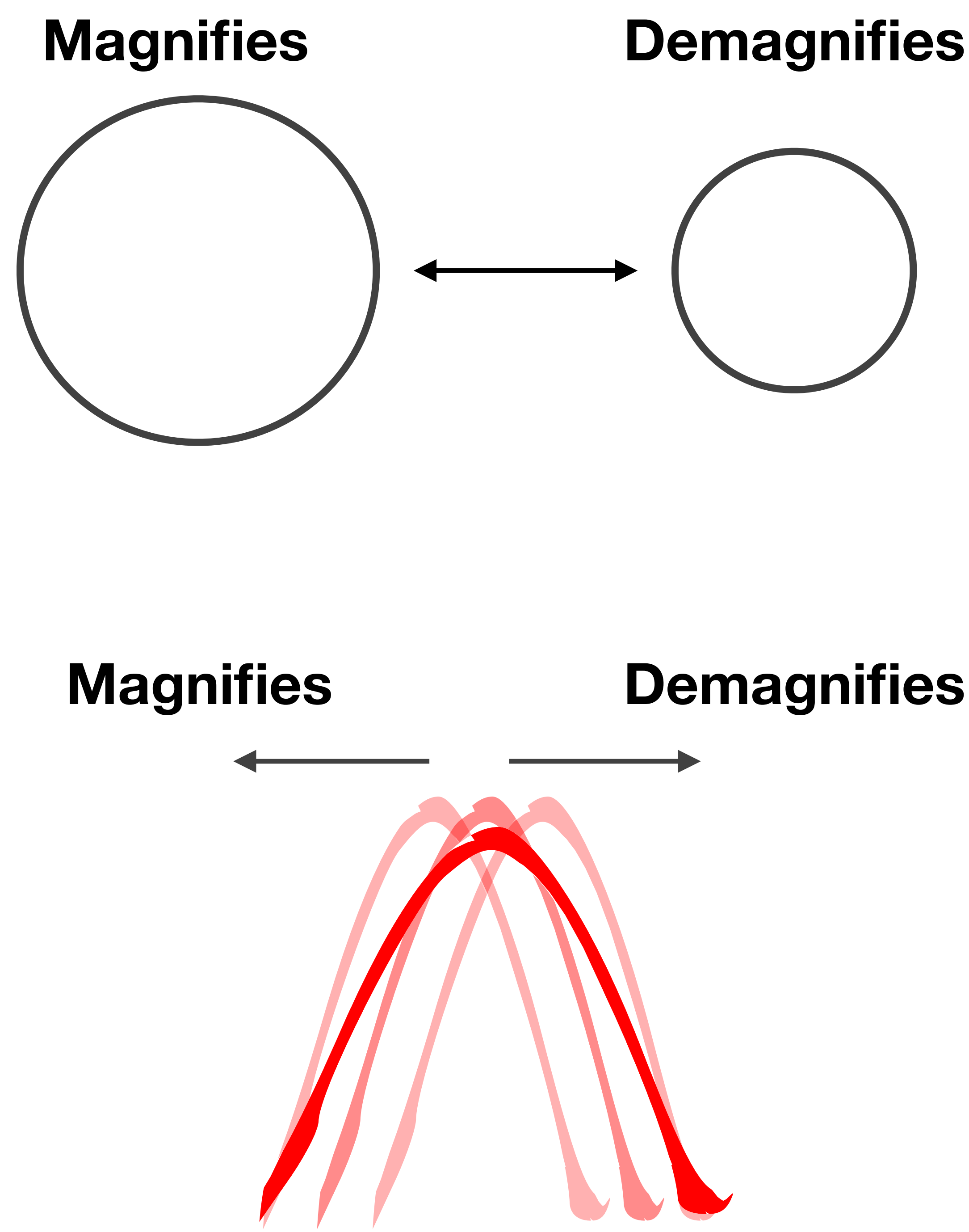
ϕ: weighted gravitational potential integrated along the line of sight


T($\hat{n}$) ($\pm 350\mu K$)
E($\hat{n}$) ($\pm 25\mu K$)
B($\hat{n}$) ($\pm 2.5\mu K$)
(no primordial B-modes)
unlensed

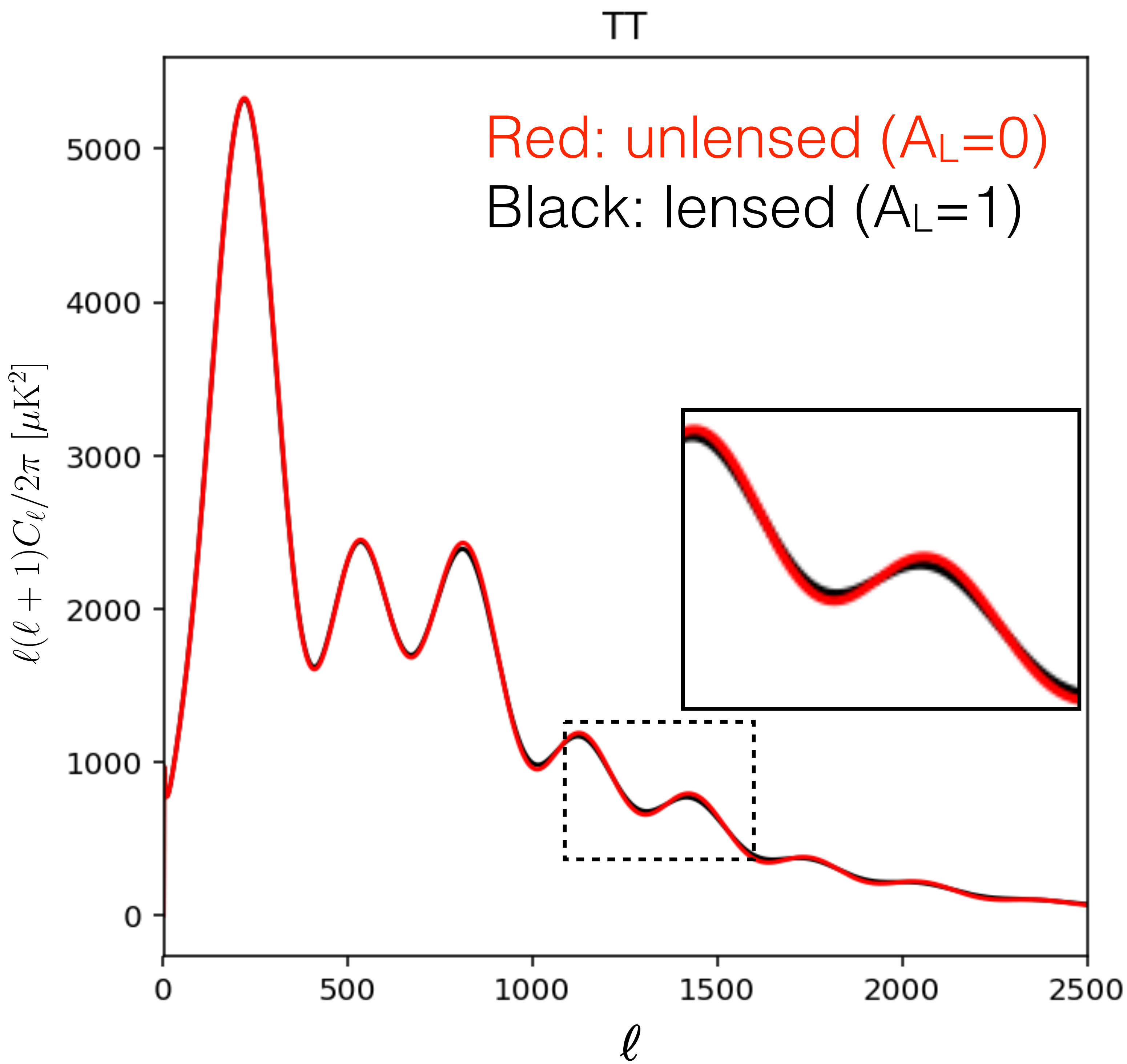

$T(\hat{n})$ ($\pm 350\mu K$)
$E(\hat{n})$ ($\pm 25\mu K$)
$B(\hat{n})$ ($\pm 2.5\mu K$)
(no primordial B-modes)
lensed

(De)magnification in map = smoothing of peaks in spectra





What is the A_{lens} tension?



A_L: unphysical parameter that controls peak smoothing

The amount of peak smoothing measured in the Planck spectra is 2.8σ higher than the A_L=1 expectation.

Kimmy Wu, KICP/UChicago

If we directly measure the integrated gravitational potential from lensed CMB maps,
is that lensing amplitude consistent with LCDM expectation?

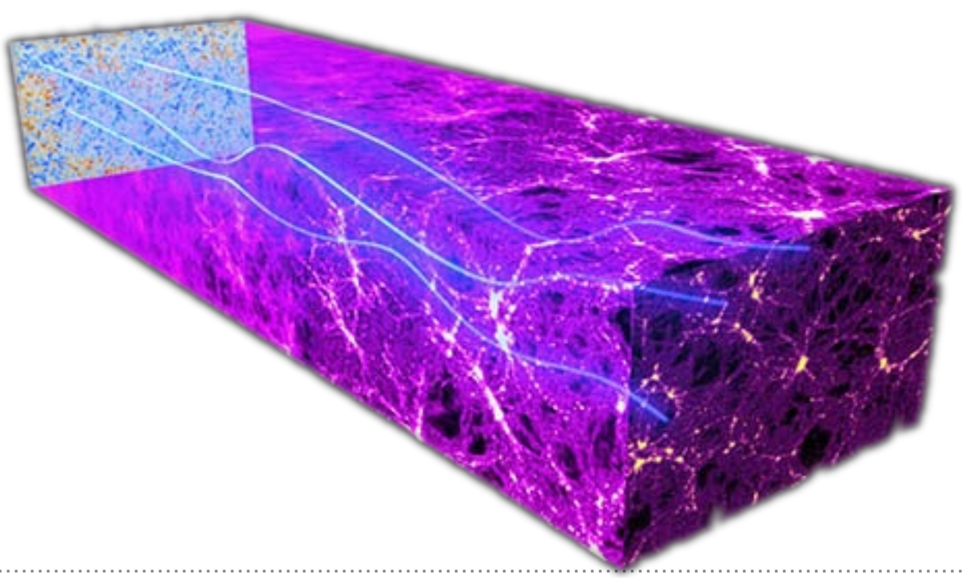
Lensing introduces off-diagonal correlations in CMB map covariances

$$\langle x(\boldsymbol{\ell}) x'(\boldsymbol{\ell}') \rangle_{\mathrm{CMB}} = f_\alpha(\boldsymbol{\ell}, \boldsymbol{\ell}') \phi(\boldsymbol{L})$$

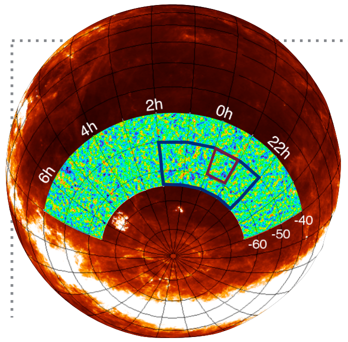
$$x, x' = T, E, B$$

$$\boldsymbol{L} = \boldsymbol{\ell} + \boldsymbol{\ell}'$$

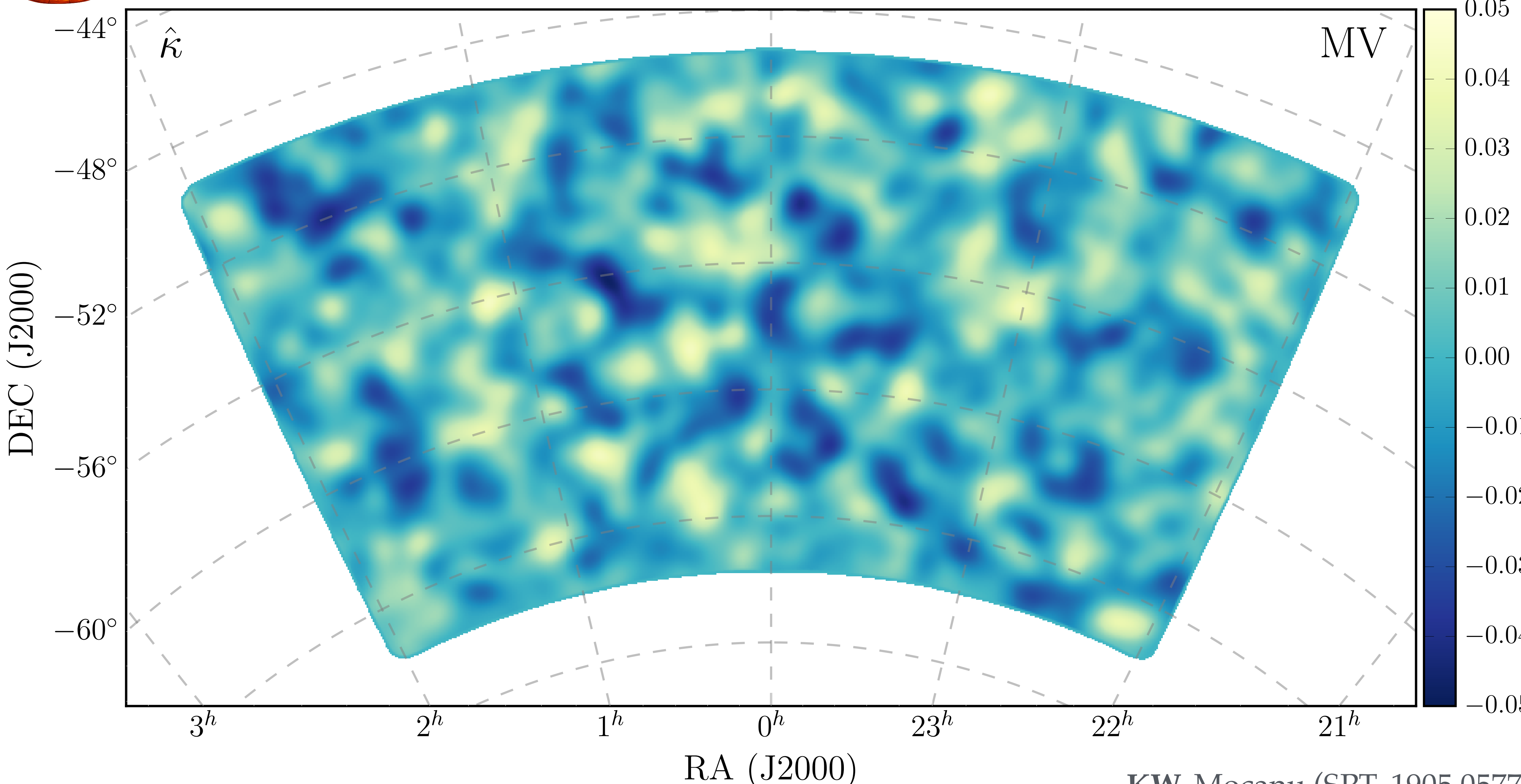
functions of unlensed T/E/B spectra



We can use the off-diagonal correlations to reconstruct ϕ!



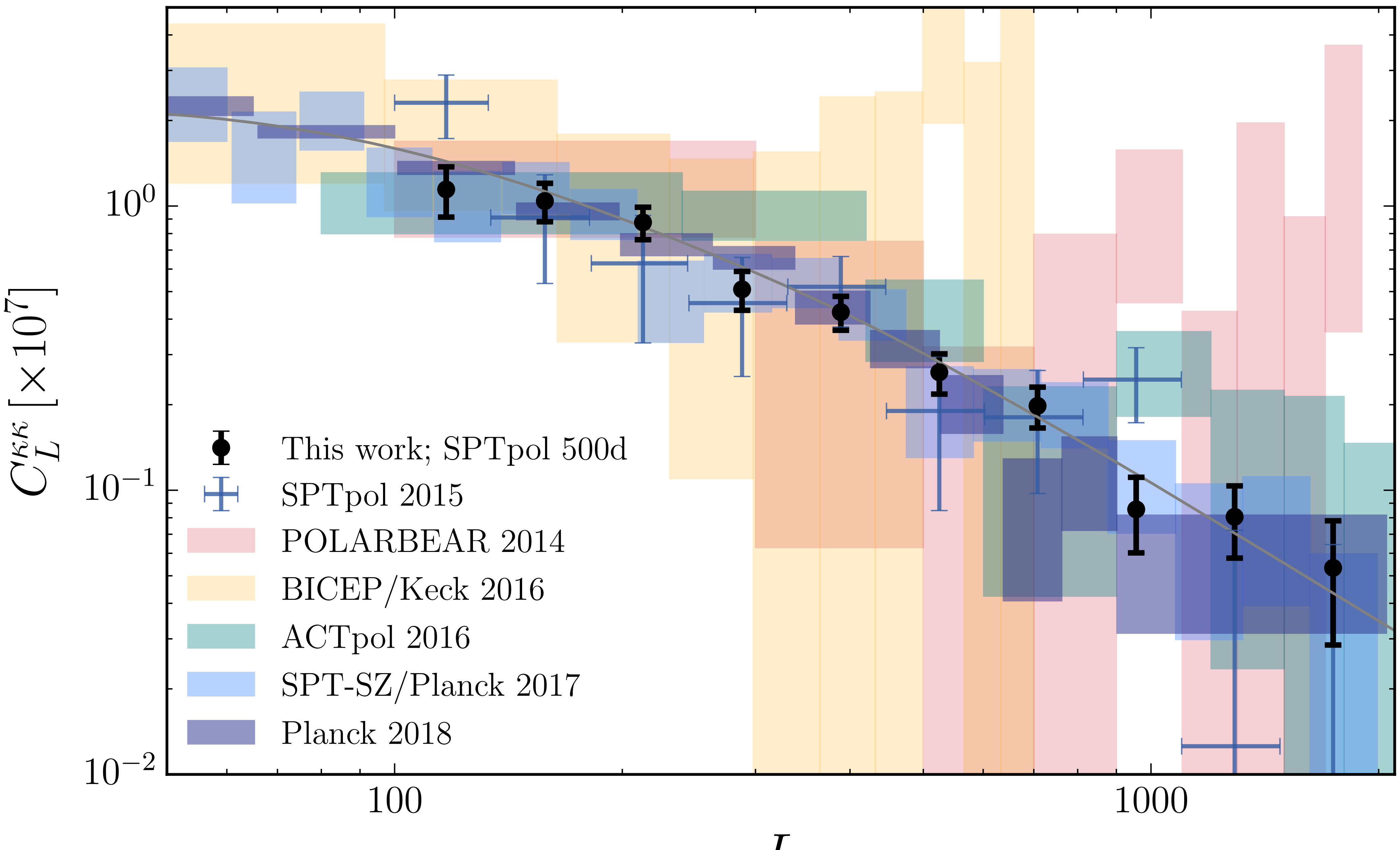
SPTpol lensing convergence map



KW, Mocanu (SPT, 1905.05777)

150GHz; Smoothed by 1 degree FWHM Gaussian; deepest lensing map to date.

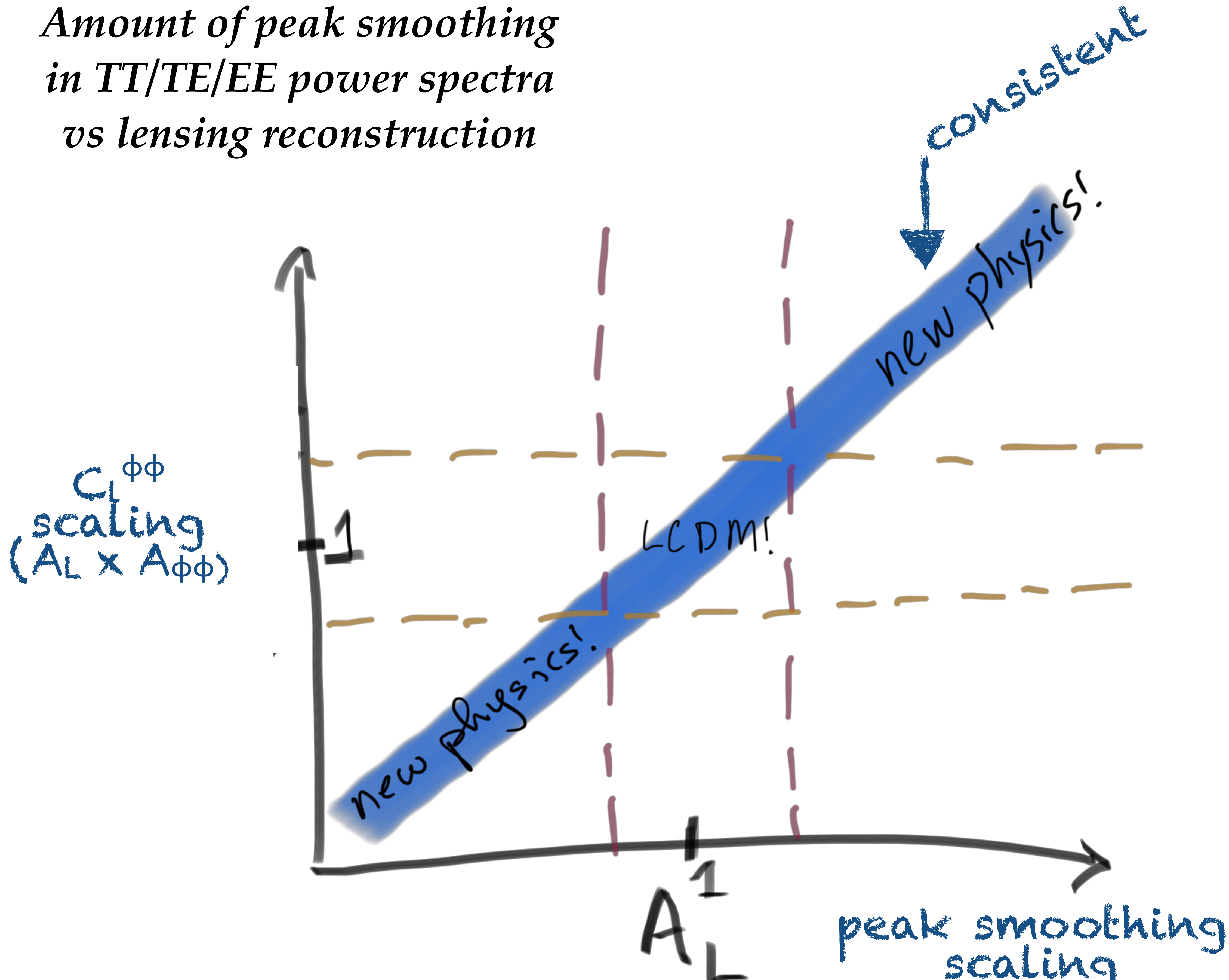
Is the lensing power spectrum consistent with LCDM parameters from TT/TE/EE power spectra?



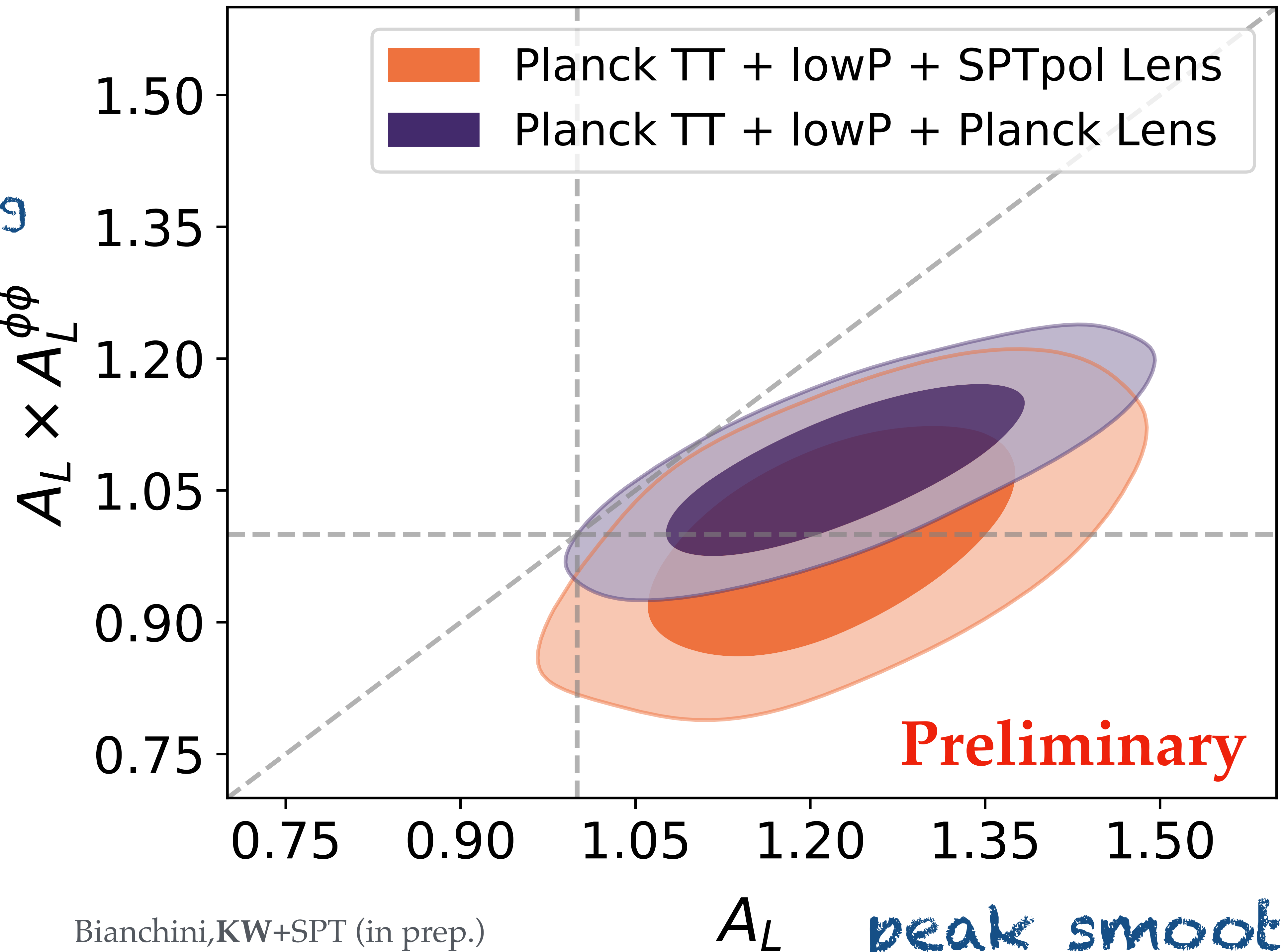
KW, Mocanu (SPT, 1905.05777)

Test with artificially scaling the lensing spectrum.

Amount of peak smoothing in TT/TE/EE power spectra vs lensing reconstruction



Lensing is consistent with LCDM prediction



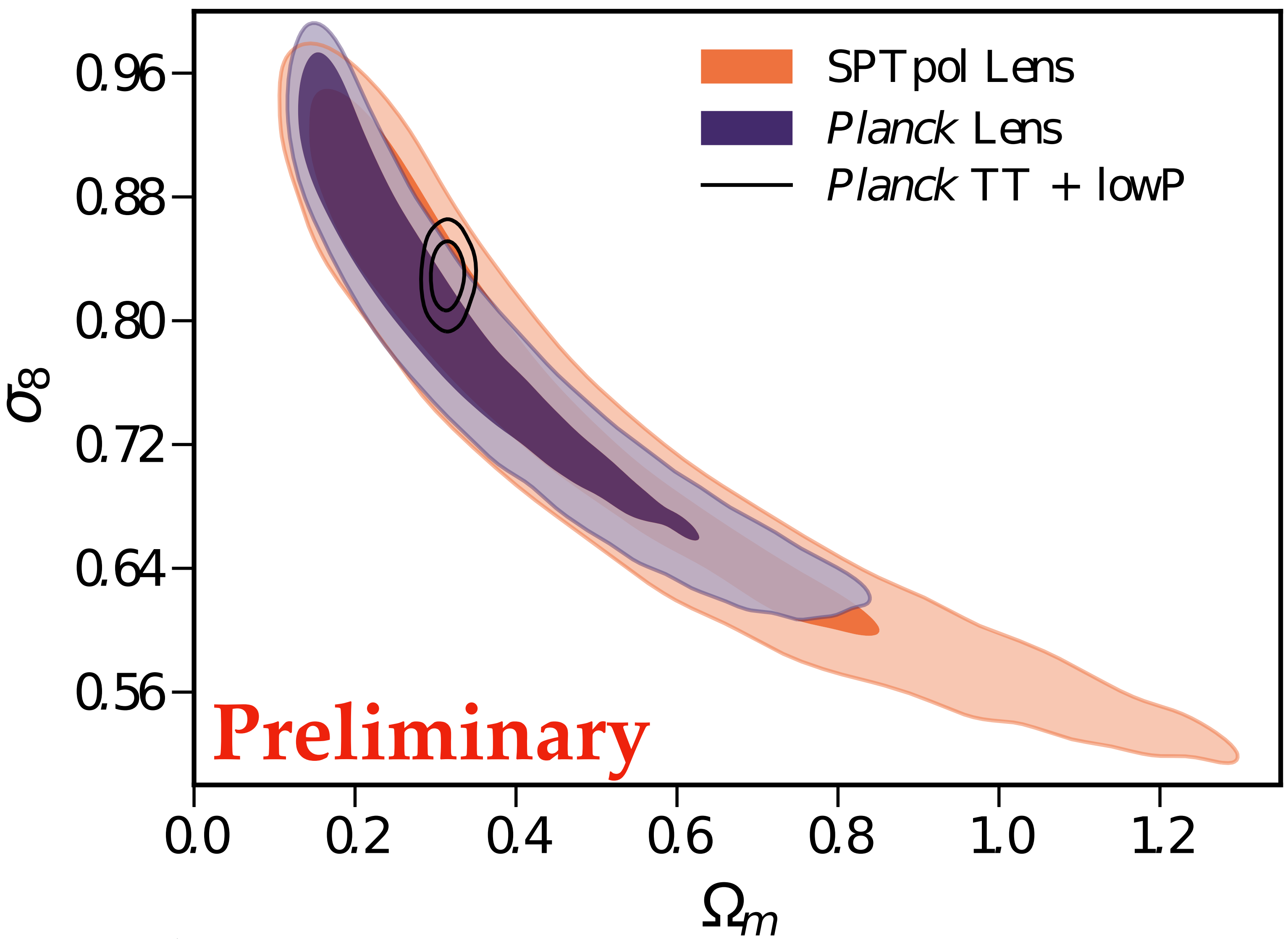
$C_l^{\phi\phi}$ scaling

peak smoothing scaling

Bianchini,**KW**+SPT (in prep.)

Model solutions to the H_0 crisis should not worsen other tensions.

$\sigma_8\Omega_m^{0.25}$: consistent with Planck lensing



Bianchini,**KW**+SPT (in prep.)

SPTpol lensing

$$\sigma_8\Omega_m^{0.25} = 0.593 \pm 0.025$$

(4% constraint)

Planck lensing

$$\sigma_8\Omega_m^{0.25} = 0.590 \pm 0.020$$

(3% constraint)

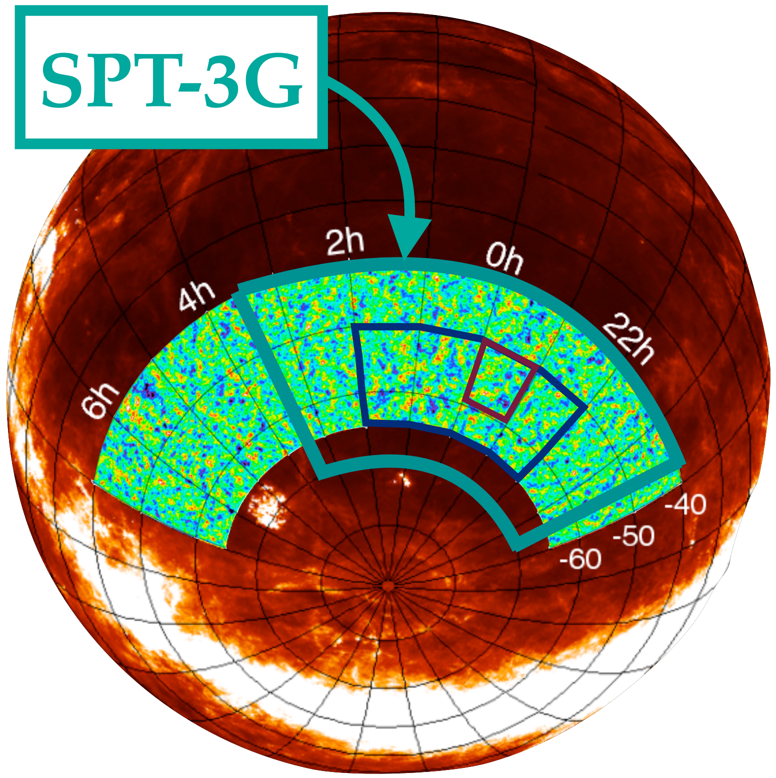
Planck + SPTpol lensing

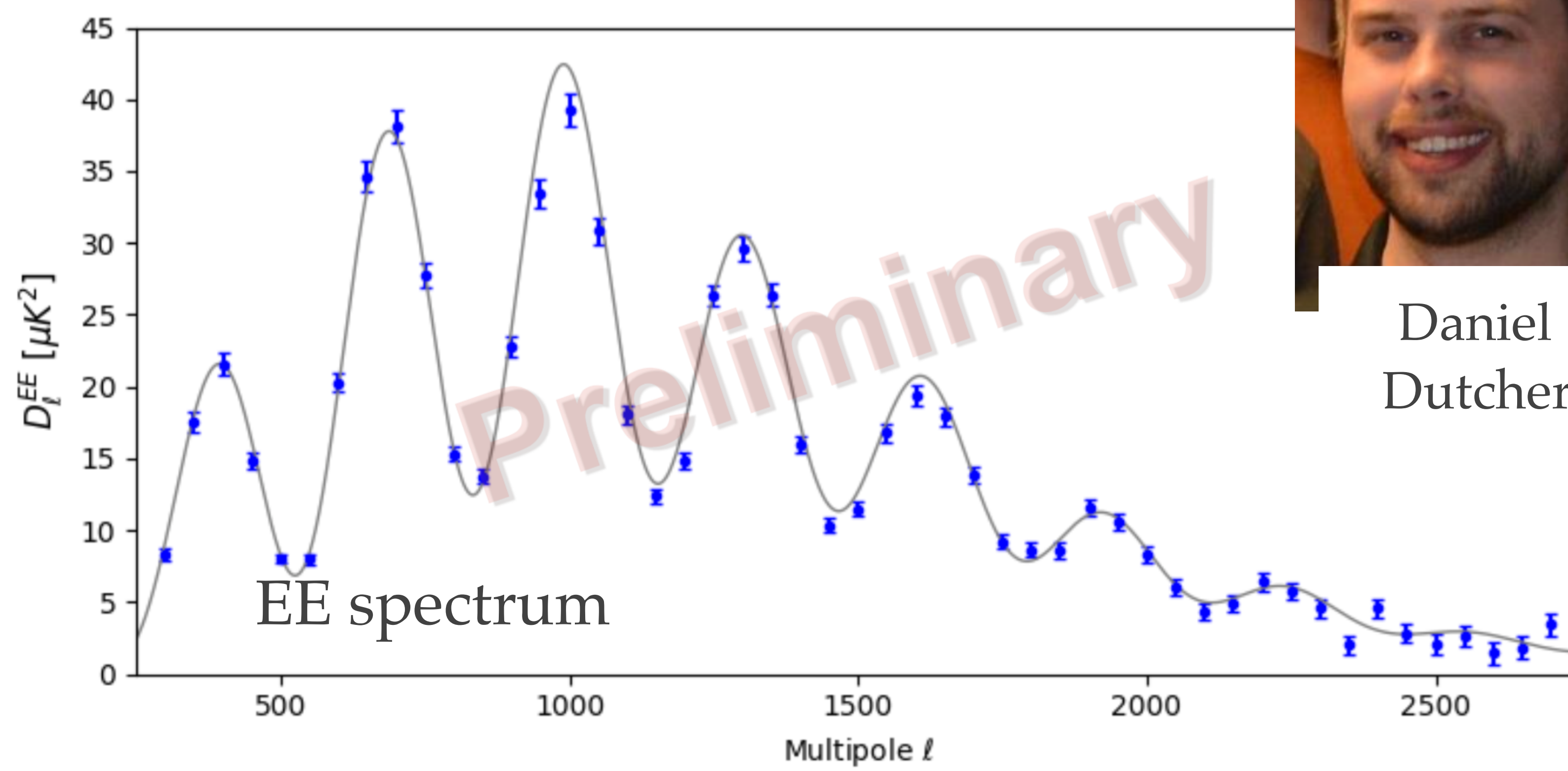
$$\sigma_8\Omega_m^{0.25} = 0.587 \pm 0.015$$

(2.5% constraint)

What's next?

SPT-3G: projected H_0 constraint comparable with Planck





Daniel Dutcher

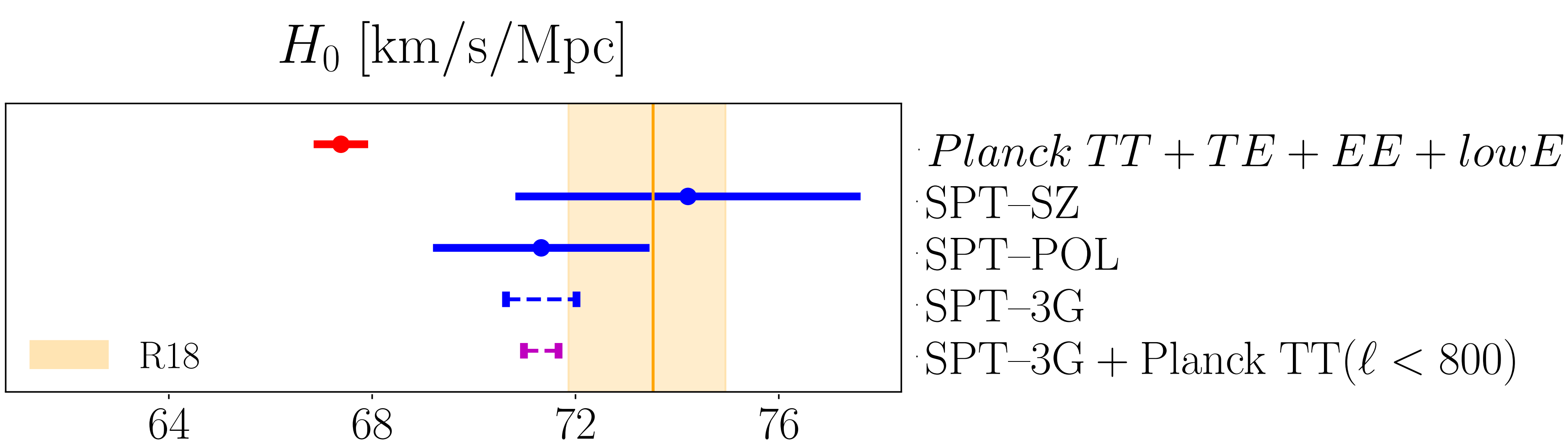


Figure by Kevin Aylor

Summary

- SPT-SZ TT consistent with Planck in same patch over same angular scales (if systematics, likely outside patch or angular range);
- SPT-SZ and SPTpol both show trend of higher H_0 when smaller scales are included in parameter constraints; SPT-3G's lower noise will be useful for investigating this trend.
- SPTpol lensing amplitude is consistent with LCDM expectation; $\sigma_8\Omega_m^{0.25}$ is consistent with Planck lensing. Stay tuned for the parameters paper!

Thank you for your attention!