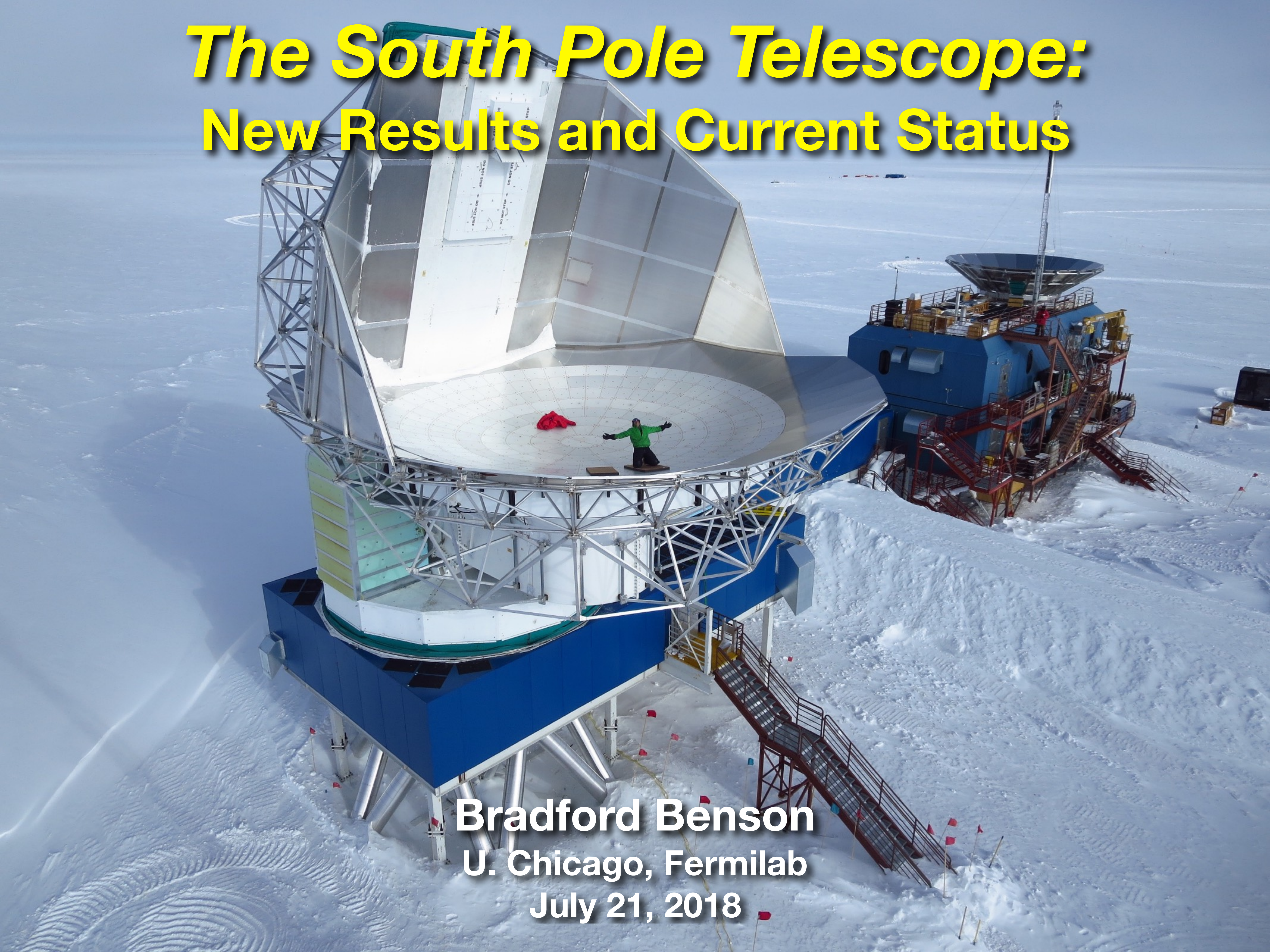
The South Pole Telescope:
New Results and Current Status



Bradford Benson

U. Chicago, Fermilab

July 21, 2018

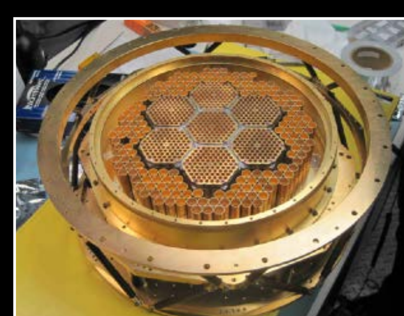
The South Pole Telescope (SPT)

10-meter sub-mm quality wavelength telescope

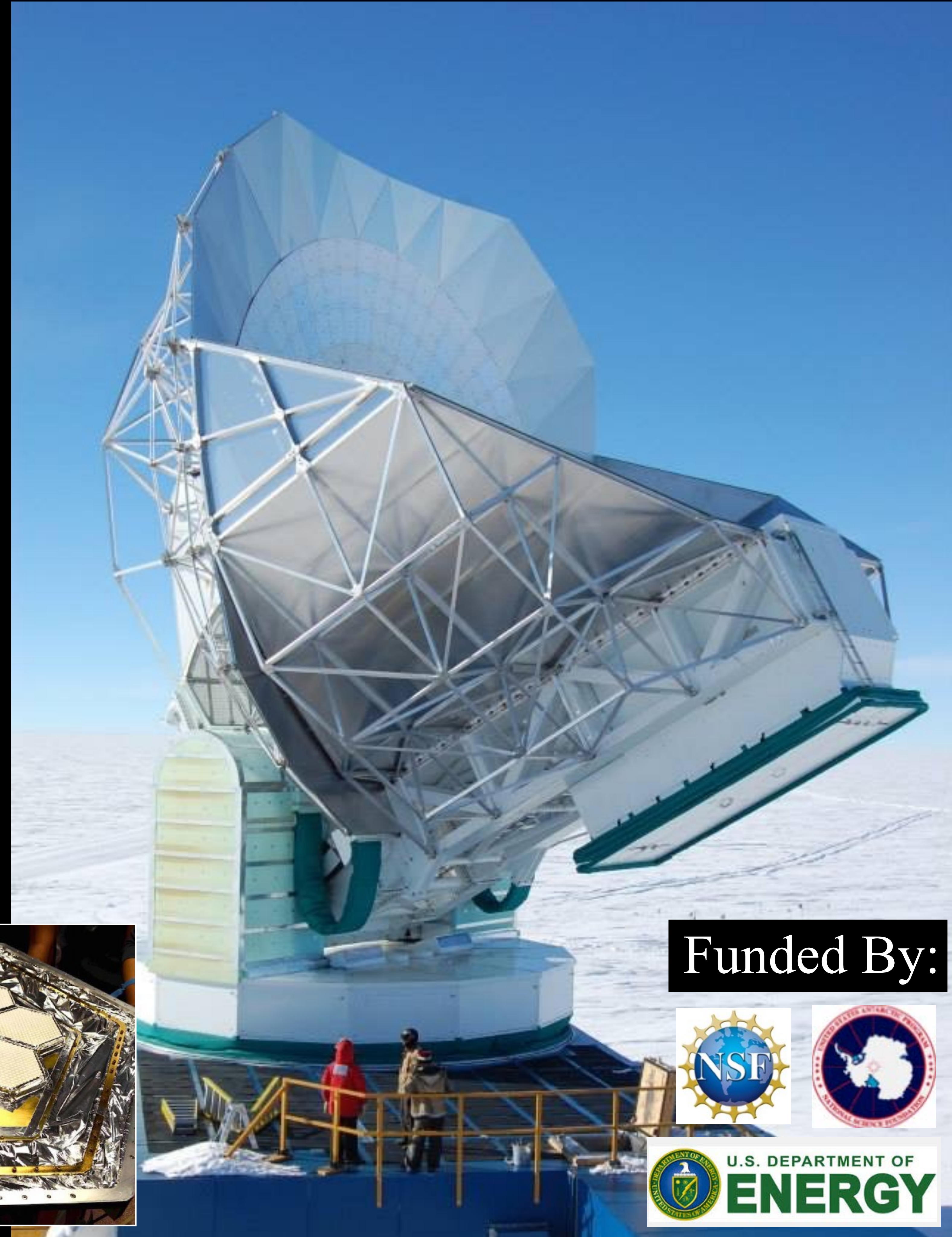
100, 150, 220 GHz and
1.6, 1.2, 1.0 arcmin resolution

2007: SPT-SZ
960 detectors
100,150,220 GHz

2012: SPTpol
1600 detectors
100,150 GHz
+Polarization



2016: SPT-3G
~16,200 detectors
100,150,220 GHz
+Polarization



Funded By:

U.S. DEPARTMENT OF ENERGY

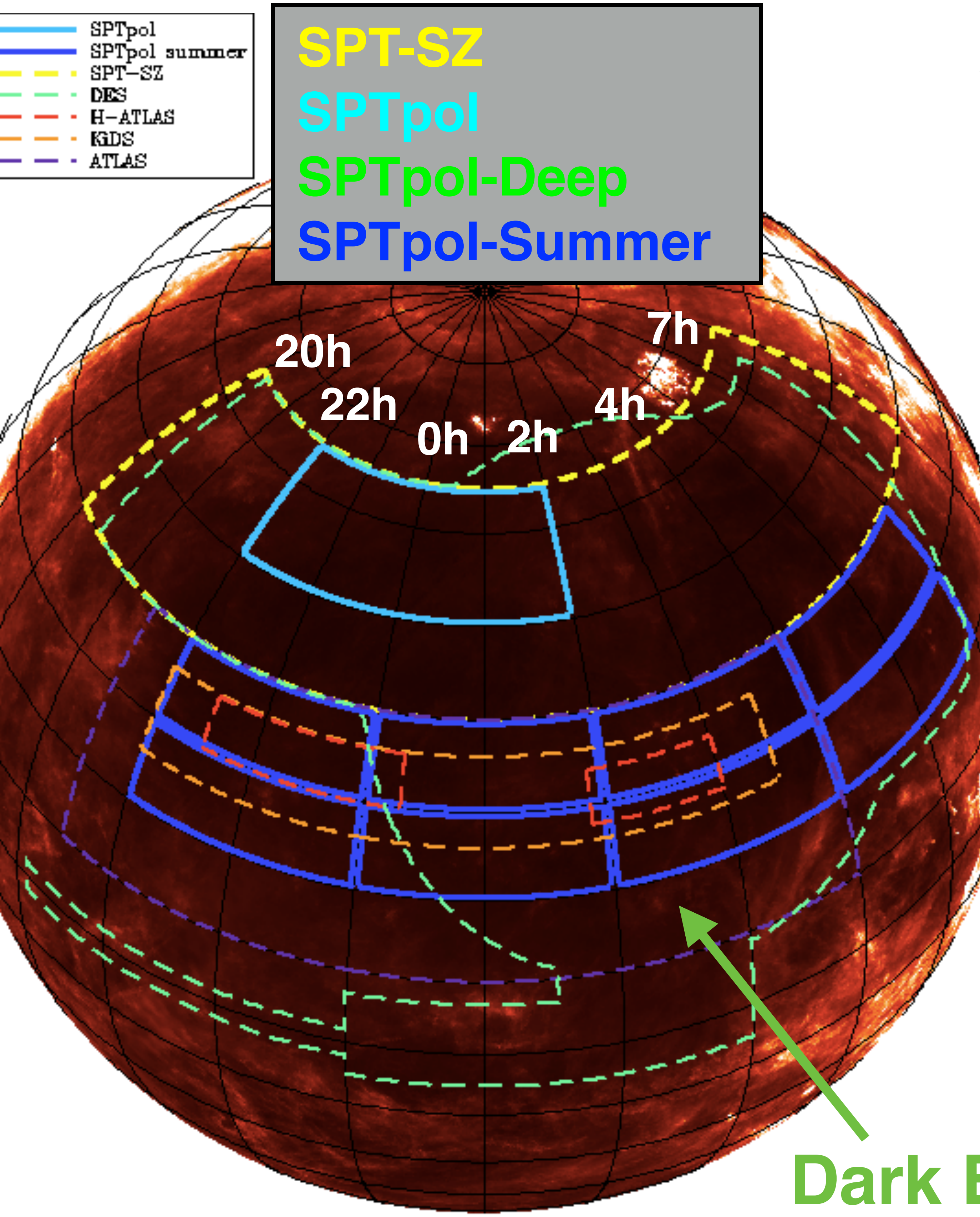
The SPT-3G Collaboration (July 2018)

~70 scientists (~half postdocs and students)

across ~20 institutions

Funded By:

The SPT Surveys: 5000 deg²



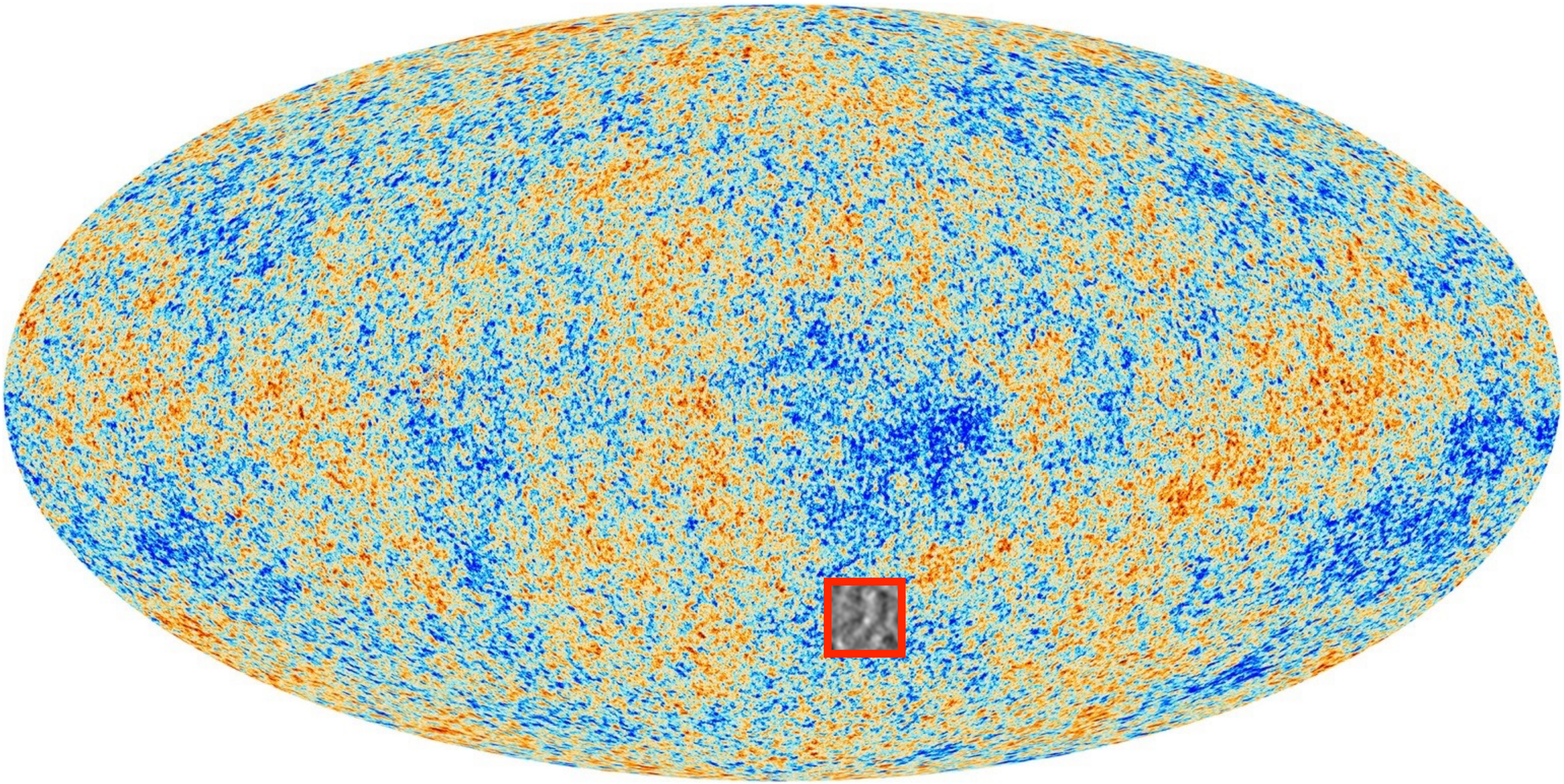
Dark Energy Survey (DES)

Between first two SPT surveys, we have surveyed 5000 deg² to ~Planck depths or better

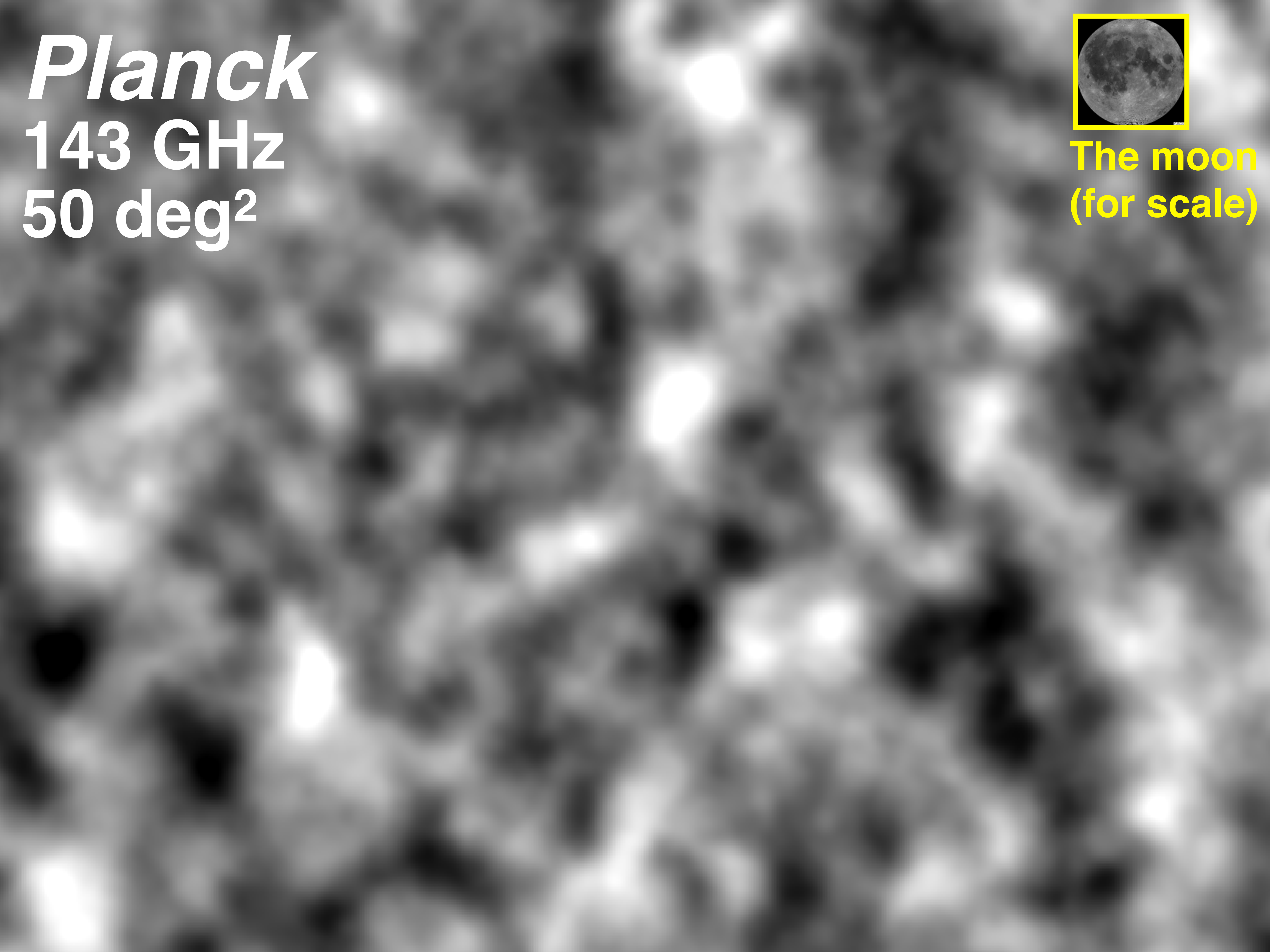
	Obs. Years	Area (deg²)	95 GHz (uK-arcmin)	150 (uK-arcmin)	220 (uK-arcmin)
SPT-SZ	**2007-11**	**2500**	**40**	**17**	**80**
SPTpol-Main	**2012-16**	**500**	**12**	**5**	**-**
SPTpol-Deep	2012-16	100	10	3.5	-
SPTpol-Summer	2012-16	2500	47	28	-
SPT-3G ***(projected)***	**2017-23**	**1500**	**3.0**	**2.2**	**8.8**

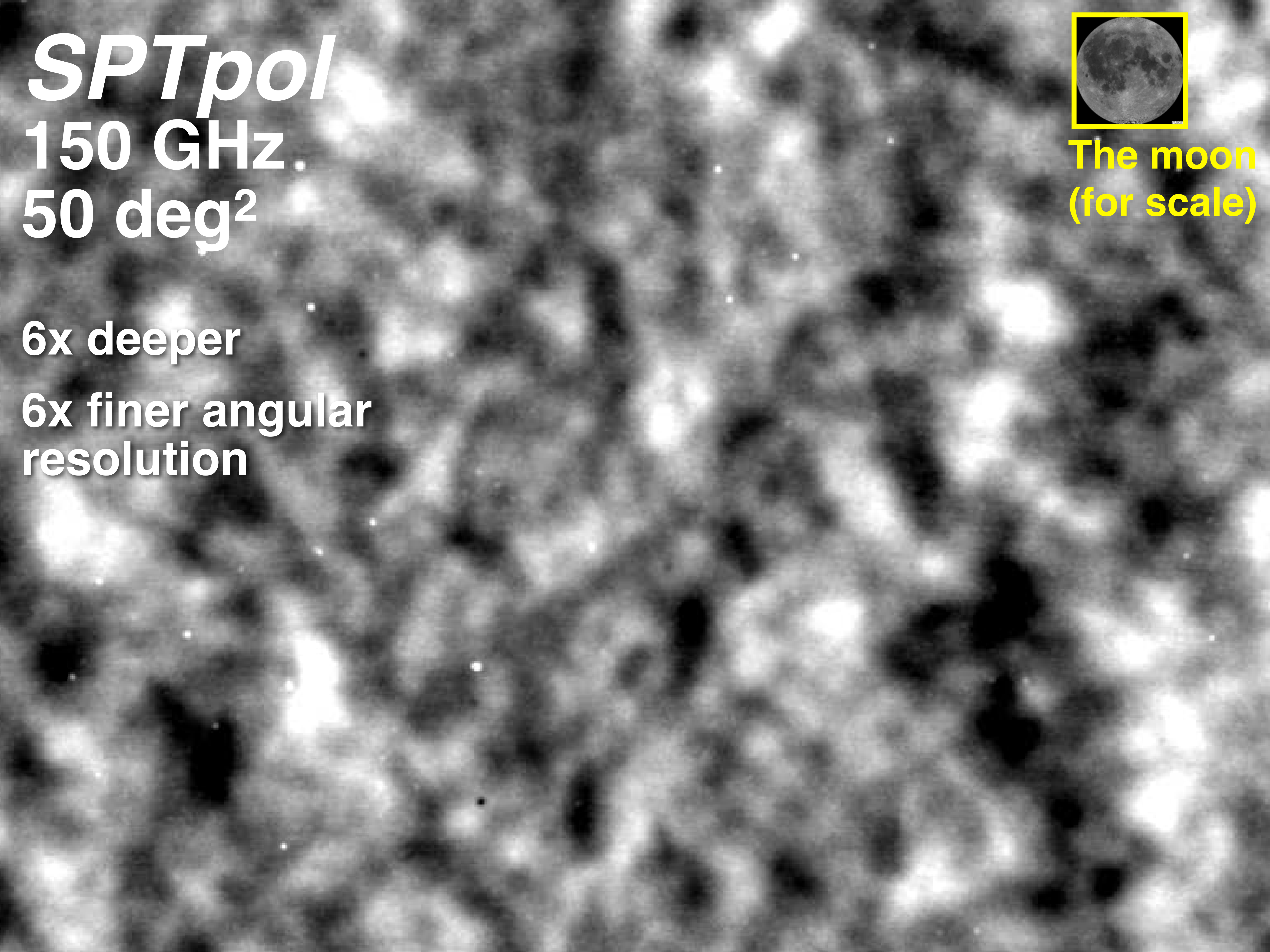
2013: Planck

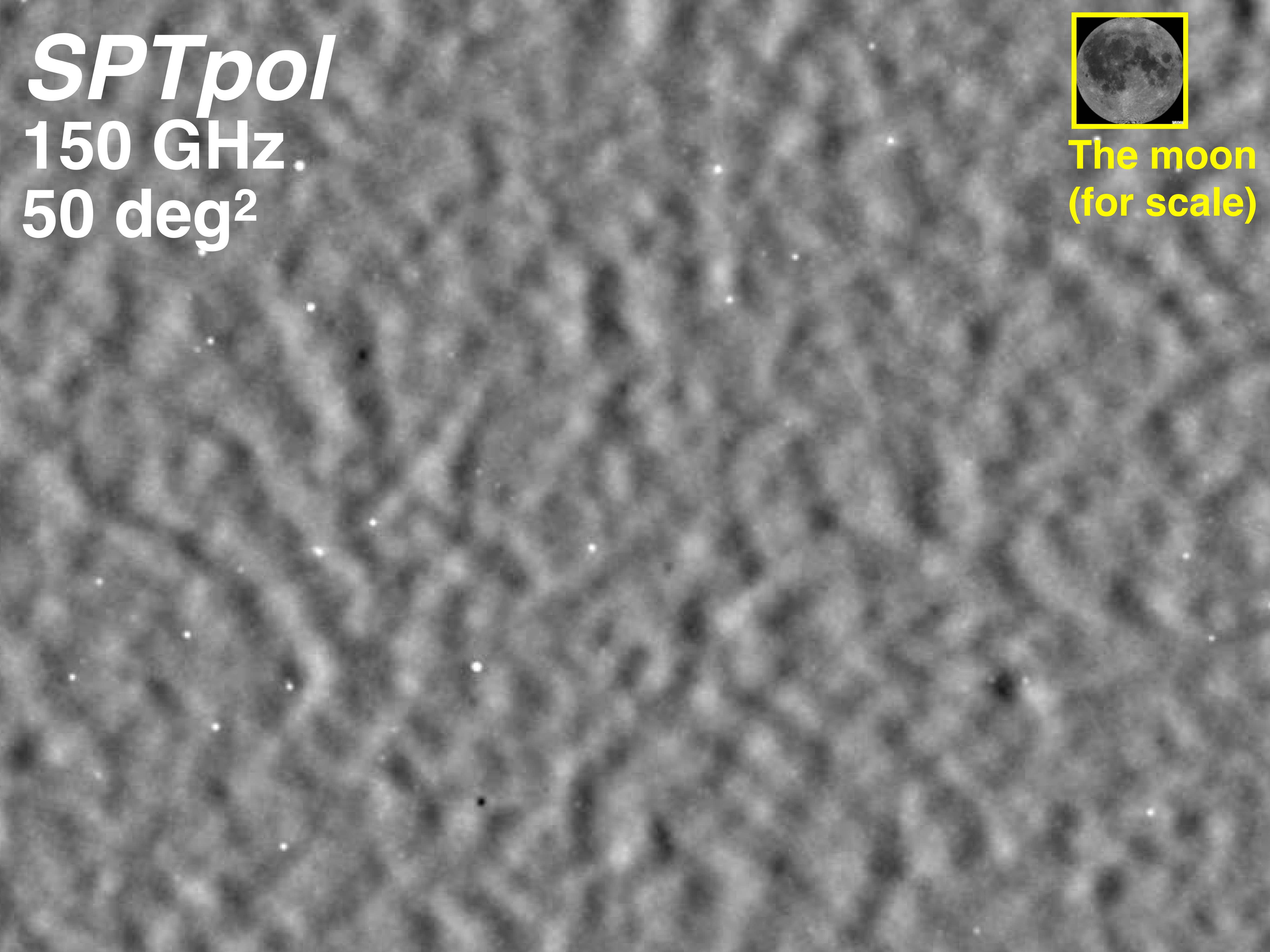
30μK RMS fluctuations on 3 K background

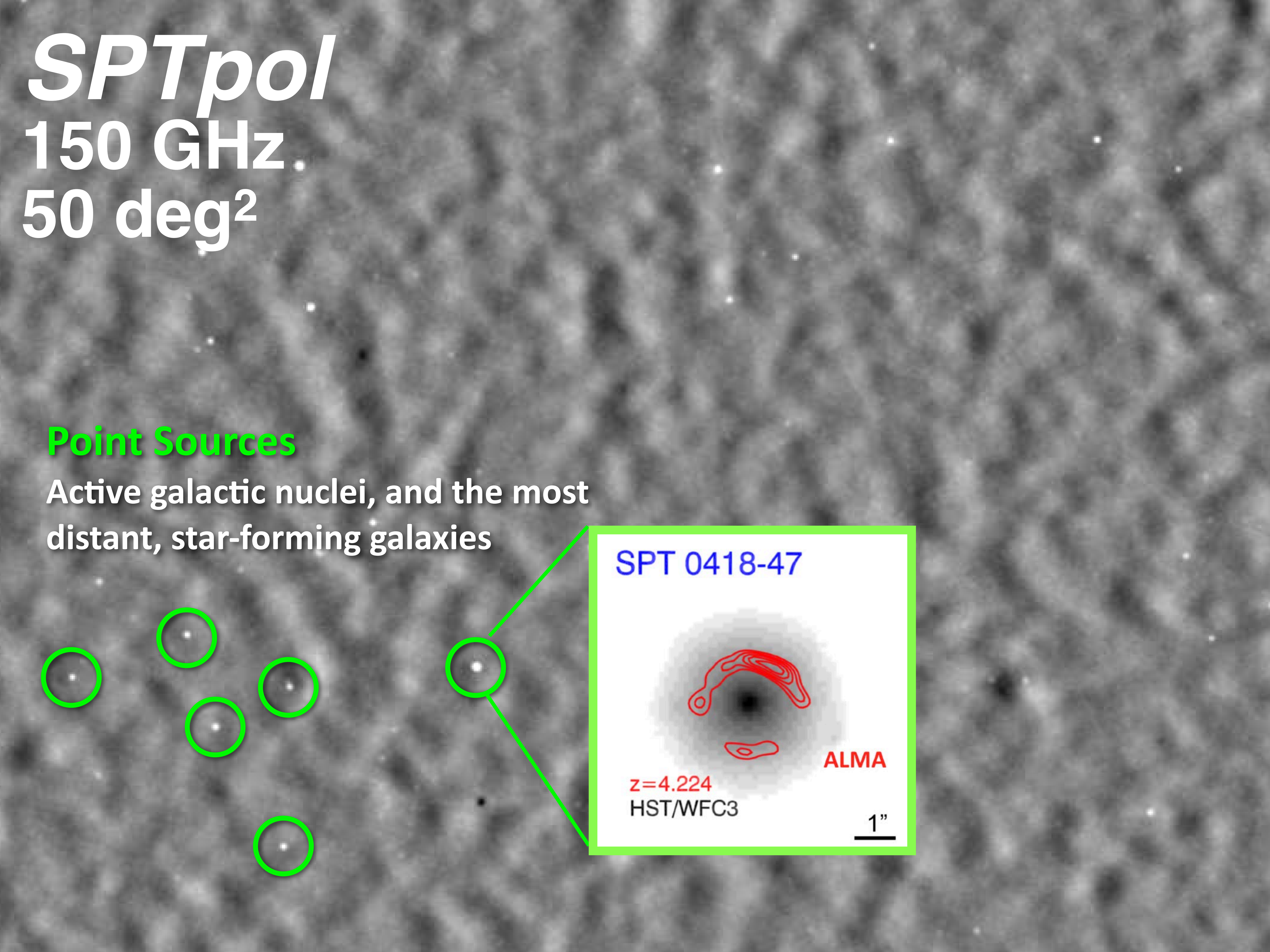


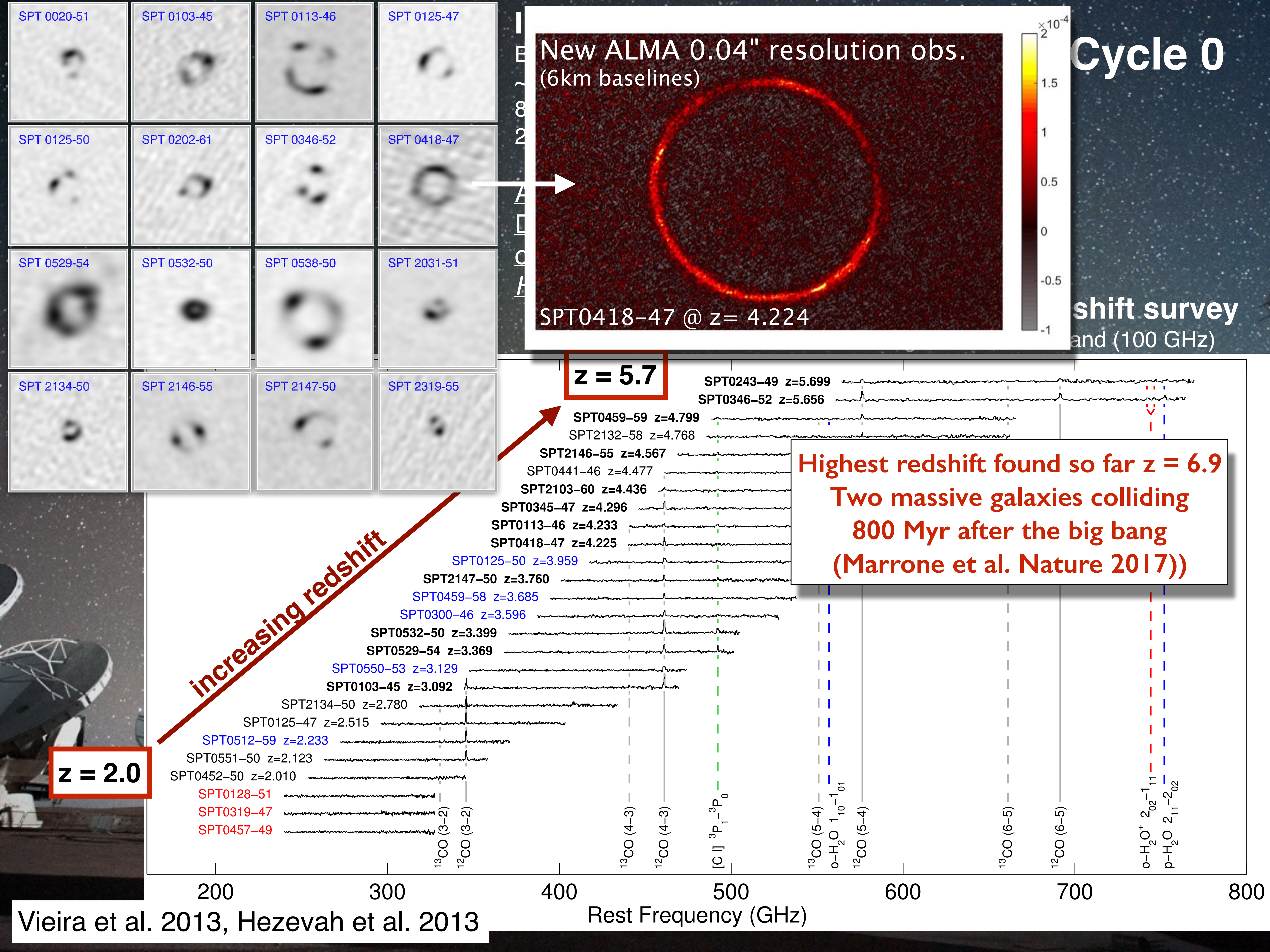
Credit: ESA (Planck)


Planck
143 GHz
50 deg^2
The moon
(for scale)


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

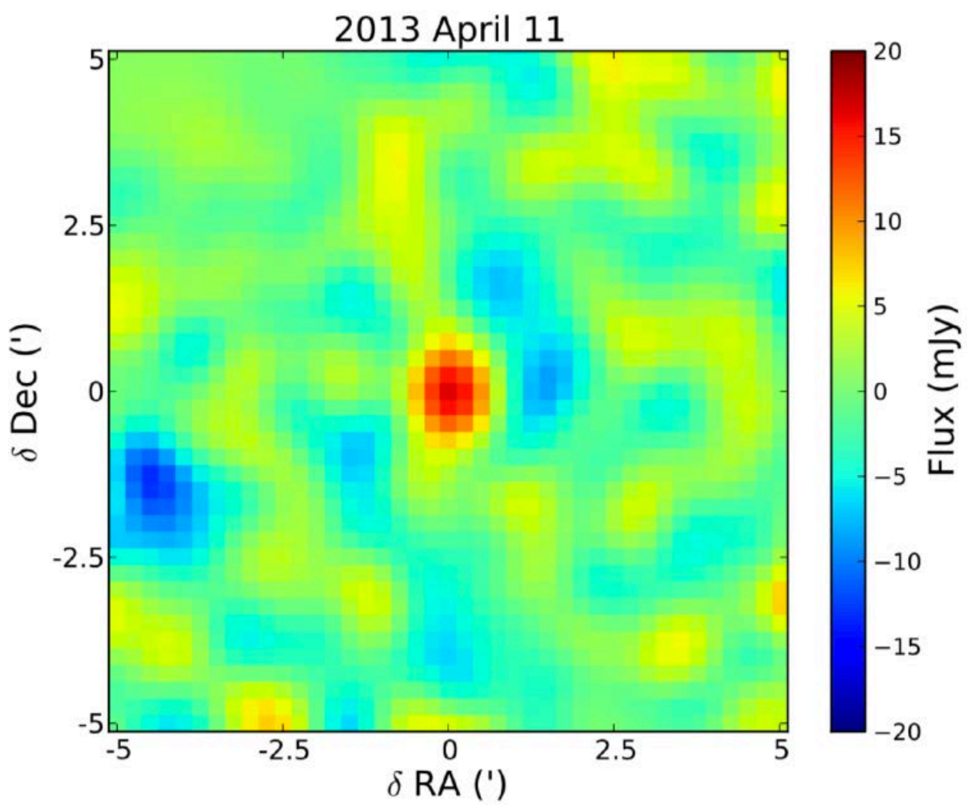

SPTpol
150 GHz
50 deg²
The moon
(for scale)


SPTpol
150 GHz
50 deg²
Point Sources
Active galactic nuclei, and the most distant, star-forming galaxies
SPT 0418-47
ALMA
z=4.224
HST/WFC3
1"

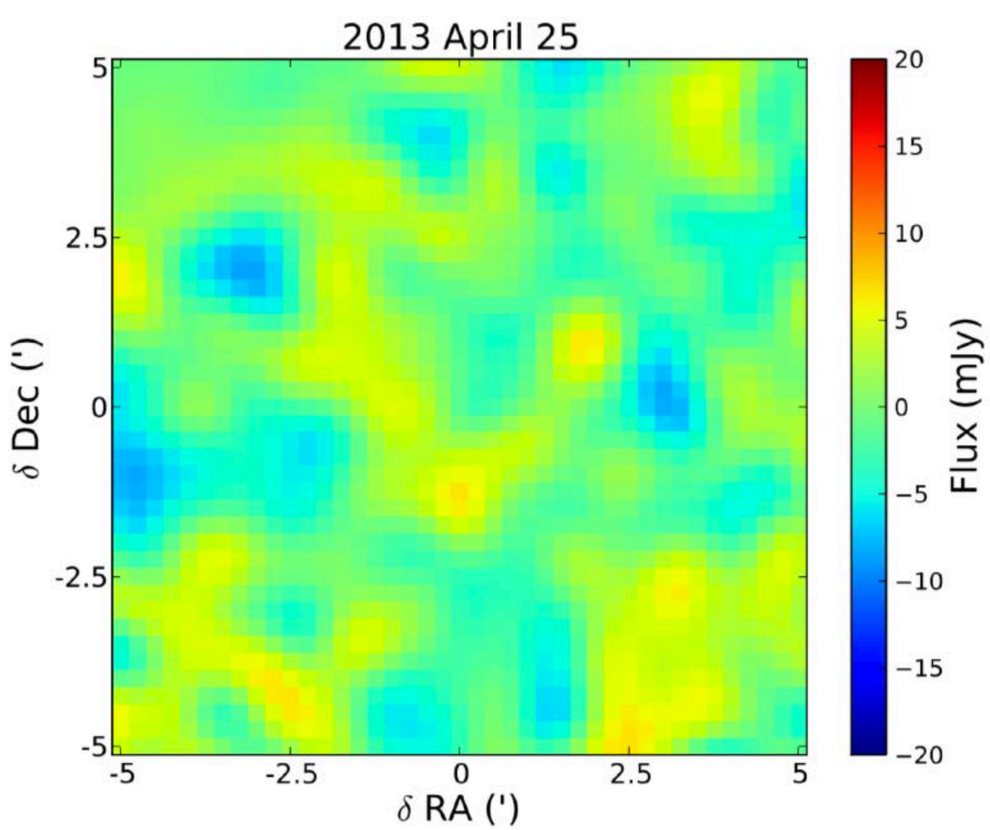


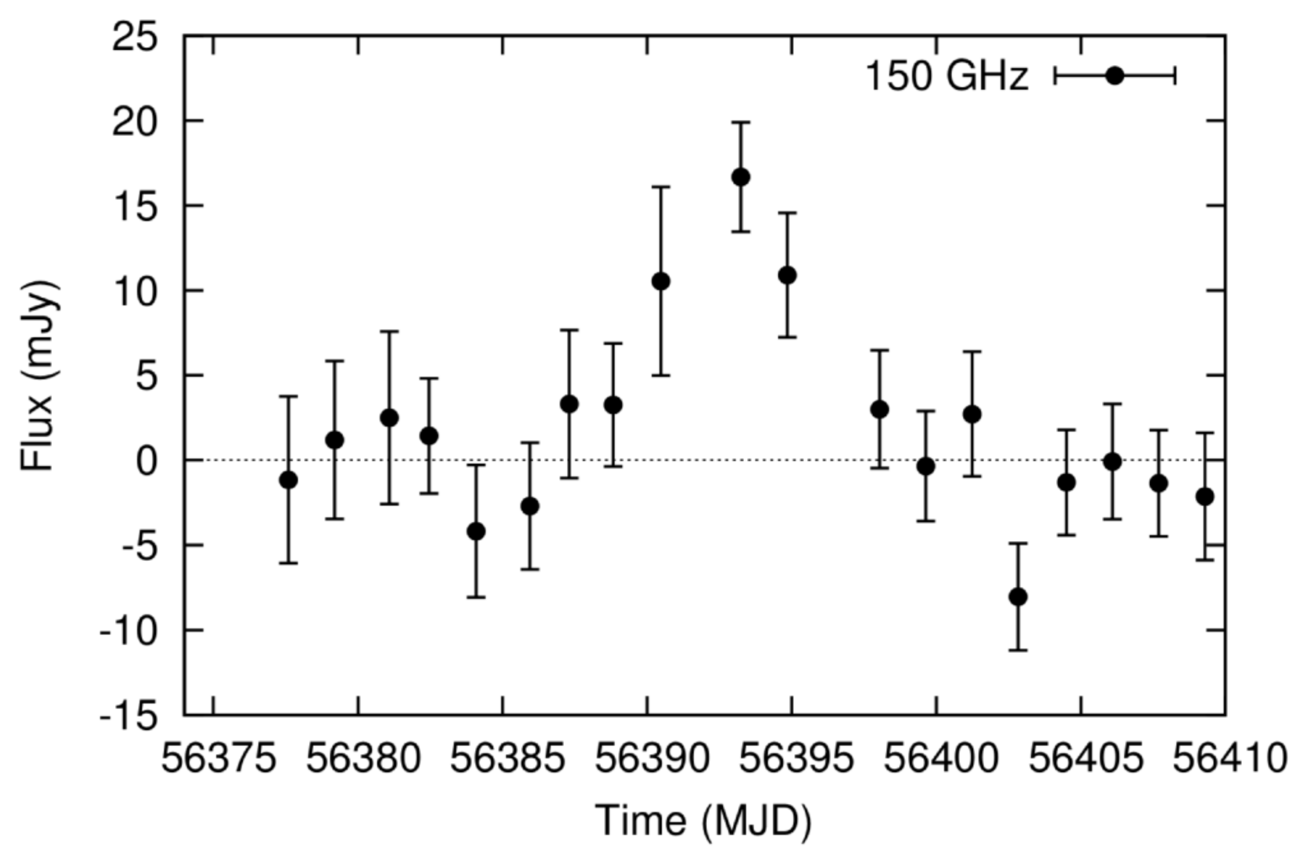
SPT 0020-51
SPT 0103-45
SPT 0113-46
SPT 0125-47
SPT 0125-50
SPT 0202-61
SPT 0346-52
SPT 0418-47
SPT 0529-54
SPT 0532-50
SPT 0538-50
SPT 2031-51
SPT 2134-50
SPT 2146-55
SPT 2147-50
SPT 2319-55
New ALMA 0.04" resolution obs.
(6km baselines)
SPT0418-47 @ z= 4.224
Cycle 0
shift survey
and (100 GHz)
z = 5.7
z = 2.0
increasing redshift
Highest redshift found so far z = 6.9
Two massive galaxies colliding
800 Myr after the big bang
(Marrone et al. Nature 2017))
SPT0243–49 z=5.699
SPT0346–52 z=5.656
SPT0459–59 z=4.799
SPT2132–58 z=4.768
SPT2146–55 z=4.567
SPT0441–46 z=4.477
SPT2103–60 z=4.436
SPT0345–47 z=4.296
SPT0113–46 z=4.233
SPT0418–47 z=4.225
SPT0125–50 z=3.959
SPT2147–50 z=3.760
SPT0459–58 z=3.685
SPT0300–46 z=3.596
SPT0532–50 z=3.399
SPT0529–54 z=3.369
SPT0550–53 z=3.129
SPT0103–45 z=3.092
SPT2134–50 z=2.780
SPT0125–47 z=2.515
SPT0512–59 z=2.233
SPT0551–50 z=2.123
SPT0452–50 z=2.010
SPT0128–51
SPT0319–47
SPT0457–49
13CO (3–2)
12CO (3–2)
13CO (4–3)
12CO (4–3)
[C I] 3P1–3P0
13CO (5–4)
o–H2O 110–101
12CO (5–4)
13CO (6–5)
12CO (6–5)
o–H2O+ 202–111
p–H2O 211–202
200
300
400
500
600
700
800
Rest Frequency (GHz)
Vieira et al. 2013, Hezevah et al. 2013

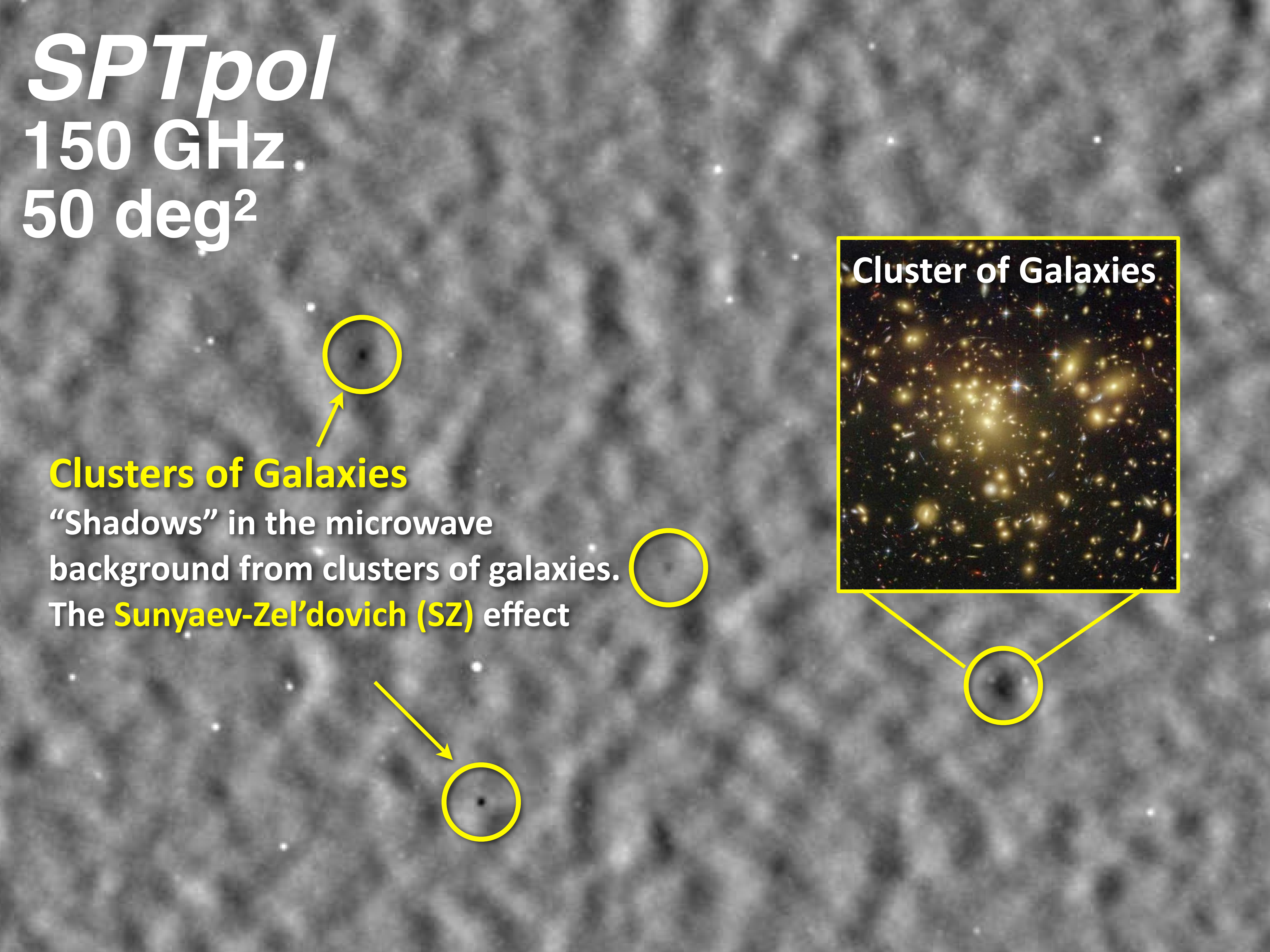
SPTpol: mm-Wavelength Transients



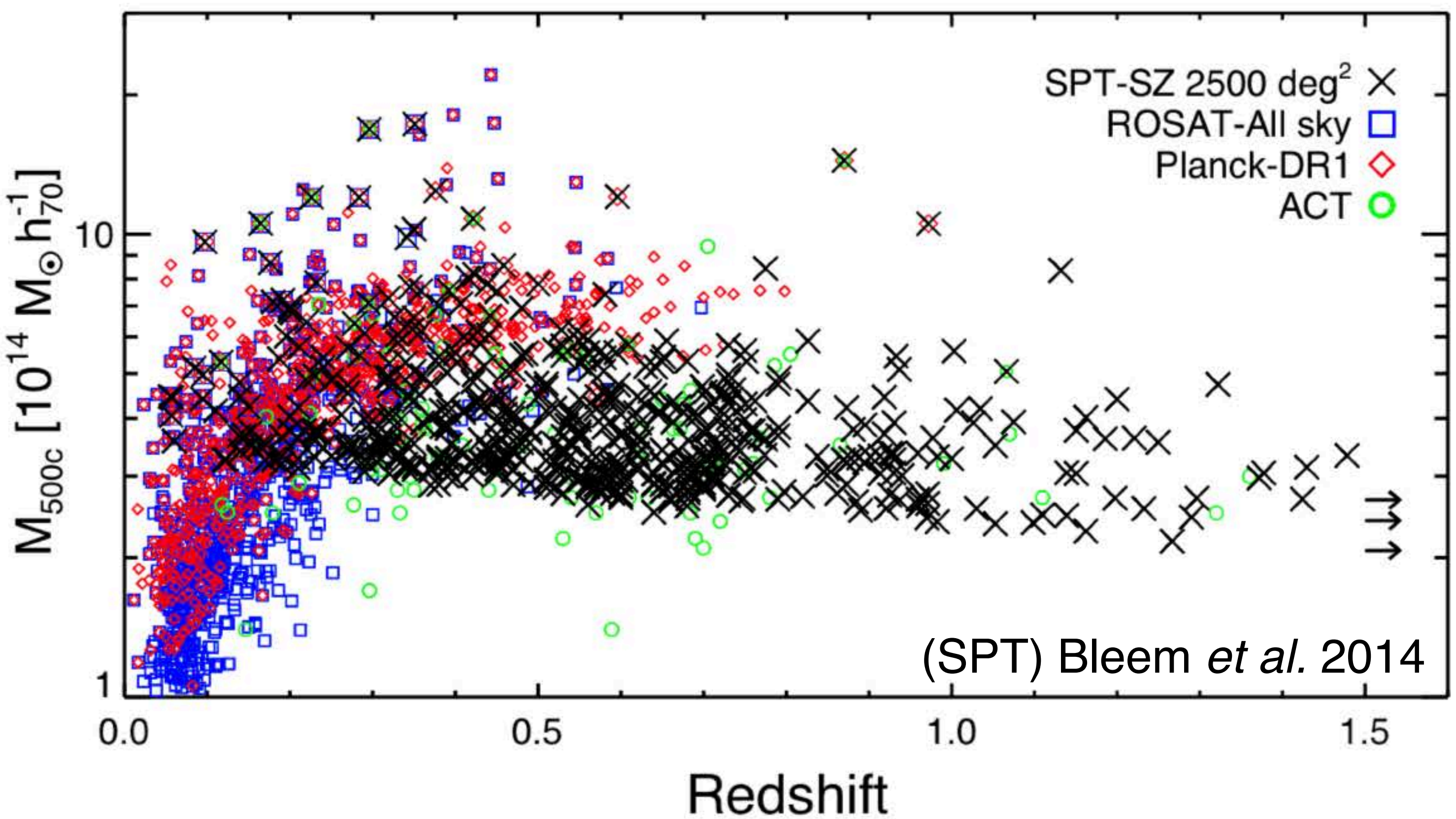
- First ~1.3 years of SPTpol survey used for mm-wave transient search (**SPTpol: Whitehorn et al., 2016, ApJ, 830, 142**)
- Detected one ~15 mJy candidate consistent with gamma-ray burst afterglow, but measured at low significance (Prob=0.01)
- Search using rest of SPTpol underway. SPT-3G survey will be 10x more sensitive to mm-wave transients.

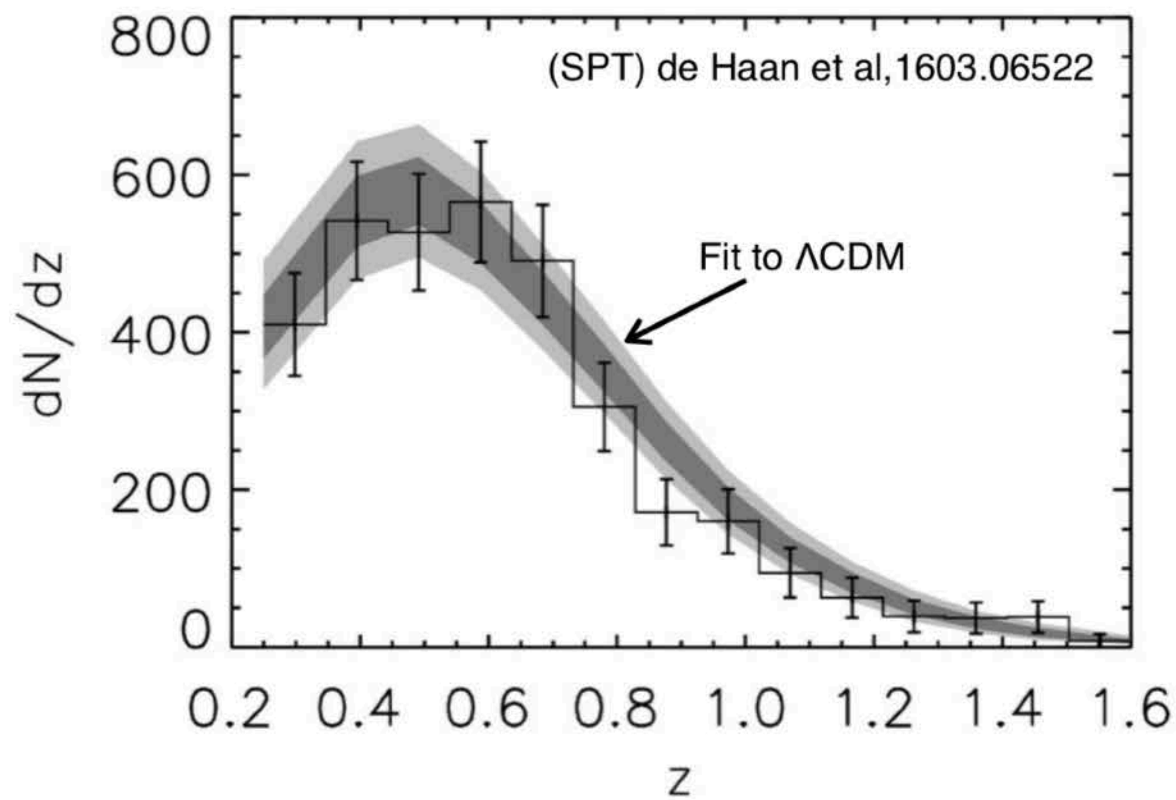





SPTpol
150 GHz
50 deg²
Clusters of Galaxies
"Shadows" in the microwave background from clusters of galaxies.
The Sunyaev-Zel'dovich (SZ) effect
Cluster of Galaxies

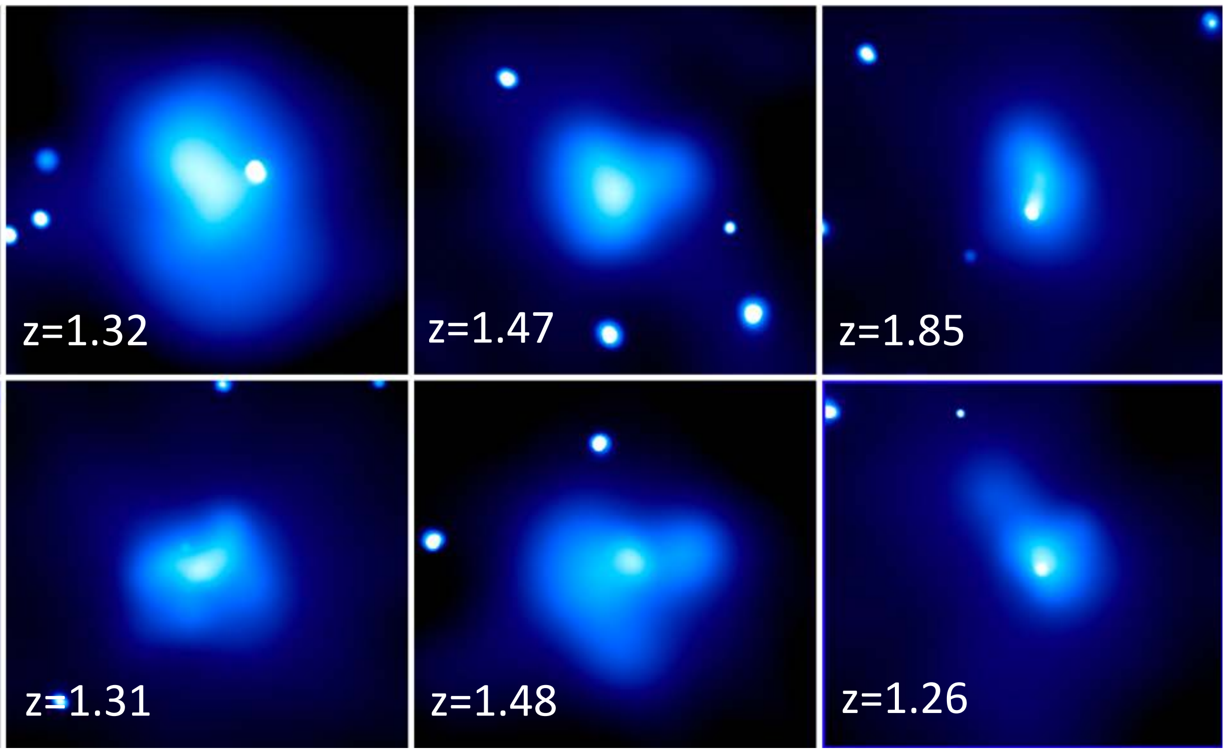
Sunyaev-Zel'dovich (SZ) Clusters





- First SZ-discovered clusters of galaxies found in 2008 (SPT, Staniszewski+2008), with Planck+ACT, there are ***now >1000 SZ-identified clusters***
- SZ uniquely provide "clean" samples of the most massive, high-redshift clusters of galaxies. Useful for:
  - ***Growth of structure / cosmological constraints***
  - ***Cluster astrophysics and formation at high-redshift***

Unique High-z Cluster Sample



The Chandra-SPT Survey

(McDonald+13,14,16,17; Chiu+14; Hlavacek-Larrondo+15; Mantz+17)

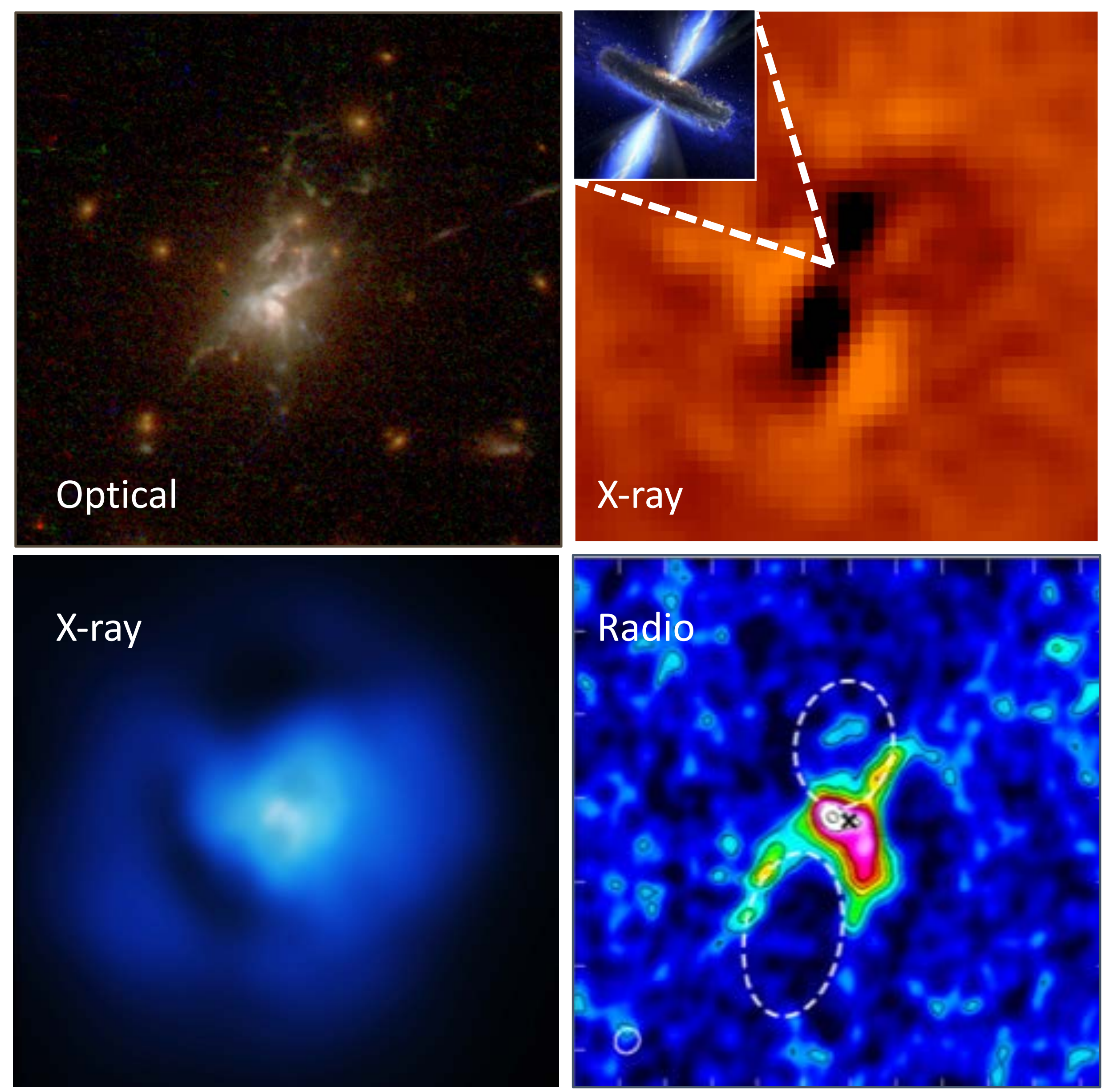
- X-ray imaging of 100 SPT SZ -selected clusters out to z = 1.85
- Evidence for long-standing (10 Gyr) feedback-cooling balance
- Early (z > 2) enrichment of ICM
- Initial formation of cool cores at z ~ 2
- Non-evolution in baryon fraction
- Central galaxy growth driven by gas-rich mergers at z > 1

The Phoenix Cluster

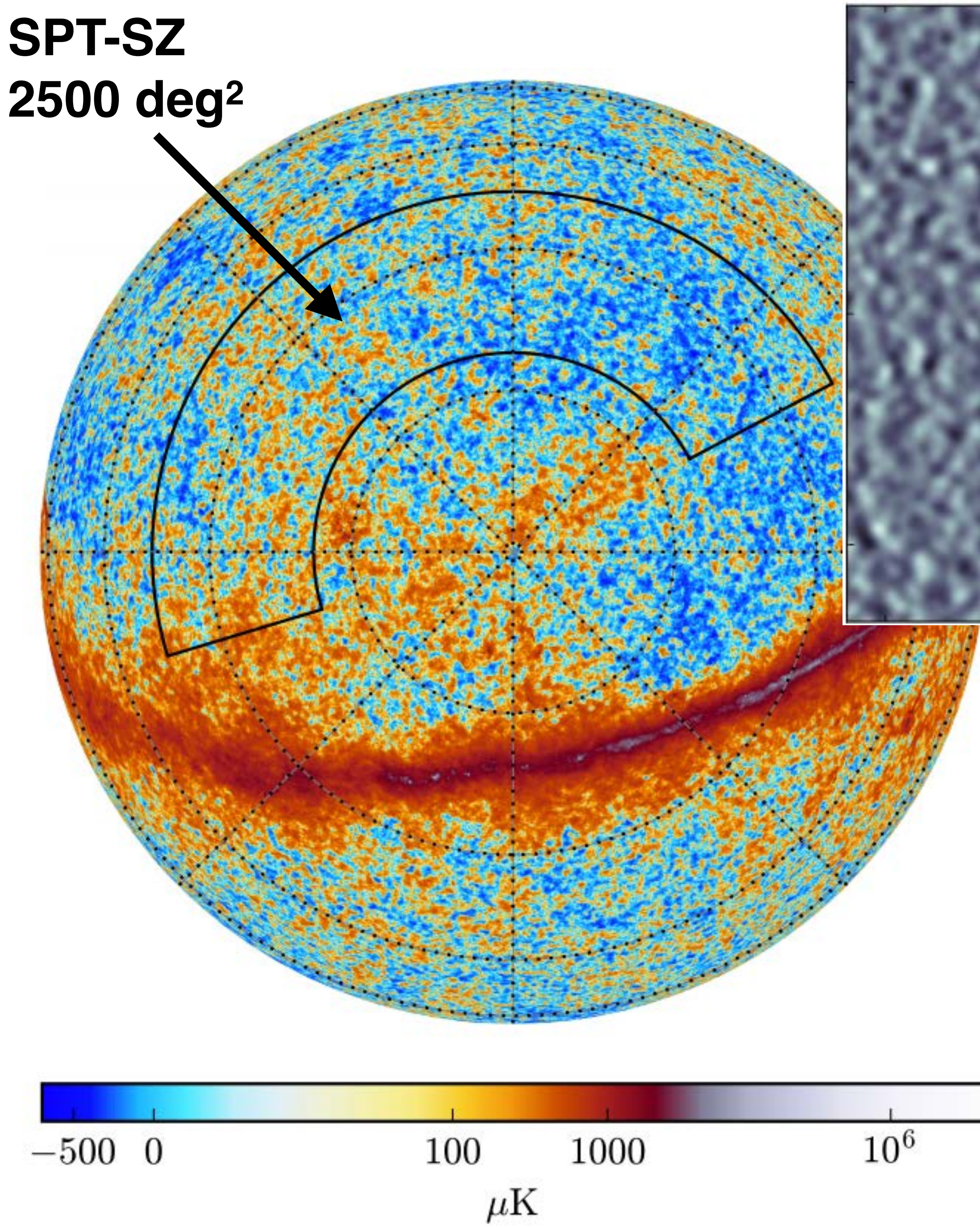
Slide from Mike McDonald

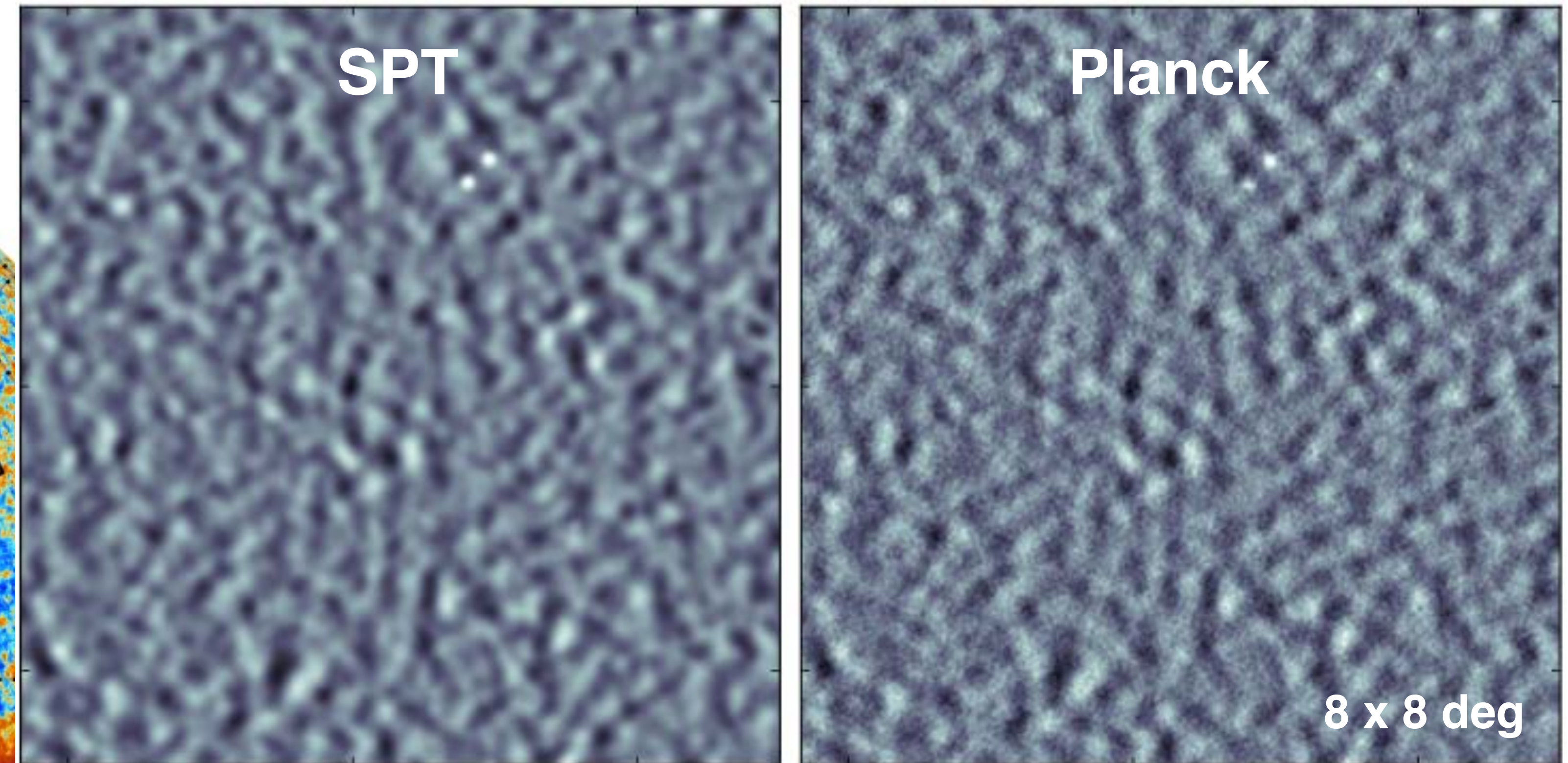
(McDonald+12,13,15; Russell+17)

- Most X-ray luminous cluster known
- Massive central starburst (~800 Msun/yr)
- Powerful AGN outburst
- Molecular gas influenced by AGN



CMB TT Power Spectrum: Planck x SPT

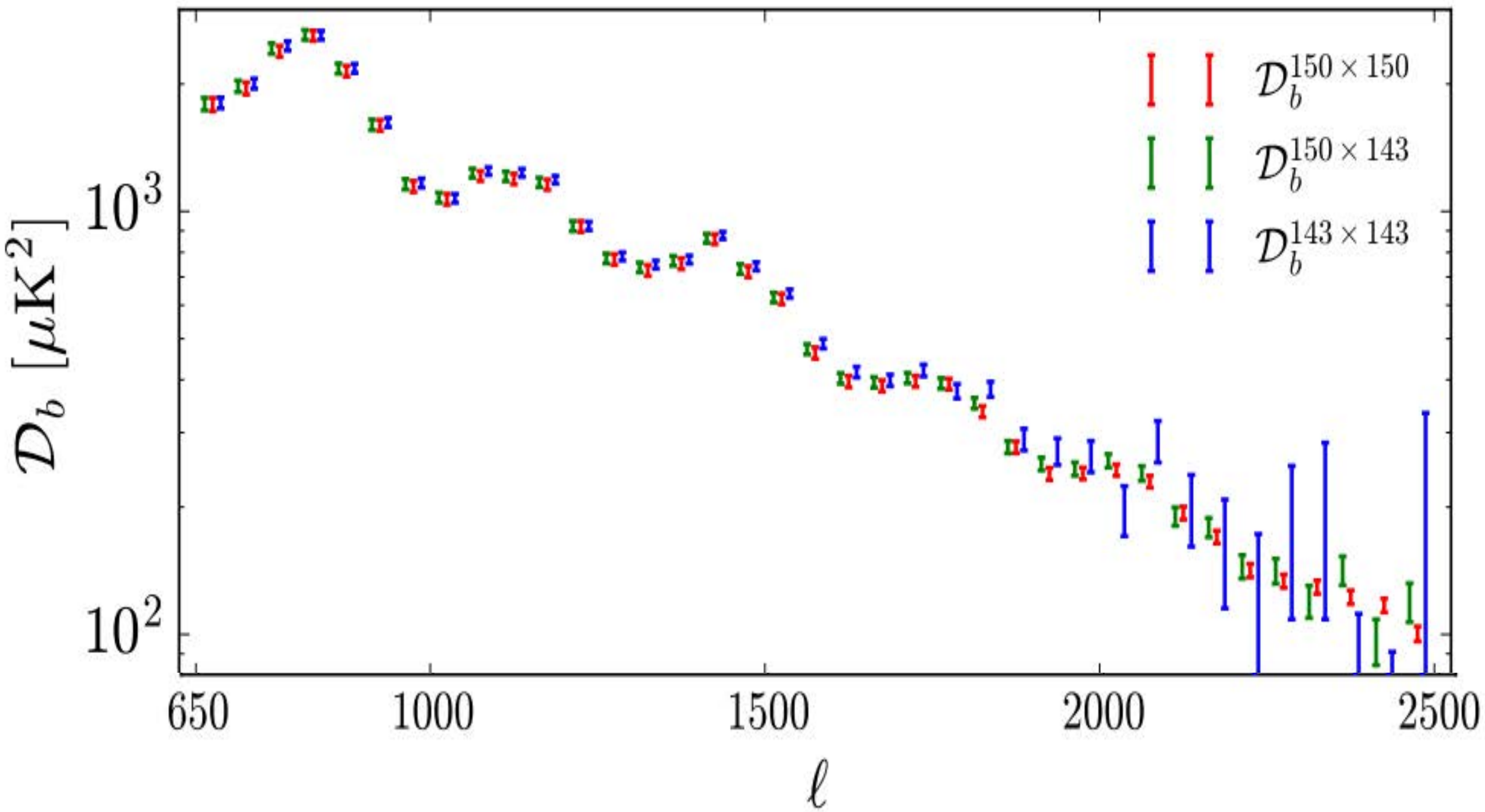




- ***Map based comparison of SPT-SZ and Planck data over 2500 deg² SPT-SZ survey patch***
- Measure cross-spectrum: 143 x 143, 143 x 150, 150 x 150 GHz (from Planck x Planck, Planck x SPT, SPT x SPT data)

(SPT) Hou et al. (2017) 1704.00884

CMB TT Power Spectrum: Planck x SPT



- *Planck in SPT-patch and SPT are consistent (PTE=0.3) over range they both measure well (650 < ℓ < 2000)*
- *SPT cosmology in 2500d patch consistent with Planck full-sky cosmology (PTE=0.032), with slight shift in some parameters including ℓ > 2000 data*

Planck Cosmo Full-Sky (FS)

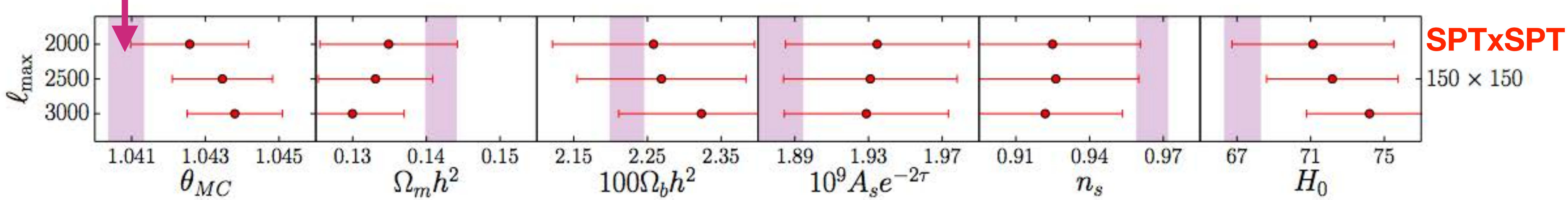


FIG. 2.— The parameter estimates for the three sets of in-patch bandpowers for various ℓ_{max} values. The estimates are based on the multipole range of $650 \leq \ell \leq \ell_{max}$. There is a noticeable trend in the 150×150 density parameters towards better agreement with PlanckFS as ℓ_{max} is lowered.

(SPT) Hou et al. (2017) 1704.00884 (SPT) Aylor et al. (2017) 1706.10286

CMB TT Lensing: Planck + SPT

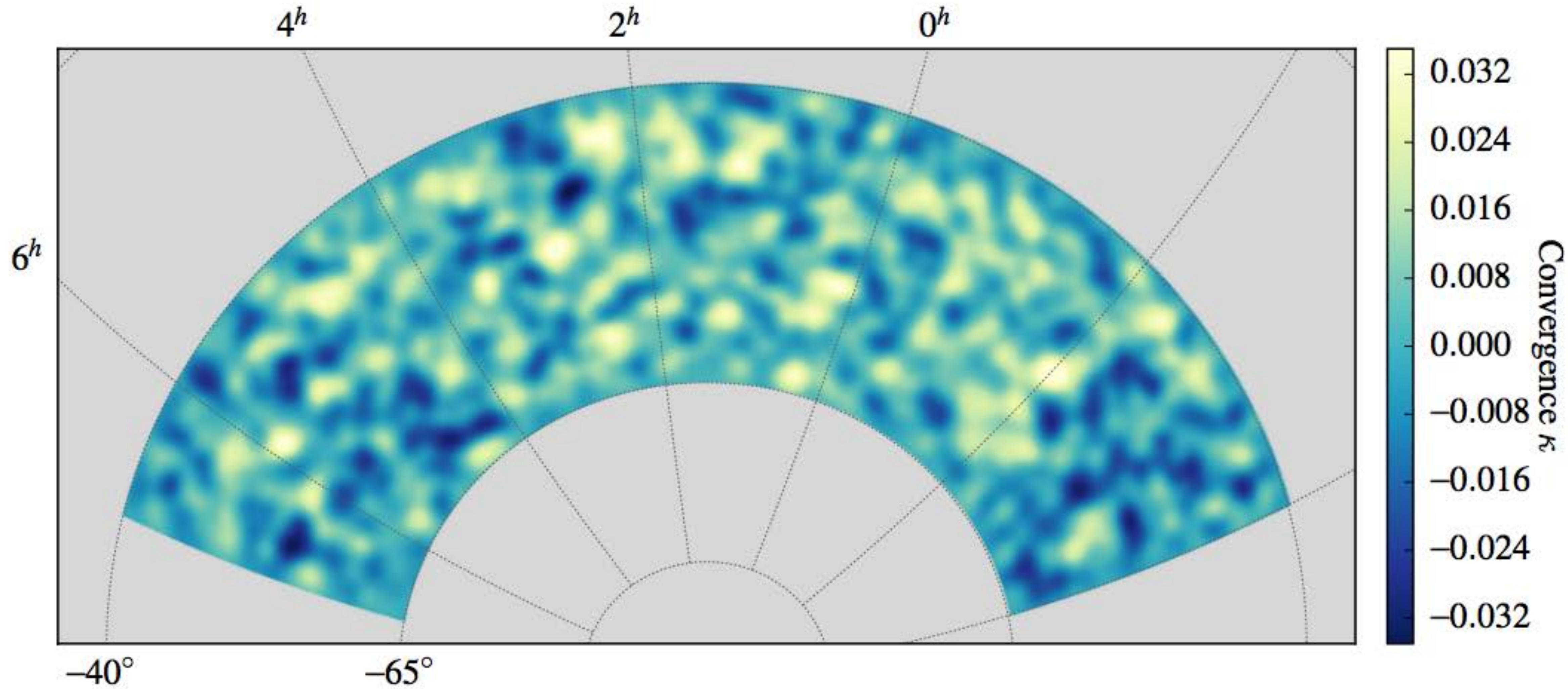
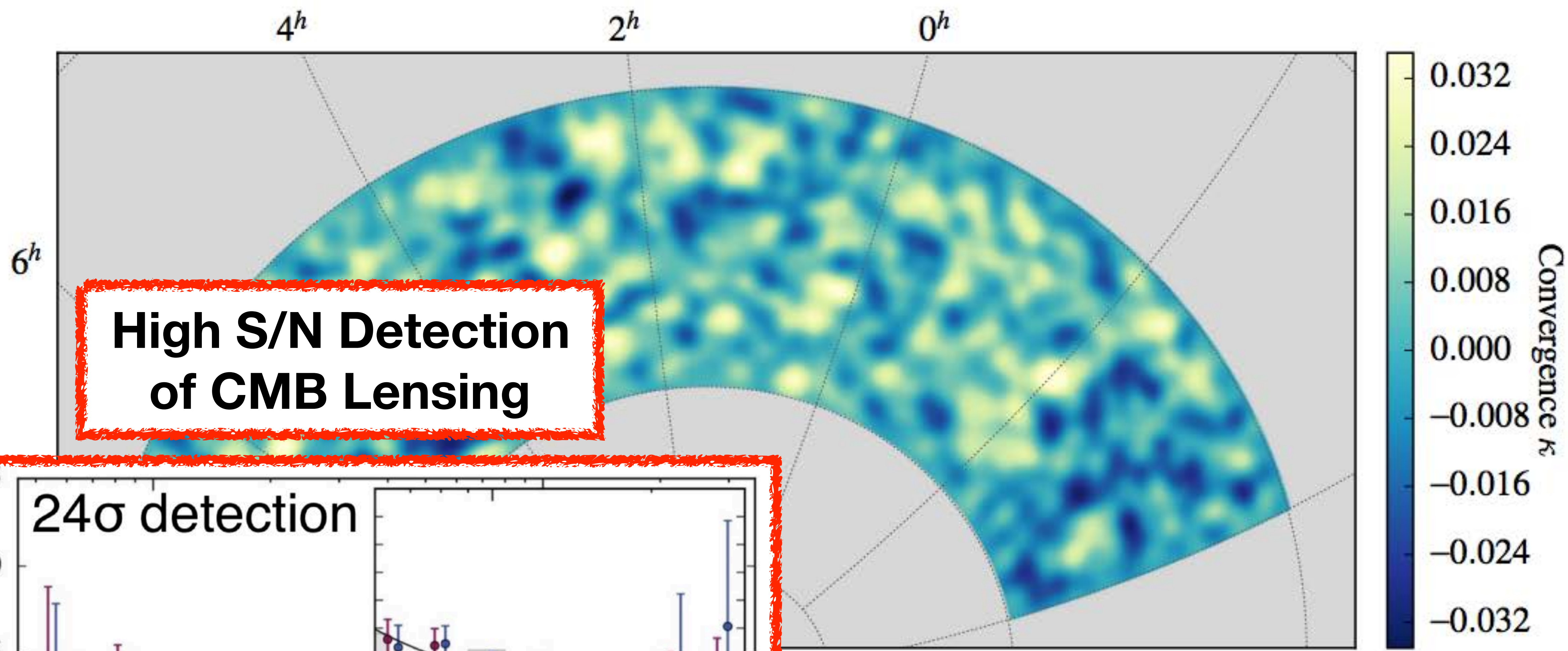


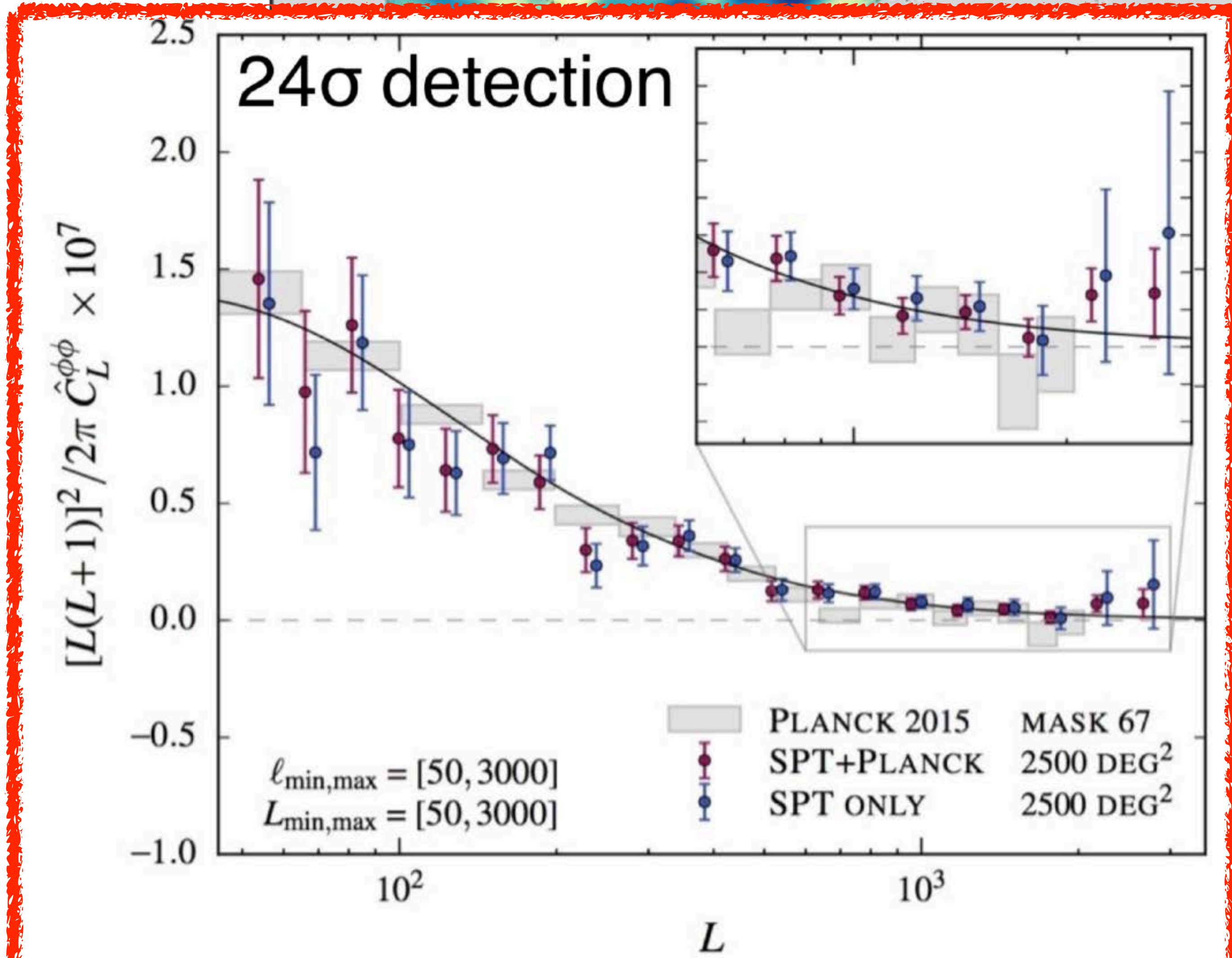
FIG. 4.— The reconstructed lensing map on a zenithal equal-area projection. The map has been smoothed with a Gaussian kernel with FWHM = 2 degrees.

(SPT) Omori et al. (2017) 1705.00743

CMB TT Lensing: Planck + SPT

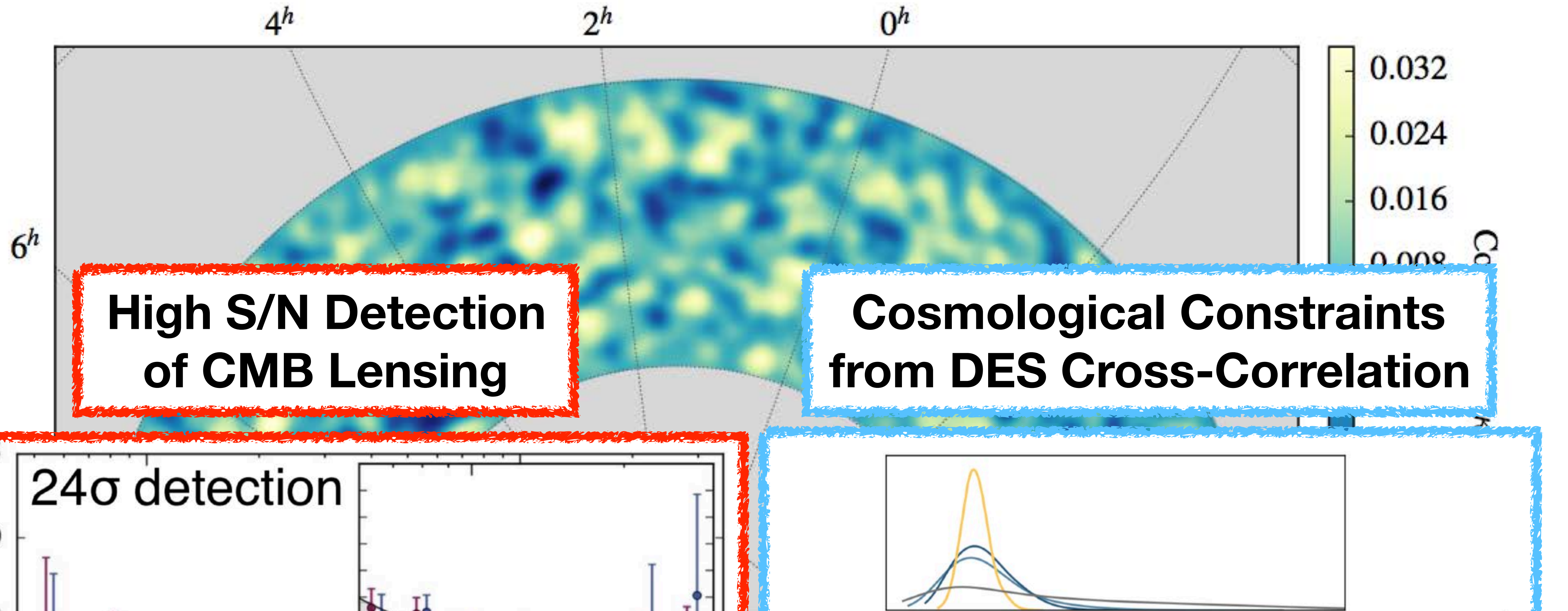


High S/N Detection of CMB Lensing



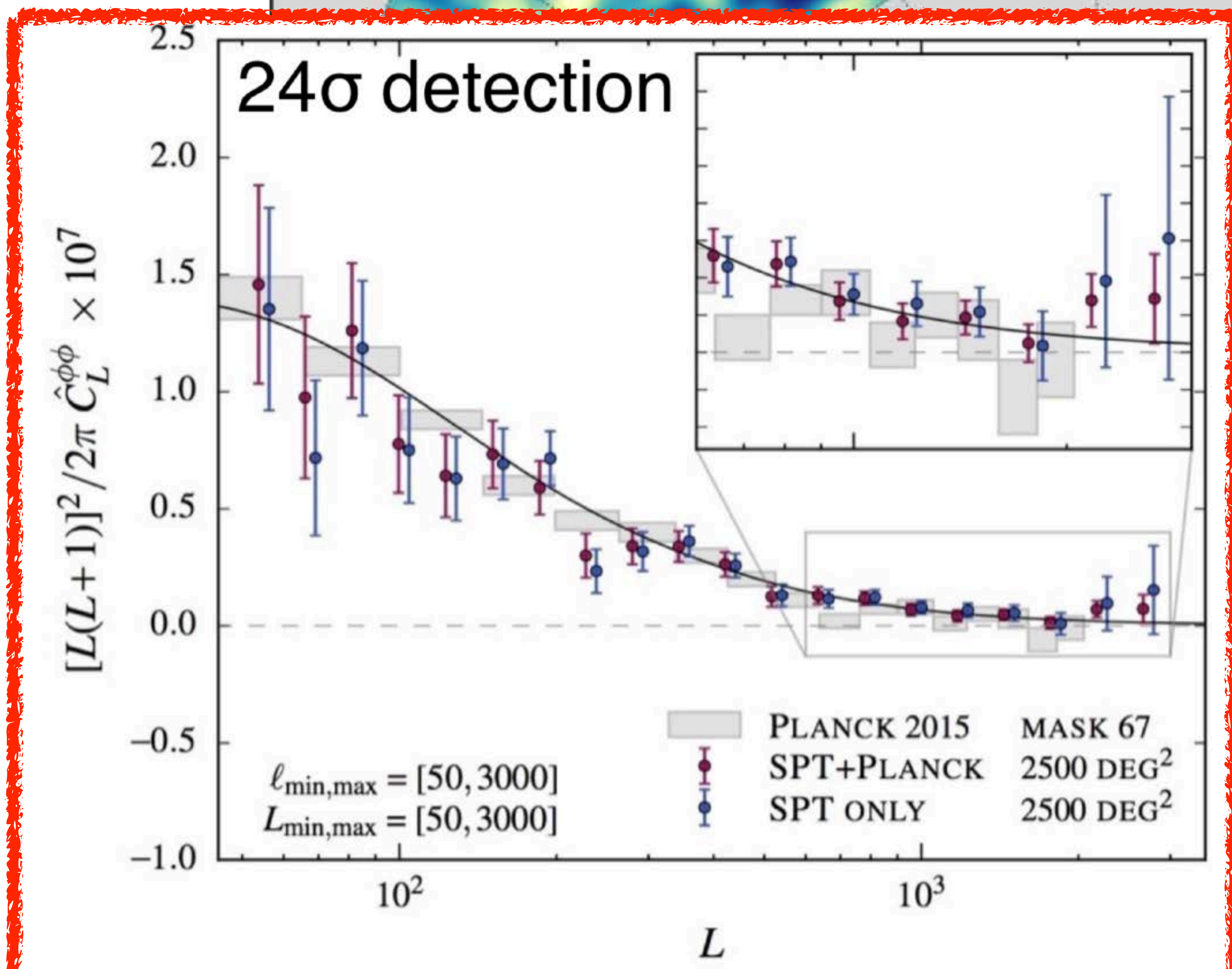
rojection. The map has been smoothed with a Gaussian kernel with

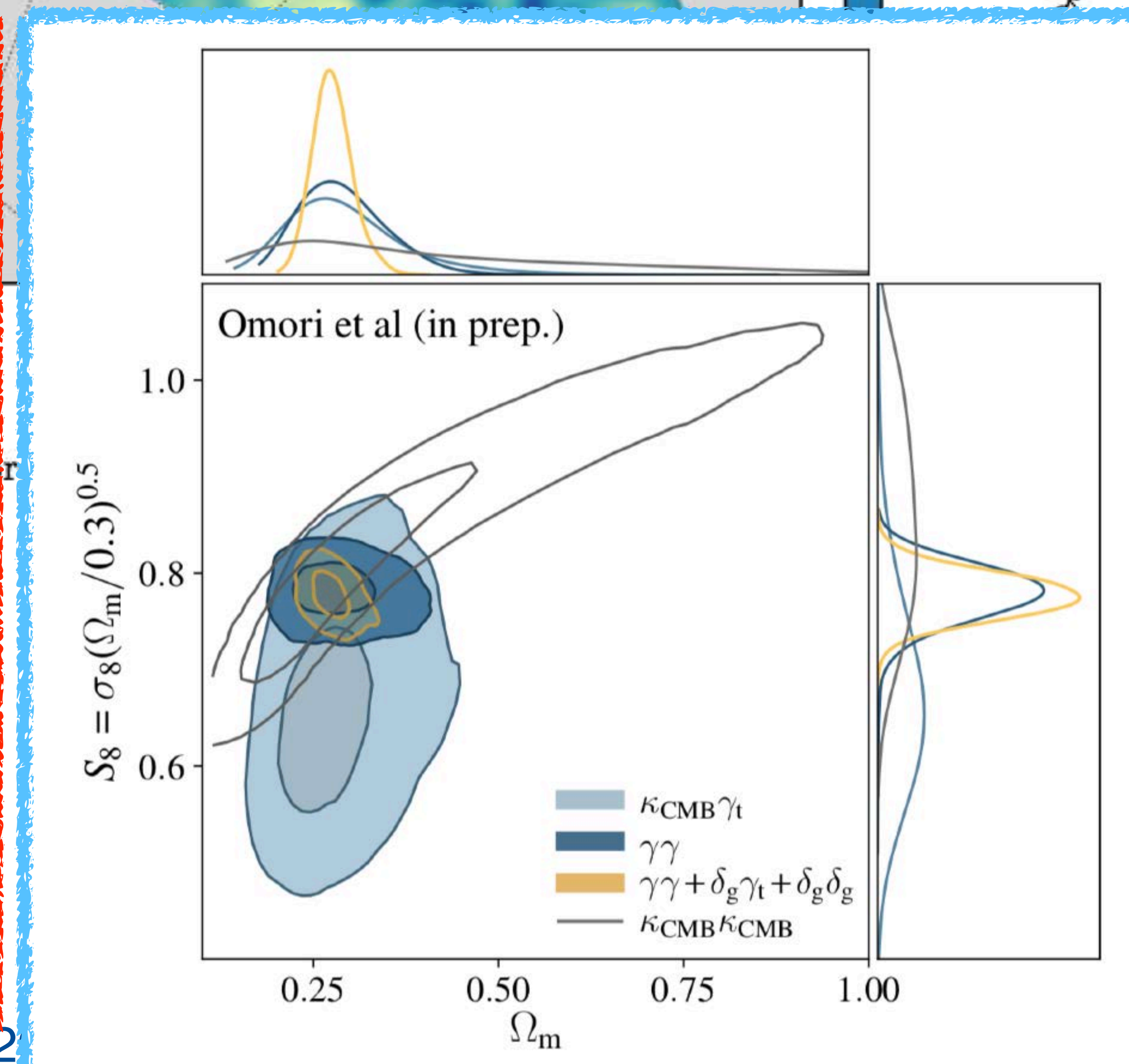
CMB TT Lensing: Planck + SPT



High S/N Detection of CMB Lensing

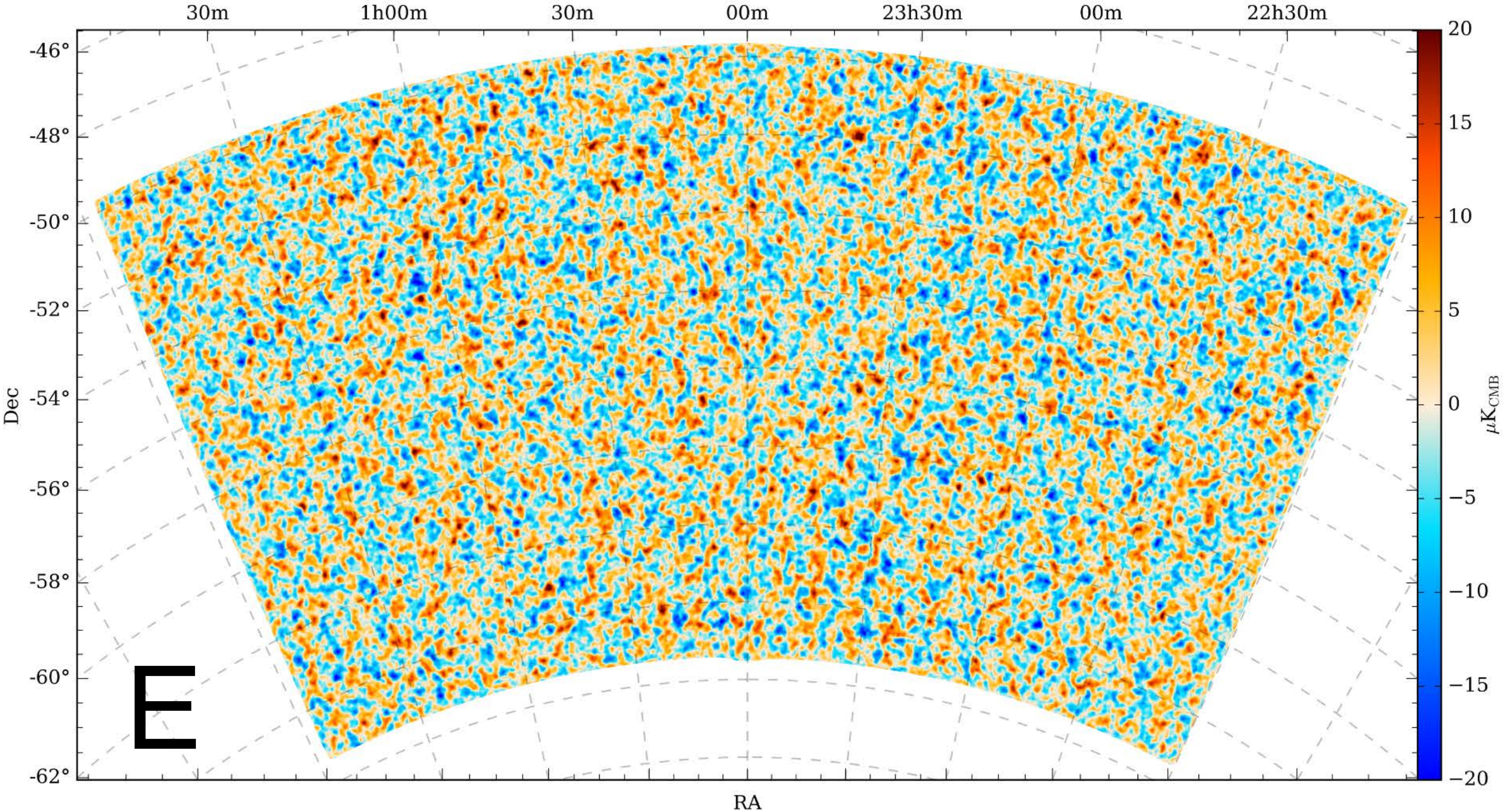
Cosmological Constraints from DES Cross-Correlation





(SPT) Omori et al. (2017) 1705.00743

SPTpol Polarization

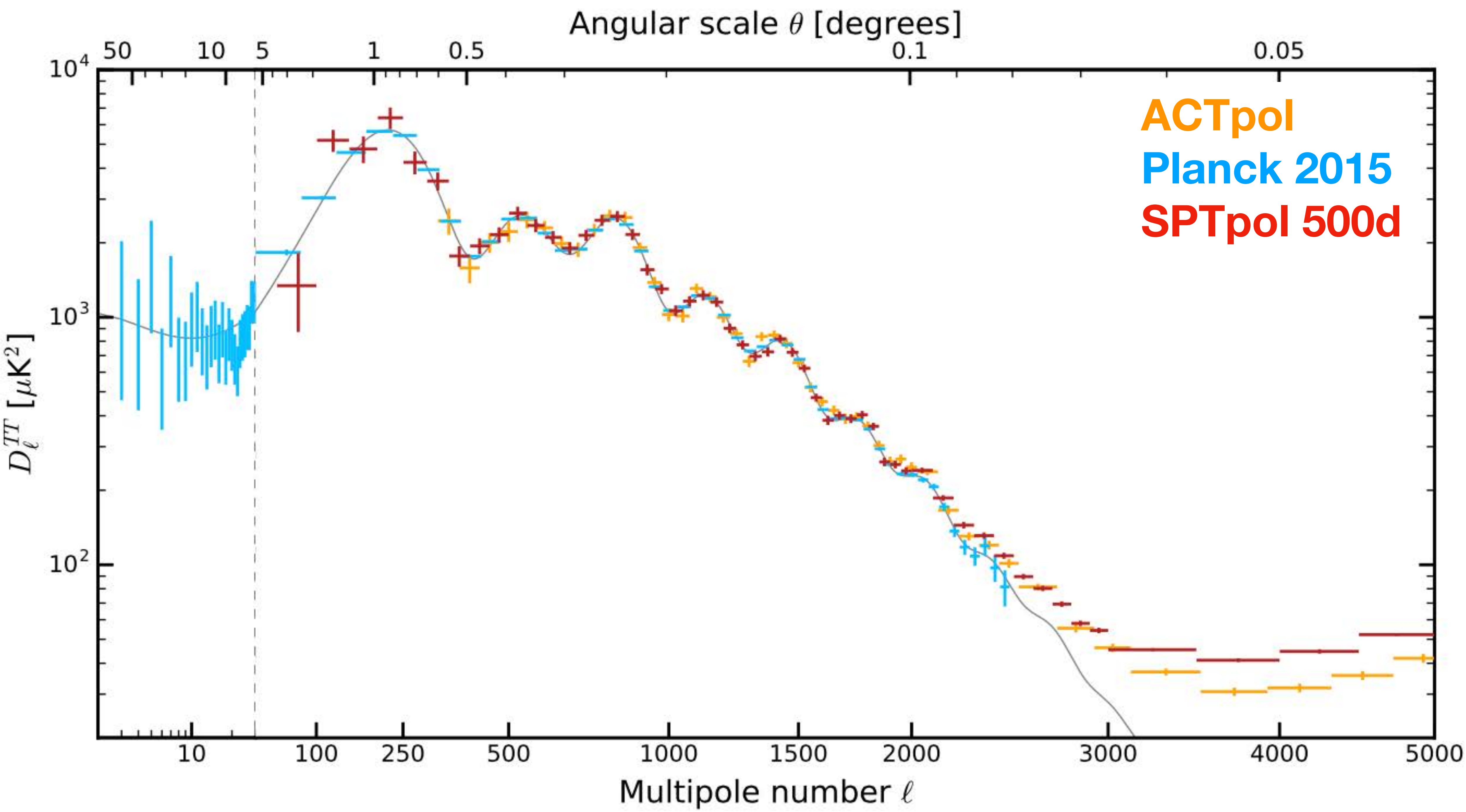


SPTpol 150 GHz

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

Henning et al. (2017) 1707.09353

SPTpol Temperature Power Spectrum

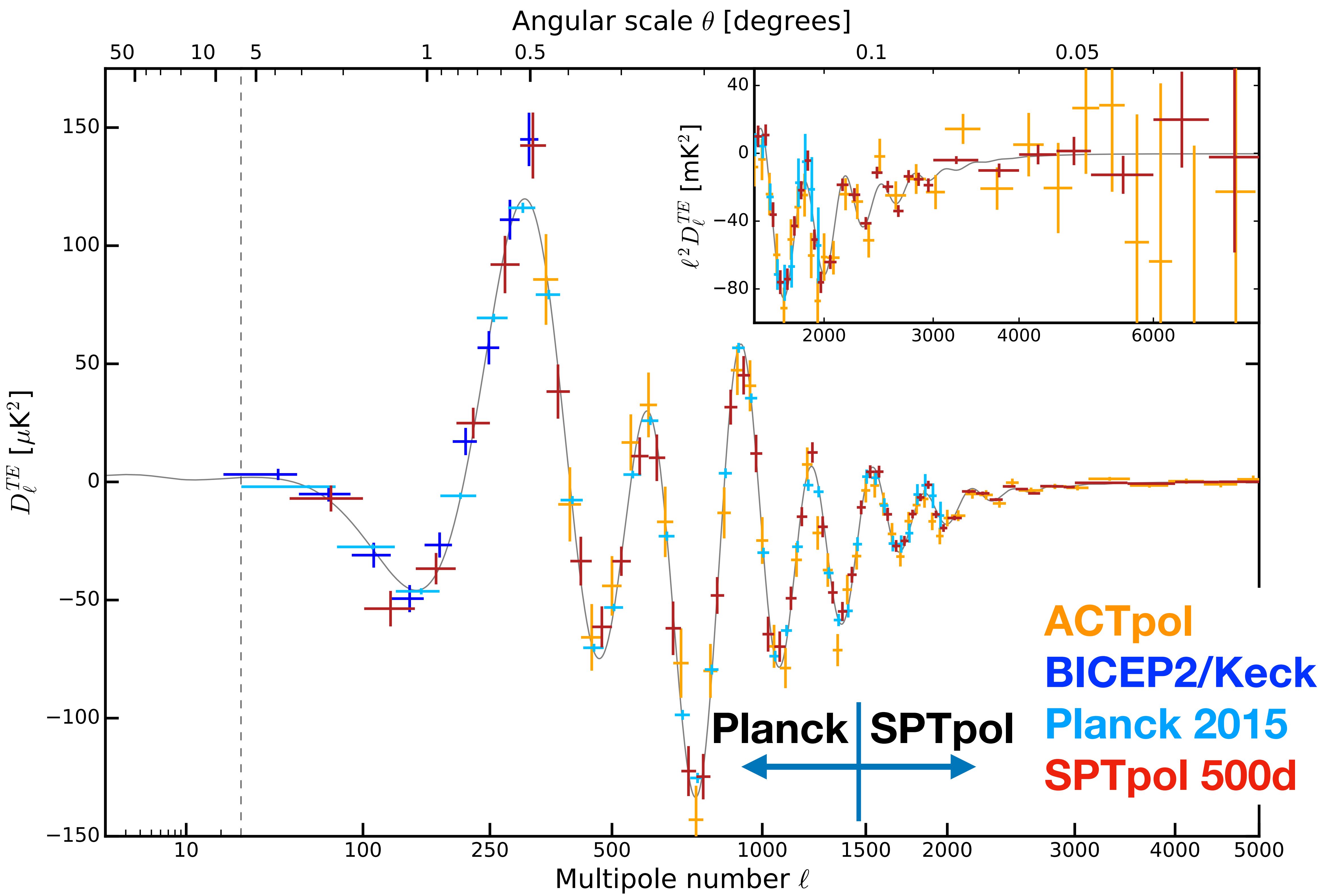


- SPTpol Temperature power spectrum from 50 < ℓ < 8000

- Lowest ℓ measurements reported from SPT

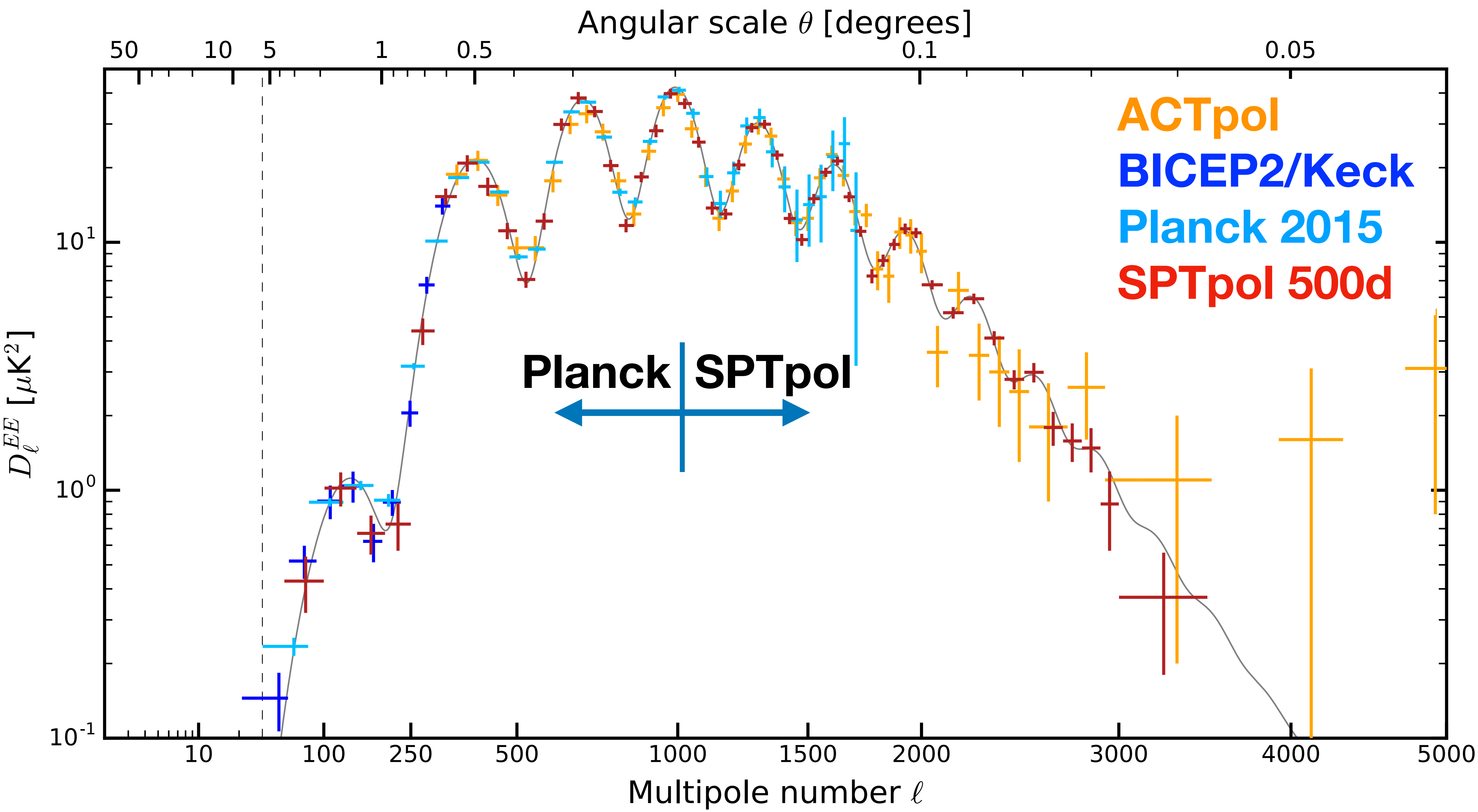
Henning et al. (2017) 1707.09353

SPTpol TE Power Spectrum



Henning et al. (2017) 1707.09353

SPTpol: Polarization Power Spectrum

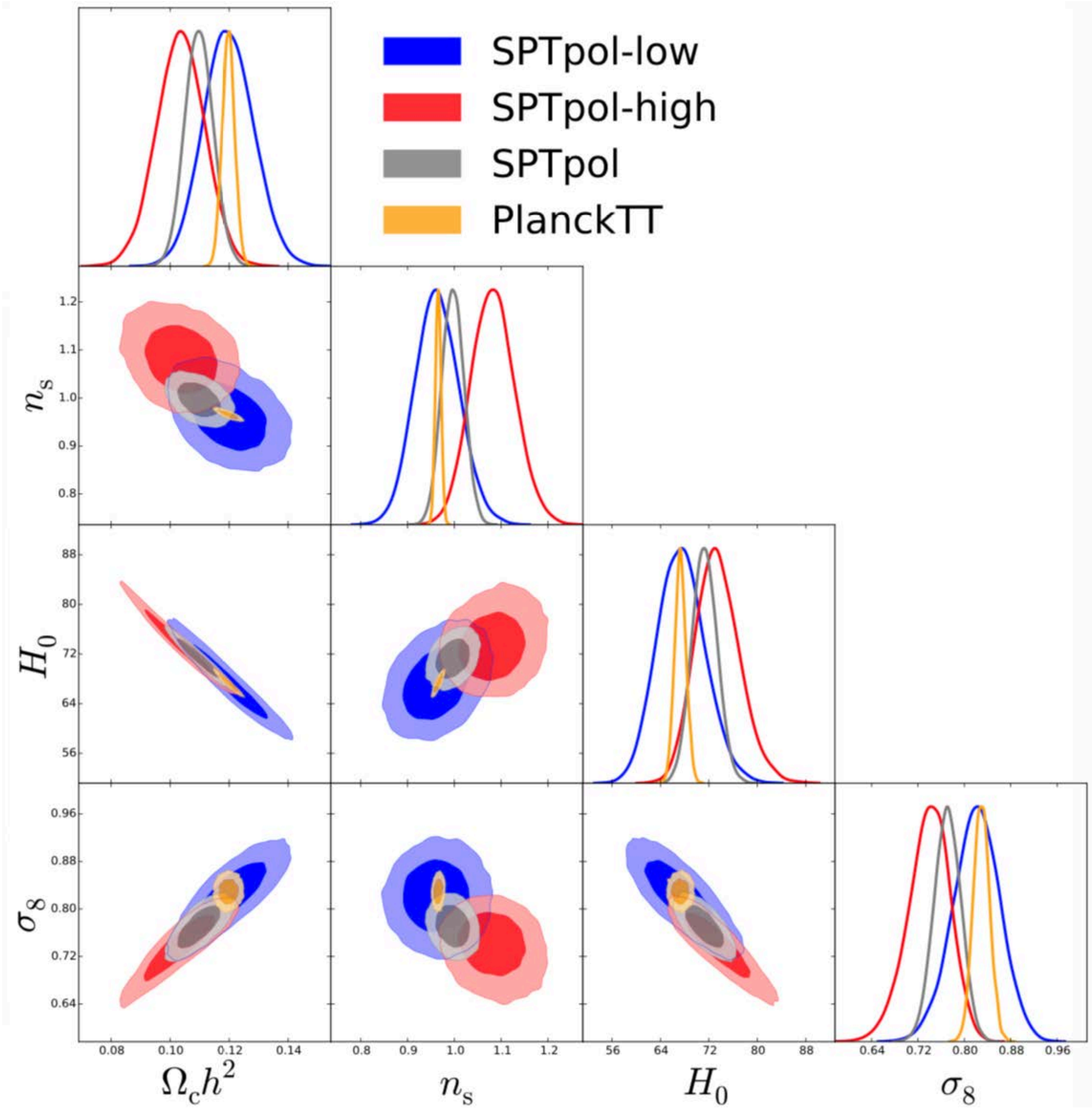


- Most precise constraints on EE, TE spectrum at ℓ > 1050 and > 1475, respectively.
  - EE Point source power limit: $D_\ell^{PS} < 0.1\ \mu K^2$ at 95% confidence
- ***9 acoustic peaks measured in TE, EE spectrum!***

Henning et al. (2017) 1707.09353

SPTpol: LCDM Constraints

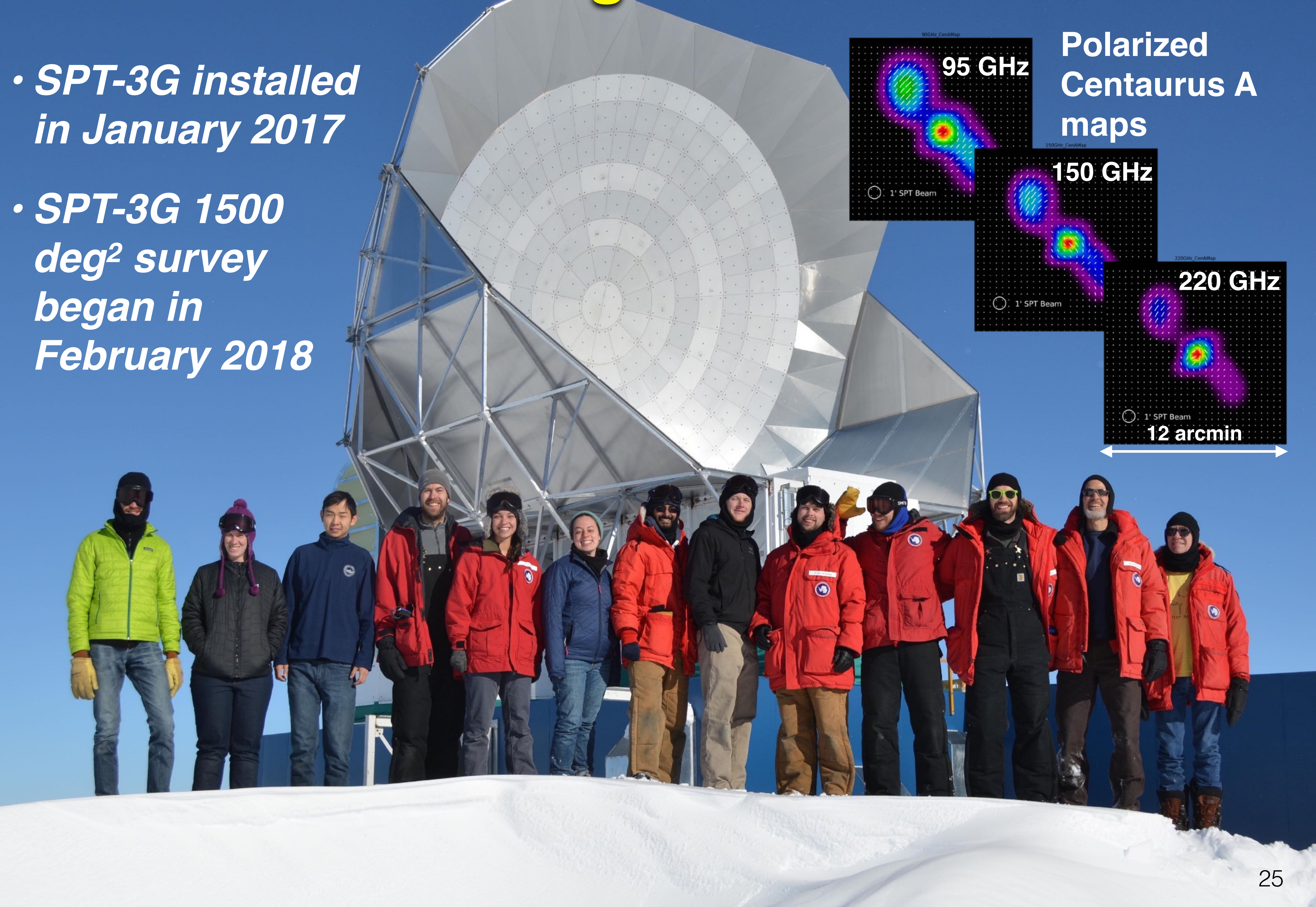
- SPTpol low-ell ($\ell < 1000$) data in good agreement with Planck cosmology
- Adding SPTpol hi-ell ($\ell < 1000$) data pushes σ_8 2.1-σ and H_0 1.7 σ higher than Planck TT:
  - $\sigma_8 = 0.770 +/- 0.023$
  - $H_0 = 71.2 +/- 2.1$ km s^{-1} Mpc^{-1}
  - ***Will need to re-visit these results with new Planck 2018 data to see effects of pol-calibration and tau!***
- SPTpol 500d data reduces $\Lambda CDM+N_{eff}$ parameter volume by factor of ~3 when added to Planck



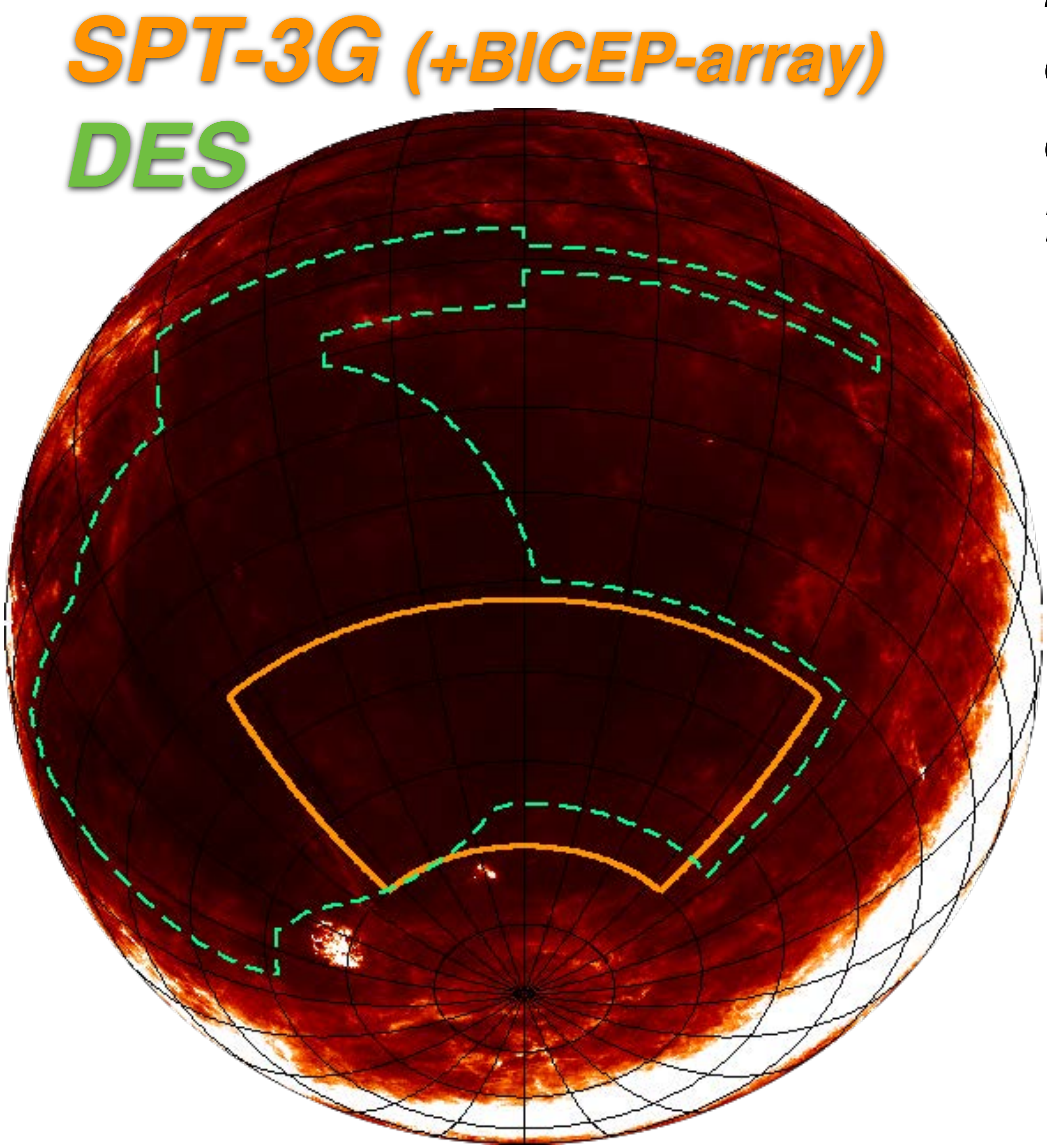
Henning et al. (2017) 1707.09353

SPT-3G "First Light" for 2018 Season

- *SPT-3G installed in January 2017*
- *SPT-3G 1500 deg² survey began in February 2018*



The SPT-3G 1500 deg² Survey



New SPT-3G 1500 deg2 survey overlaps with BICEP-array, to optimize Inflation r-constraints from CMB-de-lensing

	Obs. Years	Area (deg^2)	95 GHz (uK-arcmin)	150 (uK-arcmin)	220 (uK-arcmin)
SPT-SZ	**2007-11**	**2500**	**40**	**17**	**80**
SPTpol-Main	**2012-16**	**500**	**12**	**5**	**-**
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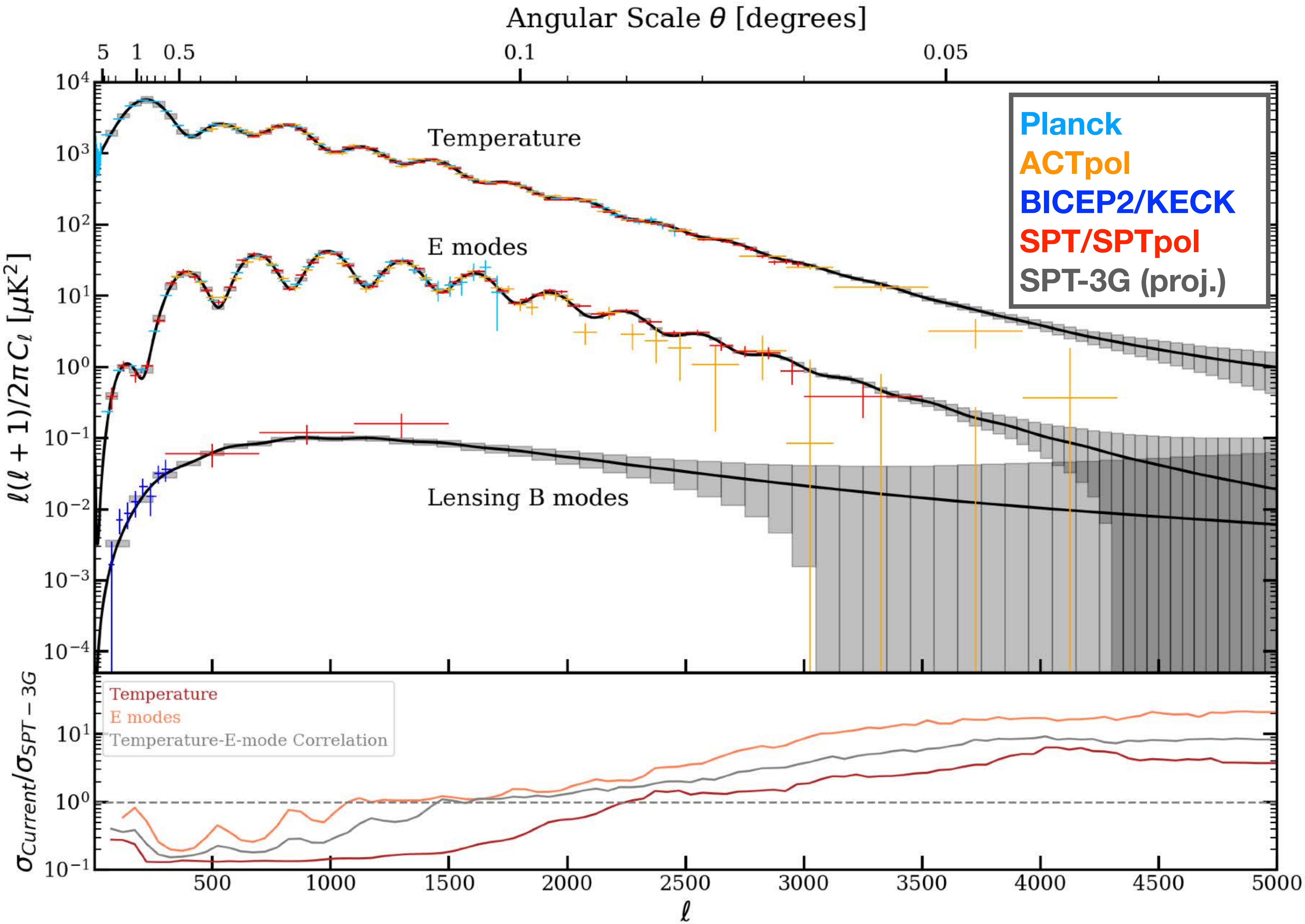
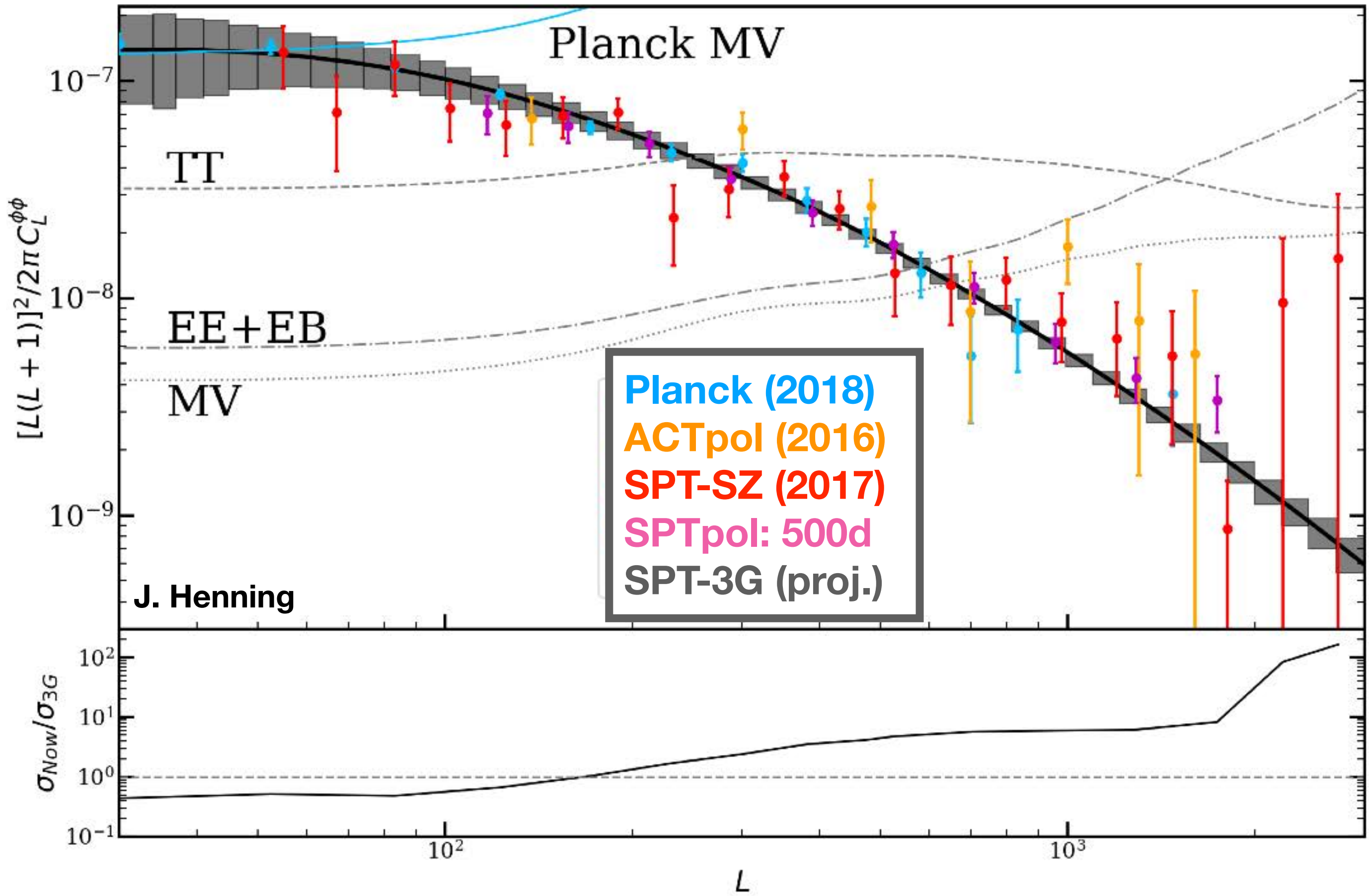
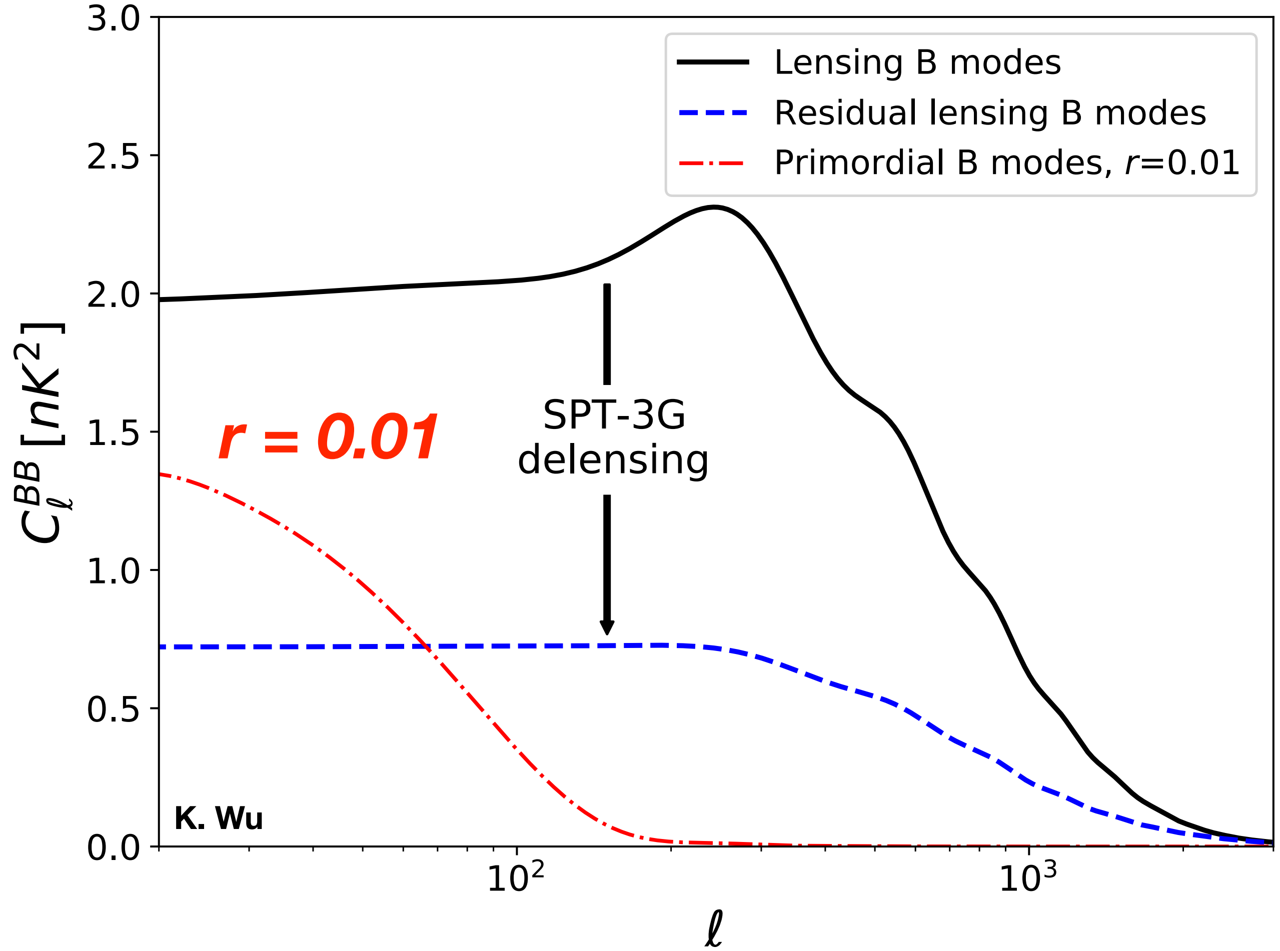
SPT-3G ***(projected)***	**2017-23**	**1500**	**3.0**	**2.2**	**8.8**

SPT-3G: CMB Power Spectra



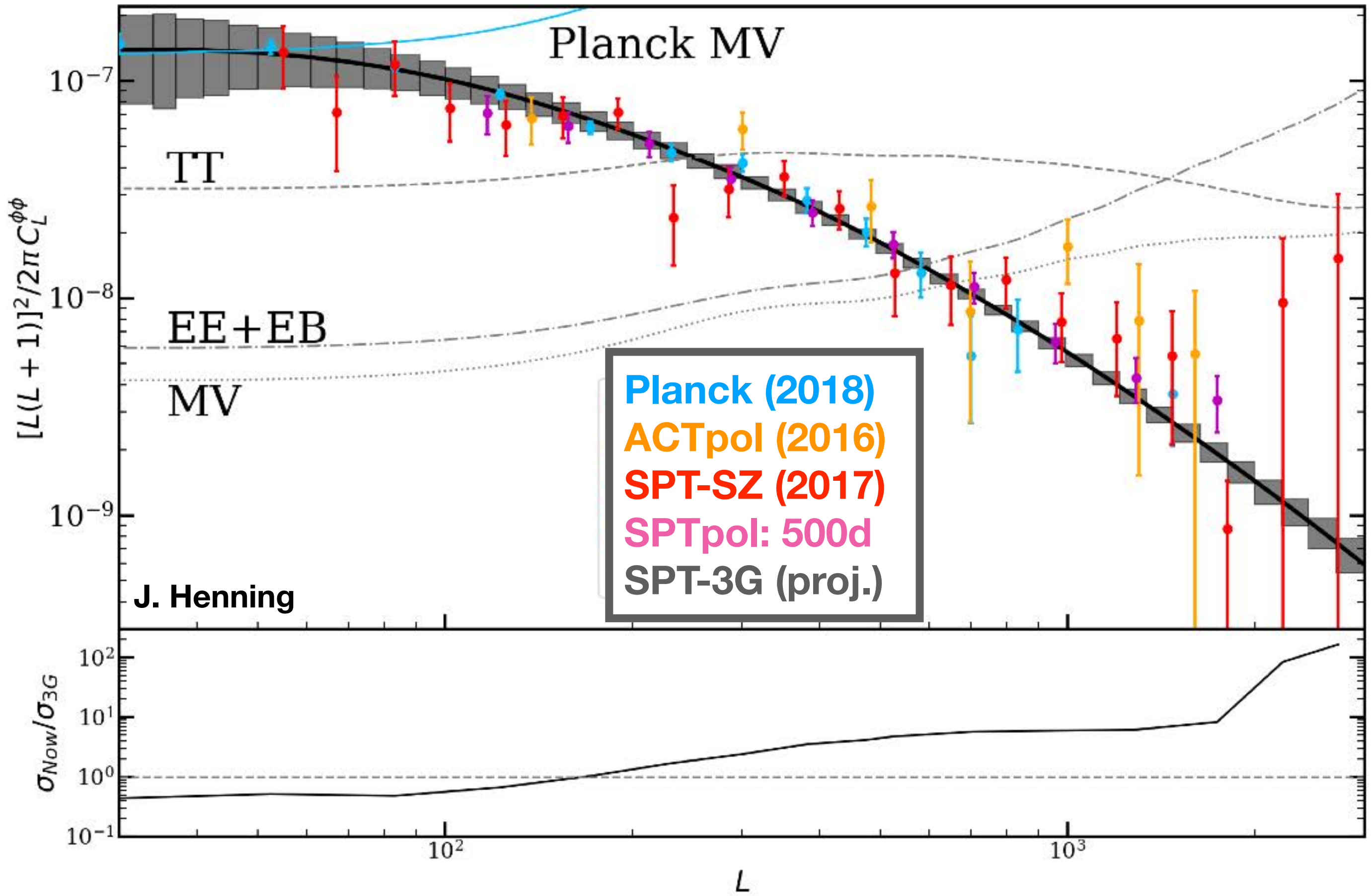
SPT-3G: Inflation and De-lensing

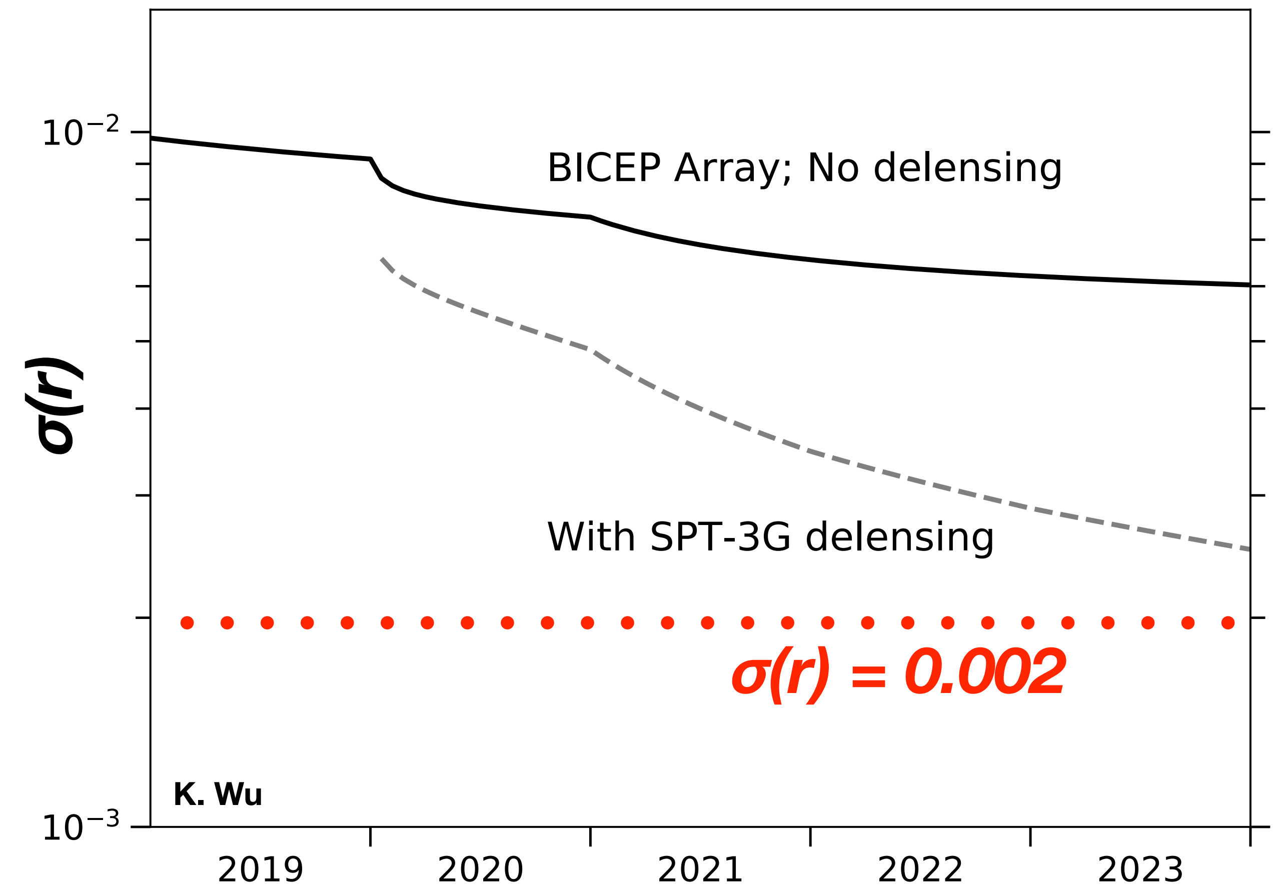




- ***Deep polarization data provides high S/N lensing maps, measures lensing modes with S/N>1 out to L~700 over 1500 deg². Ideal for:***
  - Cross-correlation with optical surveys (DES, LSST, Euclid)
  - CMB cluster lensing
  - CMB de-lensing to better constrain Inflationary B-modes.
    - ***Joint BICEP-array, SPT-3G constrains achieves σ(r) ~ 0.0025***

SPT-3G: Inflation and De-lensing





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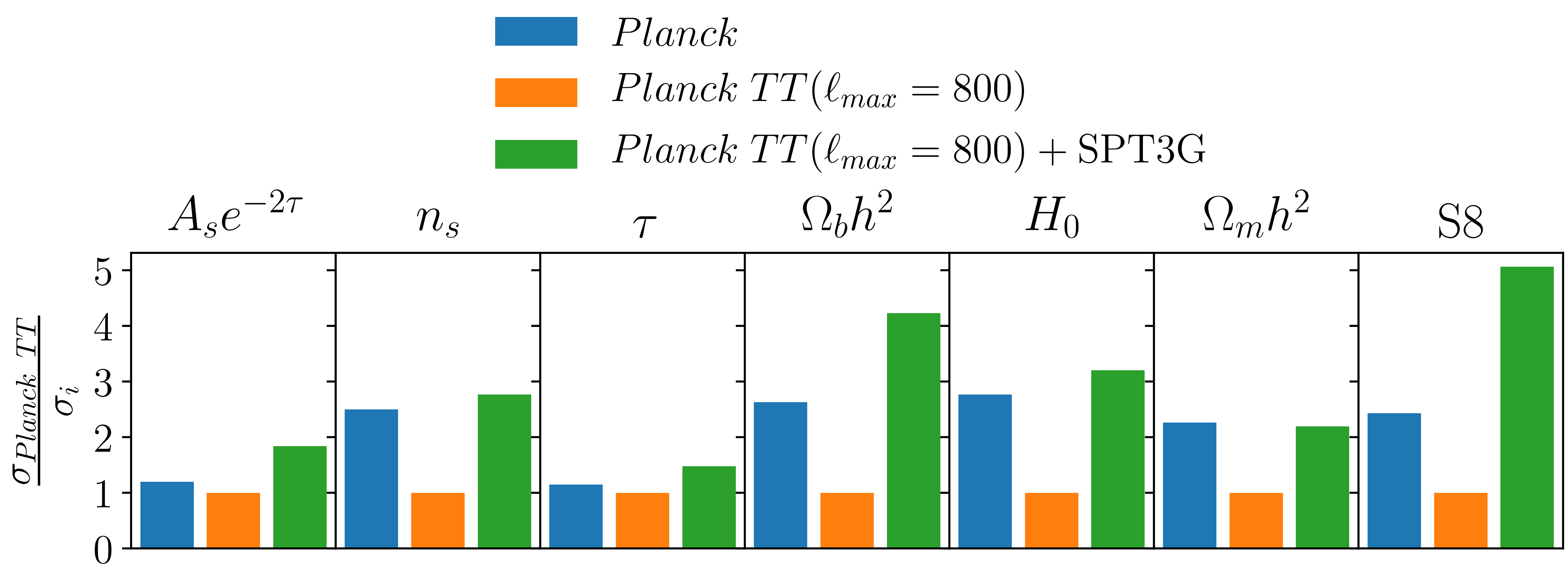
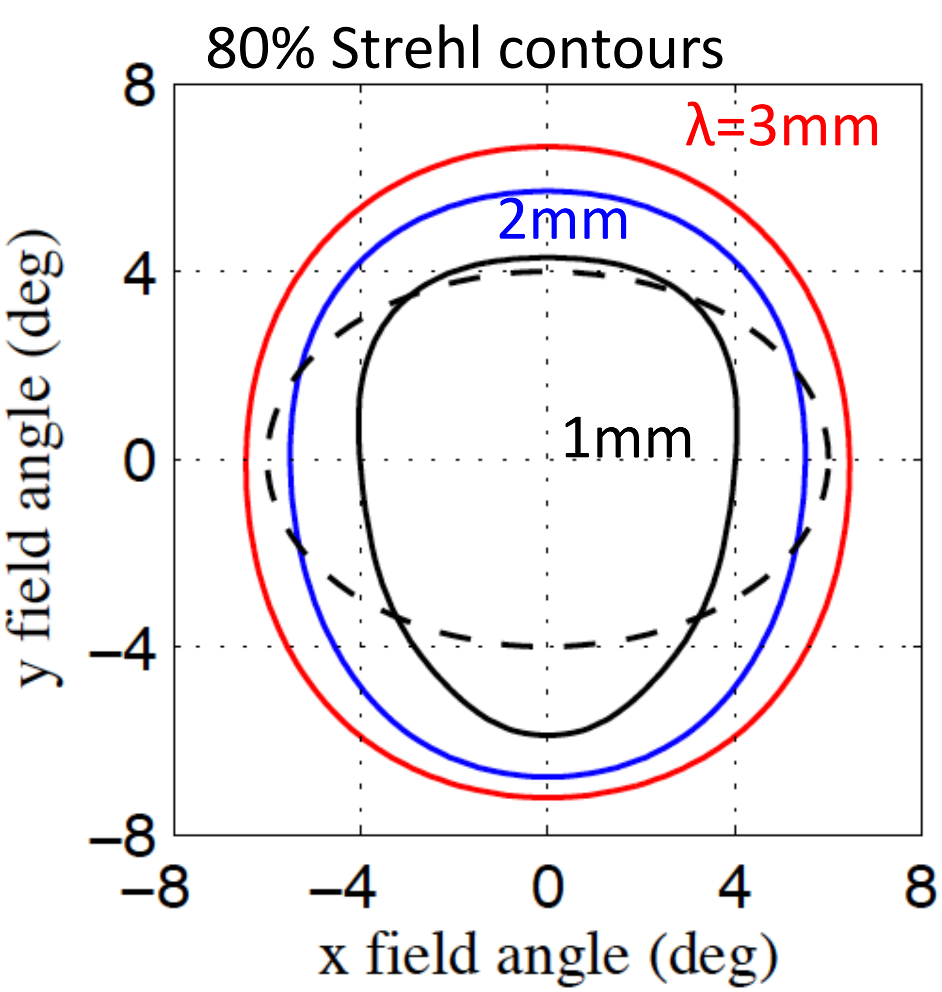
SPT-3G: Cracks in LCDM Cosmology?

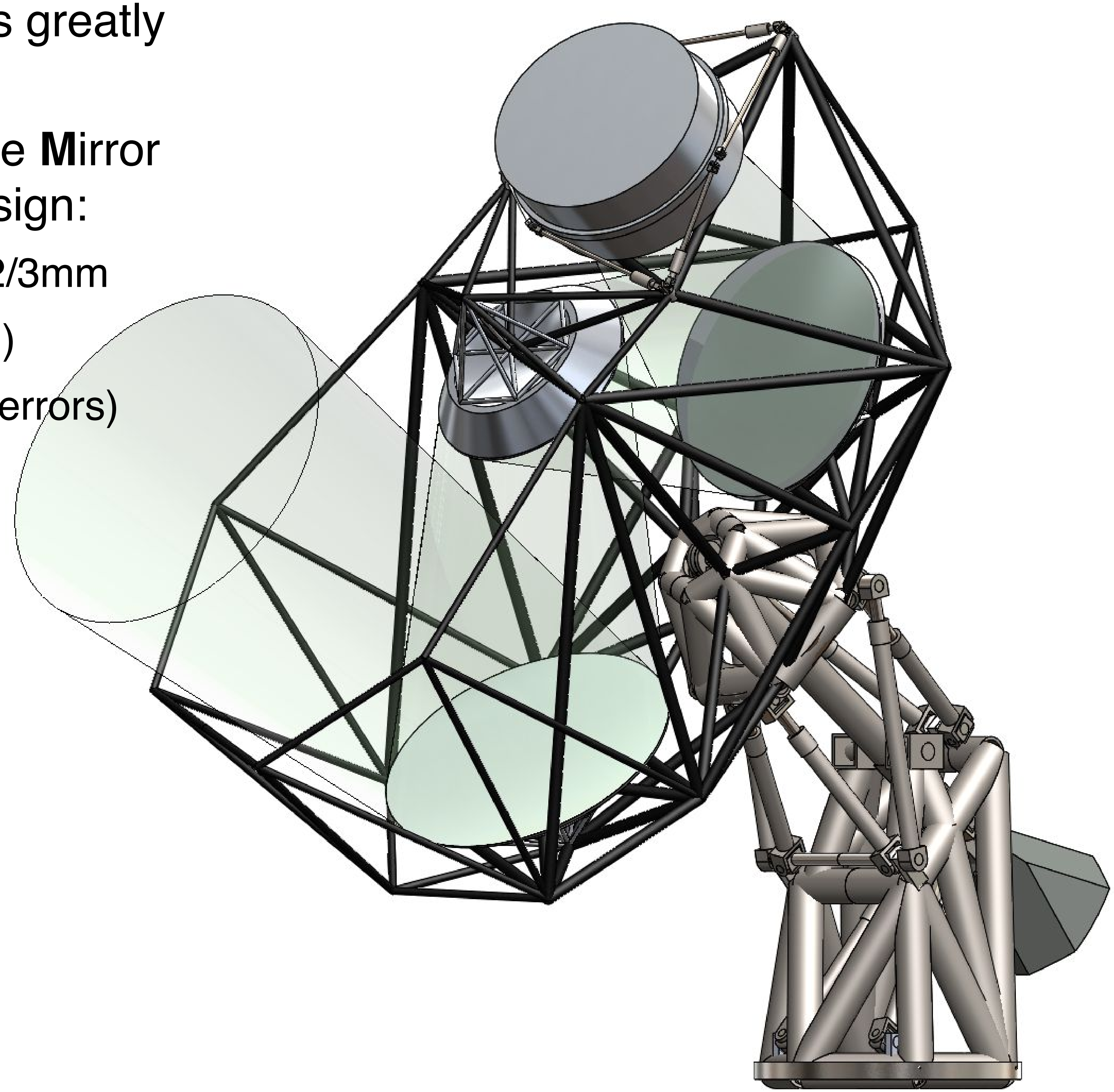


- New SPT-3G polarization data will offer cross-check of LCDM cosmology, from new constraints at high-ℓ, polarization and lensing power spectrum.
  - ***SPT-3G + Planck TT (ℓ < 800) will have more constraining power than full Planck data set on base LCDM parameters***
  - *Improved CMB constraints on LCDM extension parameters (e.g., neutrino mass, effective number of relativistic species, primordial Helium)*

Future Surveys from the South Pole

- Next scientific advances requires greatly improved throughput.
- Investigating novel 5-meter **T**hree **M**irror **A**nastigmat (**TMA**) telescope design:
  - 424k/136k/63k Fλ pixels at λ=1/2/3mm
  - Monolithic mirrors (low scattering)
  - Boresight rotation (measure pol. errors)
  - Comoving baffle (low pickup)





Padin, Applied Optics, 57, 9, 2314 2018
https://www.osapublishing.org/ao/upcoming_pdf.cfm?id=320108

SPT Summary

- **SPT is providing exciting new results on Astrophysics:**
  - Hi-z star-forming galaxies
  - Cluster cosmology and astrophysics
  - mm-wave transients
- **New high-l constraints on CMB polarization:**
  - Slight tension with Planck/LCDM from SPTpol TE/EE spectrum
  - New SPTpol results soon on:
    - CMB lensing, B-mode, updated TT/TE/EE power spectra, ….
- **Future from South Pole is bright!**
  - Broad science goals from SPT-3G survey
  - Joint constraints between BICEP-array and SPT-3G on Inflation, De-lensing
  - Future large aperture survey instrument
  - Planning for future collaborations with Planck experts!