ALEXANDRA RAHLIN

COSMOLOGY WITH SPT-3G AND BEYOND

SPT3G COLLABORATION

Argonne NATIONAL LABORATORY

Kavli Institute for Cosmological Physics AT THE UNIVERSITY OF CHICAGO

Berkeley University of California

Case Western Reserve University

McGill

Colorado University of Colorado at Boulder

SLAC National Accelerator Laboratory

NIST

Berkeley Lab

THE UNIVERSITY OF CHICAGO

LMU Ludwig-Maximilians-Universität München

Harvard-Smithsonian Center for Astrophysics

University of Illinois

Stanford University

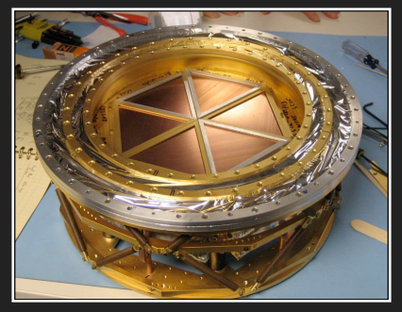
Cardiff University / Prifysgol Caerdydd

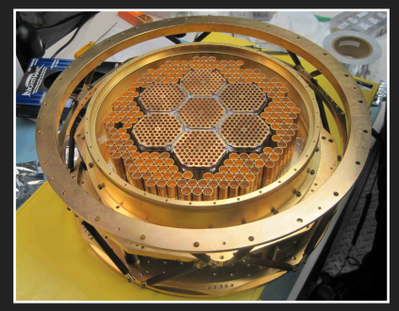
UC Davis University of California

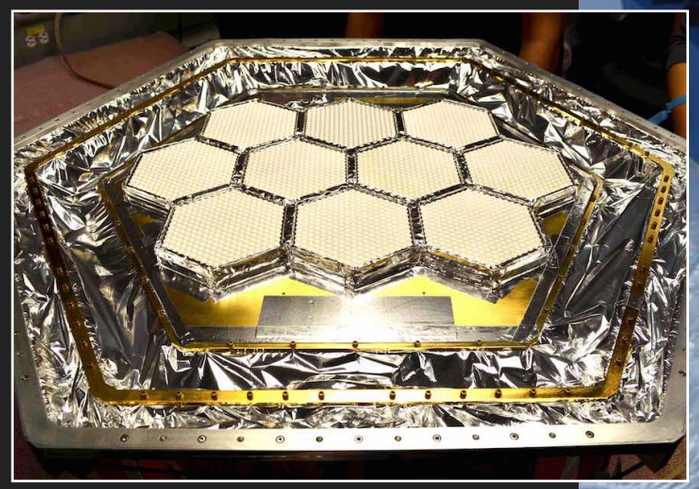
Fermilab

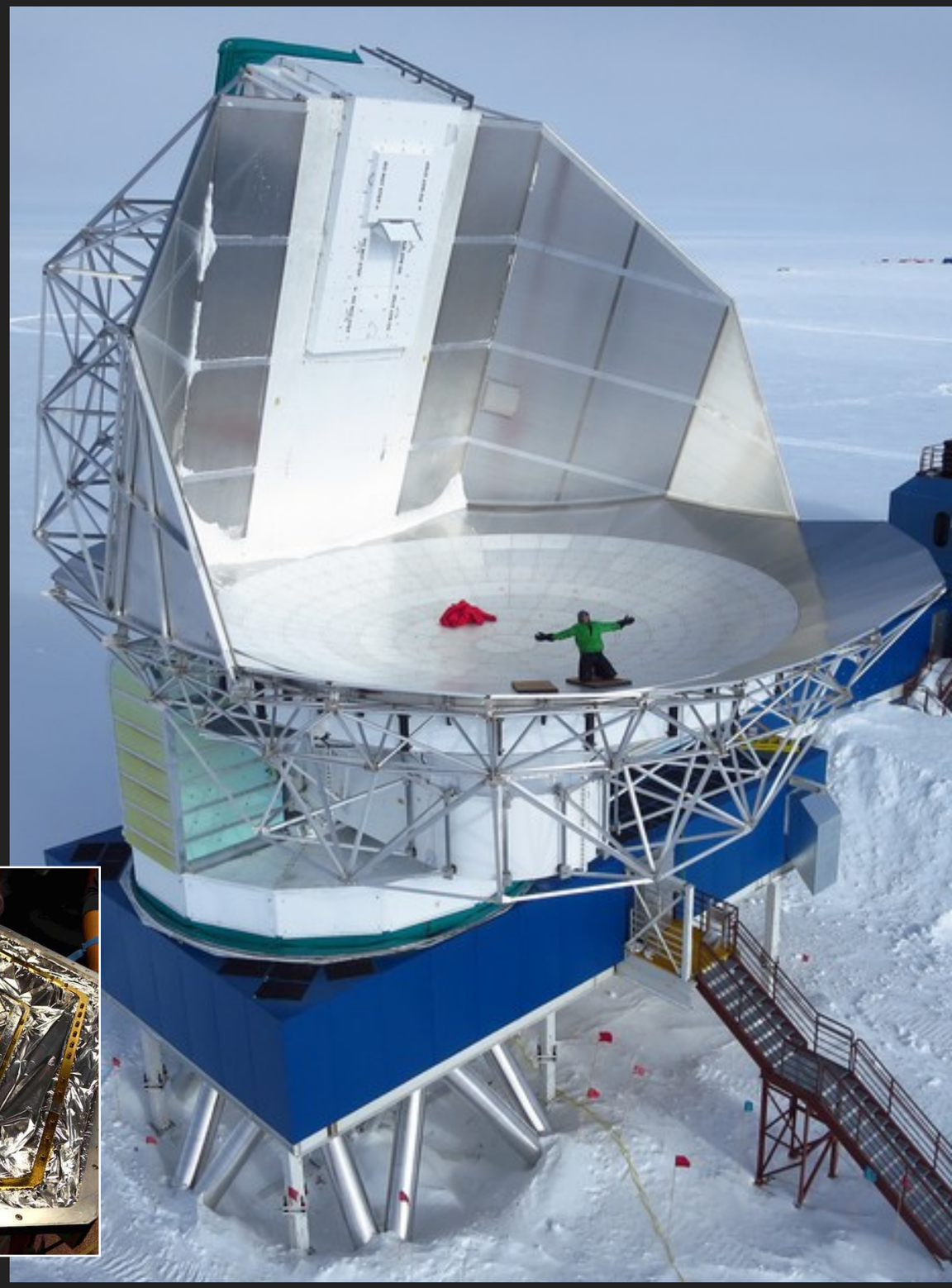
THE SOUTH POLE TELESCOPE

- 10-m submm-quality wavelength telescope
  - 90, 150, 220 GHz
  - 1.6, 1.2, 1.0 arcmin resolution
- **2007: SPT-SZ**
  - 960 detectors
  - 90, 150, 220 GHz
- **2012: SPTpol**
  - 1600 detectors
  - 90, 150 GHz
  - +polarization
- **2017: SPT-3G**
  - ~16,200 detectors
  - 90, 150, 220 GHz
  - +polarization







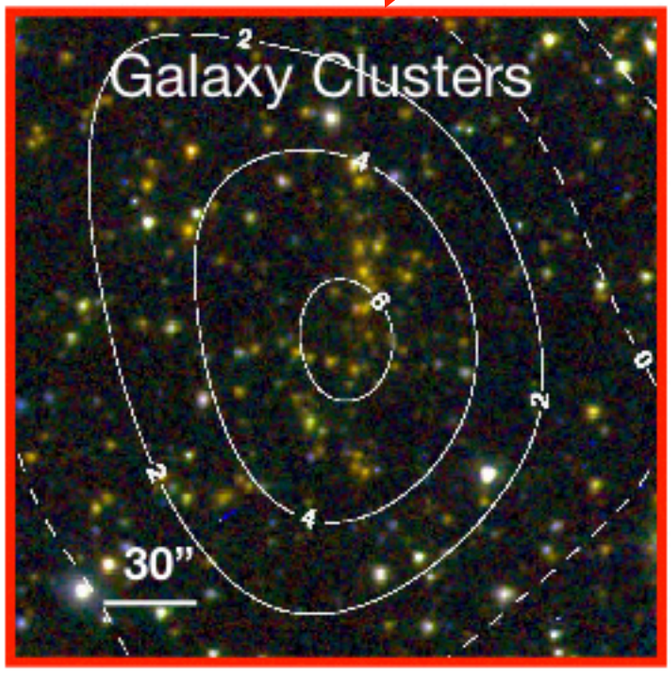


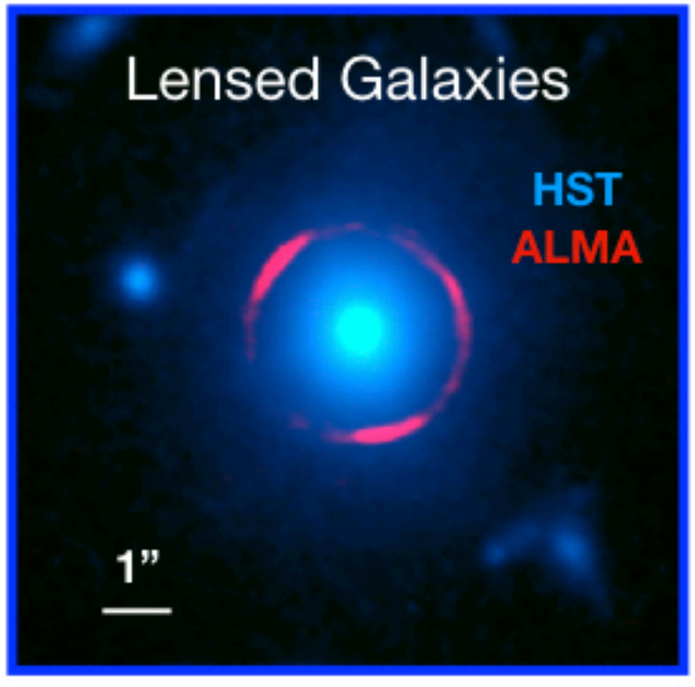
SPTpol

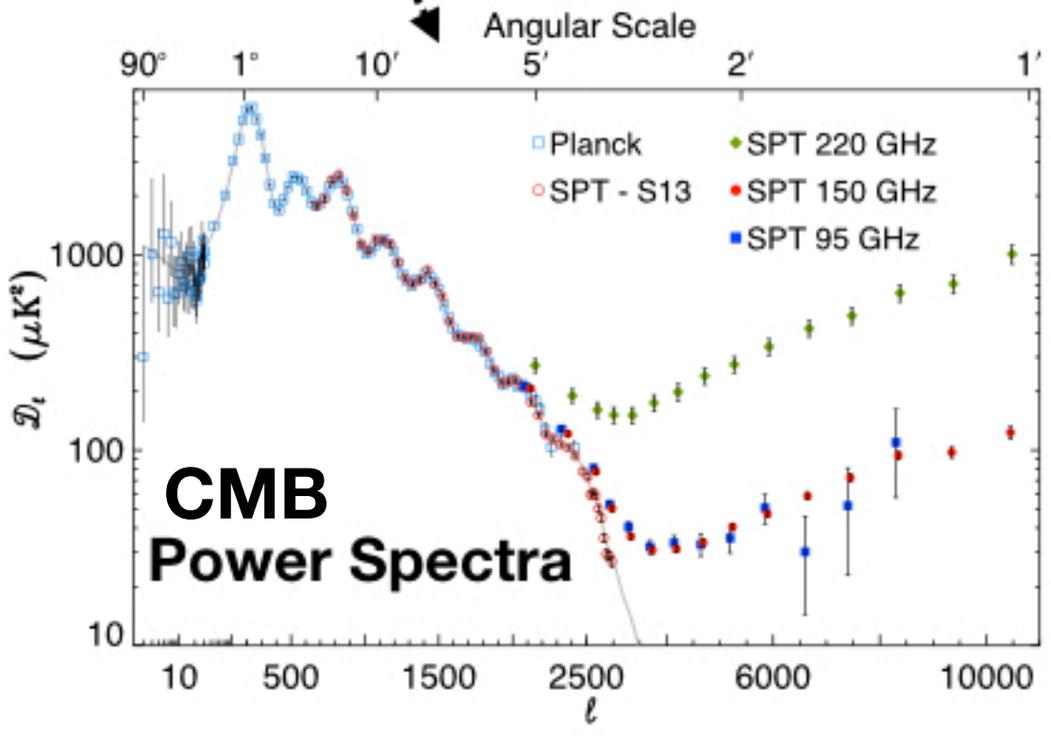
6x deeper
6x finer angular resolution

1°

Planck

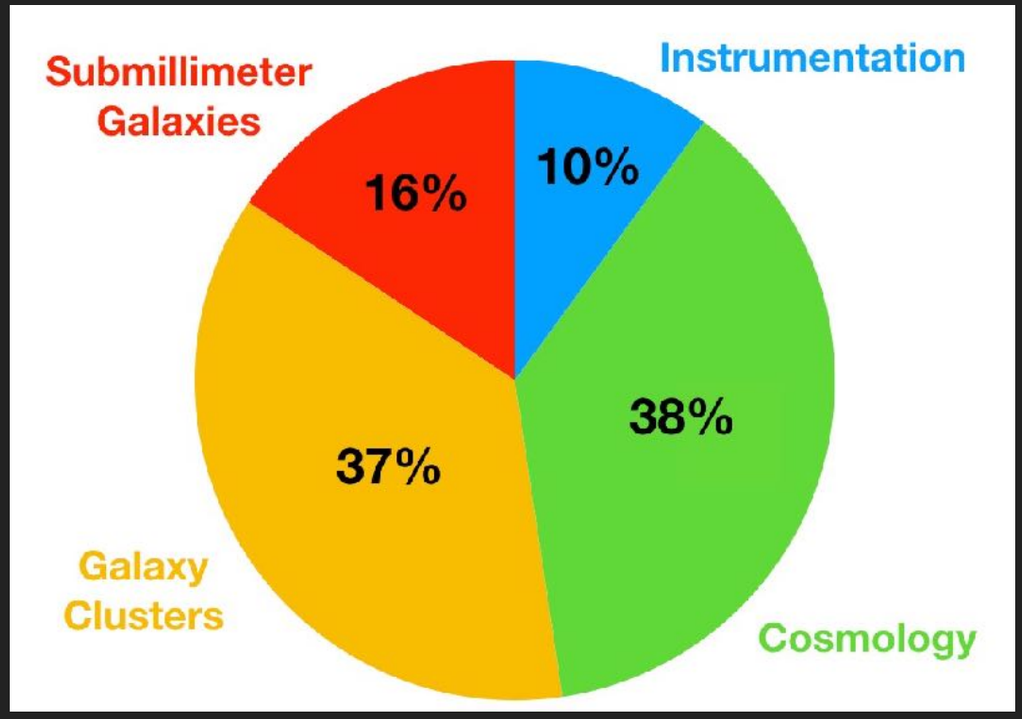






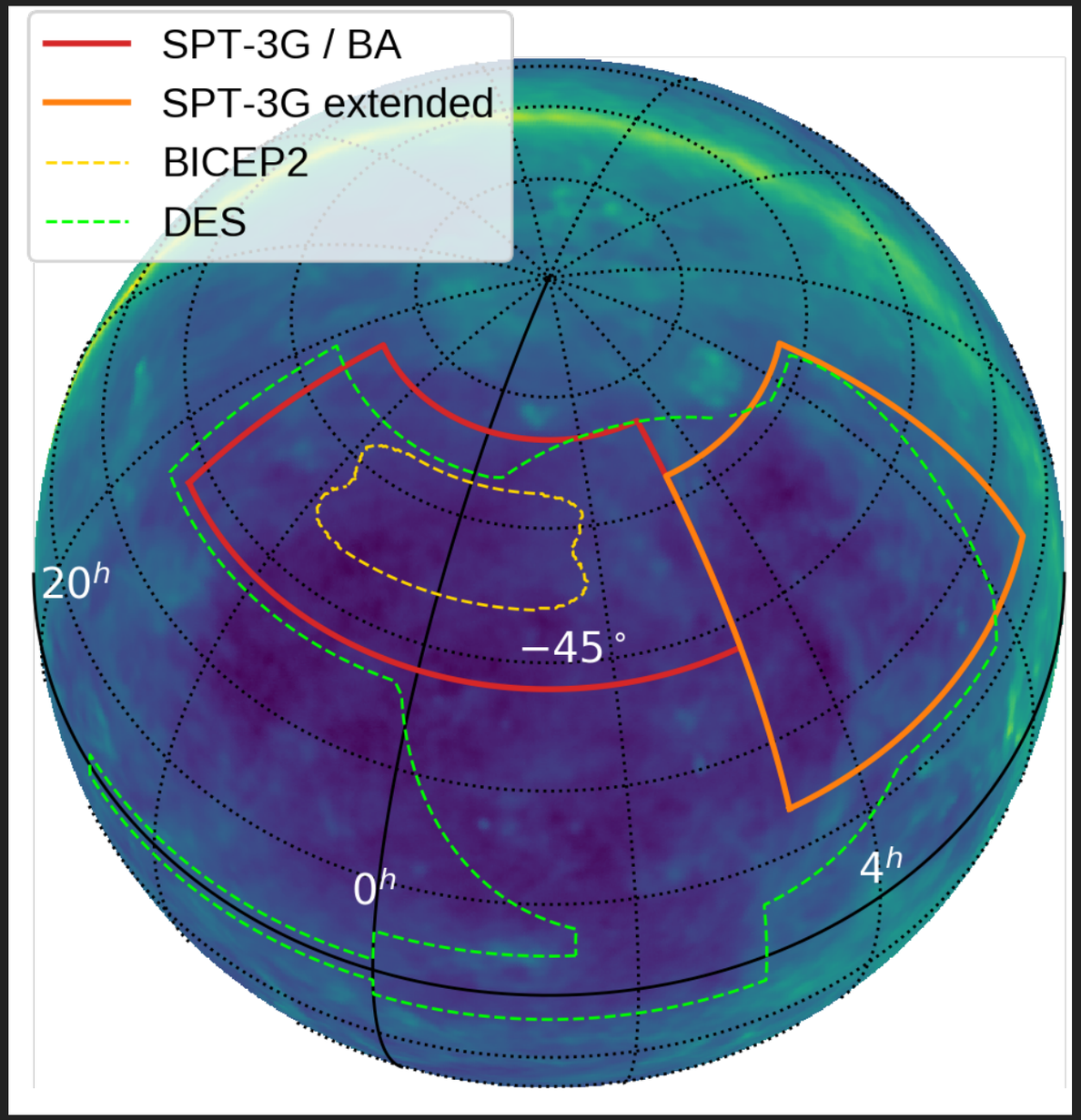
BREADTH OF SPT RESULTS (>130 SCIENCE PUBLICATIONS)

- **CMB anisotropy:** Power spectra and cosmological parameters
- **CMB B-Modes:** First detection of lensing B-mode polarization; demonstration of delensing for improved constraints on inflationary tensor-to-scalar ratio
- **CMB lensing:** power spectra; cross-correlations; cluster-lensing mass calibration
- **Sunyaev-Zel'dovich (SZ):** Diffuse kinematic and thermal SZ effect constraints: bispectrum, pairwise kSZ, patchy reionization
- **Galaxy Clusters:** First SZ discovery clusters, cluster catalog and cosmology
- **High-Redshift Galaxies**: Discovered population of lensed dusty star forming galaxies
- **Transients:** mm-wave phenomena (GRBs, FRBs), mJy-level monitoring of 1000s of blazars, AGNs
- Participating in the **Event Horizon Telescope**
- …



Publications: pole.uchicago.edu

THE SPT-3G 1500 DEG² SURVEY



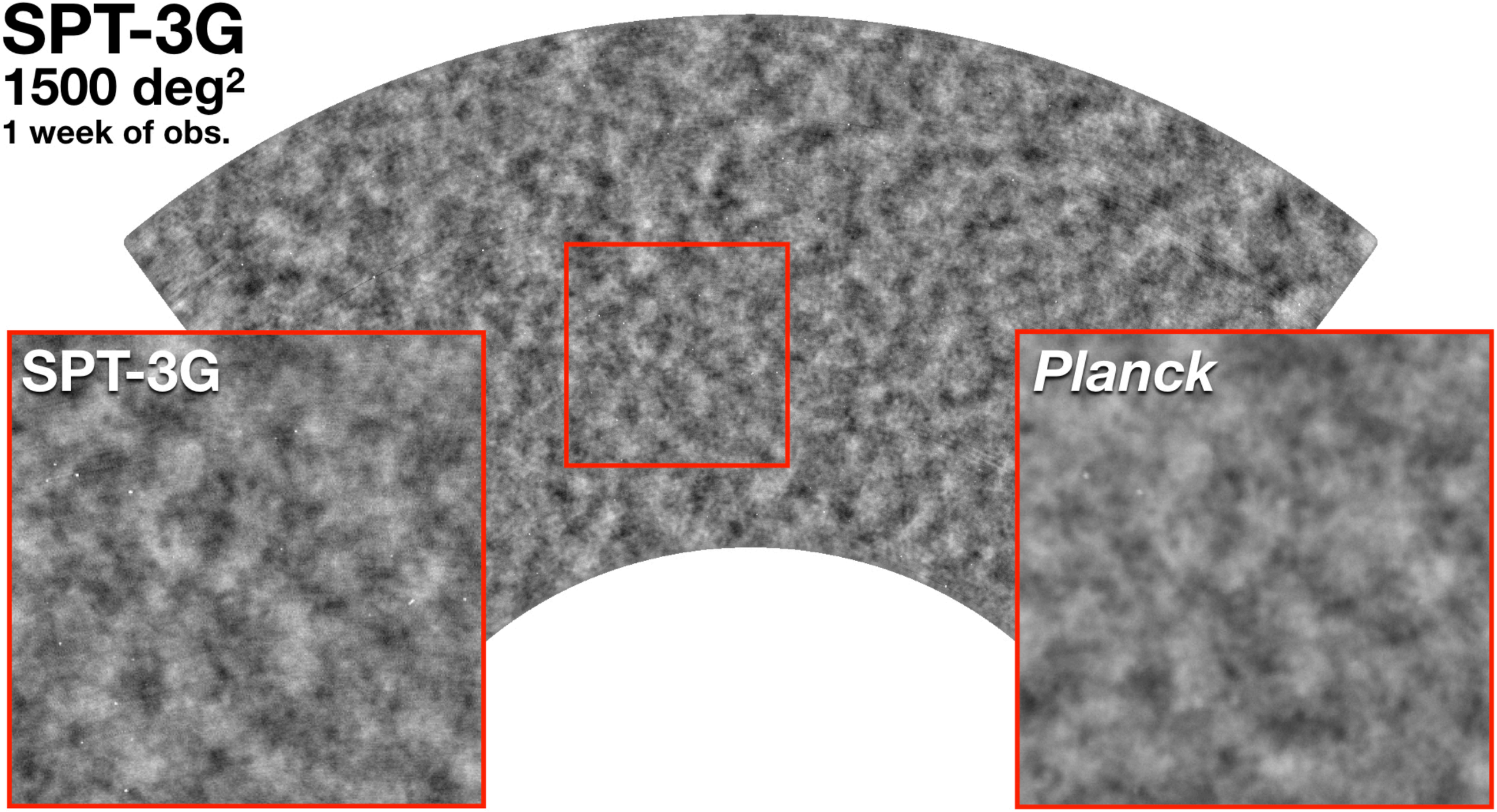
- SPT-3G 1500 deg² survey will be ~10x deeper than SPT-SZ
- Overlaps BICEP Array, to optimize inflationary constraints from CMB delensing

	Obs. Years	Area (deg²)	95 GHz (uK-arcmin)	150 (uK-arcmin)	220 (uK-arcmin)
SPT-SZ	2007-11	2500	40	17	80
SPTpol- 500d	2012-16	500	13	6	-
SPTpol- 100d	2012-16	100	10	5	-
SPTpol- 2700d	2012-16	2700	47	28	-
SPT-3G (projected)	***2018-23***	***1500***	***3.0***	***2.2***	***8.8***

SPT-3G

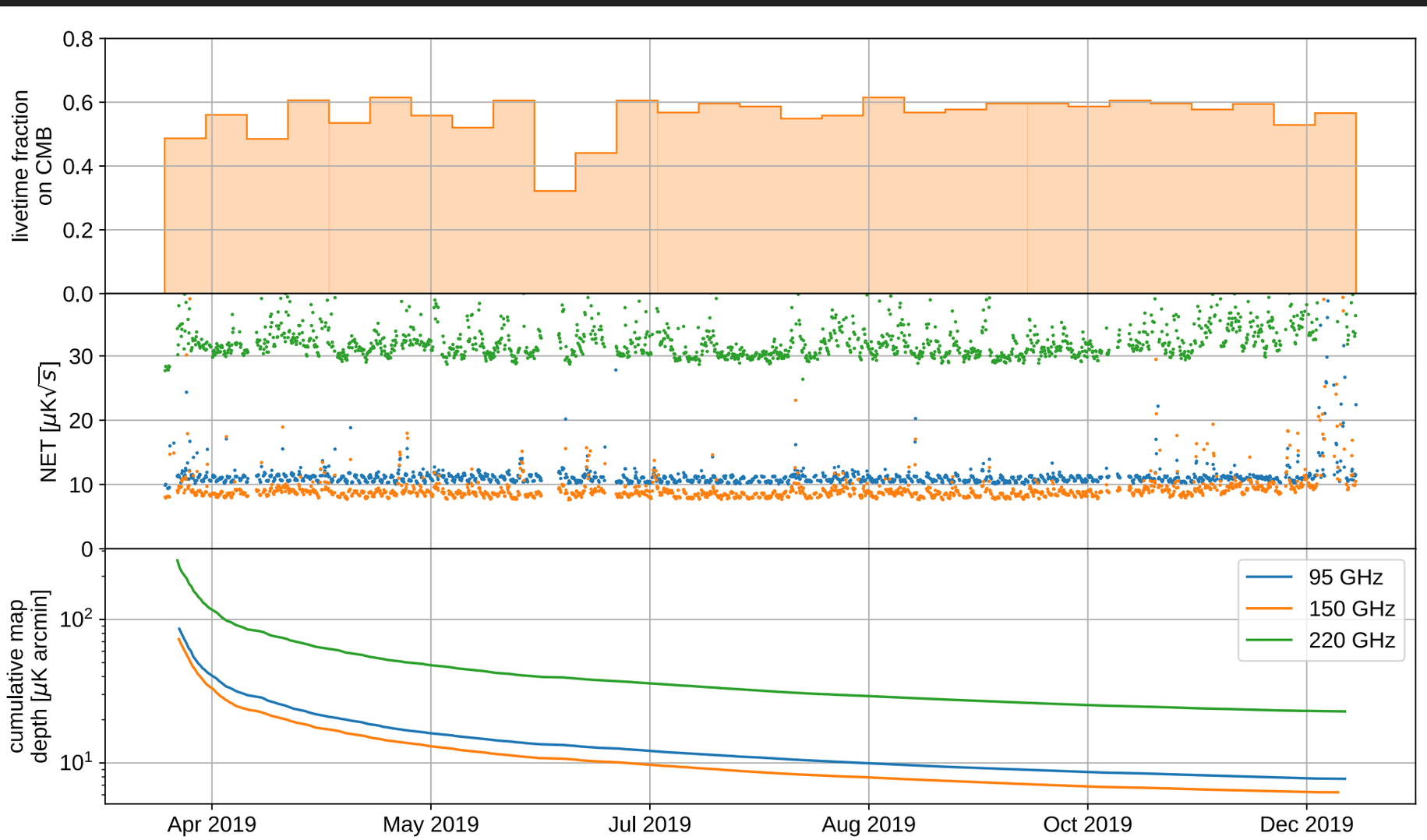
1500 deg²

1 week of obs.



- Reach Planck depth on 1500 deg² field with < 1 week of data
- Observe 1500 deg² survey field every ~2 days for 6 years

SPT-3G: 2019 DATA QUALITY



~60% observing efficiency in 9-month observing season

Daily camera sensitivity is stable over season

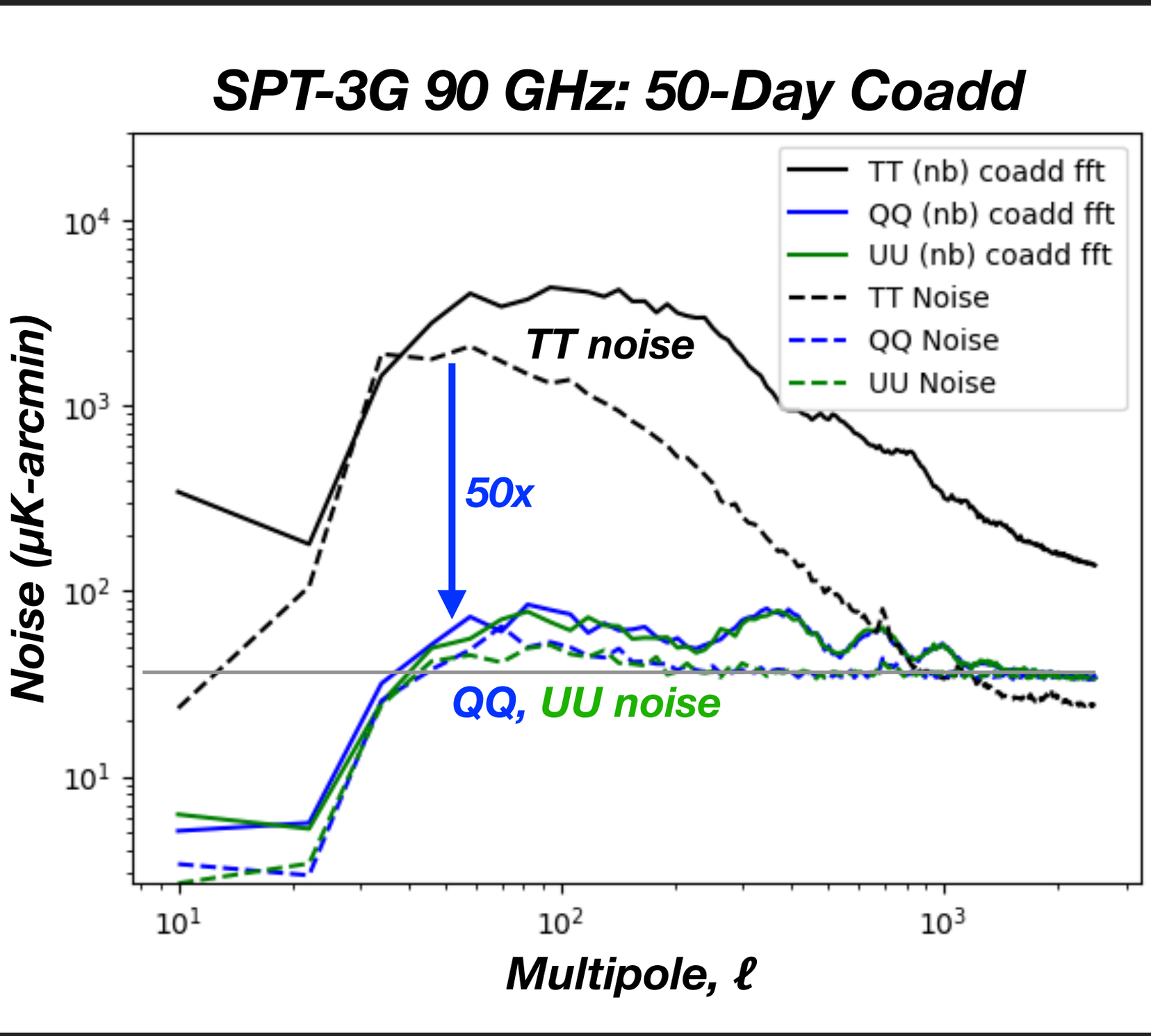
Freq. (GHz)	95	150	220
2018 Season	19	14	50
2019 Season	**7.7**	**6.2**	**23**
Full survey (2023)	3.0	2.2	8.8

SPT-3G Temperature Noise (uK-arcmin)

← Approx. Simons Observatory "goal" survey depth (fsky = 0.4)

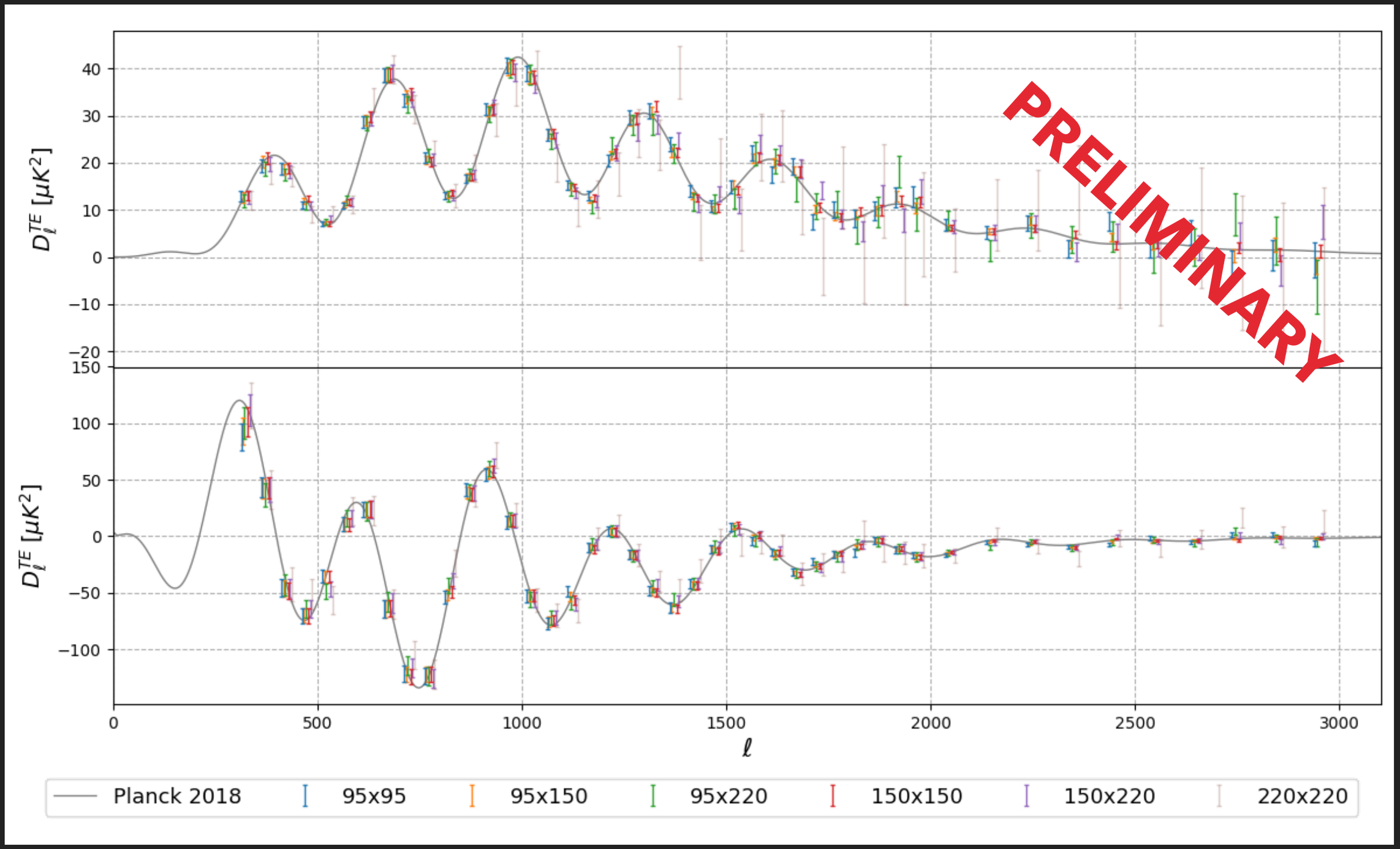
← Approx. CMB-S4 wide survey depth (fsky = 0.7)

SPT-3G: 2019 DATA QUALITY



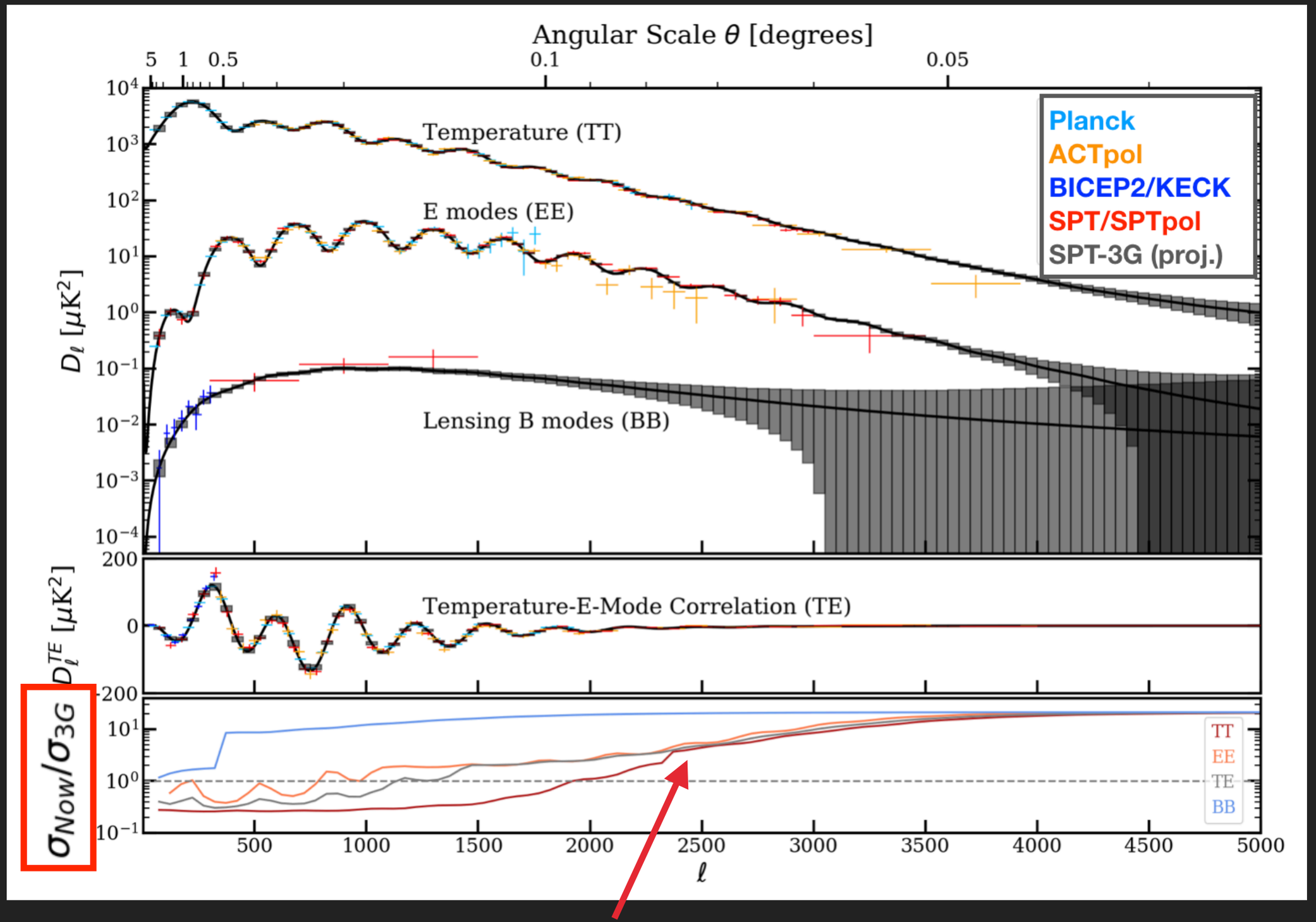
- Atmosphere is relatively uniform and unpolarized
- SPTpol low-ℓ noise was limited by temperature sensitivity of electronics
- SPT-3G has improved low-ℓ performance over SPTpol:
  - Electronics ℓ_{knee}=24 (Bender et al, 2019; arxiv: 1907.10947)
  - QU noise has ℓ_{knee} < ~50 at 90 GHz!

SPT-3G RESULTS: 2018 POWER SPECTRA



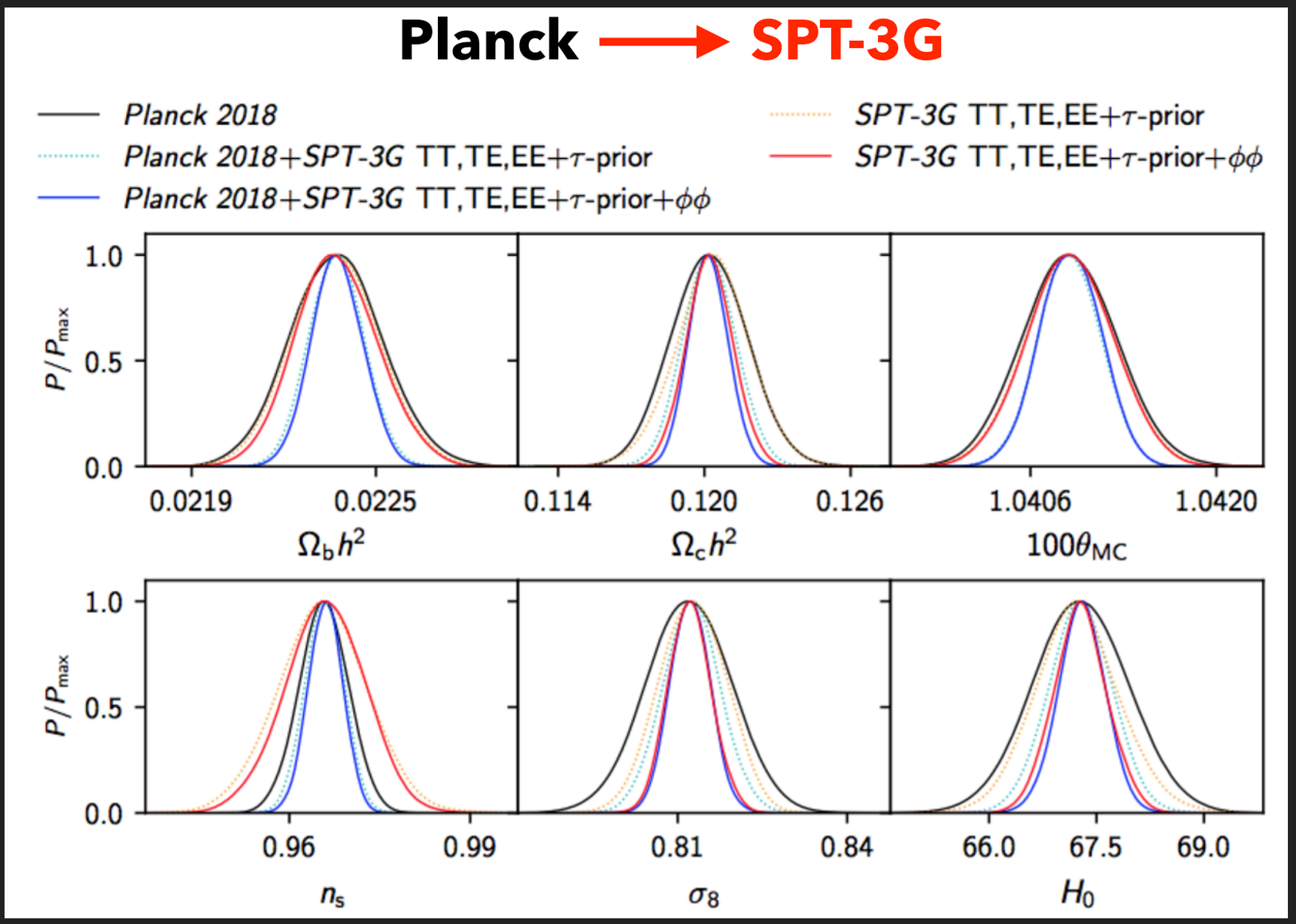
Frequency cross spectra are consistent with the same underlying cosmology (PTE = 0.61); minimal foreground contamination and systematics

SPT-3G FORECAST: CMB POWER SPECTRUM



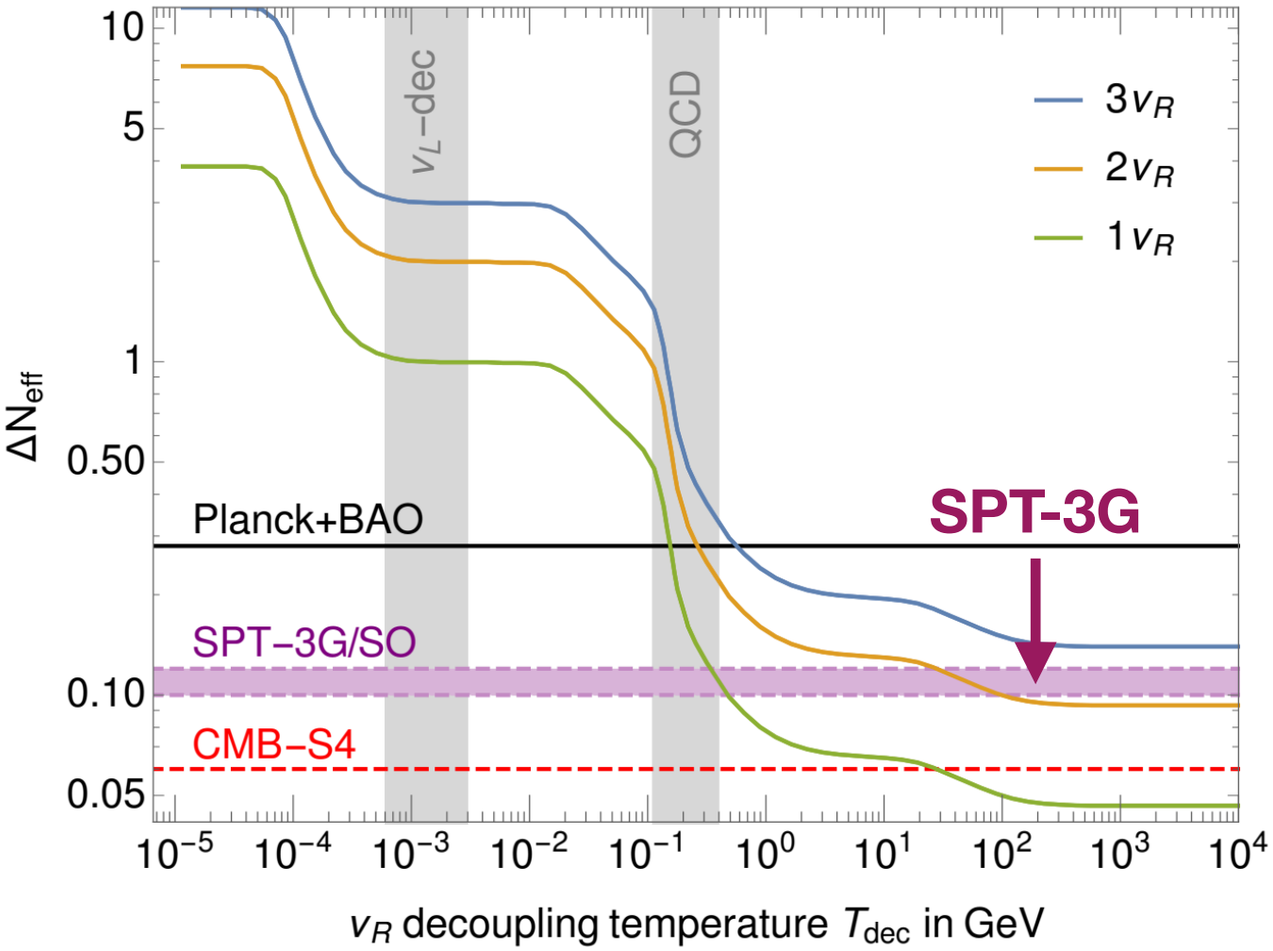
Improve S/N of CMB power spectra by factors of > ~10 at ℓ > 2500 over current constraints

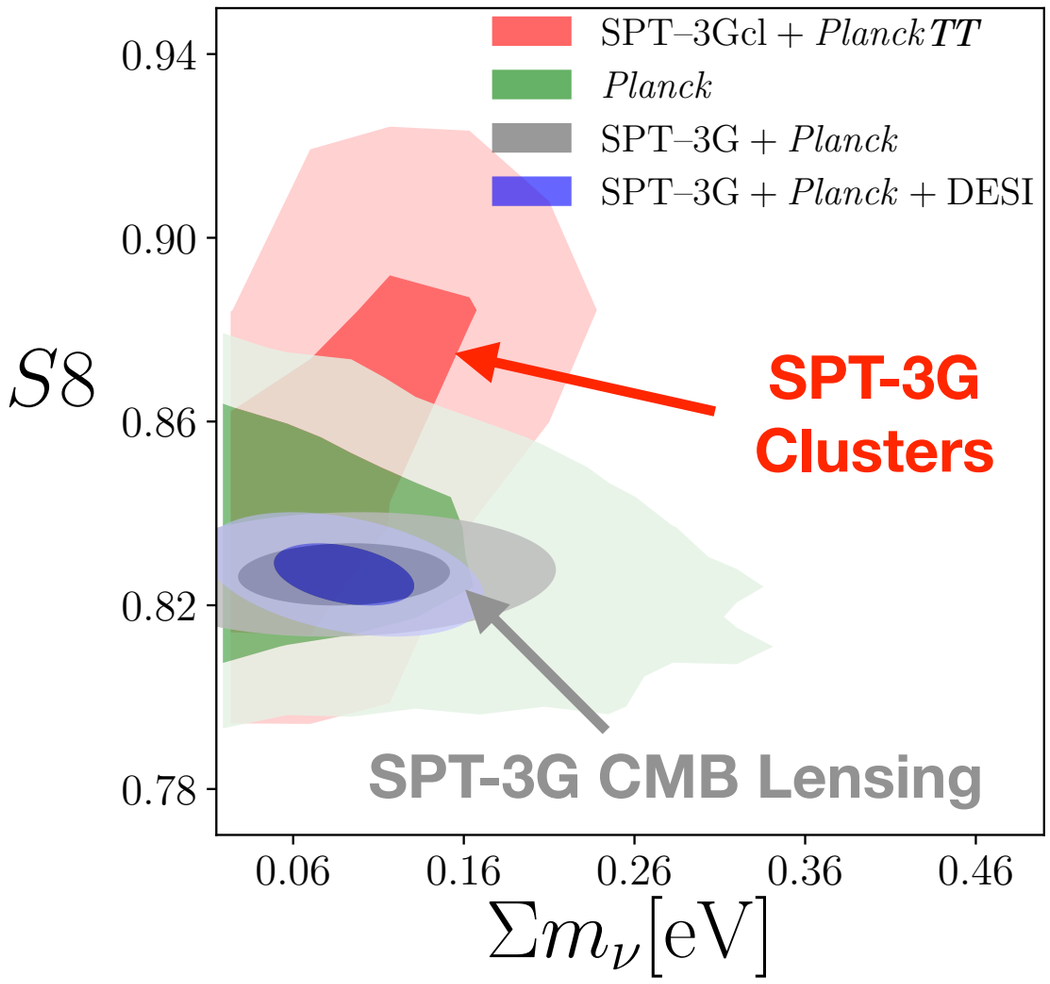
SPT-3G FORECAST: ΛCDM CONSTRAINTS



- SPT-3G alone will do as well as Planck on most parameters (except τ, n_s)
  - e.g., $\sigma(H_0)$=0.6 km/s/Mpc from SPT-3G lensed TT,TE,EE spectra
- SPT-3G gives ~independent cosmological information from high-ℓ CMB polarization spectrum
- SPT-3G + Planck will improve most parameters >2x over Planck alone

SPT-3G FORECAST: NEUTRINO CONSTRAINTS



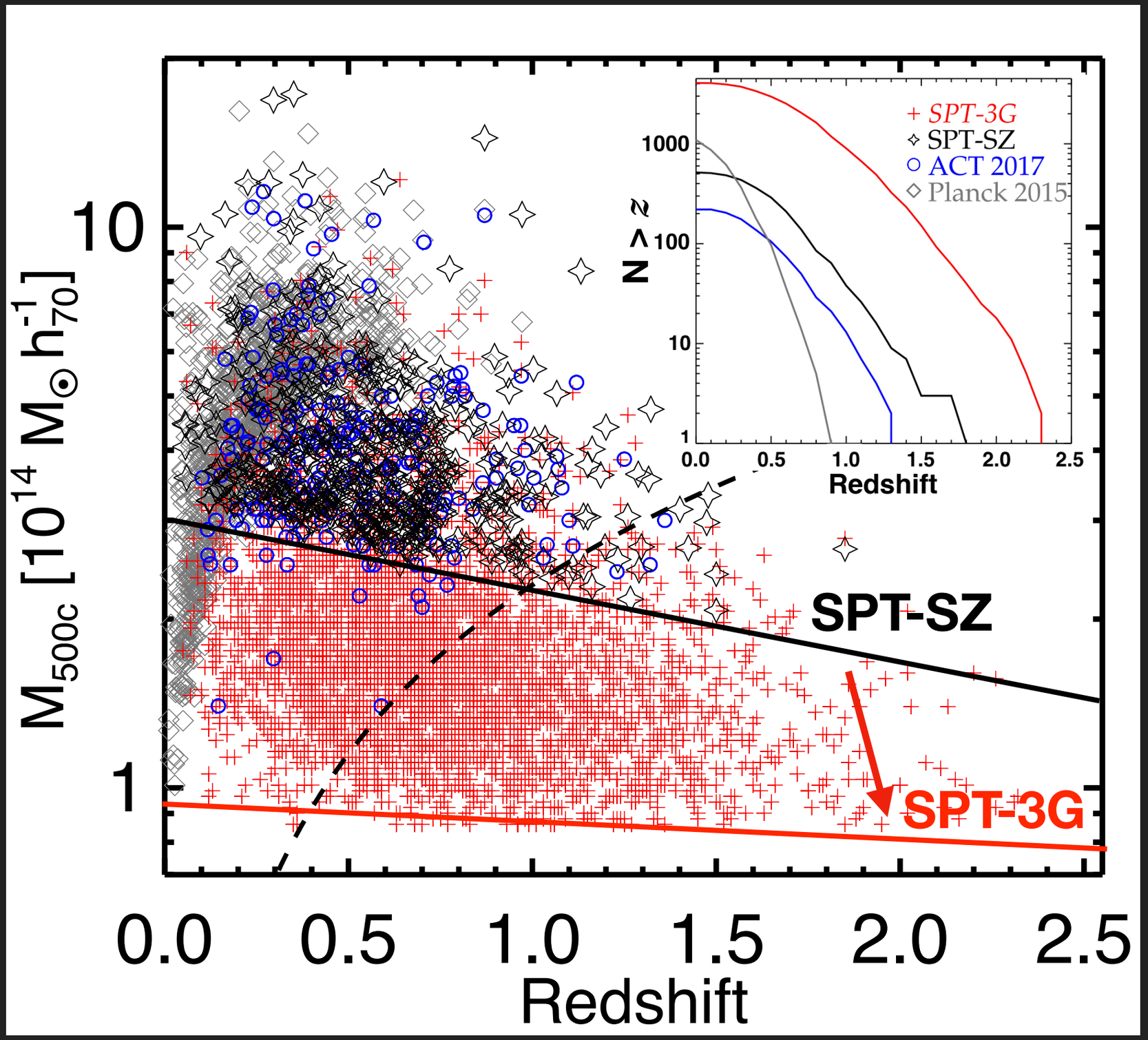


- SPT-3G + Planck will improve constraints on N_{eff} by almost 2x

- Independent constraints on Σm_ν from lensing and clusters
- $\sigma(\Sigma m_\nu)$=38 meV from SPT-3G (CMB) + Planck + DESI (BAO)

Abazajian & Heeck, arXiv:1908.03286
K. Aylor, S. Bocquet

SPT-3G FORECAST: CLUSTER SAMPLE

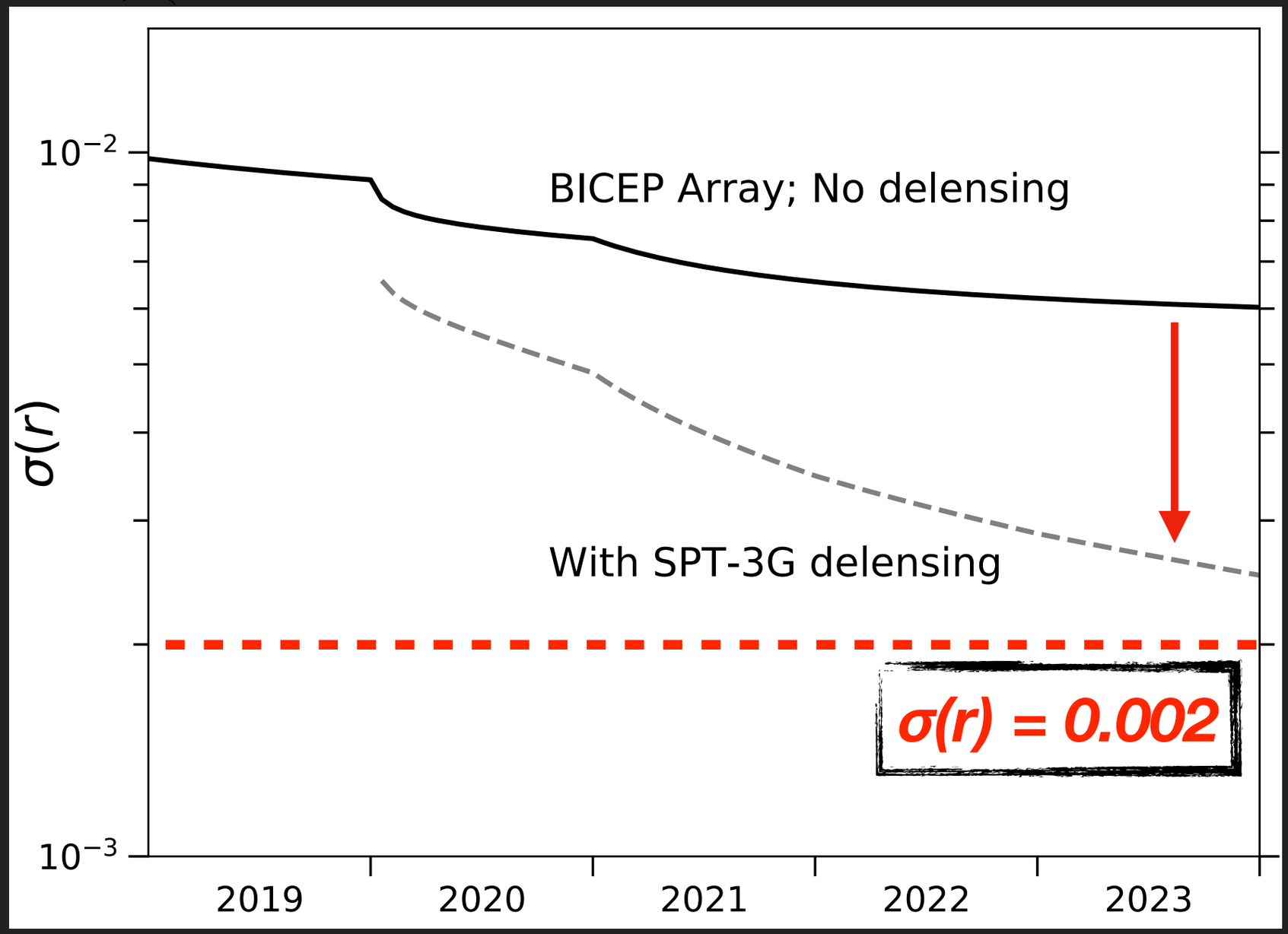


- SPT-3G mass limit will be ~10^{14} M_{sun}
  - ~3x lower than SPT-SZ survey
  - Deep 3-band data enables check of astrophysical confusion
- At z > 1: Nearly 1000 clusters!
- At z > 2: ~10s of clusters?

SOUTH POLE OBSERVATORY FORECAST: INFLATION

Current (BK15)
$\sigma(r) = 0.02$

South Pole Observatory



BICEP Array and SPT-3G have both started observing, together will improve constraint on tensor-to-scalar ratio (*r*) by nearly an order of magnitude!

2017

2018

2019

2020

2021

2022

2023

2024

2025

2026

>2027

Stage 2
1000's detectors

Stage 3
10,000's detectors

South Pole

SPTpol

SPT-3G

BICEP3 & Keck Array

SPT-3G

BICEP3 & BICEP Array

South Pole Obs

10m + 5 x 0.5m

52,000 detectors

New South Pole Wide-Field Survey Telescope

Chile

POLAR-BEAR

Simons Array (3x PB)

ACTPol

ADV-ACT

Simons Obs

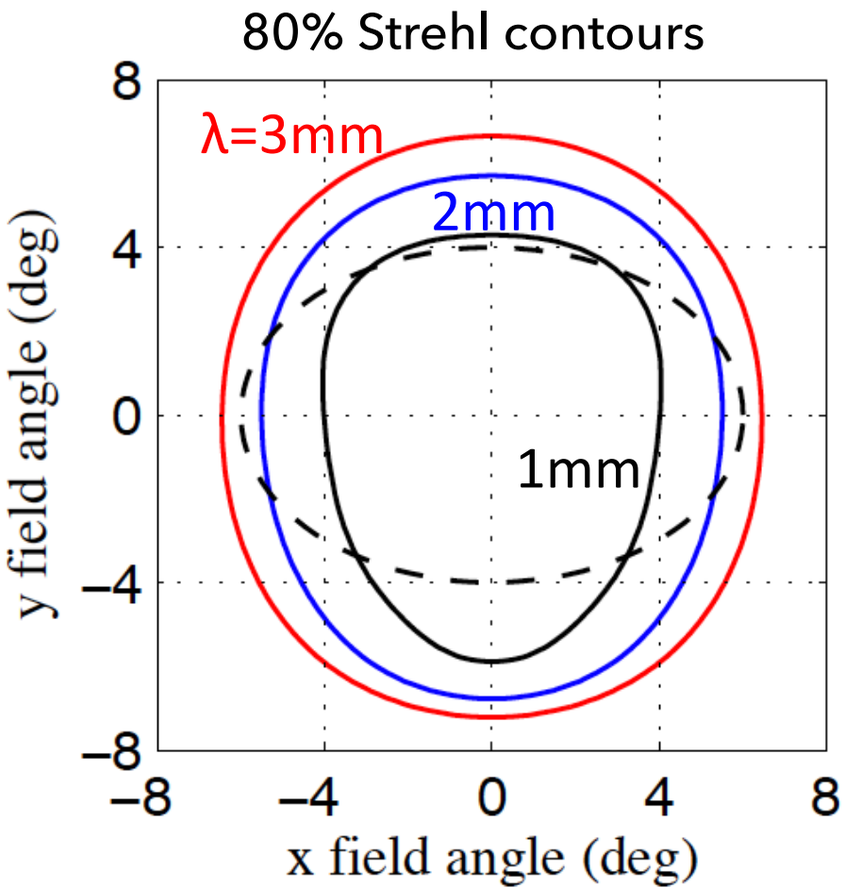
6m + 3 x 0.4m

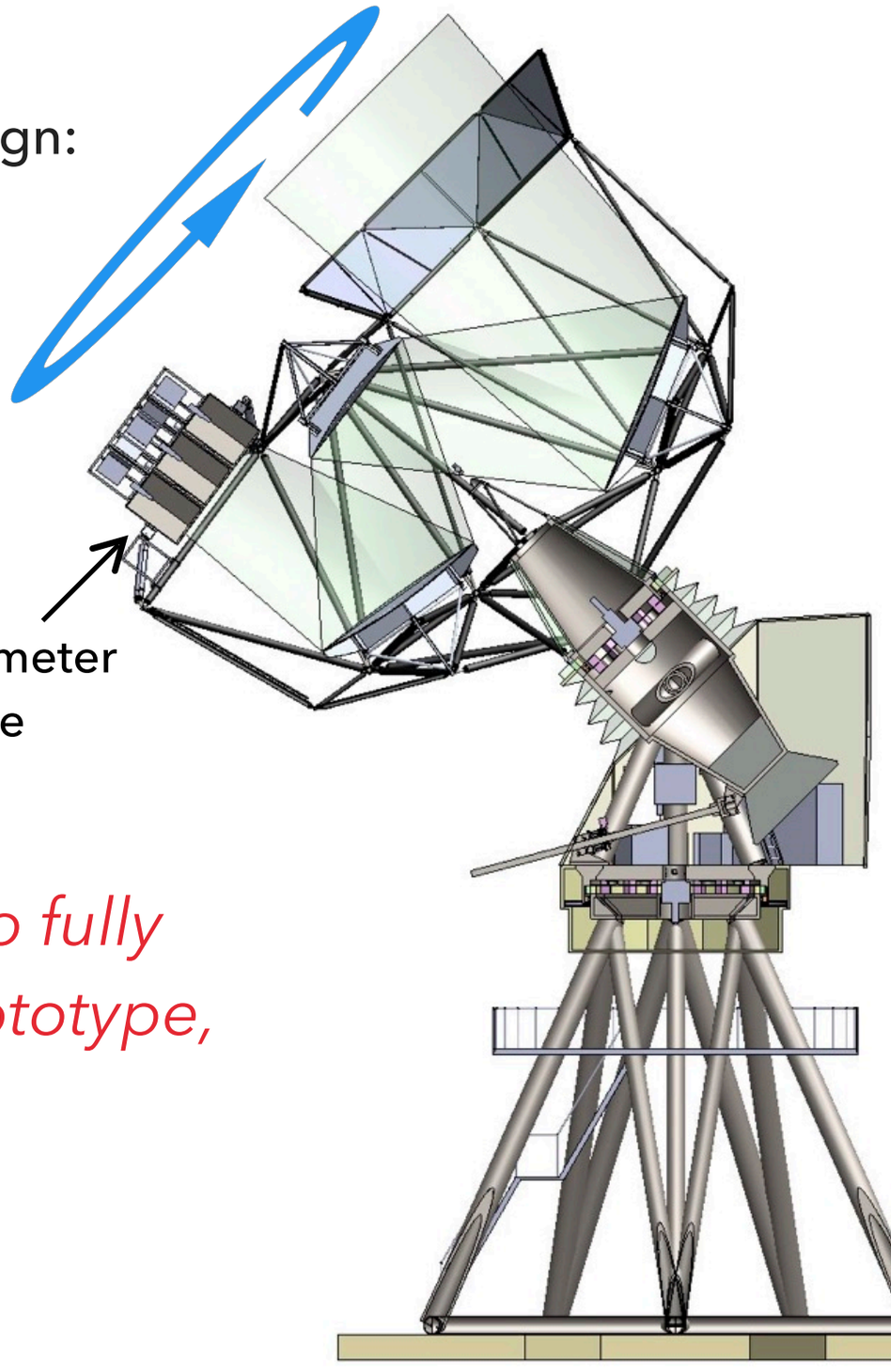
60,000 detectors

Stage 4 500,000 detectors: CMB-S4 Start operations

SP–TMA: SOUTH POLE THREE MIRROR ANASTIGMAT

- Degree B-modes and arc minute resolution with extremely high throughput.
- 5-meter Three Mirror Anastigmat (TMA) telescope design:
  - 75 deg² field of view
  - 424k/136k/63k Fλ pixels at λ=1/2/3mm
  - Monolithic mirrors (low scattering)
  - Boresight rotation for polarization systematics





Now working to fully design and prototype, targeting 2024 deployment

Padin, Applied Optics, 57, 9, 2314 2018

SUMMARY

- SPT-3G survey is ongoing
  - SPT-3G survey data from 2019 season has achieved high observing efficiency (60%), with impressive CMB sensitivity and performance at large scales
  - First SPT-3G science publications from 2018 season coming soon
- SPT-3G science forecasts through 2023 season
  - ΛCDM constraints as good as Planck on most cosmological parameters
  - With Planck, factor of ~2x improved constraints on N_{eff} and neutrino mass
  - With BICEP Array, factor of ~10x improvement on current BK15 tensor-to-scalar ratio constraint
- Future plans for CMB science at the South Pole
  - High through-put SP-TMA to enable higher sensitivity measurements to reach our ultimate goal on tensor-to-scalar ratio
  - CMB-S4 coming online in 2027

Thank you!