

South Pole Telescope

Srinivasan Raghunathan

On behalf of SPT collaboration

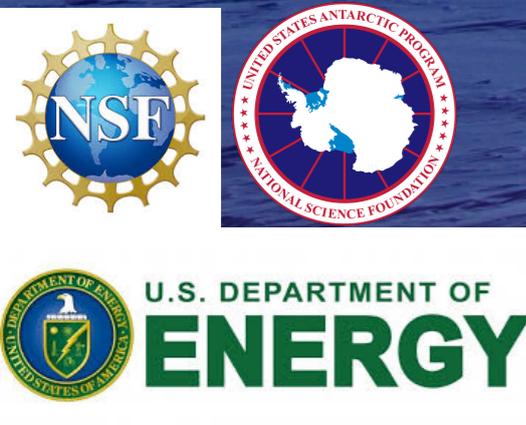
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Centre for AstroPhysical Surveys

National Center for Supercomputing Applications, University of Illinois Urbana Champaign

CMB-S4 2024 summer
collaboration meeting

31 July, 2024



SPT collaboration 2024 F2F meeting

*~100 scientists (1/3 senior, 1/3 postdocs, 1/3 students)
across more than 20 institutions*



Harvard-Smithsonian Center for Astrophysics



South Pole Telescope

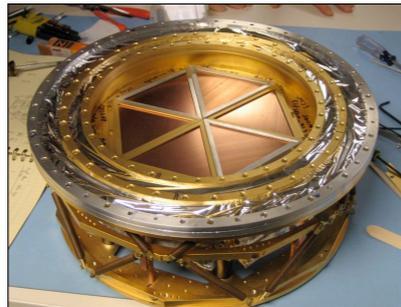
10 meter submm-quality telescope located at the geographic south pole.

Three bands: 90 / 150 / 220 GHz.

Resolution: 1.7 / 1.2 / 1 arcmin.

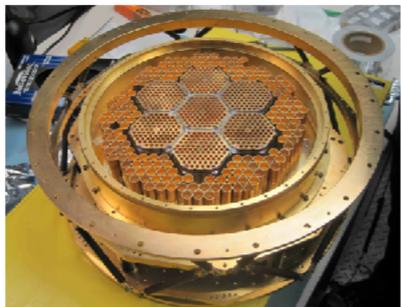
2007: SPT-SZ

960 detectors
100, 150, 220 GHz



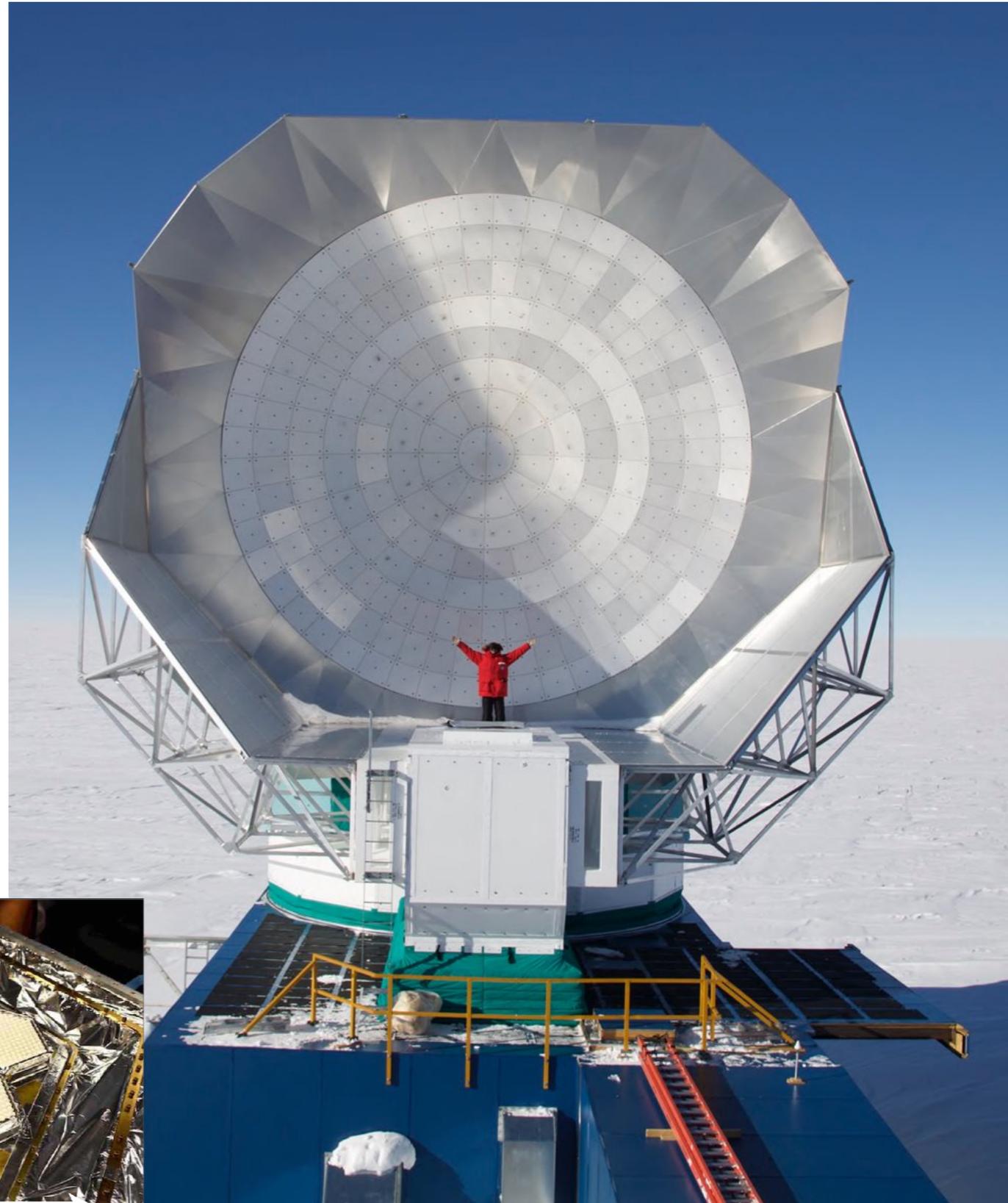
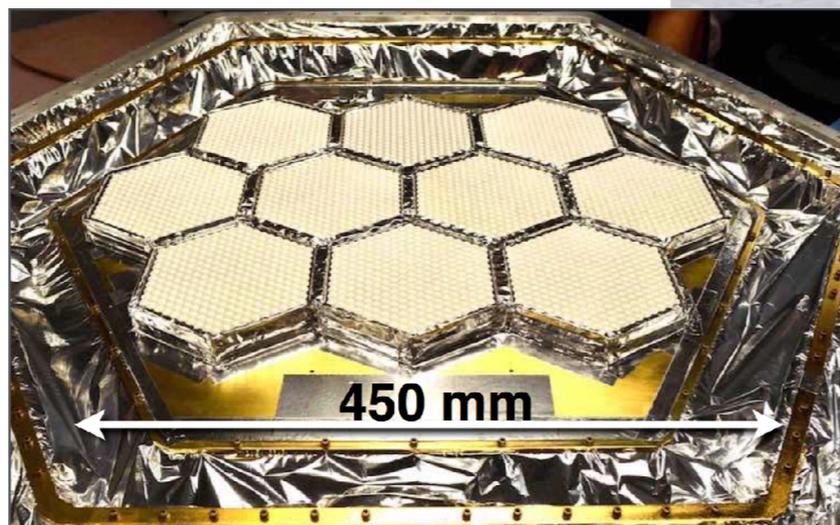
2012: SPTpol

1600 detectors
100, 150 GHz
+Polarization



2017: SPT-3G

16,000 detectors
100, 150, 220 GHz
+Polarization

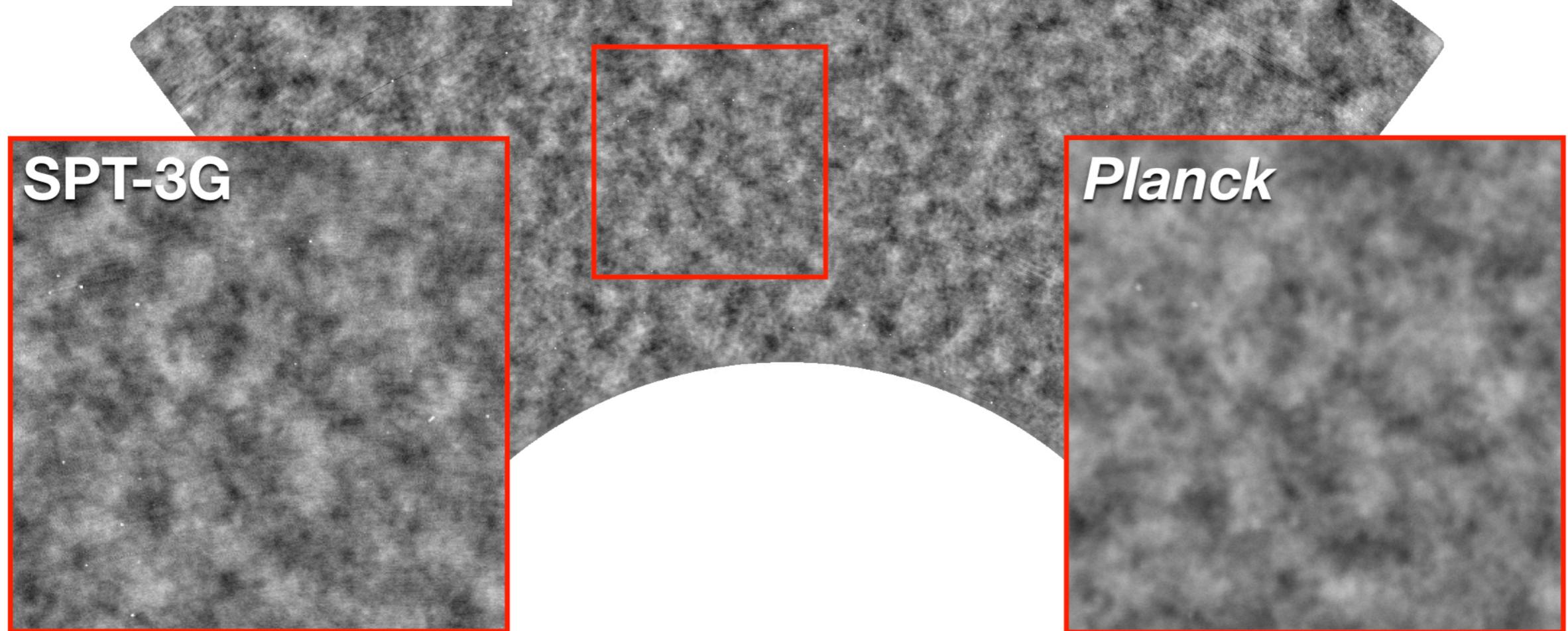


South Pole Telescope

SPT-3G

Main Field: 1500 deg²

Duration: 1 week

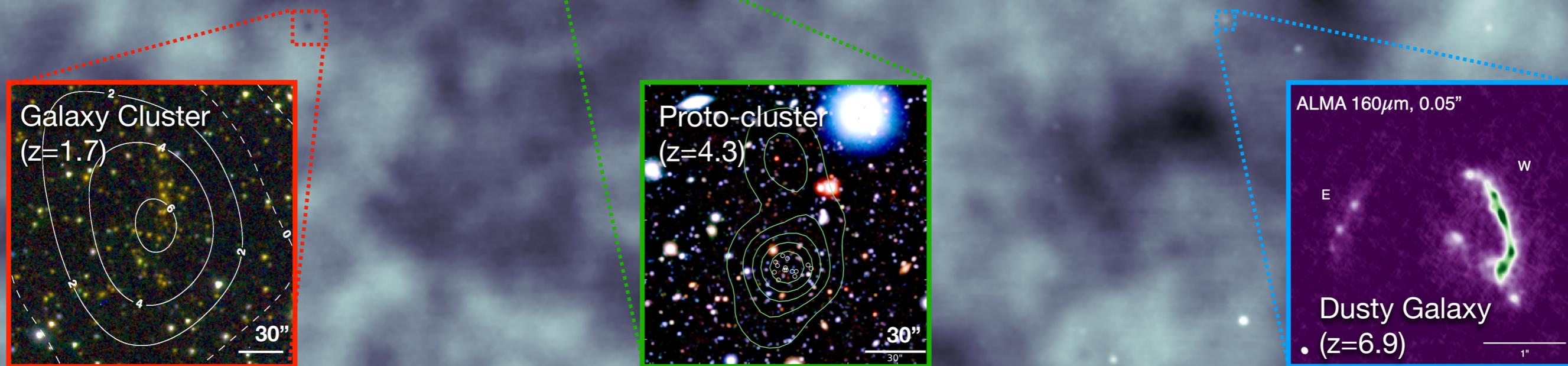


SPT-3G can achieve Planck's depth in roughly 1 week and we have 5 years (Austral winter) of data at the moment.

Credit: Brad Benson

South Pole Telescope (SPT)

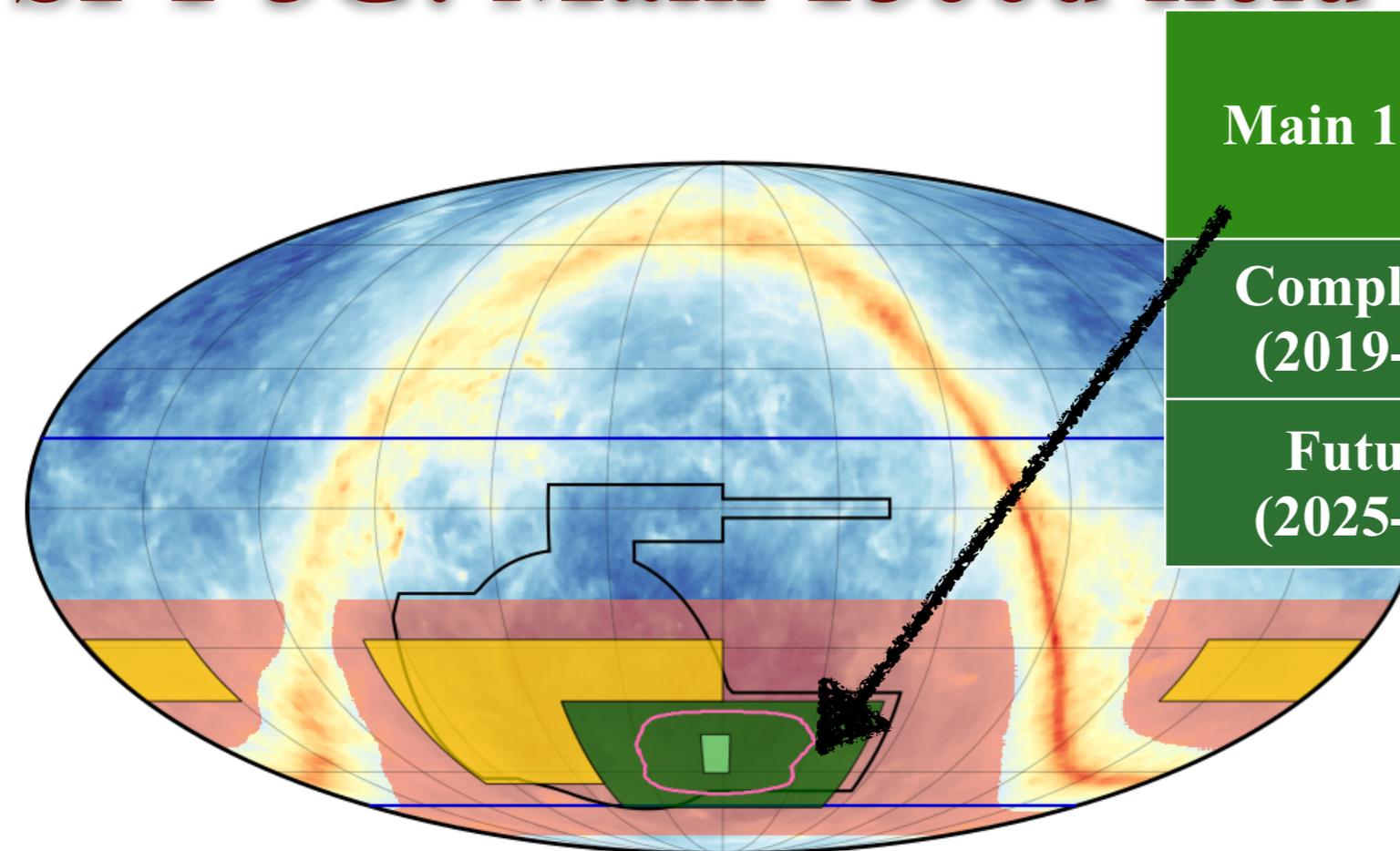
SPT



Science drivers for the Main-1500d field:

- 1. Inflation in combination with BICEP using CMB delensing.*
- 2. Cosmology using primary and secondary CMB anisotropies.*
- 3. Physics of reionization using $k\text{SZ}$.*
- 4. Cross-correlation with galaxy surveys.*
- 5. Blind cluster and high redshift galaxy catalogues.*
- 6. mm-wave transients, AGN monitoring, Asteroids, Stellar Flares, Planets, +++*

SPT-3G: Main 1500d field



Main 1500d	Noise level Δ_T [$\mu\text{K-arcmin}$]			
	90 GHz	150 GHz	220 GHz	Coadd
Completed (2019-23)	3	2.5	8.9	1.9
Future (2025-26)	2.5	2.1	7.6	1.6

- BICEP3 ■ SPT 100d-megadeep ■ SPT-3G Summer
- DES ■ SPT-3G Main ■ SPT-3G Wide
- SO/LSST

See Anna Coerver's talk later today on polarised atmosphere at the South Pole using SPT-3G data

How is SPT-3G relevant for CMB-S4?

- *SPT-3G will achieve same noise levels as S4-Wide (CHLAT) and hence will nail down / solve all relevant systematics that will be important for S4's low-noise data.*
- *SPT-3G facilitates delensing for BICEP/Keck to constrain inflation.*
- *SPT-3G has excellent overlap with current/upcoming galaxy surveys facilitating cross-correlations.*

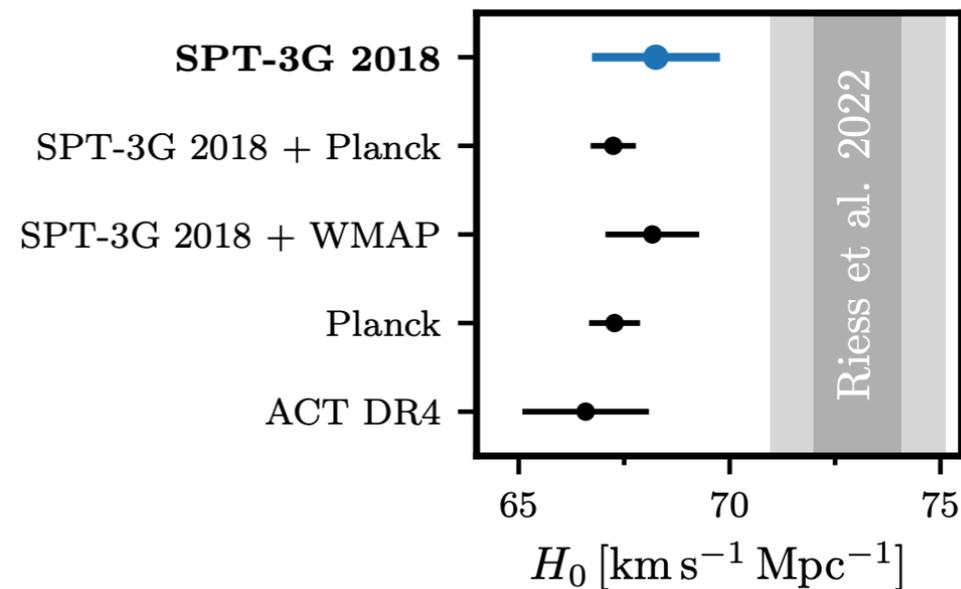
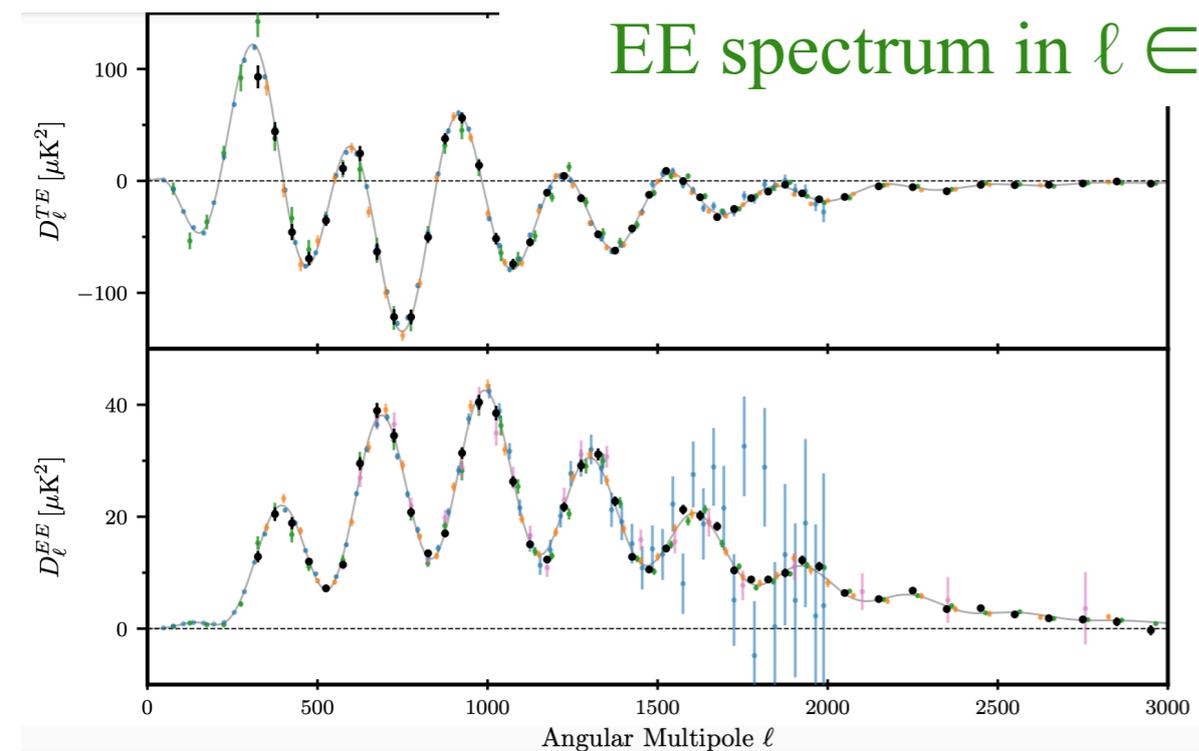
Highlighting some of the past/recent SPT-3G results

Other SPT-3G results not discussed here:

1. *CMB-lensing based mass calibration of DES clusters (Ansarinejad et al. 2024, [arXiv: 2404.02153](#)).*
2. *Catalog of flaring Stars (Tandoi et al. 2024, [arXiv: 2401.13525](#)).*
3. *Pairwise- k SZ with DES clusters (Schiappucci et al. 2022, [arXiv: 2207.11937](#)).*
4. *Axion DM limits (Ferguson et al. 2022, [arXiv: 2203.16567](#)).*
5. *Asteroids (Chichura et al. 2022, [arXiv: 2202.01406](#)).*
6. *Galactic and Extragalactic mm-wave transients (Guns et al. 2022, [arXiv: 2103.06166](#)).*

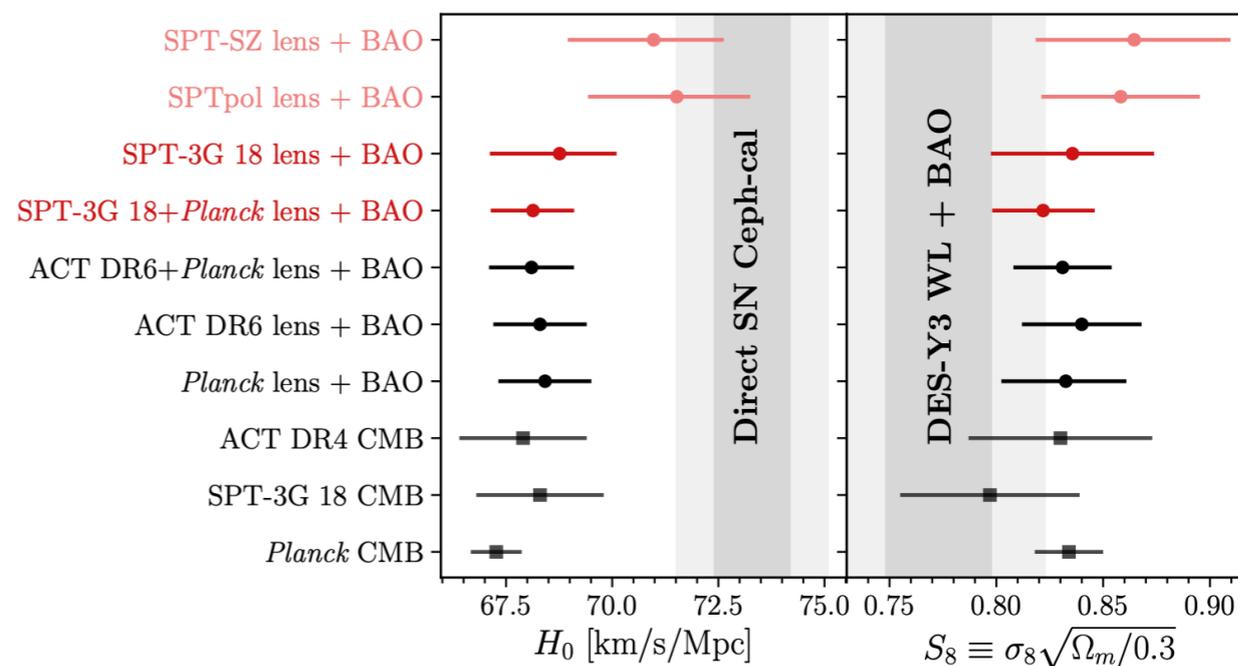
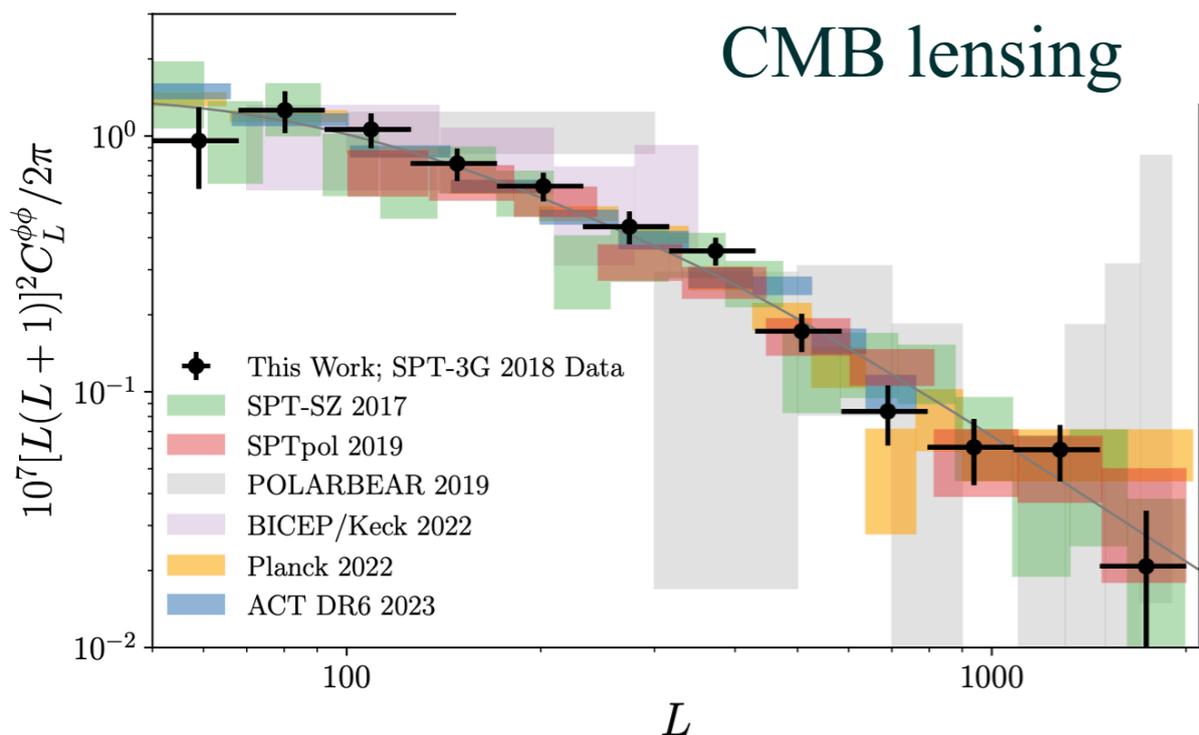
SPT-3G 2018 TT/EE/TE and lensing

Most sensitive measurement of the EE spectrum in $\ell \in [700, 1700]$



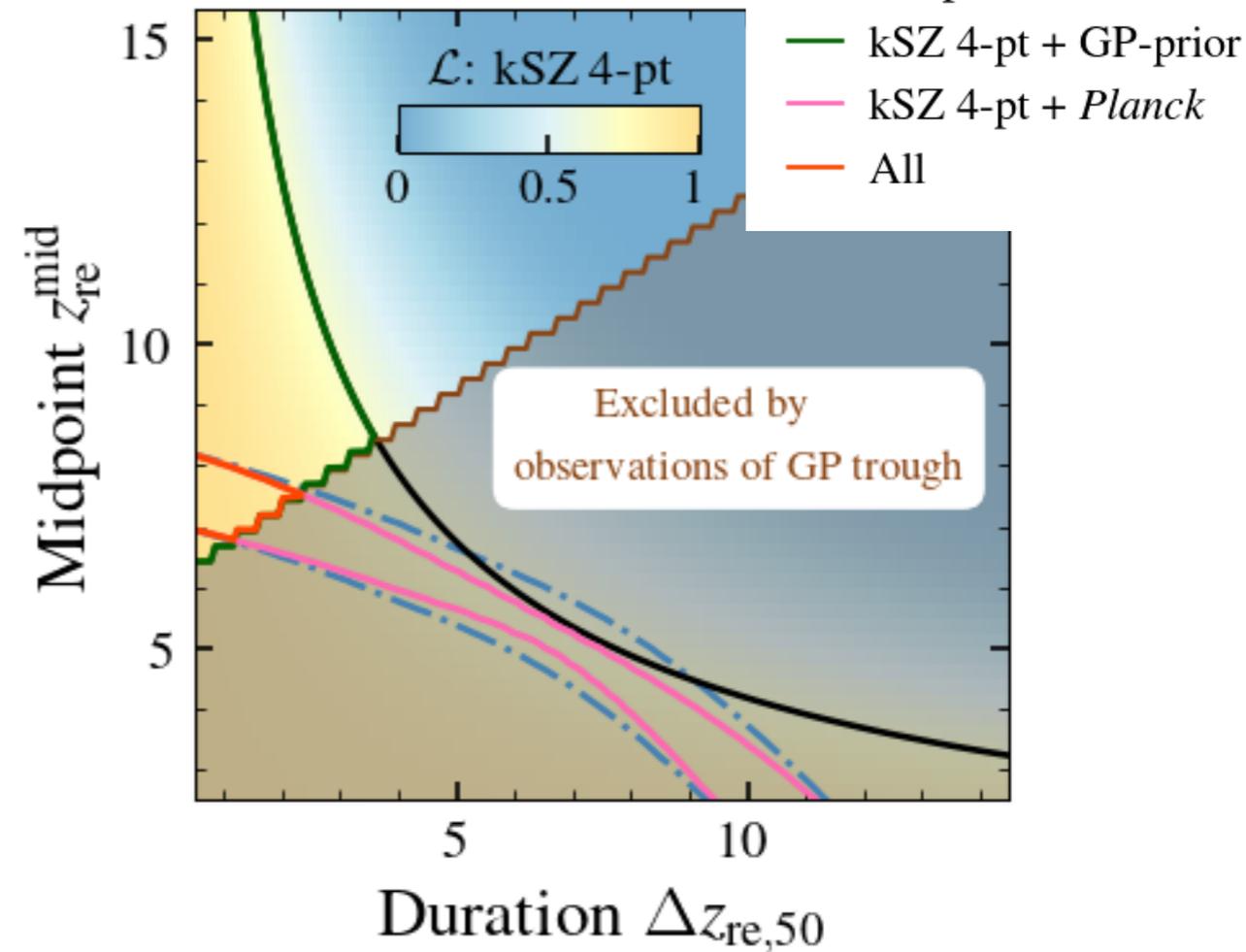
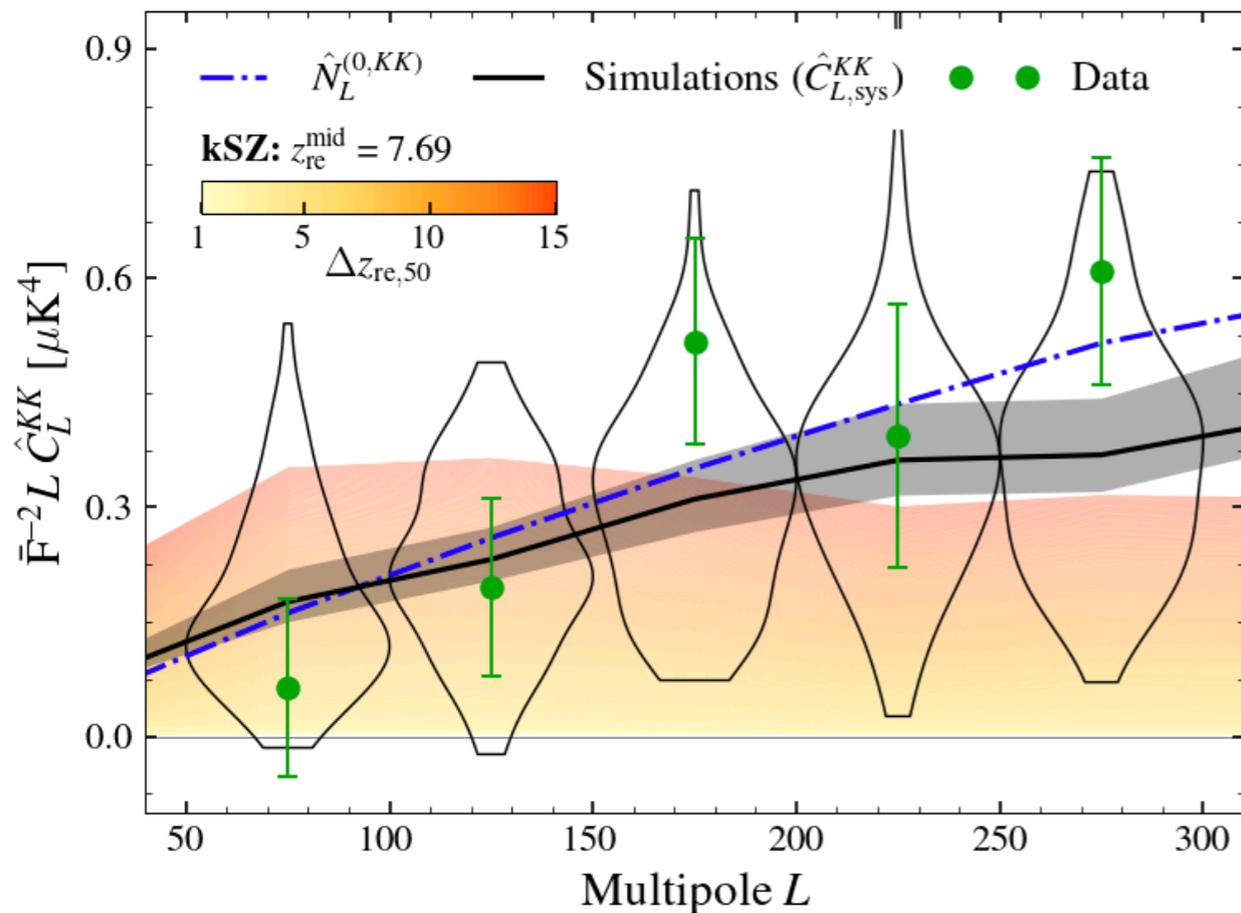
Credit: Balkenhol, Dutcher et al. 2022, [arXiv: 2212.05642](https://arxiv.org/abs/2212.05642) & Dutcher, Balkenhol et al. 2022, [arXiv: 2101.01684](https://arxiv.org/abs/2101.01684)

17σ measurement of CMB lensing



Credit: Pan, Bianchini et al. 2023, [arXiv: 2308.11608](https://arxiv.org/abs/2308.11608)

SPT-3G 2019/20 + SPTpol kSZ 4-pt



First constraints on epoch of reionisation using kSZ trispectrum from a deep ($\Delta_T = 3 \mu\text{K-arcmin}$) 100 sq. deg. patch

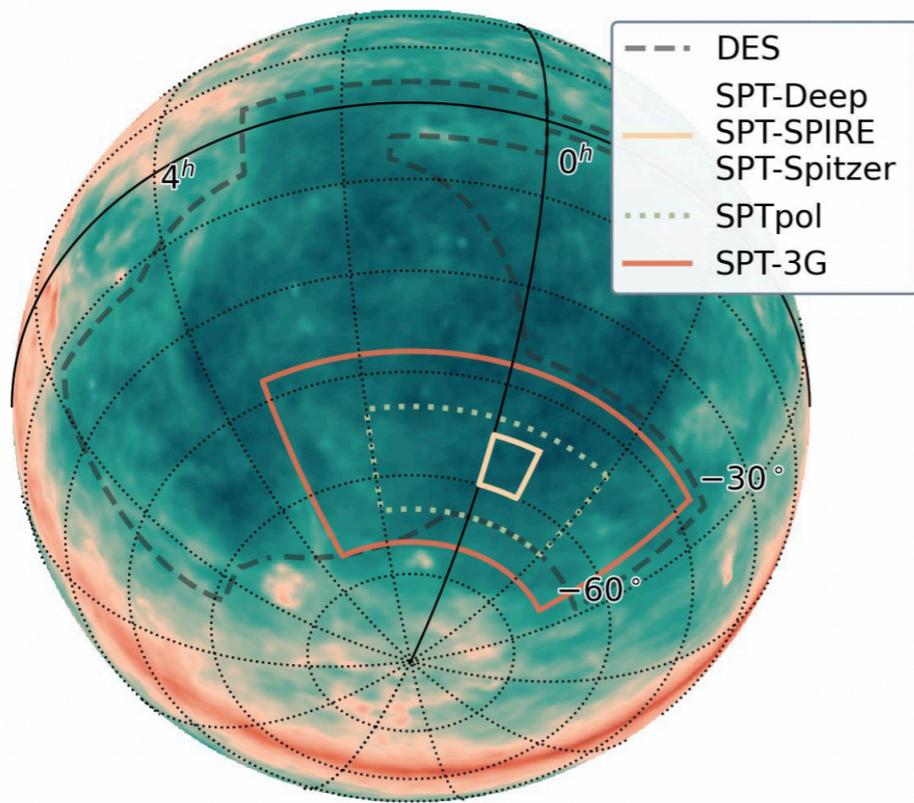
kSZ-4pt + GP trough:
 $\Delta z_{re} < 4.5$ (95 % C.L.)

Independent of, but consistent with, the low- ℓ measurements from *Planck*.

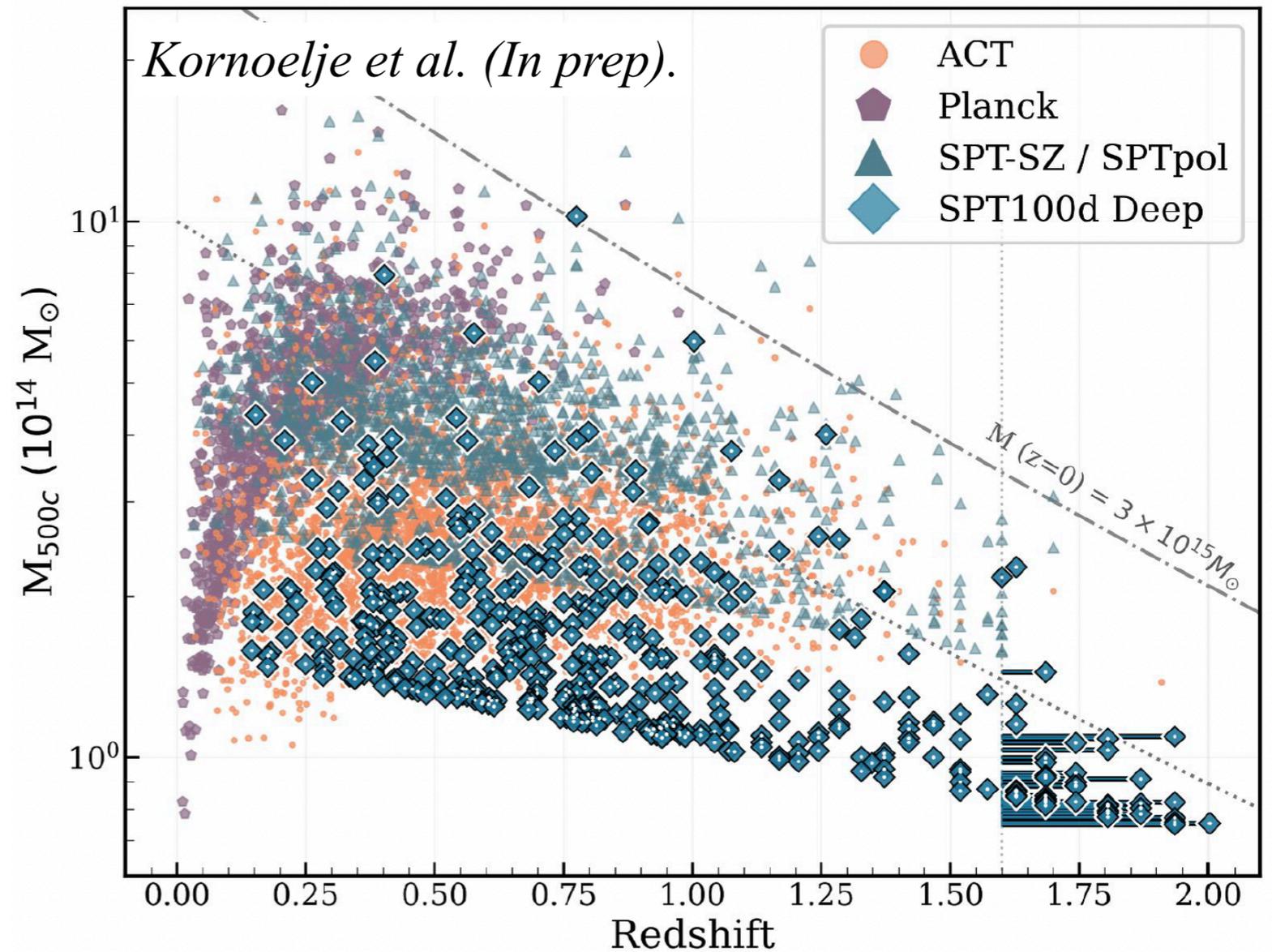
Credit: Raghunathan et al. 2024, [arXiv: 2403.02337](https://arxiv.org/abs/2403.02337)

Upcoming SPT-3G results

SPT-3G 2019/24 + SPTpol Deepest SZ cluster catalogue



SPT's 100d deep field overlaps with DES, Herschel, and Spitzer.

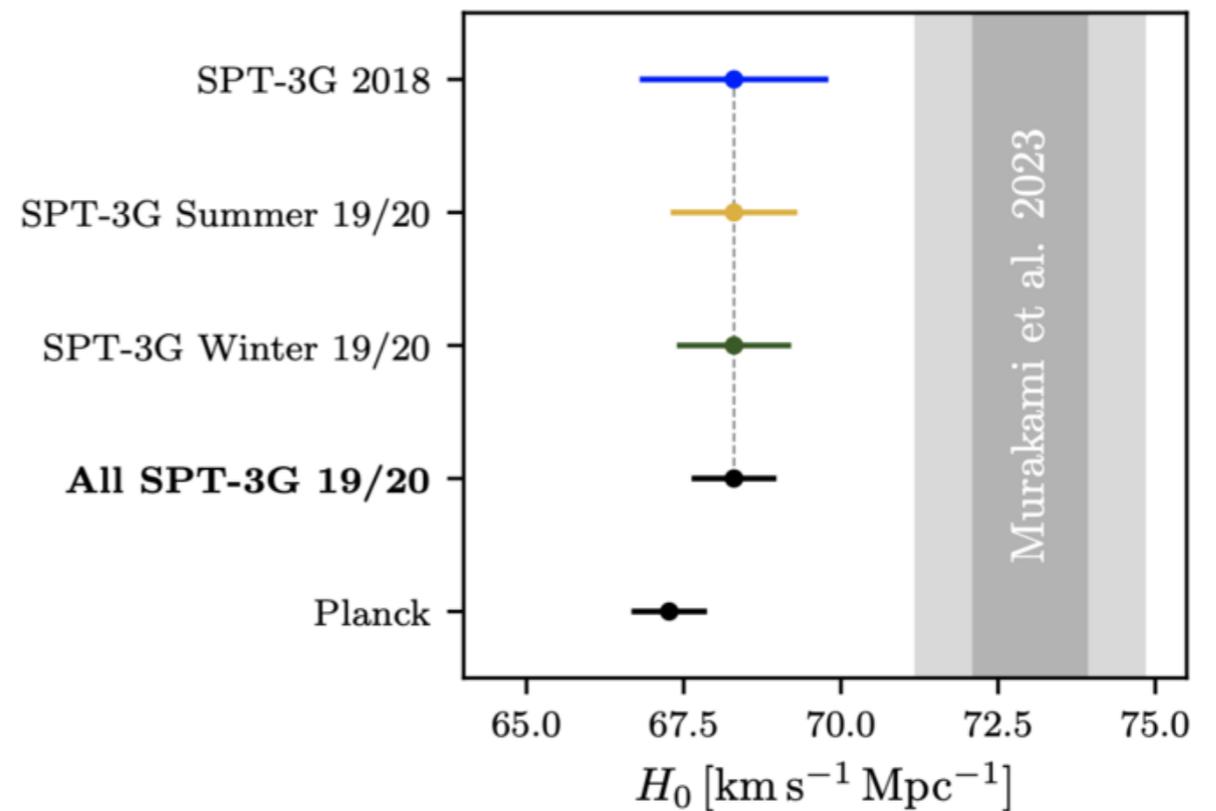
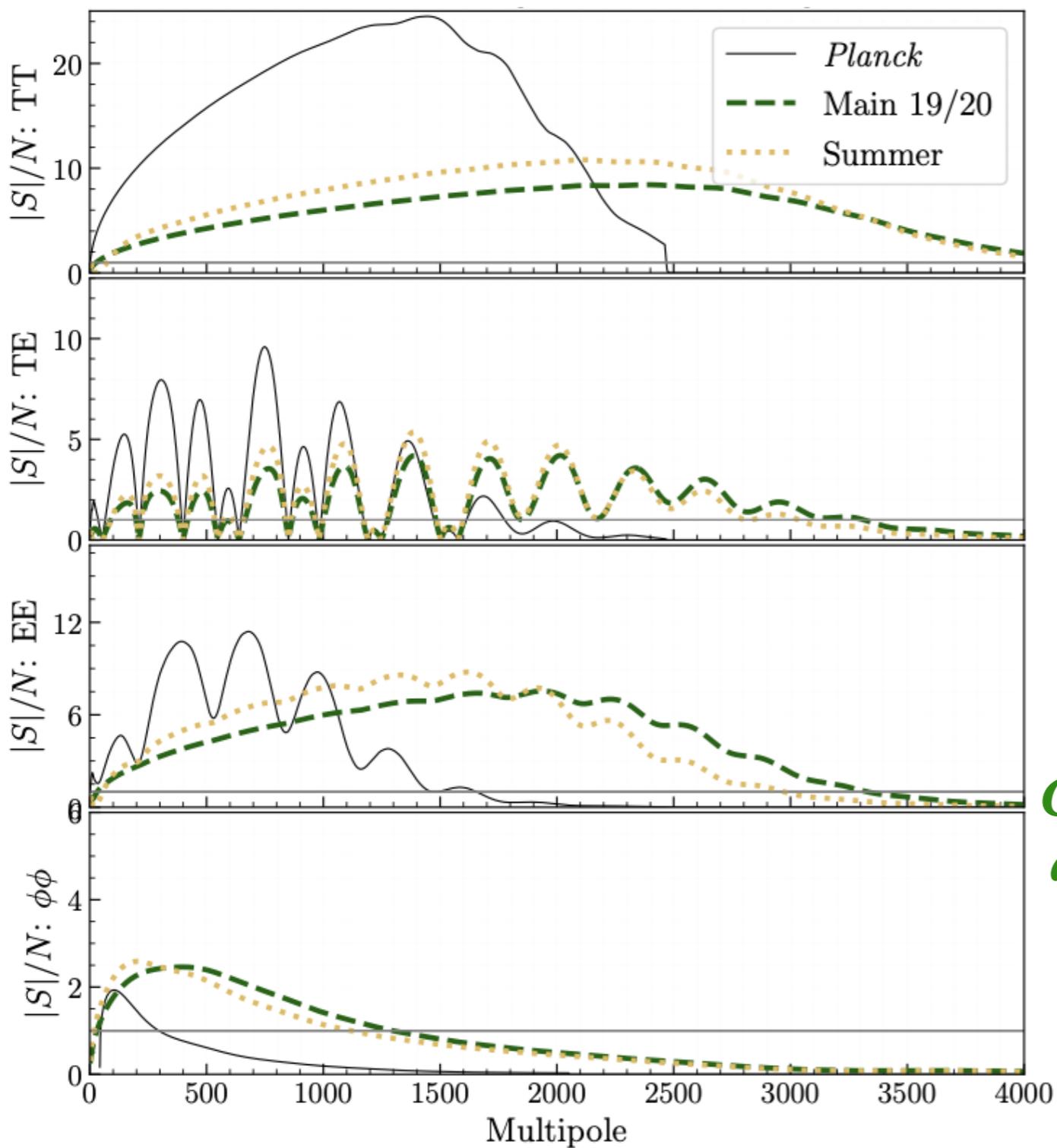


Pushing the cluster mass threshold to $< 10^{14} M_{\odot}$ at $z \gtrsim 1$.

< 2 per cent contamination from CIB at high-z. Highly relevant for CMB-S4.

Credit: Kayla Kornoelje and Lindsey Bleem.

SPT-3G 2019/20 TT/EE/TE

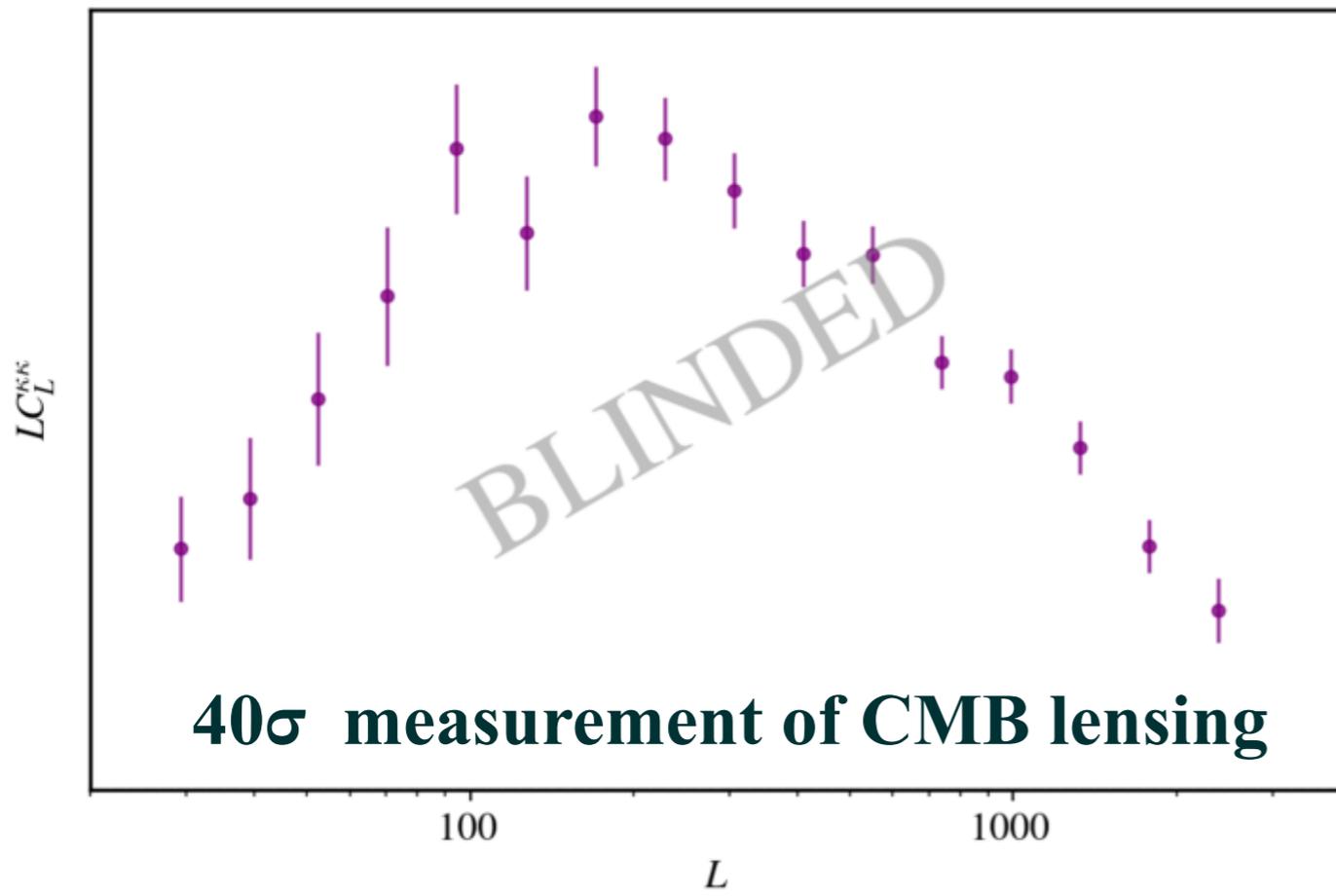


Constraining power from 2 years of SPT-3G data (2019/20) will be better than Planck at $\ell > 2200$ in TT, $\ell > 1000$ in EE/TE.

~30% better constraints on H_0 when lensing is included.

Credit: Etienne Camphuis, Wei Quan, Federica Guidi and Lennart Balkenhol.

SPT-3G 2019/20 Lensing

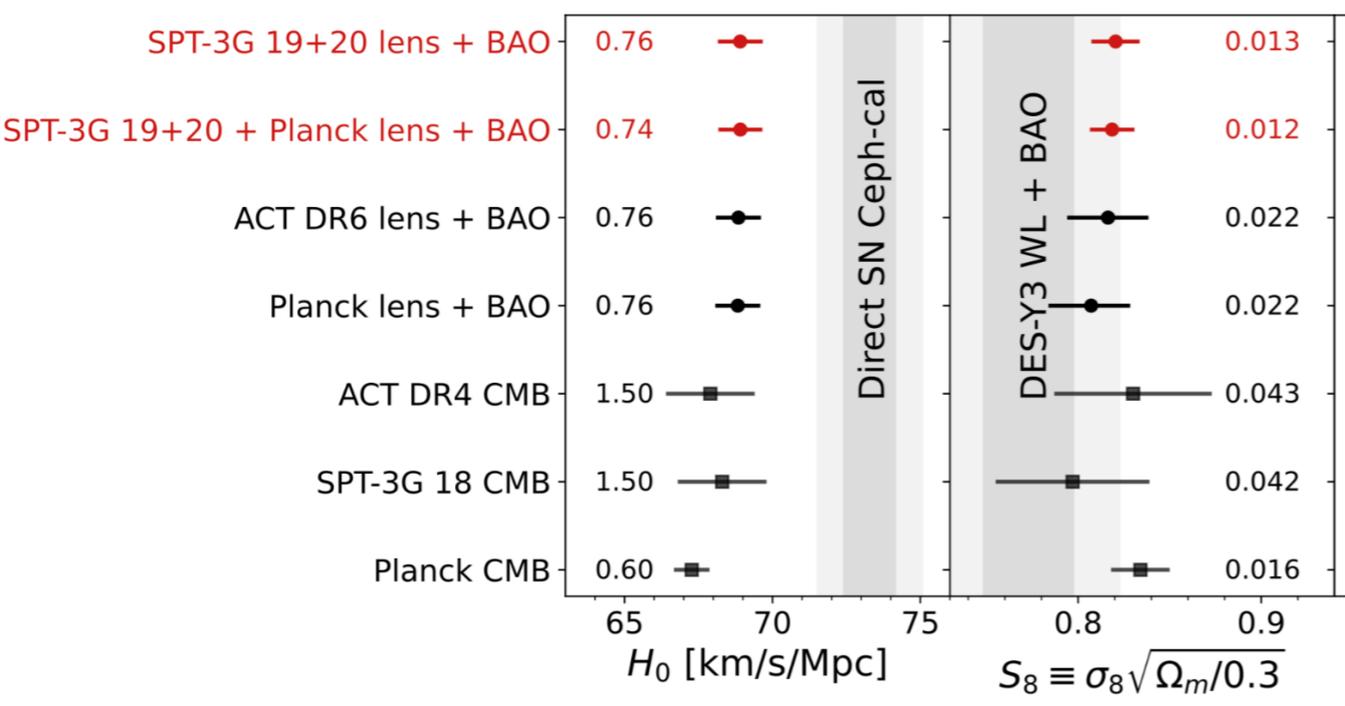


Constraining power from 2 years of SPT-3G data (2019/20) will be better than Planck at $L \sim > 100$.

Two different QE lensing pipelines for consistency checks.

1 σ uncertainties

Estimator: Global minimum variance (GMV) with $\ell_{max} = 4000$ (3500) for P (T).

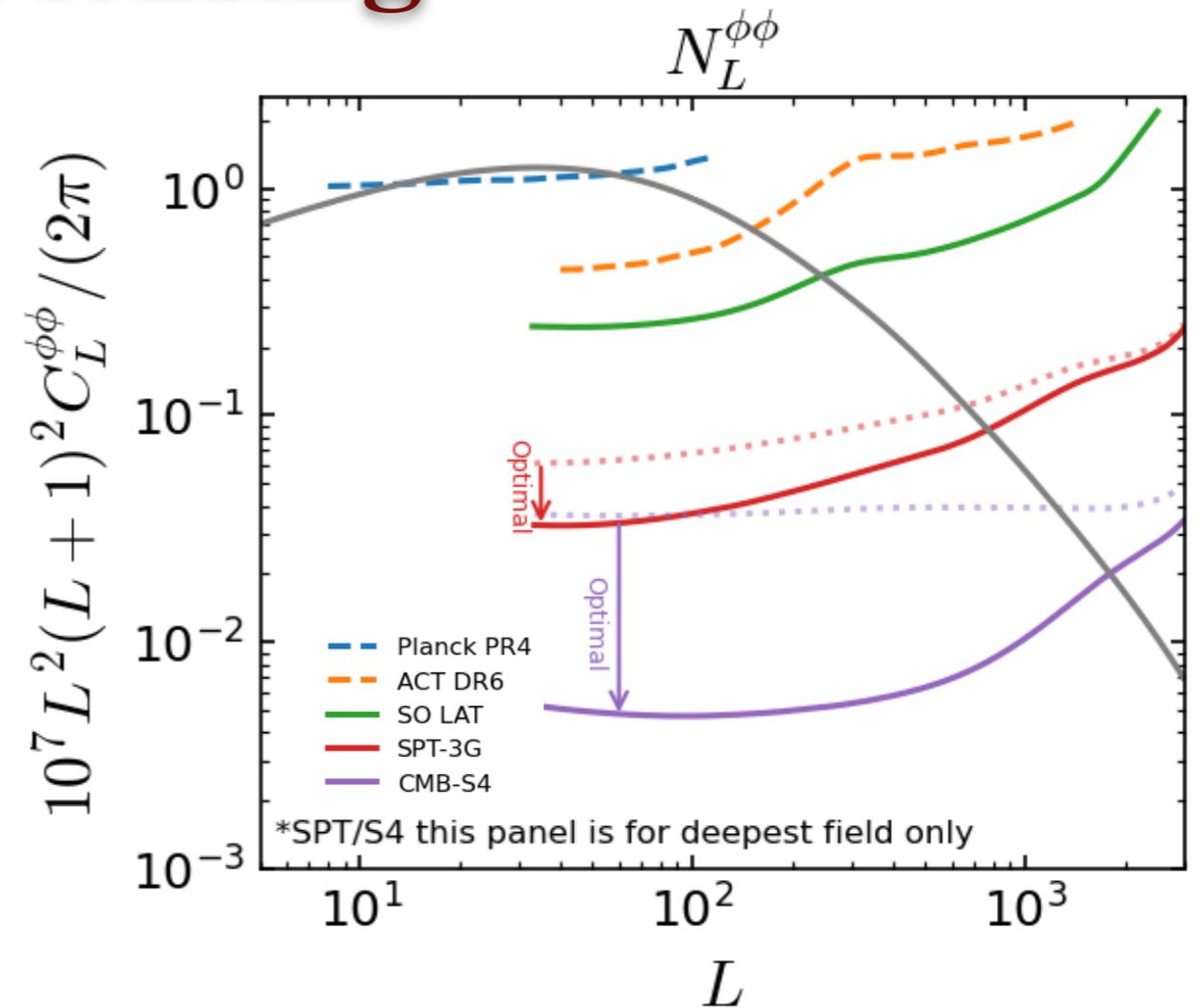
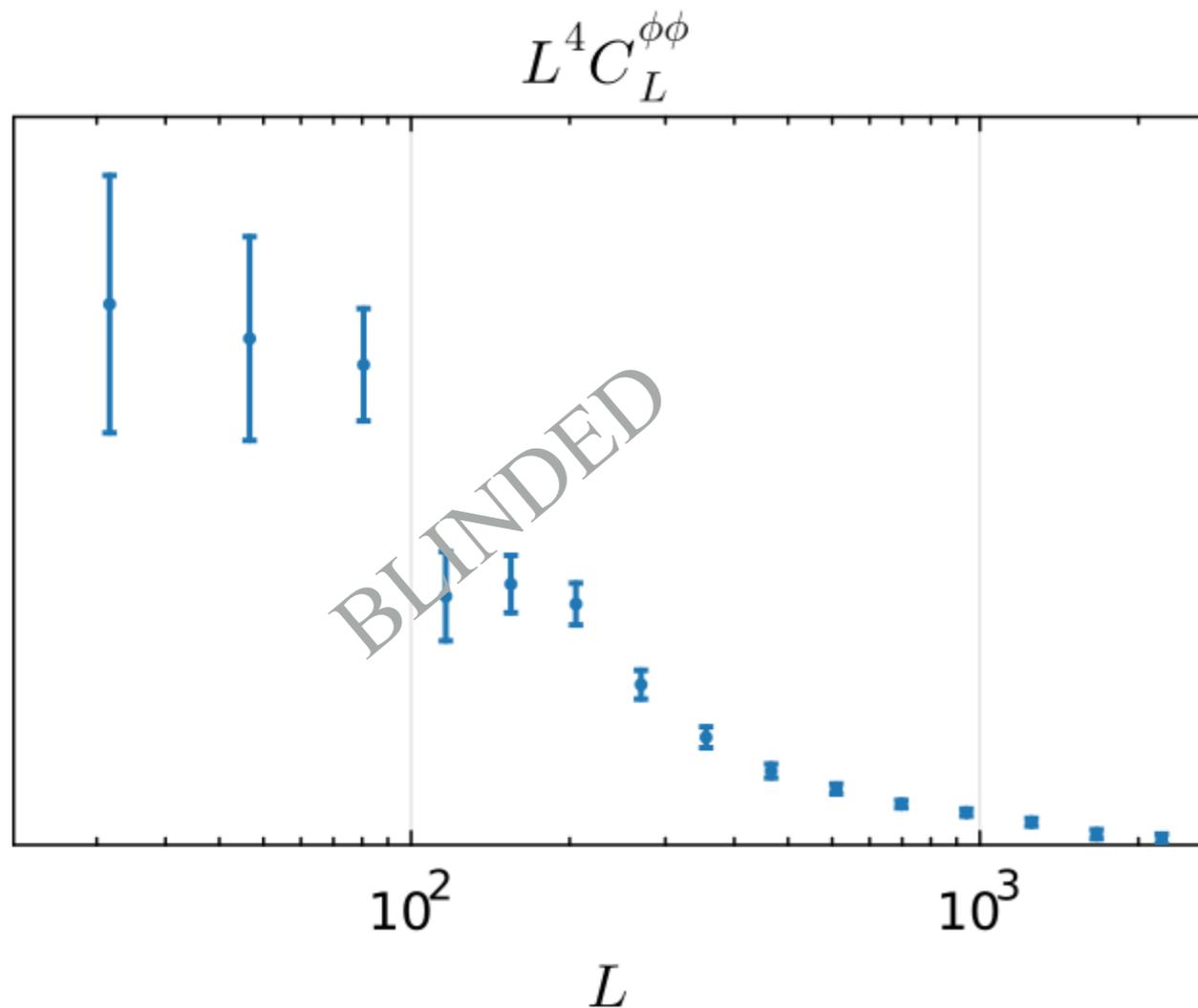


Polarization data contributes roughly equal amount to the total SNR

Credit: Yuuki Omori, Yuka Nakato, Cail Daley, Federico Bianchini and Kimmy Wu

SPT-3G 2019/20 Optimal lensing

Current noise level of SPT-3G has already reached the stage where QE-based lensing is suboptimal (Highly relevant for CMB-S4).

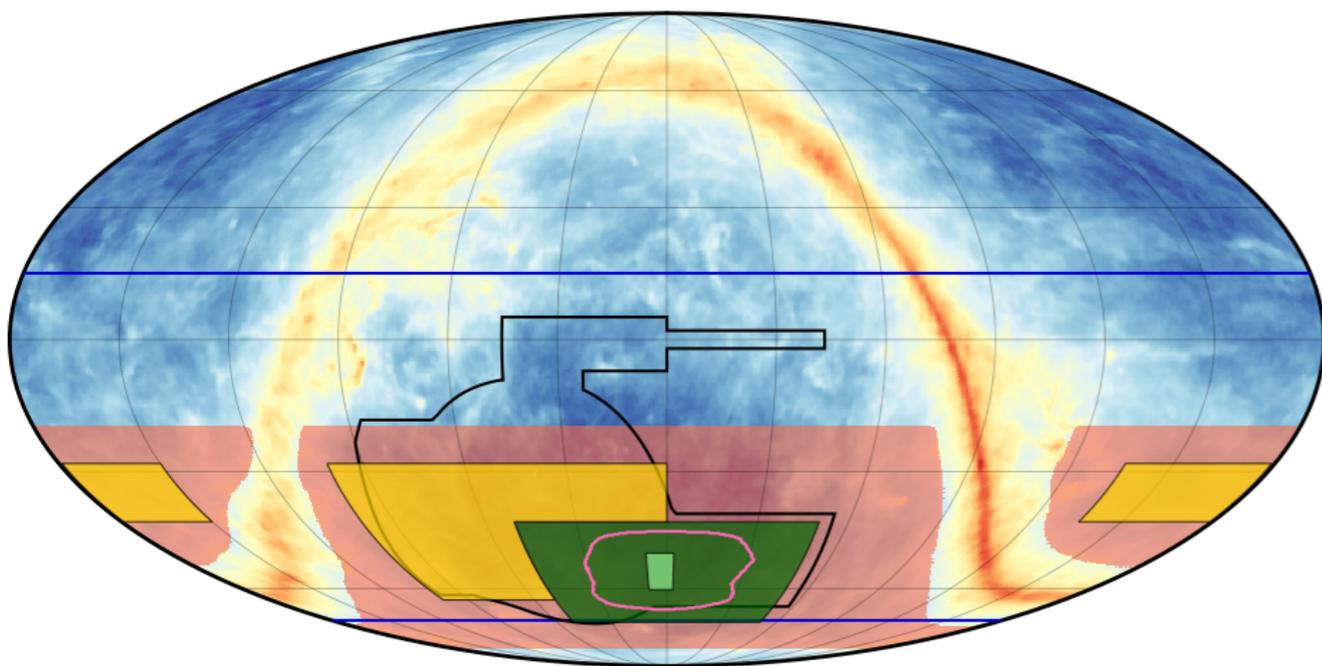


Alternative SPT-3G pipeline for optimal lensing reconstruction.

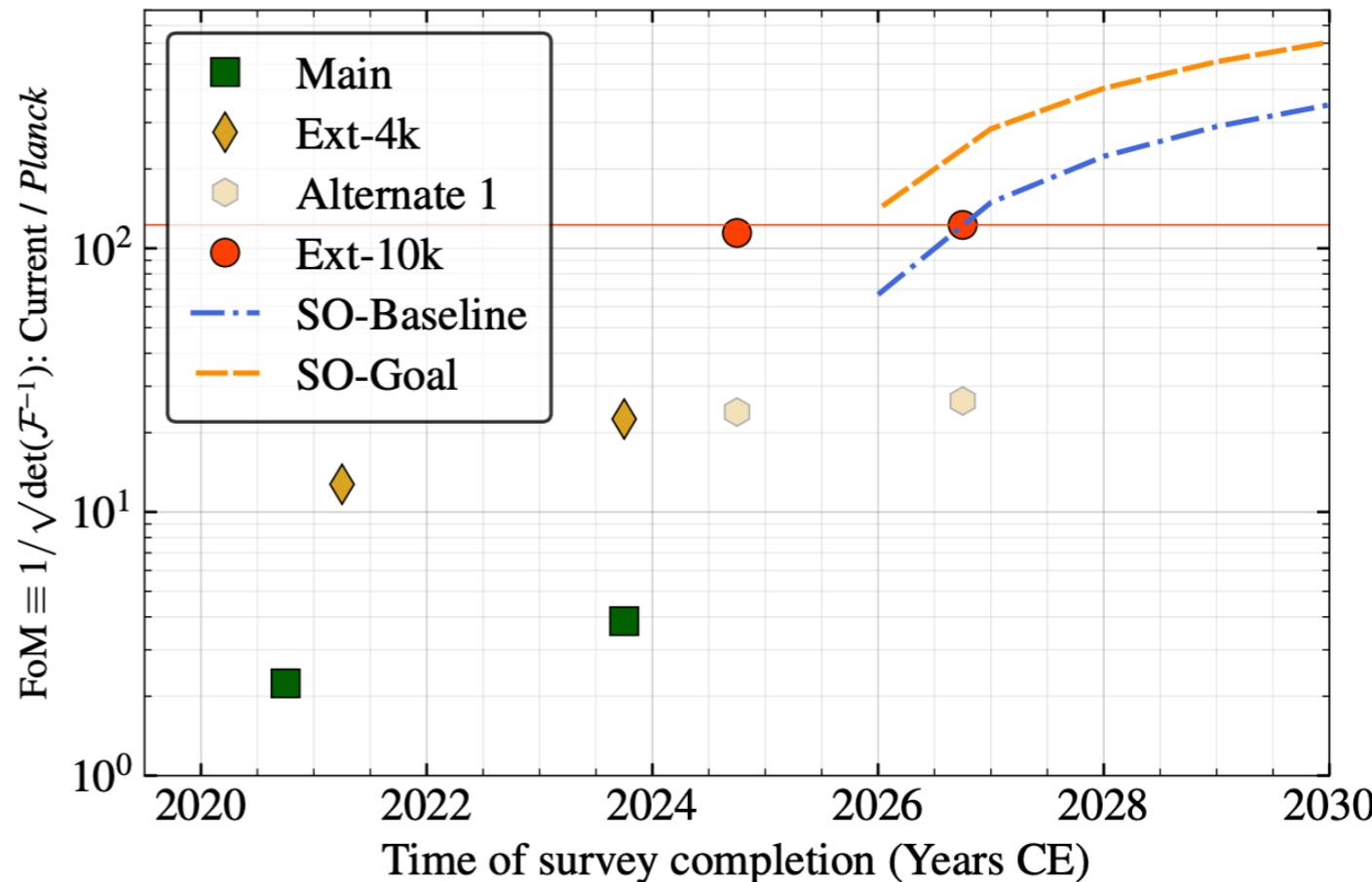
See Fei Ge's talk at the JSAC session on Thursday

Ongoing / near-term future for SPT-3G

SPT-3G - 10,000 deg² Survey



- BICEP3 ■ SPT 100d-megadeep ■ SPT-3G Summer
- DES ■ SPT-3G Main ■ SPT-3G Wide
- SO/LSST



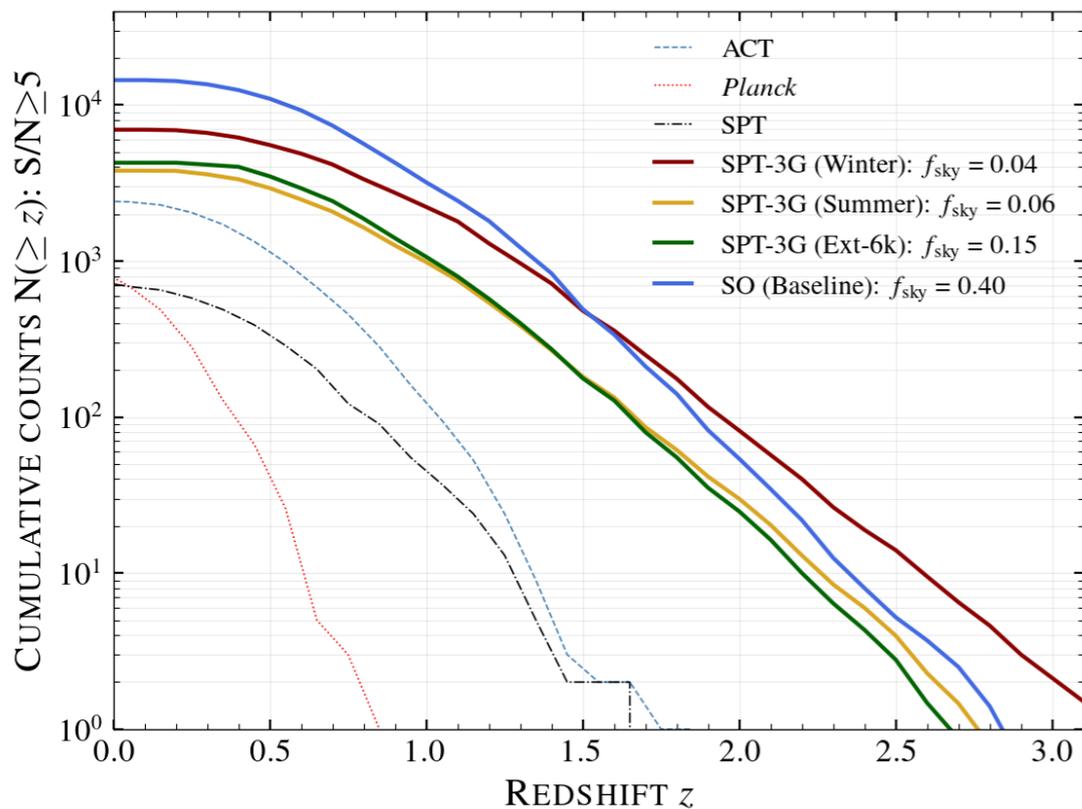
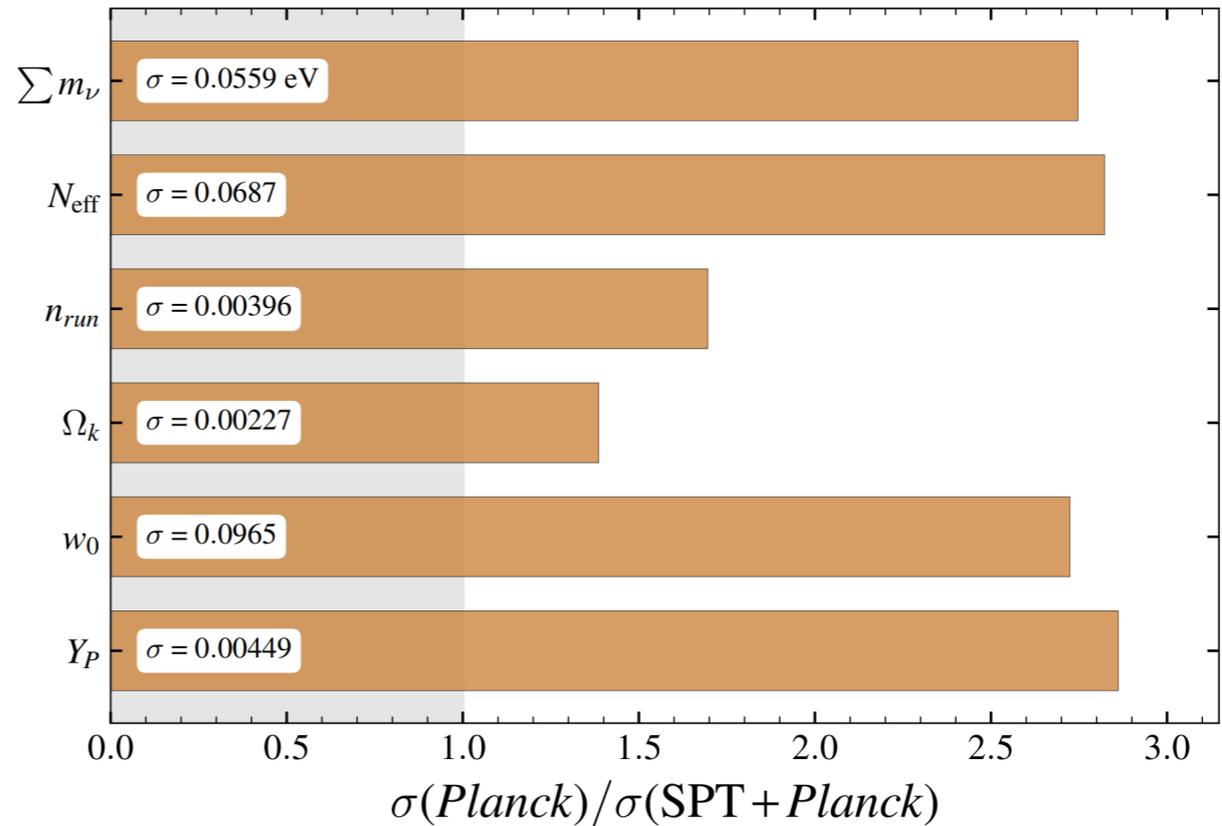
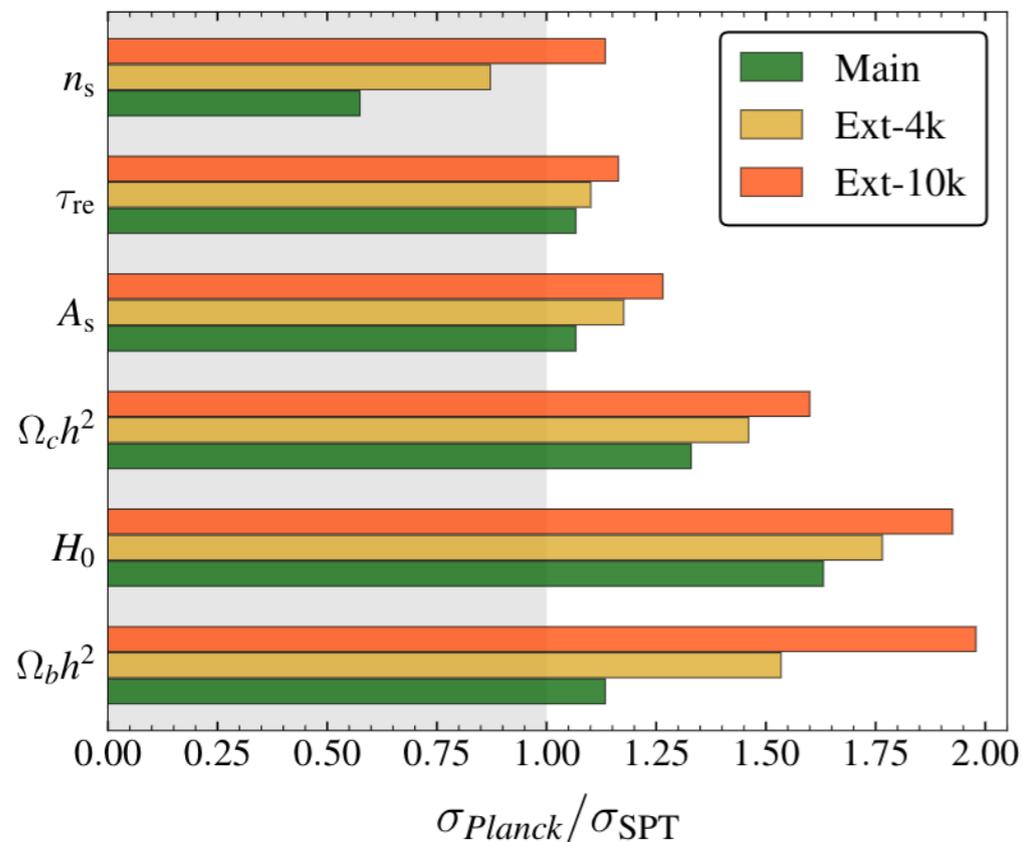
We are scanning a wide area patch (6000 deg²) this year.

SPT-3G's total sky area is 10,000 deg².

Survey	Noise level Δ_T [$\mu\text{K-arcmin}$]			
	90 GHz	150 GHz	220 GHz	Coadd
Main 1500d	2.5	2.1	7.6	1.6
Summer 2650d	10	9	29	6.6
Wide 6000d	14	12	42	8.8

Credit: Prabhu, Raghunathan, Millea et al. 2024, [arXiv: 2403.17925](https://arxiv.org/abs/2403.17925)

SPT-3G - 10,000 deg² Survey



x1.5-2 better than *Planck* for many Λ CDM parameters

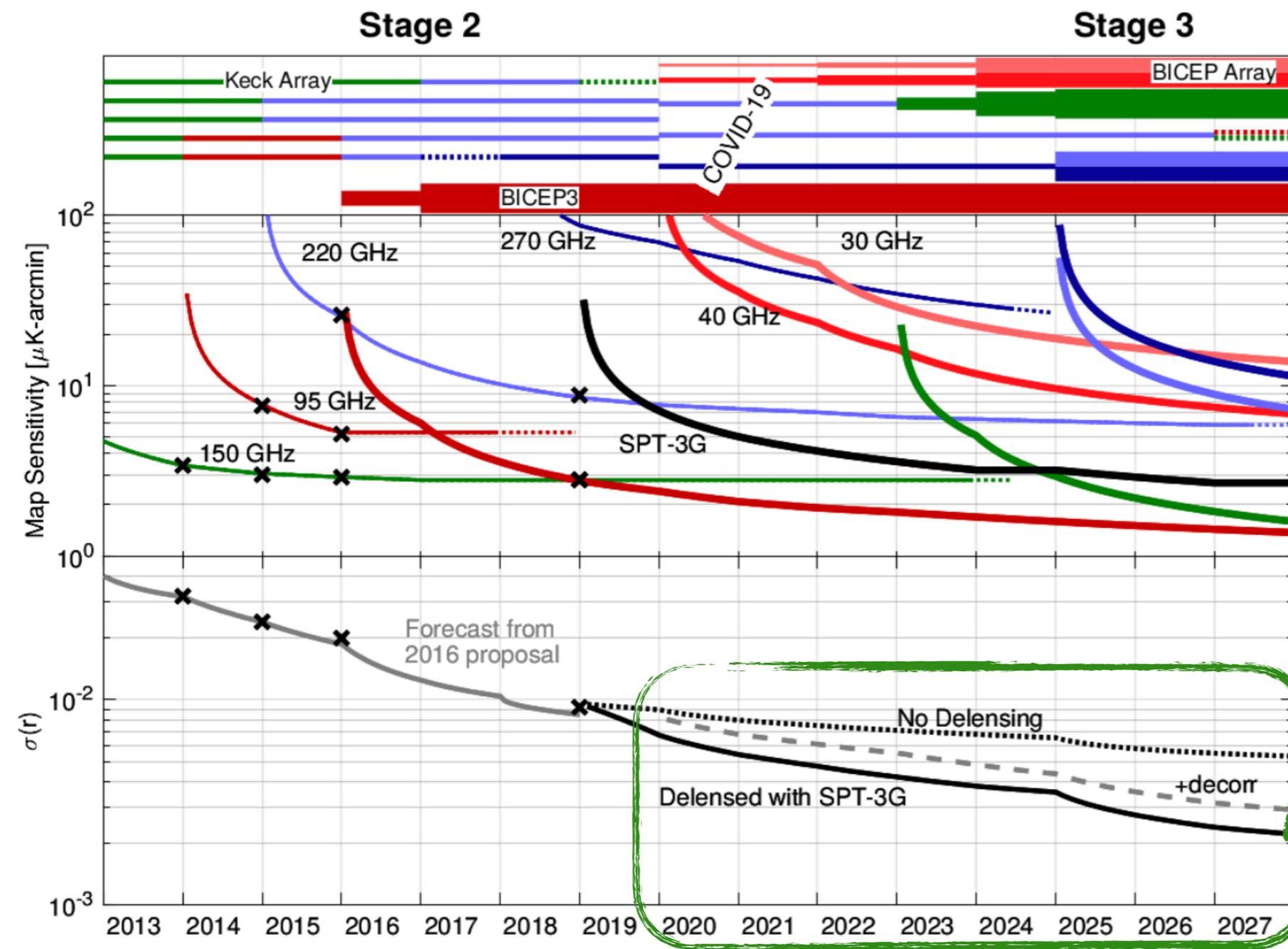
More than x2 improvement over *Planck* for Λ CDM extensions

Roughly 14,000 tSZ-selected clusters with few hundred above $z > 1.5$

Credit: Prabhu, Raghunathan, Millea et al. 2024, [arXiv: 2403.17925](https://arxiv.org/abs/2403.17925)

SPT-3G - Delensing BICEP/Keck for inflationary B-modes

Reduce sample variance from lensed B-modes by **delensing** to facilitate the **inflationary B-mode** search for **BICEP/Keck**.



BK+SPT-3G will constrain $\sigma(r) = 0.002$, offering x3 improvement from SPT-3G delensing

Credit: The BICEP/Keck Collaboration, [arXiv:2405.19469](https://arxiv.org/abs/2405.19469) and Kimmy Wu

SPT-3G+: An upgraded camera for new SPT focal planes

- SPT-3G+ camera supports 7x optics tubes at 100 mK:
 - Planned 1st focal plane: 220, 285, and 345 GHz bands with polarization sensitivity, **aiming to deploy in 2027.**
 - **Science Goals:**
 - ▶ **Inflation:** Improved constraints on polarized Galactic dust and CMB de-lensing.
 - ▶ **Reionization:** High SNR detection of kSZ 2-pt and 4-pt.
 - ▶ **High-z structure:** Improved CIB constraints; larger, more distant high-z galaxies and cluster catalogs.
 - ▶ **Transients:** Continue high-cadence SPT-3G transient observations into LSST era.
- In light of recent CMB-S4 changes, we are considering a focused 90 / 150 GHz de-lensing focal plane:
 - **SPT observations with an optimized delensing focal plane in combination with BICEP-Array could achieve $\sigma(r) \sim 0.001$ with 5-years of data (potentially as early as 2033).**

Thank you for your attention!

Back up slides

WMAP

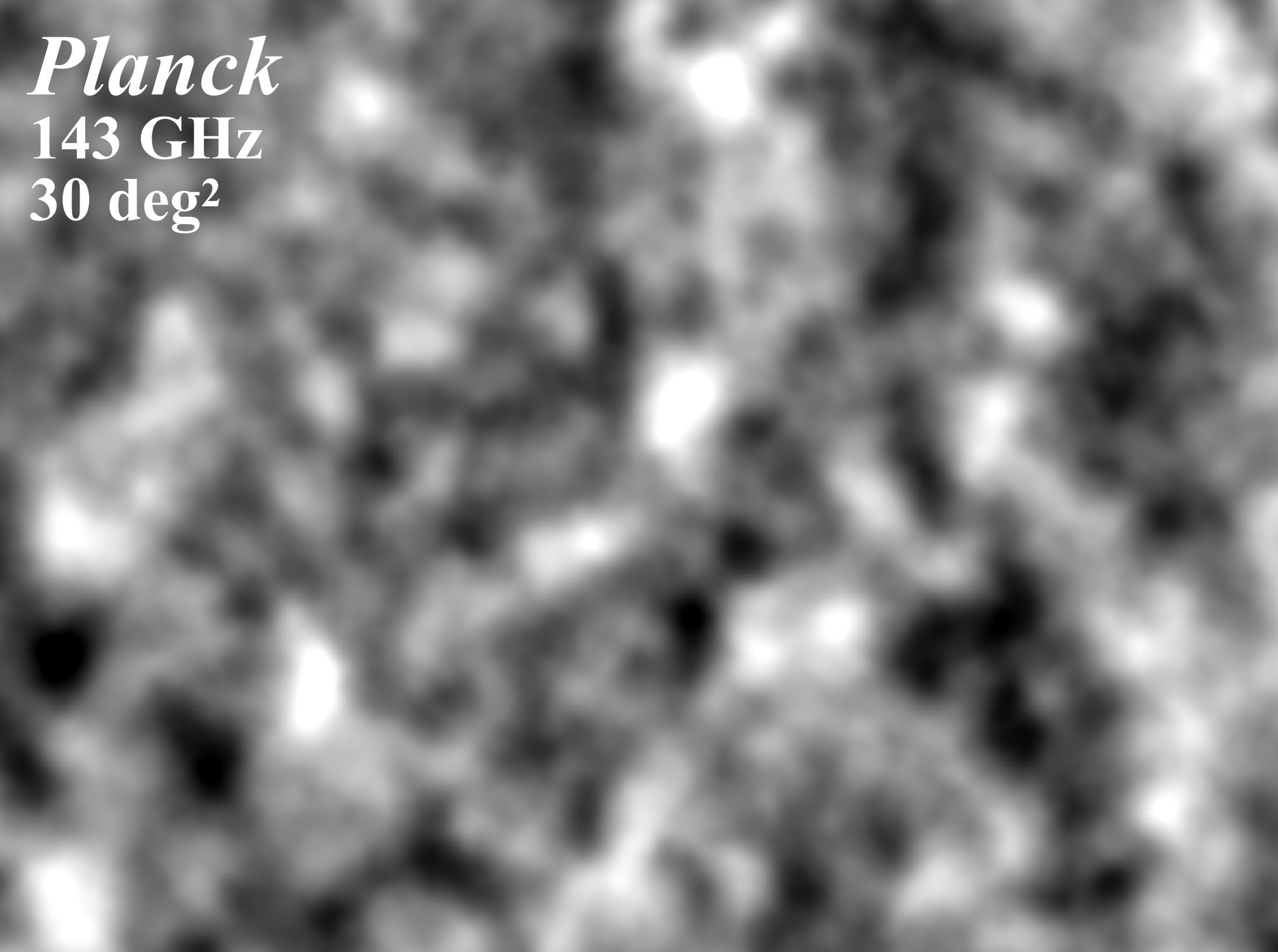
W-band

30 deg²

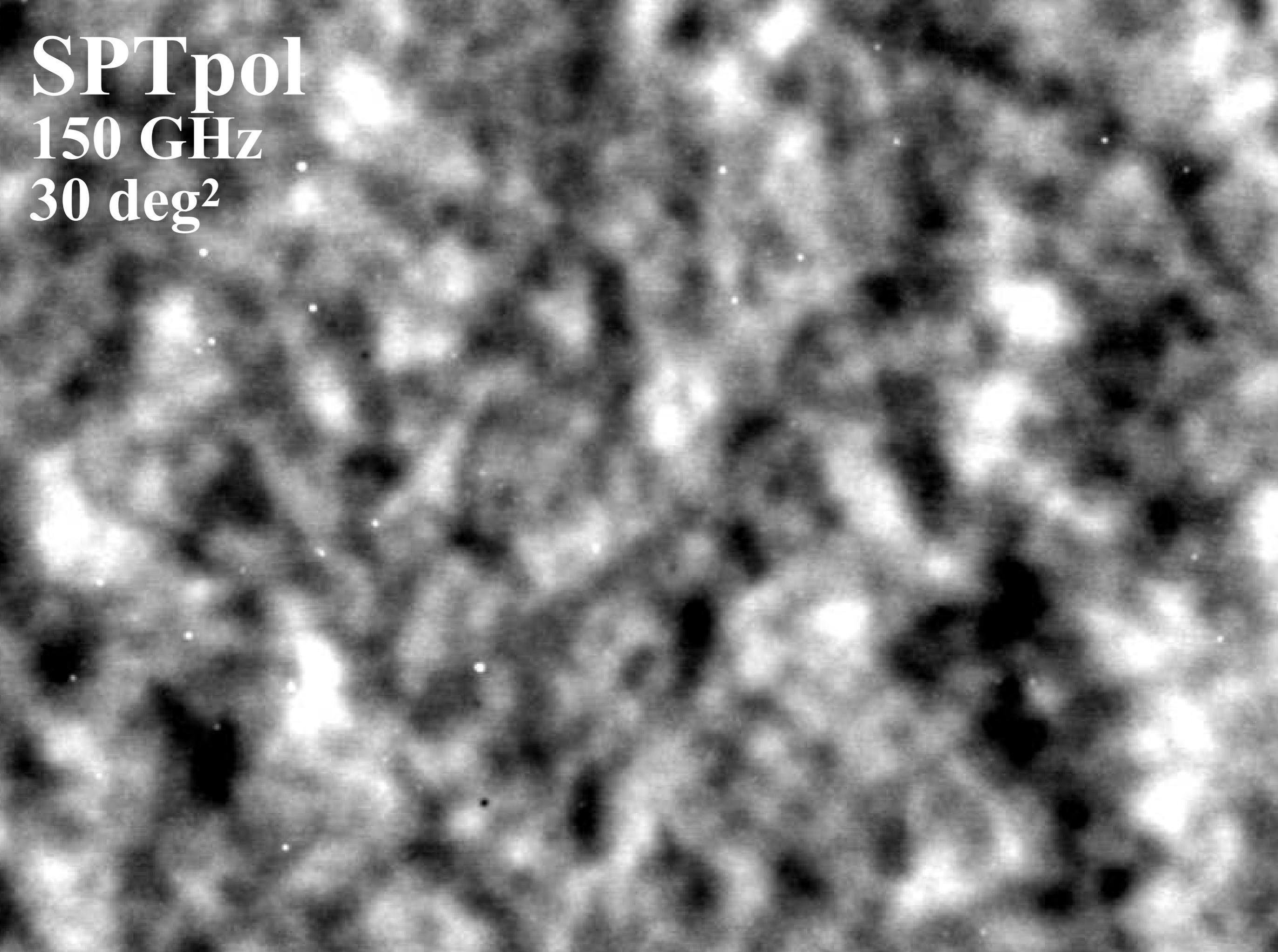
Planck

143 GHz

30 deg²



SPTpol
150 GHz
30 deg²



SPT_{pol}
150 GHz
30 deg²

SPT-3G is roughly x1.5 more sensitive

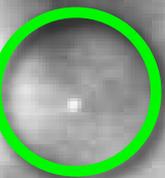
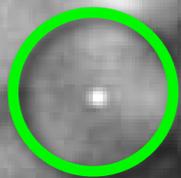
**Cosmic microwave background
(CMB)**

SPT_{pol}
150 GHz
30 deg²

SPT-3G is roughly x1.5 more sensitive

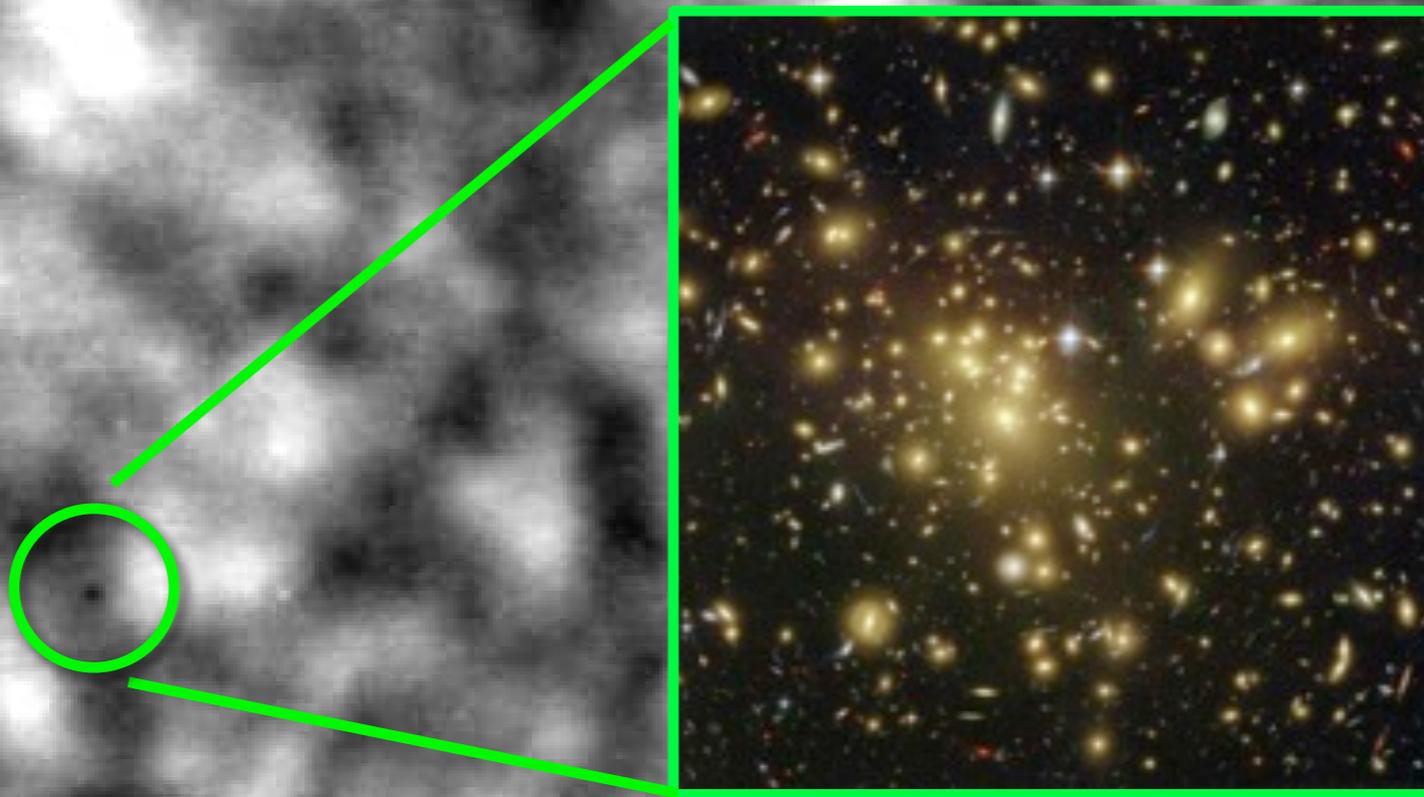
Radio and dusty galaxies show up
as bright spots

Dusty, starforming galaxy



SPT_{pol}
150 GHz
30 deg²

SPT-3G is roughly x1.5 more sensitive



High signal to noise Sunyaev-Zel'dovich (SZ) galaxy cluster detections as “shadows” against the CMB!

