Cosmology with the South Pole Telescope

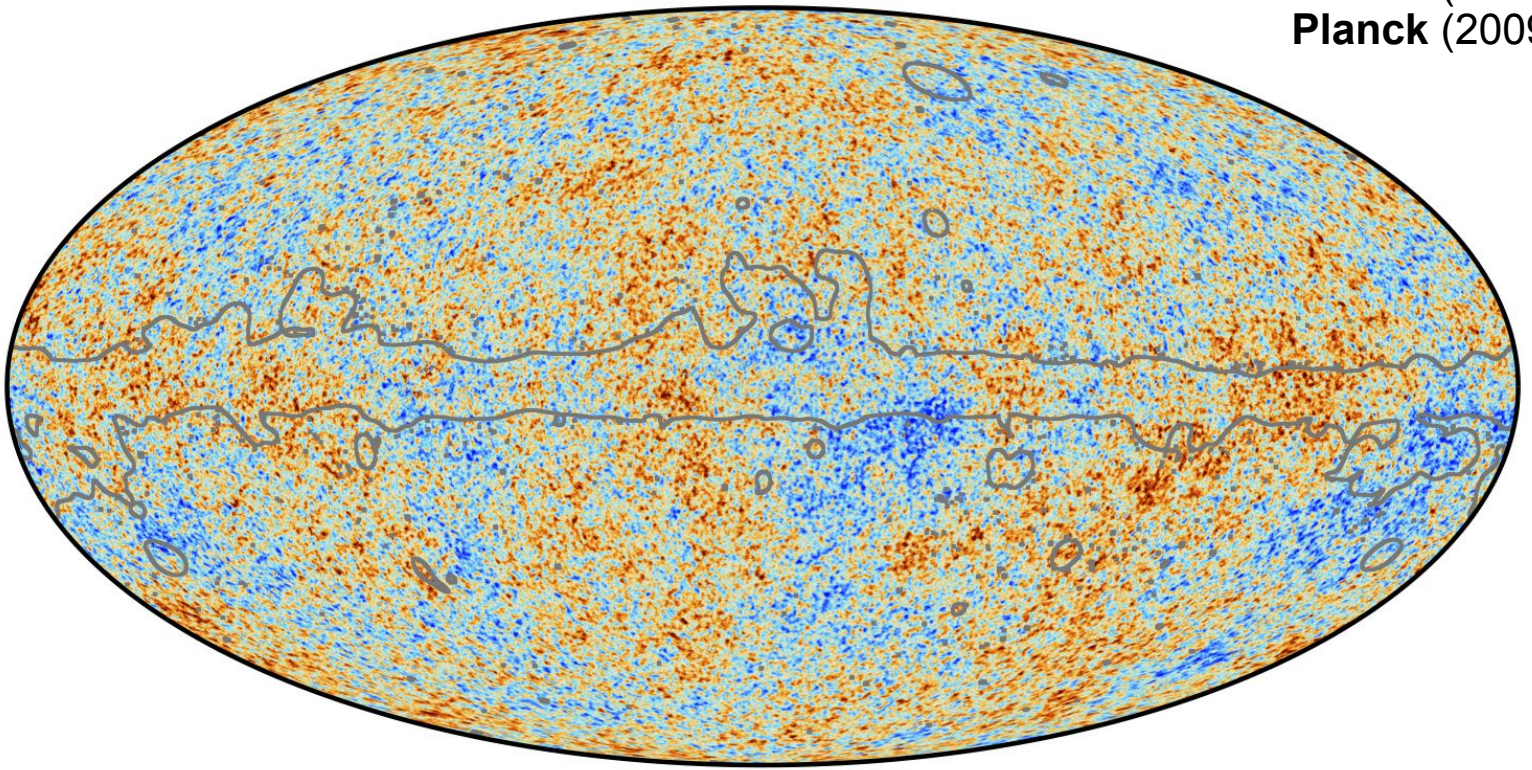
Federica Guidi (IAP, Paris, guidi@iap.fr)
on behalf of the NEUCosmoS team
and the SPT-3G collaboration

Understanding cosmological observations
Benasque, 24 July 2023

Corpse and Mirror II | The Art Institute of Chicago

CMB temperature anisotropies

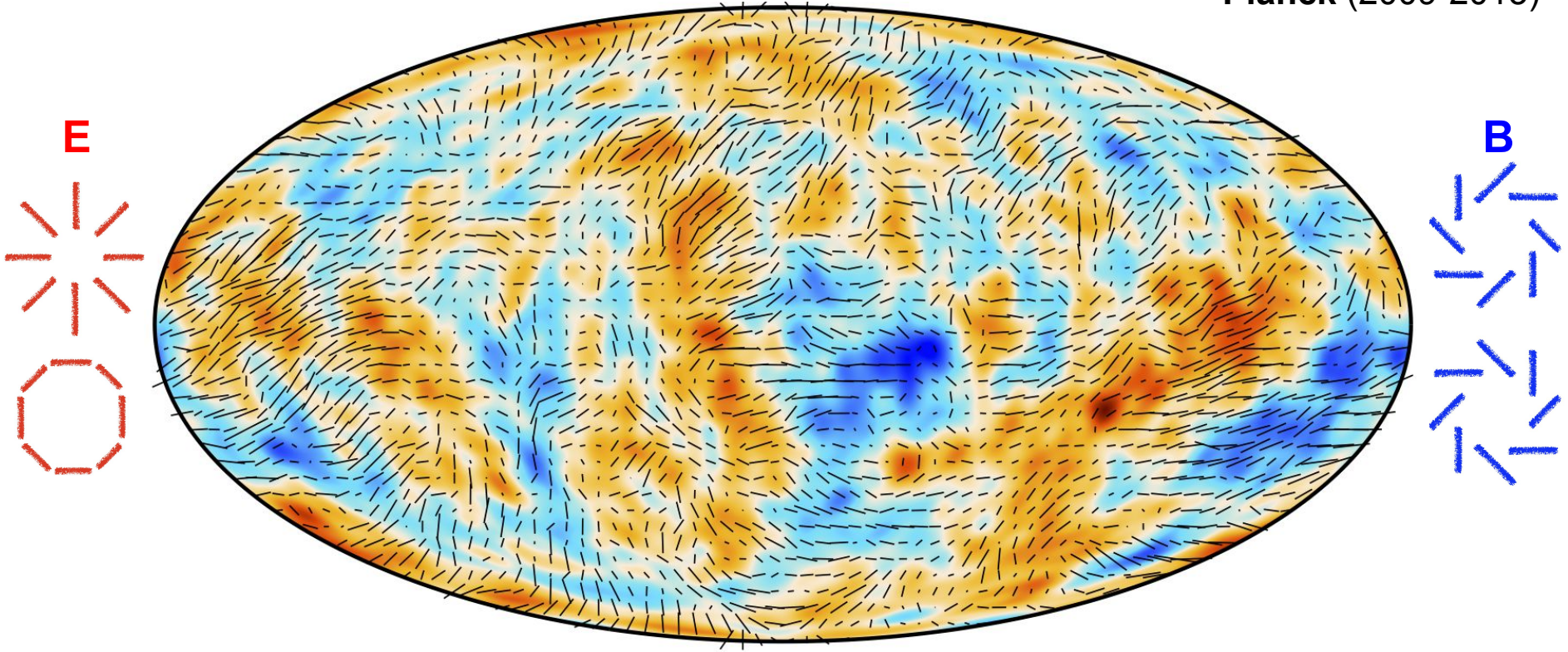
Space missions:
COBE(1989-1993)
WMAP (2001-2012)
Planck (2009-2013)



Credit: Planck
Legacy Archive

CMB polarization anisotropies

Space missions:
WMAP (2001-2012)
Planck (2009-2013)



Credit: Planck Legacy Archive

Cosmology with CMB power spectra

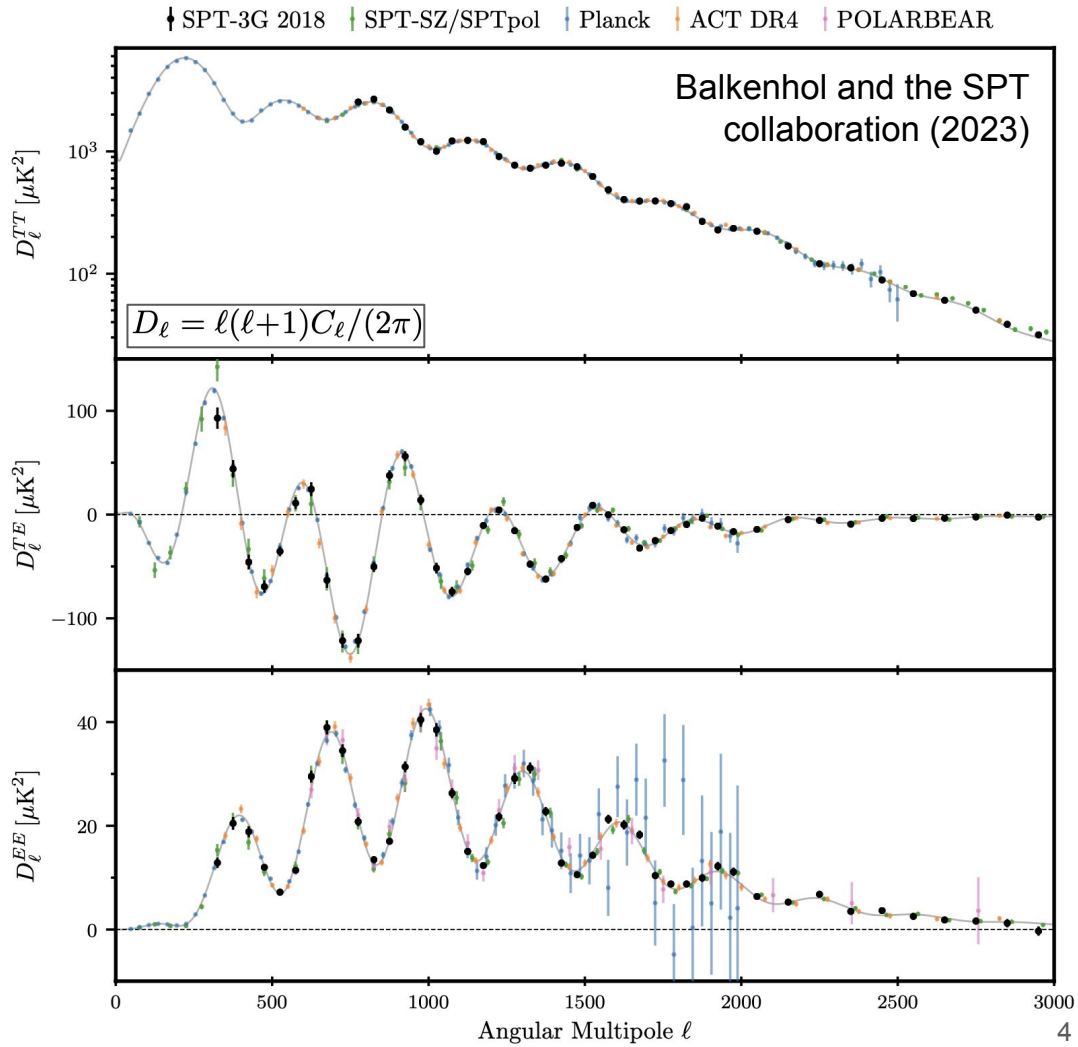
Observations

Maps

$$\left(a_{\ell m}\ , Y_{\ell m}(\hat{\mathbf{n}})\right) \longrightarrow C_\ell$$

TT, EE, TE
angular power spectra

Cosmological parameters of a given model



The South Pole Telescope

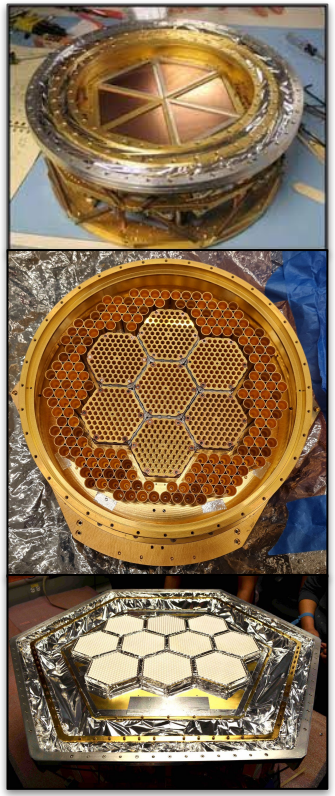
Credit Aman Chokshi

The South Pole Telescope

- **10 m** primary mirror telescope
- Off-axis Gregorian optics design
- Location:
  Amundsen-Scott station,
  South Pole
- Dedicated to CMB observations with high angular resolution
  (~1 arcmin)
- Funded by

The South Pole Telescope

1. **SPT-SZ** (2007–2011)
2. **SPTpol** (2012–2016)
3. **SPT-3G** (2017–present)
   - ~**16 000** transition-edge sensor (**TES**) bolometers
   - Frequency bands: **95, 150, 220 GHz**
   - FWHM: **1.6', 1.2', 1.0'**

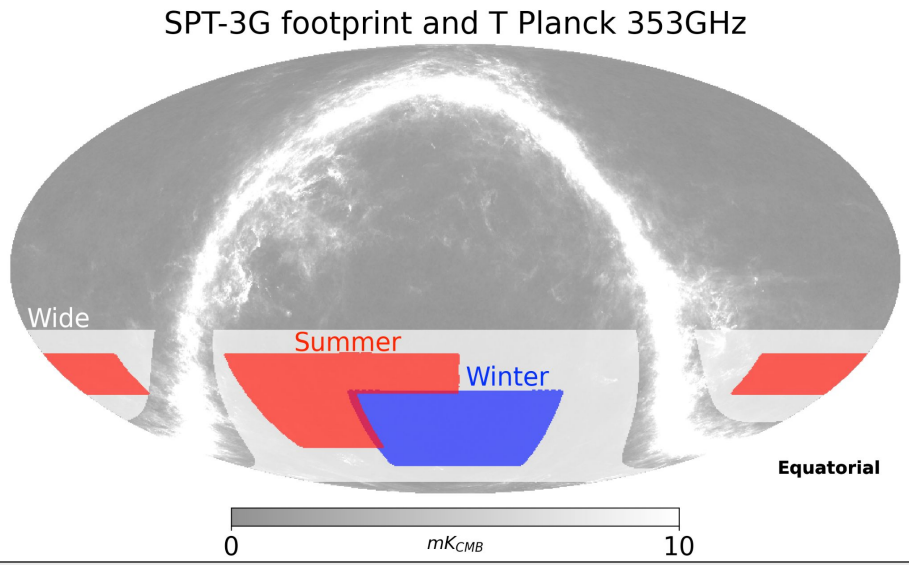


SPT-3G science

- ➔ **Cosmological constraints from CMB primary anisotropies**
- ➔ CMB lensing
- ➔ Delensing the BICEP/Keck field
- ➔ High-ℓ TT
- ➔ Low-ℓ BB
- ➔ DES x SPT
- ➔ tSZ kSZ
- ➔ Cosmic birefringence
- ➔ Axions
- ➔ Galaxy clusters
- ➔ Point sources, transients, asteroids, planet 9
- ➔ …


SPT Collaboration meeting July 2023

SPT-3G observations and timeline



Half focal plane
Effective time:
4 months
Winter field

Full focal plane
Winter field:
8 months/yr
Summer fields:
4 months/yr

2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027

SPT-3G Deployment

2018 Early survey

2019/20 Nominal survey

… observations continue …

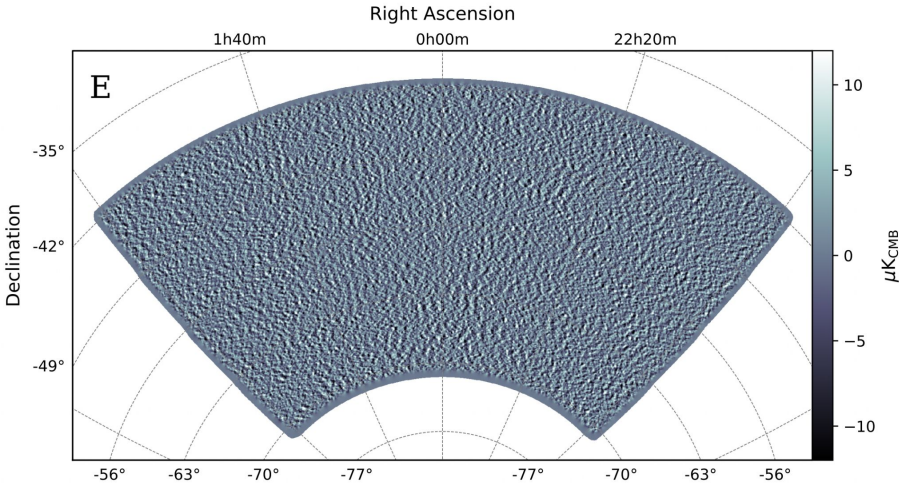
SPT-3G early results

Credit Aman Chokshi

SPT-3G 2018

Early survey:

- **4 months** during the 2018 winter season (April–November)
- **~ half of the focal plane**: 6600 active detectors on average
- **Winter field**: ~1500 deg2 (fsky~4%)
  - Overlap with the BICEP/Keck field



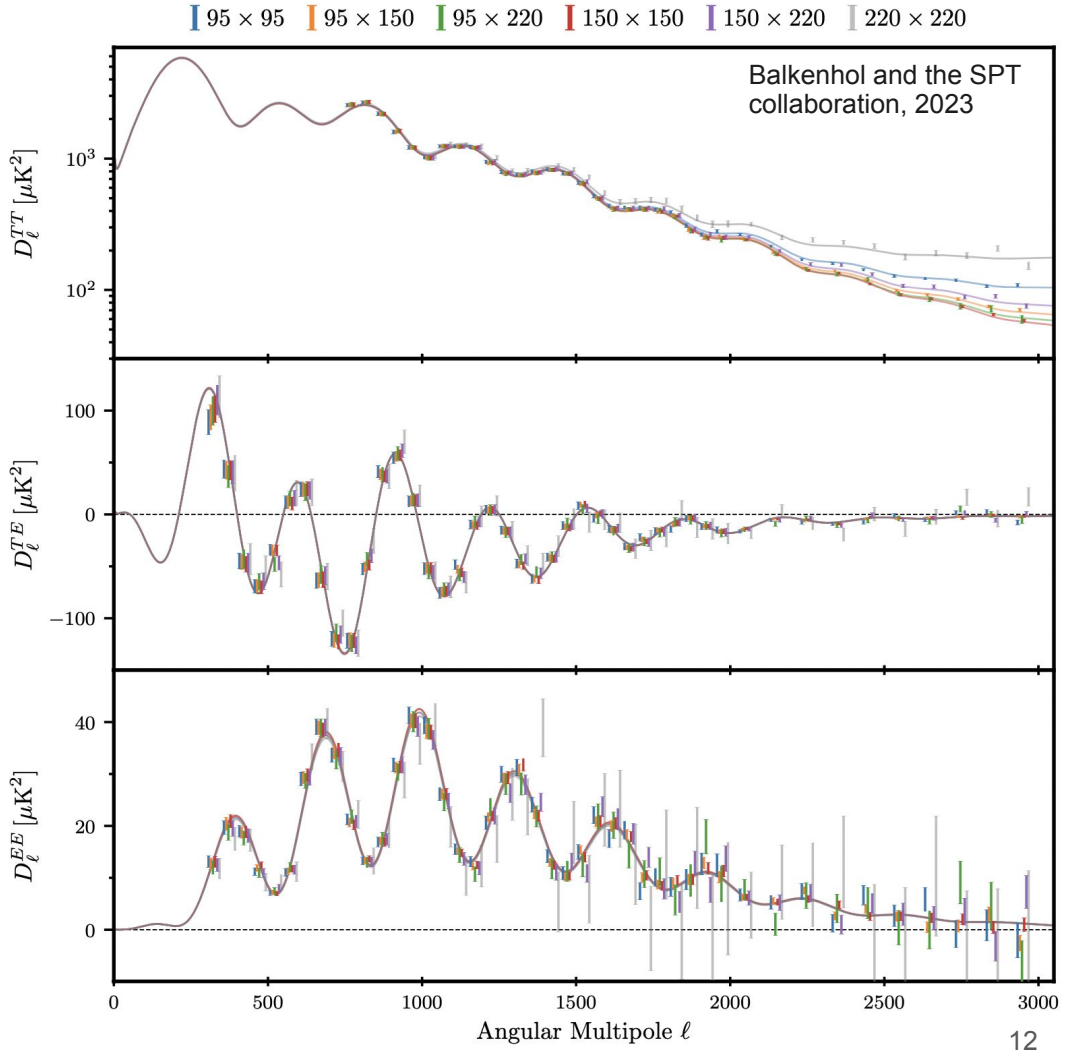
Dutcher and the SPT collaboration, 2021

First scientific results:

➔ Dutcher et al. 2021 (arXiv:2101.01684, maps, TE/EE bandpowers, ΛCDM)
➔ Balkenhol et al. 2021 (arXiv:2103.13618, ΛCDM Extensions from TE/EE)
➔ Balkenhol et al. 2023 (arXiv:2212.05642, adding TT)

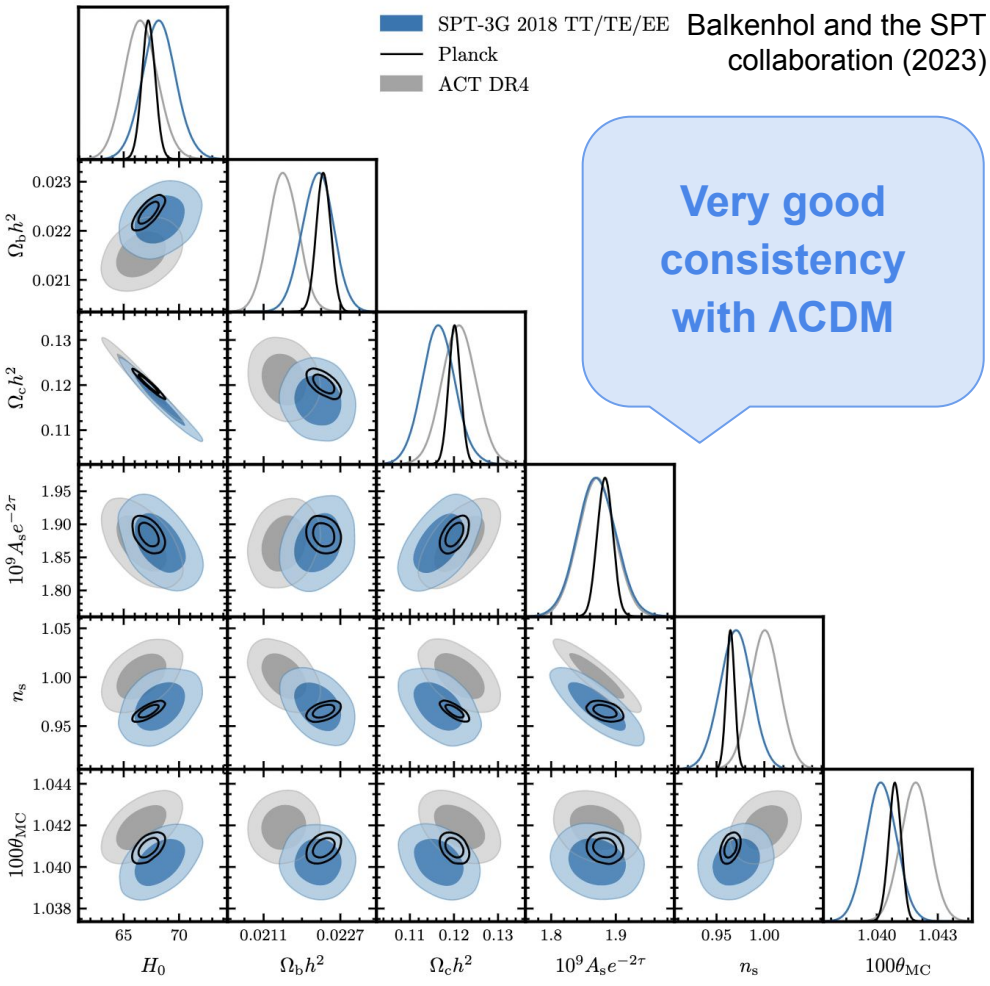
SPT-3G 2018 angular power spectra

- **TT** $750 \leq \ell < 3000$
- **EE, TE** $300 \leq \ell < 3000$
- Binning scheme:
  - $\Delta\ell = 50$ at $\ell \leq 2000$
  - $\Delta\ell = 100$ at $\ell > 2000$
- Sample-variance-limited at
  - TT: whole ℓ range
  - EE: $\ell < 1275$
  - TE: $\ell < 1425$



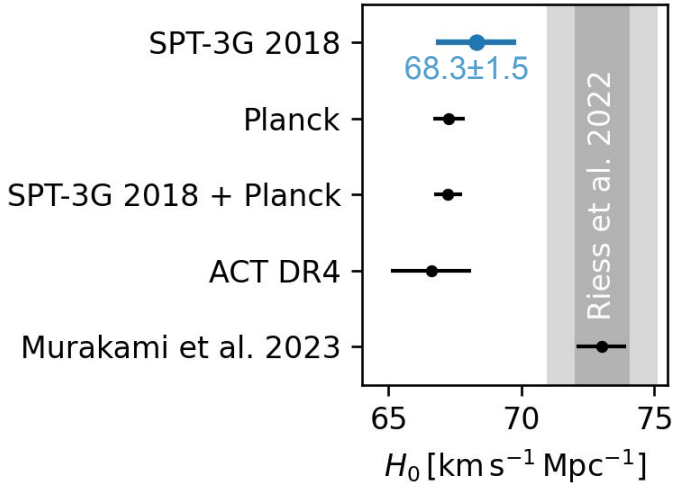
SPT-3G 2018 cosmological constraints

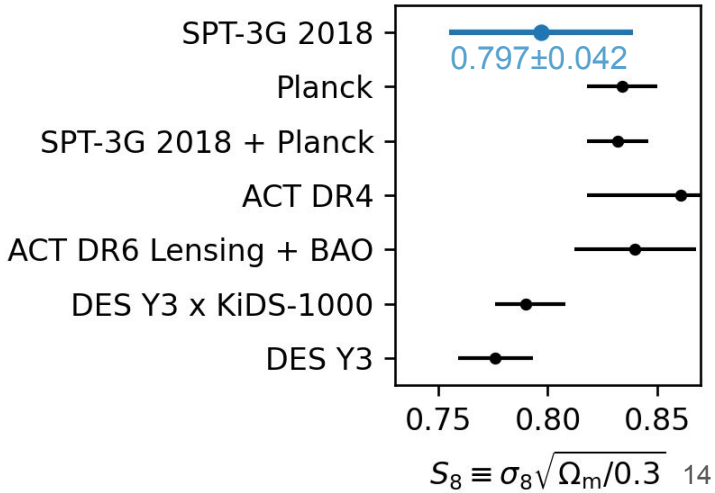
- **Consistent with Planck** (deviations < 1σ) although largely **independent**
  - SPT-3G sensitive at intermediate and small angular scales (EE/TE mostly), while Planck sensitive at large scales (TT mostly)
  - A small area is shared by the two surveys
  - Only a global re-calibration of SPT-3G relies on Planck
- Consistent with ACT (DR4), with **similar constraining power**



SPT-3G 2018 tensions highlight

- **Hubble constant (H_0)** is as low as other CMB measurements
  - H_0 = 67.24 ± 0.54 km/s/Mpc (SPT-3G-TTEETE-2018+Planck)
  - ~5σ tension with Riess et al. (2022)
- **Structure growth parameter (S_8)** aligns with low-z data, but is also compatible with Planck's
- Constraints of **ΛCDM extensions** (A_L, N_{eff}, N_{eff}+Y_P, PMFs): no significant improvement over ΛCDM






SPT-3G next release:
2019/20 data
Credit Aman Chokshi

SPT-3G 2019/20

Fields:

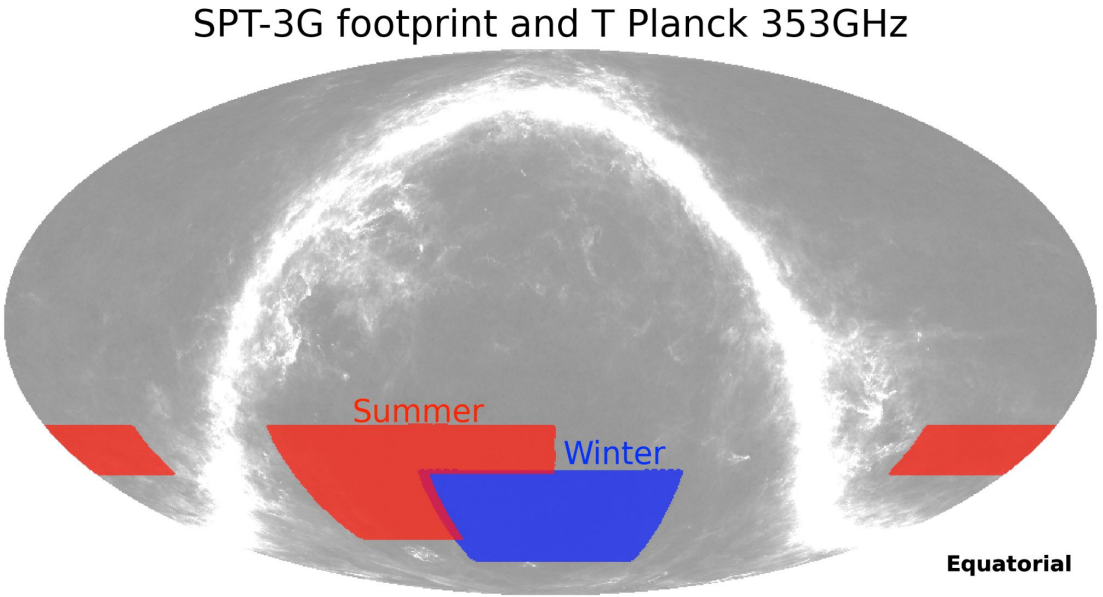
- **Winter**: deep but small → very sensitive at intermediate and high multipoles
- **Summer**: shallow but wide → reduce sample variance, powerful to test extended models

Noise levels:
(at 90, 150, 220 GHz):

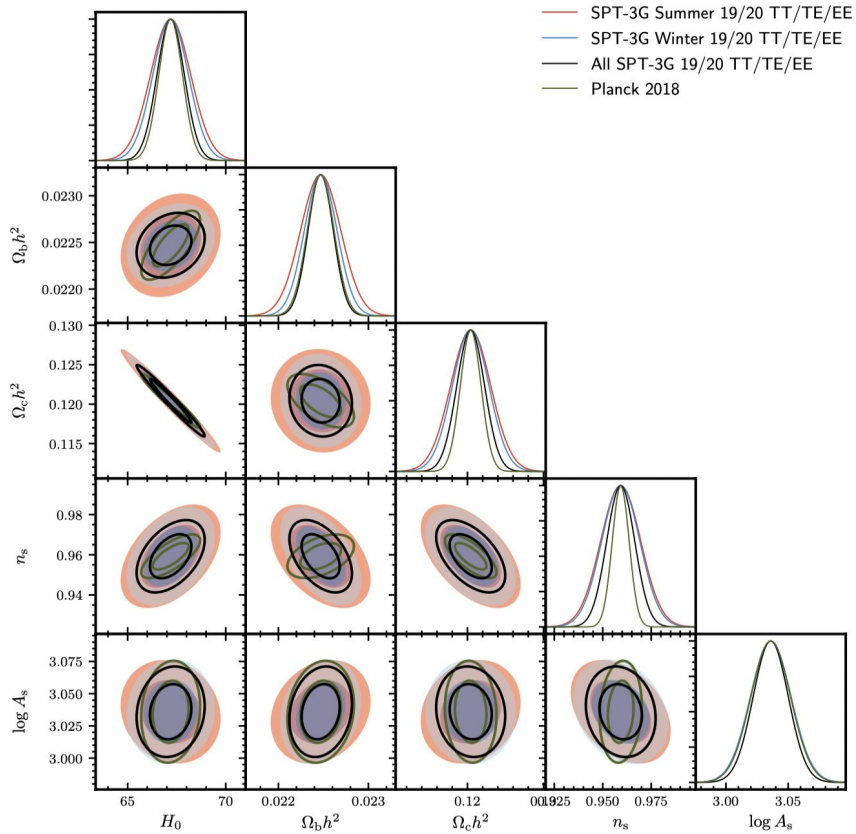
- **6, 5, 16** μK-arcmin
- **14, 13, 41** μK-arcmin

Covered sky fraction:

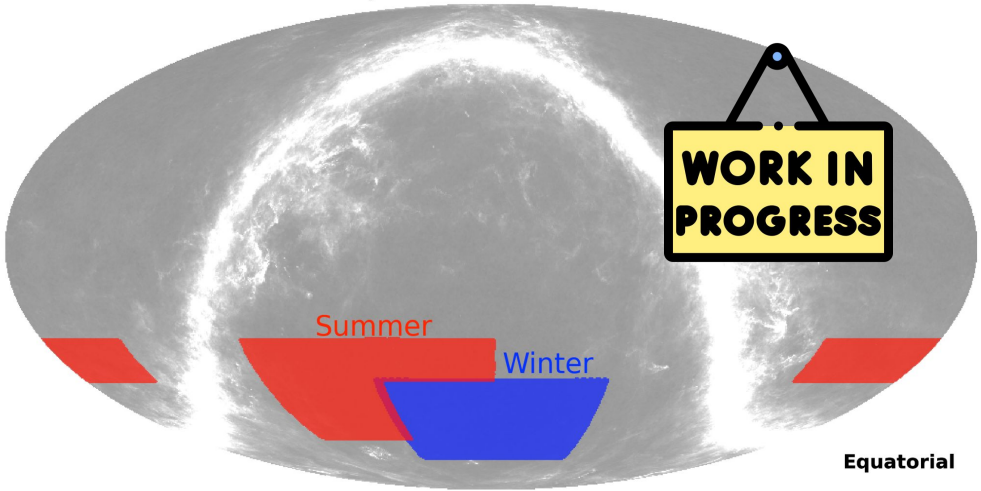
- **4%** (1650 deg2)
- **6.6%** (2800 deg2)



SPT-3G 2019/20: ΛCDM forecasts



SPT-3G footprint and T Planck 353GHz



σ(H₀) [Km/s/Mpc] TT/TE/EE angular power spectra (ΛCDM)		
Planck	SPT-3G Winter	SPT-3G Summer
0.6	**0.9**	**1.0**
	0.7	
0.43		

Additional 30–40% improvement of the SPT-3G constraints when including the SPT-3G lensing information (TT/TE/EE+ϕϕ)

Forecasts by L. Balkenhol and S.Raghunathan

SPT-3G complete survey

Credit Aman Chokshi

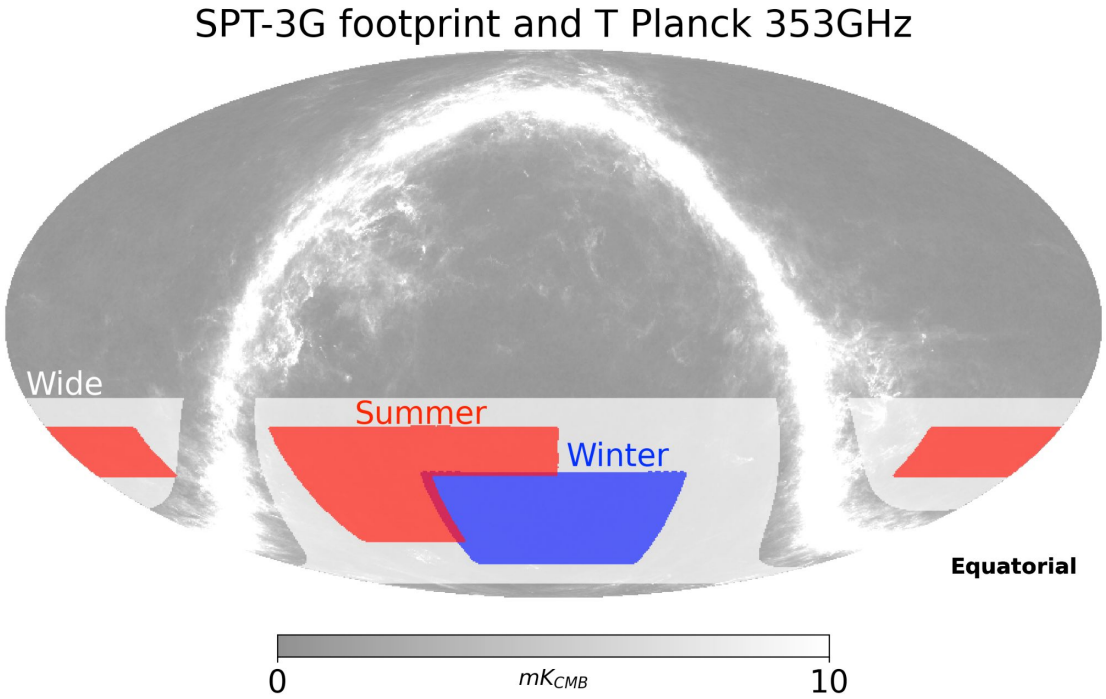
SPT-3G observations: the wide survey

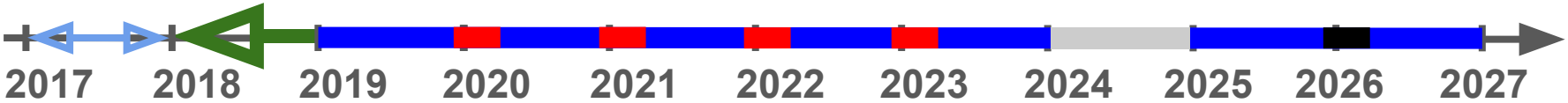
Wide survey !

- Additional 6000 deg2
- To be observed in 2024
- Total covered sky fraction ~25%
- -80°< declination < -20°
- Excluding Galaxy
- **Ext-10K** = Winter+Summer+Wide

Target noise levels
(at 90, 150, 220 GHz):

- **2.5, 2.1, 7.6** μK-arcmin in 7 years
- **8.5, 9, 31** μK-arcmin in 4 years
- **14, 12, 42** μK-arcmin in 1 year





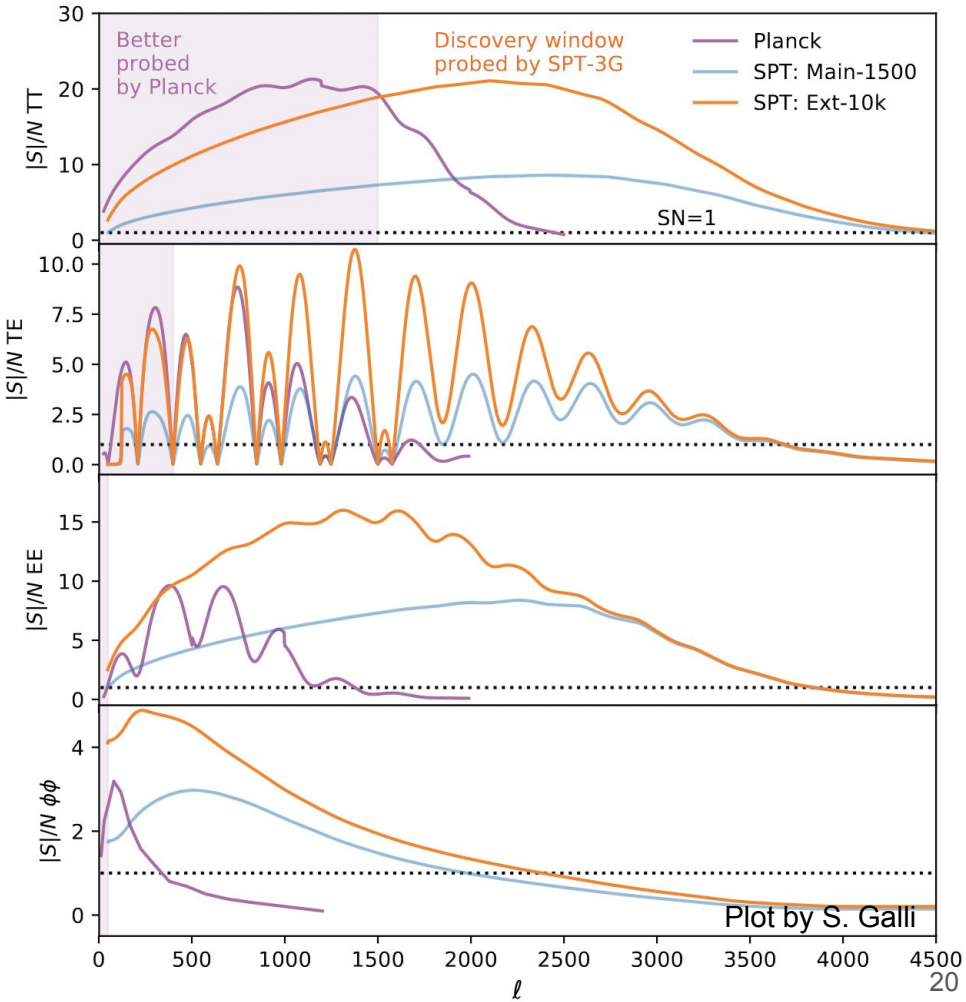
SPT-3G observations: the wide survey

Wide survey !

- Additional 6000 deg2
- To be observed in 2024
- Total covered sky fraction ~25%
- -80°< declination < -20°
- Excluding Galaxy
- **Ext-10K** = Winter+Summer+Wide

Target noise levels
(at 90, 150, 220 GHz):

- **2.5, 2.1, 7.6** μK-arcmin in 7 years
- **8.5, 9, 31** μK-arcmin in 4 years
- **14, 12, 42** μK-arcmin in 1 year



Summary

- SPT-3G is providing a powerful dataset to test cosmology with the CMB
  - almost independently from Planck
  - in a complementary range of multipoles (low:Planck, intermediate–high: SPT)
  - in a small region of the sky
- Reaching Planck's constraining power very soon
- Going beyond Planck's constraining power in few years
- Allowing us to test models beyond ΛCDM