

# ***Prospects for Neutrino Physics with SPT-3G and Future CMB Experiments***

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Topics in Cosmic Neutrino Physics

# **Two Probes of Neutrinos**

## ***Early Times***

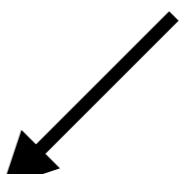
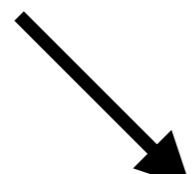
*Relativistic energy density ( $N_{\text{eff}}$ )*

- Neutrinos, other light relics contribute to relativistic energy density at recombination
- Suppresses small-scale features in primary CMB

## ***Late Times***

*Sum of neutrino masses ( $\sum m_\nu$ )*

- Massive neutrinos suppress large-scale structure
- LSS imprinted on CMB via:
  - Clusters of galaxies (SZ)
  - Gravitational lensing of CMB



***high-resolution measurements of CMB polarization***

# *High-Resolution Ground-Based CMB*

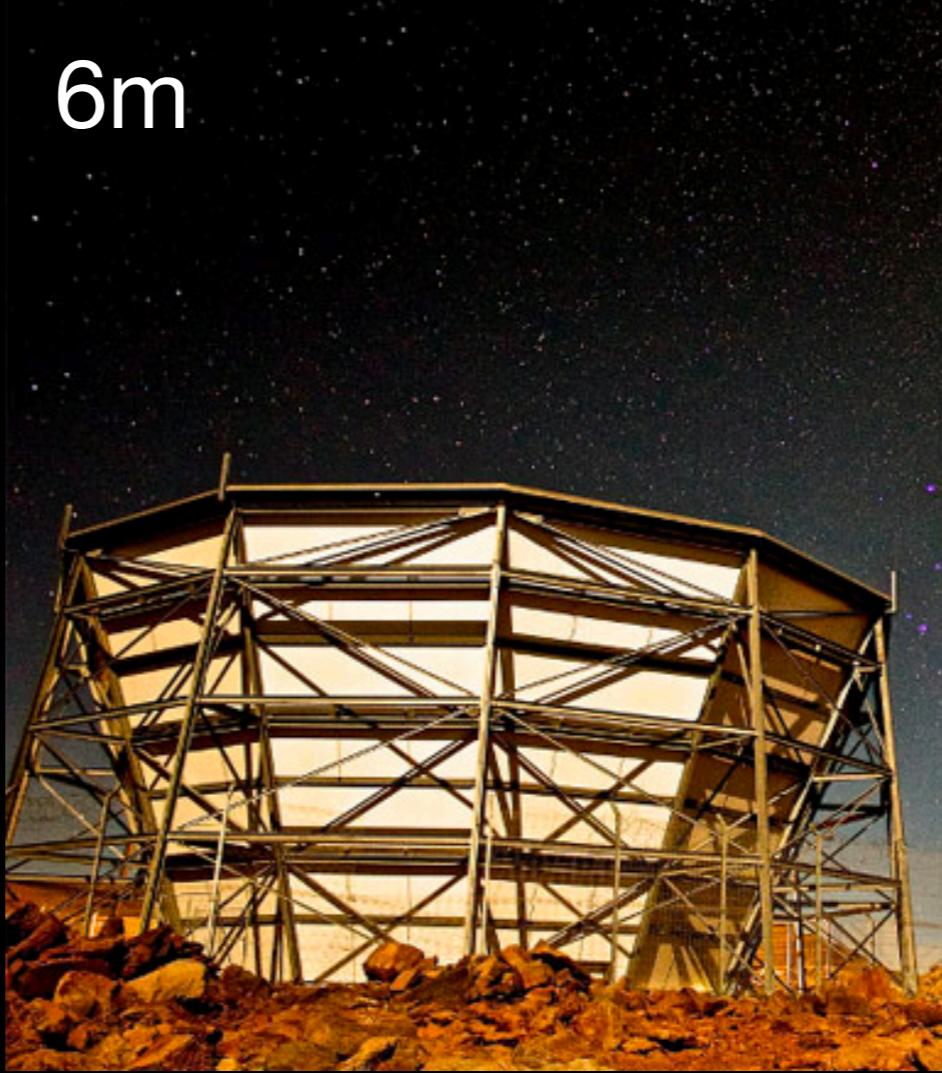
Simons Array

2.5m



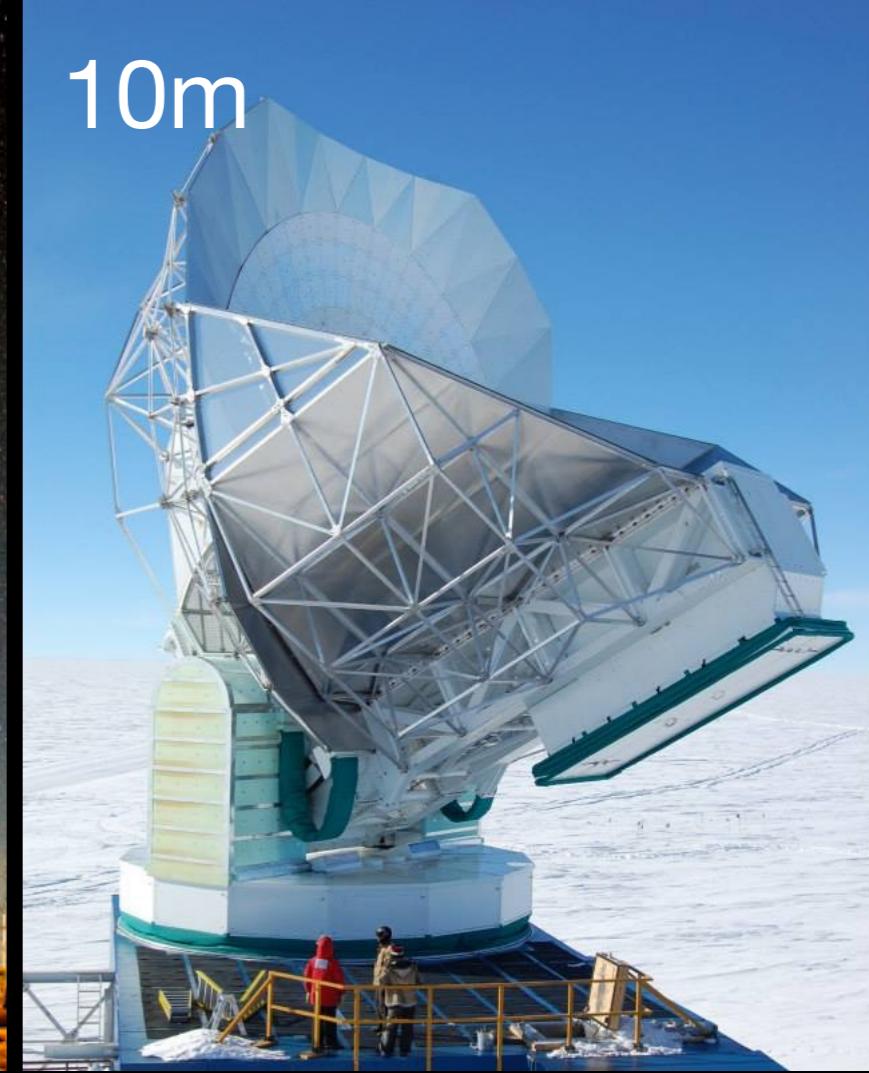
Advanced ACTPol

6m



SPT-3G

10m



22,764 detectors  
(95, 150, 220 GHz)  
In deployment

5,612 detectors  
(30, 40, 90, 150, 230 GHz)  
Deployed 2016

15,000 detectors  
(95, 150, 220 GHz)  
Deployed 2017

# *High-Resolution Ground-Based CMB*

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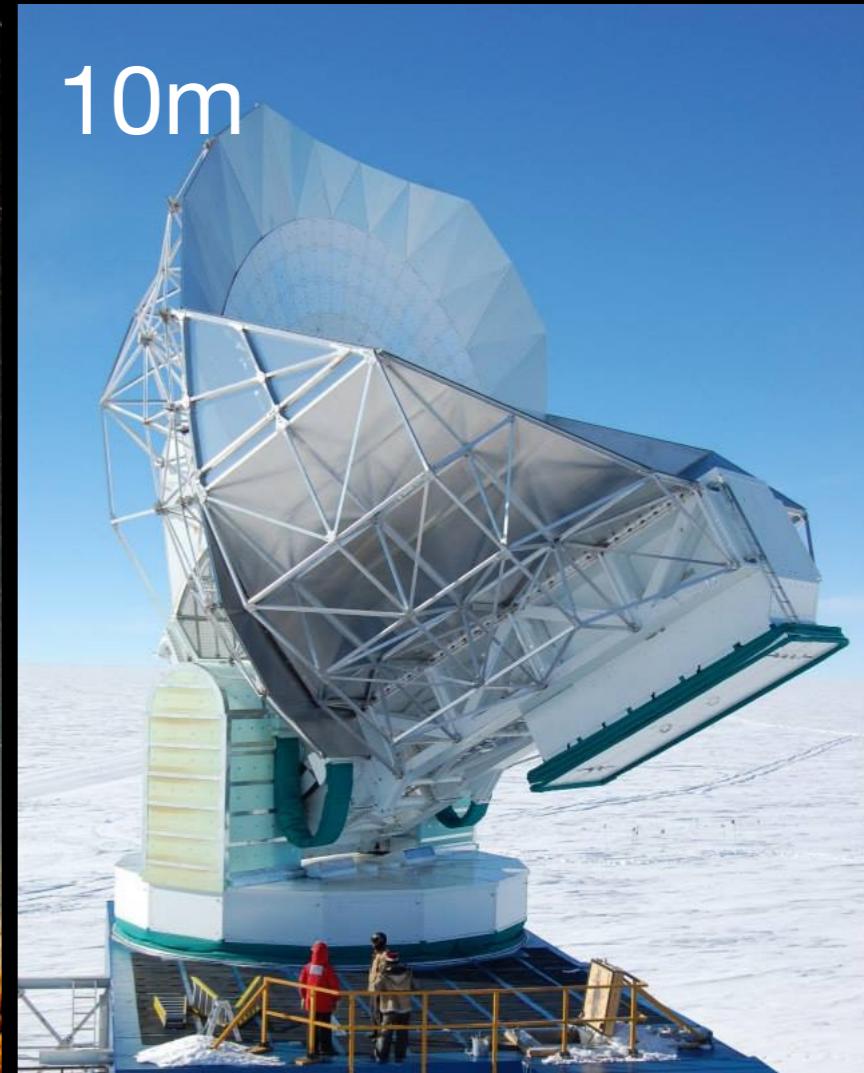
- Unique 10 m primary mirror, largest of its kind
- resolution of ***1.0 to 1.5 arcmin***, highest resolution CMB maps
- 24-hour observing during polar winter enables continuous deep integration



Advanced ACTPol



SPT-3G



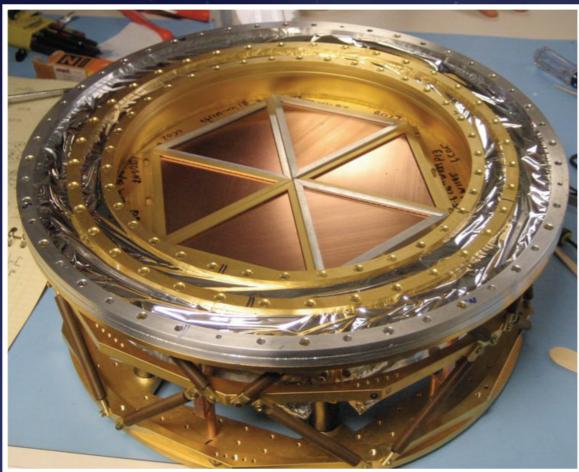
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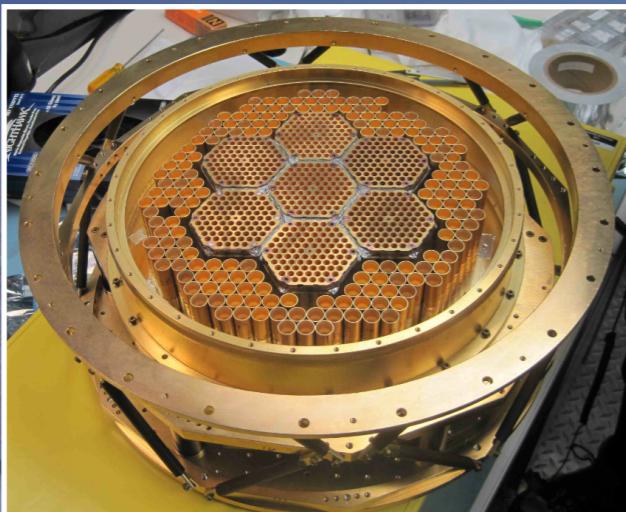
# South Pole Telescope

SPT-SZ (2007)



960 detectors at 95, 150, 220 GHz

SPTpol (2012)

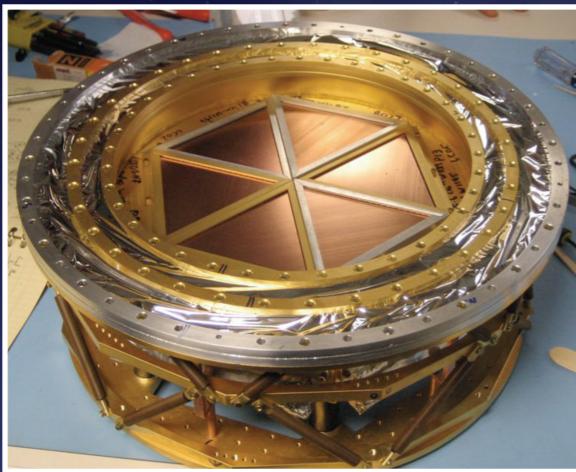


1500 detectors at 95, 150 GHz  
w/polarization



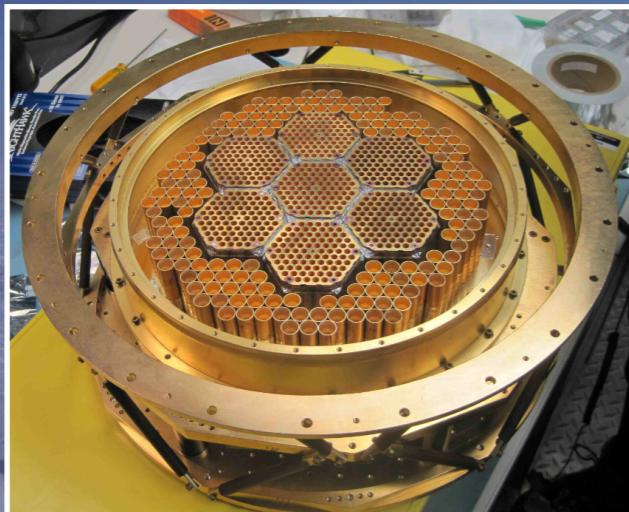
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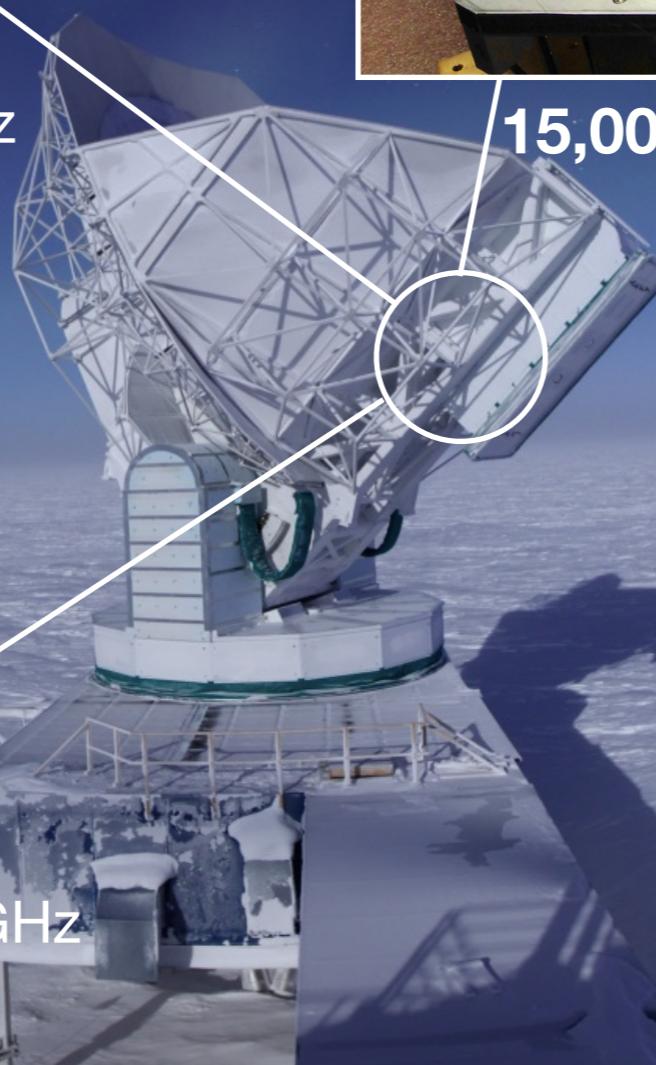


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## SPT-3G (2017)



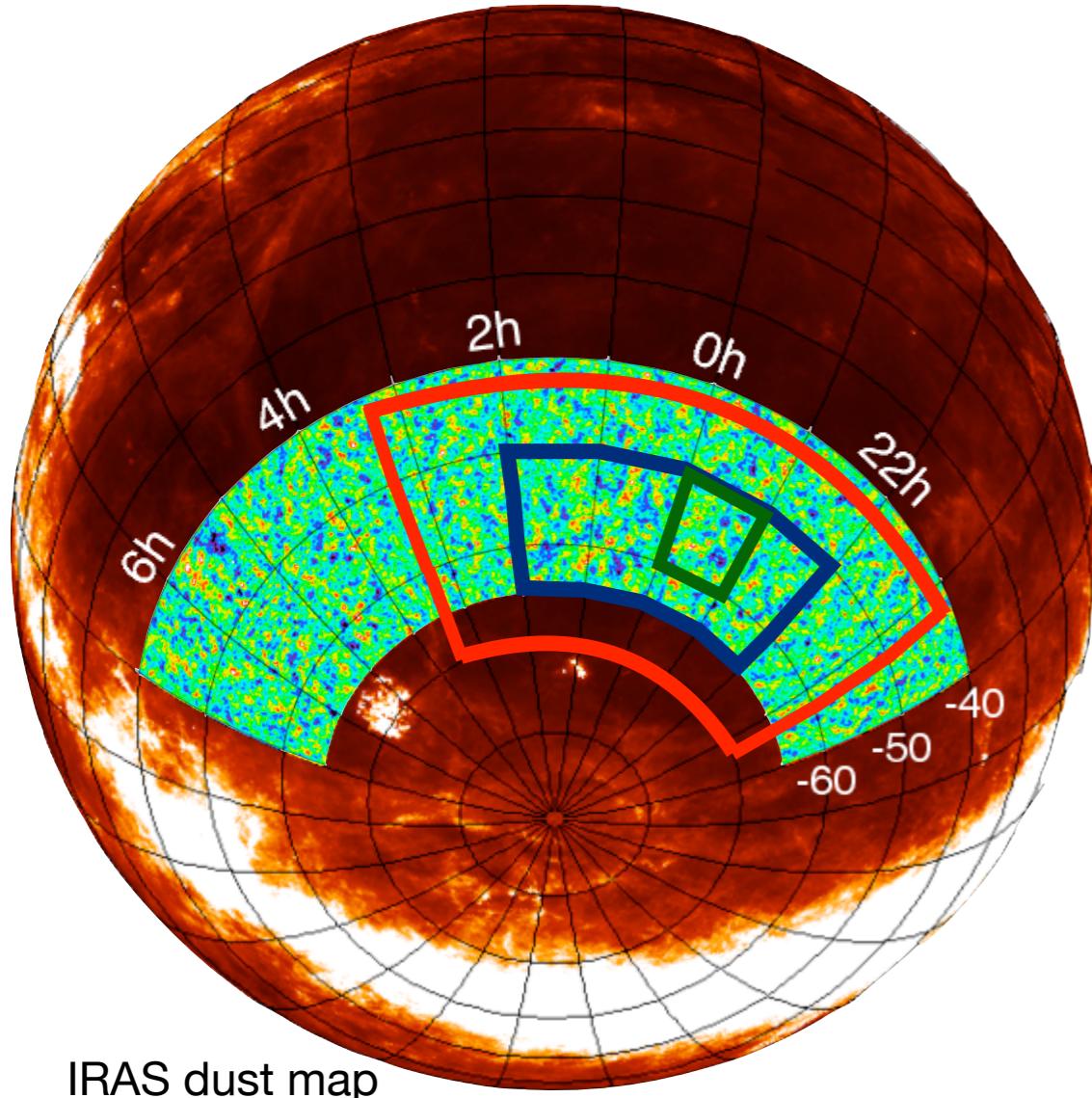
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# SPT-3G Collaboration



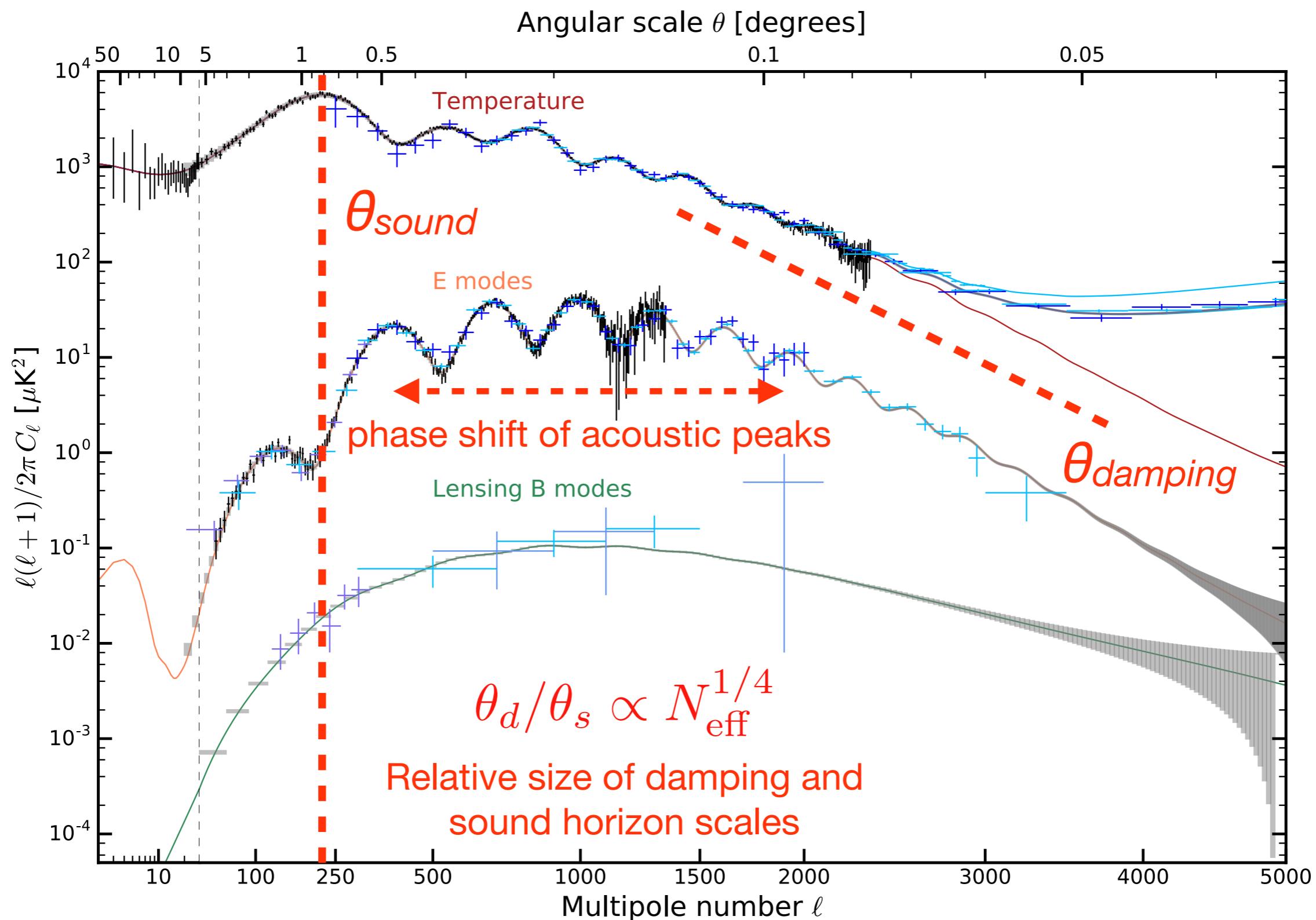
# SPT-3G Survey and Sensitivity



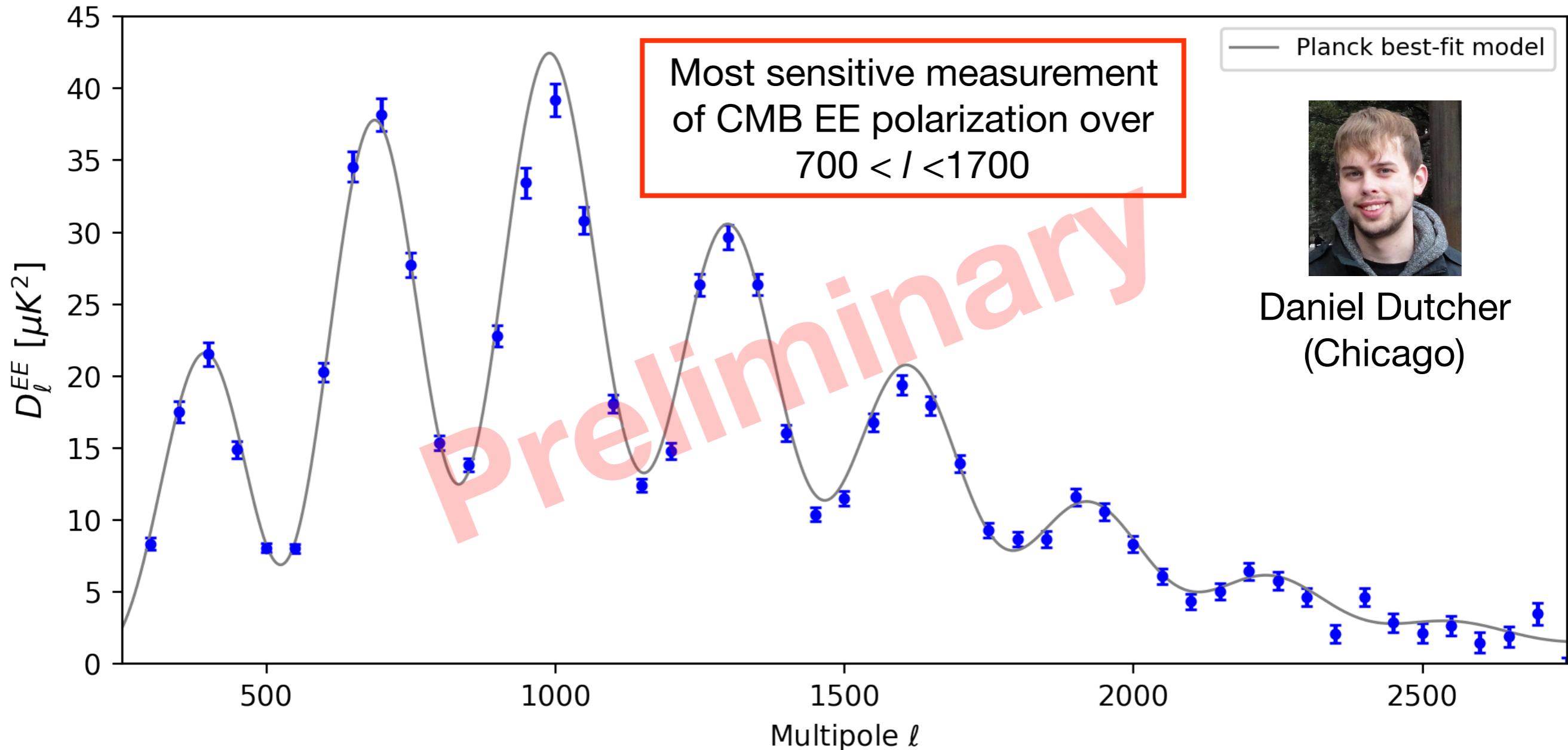
	Obs. Years	Area (deg <sup>2</sup> )	95 GHz (uK-arcmin)	150 (uK-arcmin)	220 (uK-arcmin)
<b>SPT-SZ</b>	2007-11	2500	40	17	80
<b>SPTpol-Main</b>	2012-16	500	13	5	-
<b>SPTpol-Deep</b>	2012-16	100	10	3.5	-
<b>SPT-3G projected</b>	<b>2018-23</b>	<b>1500</b>	<b>3.0</b>	<b>2.2</b>	<b>8.8</b>

- Started observing 1500d field in March of 2018
- Survey strategy optimized for CMB lensing reconstruction on field observed BICEP/Keck experiment
- SPT-3G / BICEP Array mainly targeting inflation via degree-scale B mode polarization...
- **BUT** can still constrain neutrino and cosmological parameters

# Science Targets: $N_{\text{eff}}$

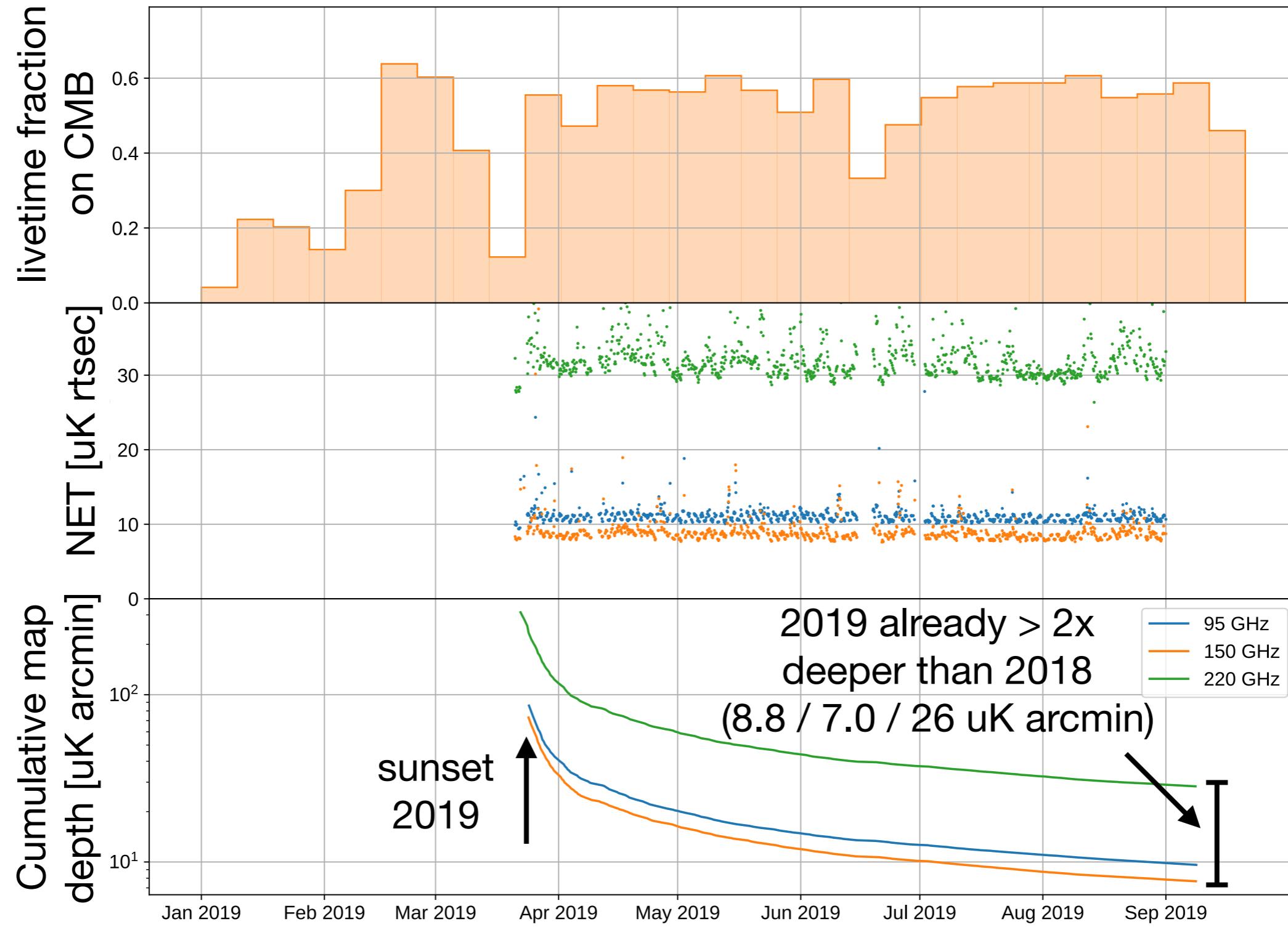


# SPT-3G 2018 E Modes



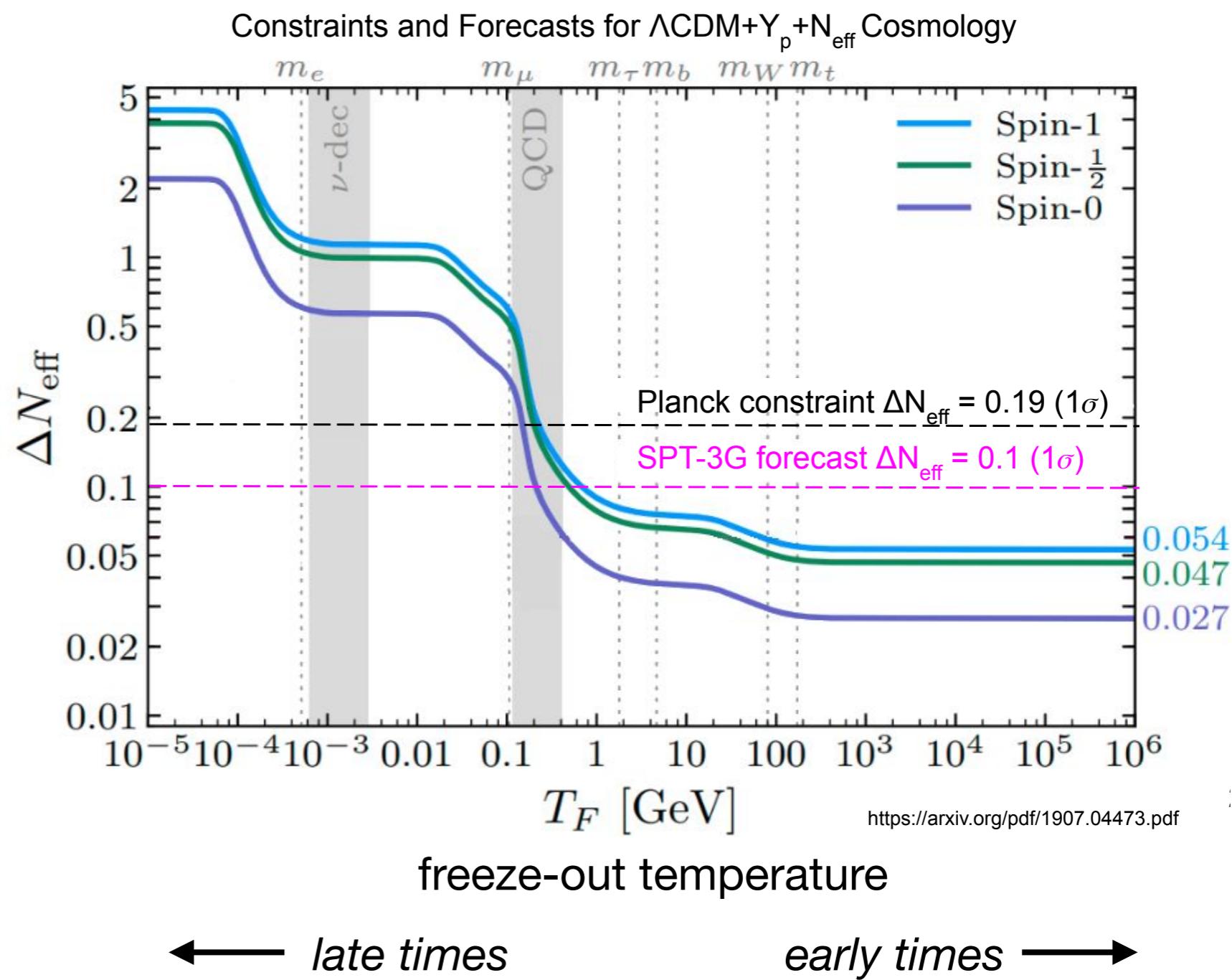
- Work in progress! Many to-dos: mode-coupling, beam, improvements in filter transfer function from simulations, etc.
- Map depths (T) of 21 / 15 / 47 uK-arcmin in 95 / 150 / 220 GHz bands

# 2019 Survey Status and Performance

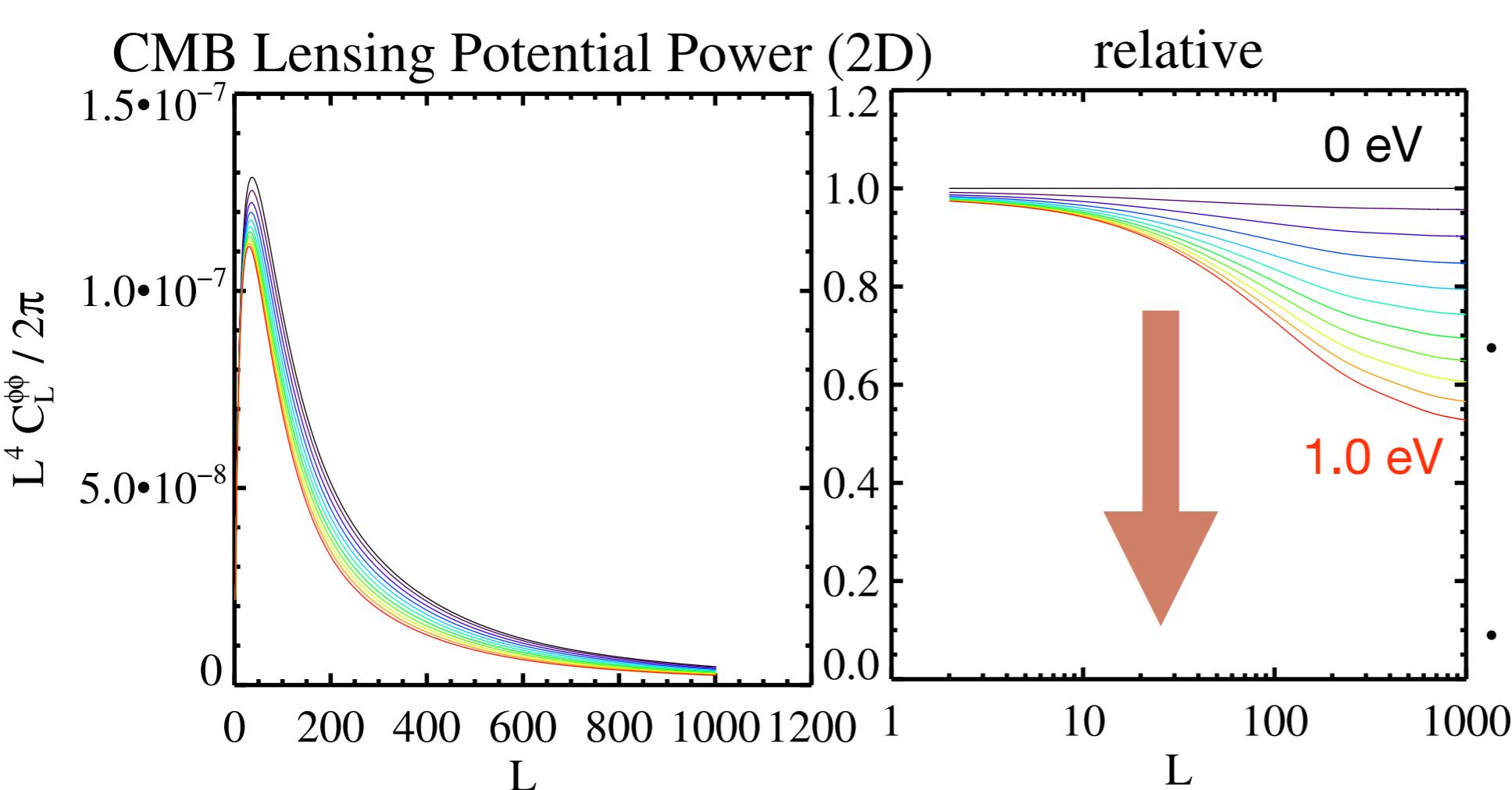


# SPT-3G $N_{\text{eff}}$ Forecasts

- **Any** light particle in thermal equilibrium contributes to relativistic energy density ( $\sim N_{\text{eff}}$ )
- After decoupling, contribution is diluted relative to active neutrinos as Standard Model particles annihilate
- Light sterile neutrinos with large mixing angles excluded
- 5-year constraint:  
 $\sigma(\Delta N_{\text{eff}}) = 0.1$



# Neutrino Mass: Lensing

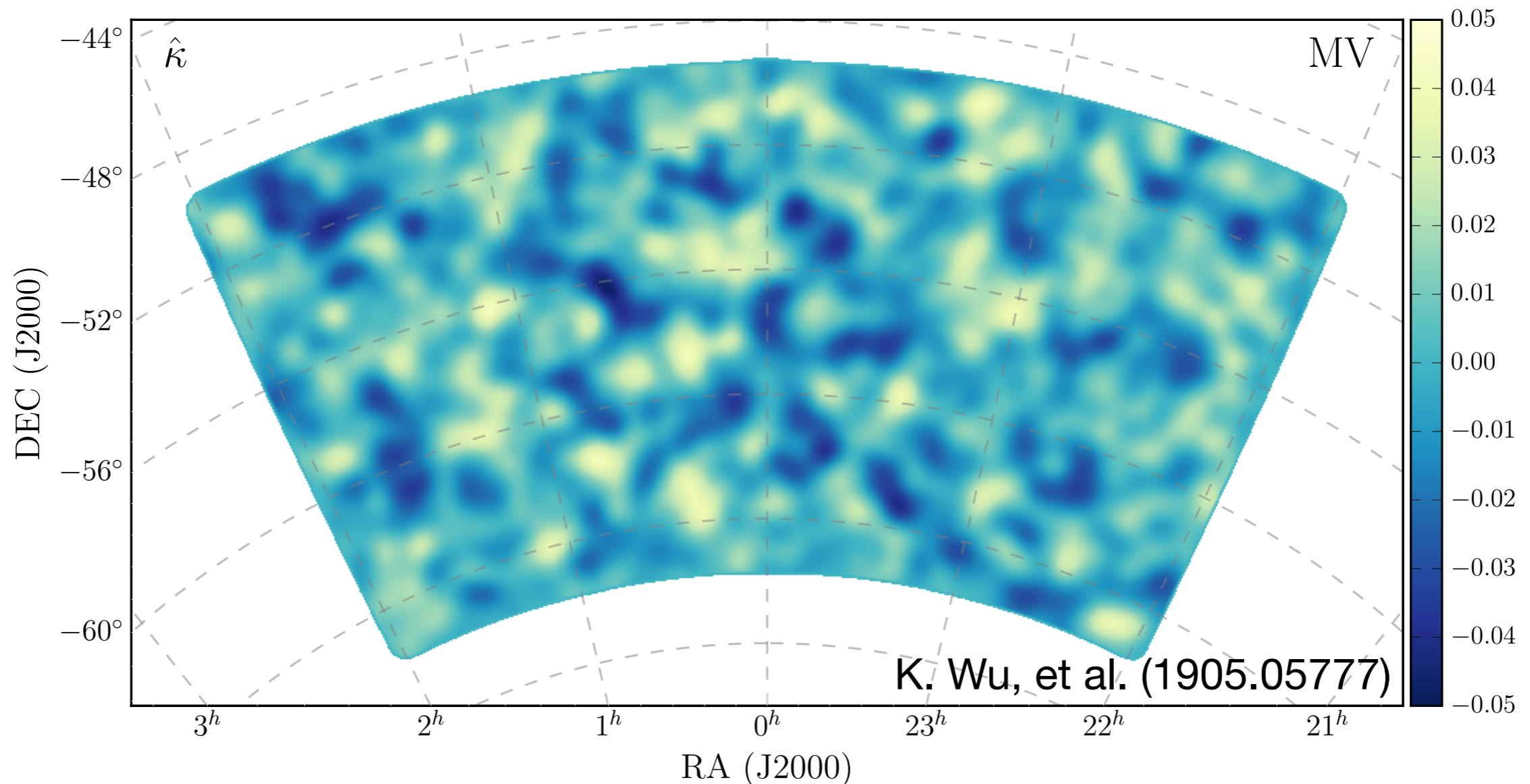


CMB-S4 science book

- ***Sum of neutrino masses affect growth of structure in universe***
- Clustering of matter suppressed at scales  $< 100 \text{ Mpc}$
- $\sim 5\%$  suppression per  $0.1 \text{ eV}$  in total mass
- ***Lower limit from oscillations:***

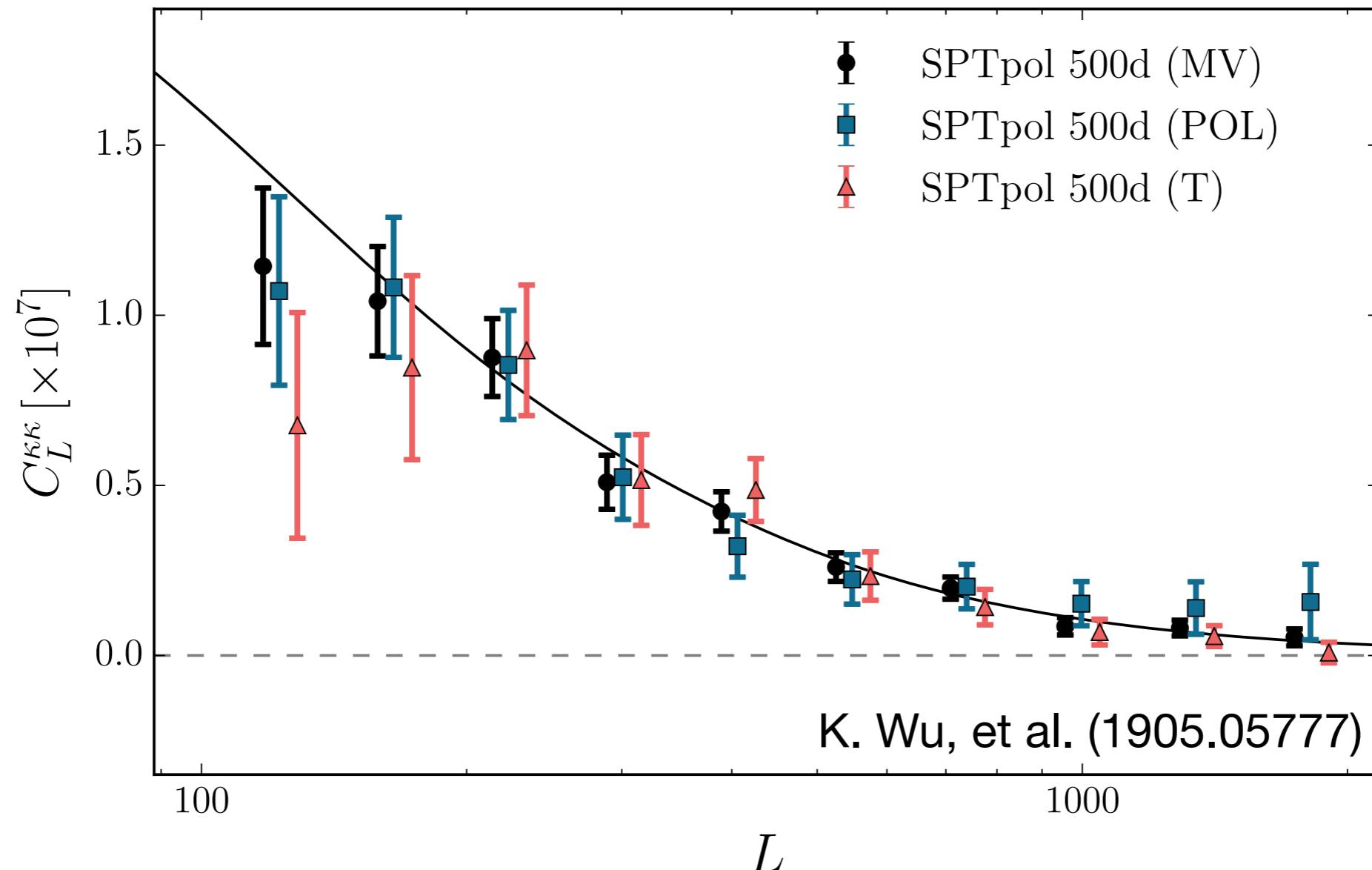
$$\sum m_\nu > 0.06 \text{ eV}$$

# SPTpol Lensing Convergence



- Map of the magnification and demagnification of the CMB due to gravitational lensing
- Based on 3 seasons of SPTpol 500 deg<sup>2</sup> survey

# *SPTpol Lensing Power Spectrum*

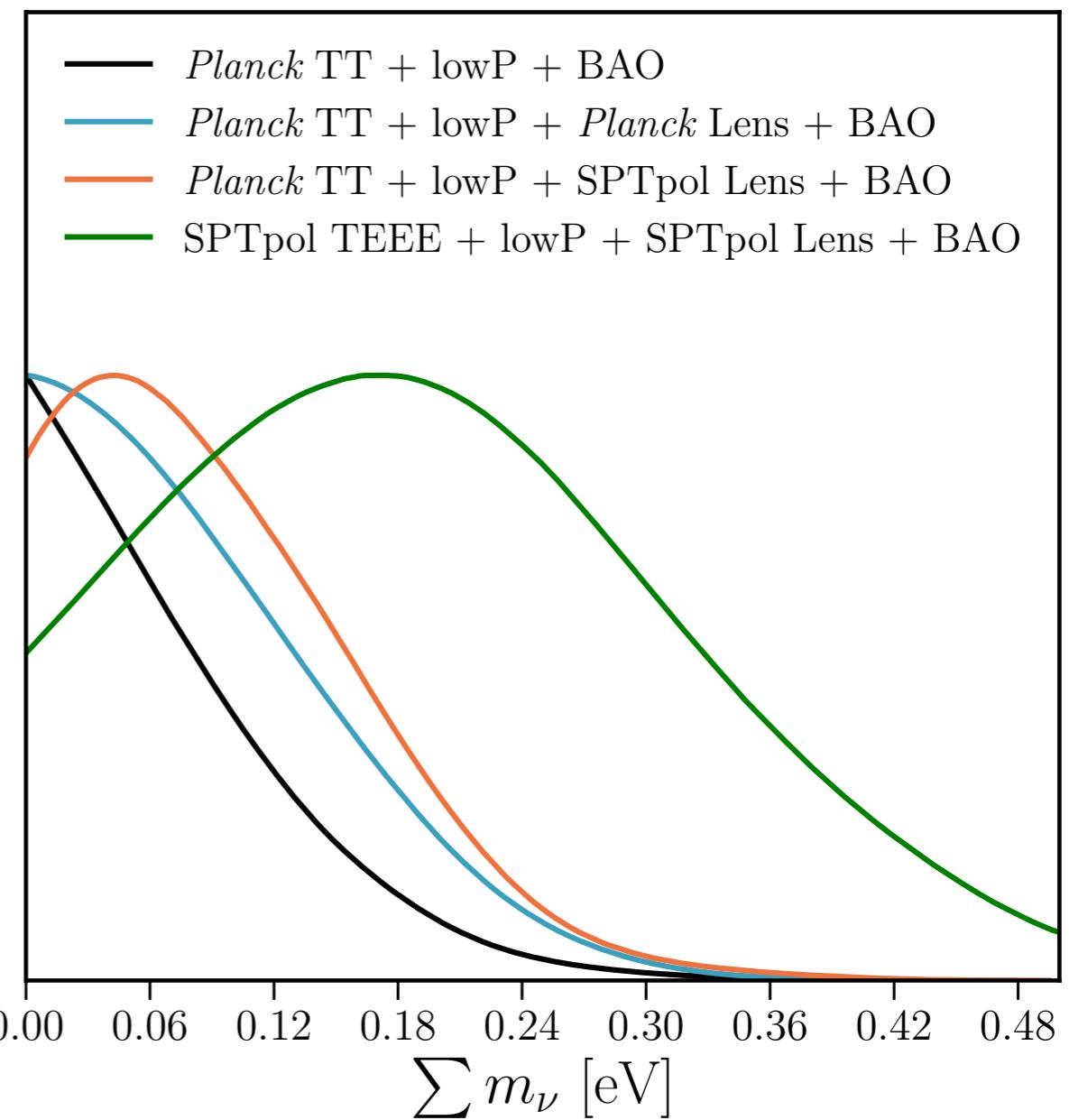


- Most precise measurement of lensing from polarization
- First time that polarization is more constraining than temperature

# Neutrino Masses from SPTpol Lensing

- Lensing both smears acoustic peaks and generates lensing power spectrum
- $\sim 2\sigma$  internal tension between two effects in Planck, but **not** in SPTpol
- Two implications:
  - Including Planck or SPTpol lensing **weakens** limit
  - Using SPTpol TEEE instead of Planck TT significantly weakens limit
- Marginalizing over tension (free  $A_L$ ), Planck and SPTpol lensing constraints are comparable

F. Bianchini, K. Wu, et al. (arXiv:[1-2 weeks!])

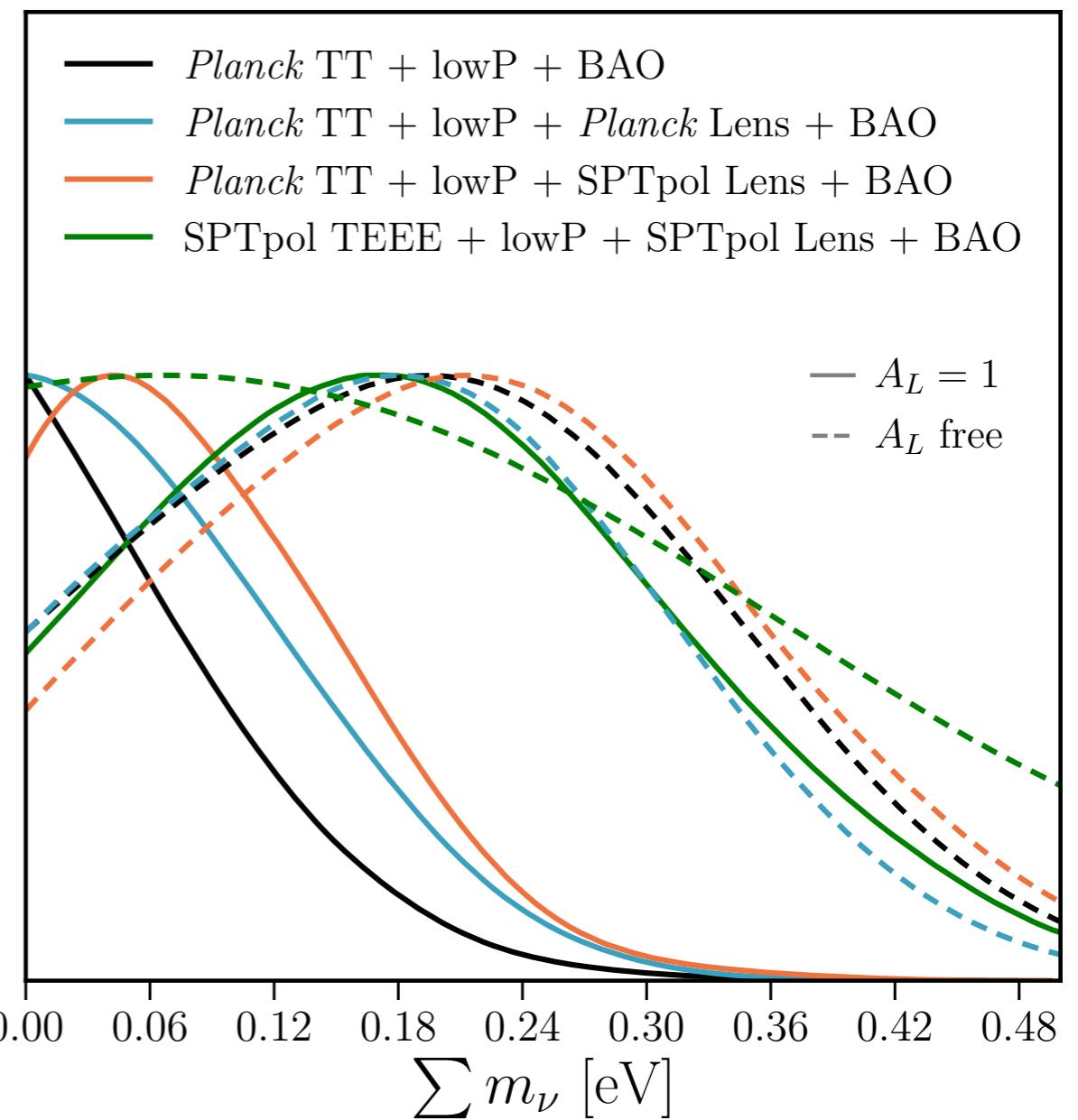


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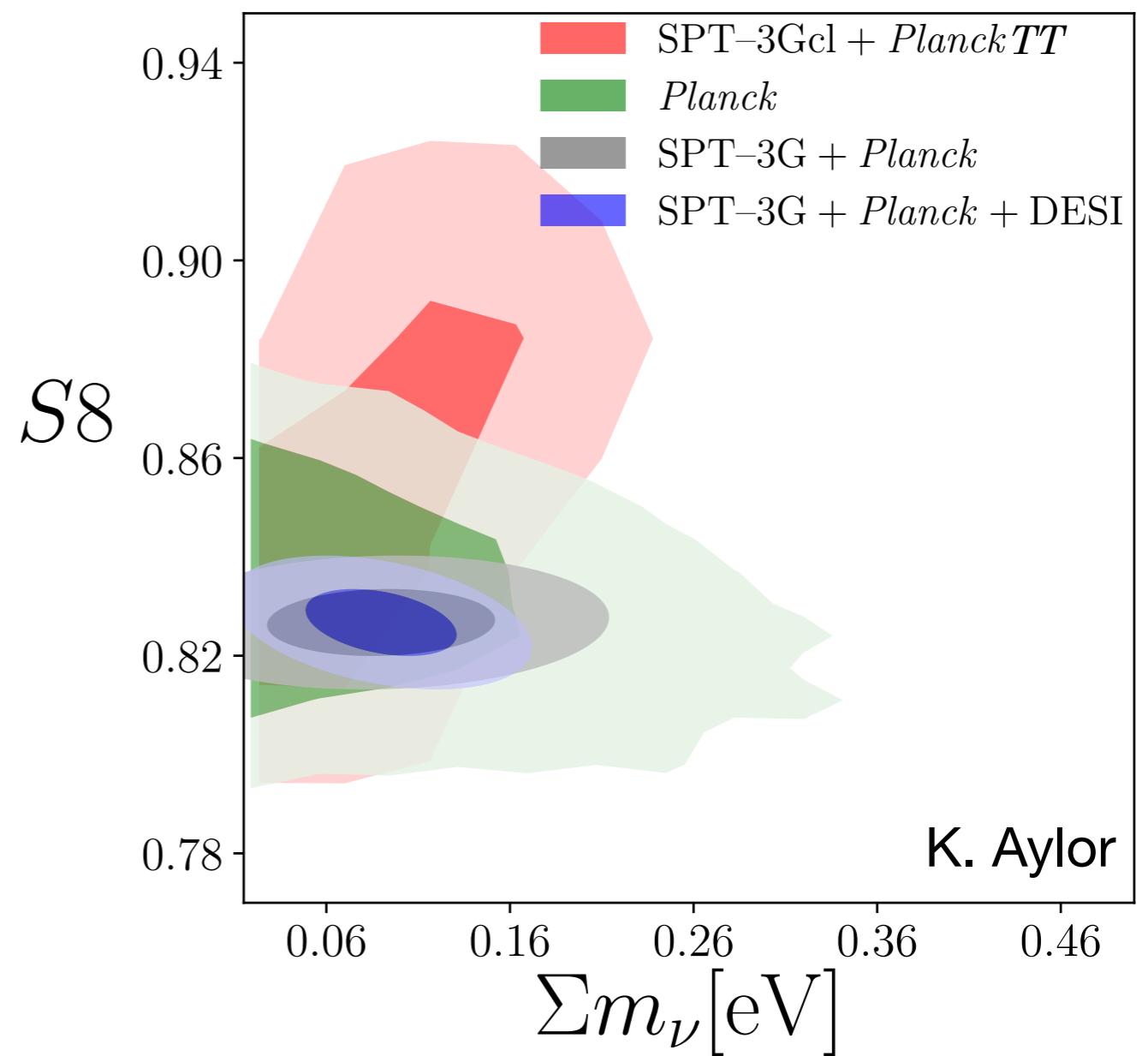
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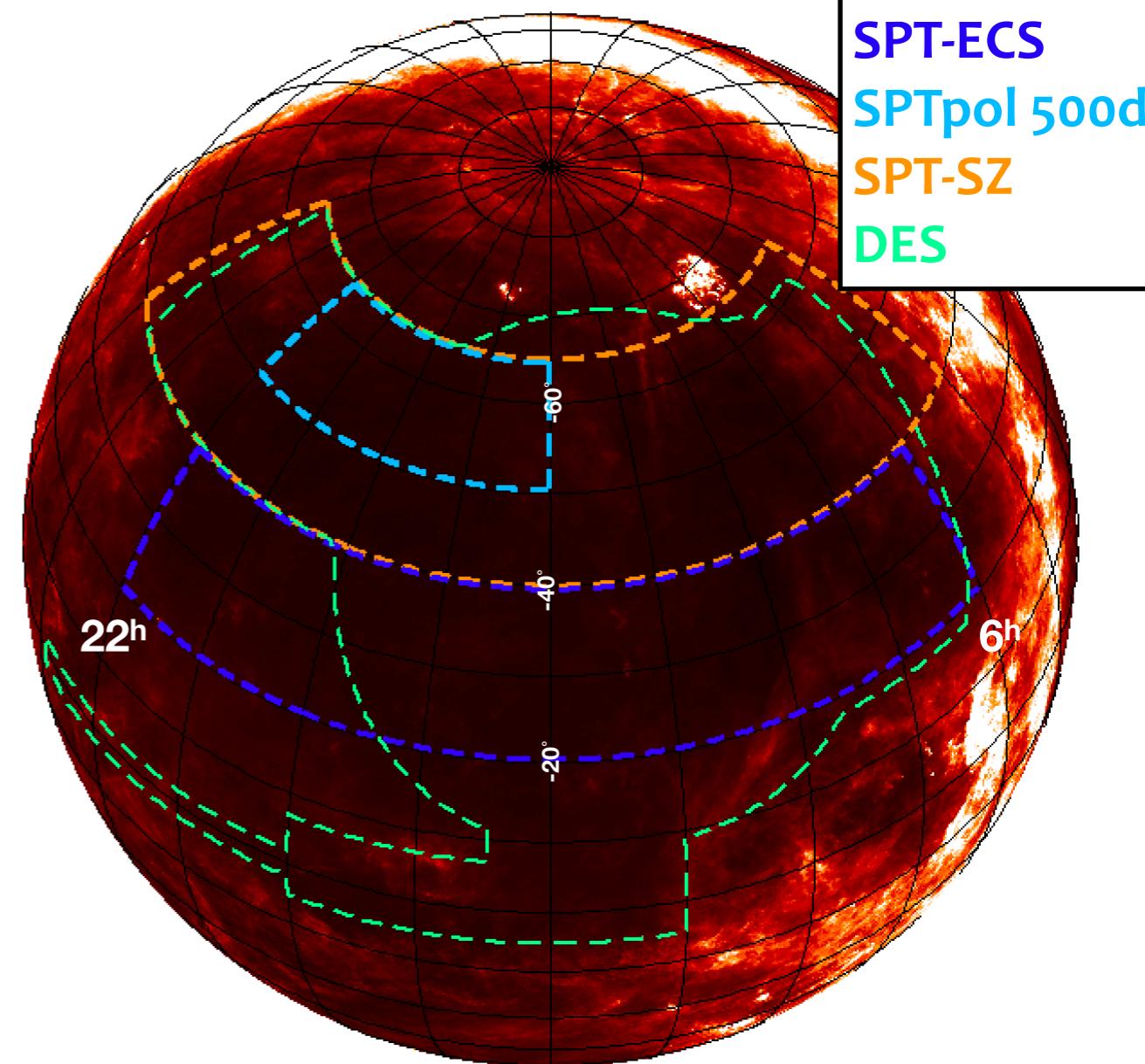
# SPT-3G Neutrino Mass Forecasts

- Complementary constraints from galaxy clusters and CMB lensing
  - SPT-3G clusters:  
 $\sigma(\Sigma m_\nu) = 55 \text{ meV}$
  - SPT-3G lensing + Planck:  
 $\sigma(\Sigma m_\nu) = 60 \text{ meV}$
  - SPT-3G lensing + Planck lensing + DESI BAO:  
 $\sigma(\Sigma m_\nu) = 38 \text{ meV}$
- Minimal masses:
  - $\sigma(\Sigma m_\nu) \geq 58 \text{ meV}$  (normal)
  - $\sigma(\Sigma m_\nu) \geq 116 \text{ meV}$  (inverted)



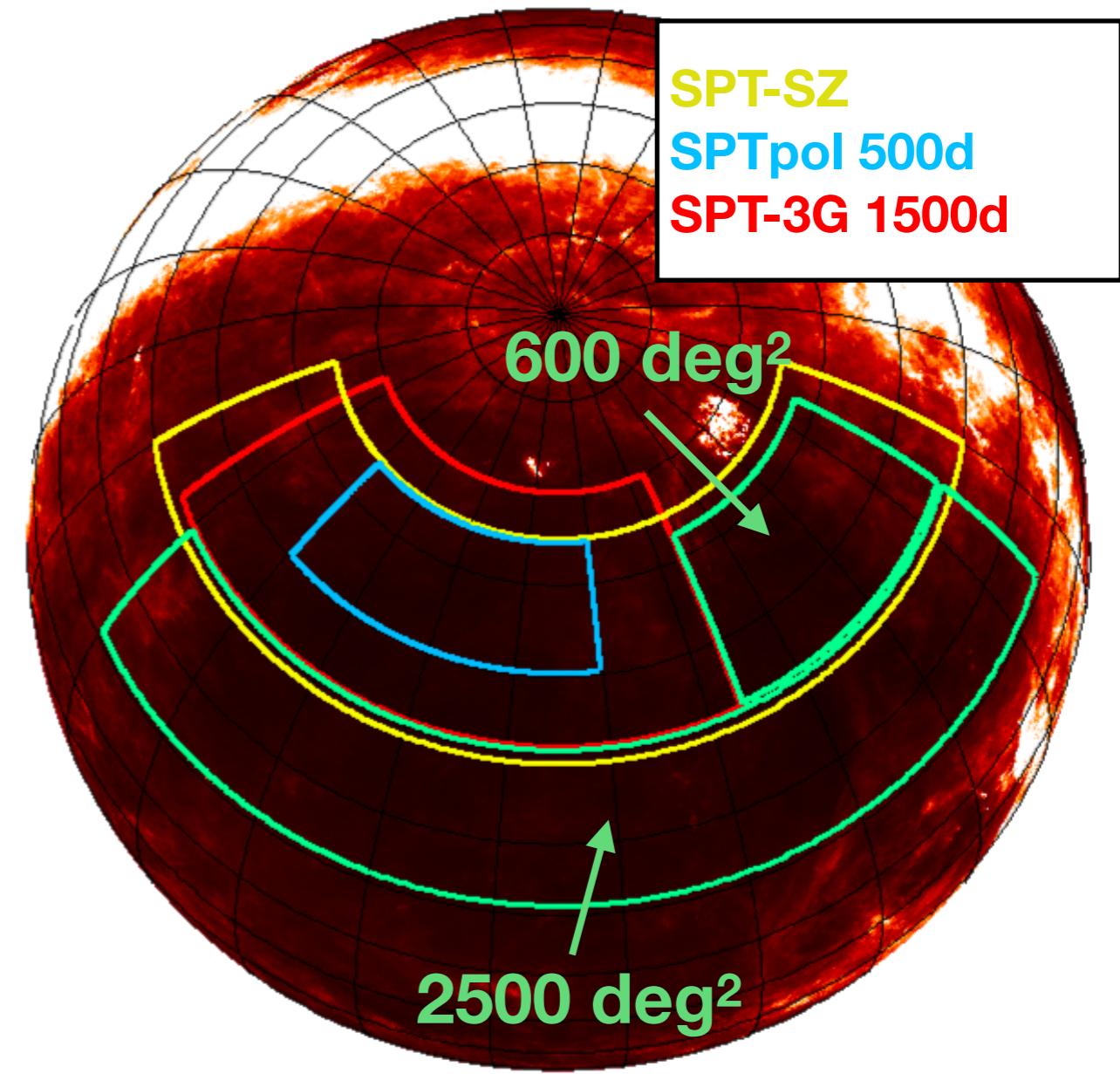
# Wide-Field Summer Survey

- Sensitivity to cosmological parameters tends to improve with increasing sky coverage
- Main 1500d field is sun-contaminated during summer, but >3000 sq. deg. of additional clean sky available
- Concept demonstrated with SPTpol Extended Cluster Survey (Bleem, et al. (arXiv:[this week!])
- ***Planning shallow survey for 4 summers 2019-2023, 3mo/year***
- Forecasts sensitive to summer instrument performance and in-progress, but should improve cosmological parameters over 1500d alone



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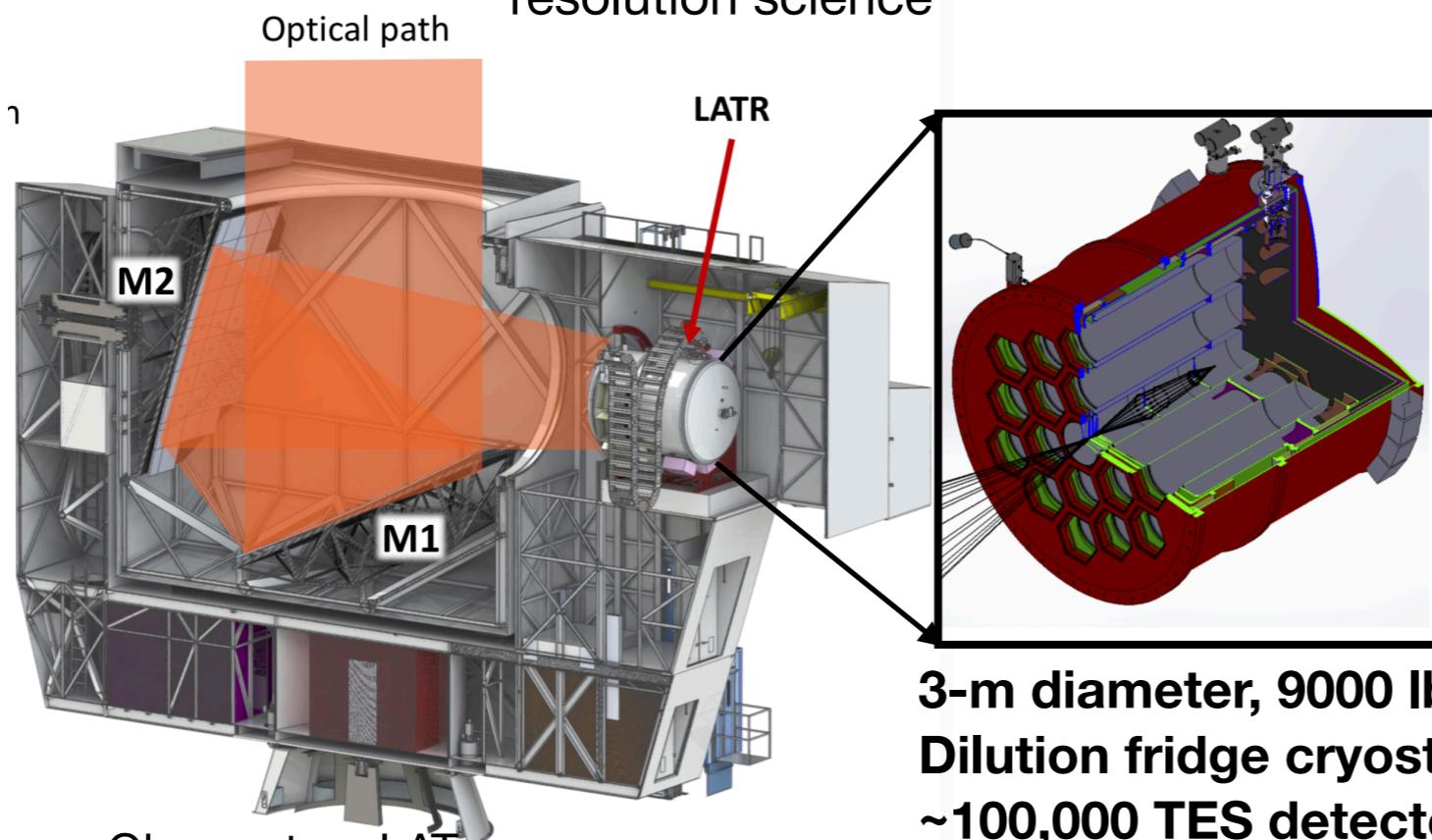
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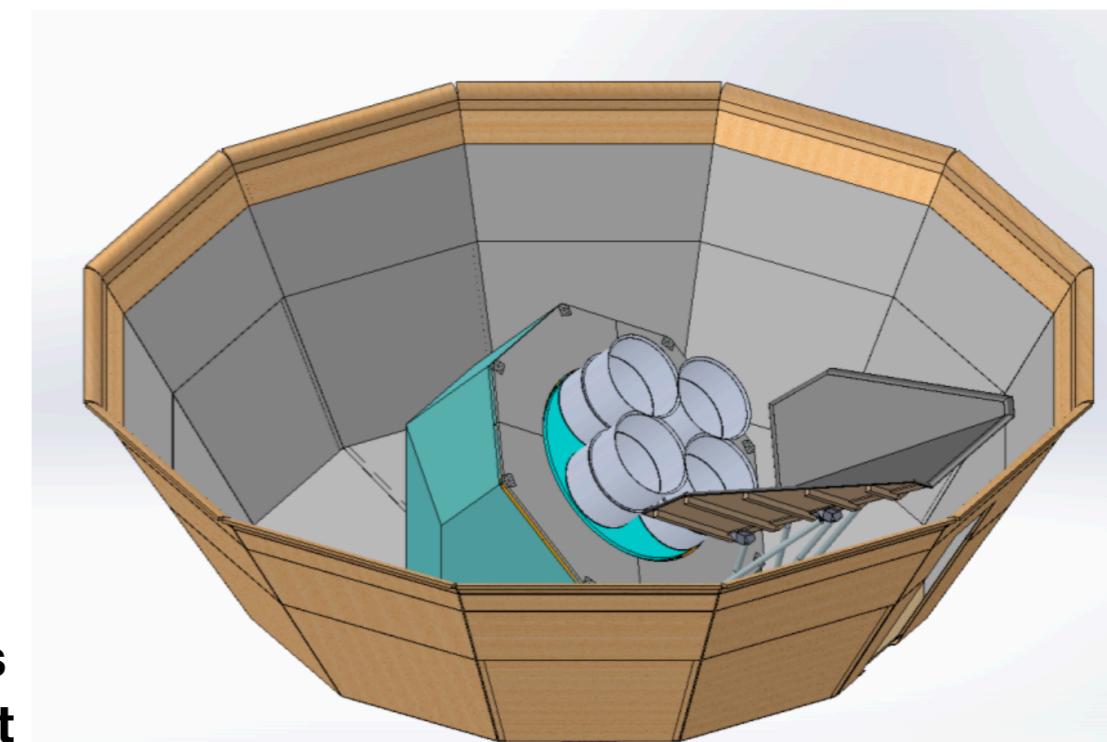
# The CMB-S4 Concept

- Endorsed by DOE/NSF P5 report, NRC/NSF Antarctic Science report, Concept Definition Taskforce (CDT) report accepted by AAAC panel
- **Concept:**
  - **400,000 detectors** split between 3x 6m-aperture, ~18x 0.5m-aperture telescopes
  - **Two sites:** Split between South Pole and Atacama in Chile
  - **Two surveys:** Inflation survey on 3-8% sky, neutrinos and cross-correlation on 40% sky

**Large aperture:** delensing, neutrinos, high-resolution science



**Small aperture:** inflationary B modes



# *Summary and Outlook*

- SPT-3G is deployed and operating at full sensitivity
- 1500 deg<sup>2</sup> survey is underway and will continue for 5 years
- Steady improvement will occur in cosmological constraints on neutrino masses and  $N_{\text{eff}}$
- Longer term, experiments like SO and S4 will provide ultimate ground-based constraints

