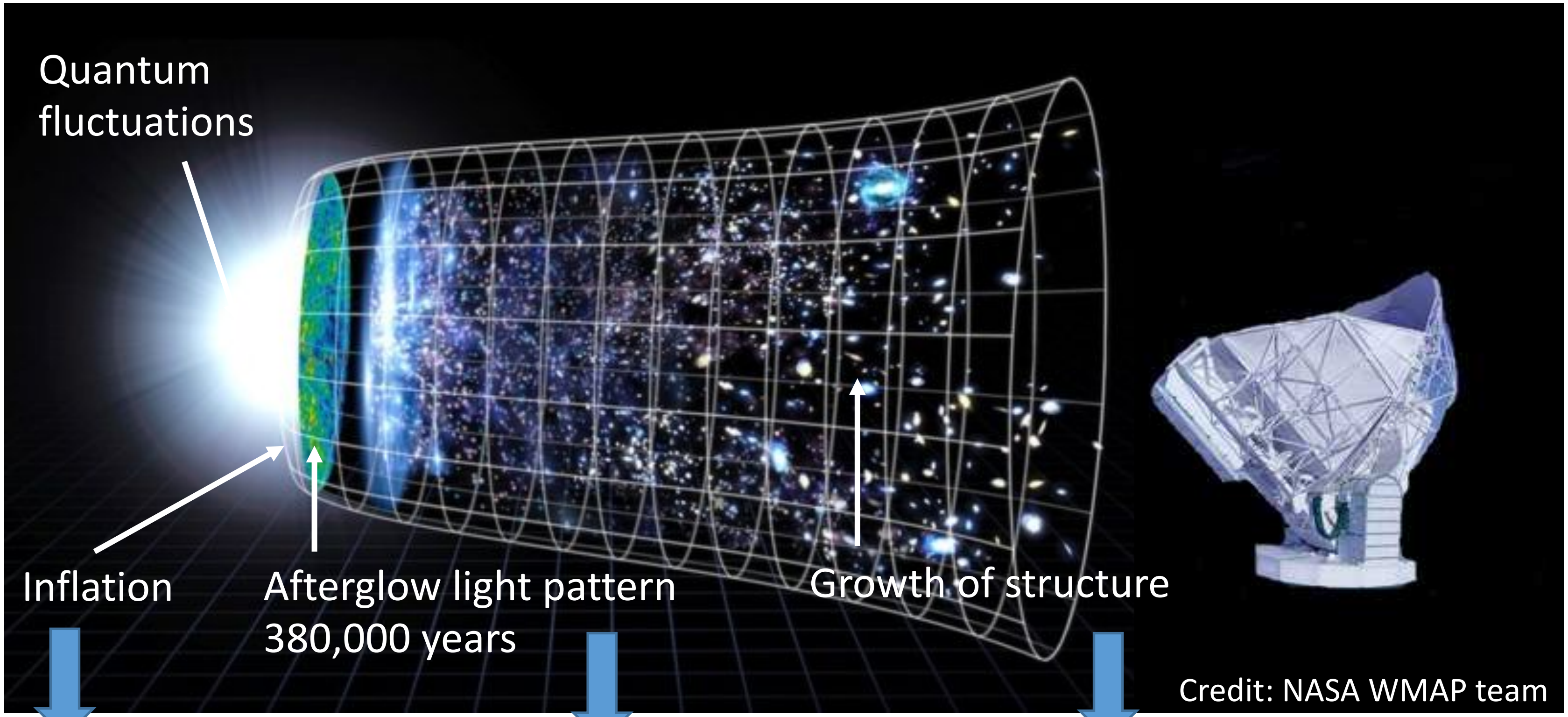
Status and Science from the SPT-3G Cosmic Microwave Background Receiver

Zhaodi Pan
for the SPT-3G collaboration
The University of Chicago, KICP

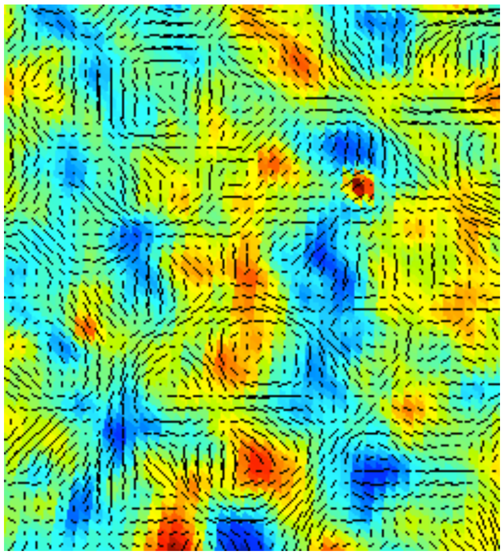
July 31, 2019, DPF meeting, Boston Email: panz@uchicago.edu Photo credit to Joshua Montgomery

CMB and the cosmic history



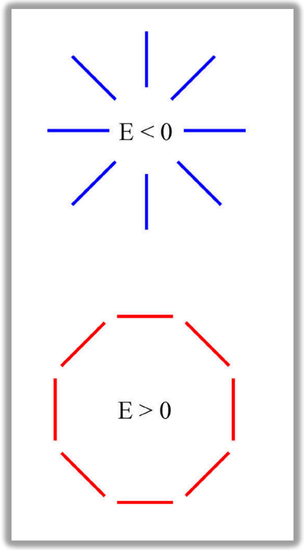
Inflation leaves signature in CMB polarization (B-mode) • Tensor-to-scalar ratio r • Spectral index of fluctuations • The energy scale of inflation • Non-Gaussianity • Can test inflation models	CMB is the image of the universe at recombination • Encodes the thermal history • Can probe the content of the universe, number of relativistic species, and other initial conditions.	Growth of structure affect the CMB at later times • Gravitational lensing • Imprint of galaxy clusters • Can probe dark energy, sum of neutrino masses, and test general relativity

CMB – temperature and polazrizations

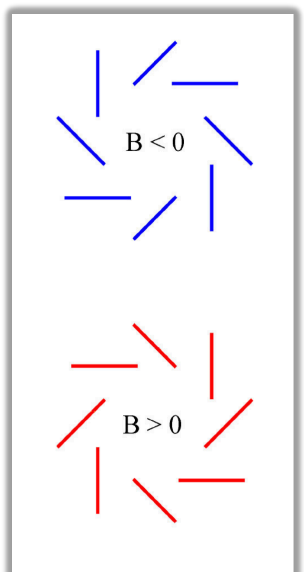


Credit: Boomerang Collaboration

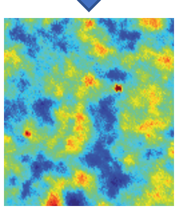
E mode



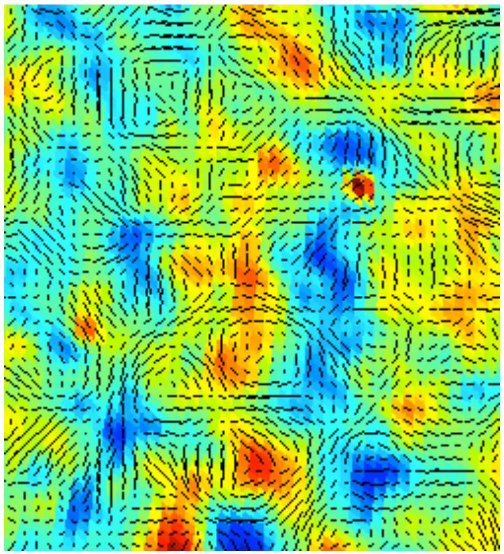
B mode



Temperature

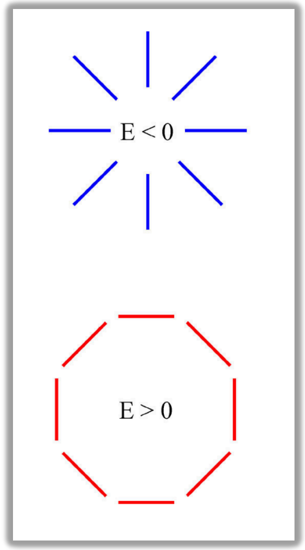


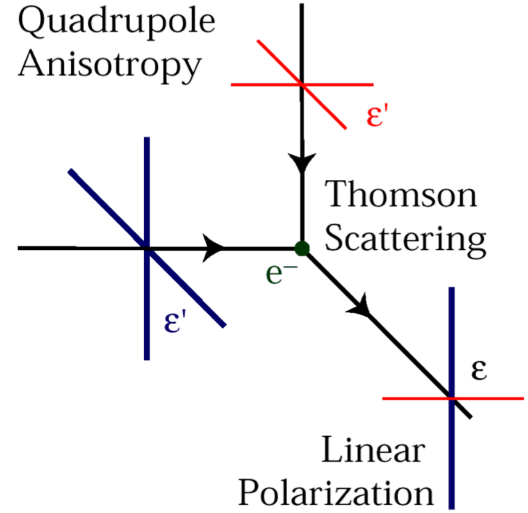
CMB – temperature and polazrizations



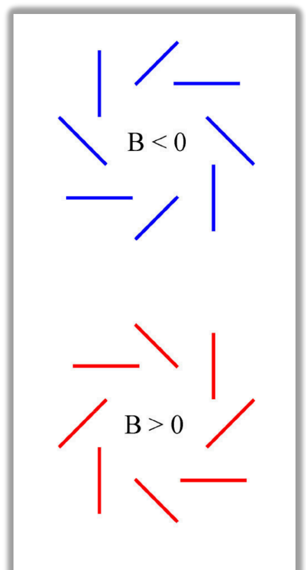
Credit: Boomerang Collaboration

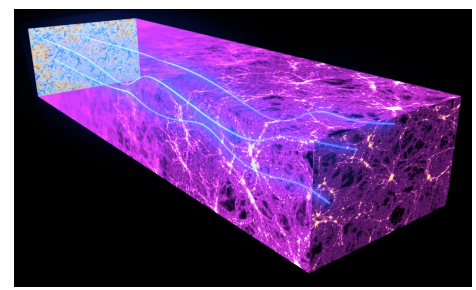
E mode



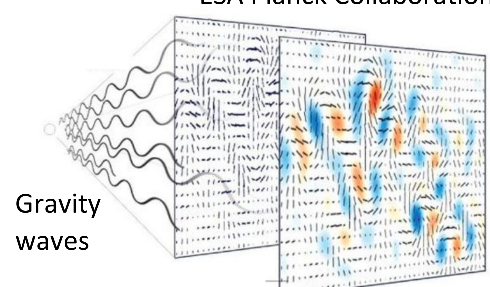


B mode



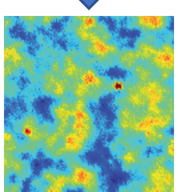


ESA Planck Collaboration

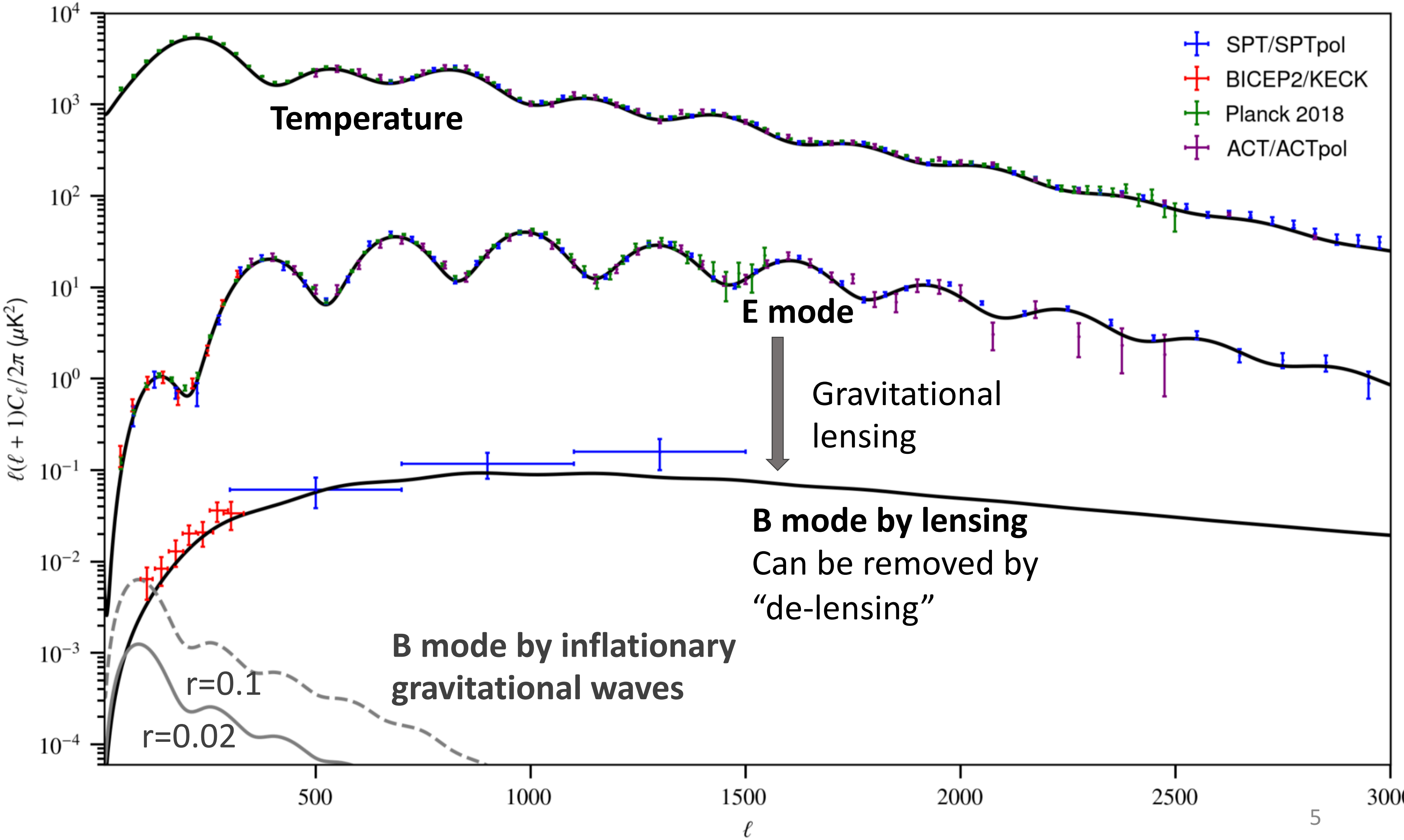


BICEP2 Collaboration

Temperature



CMB power spectra and related science



South Pole Telescope

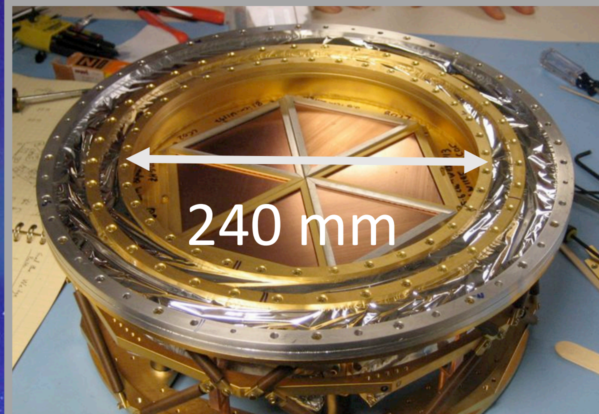
Ten meter sub-mm quality telescope

95, 150, 220 GHz and

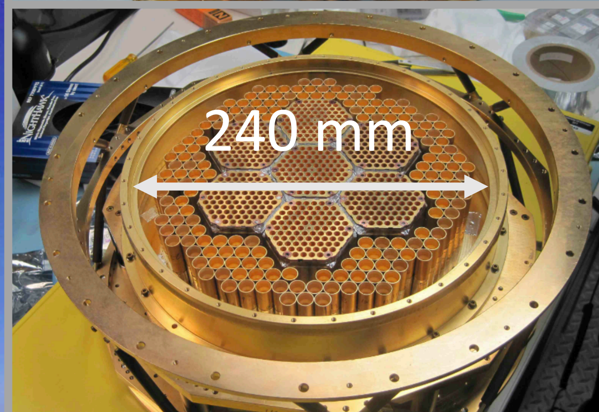
1.6, 1.2, 1.0 arcmin resolution

Credit: Jason Gallicchio

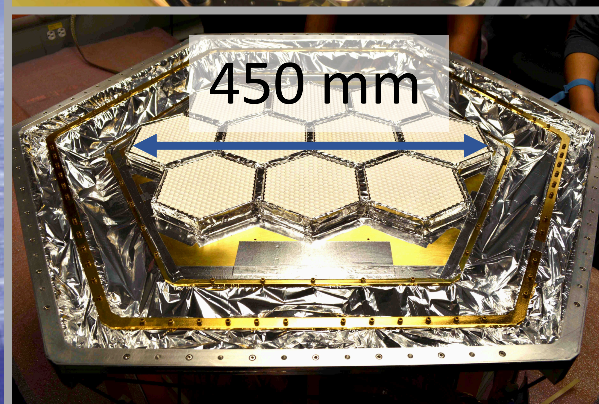
Focal planes (3 generations)



2007: SPT-SZ
960 Detectors
95, 150, 220 GHz

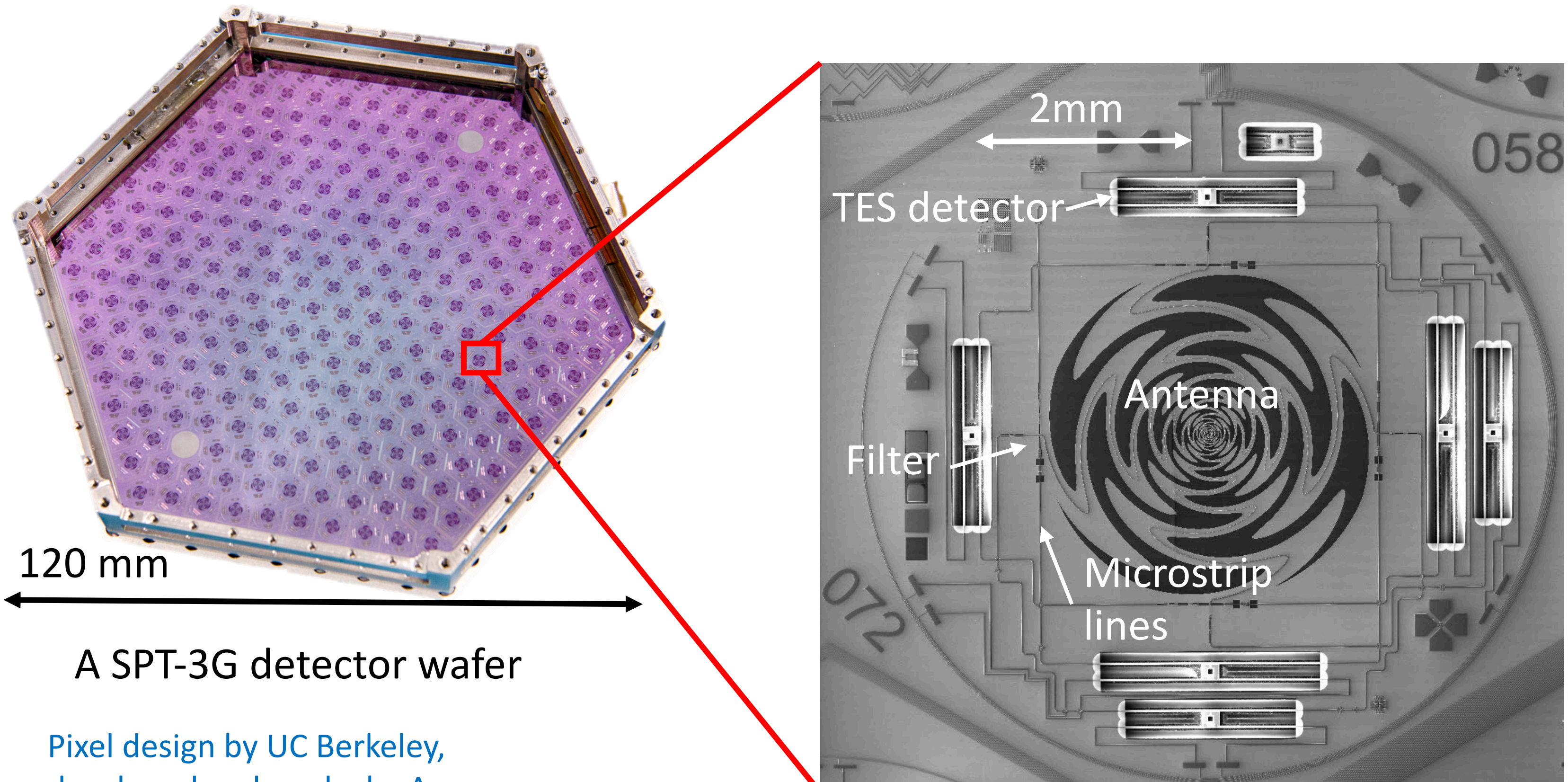


2012: SPTpol
1,500 Detectors
95, 150 GHz
+Polarization



2017: SPT-3G
~16,000 Detectors
95,150,220 GHz
+Polarization

Detector structure



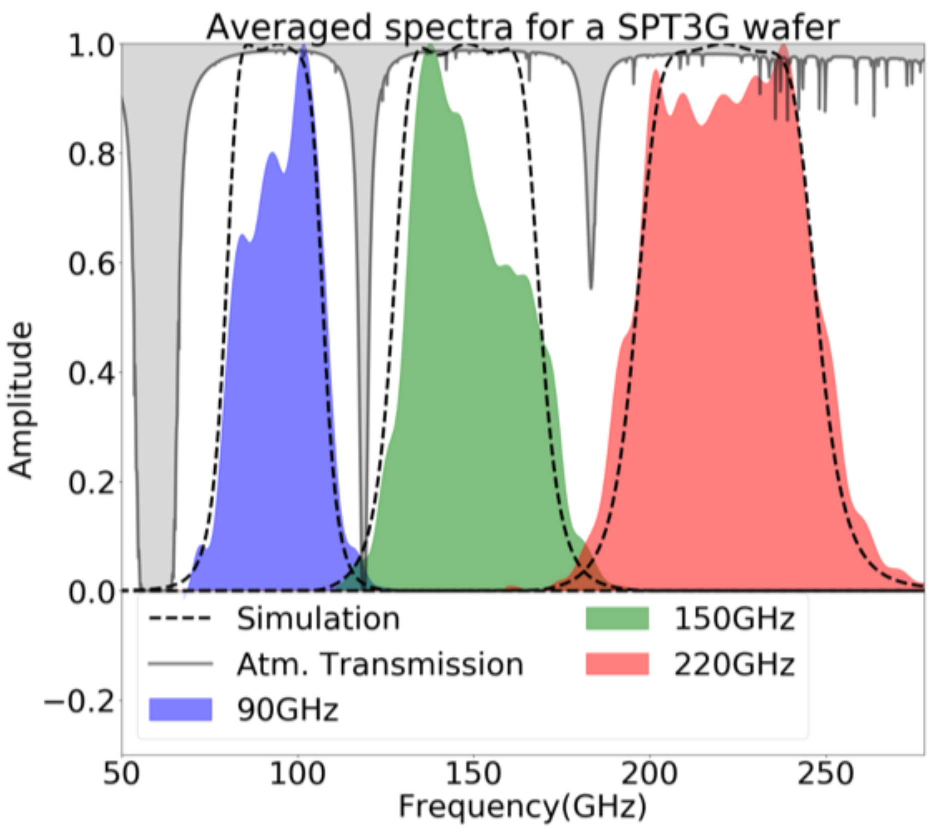
A SPT-3G detector wafer

Pixel design by UC Berkeley,
developed and made by Argonne.

- Noise is dominated by photon fluctuations → need more detectors
- Total detector count is 16,000.
- Broadband sinuous antenna coupled to TES bolometers through in-line filters and superconducting Nb striplines
- 6 transition-edge sensors (TESs) per pixel, (95, 150, 220 GHz) x 2 polarizations

C. Posada et, al J Low Temp Phys (2018) 193: 703.

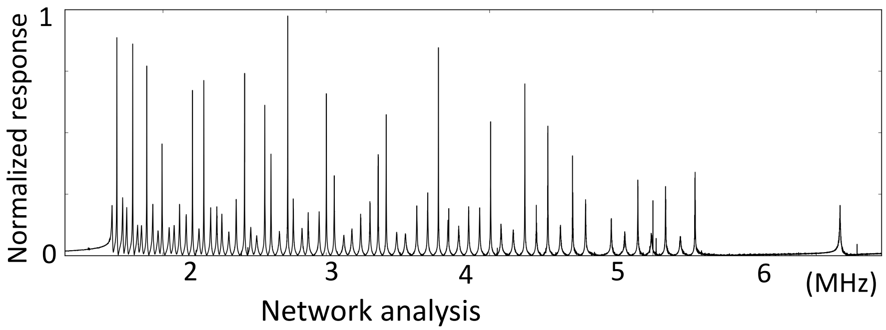
Detector properties



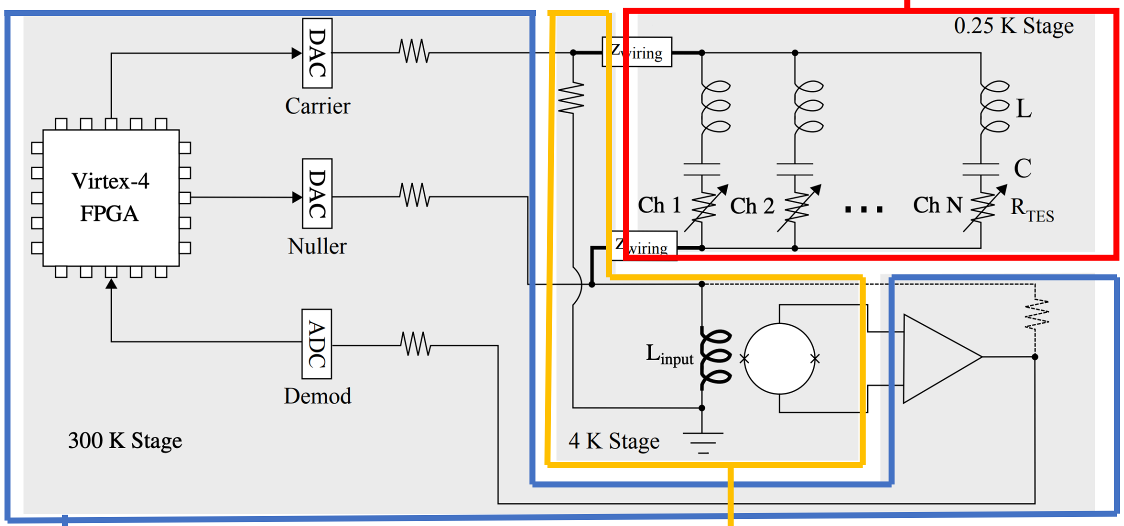
Z. Pan et, al arXiv:1805.03219
D. Dutcher et, al arXiv: 1809.00033
A. Anderson et, al. In preparation

- Frequency band edges agree with simulation within 3%.
- High uniformity: different wafers agree within 2%.
- Good optical efficiency: 0.81, 0.83, 0.73 for the 95, 150, and 220 GHz frequency bands (pixel+lenslet) .
- Tightly-controlled thermal properties, including superconducting transition temperature, saturation power, etc.
- High linearity: 2.7%, 4.3%, and 1.2% responsivity variation for the three frequency bands over the observation field.

Readout



Frequency-domain multiplexing:
68x multiplexing factor
Multiplexing resonators: fabricated on-chip by UC Berkeley and LBNL

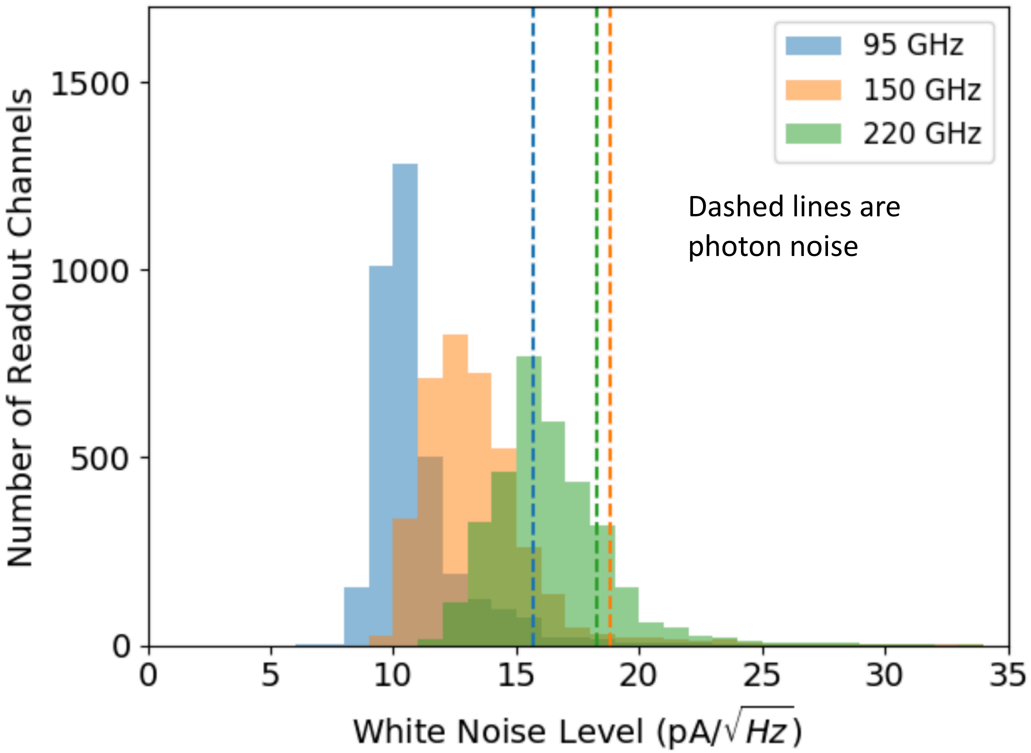


Warm electronics: made by Mcgill University.

SQUID amplifiers: fabricated by NIST, transimpedance > 300 Ohms (good)

A. Bender, et al. Proc. of SPIE (2016) Vol. 9914, p. 99141D
J. Avva, et al. J Low Temp Phys (2018) 193: 547
A. Bender, et al. arXiv 1809.00033.

Readout performance

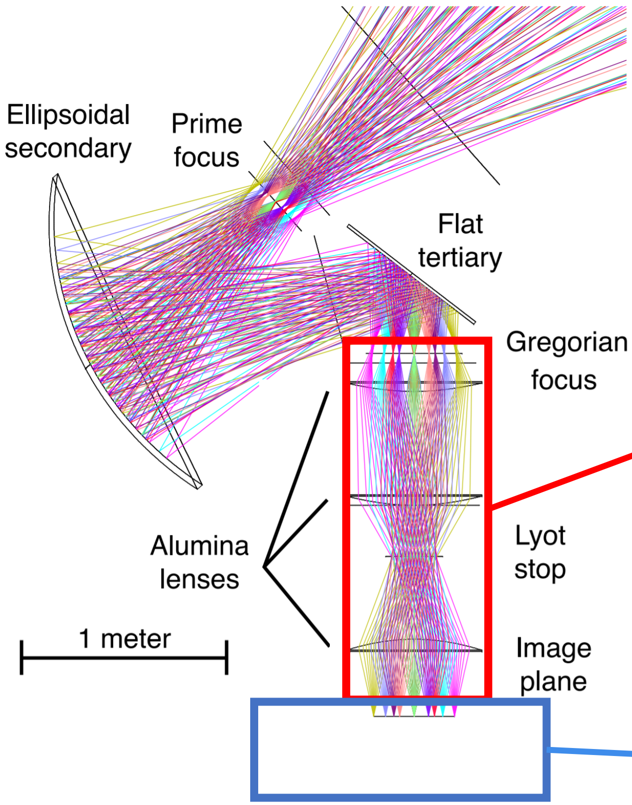


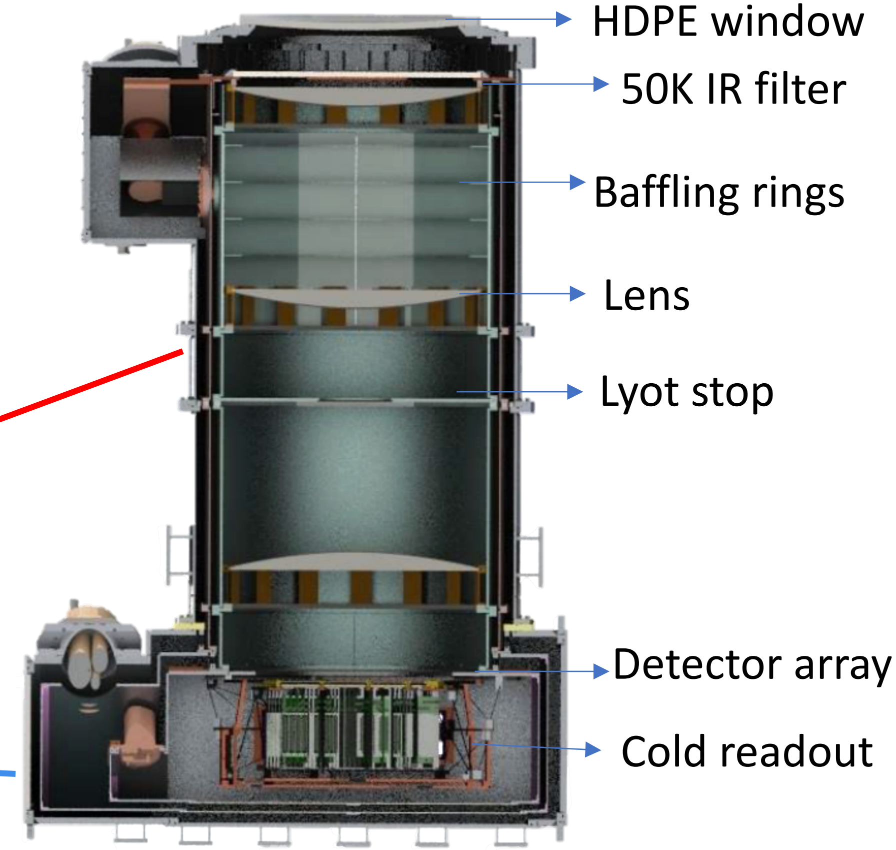
Histogram of the achieved readout noise for all readout channels.

A. Bender, et al. arXiv 1809.00033.

- The achieved readout noise is lower than the photon noise.
- 1/f noise knee frequency is at 33 mHz, which will not limit measurements on large scales.
- Crosstalk is shown to meet the design specification of ~< 0.5%.

Optics

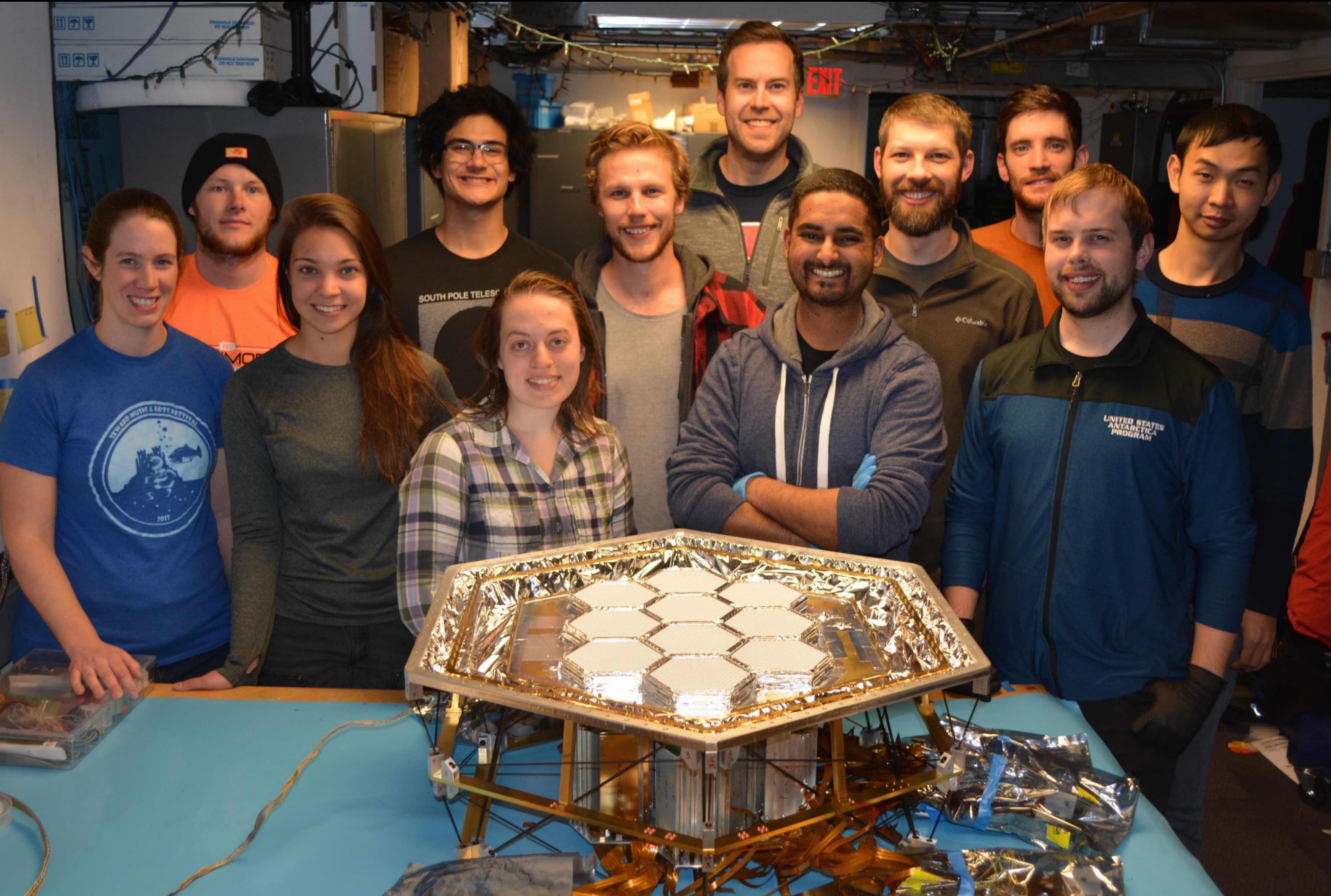




Large field of view: 2.8 deg^2 field-of-view.
Large lenses: 700mm-diameter alumina lenses with three-layer Teflon anti-reflection coating. The lenses are cooled to 4K to reduce loading.
Lyot stop and low-pass filter for cutting the stray reflections and out-of-band radiation.
Large focal plane: 450mm across.

B. Benson, et al arXiv 1407.2973
J. Sobrin, et al Proc. of SPIE (2018) Vol. 10708, p. 107081H

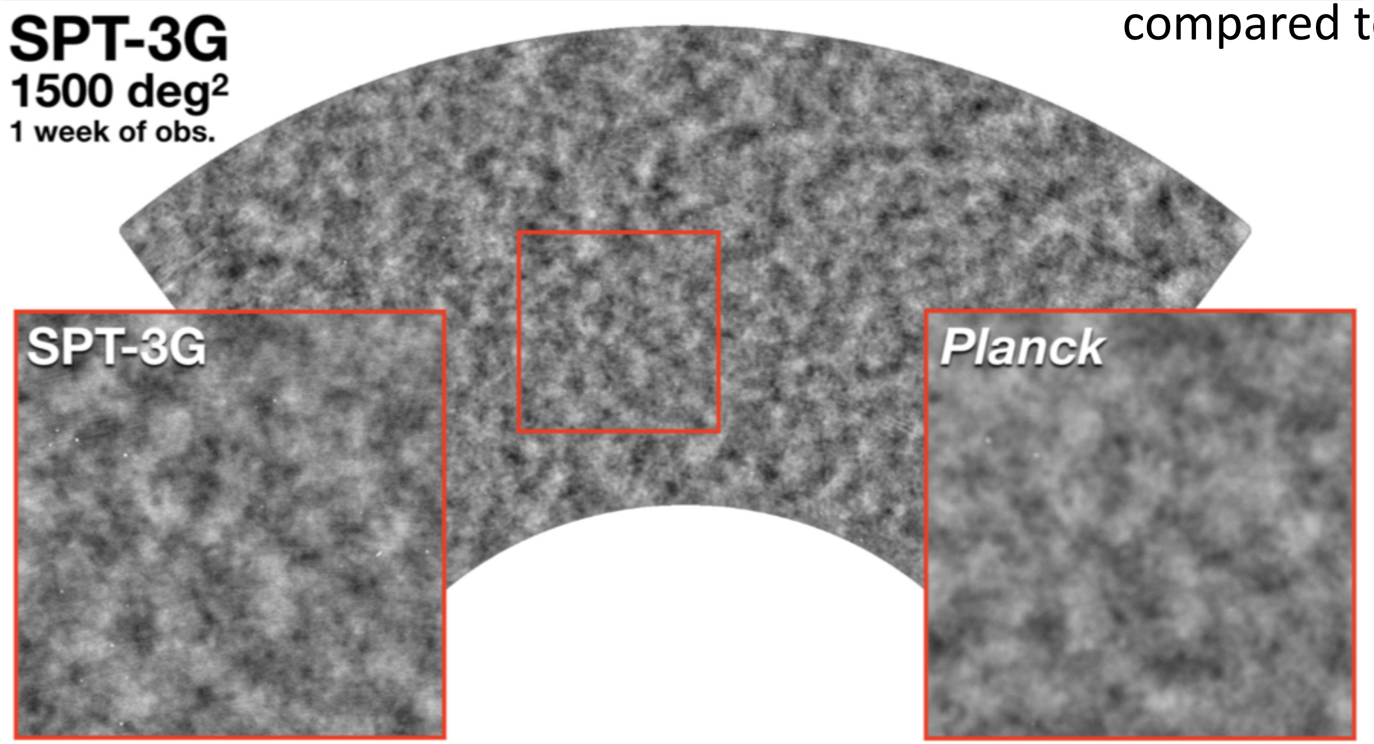
South Pole integration



Integrated performance and status

	90 GHz	150 GHz	220 GHz
NET (array) $\mu K_{CMB}\sqrt{s}$	10	8	30
First year map depth (μK_{CMB} arcmin, T)	19	14	40
Six-year map depth (μK_{CMB} arcmin, T)	3.0	2.2	8.8

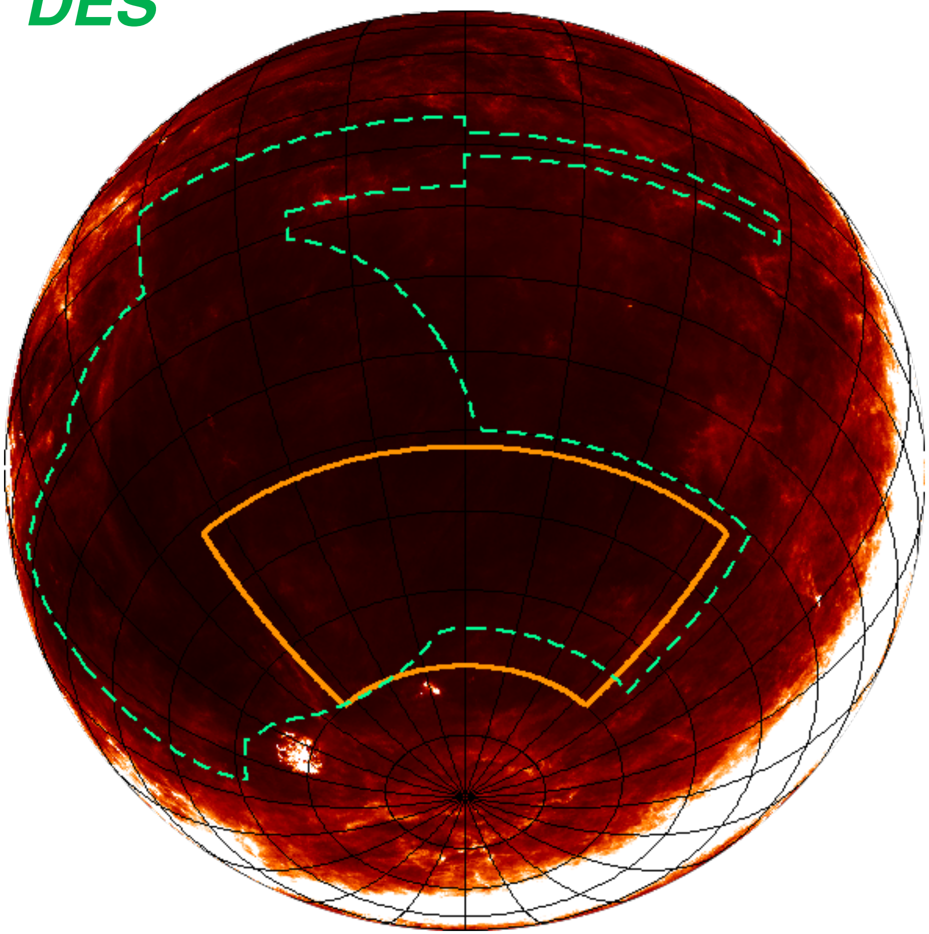
- First light on Jan 30, 2017
- 6-year 1500 deg^2 observation began in Feb, 2018.
- Improvements in 2019
  - two new detector wafers,
  - a more stable detector stage compared to 2018.



One week of SPT-3G data is deeper than Planck in a 1500 deg^2 patch.

SPT-3G survey

SPT-3G (+BICEP Array)
DES

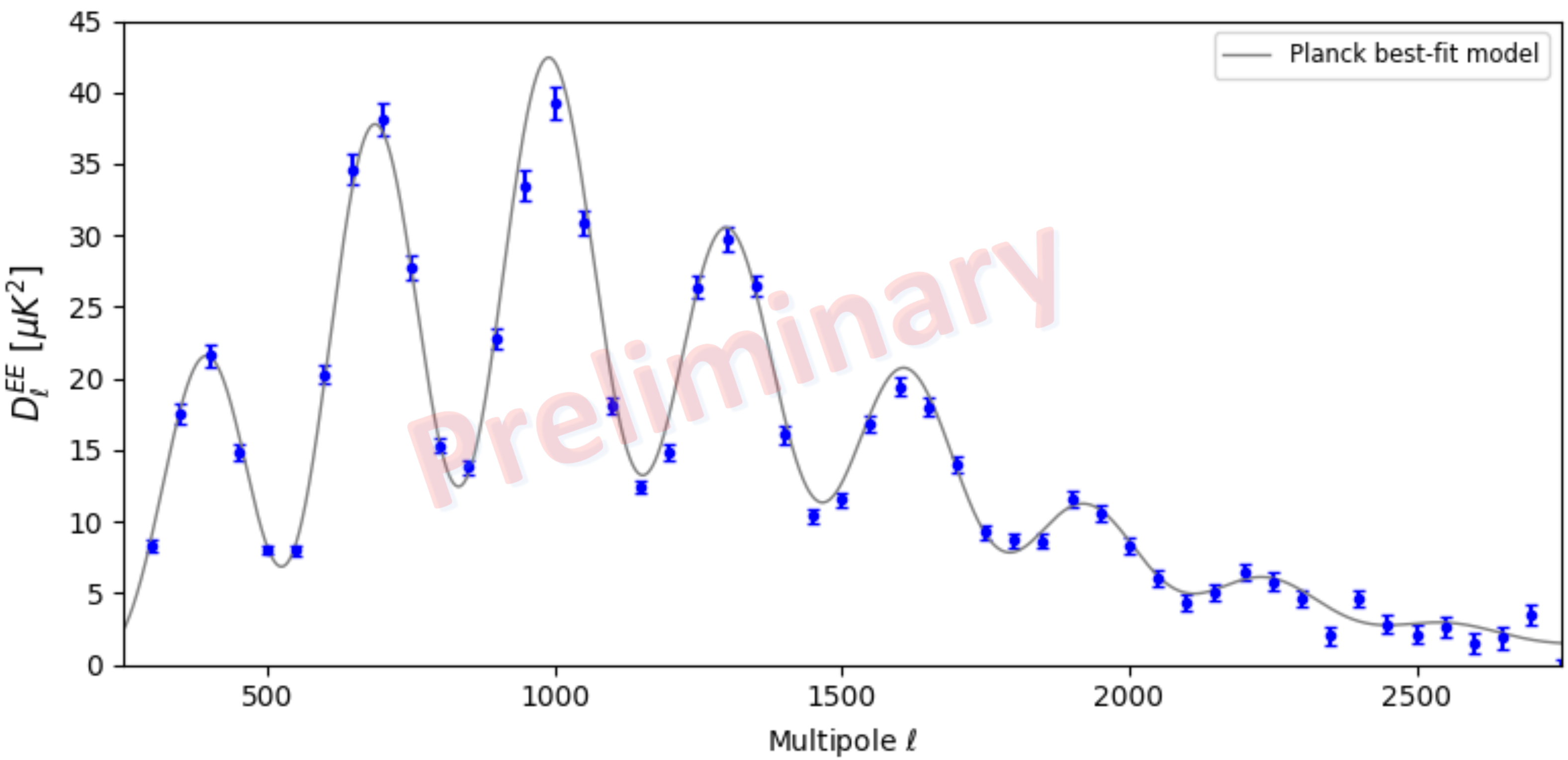


Background is IRAS dust map

- Deep, high resolution (1 arcmin) measurement for 1500 deg^2 of sky.
- Overlaps with BICEP Array to separate the lensing-induced B-mode from B-mode signature of primordial gravitational waves.
- Overlaps with Dark Energy Survey (DES) for cross-correlation.
  - CMB lensing, cluster lensing, galaxy lensing, pairwise kSZ, and more.

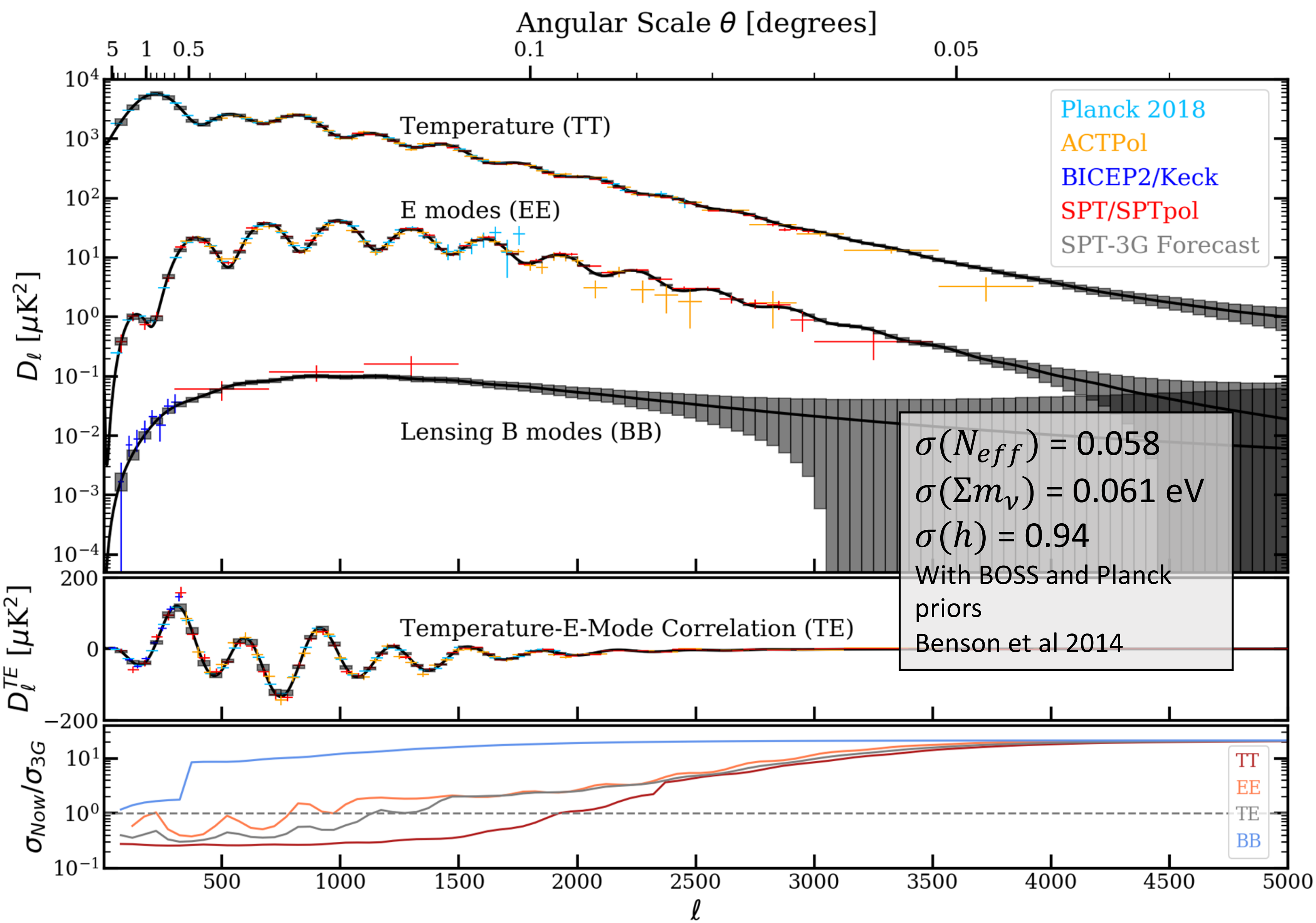
Ongoing science analysis

E-mode measurement (2018 data)



- The most sensitive measurement of the CMB E mode in the ell range of 1000 to 1700 from SPT.
- Daniel Dutcher’s PhD thesis

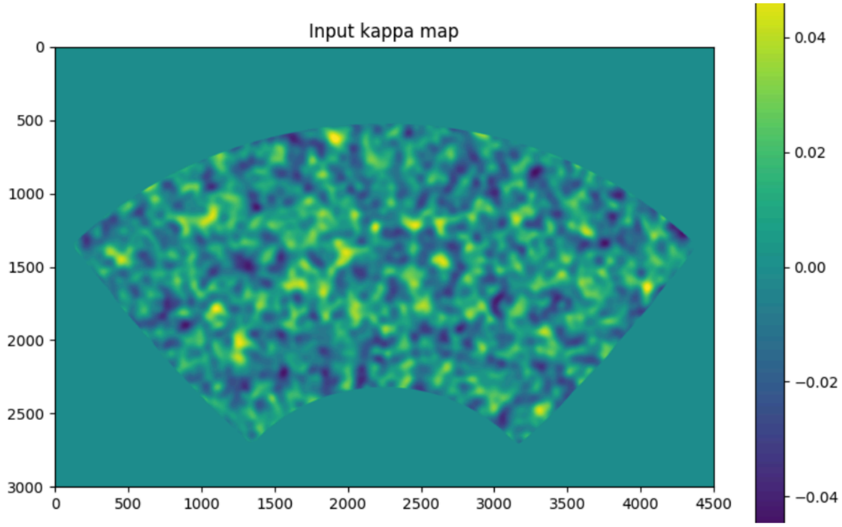
The full survey– power spectra forecast



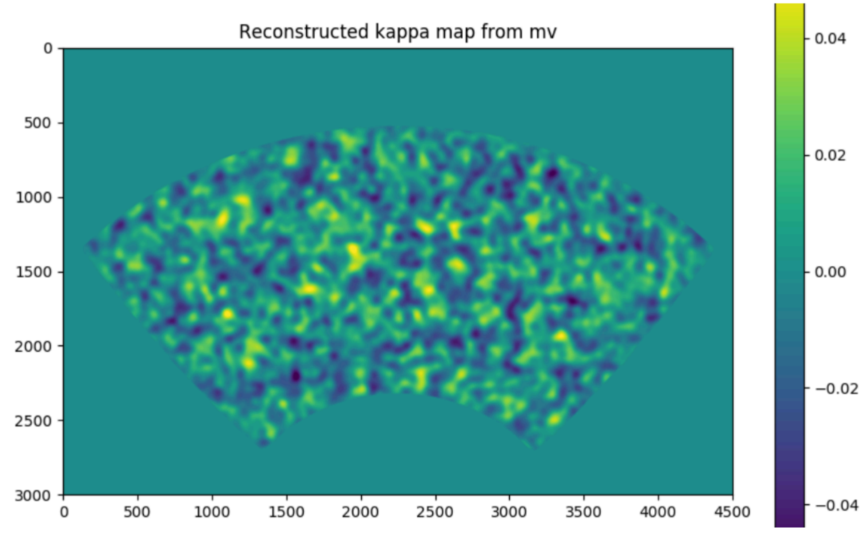
Ongoing science analysis

Lensing power spectrum measurement (2018 data)

- Per mode noise is slightly worse than SPTpol's 500 deg^2 field (arXiv:1905.05777).
- Larger area (x3 area) --> reduced sample variance --> better cosmological parameter constraints compared to SPTpol.
- Now I am building the pipeline and testing things on the simulation.
- My thesis project.

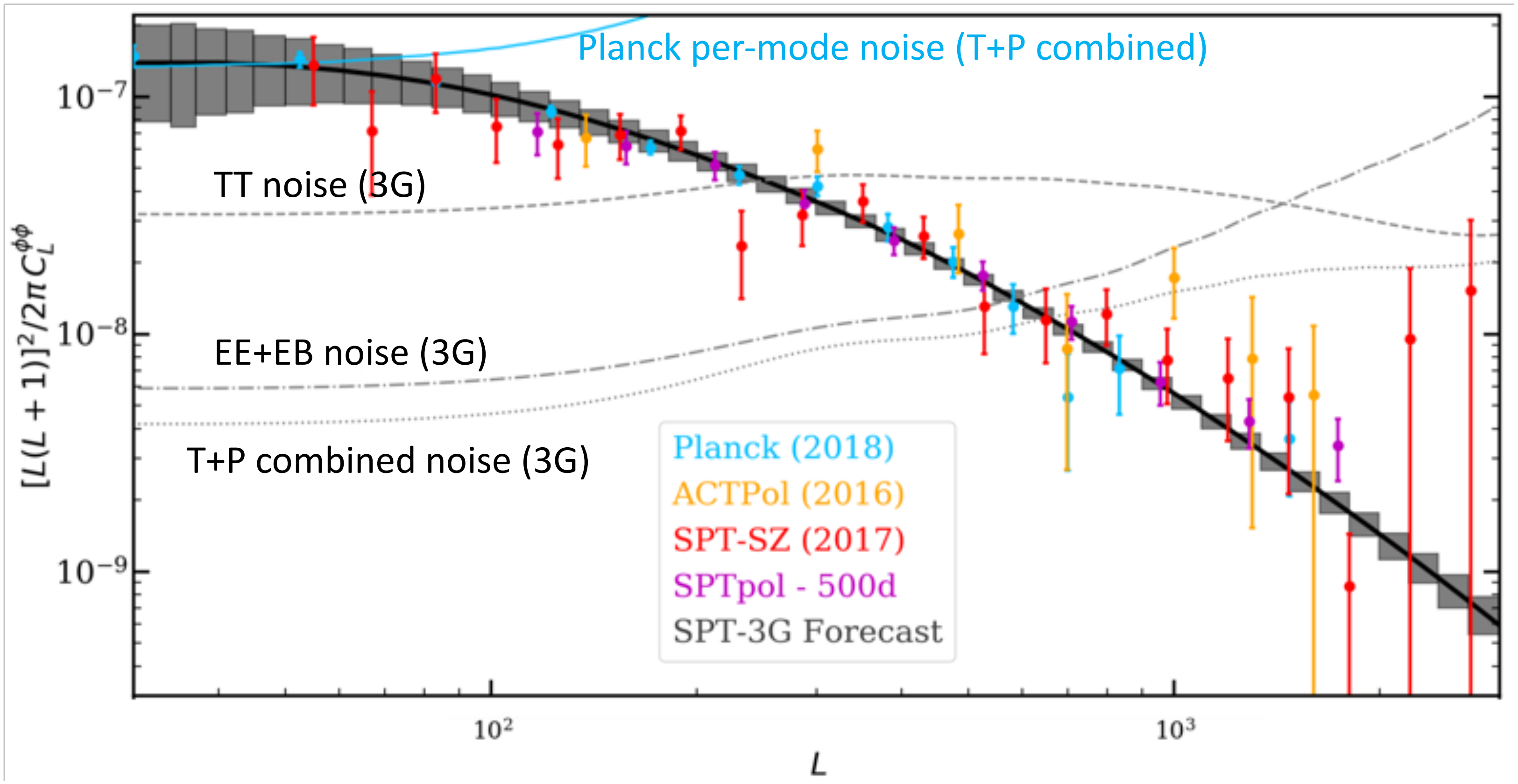


Input kappa map for simulating the input CMB map.



Reconstructed kappa map from a lensed CMB map with SPT-3G noise level.

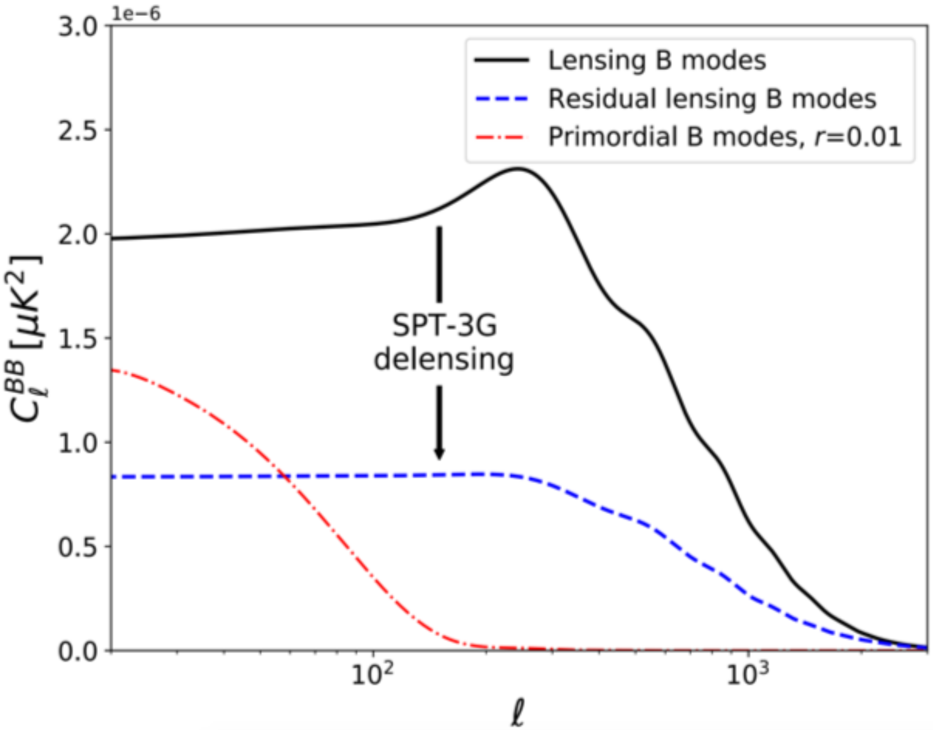
The full survey – lensing forecast

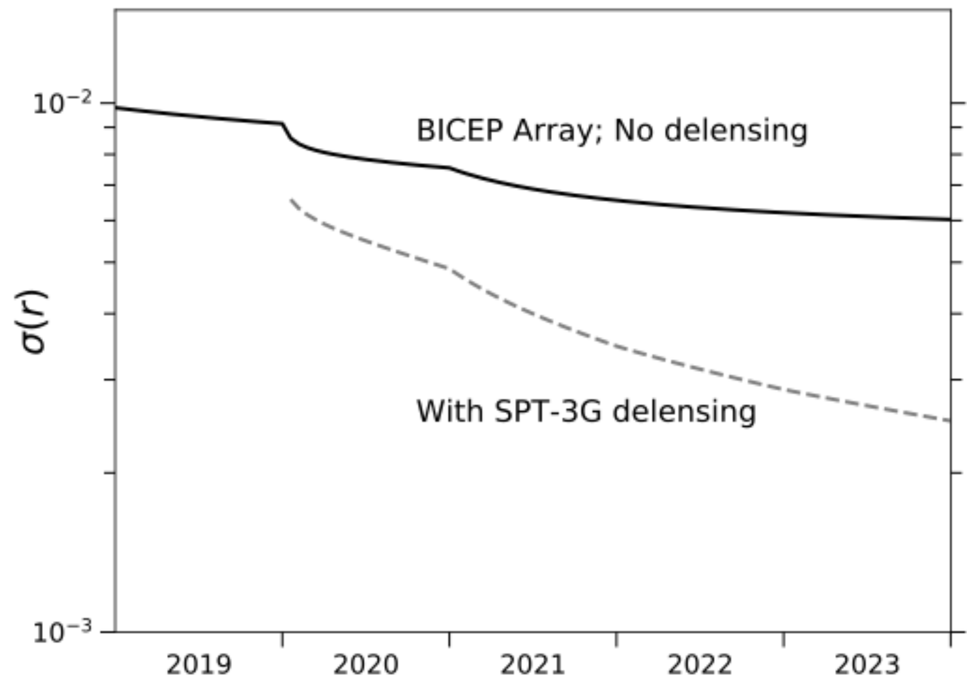


Lensing potential power spectrum forecast (Jason Henning)

- Measurement of lensing features at scale of ~14 arcmin for 1500 square degrees
- Overlaps with DES/LSST for cross-correlation
- Constrains growth of structure
- CMB lensing around known galaxy clusters → cluster lensing

Delensing

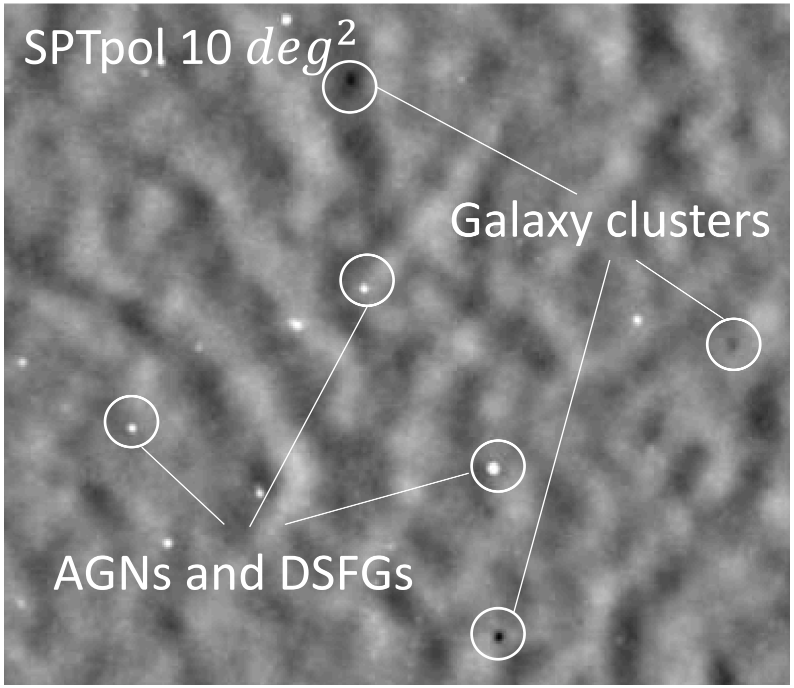


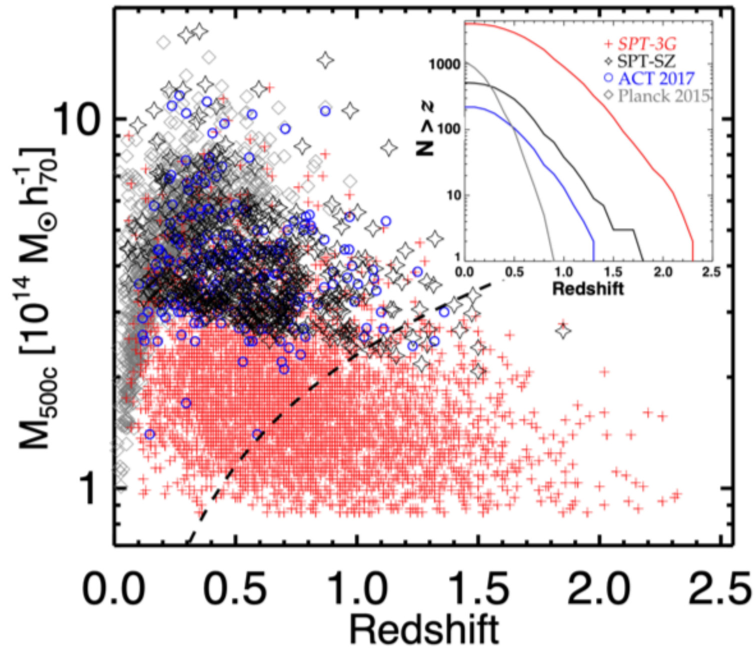


Joint SPT-BICEP delensing forecast (Kimmy Wu)

- Both CMB lensing and primordial gravitational waves generates B-modes.
- SPT-3G overlaps with BICEP for lensing B-mode removal.
- Joint SPT-BICEP delensing can help improve $\sigma(r)$ to 0.003. Without delensing it's 0.006.

Science goals- clusters, astrophysics





Cluster forecast (Lindsey Bleem)

Go to Lindsey Bleem's talk for more on galaxy clusters!

- Can find more clusters (~4000), especially at lower mass and higher redshift, can constrain the growth of structure (x10 deeper than SPT-SZ).
- Better catalogs of extragalactic mm-wave point sources (>15000 sources, including high-redshift star-forming galaxies, AGNs, and protoclusters, many of which are strongly lensed)
- Transient search (GRB, FRB ...)
- Planets (including planets from outer solar system), ...

Thank you!

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