South Pole Observatory

Probing inflation through delensed degree-scale CMB B-modes

Dominic Beck
dobeck@stanford.edu

for the

BICEP/*Keck* and the South Pole Telescope Collaborations

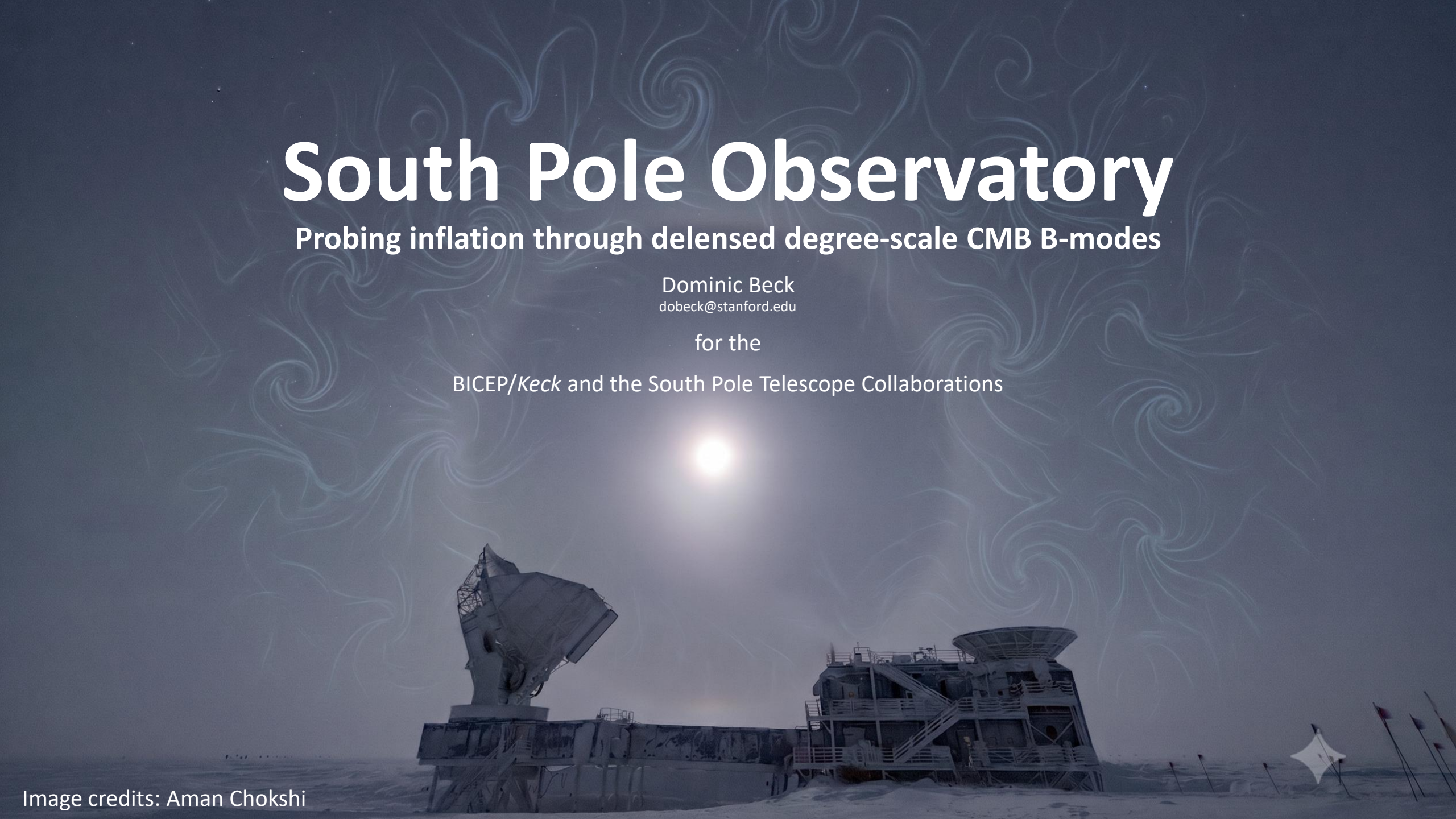
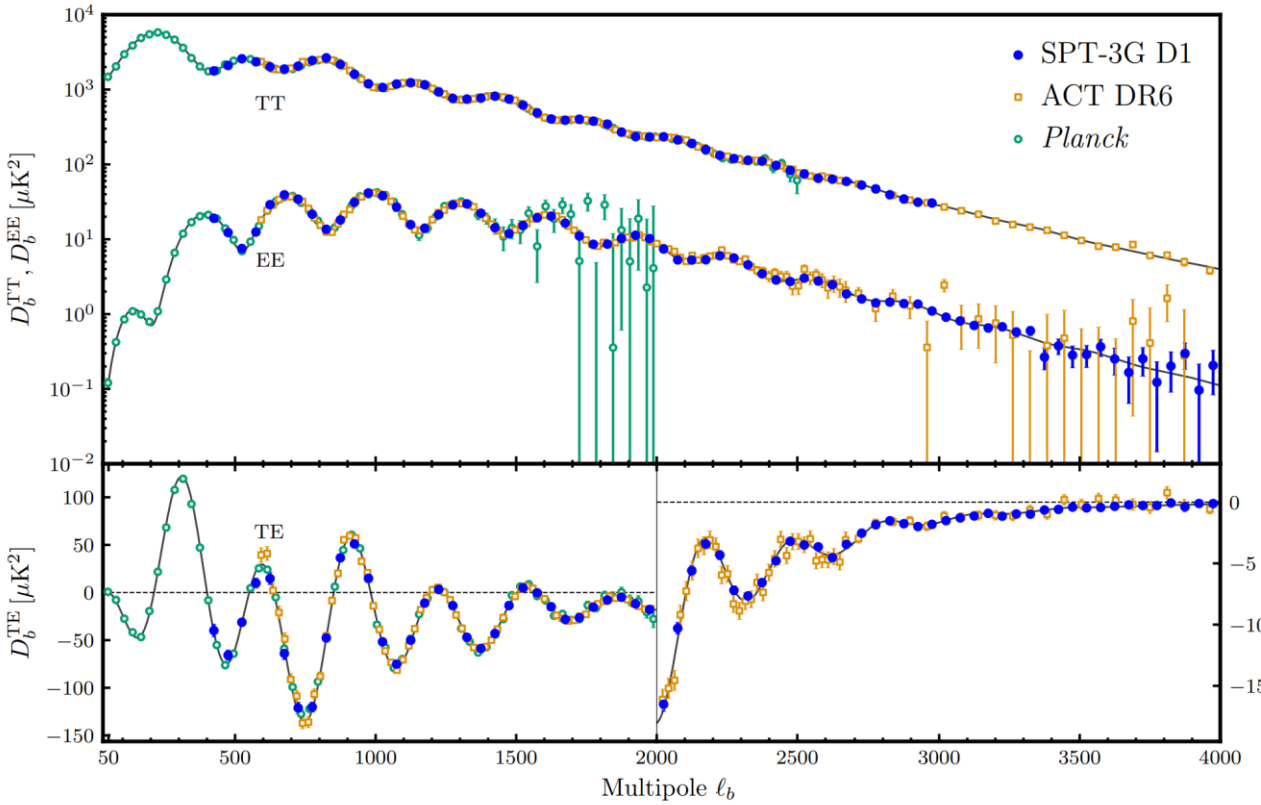


Image credits: Aman Chokshi

South Pole Telescope (SPT)

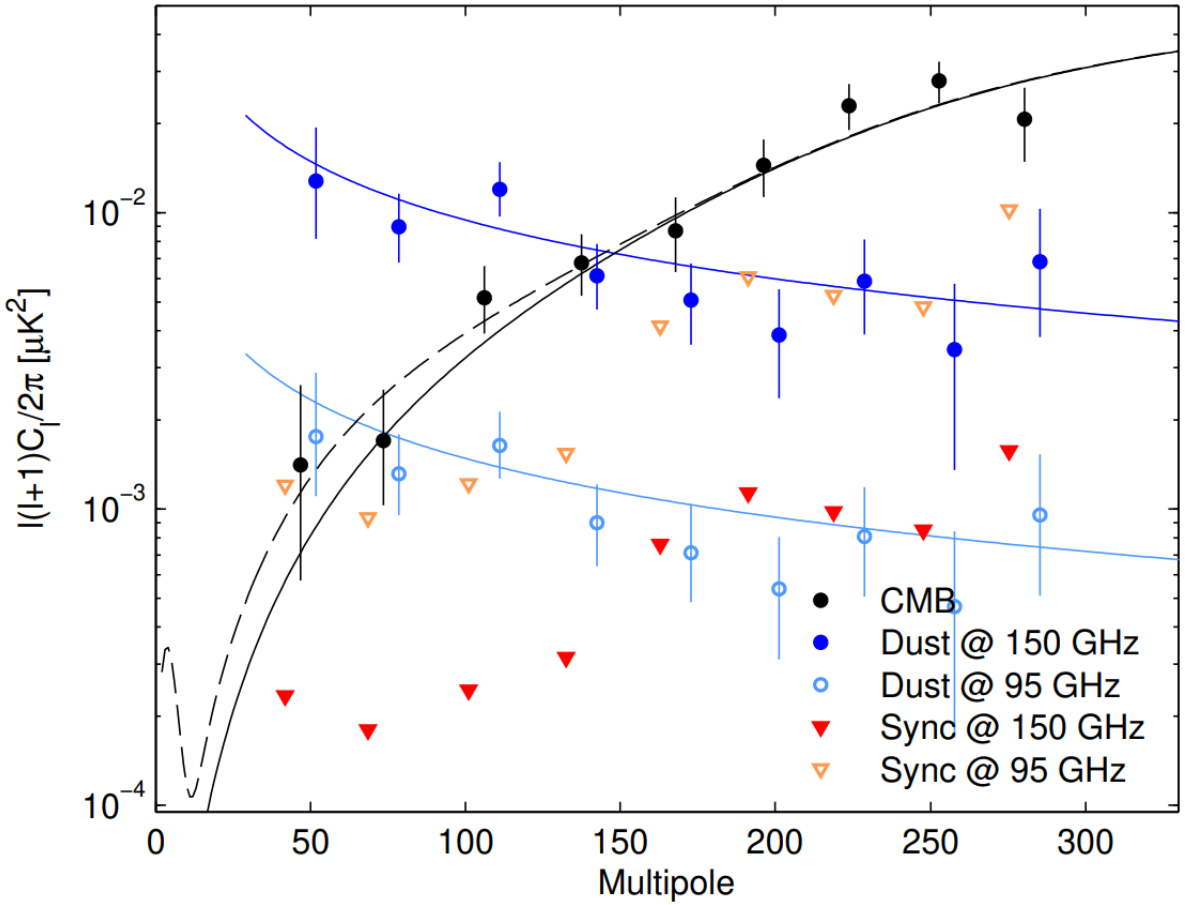
Large Aperture – Small Scales



Camphuis et al (2025)

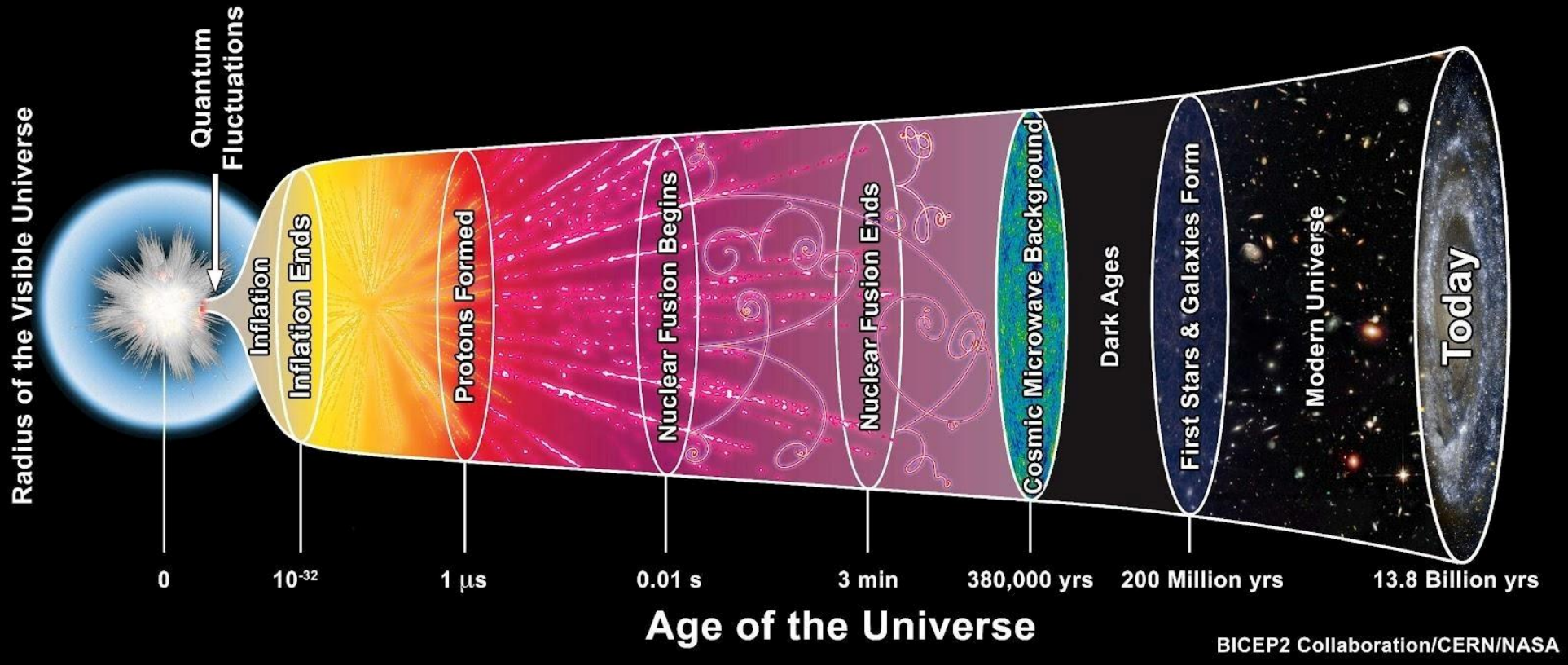
BICEP/*Keck* (BK)

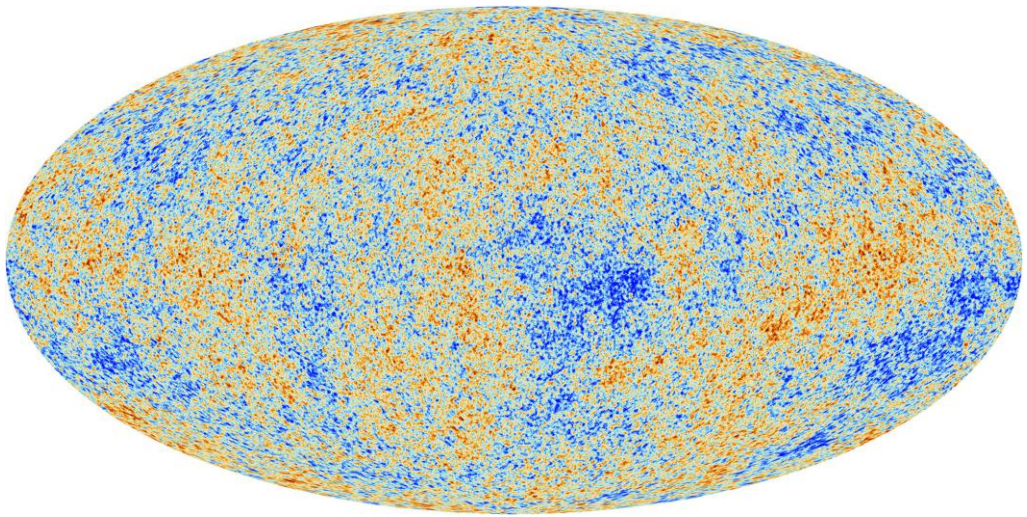
Small Aperture – Large Scales

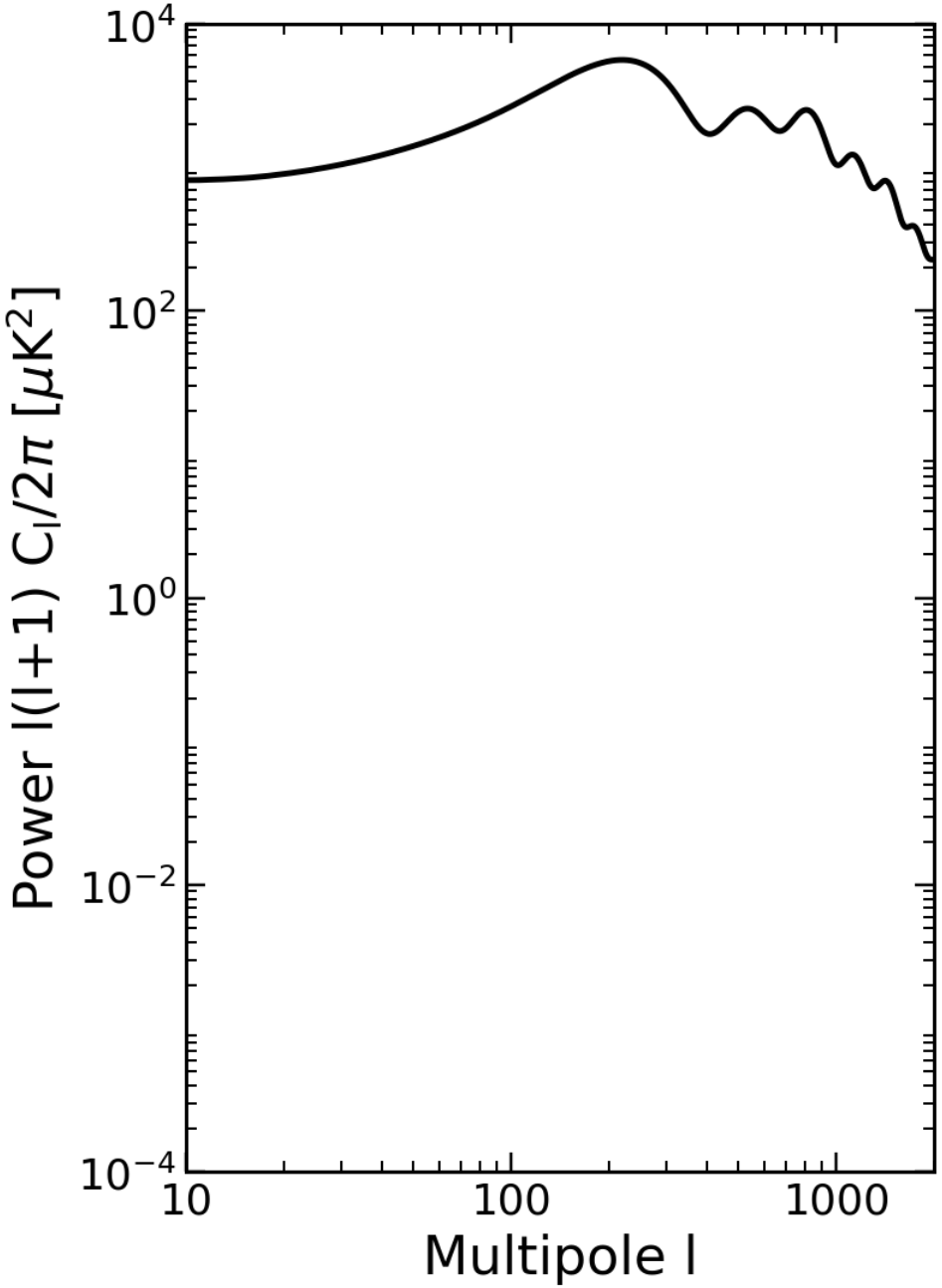


BK-XIII (2021)

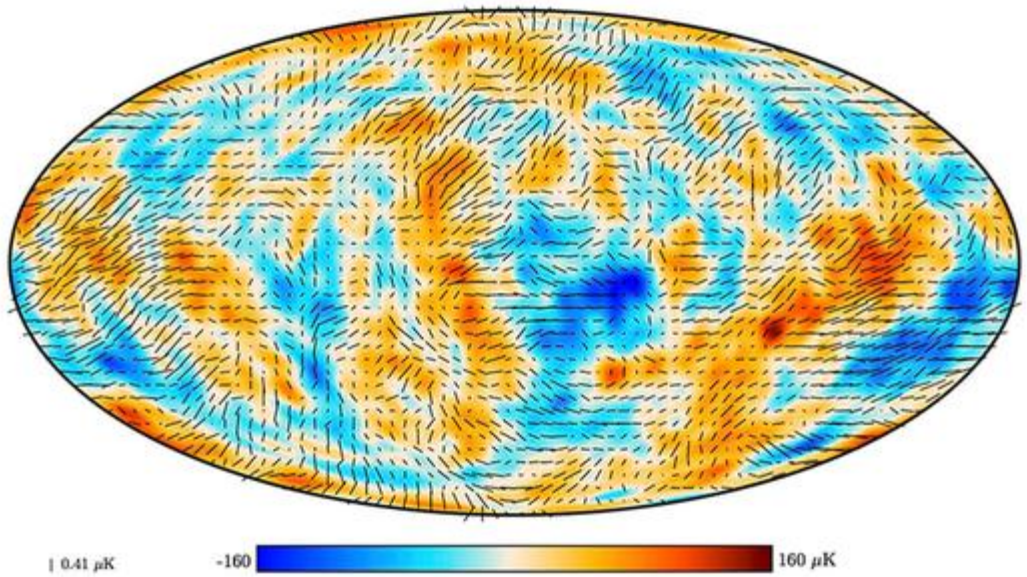
Search for Inflationary B-Modes

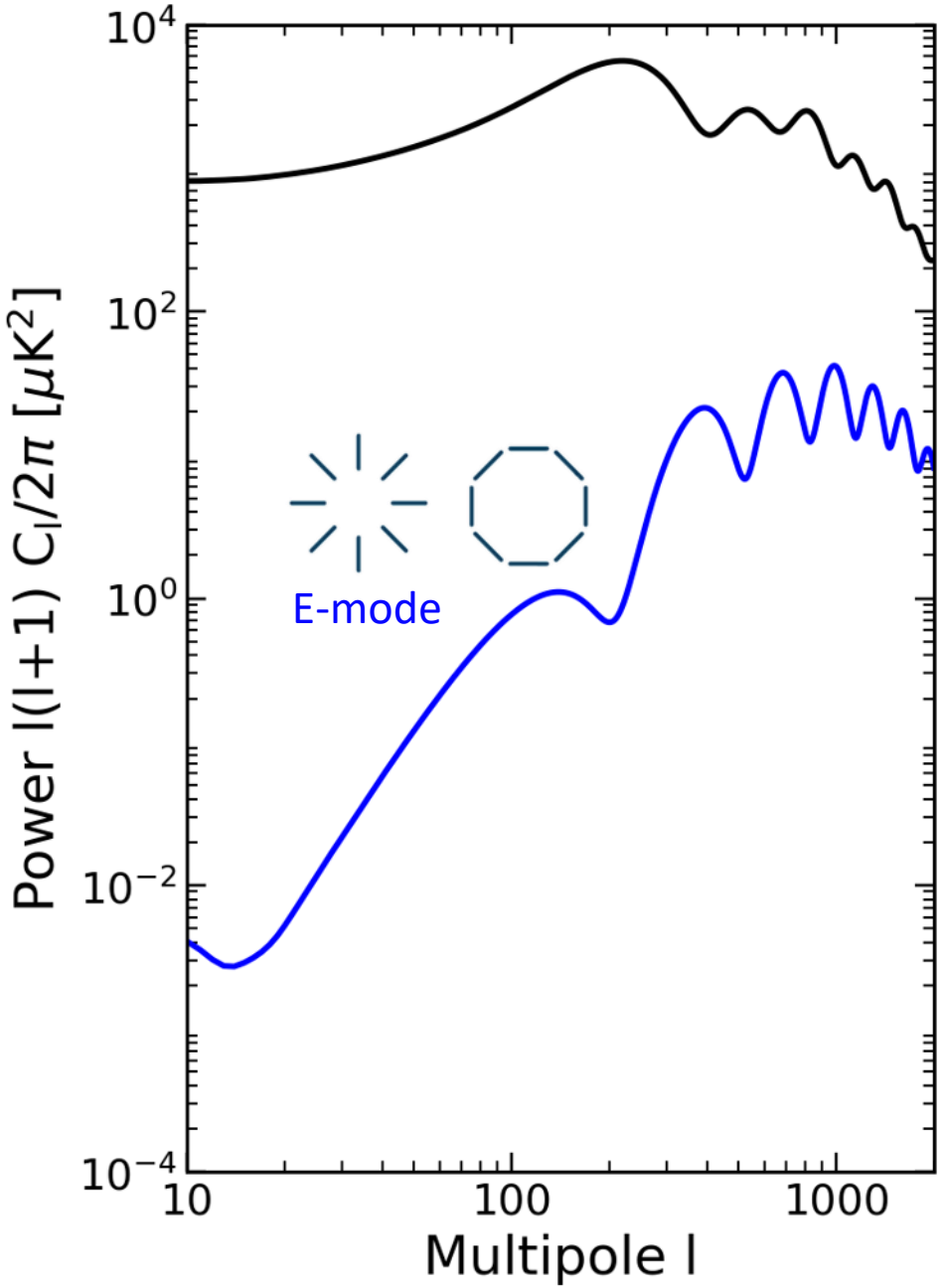






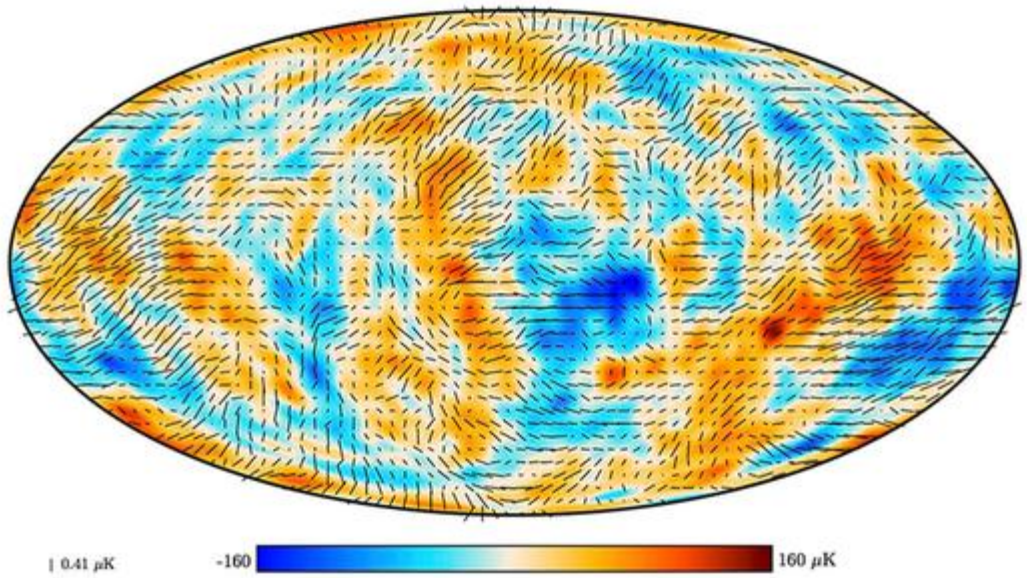
Credits: Planck

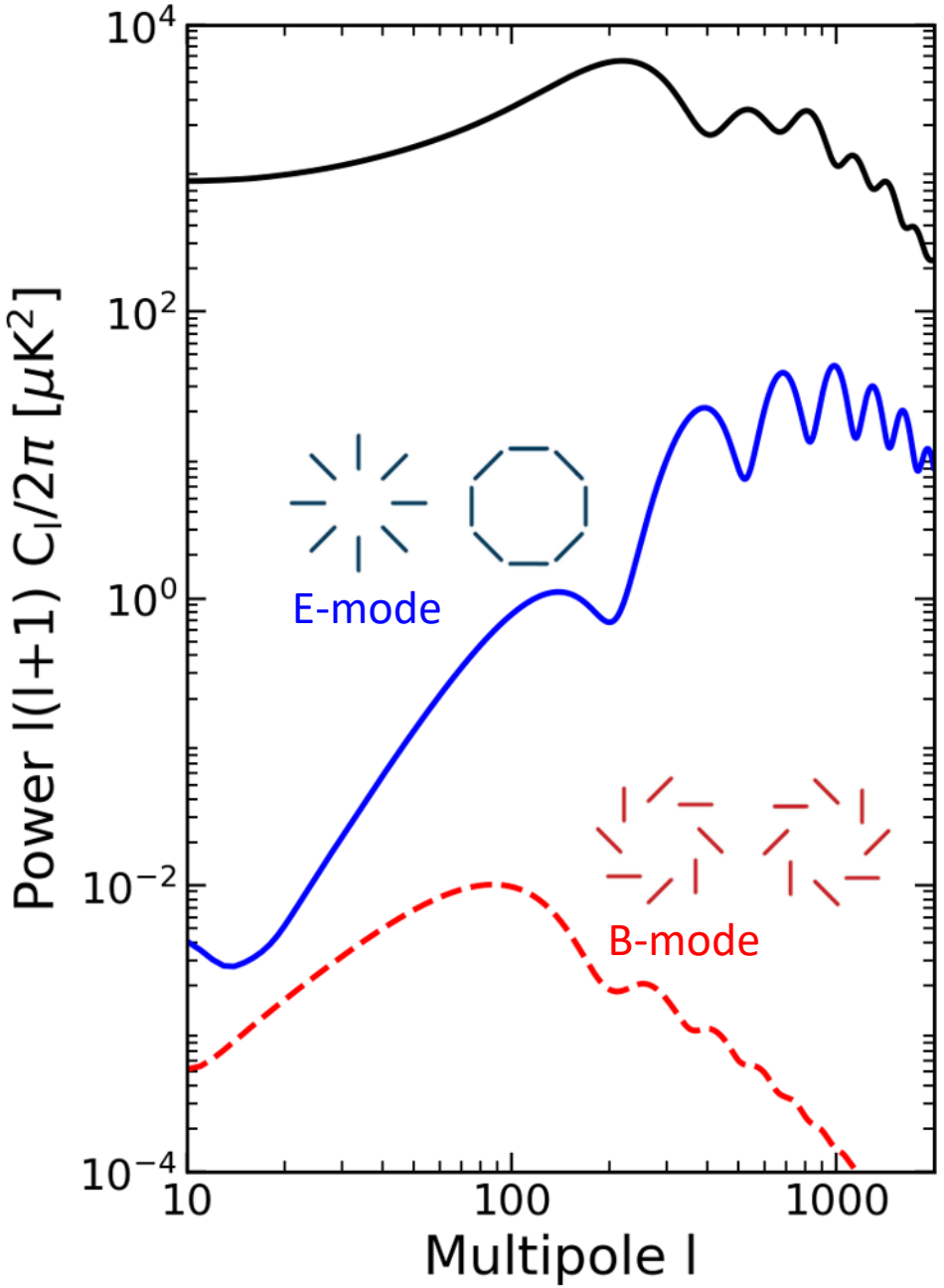




In standard ΛCDM only E-modes are present at last scattering

Credits: Planck

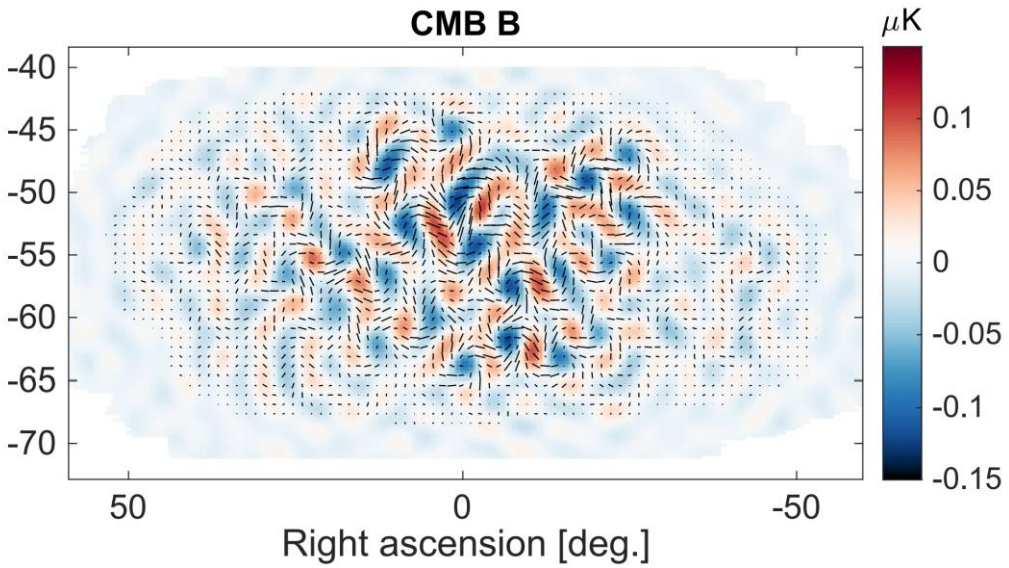


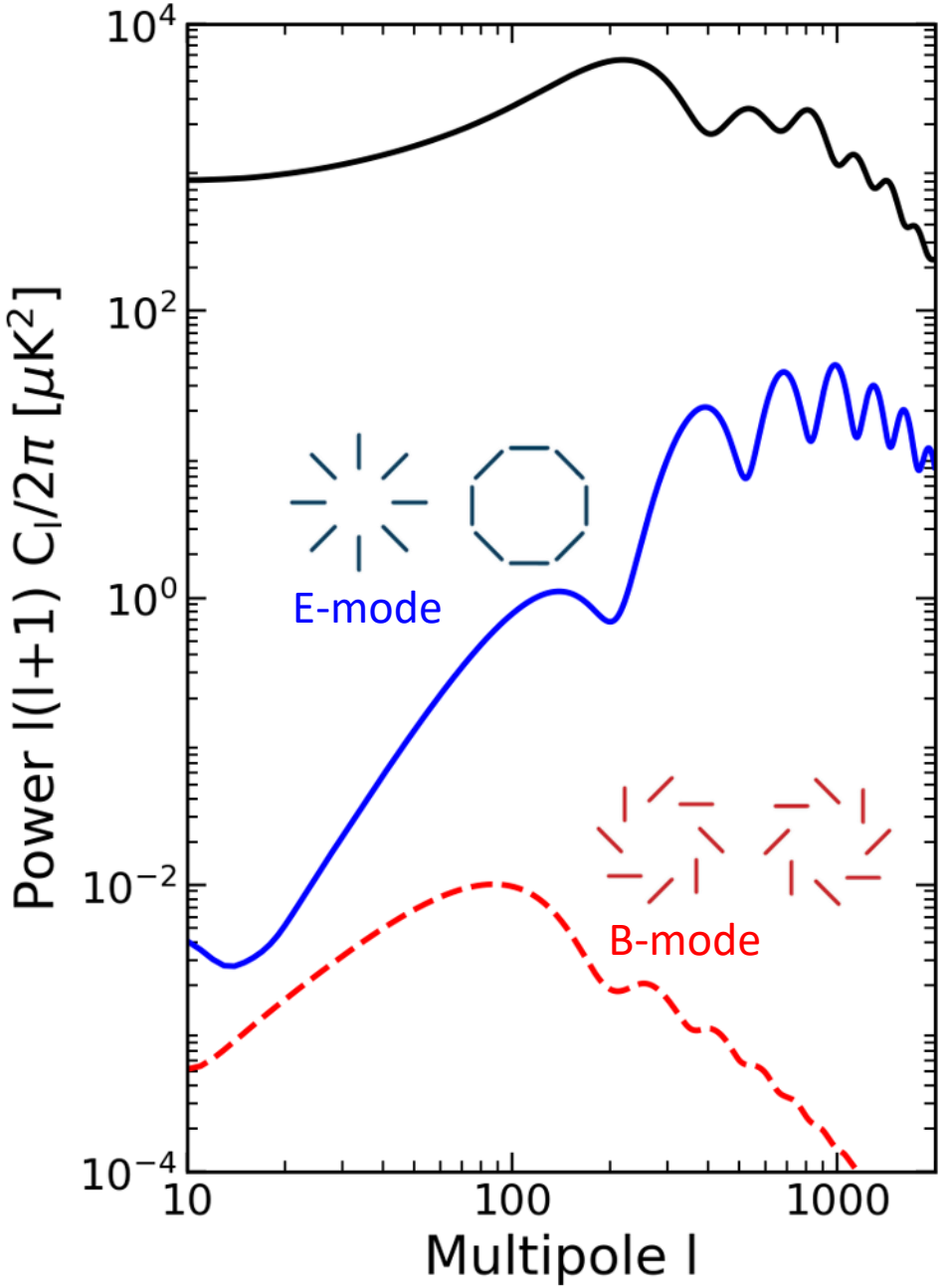


In standard ΛCDM only E-modes are present at last scattering

Inflationary gravitational waves are unique source of B-modes
→ peaking at l≈100, degree scales

Credits: Planck





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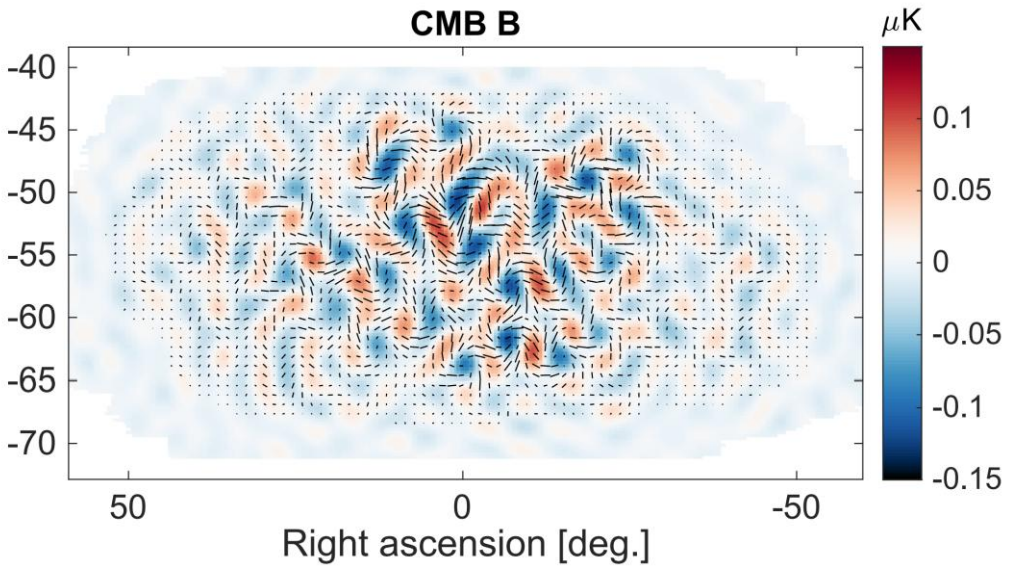

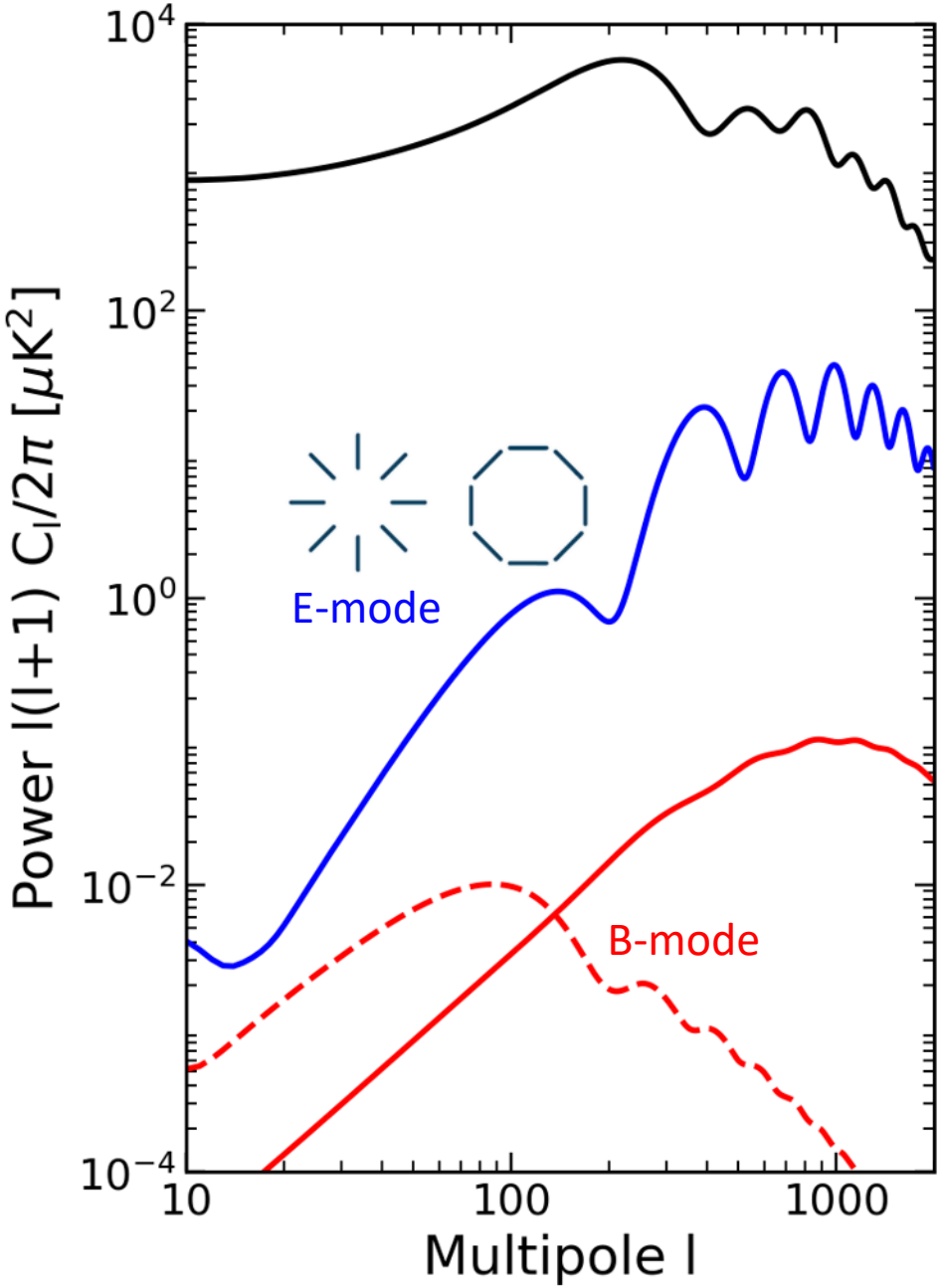

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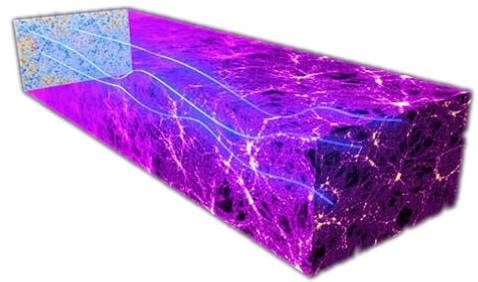
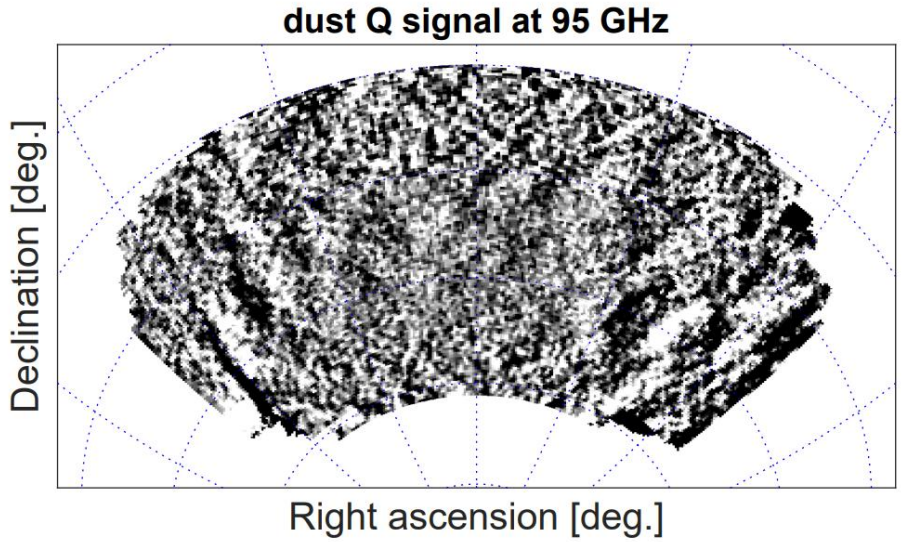
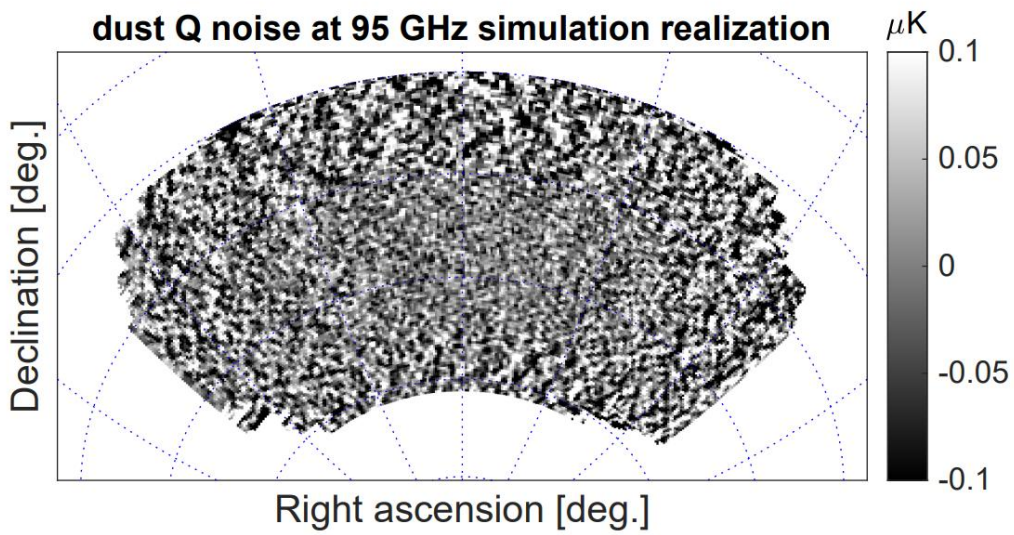


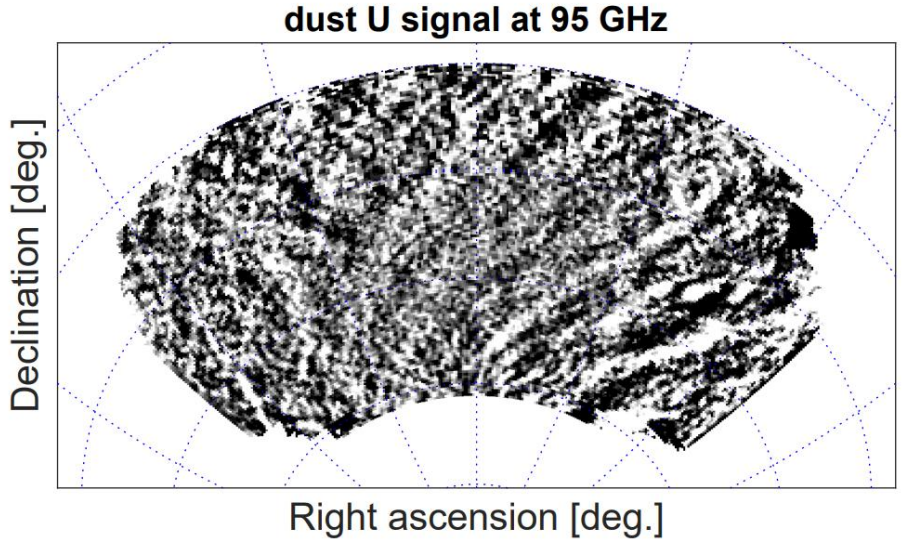
During propagation some of the E-modes are confused into B-modes by lensing

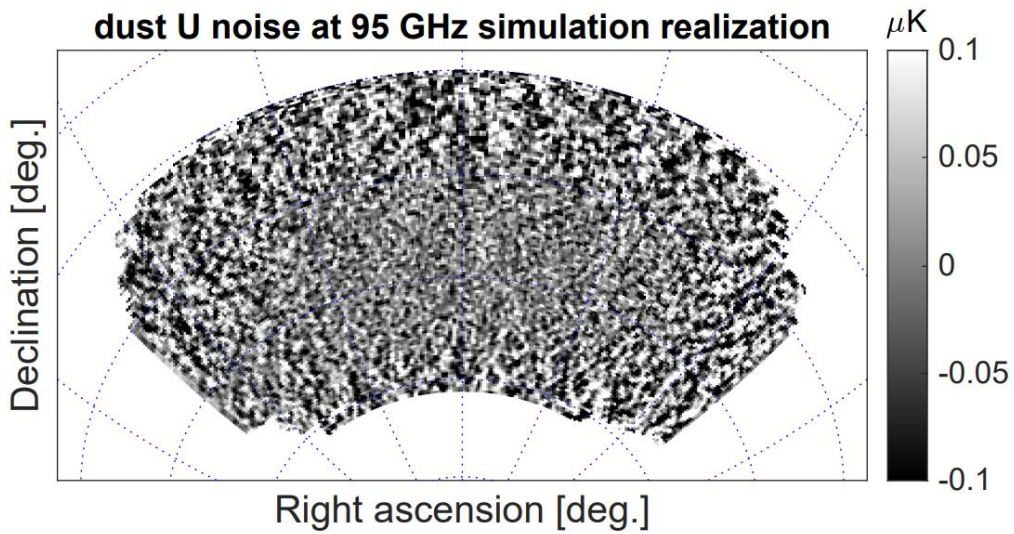
Credits: Planck

Existing Constraints from B modes ("BK18")



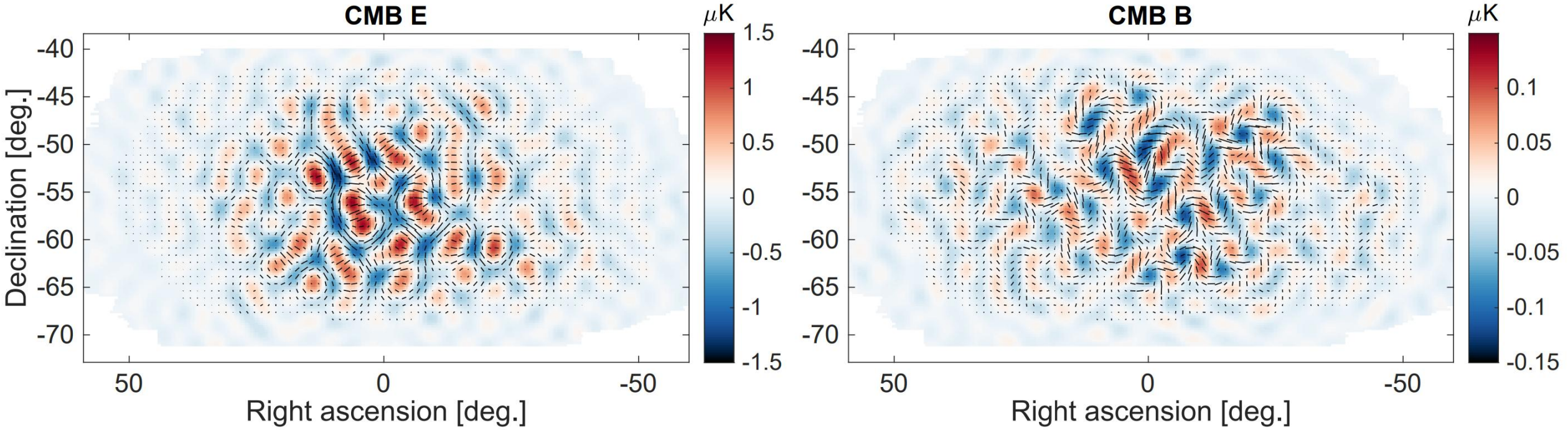






BK-XX (2025)

Existing Constraints from B modes ("BK18")



BK-XX (2025)

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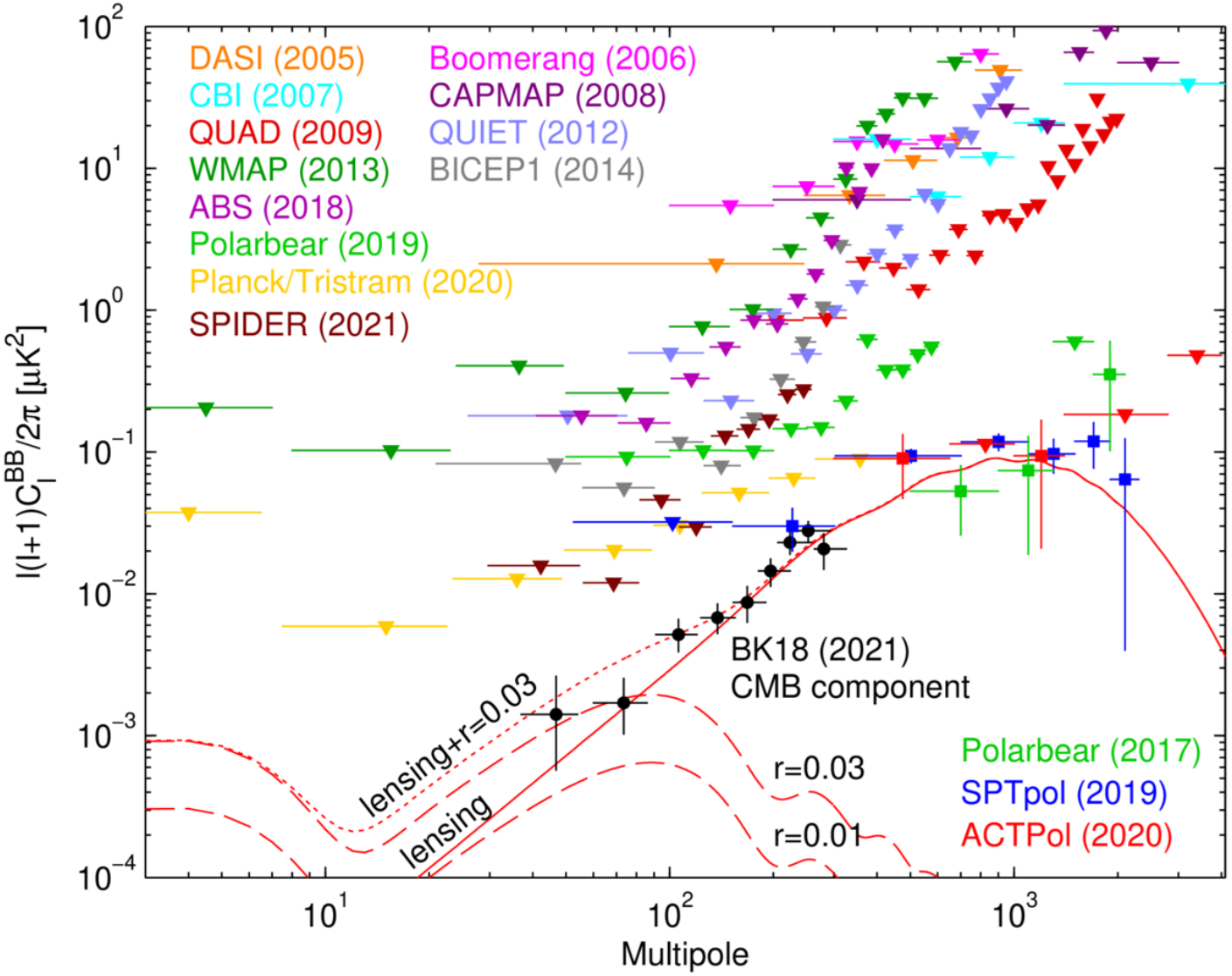
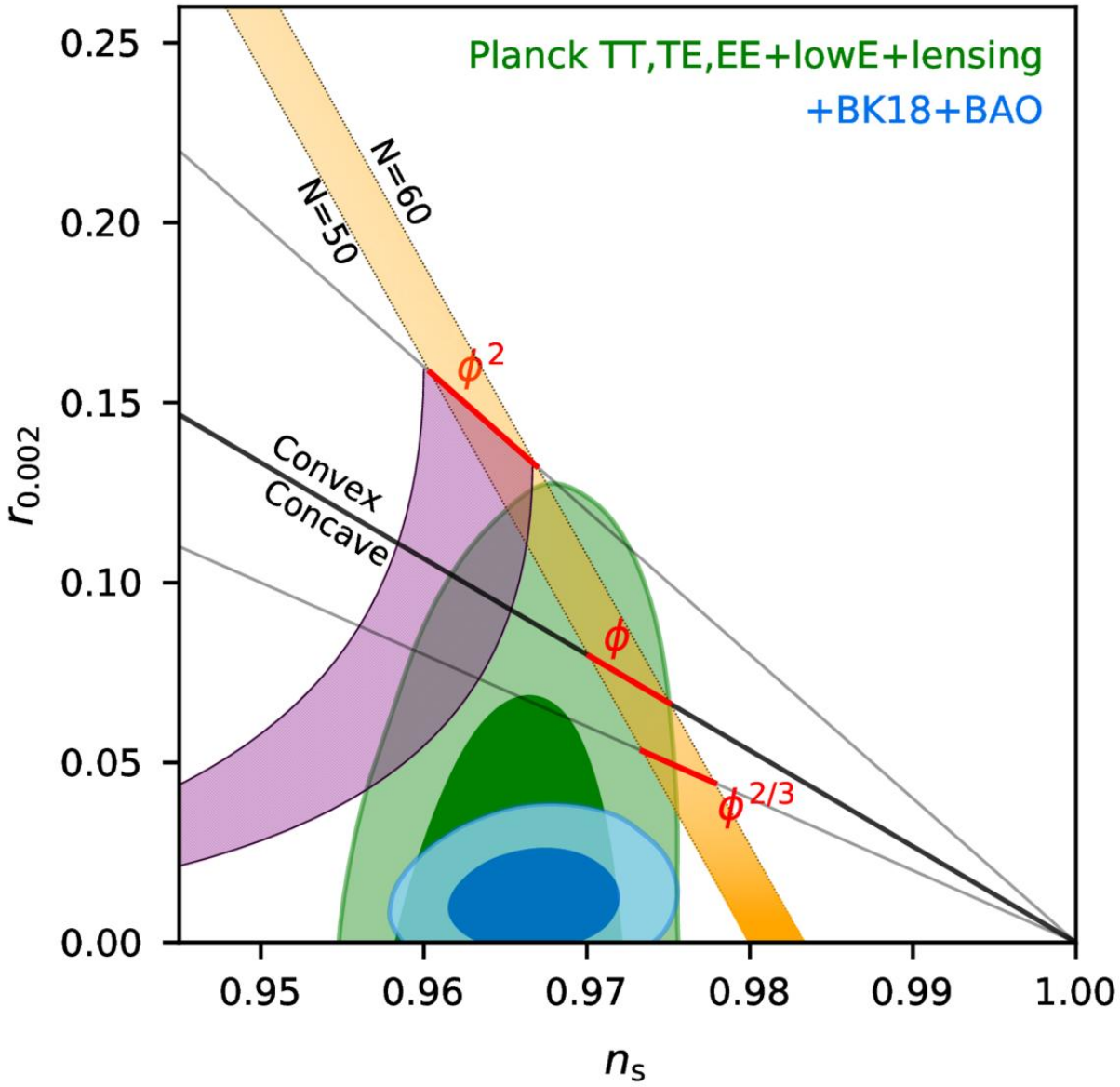


BK-XIII (2021)

Existing Constraints from B modes ("BK18")

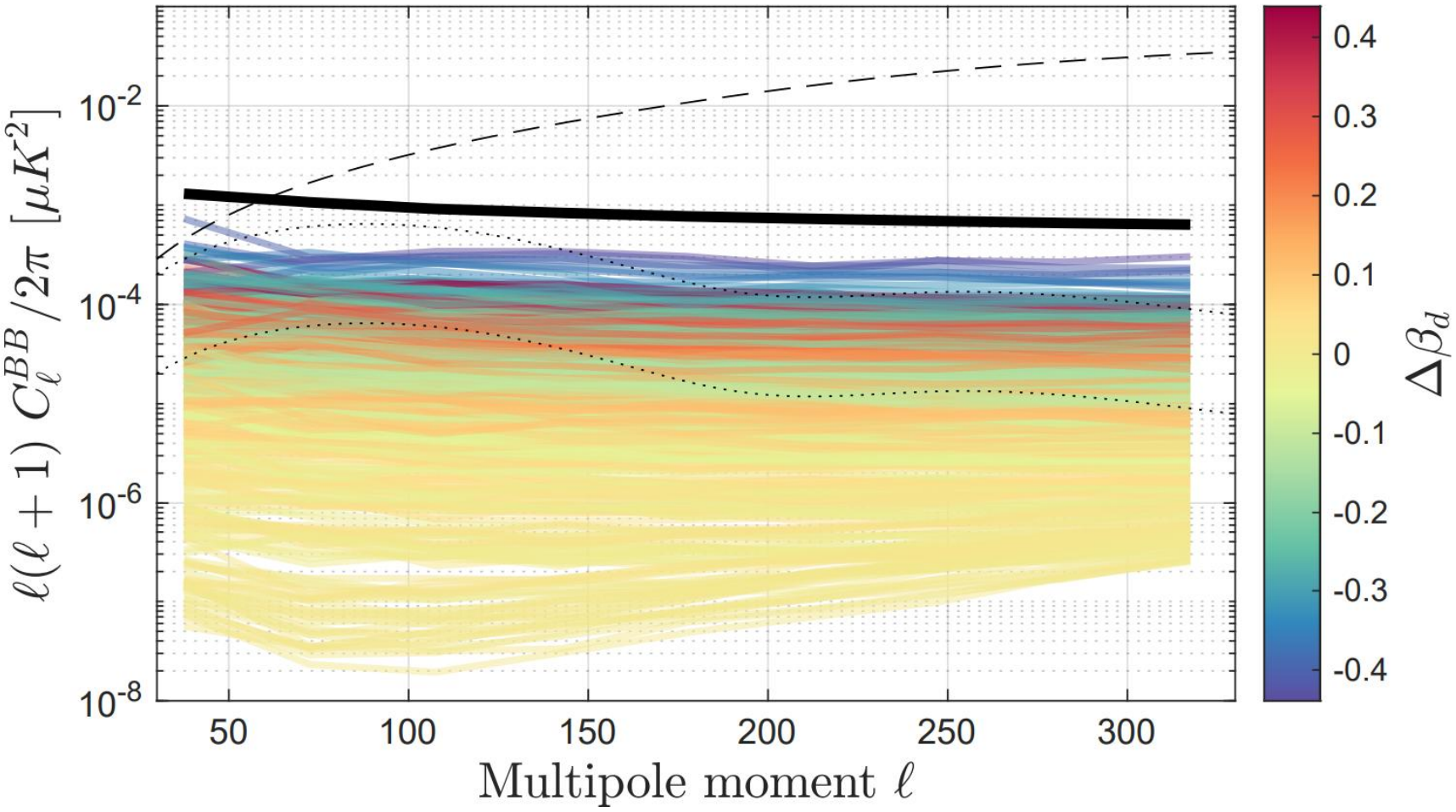


$r < 0.036$ (95% C.L.)

BK-XIII (2021)

Lensing is now dominant source of uncertainty

over foregrounds/noise



BK-XX (2025)

The South Pole Observatory (SPO)

- **SPO combines BK's deep, multi-frequency degree-scale B-mode observations with the resolution and power of SPT for delensing**
- **Makes use of existing telescope systems by upgrading focal planes**

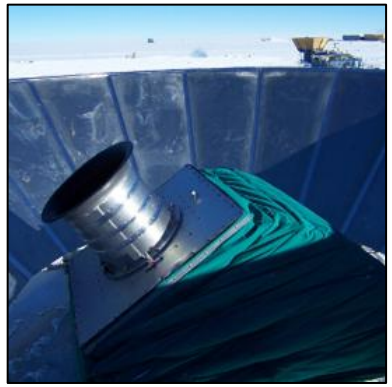
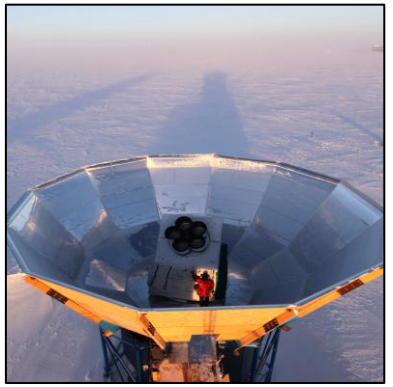
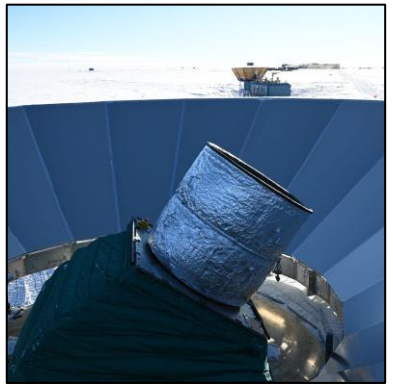
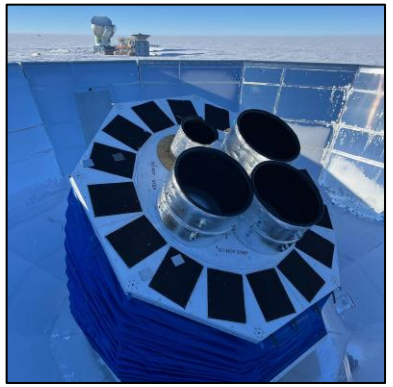
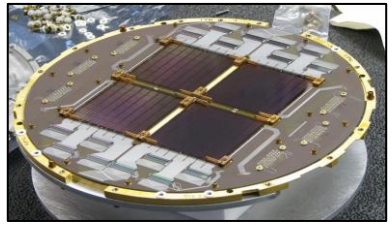
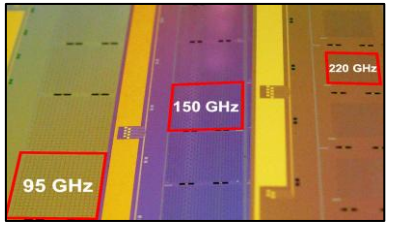
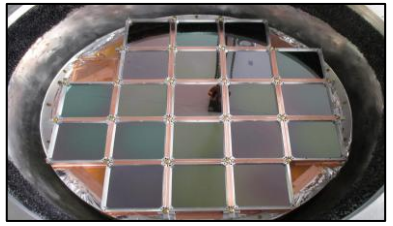
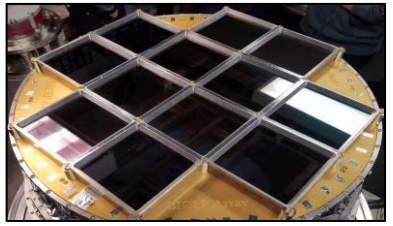
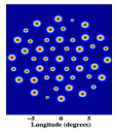
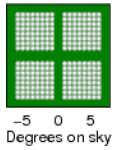
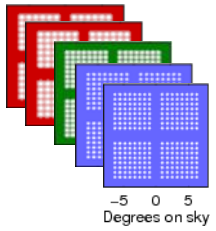
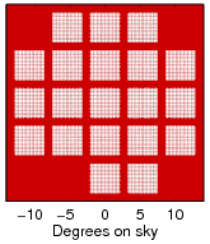
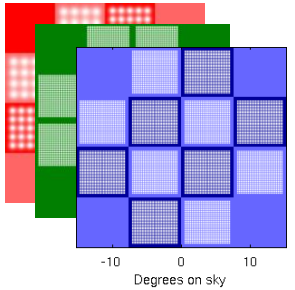
10m South Pole Telescope
SPT-SZ
SPTpol
SPT-3G

BICEP1
BICEP2
BICEP3

DASI
QUaD
Keck Array
BICEP Array

The Pole:
High, Dry, Stable
Logistical support from NSF/USAP
Year-round, 24/7 access to low-foreground Southern sky

BICEP/*Keck* Series of Experiments

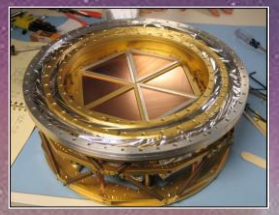
	Generation 1	Generation 2	Generation 3	Generation 4	Generation 5
	BICEP1 (2006 - 2008)	**BICEP2** (2010 - 2012)	***Keck* Array** (2012 - 2019)	**BICEP3** (2016 - present)	**BICEP Array** (2020 - present)
Telescope					
Focal Array					
Beams On Sky					
	~100 detectors 100 GHz and 150 GHz	**~500 detectors** 150 GHz	**~2,500 detectors** 95 GHz, 150 GHz, 220 GHz, and 270 GHz	**~2,500 detectors** 95 GHz	**~25,000 detectors** 30/40 GHz, 90 GHz, 150 GHz, 220 GHz, and 270 GHz

The South Pole Telescope (SPT)

10-meter diameter telescope

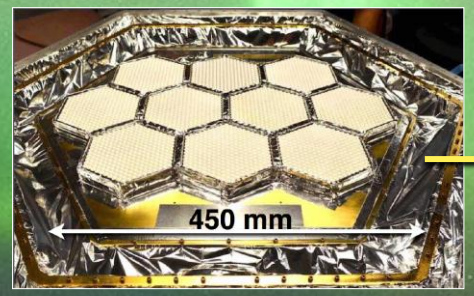
95, 150, 220 GHz frequency
1.6, 1.2, 1.0 arcmin resolution

2007: SPT-SZ
960 detectors
100,150,220 GHz



2012: SPTpol
1600 detectors
100,150 GHz
+Polarization

2017: SPT-3G
~16,200 detectors
100,150,220 GHz
+Polarization



SPT-3G has 7x larger mapping speed relative to Planck!

Funded by:

U.S. DEPARTMENT of ENERGY

Slide courtesy B. Benson (U. Chicago)

The South Pole Observatory Collaboration

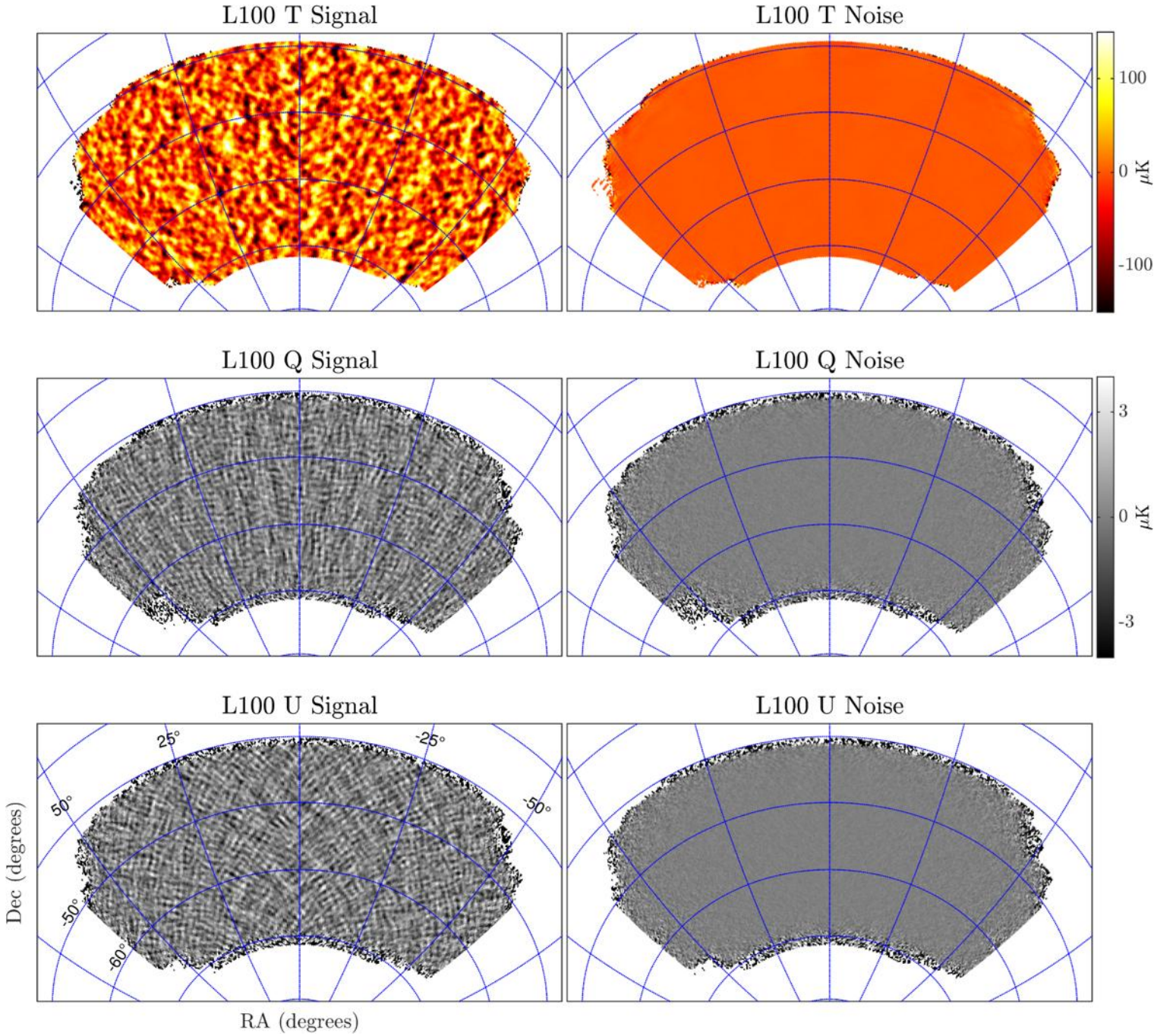
Union of the SPT and BICEP collaborations

Over 150 scientists from 25 member institutions!

New BICEP/*Keck* Low-ℓ B-mode Data

100 GHz Maps

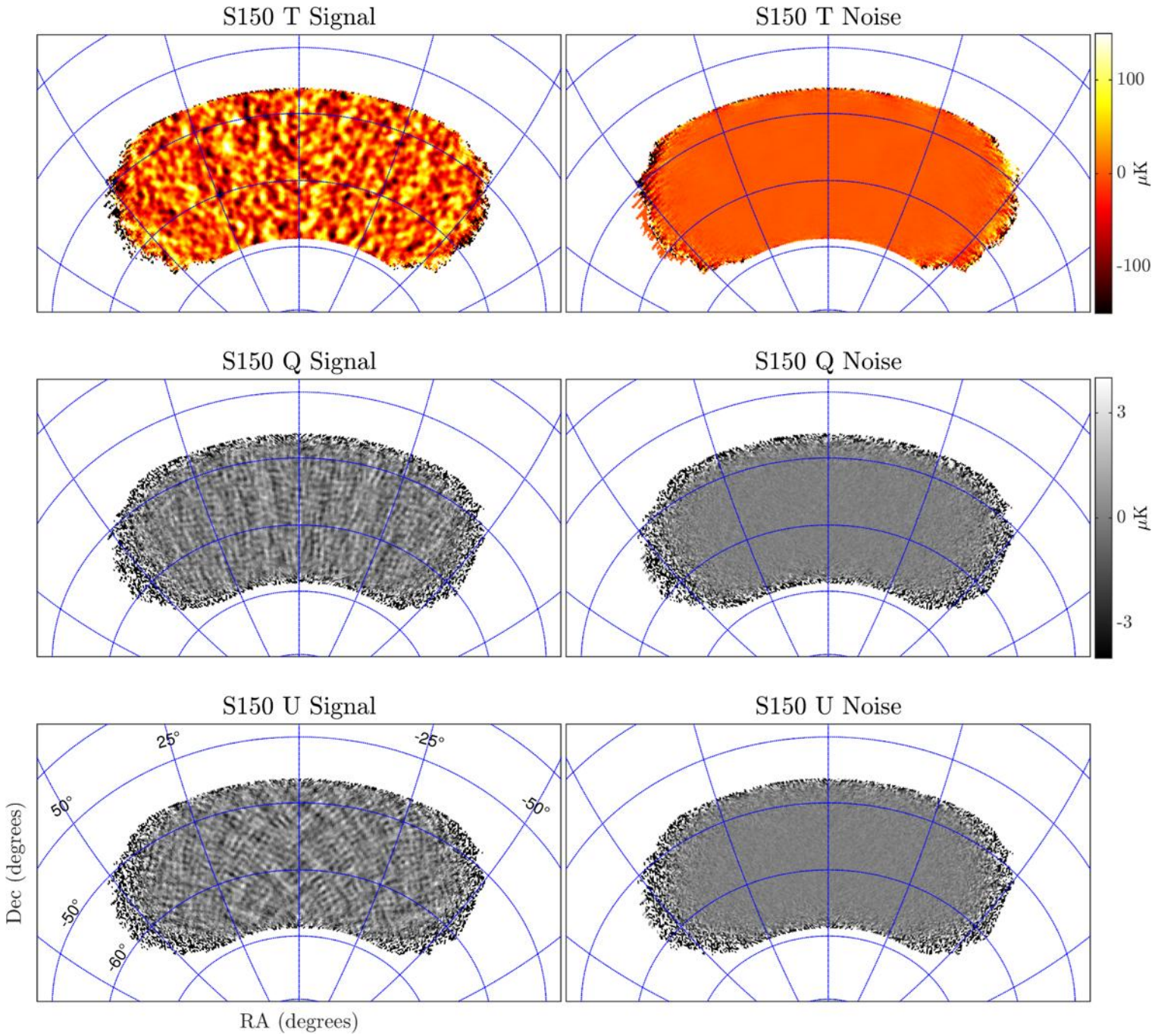
9 years of BICEP3 data



New BICEP/*Keck* Low-ℓ B-mode Data

150 GHz Maps

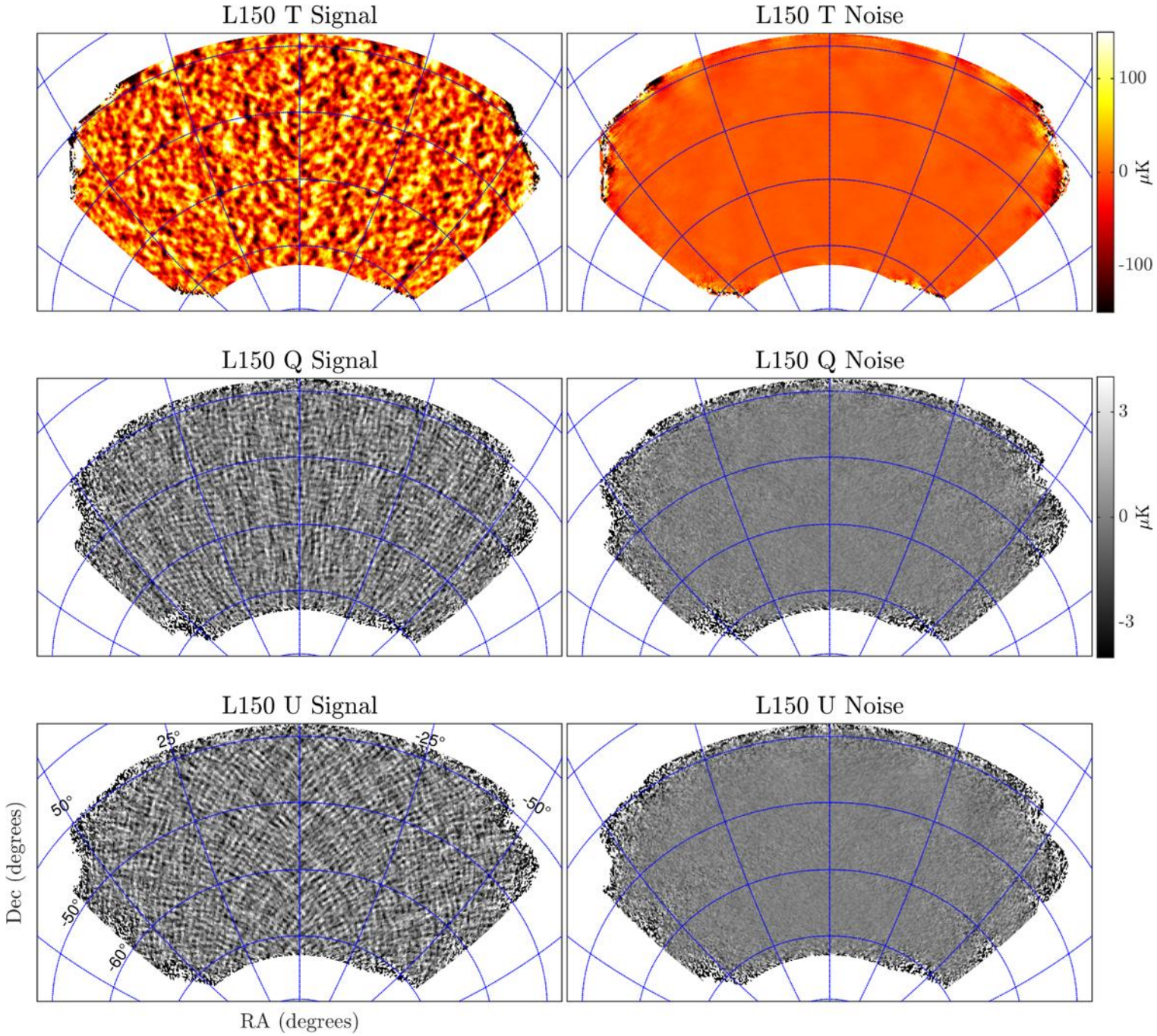
18 rx/years of BICEP2 & Keck data



New BICEP/*Keck* Low-ℓ B-mode Data

150 GHz Maps

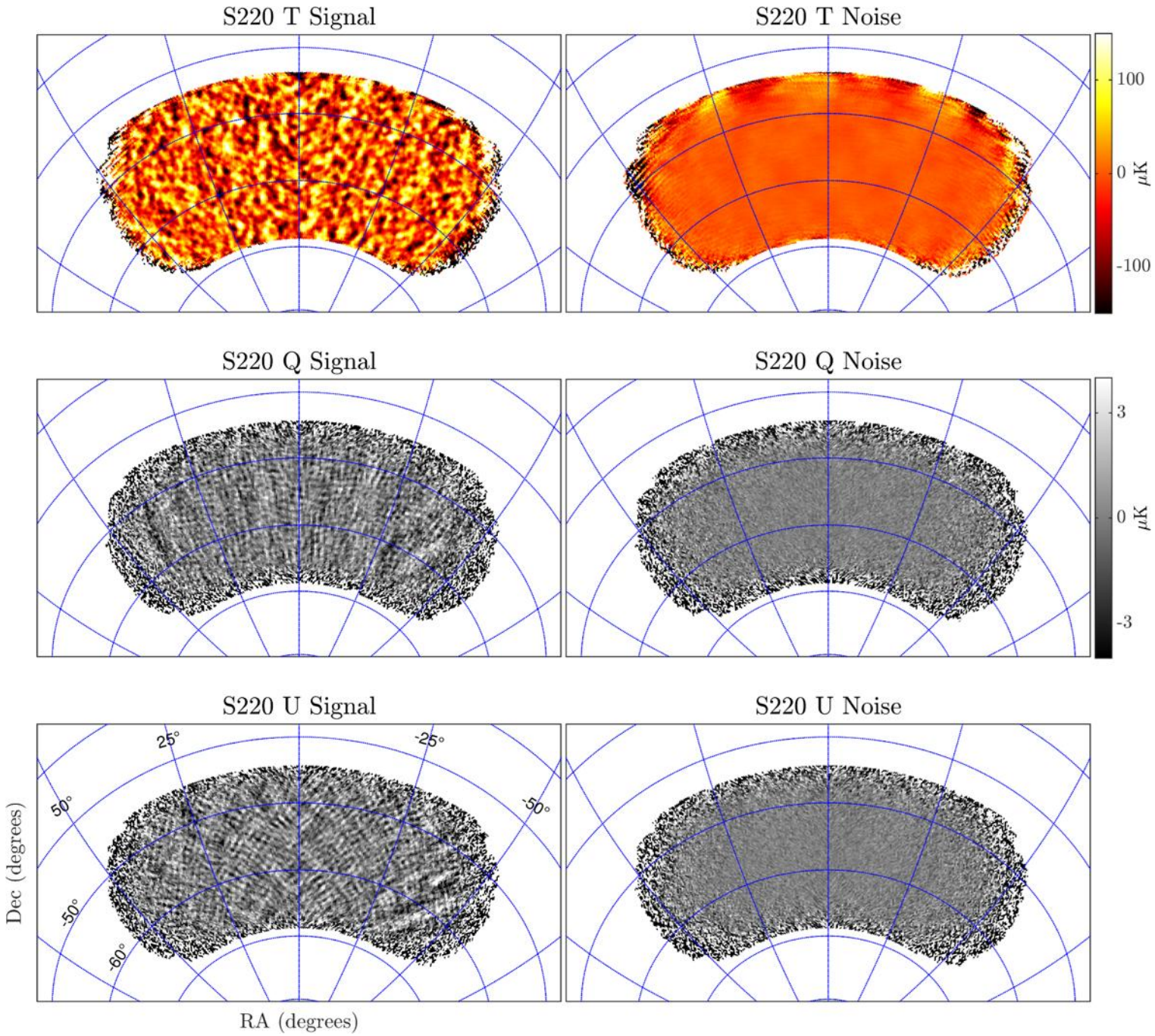
2 years of BICEP Array data



New BICEP/*Keck* Low-ℓ B-mode Data

220 GHz Maps

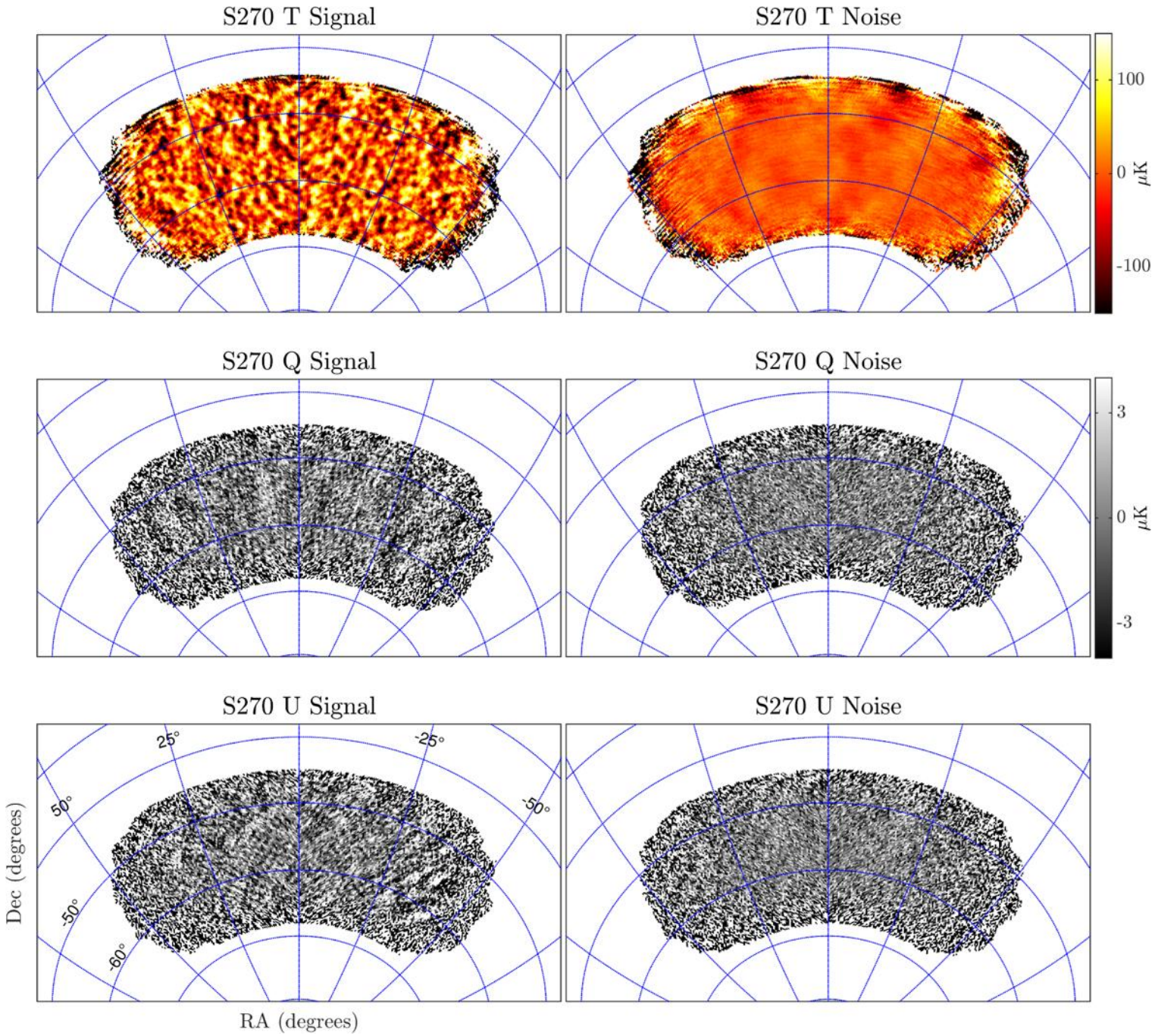
25 years of Keck Array data



New BICEP/*Keck* Low-ℓ B-mode Data

270 GHz Maps

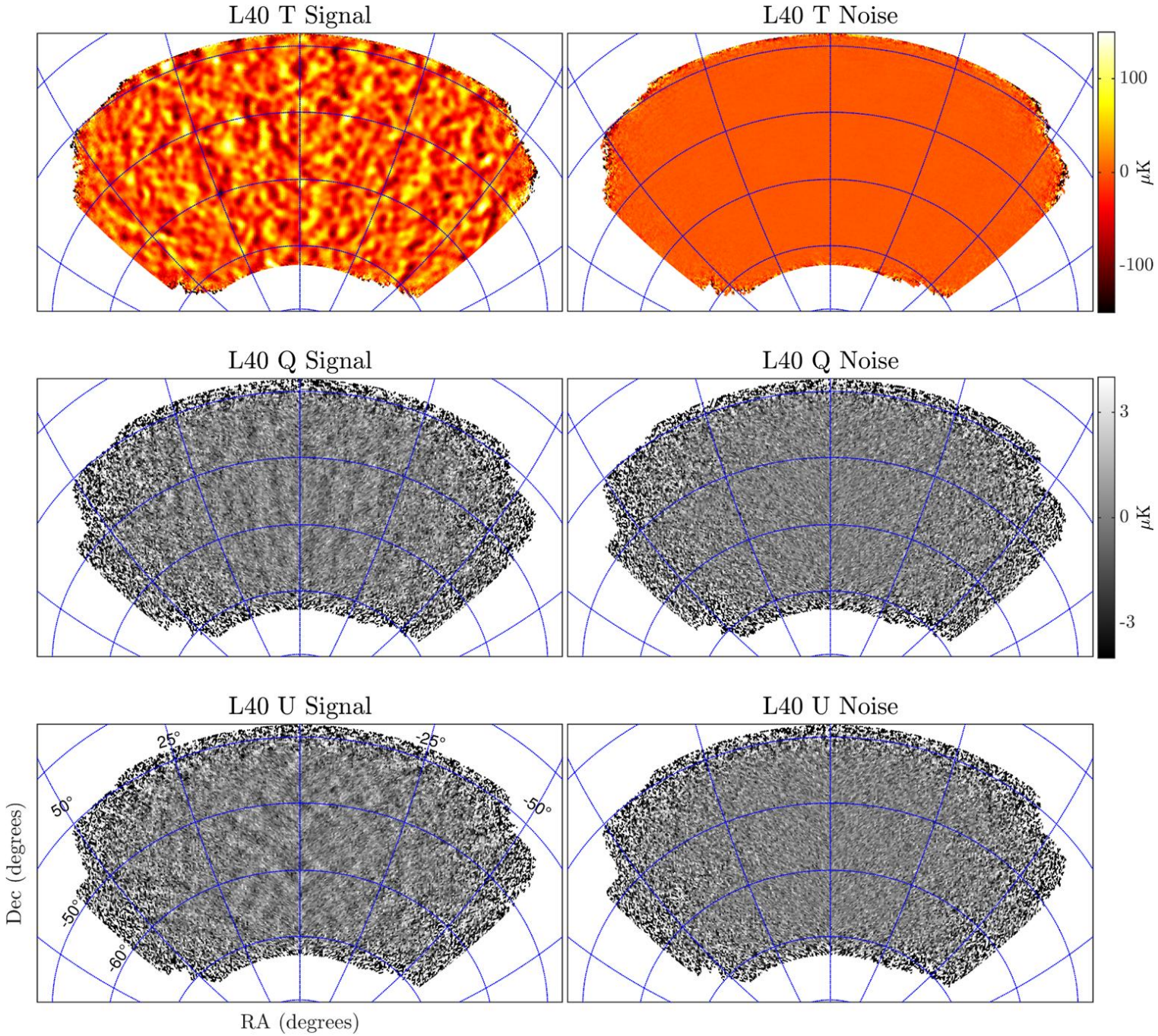
8 years of Keck Array data



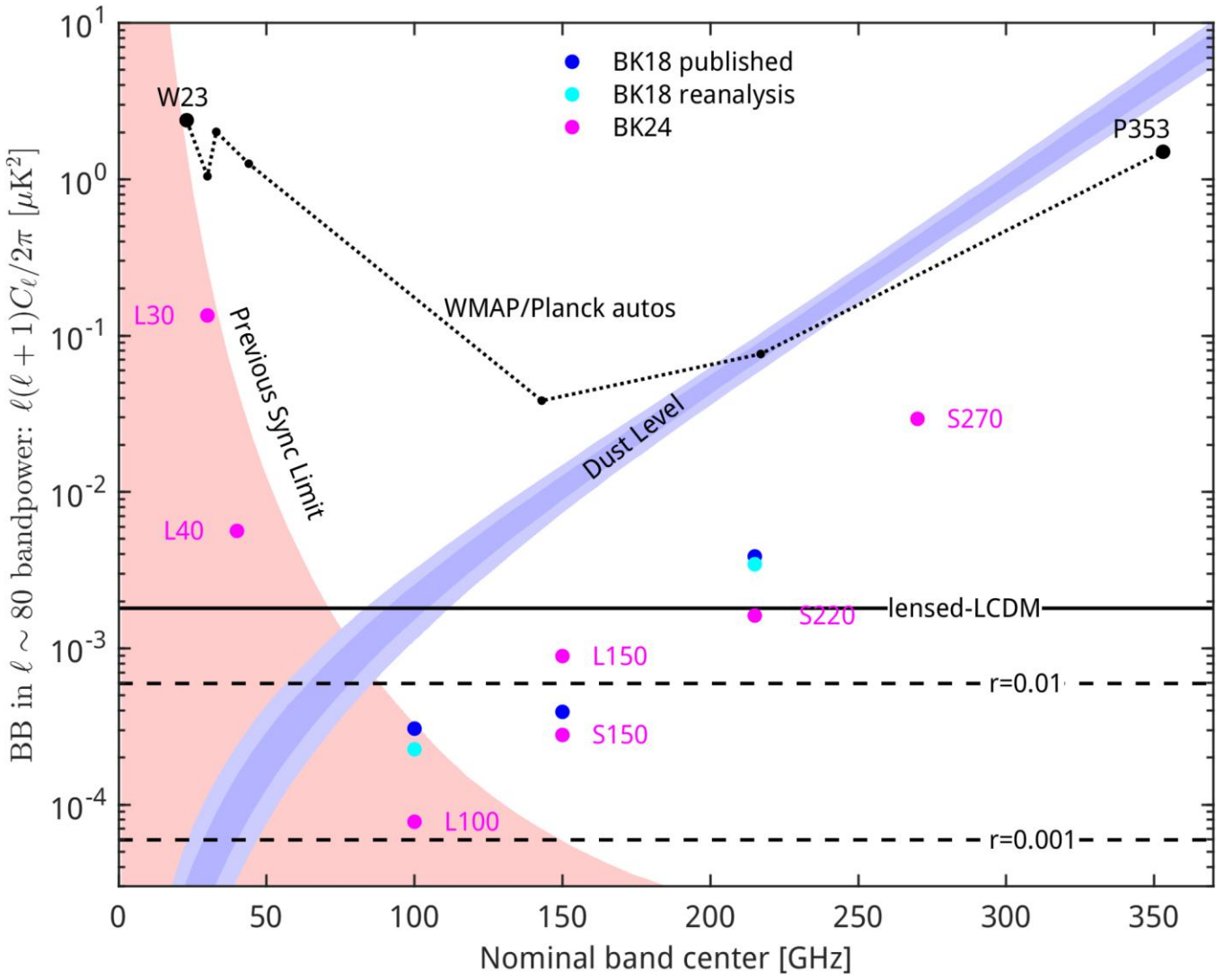
New BICEP/*Keck* Low-ℓ B-mode Data

40 GHz Maps

5 years of BICEP Array data



Since the Last Data Release ("BK18")



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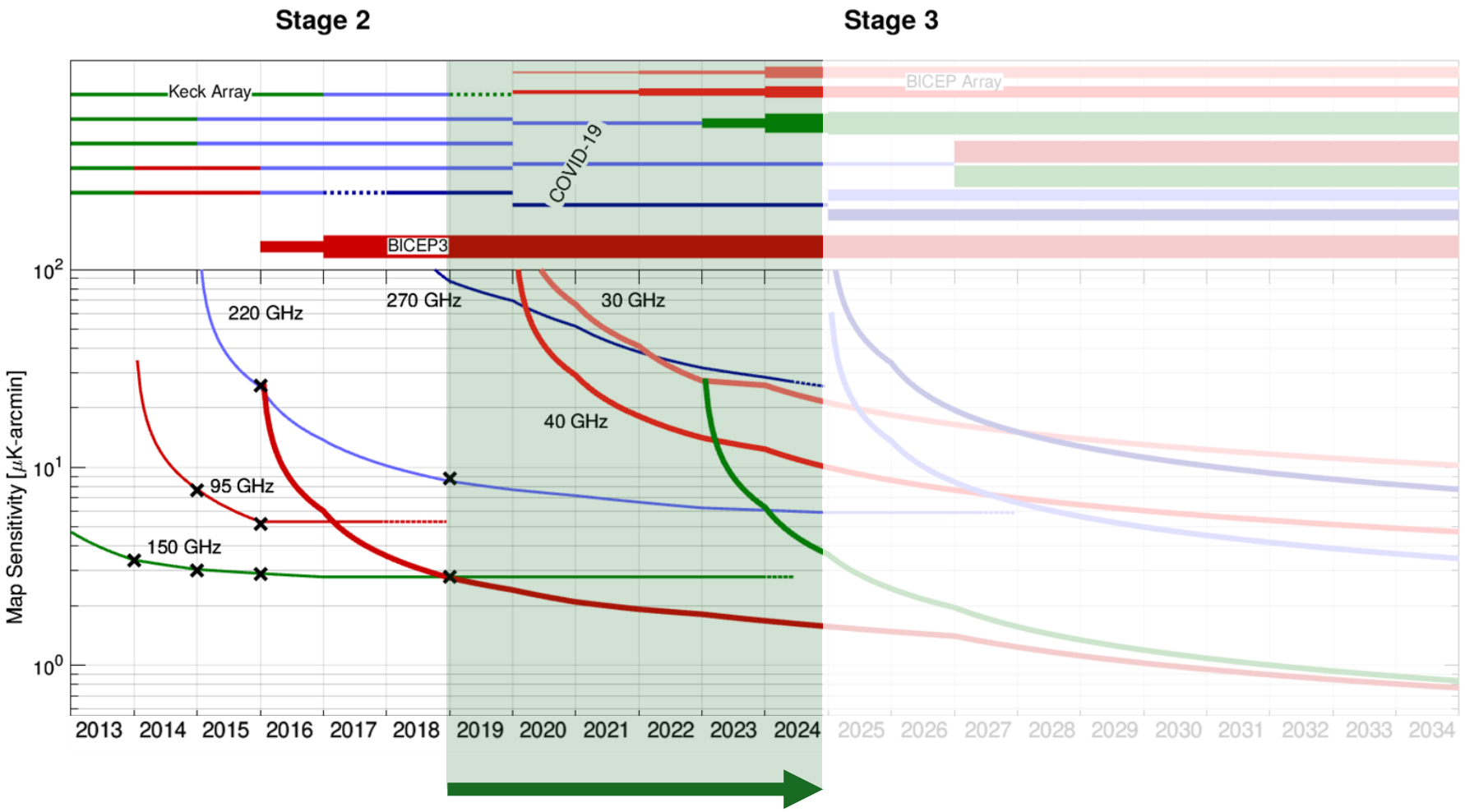
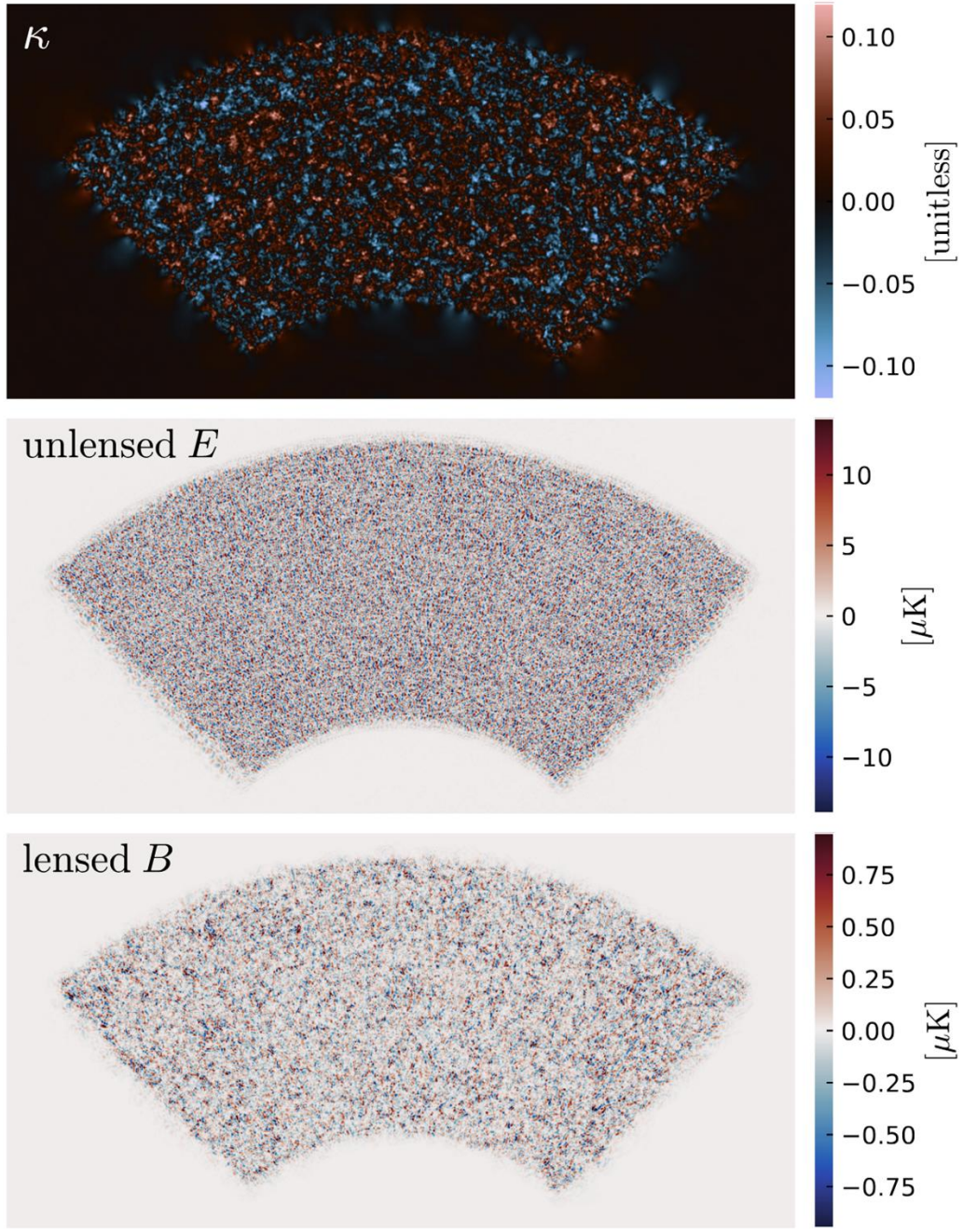


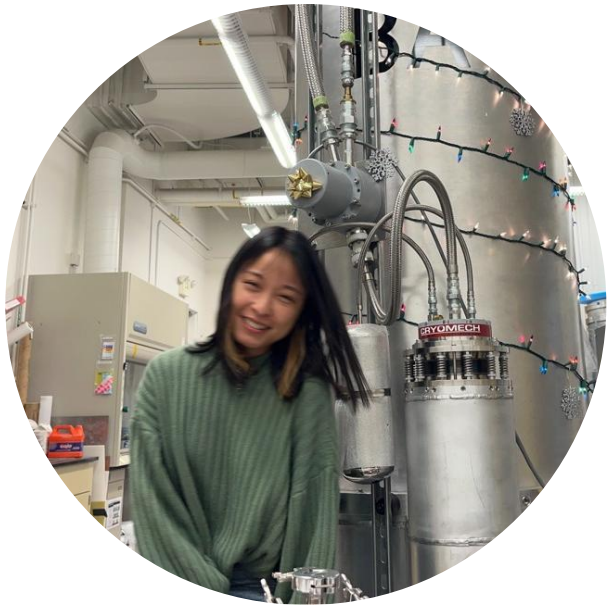
- Significantly more data at 95, 150, 220 GHz
- Expanded frequency coverage: 30, 40, and 270 GHz
- Significant improvements to data processing and analysis pipeline



F. Ge et al (2025)

SPT-3G Delensing

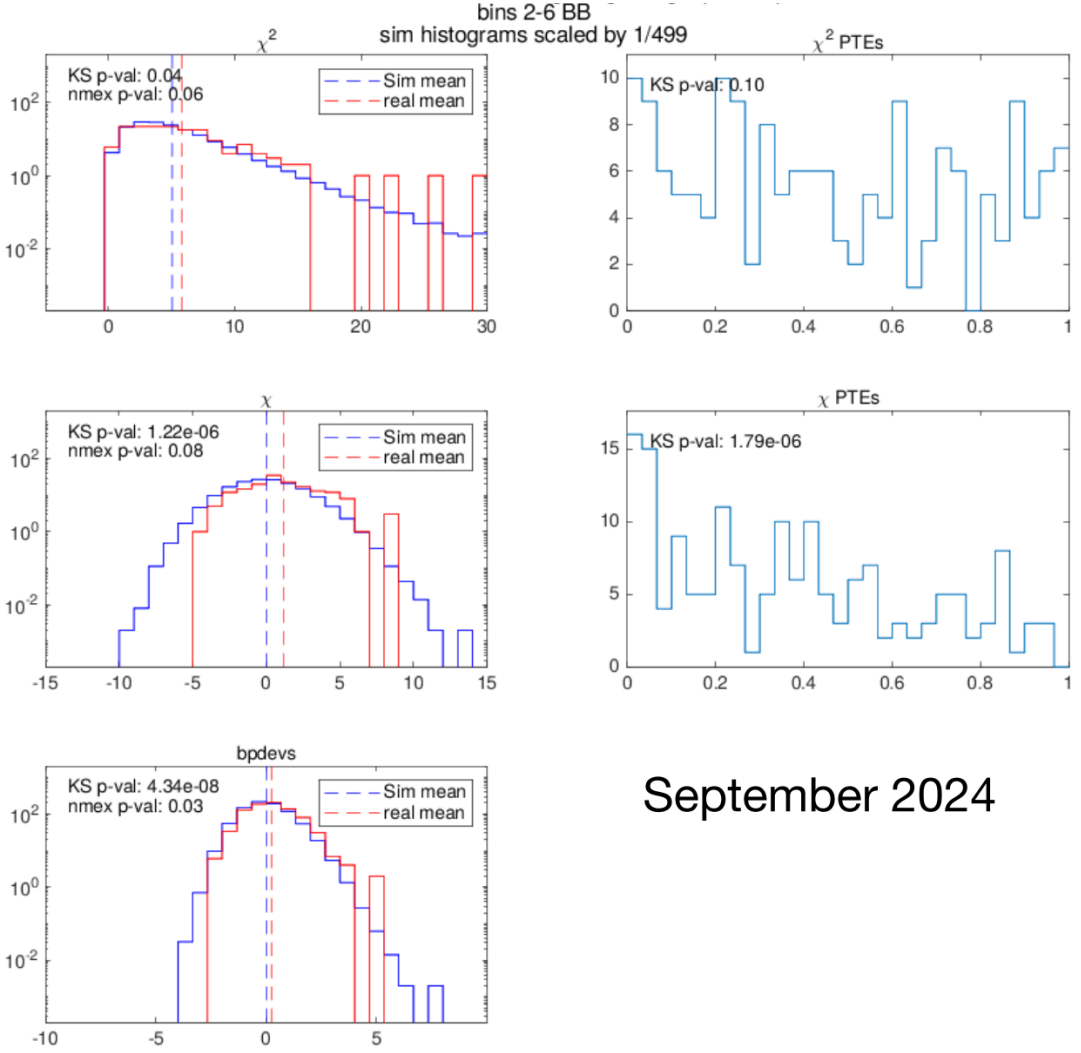
stay tuned for Yuka's presentation at 11:50



- SPT-3G is already producing high-fidelity maps of CMB lensing
  - 38σ measurement of lensing spectrum from SPT-3G polarization only!
  - Upcoming SPT-3G lensing measurement using both temperature and polarization will have even higher measurement significance (Omori, Wu, SPT-3G collaboration, in prep.)
  - Lensing reconstruction can be improved by combining with other datasets (e.g. combining CMB κ with CIB, LSS tracers)
- Delensing successfully demonstrated on SPT-pol + BK14 data (BK+SPT collaborations et al. 2021 [led by W.L.K. Wu])

Upcoming SPO results: “BK24”

- **Blind analysis**: We do not examine non-jack spectra until all the null tests pass
- **Jackknife process**:
  - split data along axes to exaggerate potential contamination, power spectrum of difference maps.
  - Compare χ^2, χ , PTEs of jackknife band powers against lensed-LCDM+noise+dust simulations
- Have identified subtle effects with null tests as maps get deeper. Clear improvements with mitigation. For example:
  - In BK18, a BICEP3 detector module with excess beam ghosting
  - In BK24, time-evolving scan-sync pickup while sun is up
  - In BK24, detector inner/perimeter jack fail, traced to readout crosstalk



September 2024

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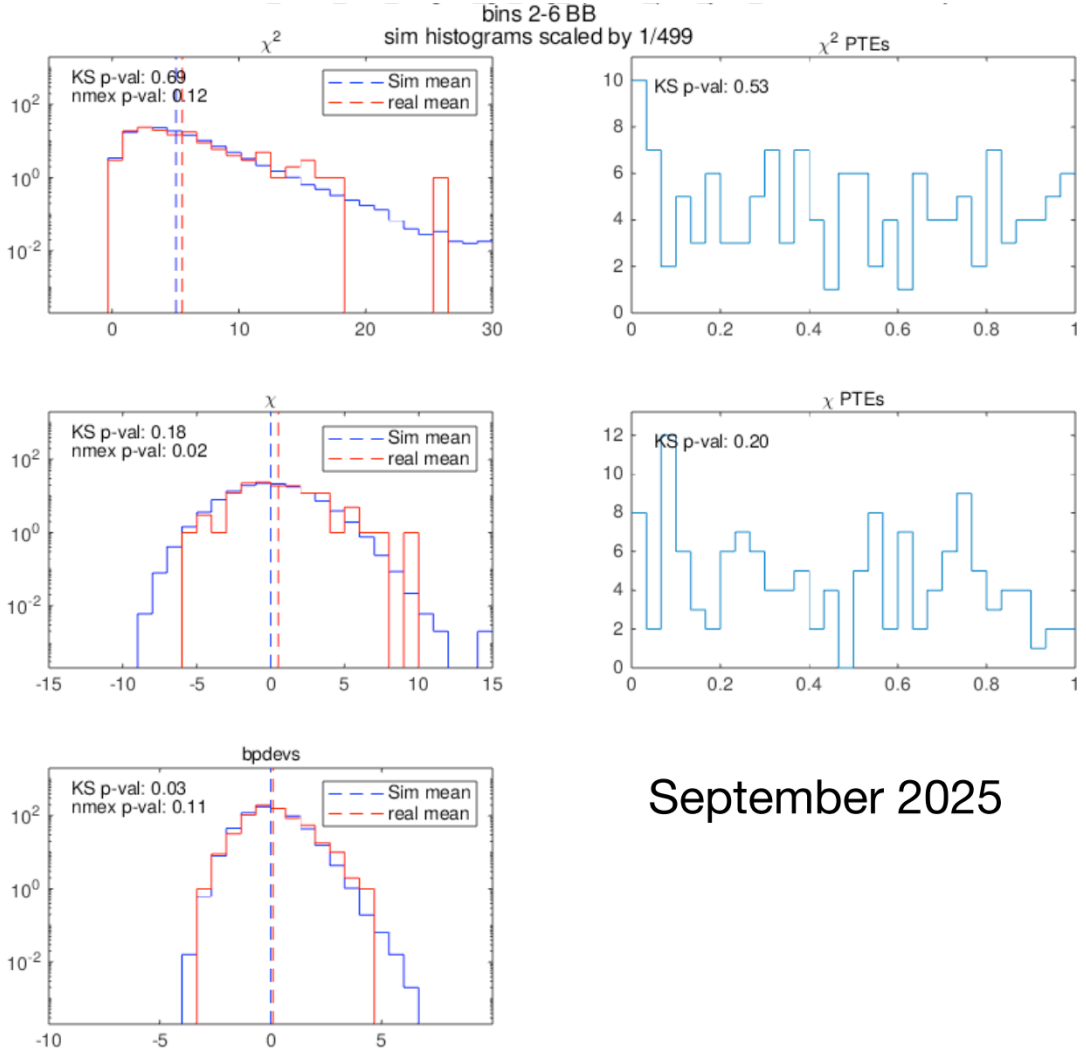
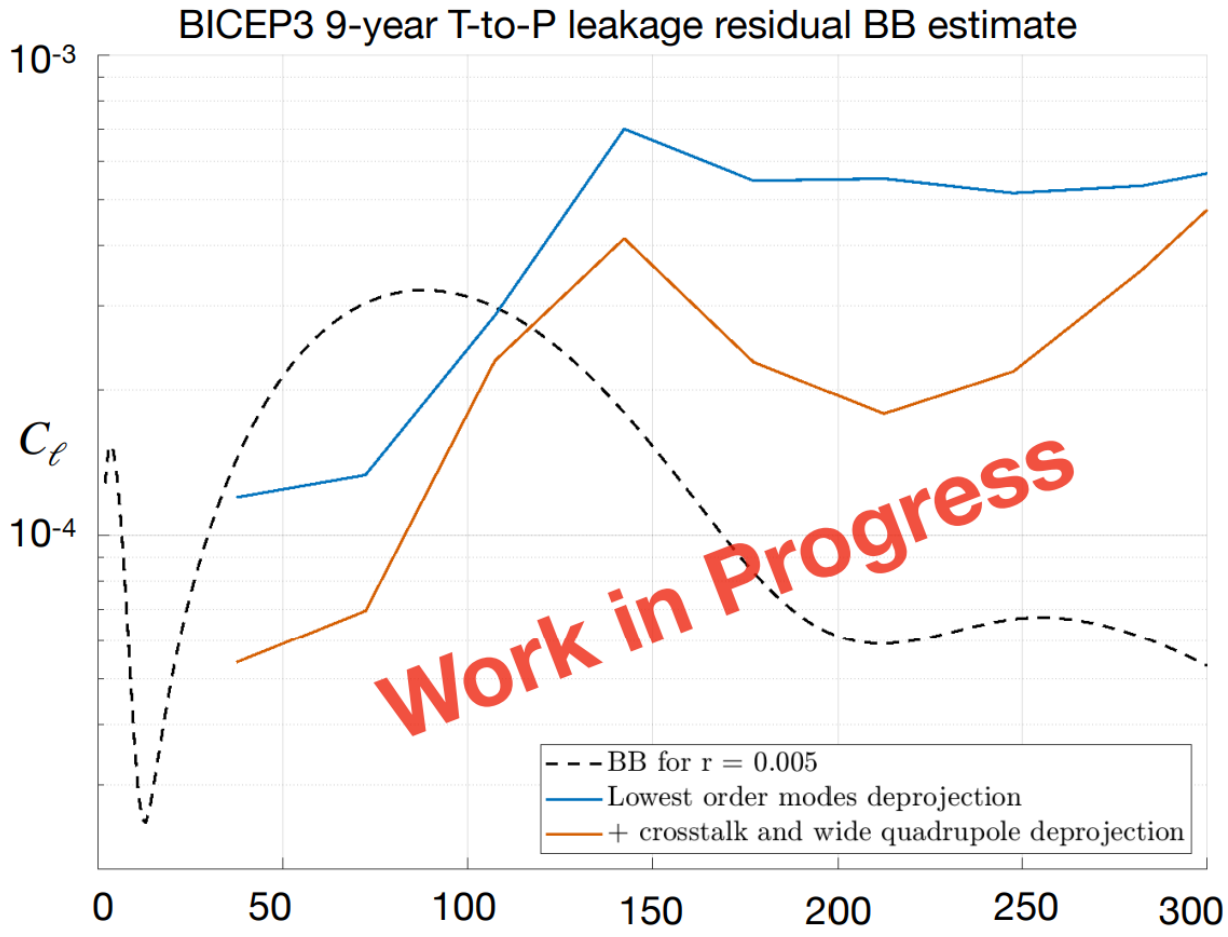
  - In BK24, time-evolving scan-sync pickup while sun is up
  - In BK24, detector inner/perimeter jack fail, traced to readout crosstalk



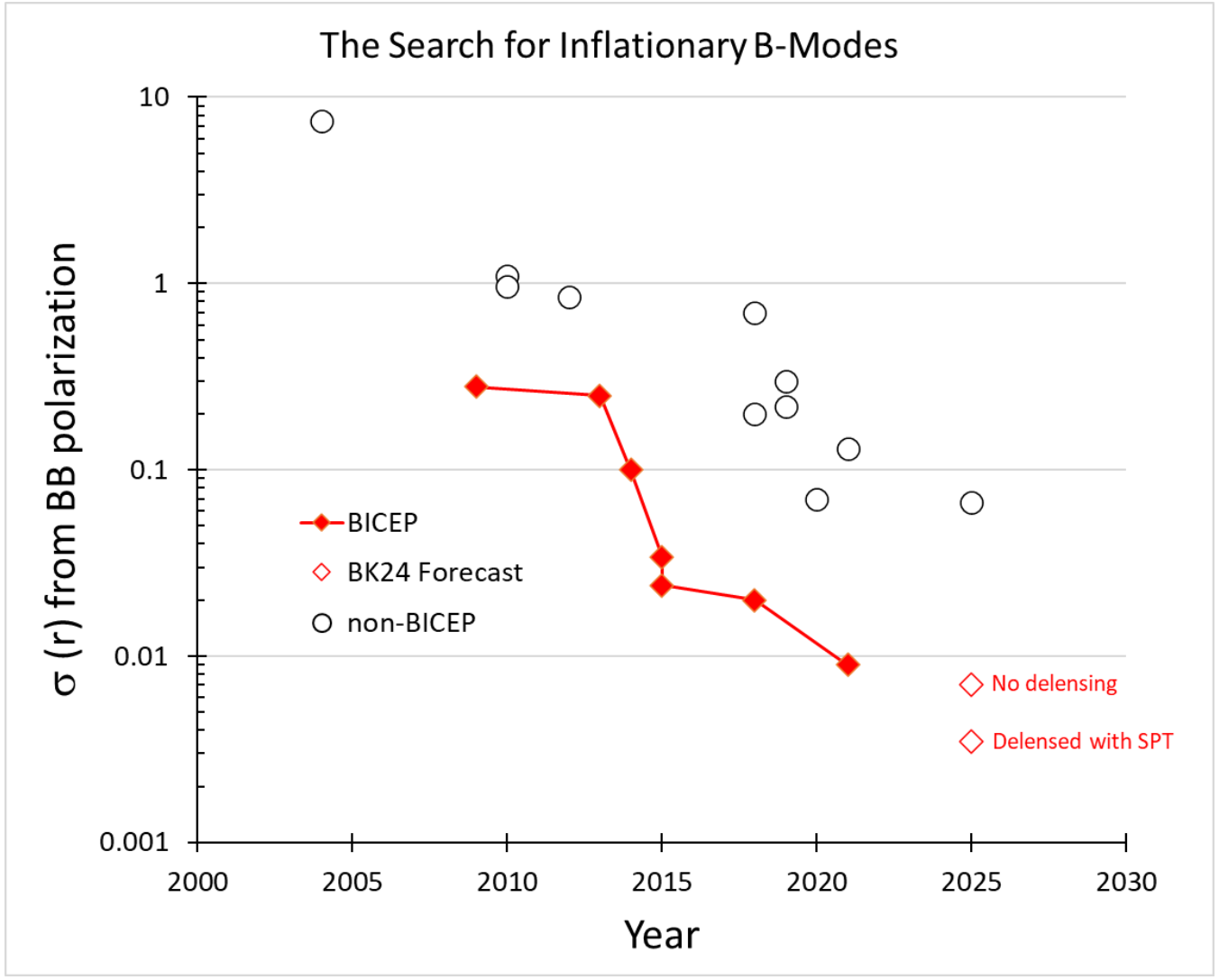
September 2025

Systematics Estimation & Mitigation

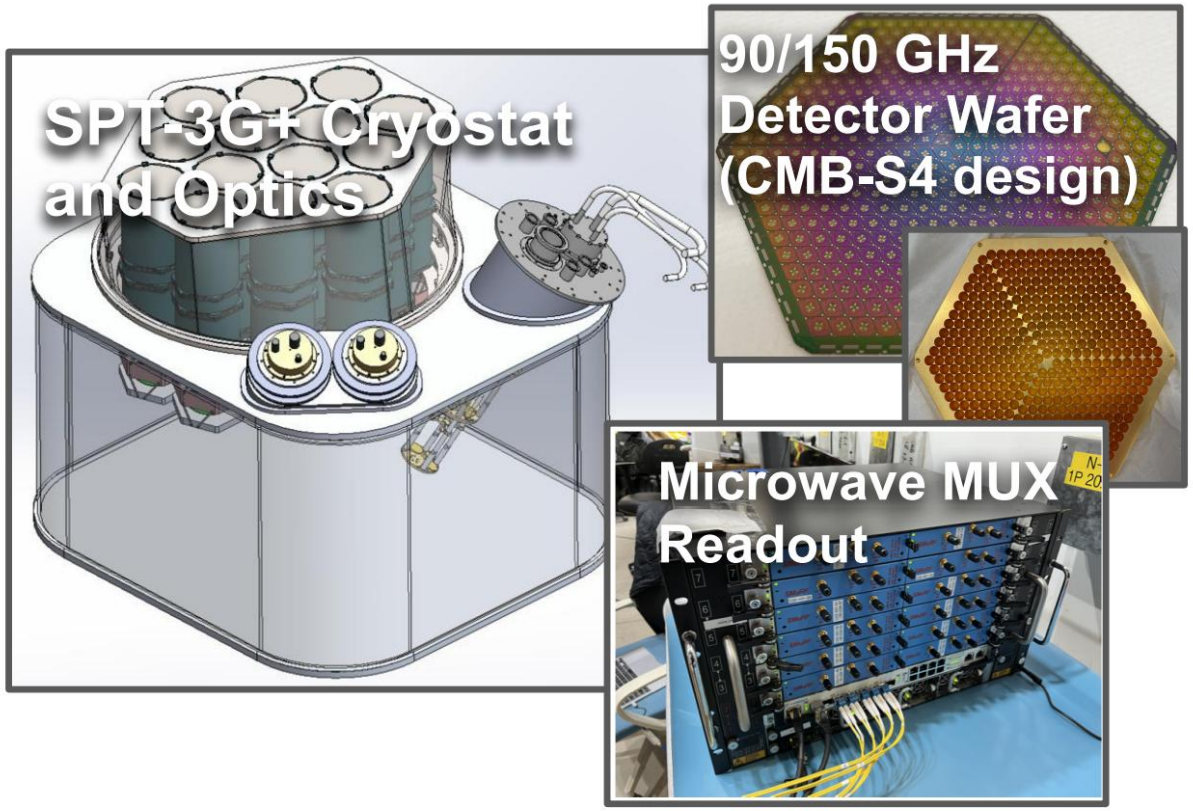
Systematics	Bias on r (upper limit) $\times 10^{-3}$
Residual main beam T→P leakage (including readout crosstalk)	< 2 (WIP)
Bandpass	< 0.9
Polarization angles	< 0.05
Cross-polar response	< 0.03
Time constants	WIP
Thermal stability	WIP



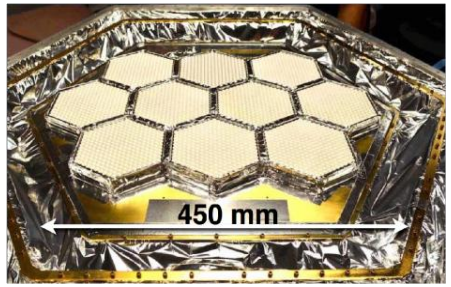
Upcoming SPO results: “BK24”



The Future of SPO: SPT-3G+ Camera

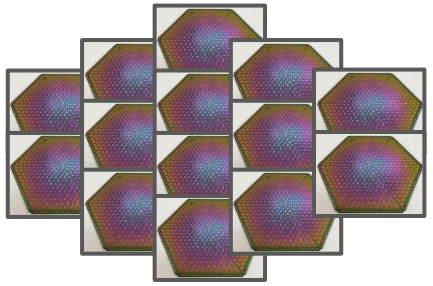


2017: SPT-3G
~16,200 detectors
100,150,220 GHz
+Polarization



SPT-3G has 7x larger mapping speed relative to Planck!

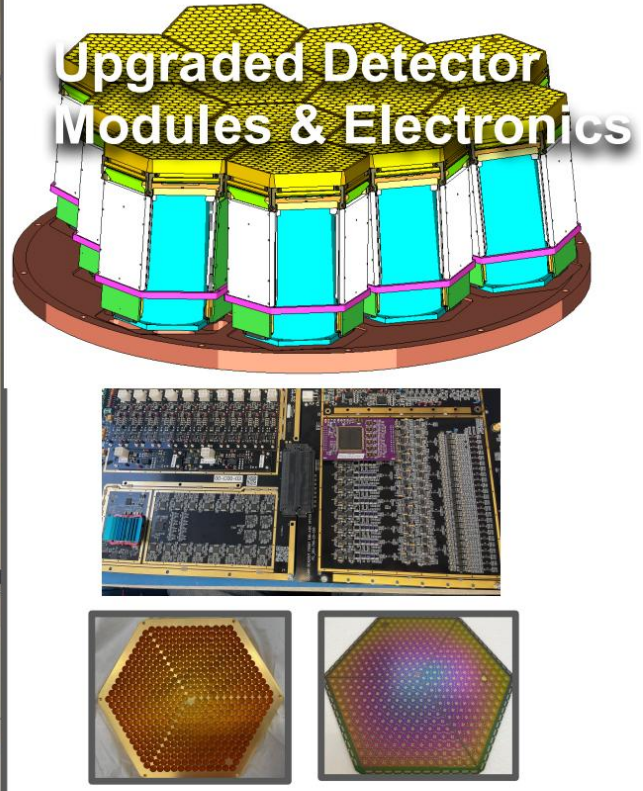
2029: SPT-3G+
~24,000 detectors
100,150 GHz
+Polarization

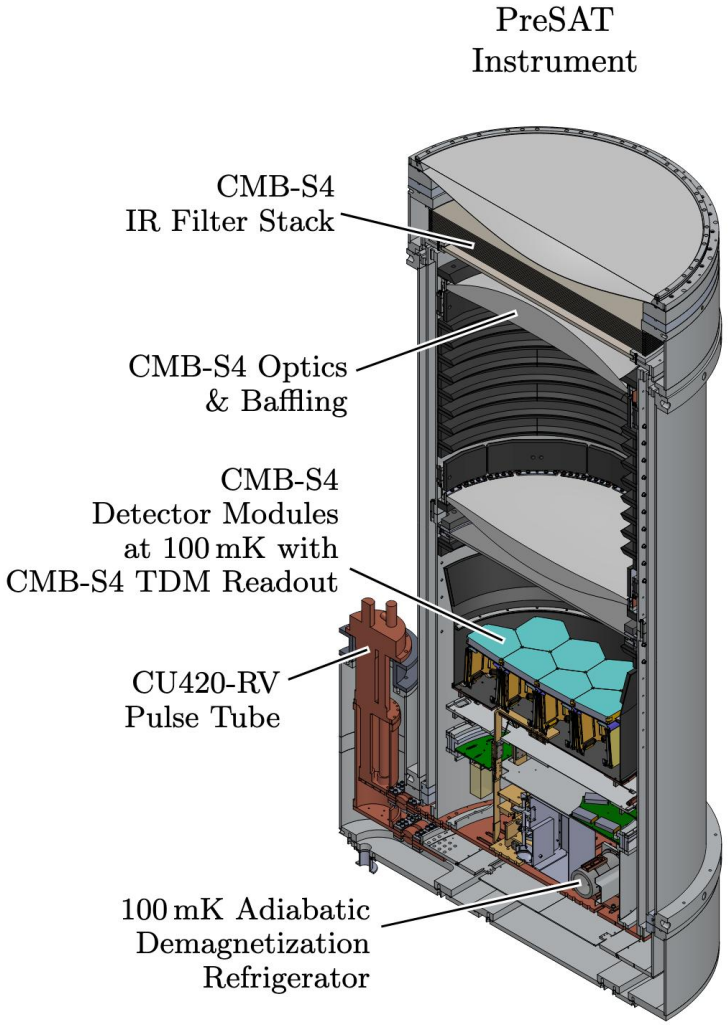


SPT-3G+ will have 50x larger mapping speed relative to Planck!

Slide adapted from B. Benson (U. Chicago)

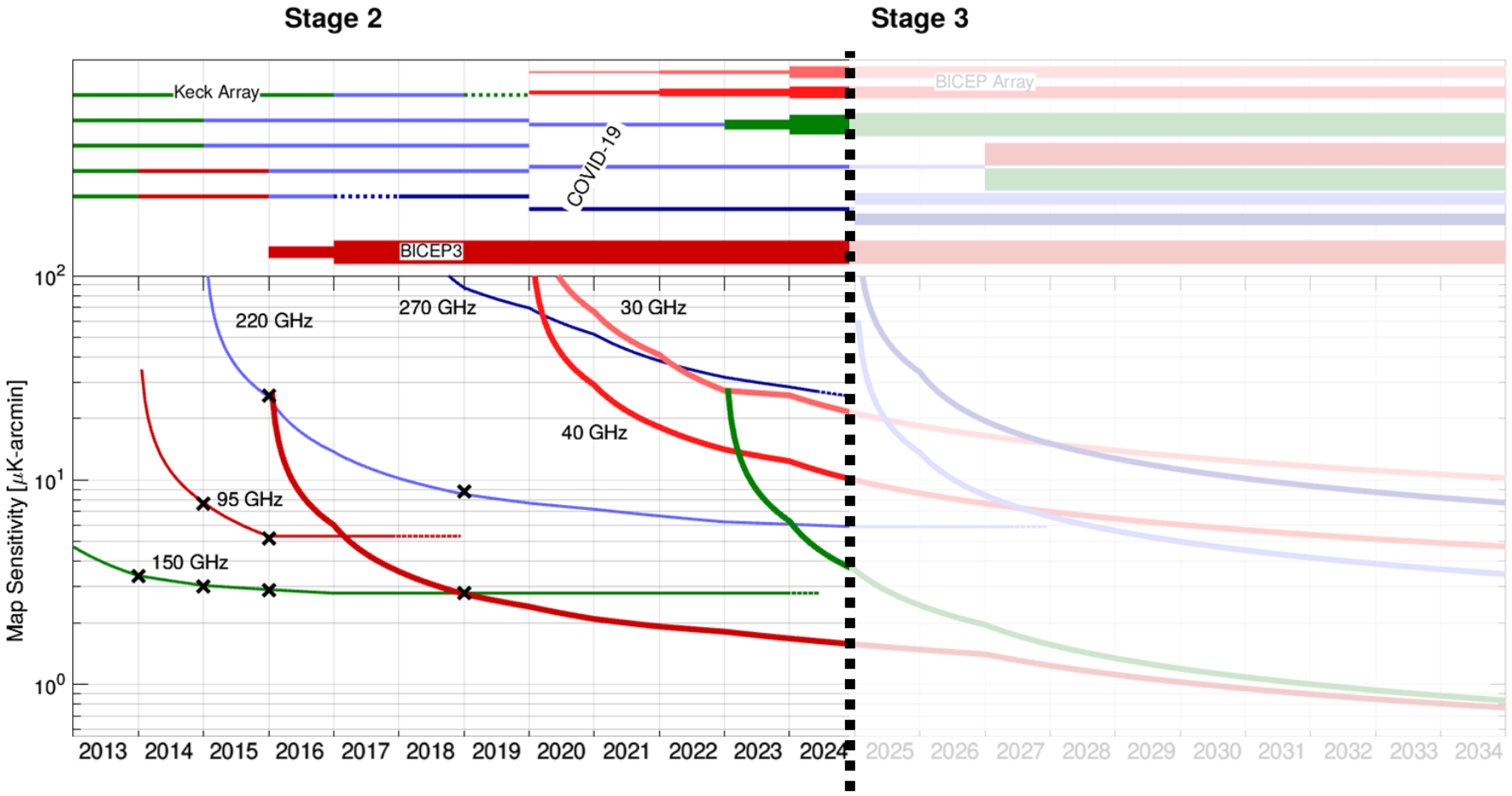
The Future of SPO: BICEP Array Receiver 4



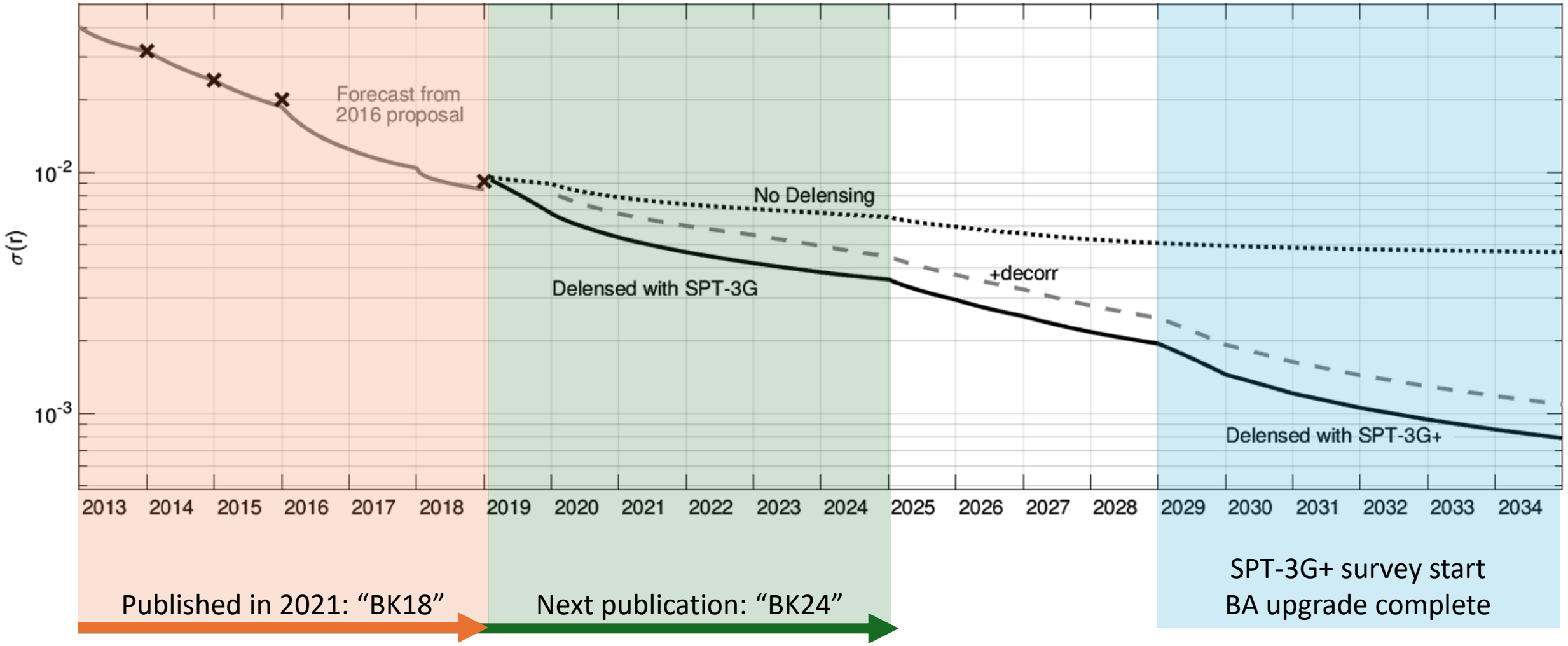


M. Petroff et al. (2024)

The Future of SPO



SPO Forecasts on *r*: σ(r) ≈ 0.001 by 2034

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