# CONSTRAINING INFLATIONARY POLARIZATION FROM THE GROUND AND SPACE

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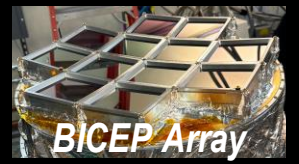
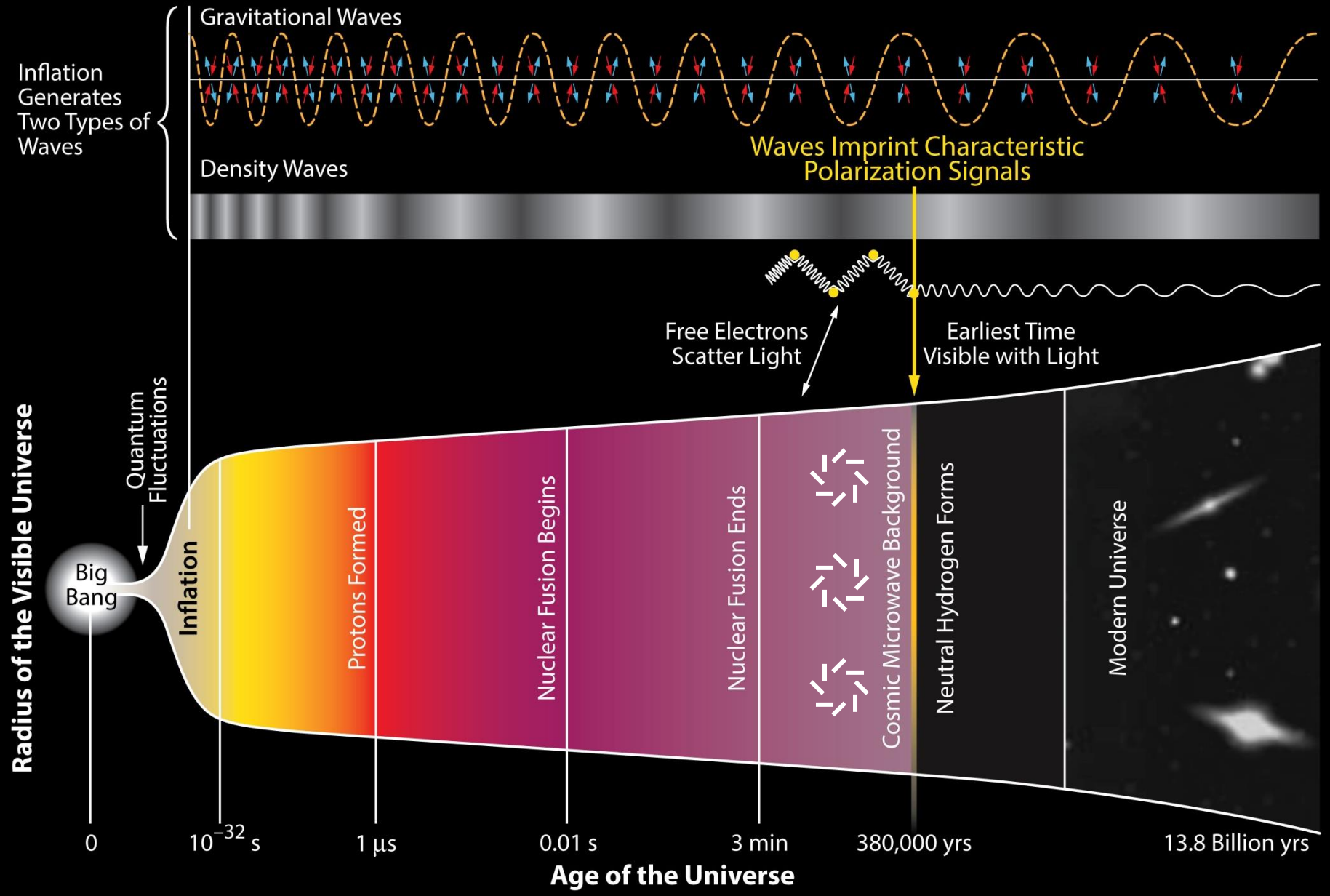
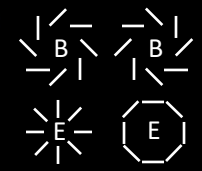
CMB@60
Turin, Italy
28-30 May 2025

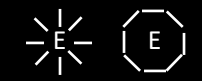
# SEARCHING FOR INFLATIONARY B-MODES




B & E




E only

CMB polarization pattern

Inflation may produce a primordial background of gravitational waves

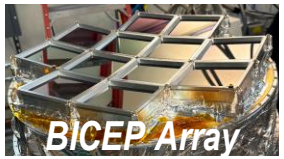
→ Amplitude (r) depends on the energy scale of inflation

→ Probed by sensitive CMB B-mode polarization measurements

# SOUTH POLE:  THE CLOSET THING TO SPACE ON THE EARTH

High and dry site
1 diurnal cycle per year: low-noise and stable atmosphere
Featureless horizon
24/7 observing access to deep sky regions
Excellent logistics for power, data, & cargo

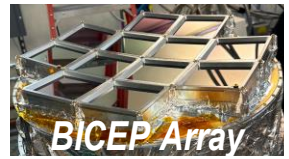
# THE SOUTH POLE OBSERVATORY

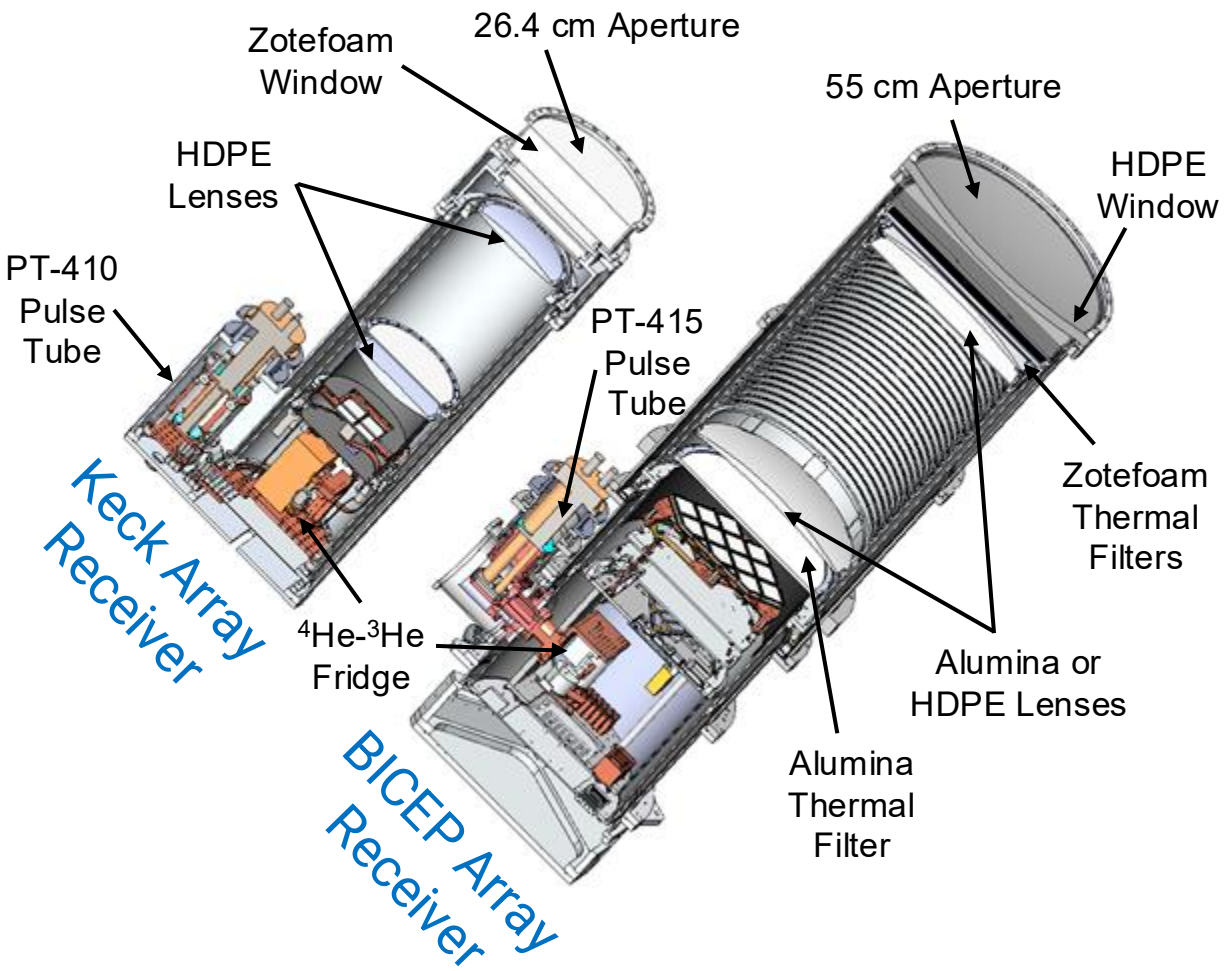




Observatories use existing telescope systems and remain state of the art by upgrading focal planes!

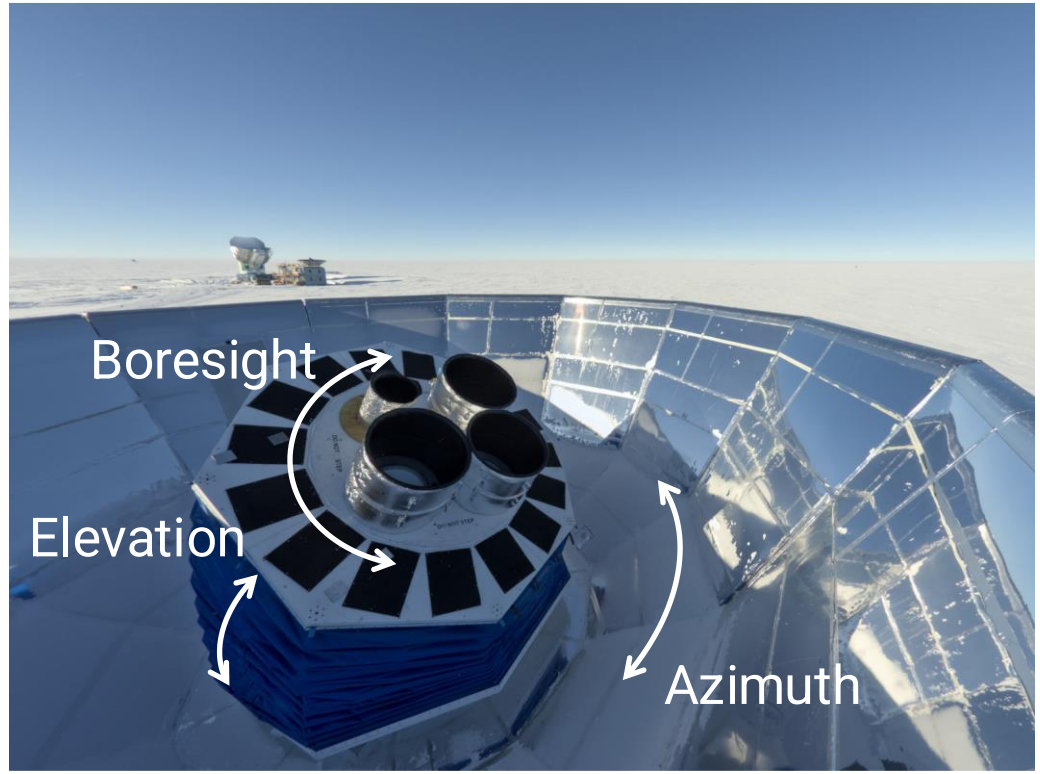
# BICEP SMALL APERTURE CONCEPT



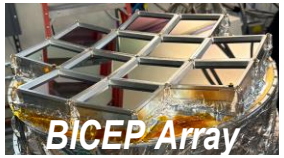

- Small aperture, large field of view
- Refracting 4K optics with low sidelobes
- 55-cm design increases mapping speed by ~15x

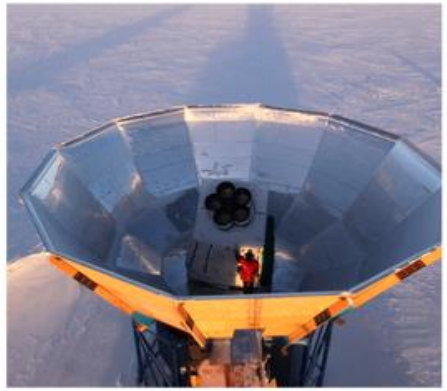
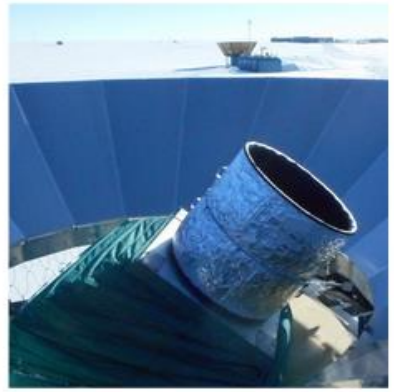
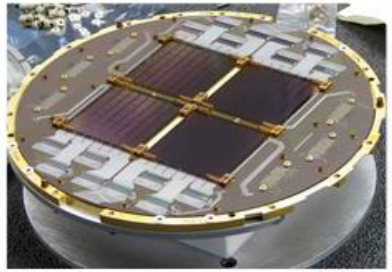
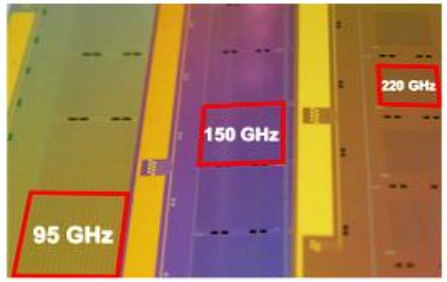
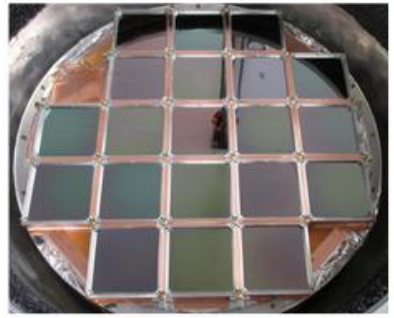
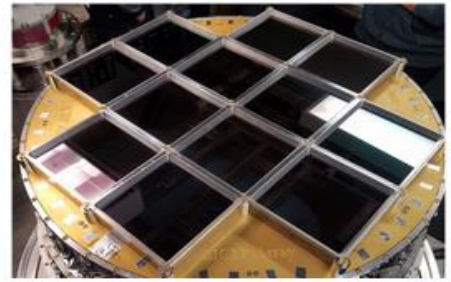
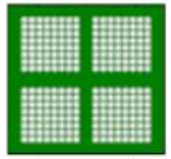
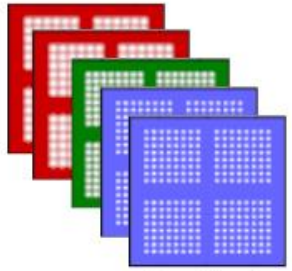
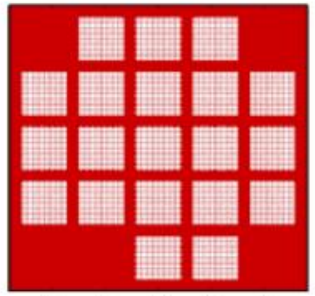
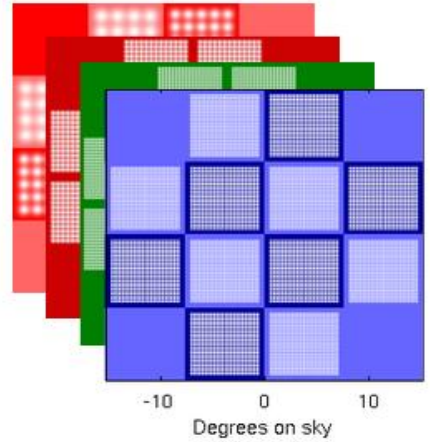
## BICEP Array Telescope Mount



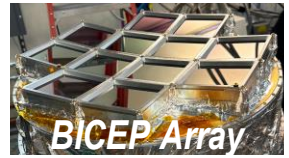

- Small aperture enables boresight rotation
- Co-rotating absorbing forebaffle
- Reflecting ground shield

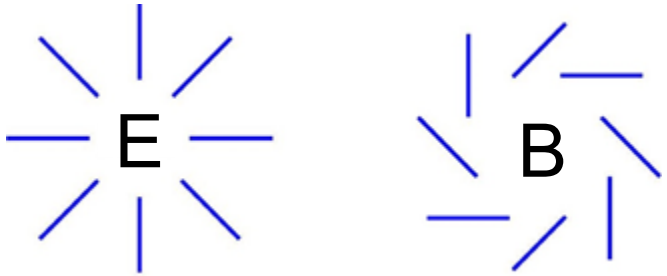
# EXPERIMENTAL PHASES SINCE 2010




| | BICEP2 (2010-2012) | Keck Array (2012-2019) | BICEP3 (2016-) | BICEP Array (2020-) |
|---|---|---|---|---|
| Telescope and Mount |  |  |  |  |
| Focal Plane |  |  |  |  |
| Beams on Sky |  |  |  |  |

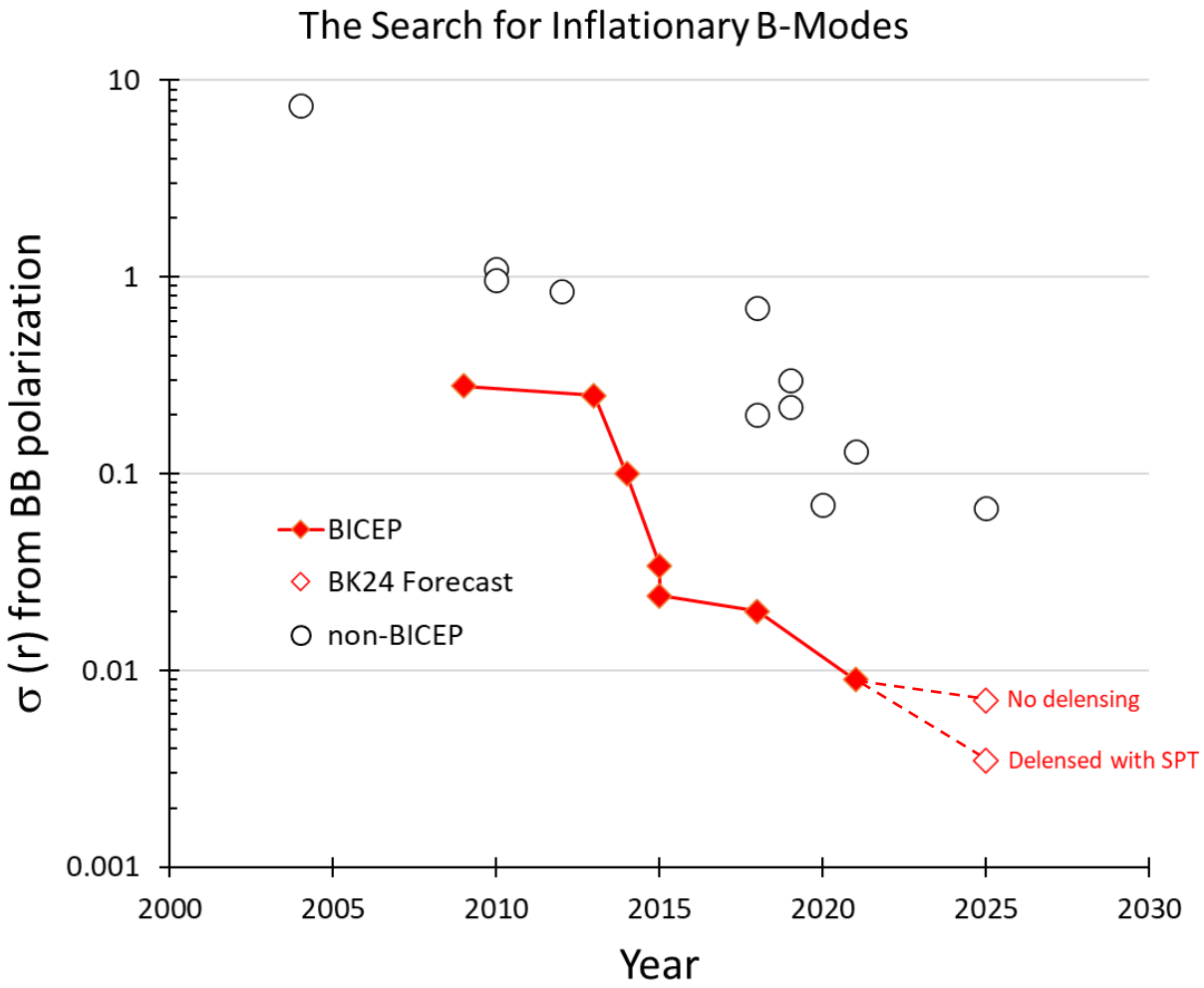
# BICEP-KECK SENSITIVITY PROGRESSION



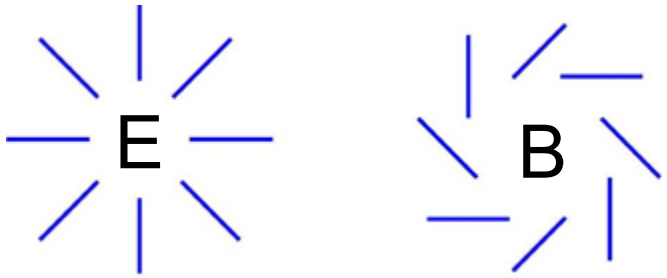




*CMB Polarization Patterns*

*BICEP Array Deployment 2023-4*

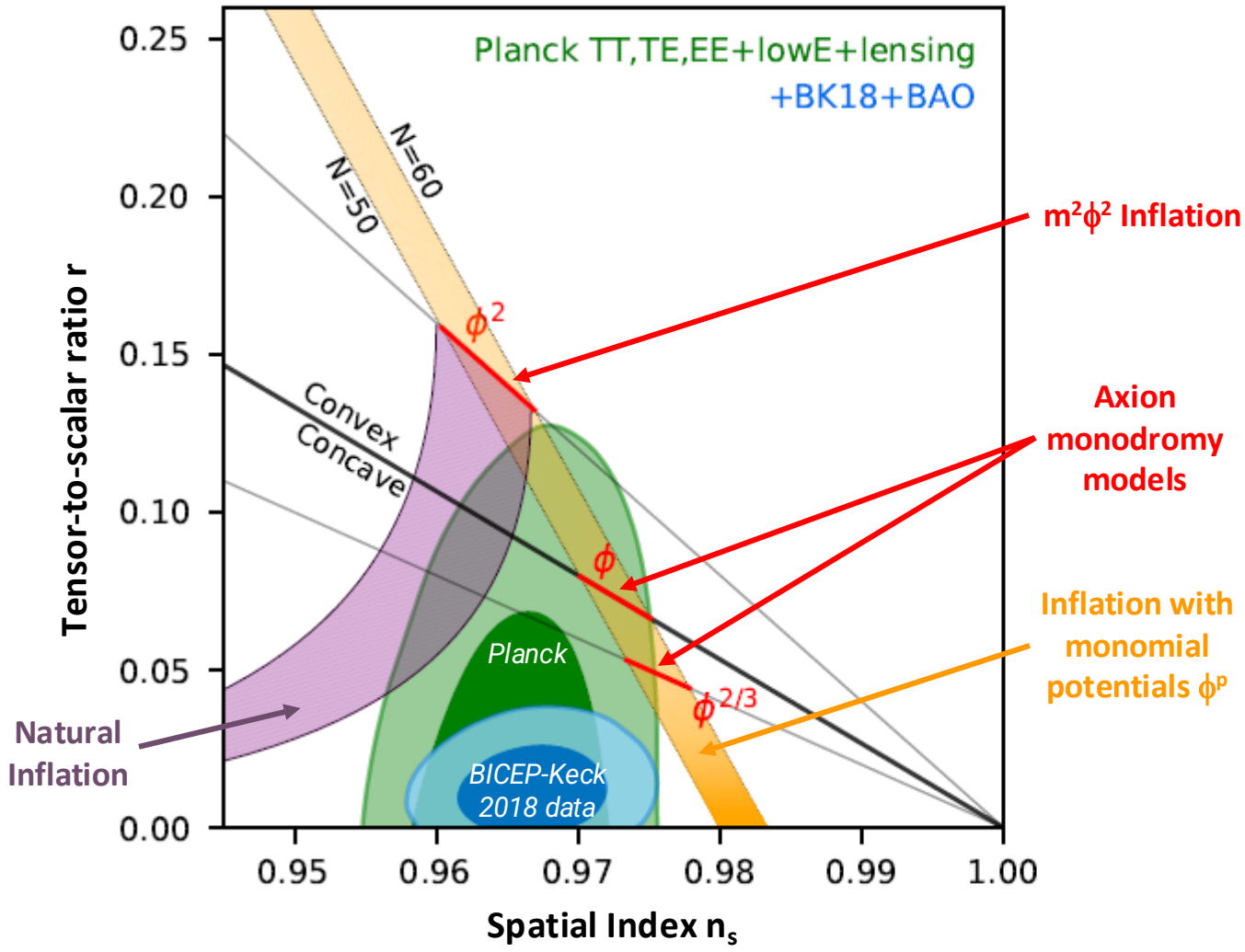


# CMB CONSTRAINTS ON INFLATION FROM BK18

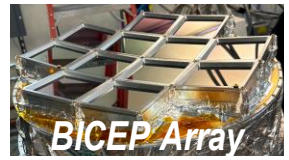

*CMB Polarization Patterns*

*BICEP Array Deployment 2023-4*




*GBMF played a key role to getting here by supporting BICEP, South Pole Telescope, and detector technology*

# BK24 LARGE-AREA MAPS



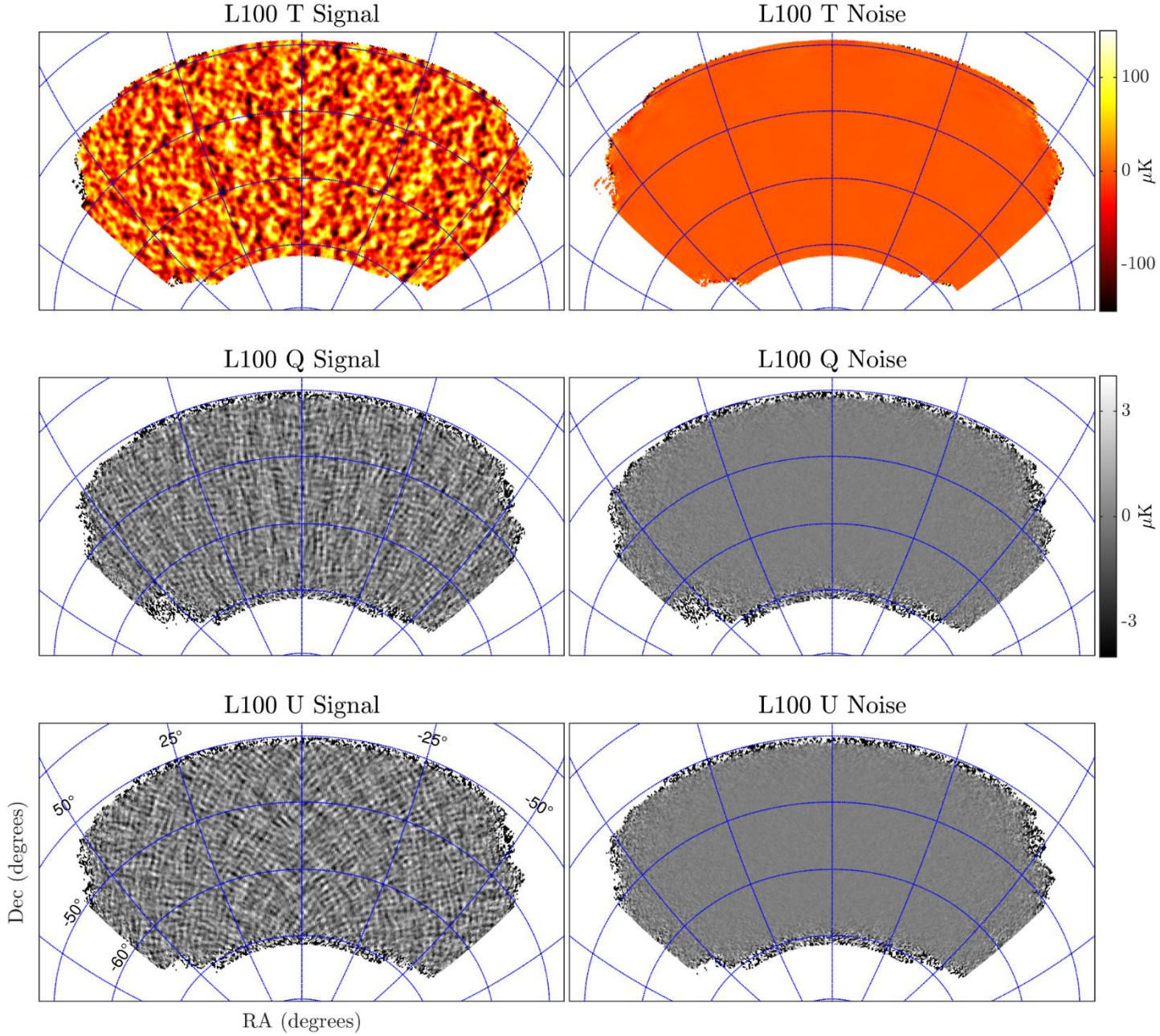

BICEP3 95 GHz
9-year temperature and polarization

Note change in scale bar

Effective polarized depth
**1.65 $\mu$K-arcmin**

→ Deepest maps of CMB polarization made to date…

although you really can't tell anything from Q&U maps!



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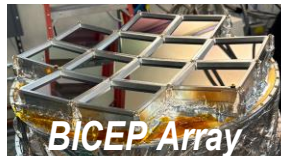
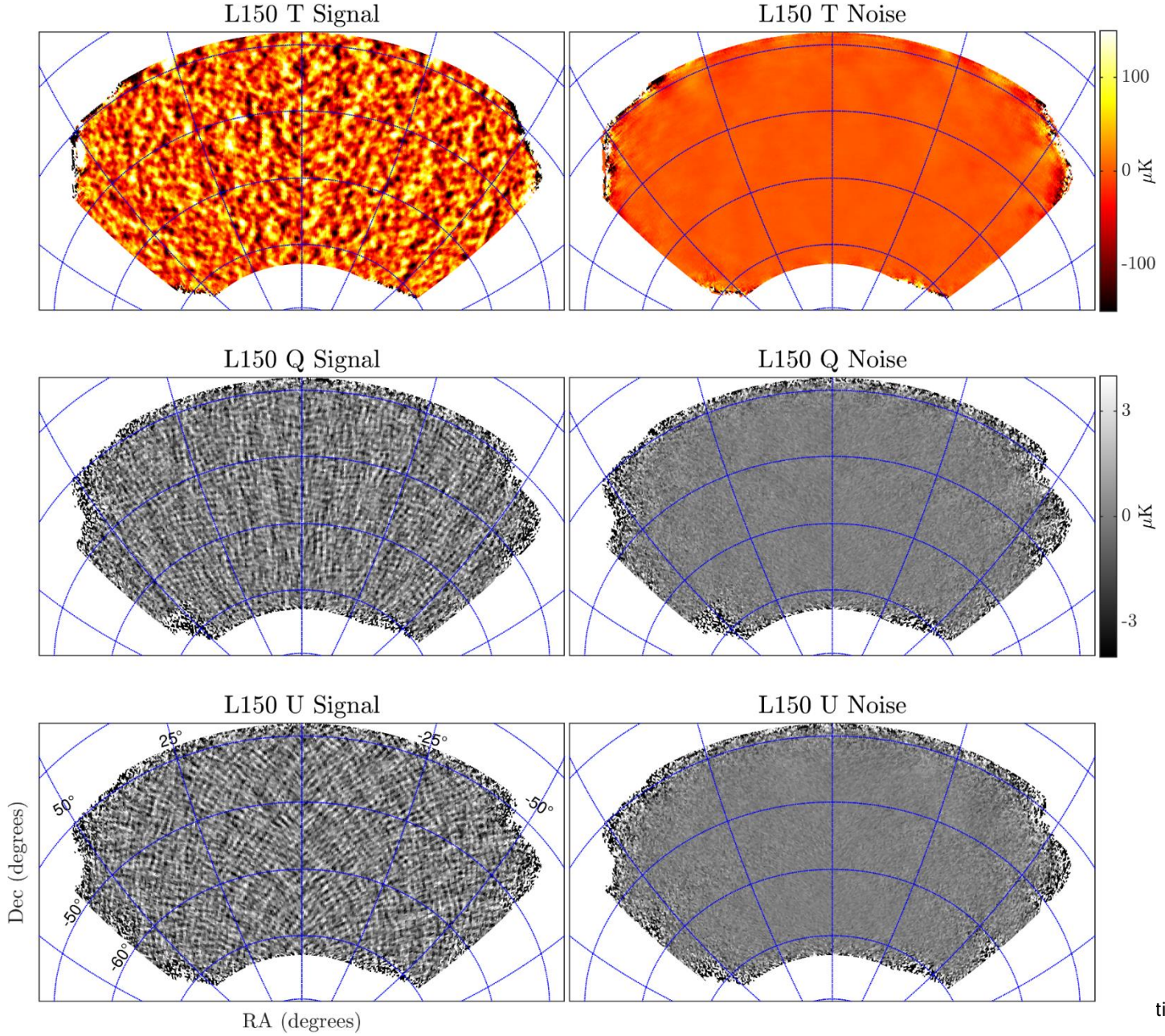



BICEP Array 150 GHz 2-year temperature and polarization

→ Overlaps existing deep 150 GHz maps from BICEP2 & Keck Array in a smaller survey area



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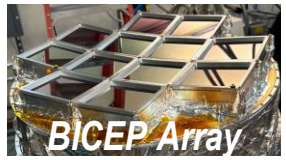
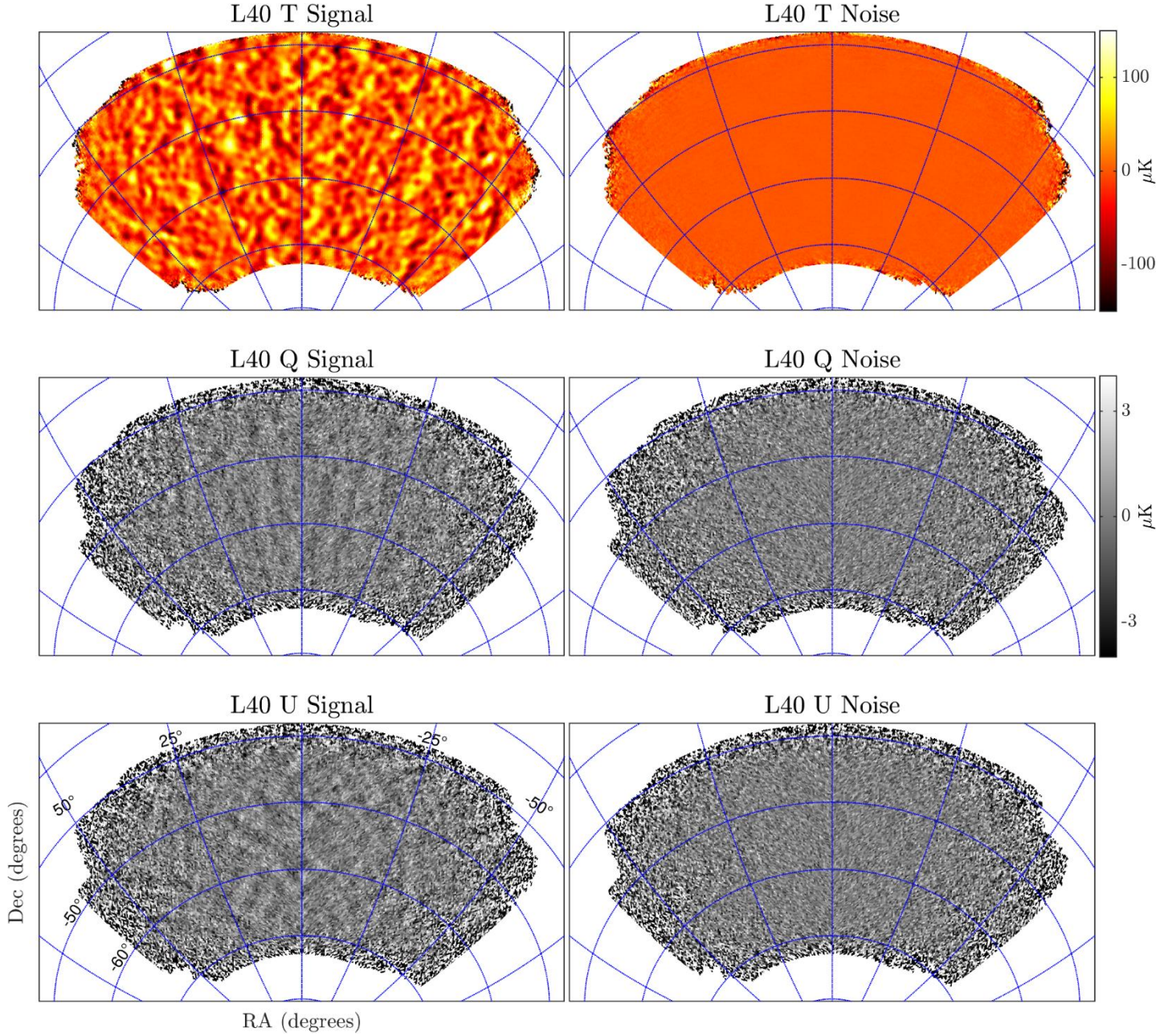
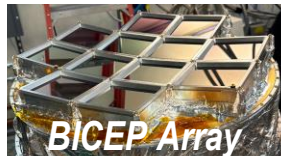



BICEP Array 40 GHz
5-year temperature and polarization

→ New low-frequency bands added for control of synchrotron emission



# BK23 SENSITIVITY

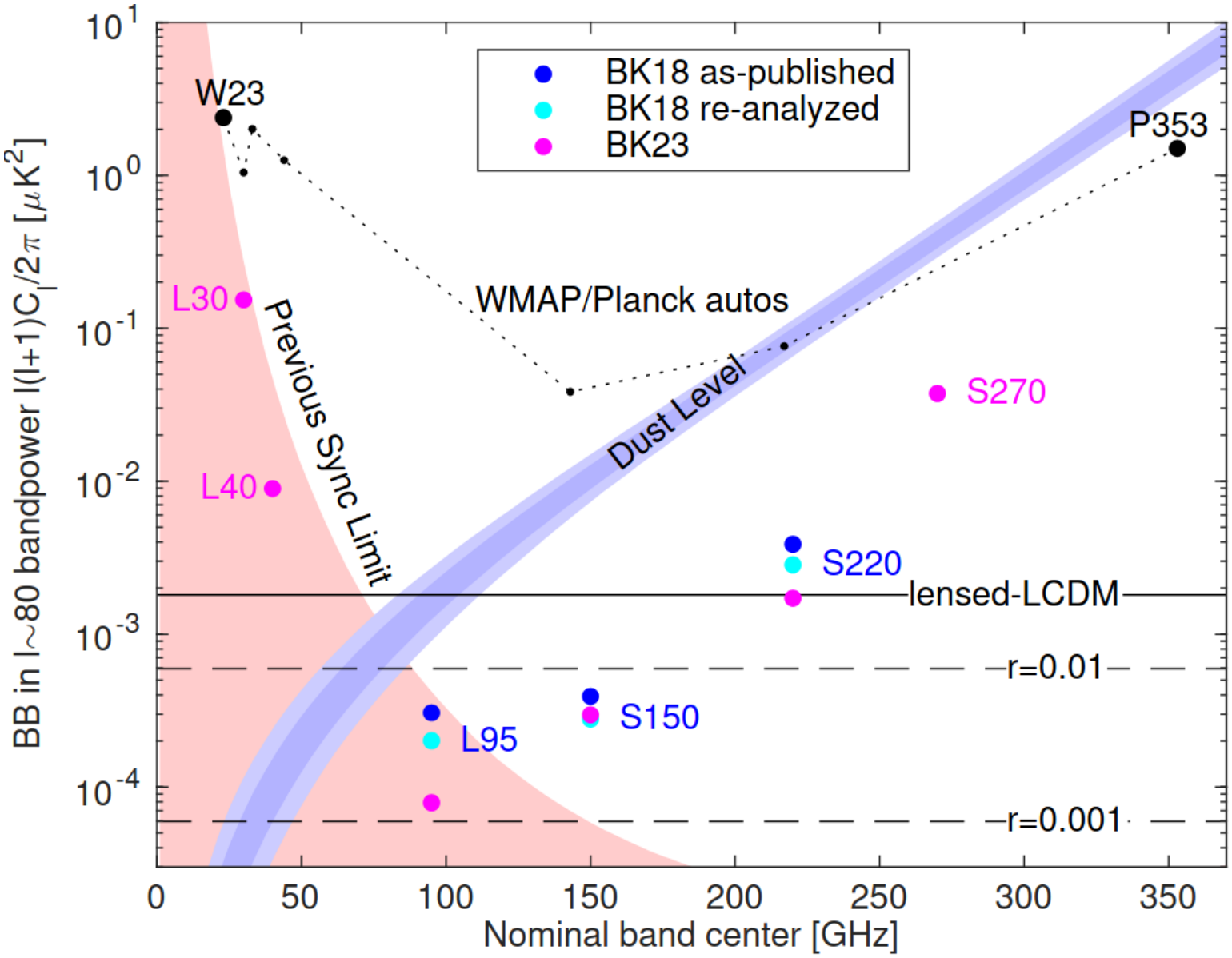



Progression of noise level in science-driving $\ell$~80 bandpower

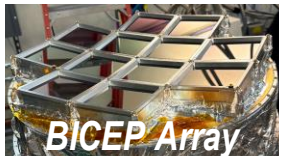
Multi-frequency observations have dramatically improved understanding of foregrounds

BK23 in analysis
- New data at 30, 40 & 270 GHz
- 4x improved sensitivity at 95 GHz

→ Gravitational lensing is now the dominant error source
- Delensing demonstrated using SPT and BK data in 2021 paper



# NSF ANNOUNCEMENT MAY 2024




## CMB-S4 and CMB Program

Importance of CMB science was highlighted in both Astro2020 and P5

CMB-S4 ranked #2 (tied) in Astro2020, #1 for new construction in P5

**After extensive analysis, the NSF has made the decision not to move the CMB-S4 project in its current form into the NSF Major Facility Design Stage at this time.**

The agency **must prioritize the recapitalization of critical infrastructure** at the South Pole so that the groundbreaking research it enables can continue to thrive. The South Pole Master Plan will outline proposed infrastructure investments and will be placed in the federal register and open for public comment later this month. NSF is committed to cosmic microwave background science and will continue to support current CMB activities at the South Pole and in Chile.

NSF

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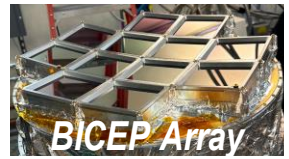
# UPGRADE ELEMENTS FOR SOUTH POLE OBSERVATORY



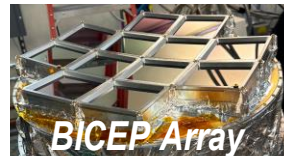


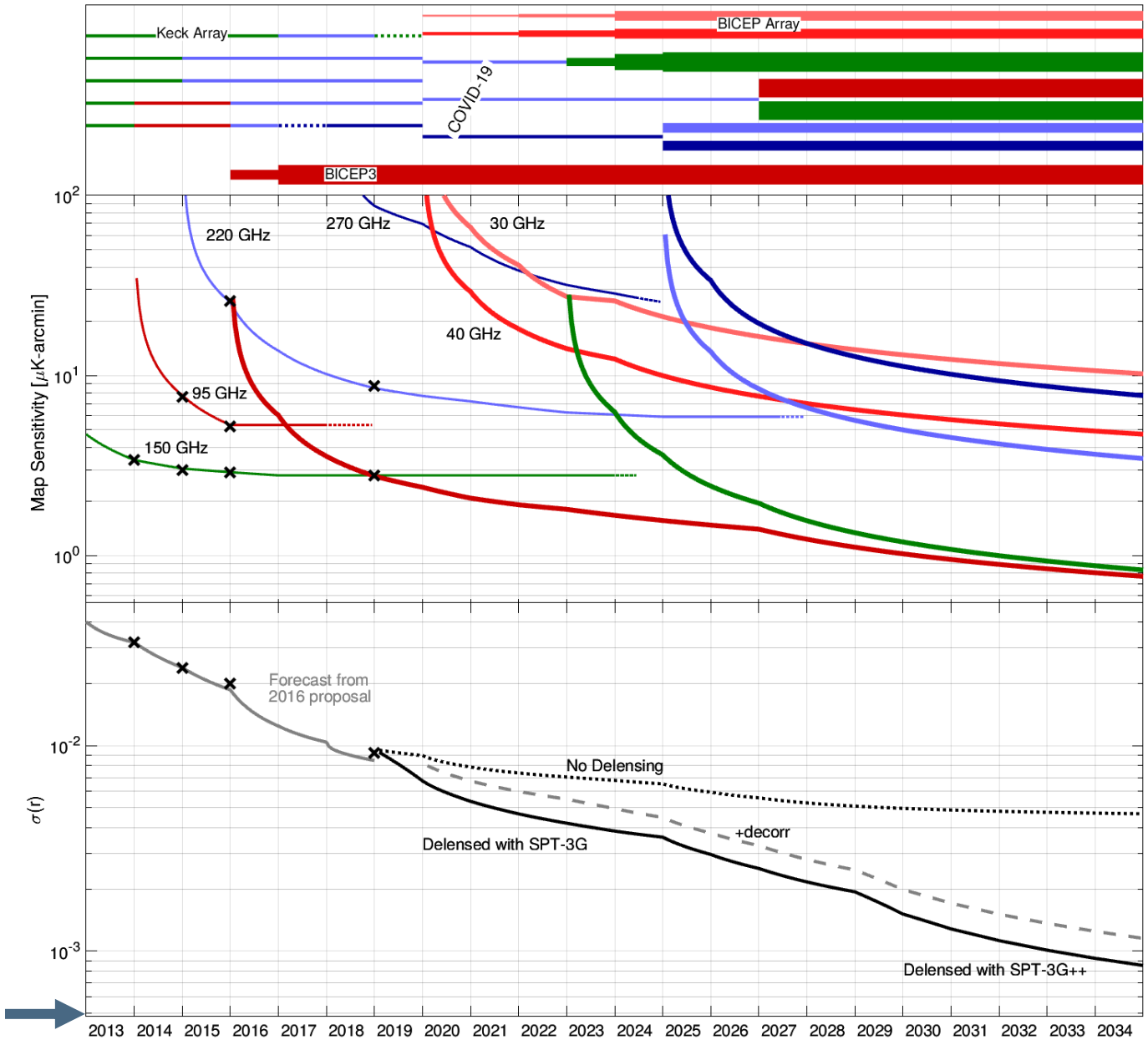
**BICEP Array in 2025**

**South Pole Telescope and BICEP3**

- Make the most of existing facilities at the South Pole
- Continue using field-proven methods from years of experience in deep polarization measurements
- Install a fourth BICEP Array receiver for improved CMB sensitivity
- Upgrade SPT focal plane (SPT-3G++) for improved CMB delensing capability

# A FUTURE BASED ON EXISTING FACILITIES AT SOUTH POLE




Three BICEP Array receivers have now been installed:

- 30/40 GHz (2019)
- 150 GHz (2022)
- 220/270 GHz (2024)
- Plan for a new 4th 95/150 GHz receiver (2026)

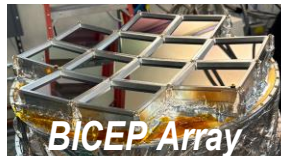
SPT is observing with SPT-3G focal plane now

- Opportunity for upgraded delensing capability with a new SPT-3G++ focal plane (2028)

Program achieves $\sigma(r) = 1 \times 10^{-3}$ with an empirically validated sensitivity model and decorrelation in polarized Galactic dust

CMB-S4 science goal: $\sigma(r) = 5 \times 10^{-4}$

# A FORECAST FOR CMB@80



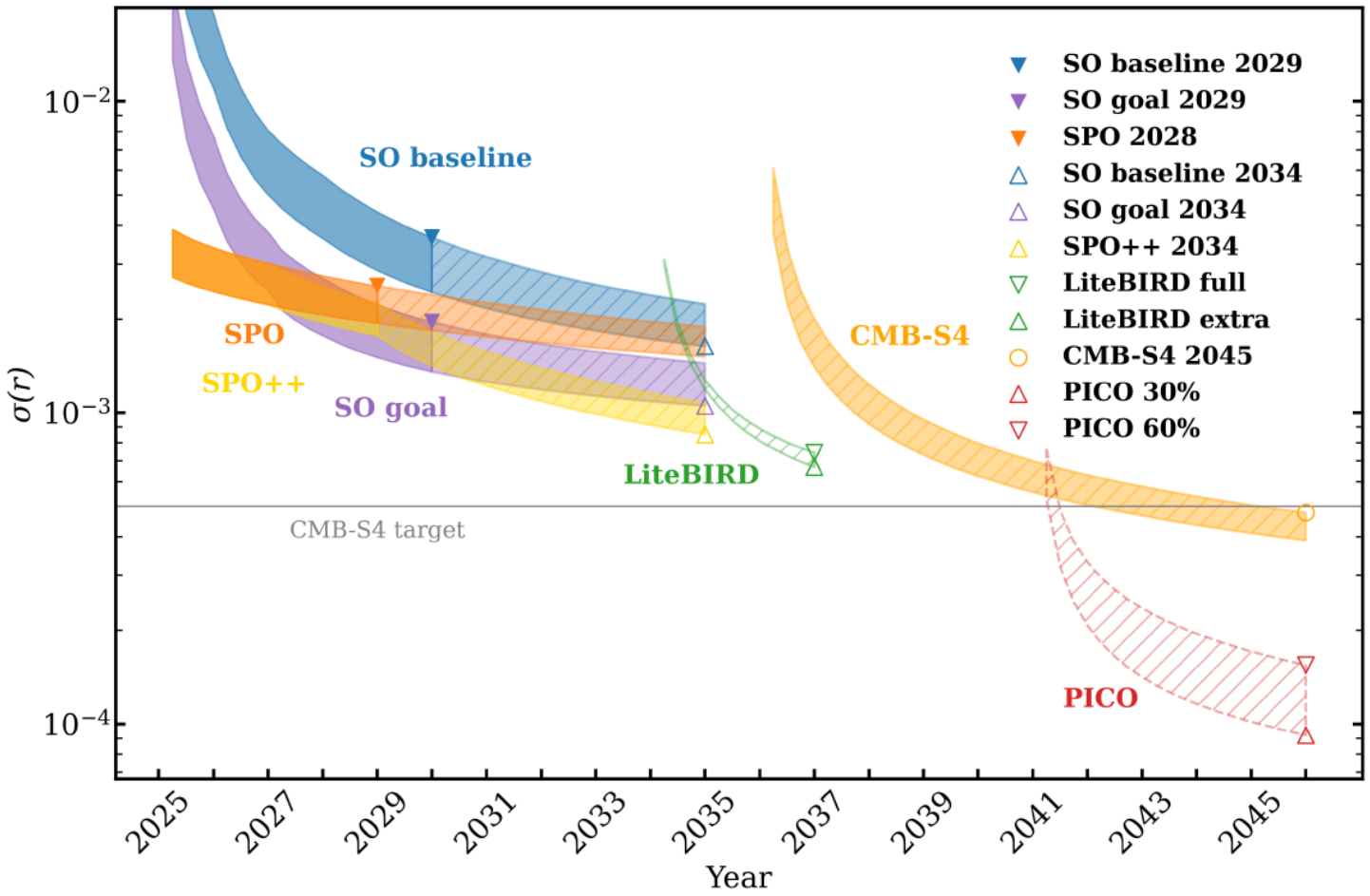

- Clear roles for South Pole Observatory (SPO) and Simons Observatory (SO) over the next decade
  - Both target σ(r) ~ 1e-3 by the mid-2030s
  - Fraction of the cost of CMB-S4 or a satellite
  - Complementary: SO is wider, SPO deeper
  - Uncertainties remain in sensitivity, systematics, foregrounds, funding

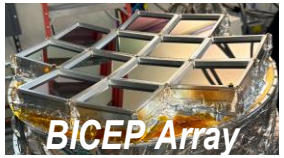
- CMB Stage-4 is evolving from the full version given in the plot
  - Redesign incorporates SPO/SO surveys
  - Deployments staged in 2 experiment phases, and phase 1 starts and finishes faster than full version
  - Redesign is still in active development

- What is the next step for the 2040s?

- The usual assumptions aren't necessarily valid!
  - Ground and space are roughly comparable in cost and timescale

*Survey of Current CMB Experiments - CMB Stage 4 Collaboration*






# BACKUP