Performance Overview of the BICEP/Keck CMB Experiments

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CMB-CAL Workshop

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Goal

Discuss current methods and lessons-learned from South Pole SATs

Summary

- BICEP/Keck Small Aperture Telescopes
- Far-Field Beam Maps
- Near-Field Beam Maps
- Sidelobe Maps
- Ground Mapping

The Beam Team

- Clara Verges (Harvard/BNL)
- Christos Giannakopoulos (UCinc)
- Brodi Elwood (Harvard)

Previous Members:

- Kirit Karkare (BU)
- James Cornelison (ANL)
- Tyler St. Germaine

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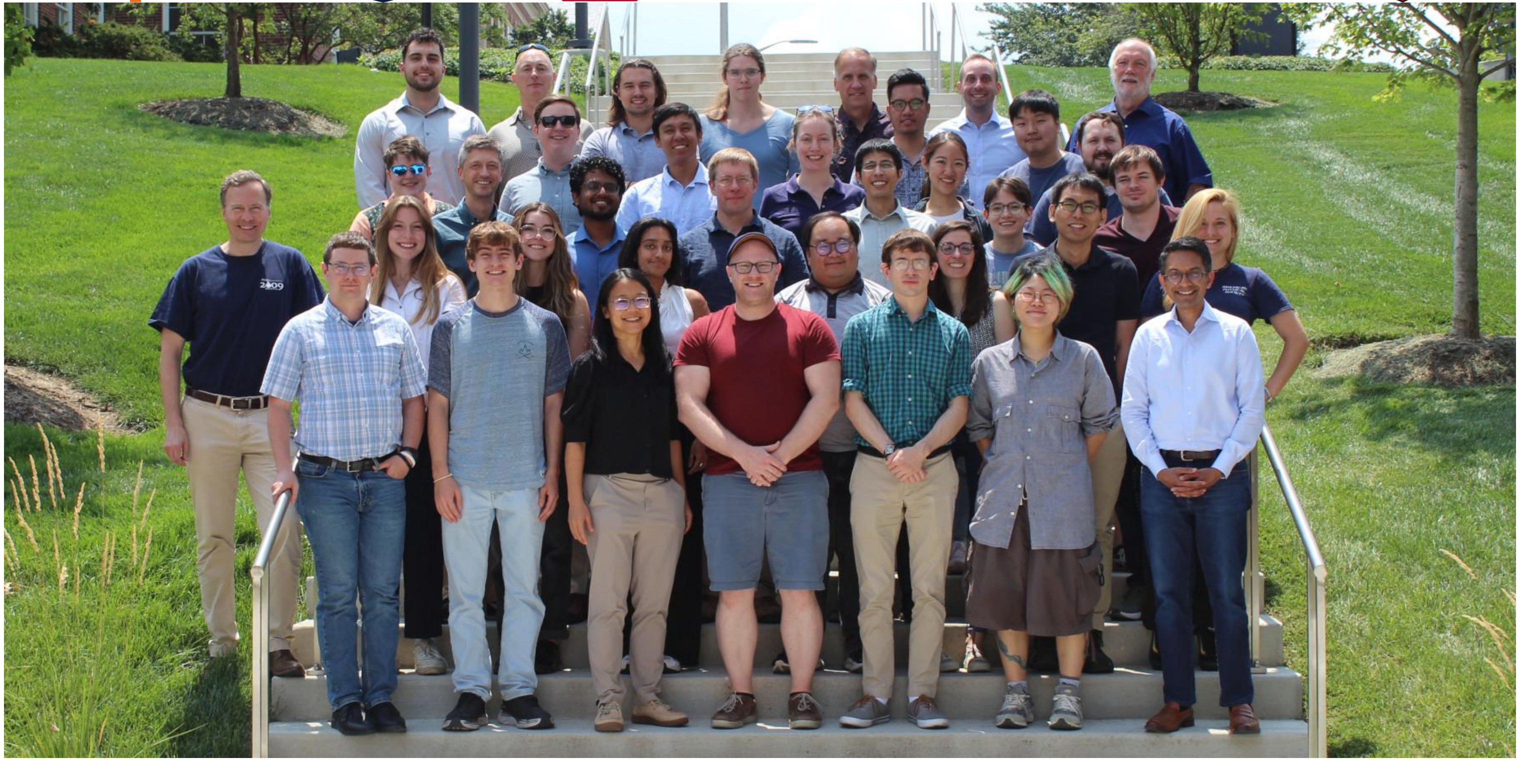

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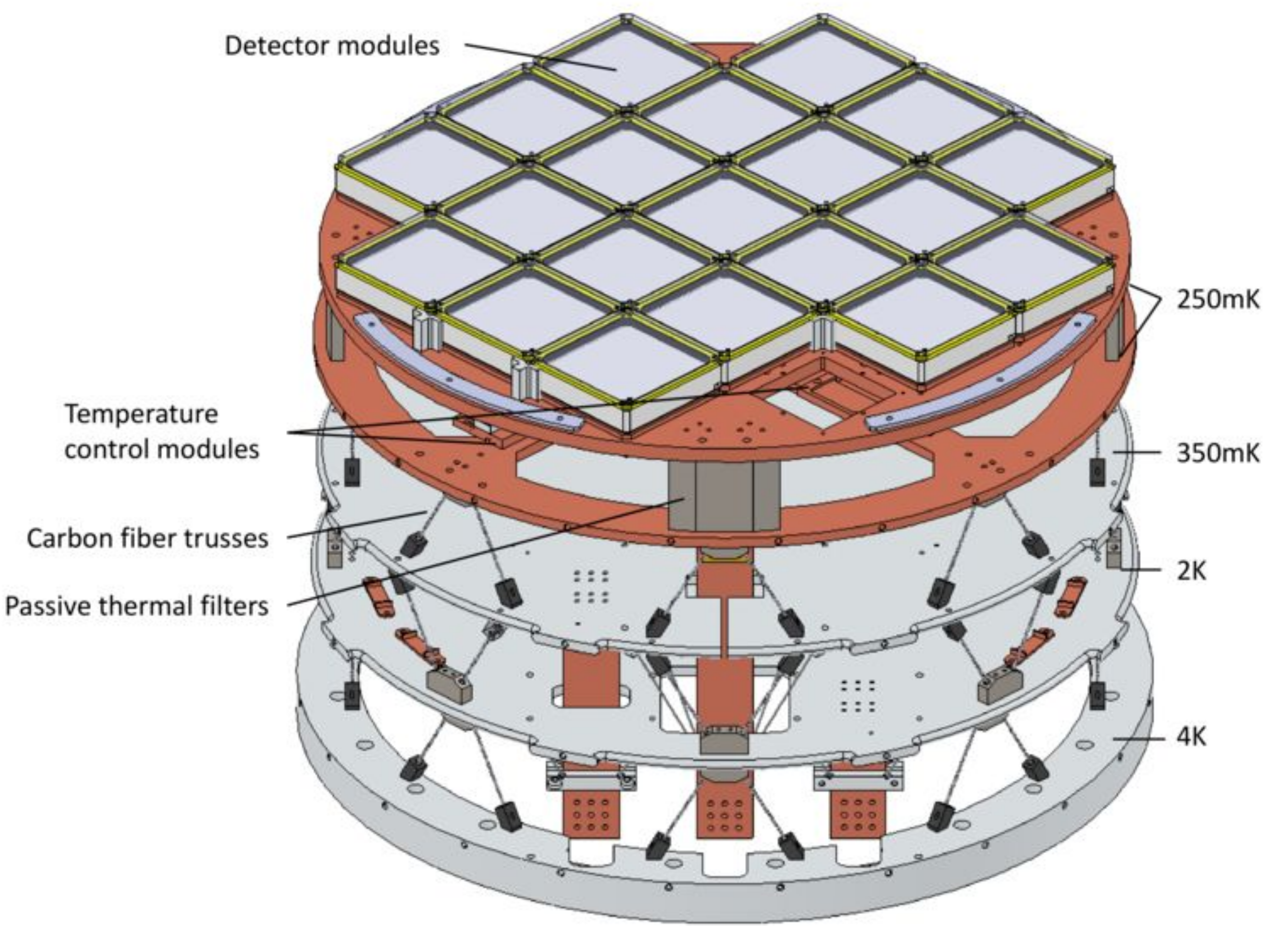
What is BICEP/Keck?

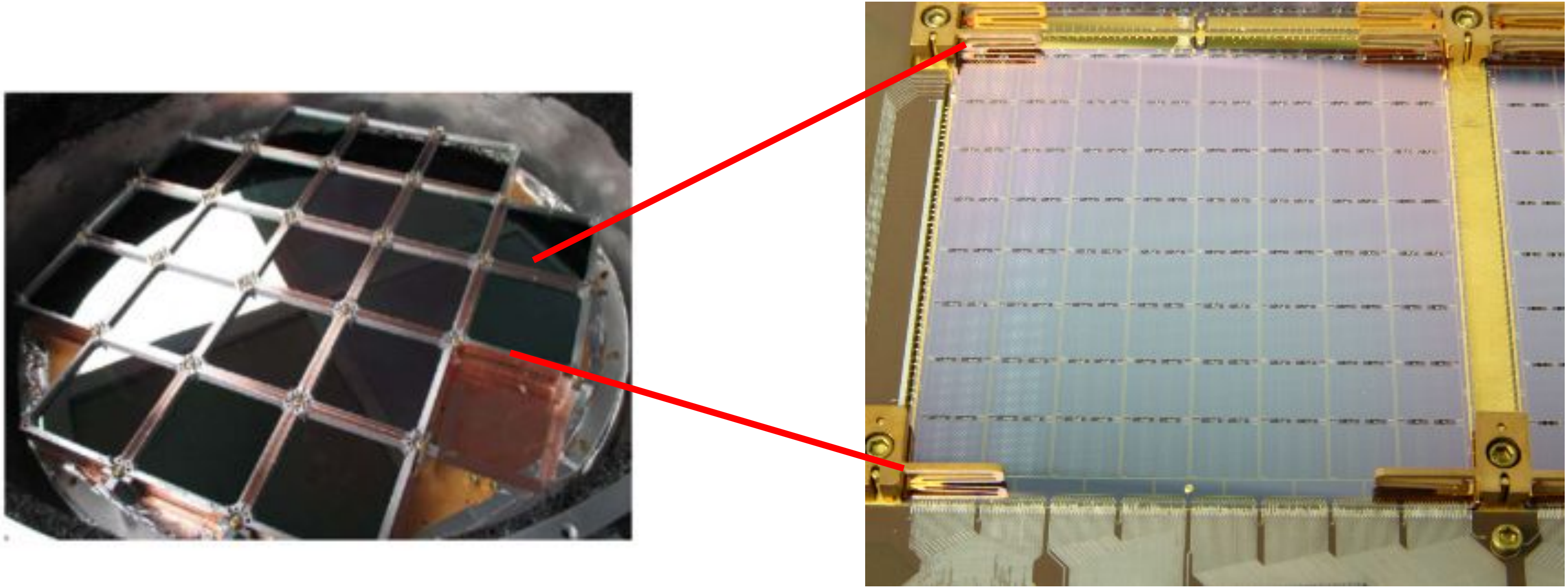
Microwave refracting telescopes built and operated by the BICEP/*Keck* collaboration

- Observes the CMB 35/95/150/220/270 GHz
- Small Aperture to probe degree-scale CMB structure
- Sensitive to linear polarization
- Located at the South Pole!
- Primary goal is to detect Cosmic Inflation

Camera (a.k.a. Focal Plane)



Camera (or Focal Plane)



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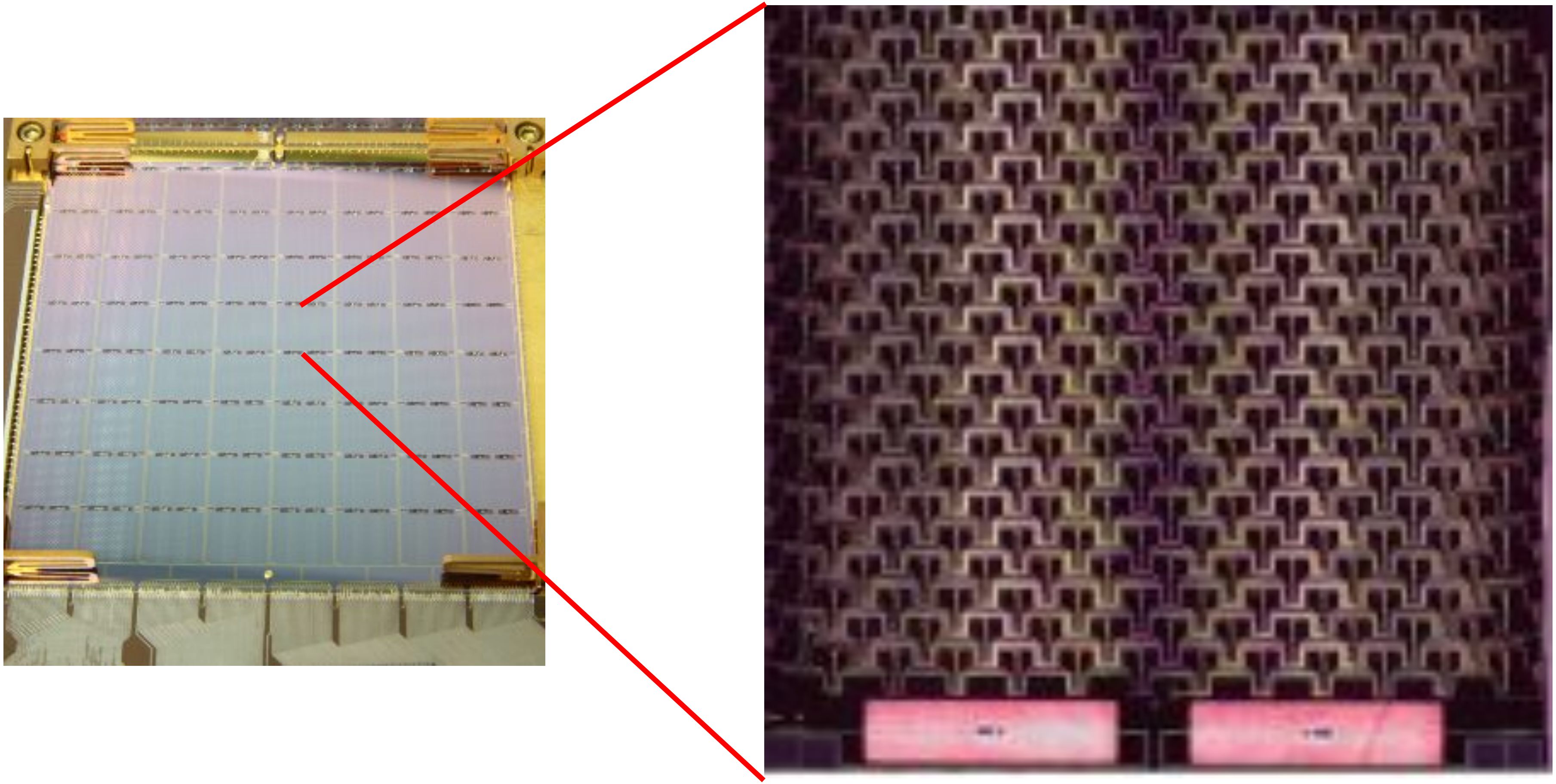

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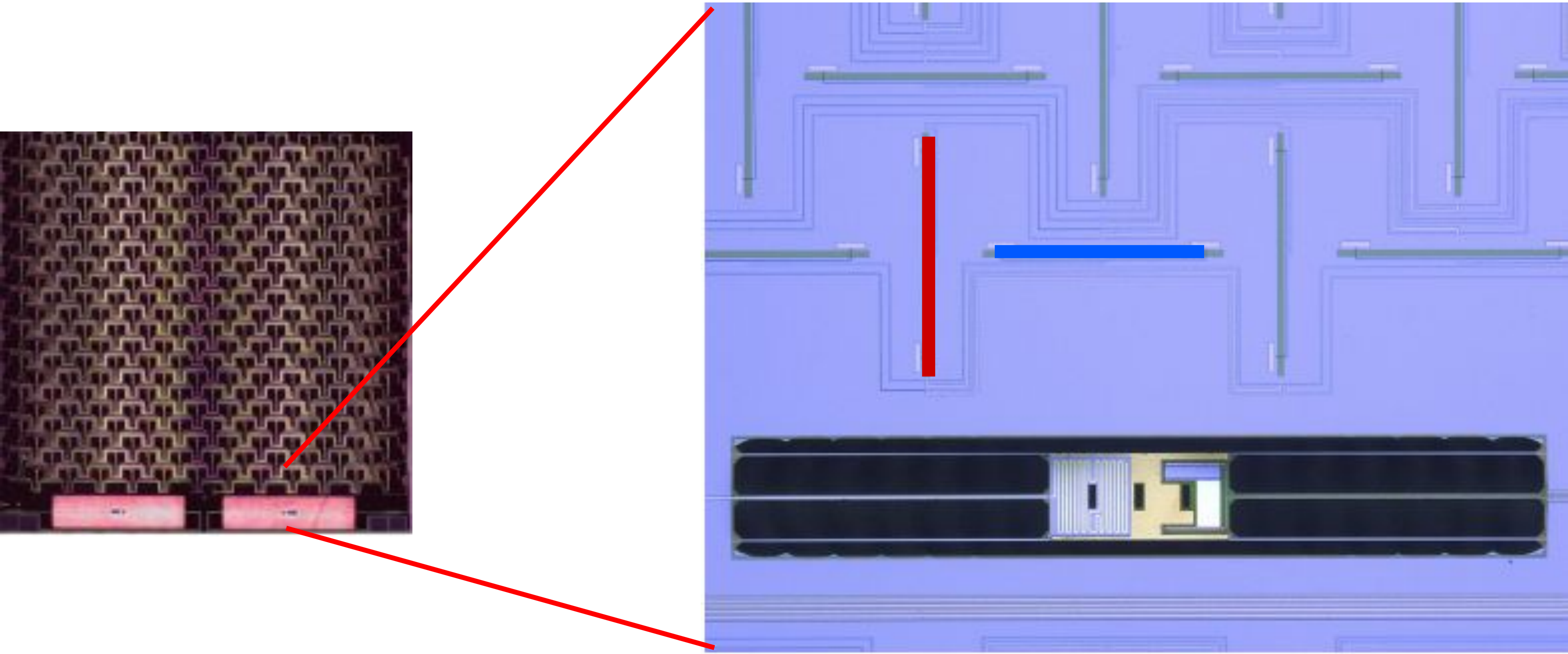
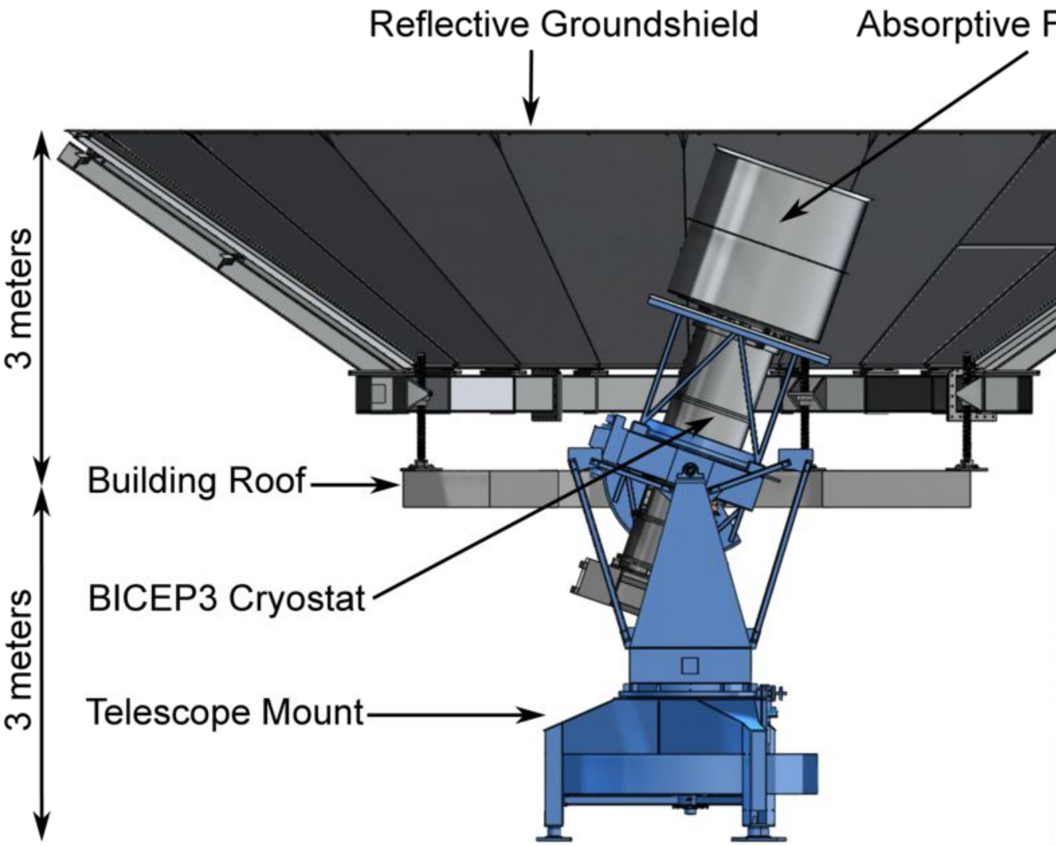


Simultaneously measuring vertical and horizontal polarization

Mount and Shielding

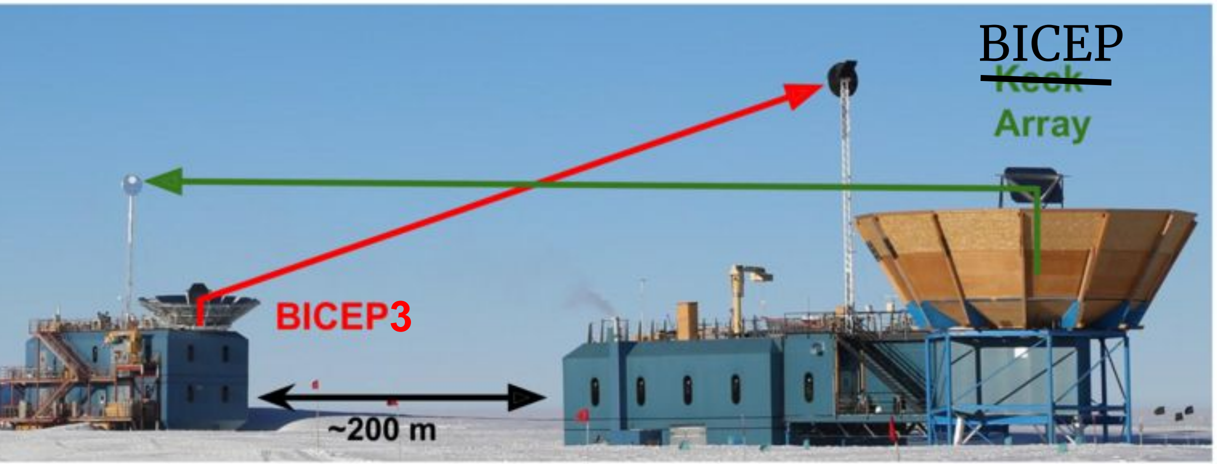


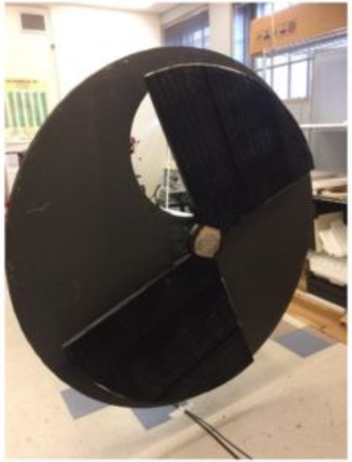
Characterizing Optical Performance

(Far Field only ~200m!)

- Large, flat, aluminum mirror redirects the view onto the horizon (like a periscope!)

- Calibrators are installed on masts

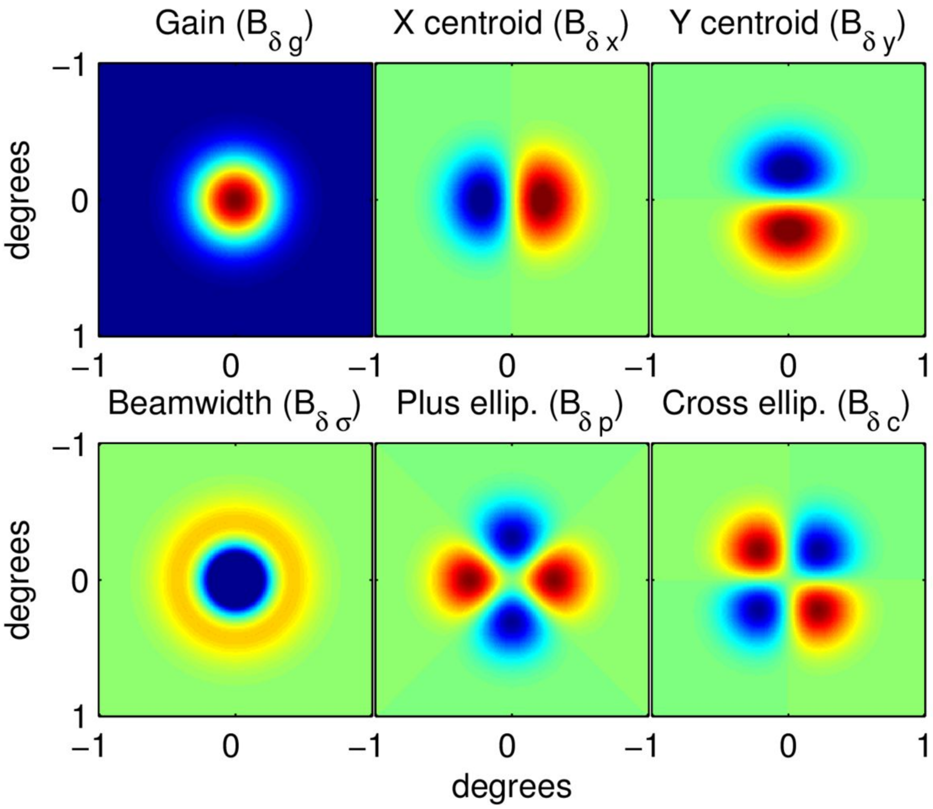




Far Field Beam Mapping

- Beam mismatch is currently our leading source of instrumental systematics
  - We spend 1 month every year beam mapping!
- What do we use the beams for
  - Channel flagging (Quality Control)
  - Beam window function
  - Differential Ellipticity Subtraction
  - T->P leakage estimation, “beam map simulations”
    - Characterizes the “false” BB from T that results from undeprojected residuals
- Of these, ellip subtraction and T->P leakage require high-fidelity beam maps for *all* beams

Beam Imperfections and how we deal with them



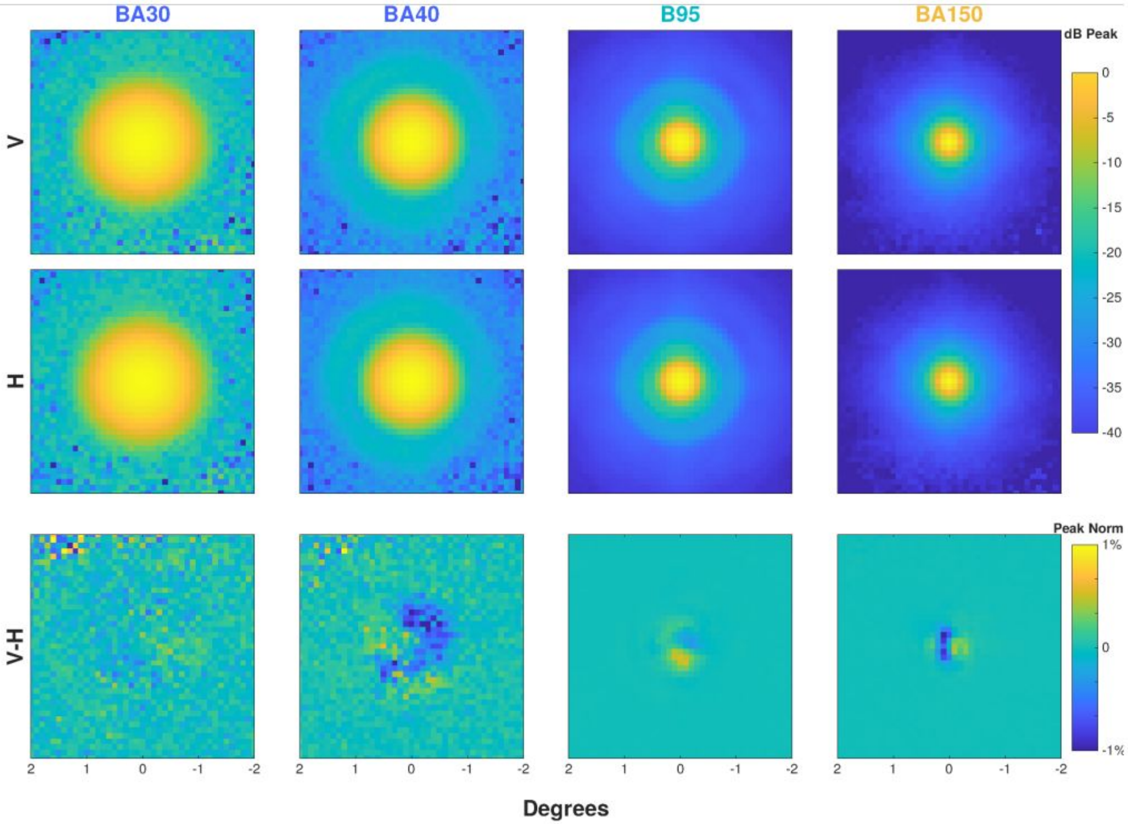
Mode	Definition	Coefficient $\alpha_{\delta k}$	Template	Baseline
Gain	$g_A - g_B$	δg	T	deproject
Pointing x	$x_A - x_B$	δx	$\nabla_x T$	deproject
Pointing y	$y_A - y_B$	δy	$\nabla_y T$	deproject
Beamwidth	$\sigma_A - \sigma_B$	$\sigma \delta \sigma$	$\left(\nabla_x^2 + \nabla_y^2\right) T$	ignore
Ellipticity +	$p_A - p_B$	$\left(\sigma^2/2\right) \delta p$	$\left(\nabla_x^2 - \nabla_y^2\right) T$	subtract
Ellipticity ×	$c_A - c_B$	$\left(\sigma^2/2\right) \delta c$	$2\nabla_x \nabla_y T$	subtract

FFBM 2023

- Deep maps out to FOV, ultra deep out to ~2deg for deprojection

- Still need to figure things out for 150 GHz
  - Significant systematics that affect repeatability
  - ~250m far field
  - Old mirror might not be sufficient

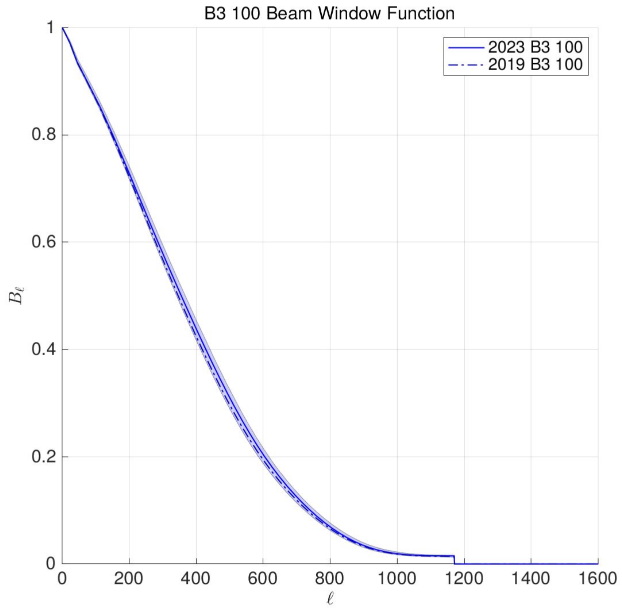
2023 Coadded Maps per RX

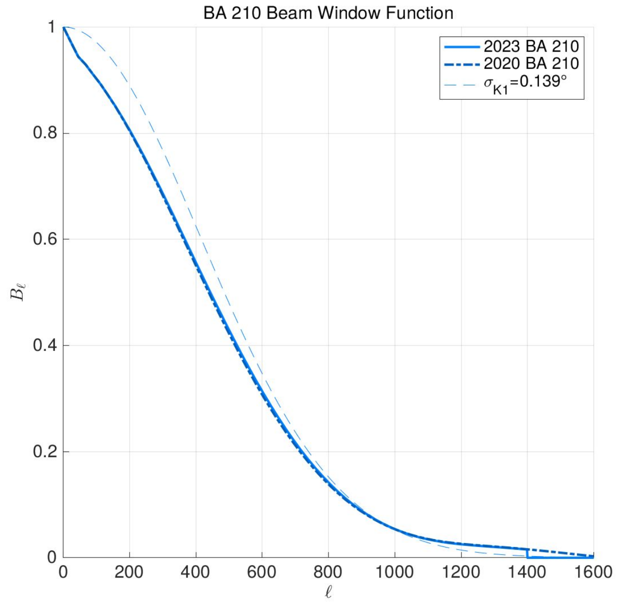


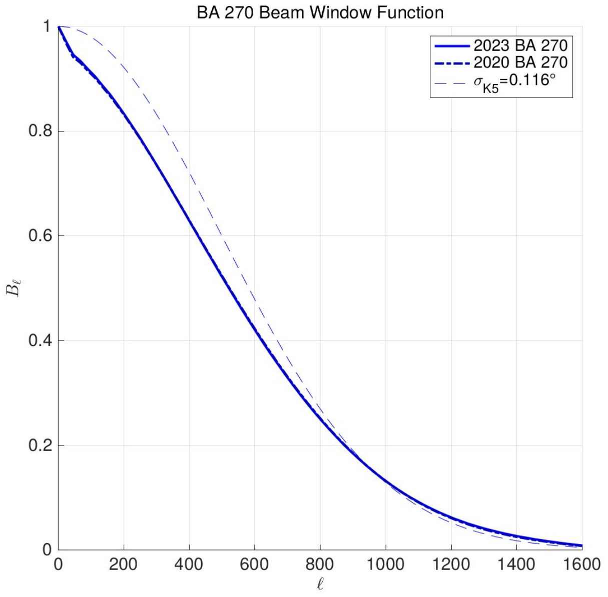
See: C. Giannakopoulos, C. Verges et al. (2024), arxiv:2409.16440

2023 Bls: B3, K1, & K5

- BICEP3's Bls are consistent between 2019 & 2023, even with optics changes
- 210 & 270 Bls also consistent between 2020 & 2023

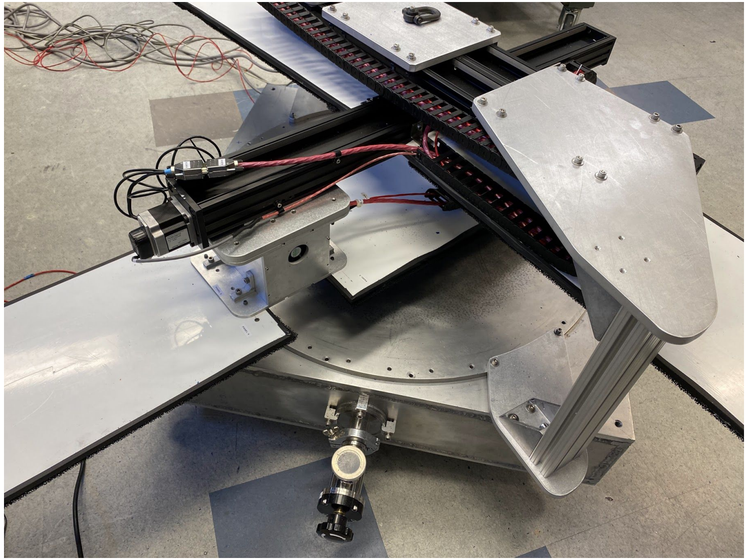




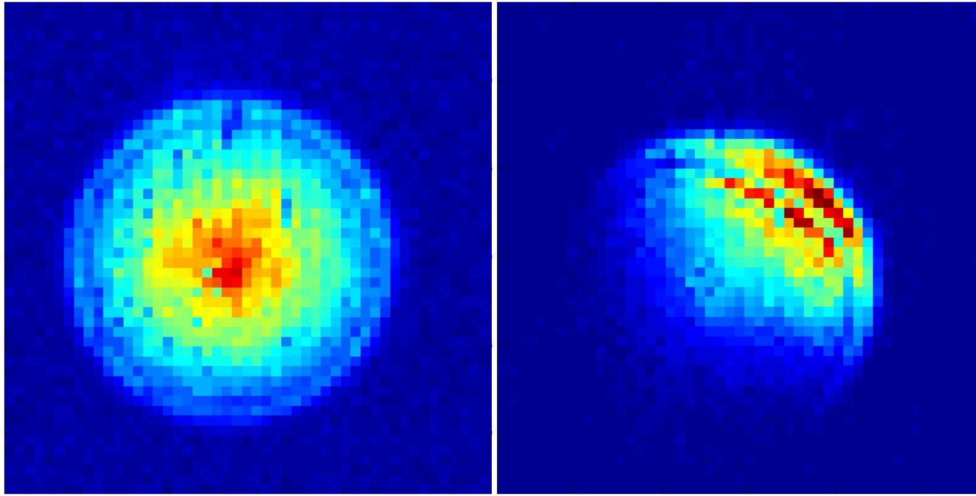


Near-Field Beam Mapping

- Thermal Source (~500K)
- Physically chop for higher SNR
- Raster a few inches above the window



- Useful for post-integration, pre-deployment quality control
- Combine with thick-grill filters to check for blue-leaks
- Combine with wire grids to check for pol-dependent systematics



Near-Field Beam Mapping

- Useful for post-integration, pre-deployment quality control
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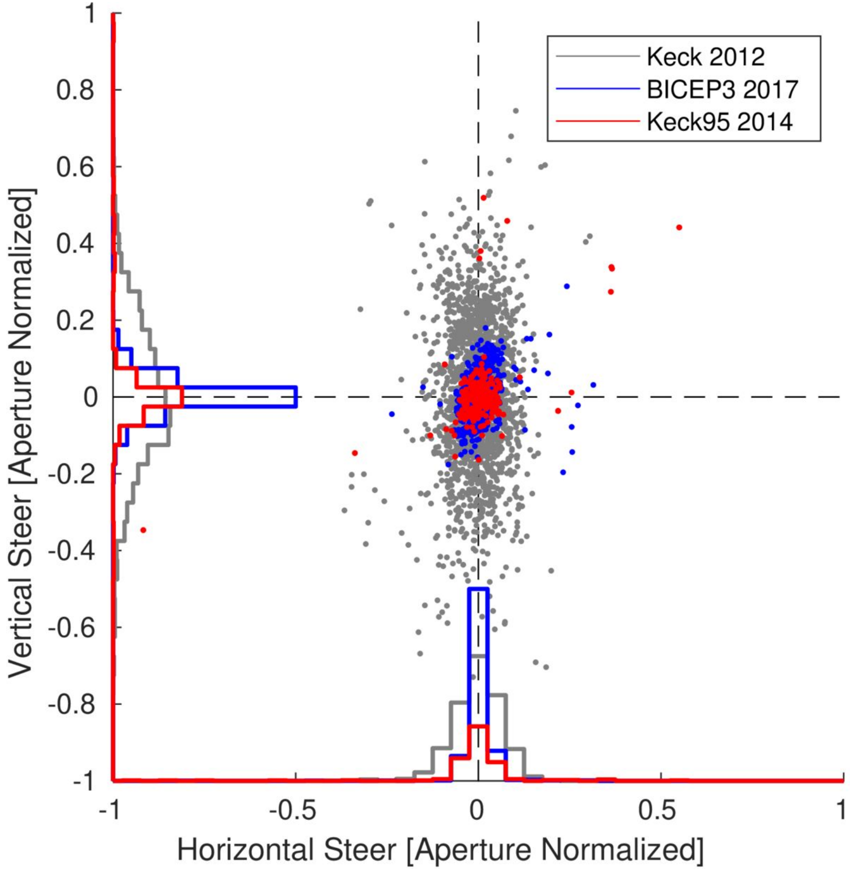
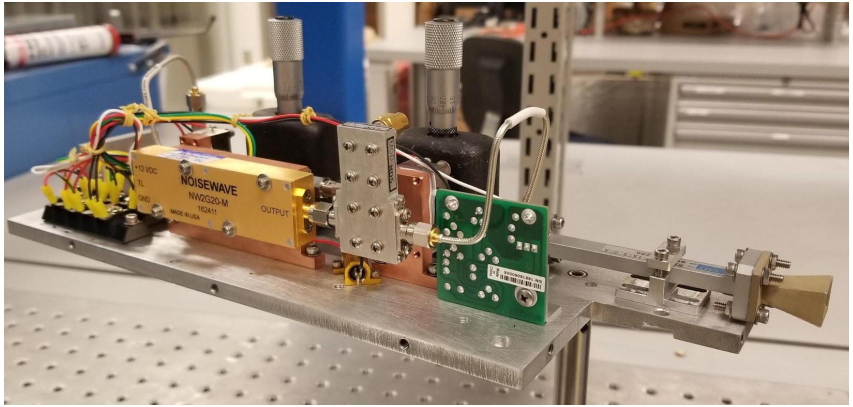
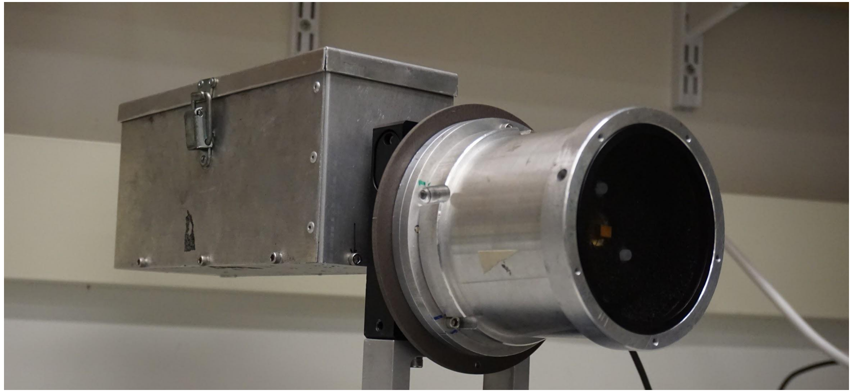
- Combine with wire grids to check for pol-dependent systematics
- Possibilities for quantitative analysis



Sidelobe Mapping

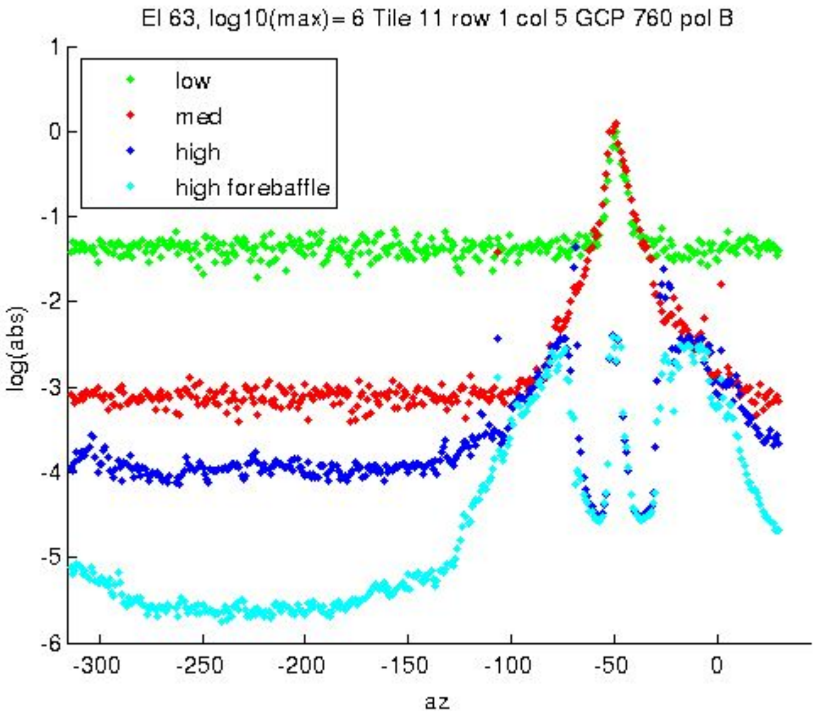
- Quasi-thermal broad spectrum noise sources
  - Very bright (~1e9 Kelvin)
- Electrically chopped
  - High phase stability
- Waveguide attenuators in series
  - High dynamic range in amplitude





Sidelobe Mapping

Source on nearby mast, at different brightnesses, with & without shielding



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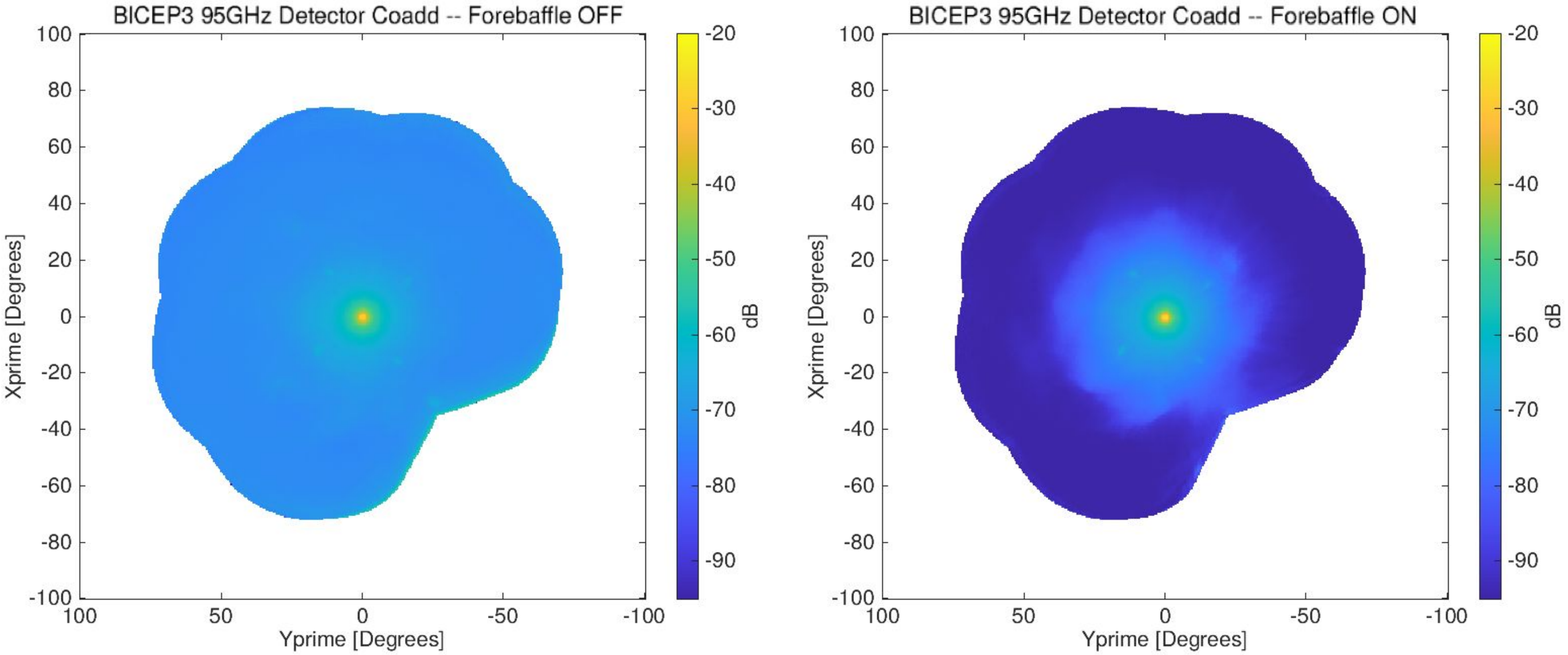

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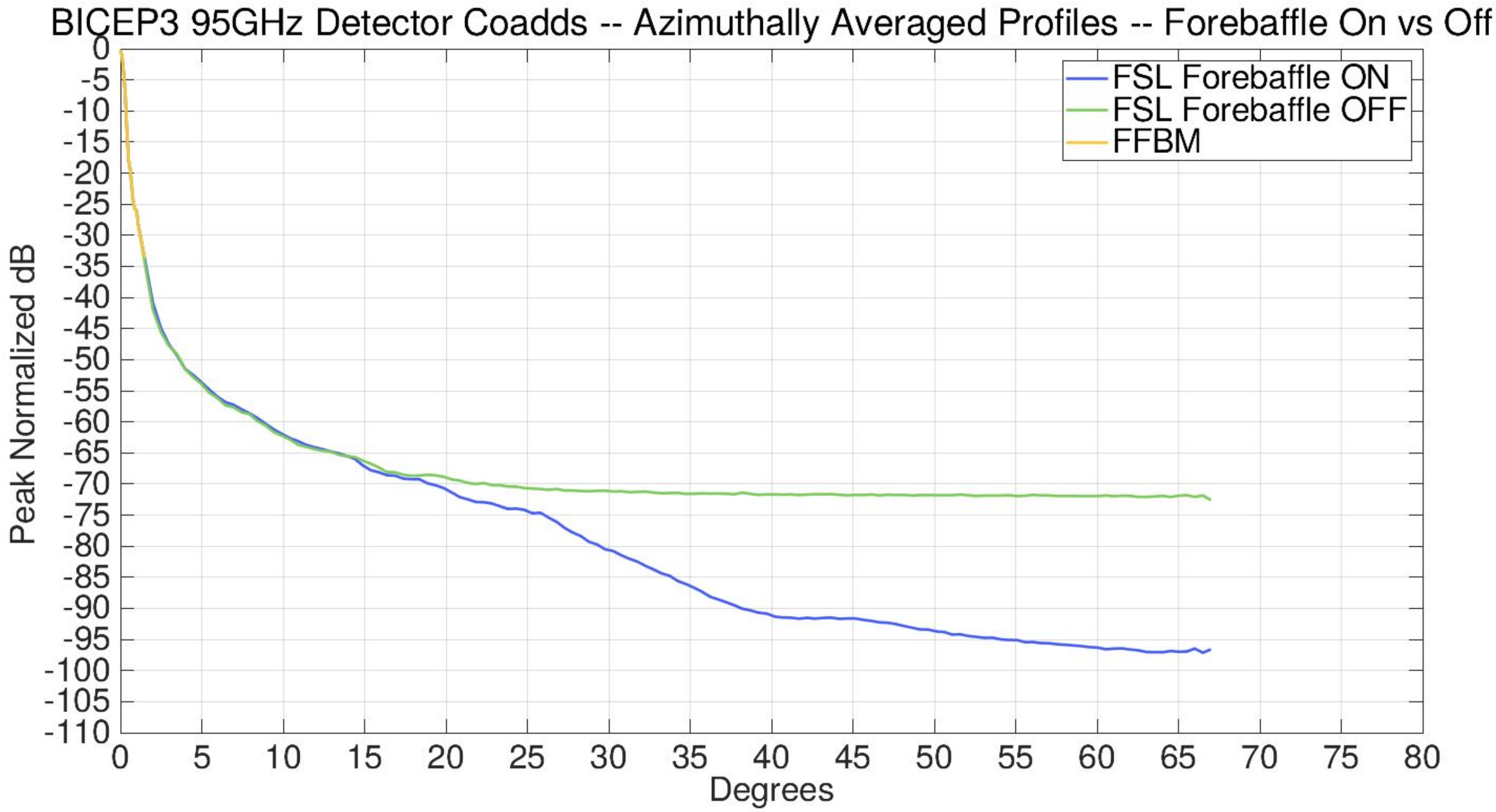

Summary

- FFBM for sims, deprojection, and T→P leakage
  - Ground thermal source, on-mast
  - Demonstrated stability over *years*
- NFBM mostly for qualitative screening
  - Rastering thermal source ~@ aperture
  - Qualitative analyses becoming more normal
- Sidelobe Mapping mostly for shielding studies
  - Quasi-thermal sources for very deep maps
  - Potential future uses like T→P leakage studies or even deprojection?

Thank you! Questions?