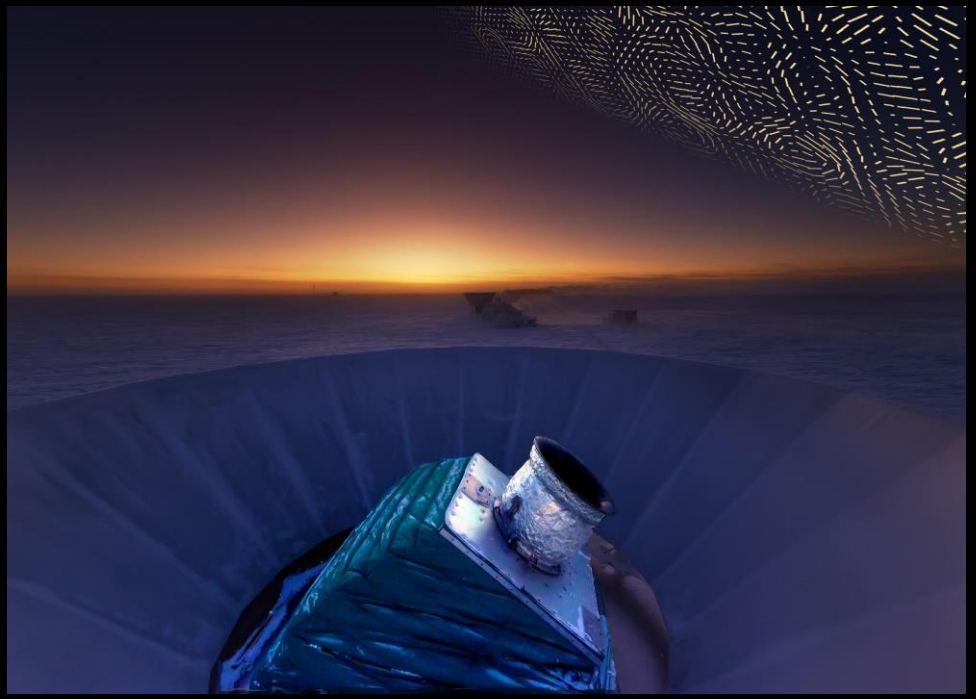
CMB Polarimetry with phased-array antenna-coupled bolometers



Roger O'Brient

Jet Propulsion Laboratory, California Institute of Technology

CORrE/M5 Workshop, CERN

Outline

- Mature Detectors
  - Overview of instruments
  - BICEP/Keck Program
  - SPIDER
- Flexible Technology
  - Tophat vs gaussian
  - Steerable beams

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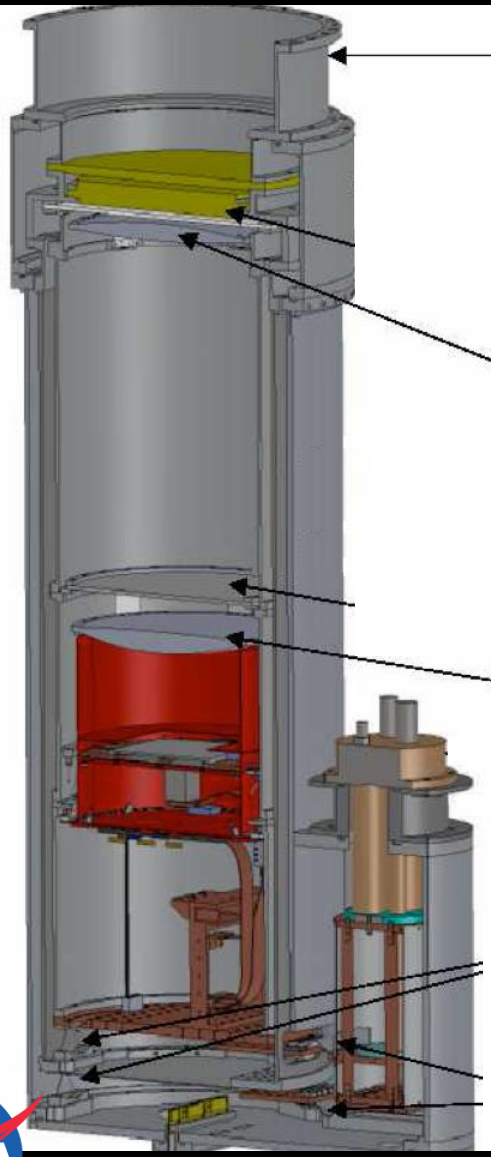
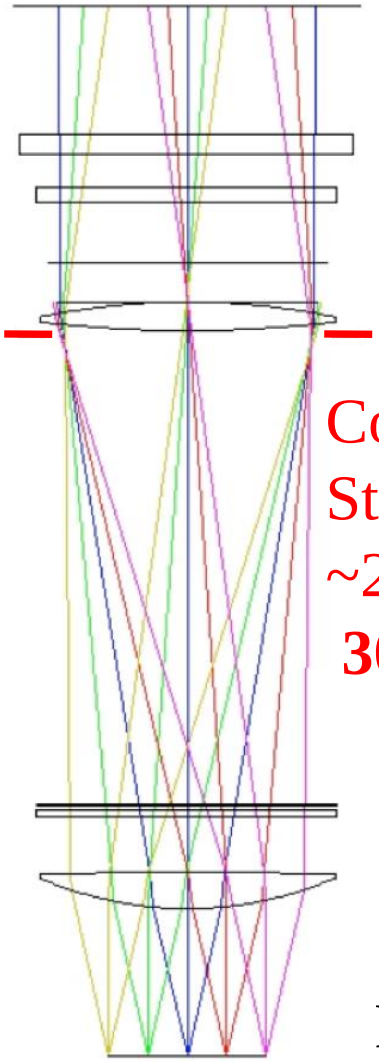
BICEP2 & Keck Array



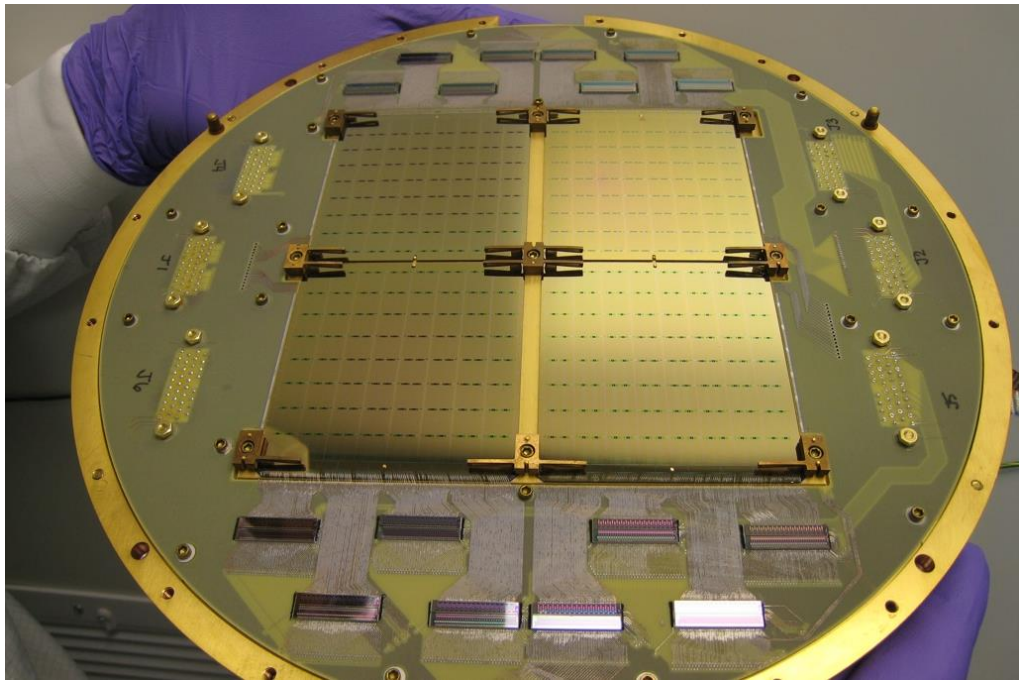


Cold Aperture Stop ~26cm

30’ resolution

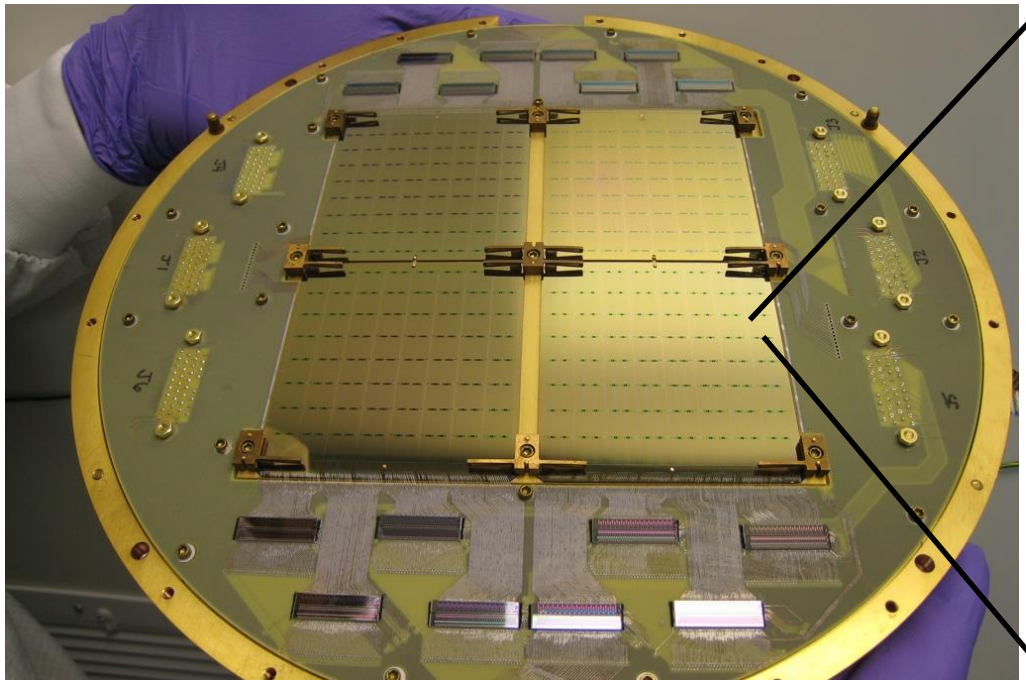
Focal Plane

Focal Plane



Fabricated by Tony Turner, Tony Bonetti, Koko Migirian, Alexis Weber

Focal Plane



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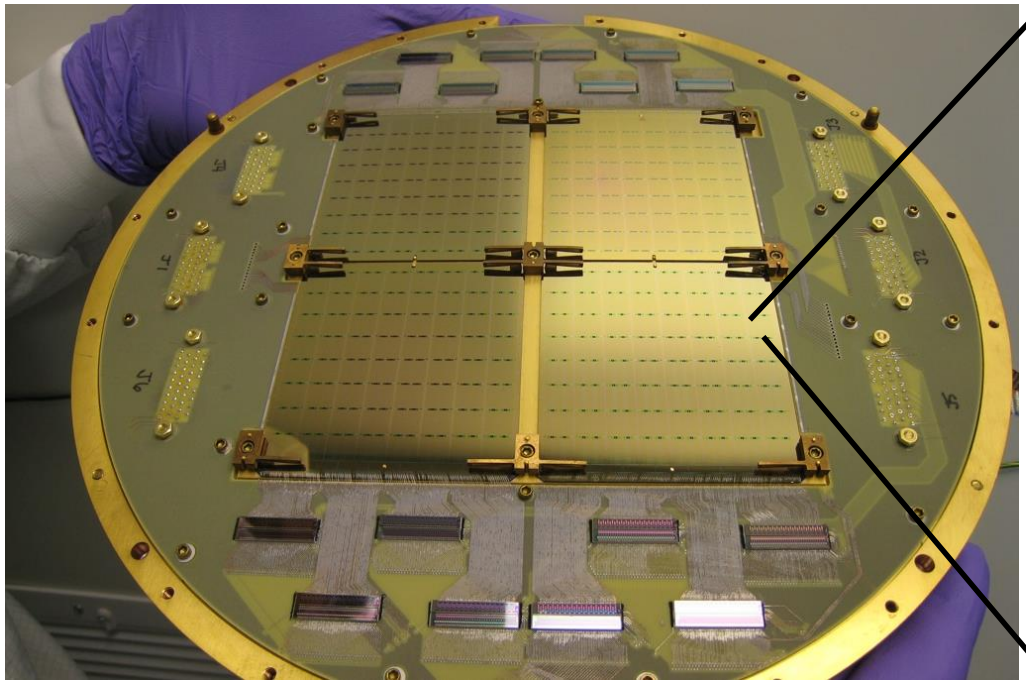
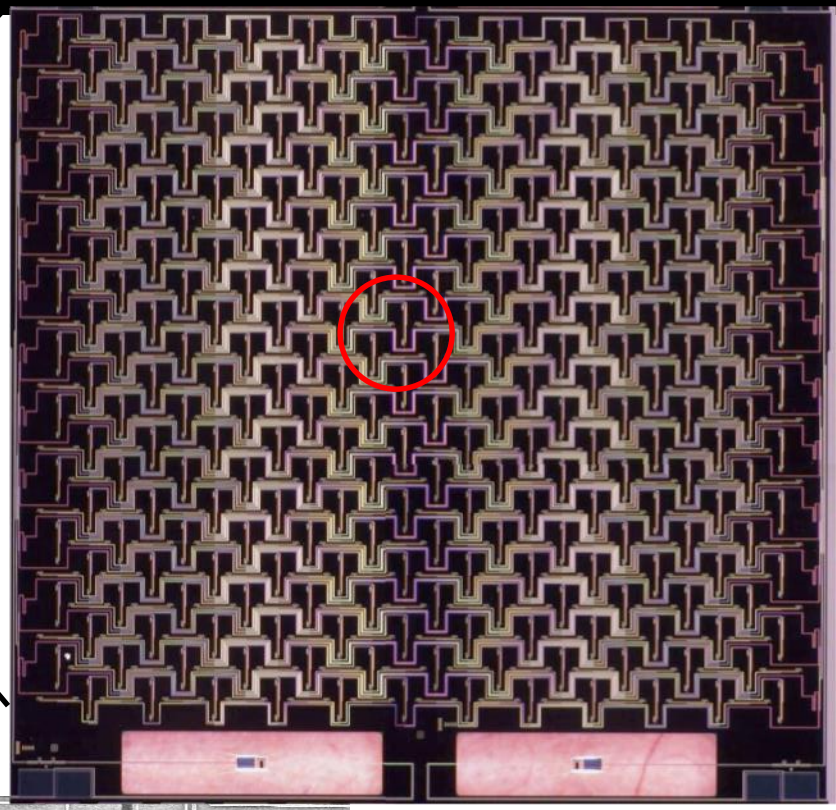
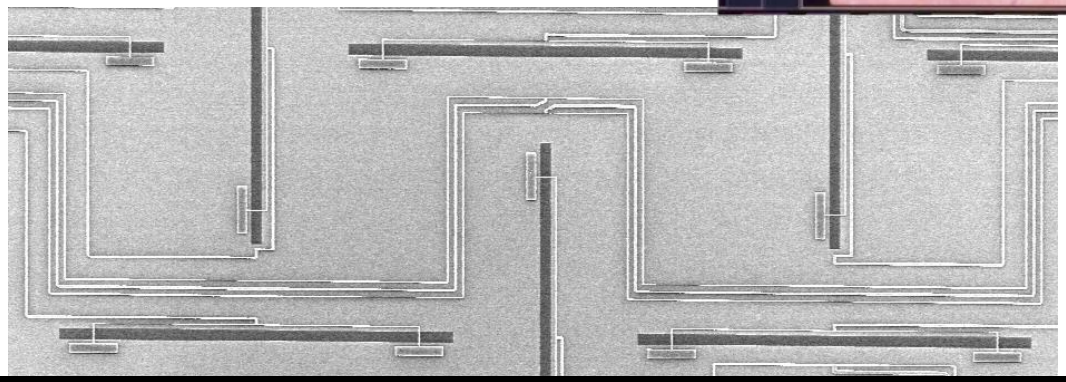
Focal Plane







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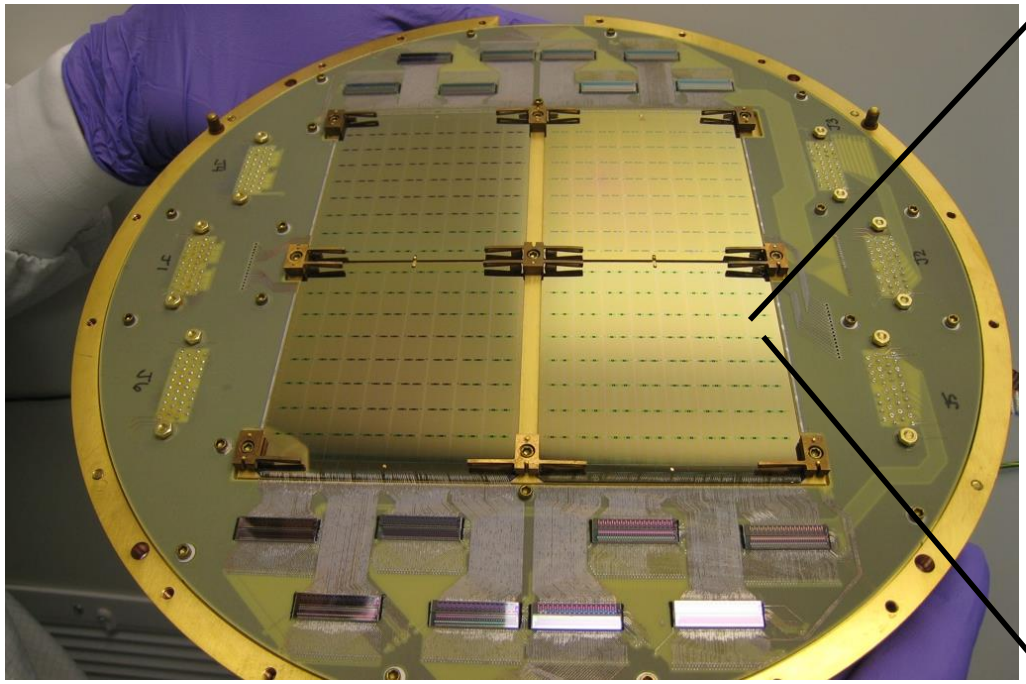
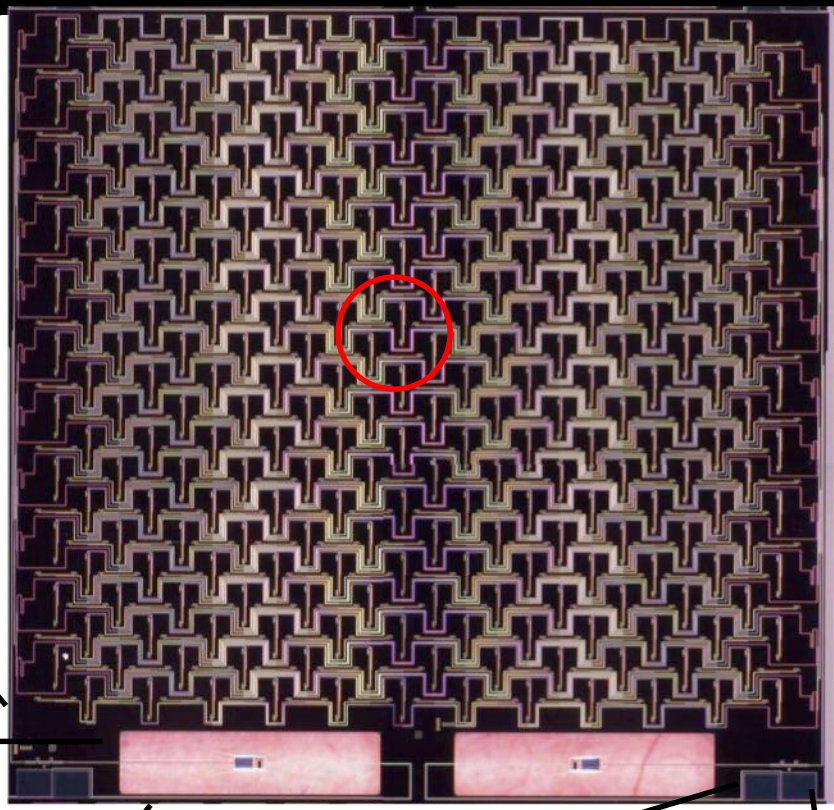
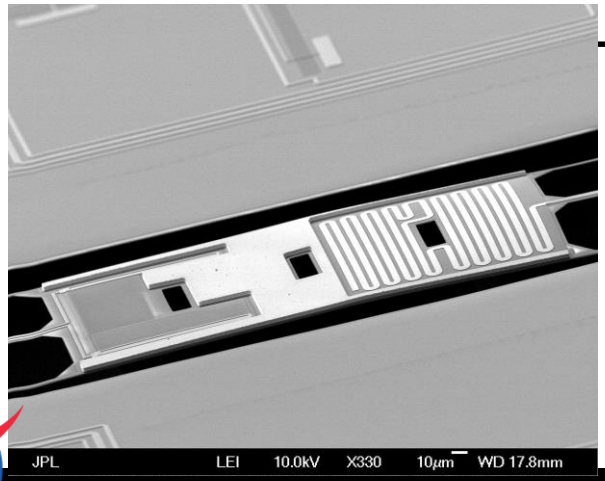
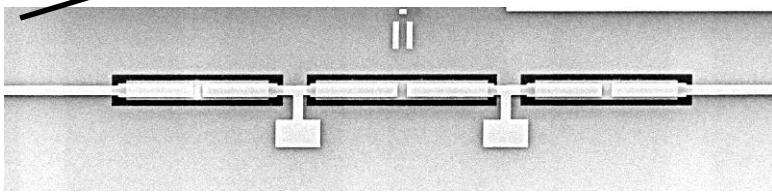
Focal Plane

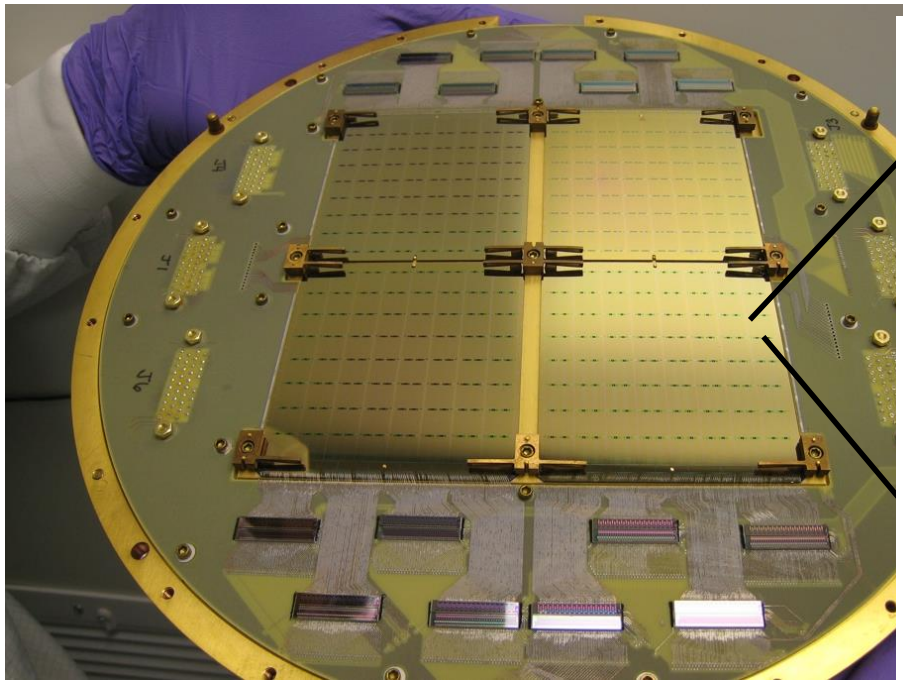


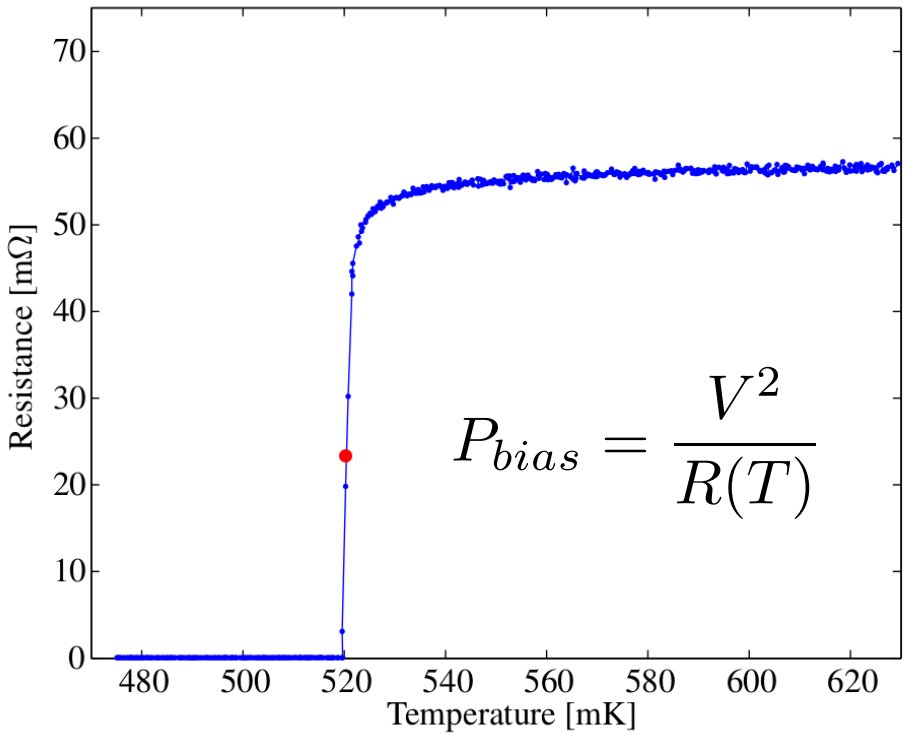




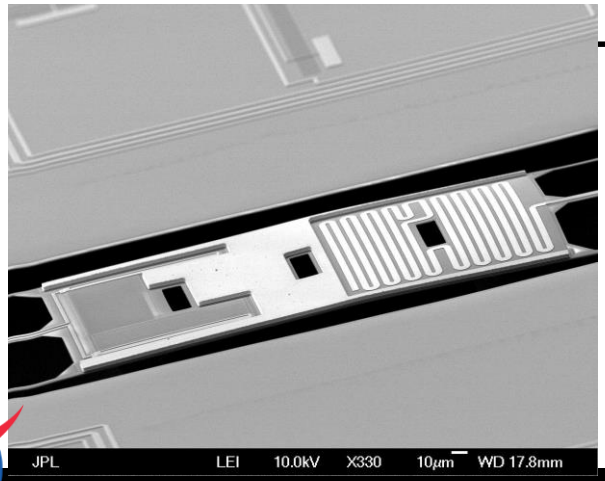


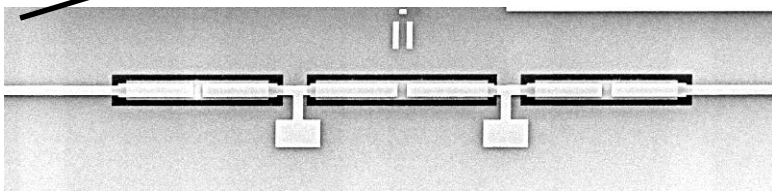
Focal Plane



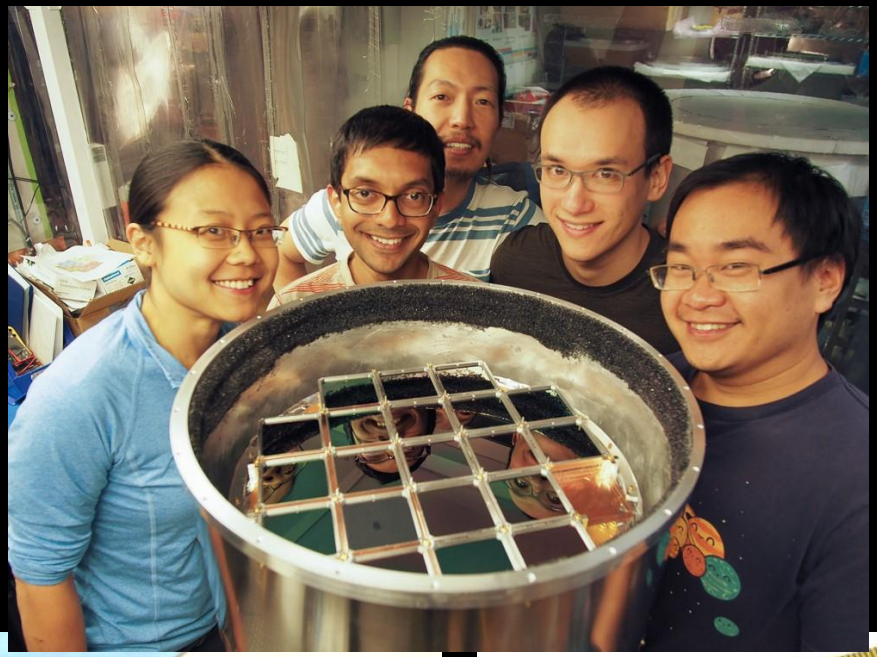


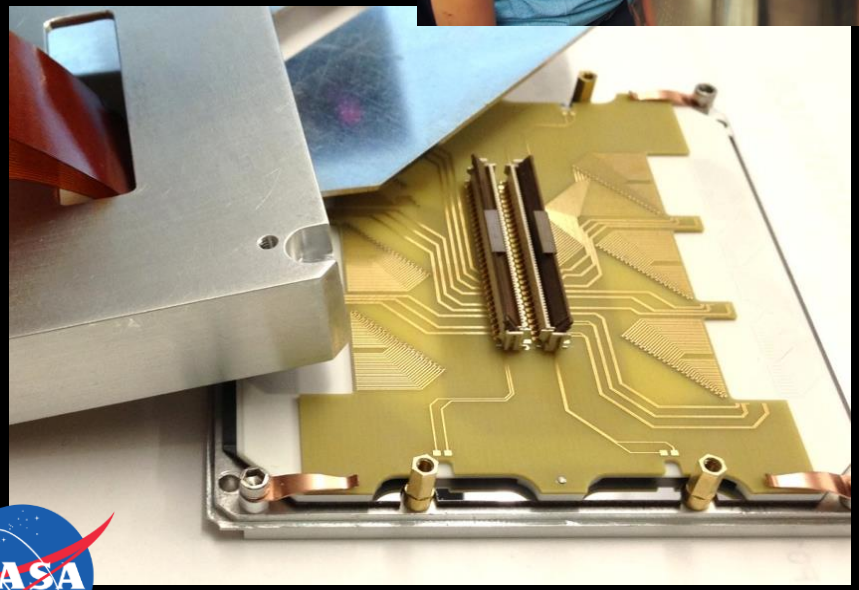
$$P_{bias} = \frac{V^2}{R(T)}$$

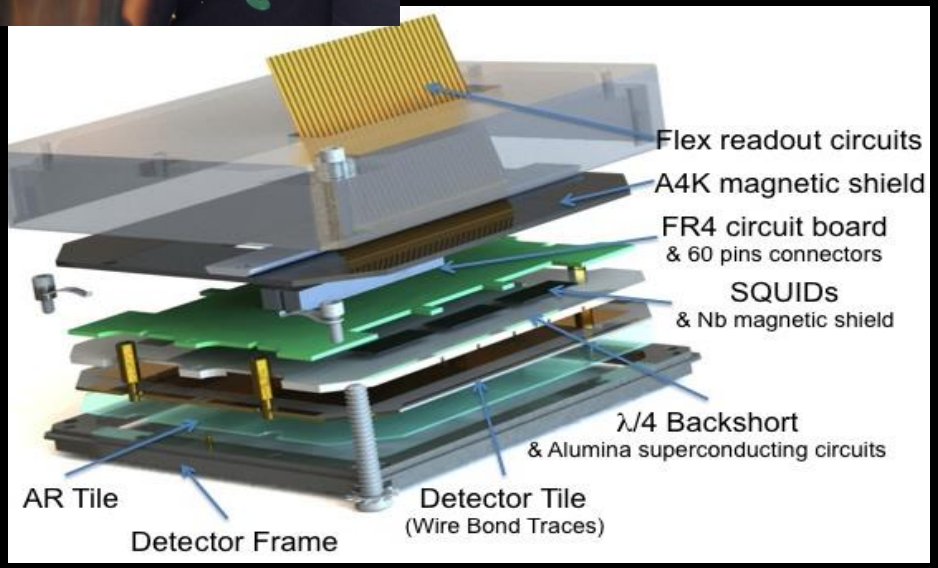




BICEP3/ BICEP Array Focal Plane







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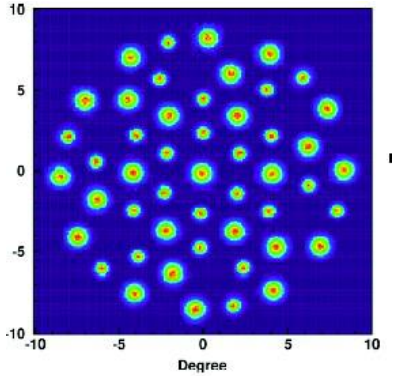
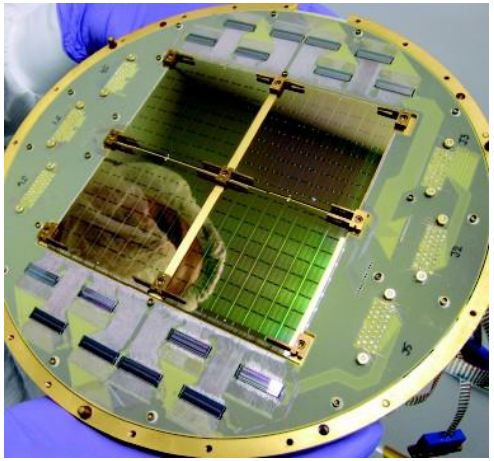
More Detectors!

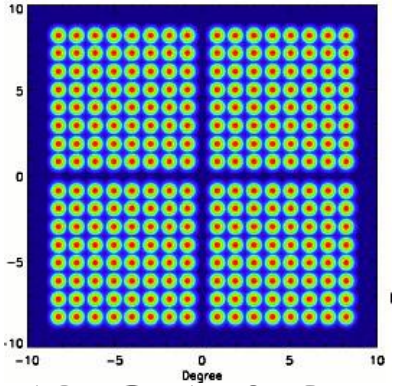
BICEP1
2006-2008



48 @ 150 GHz
50 @ 100 GHz

BICEP2
2010-2012

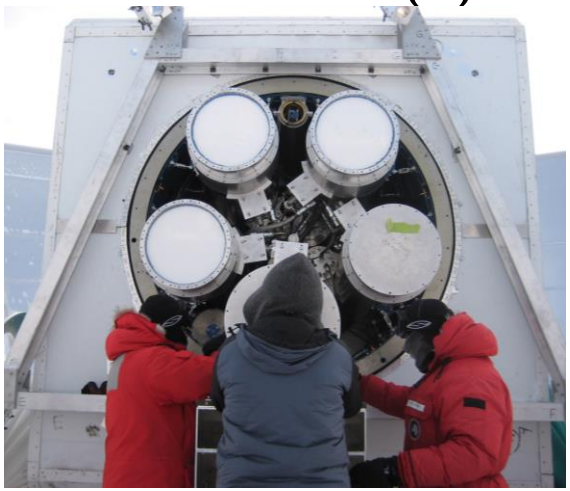


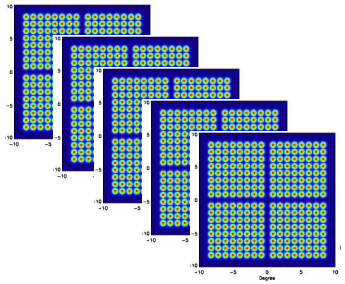


512 @ 150 GHz

x10 B1-150 speed

Keck Array
2011-2018(?)





5 x 512 @ 150 GHz

x50 B1-150 speed

More Detectors!

We have deployed:

More Detectors!

We have deployed:

- 88 tiles in scientific use

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- 10,000+ detectors

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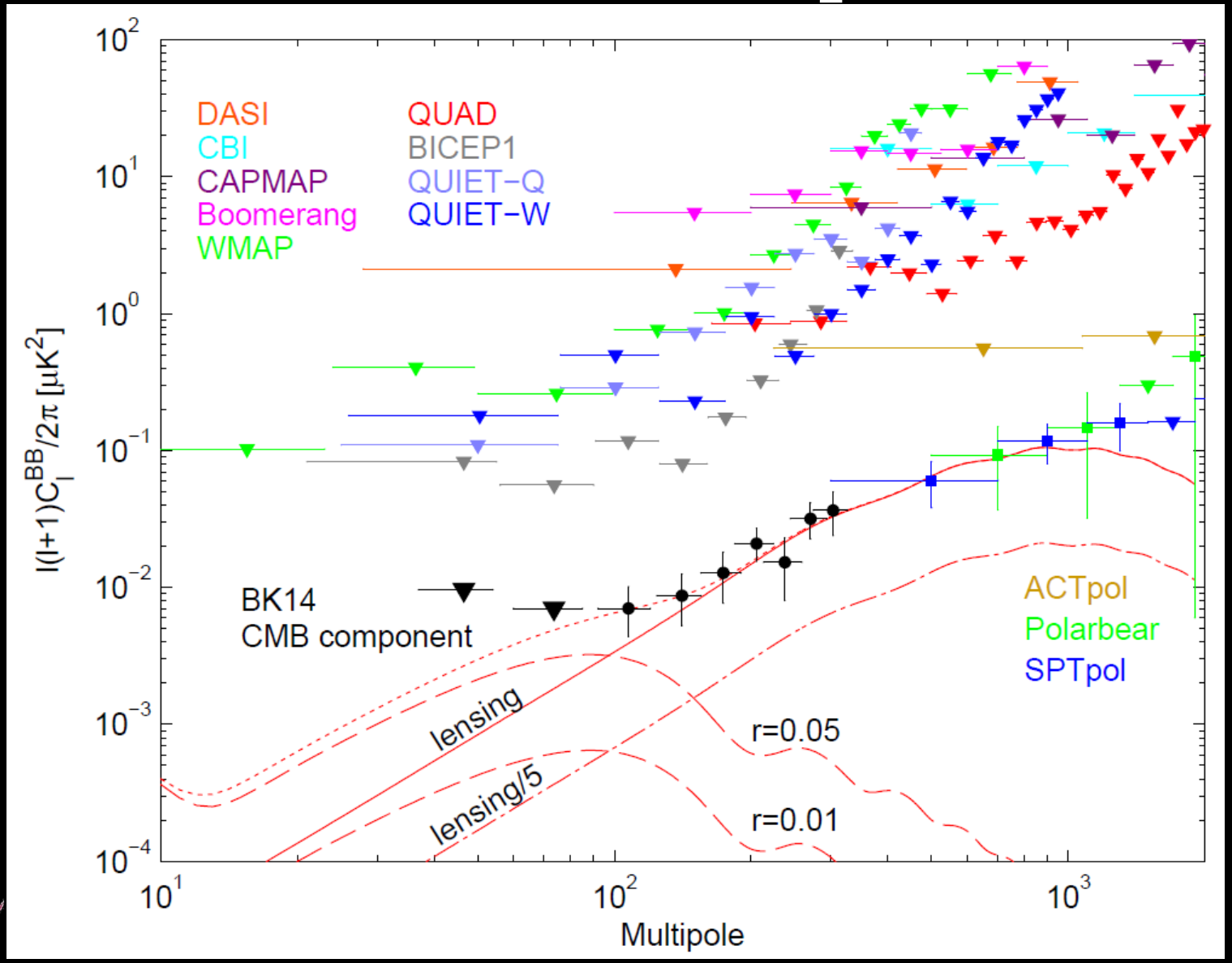
More Detectors!

We have deployed:

- 88 tiles in scientific use
- 10,000+ detectors
- Covering spectral 3 bands (95, 150, 220GHz)
- 270GHz deploys this year, 35GHz next year
- Higher frequencies under laboratory development

CMB B-Mode Spectra



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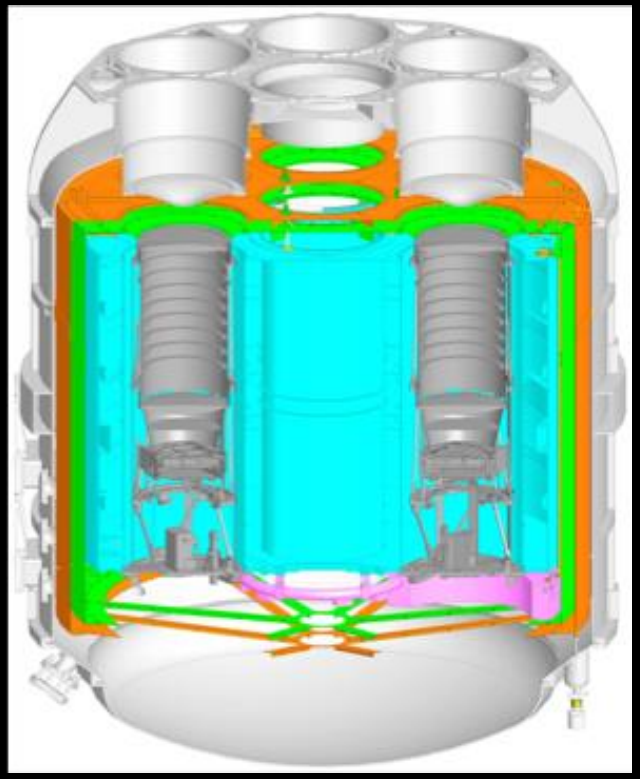
SPIDER



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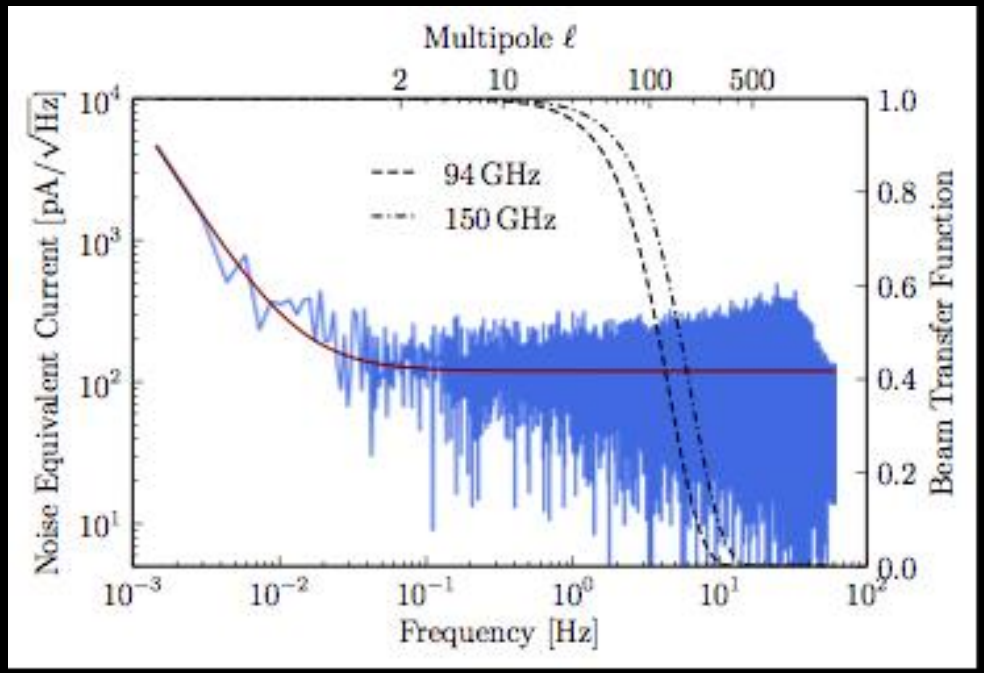
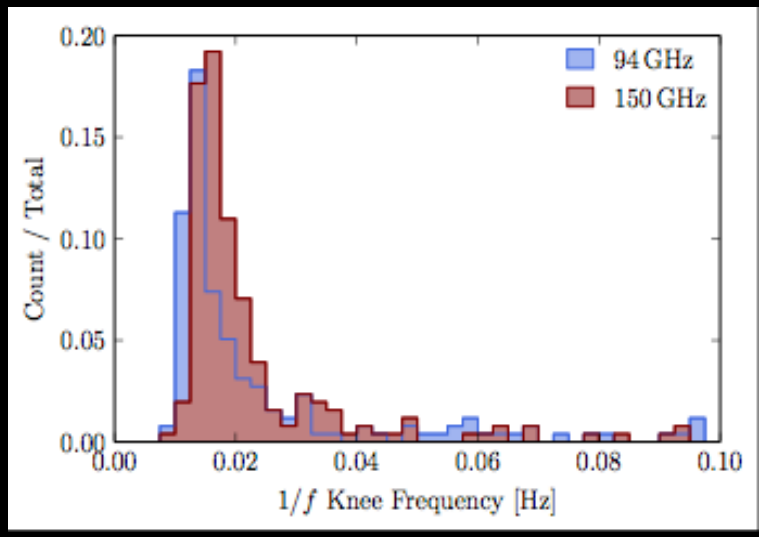
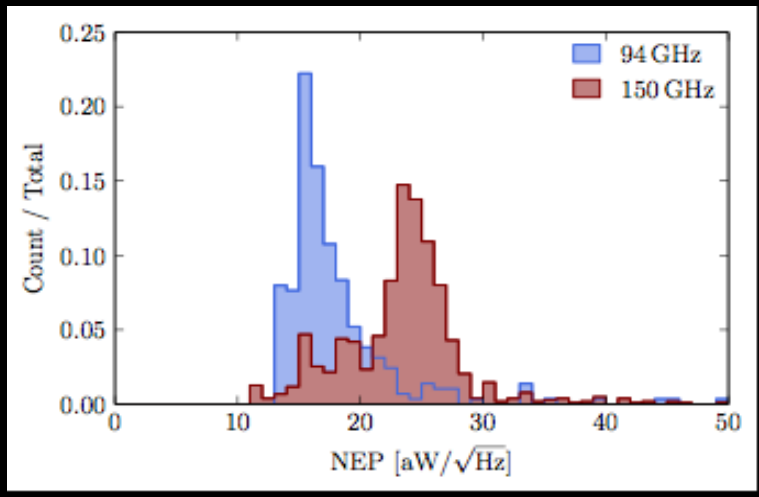
SPIDER *pre-flight* measurements

- Low 1/f knee
- White noise in science band of 0.5-8Hz (scan speed 3.6 °/s)







Anticipated NETs:

- 95GHz: 5.3μK_{CMB}√s
- 150GHz: 3.9μK_{CMB}√s

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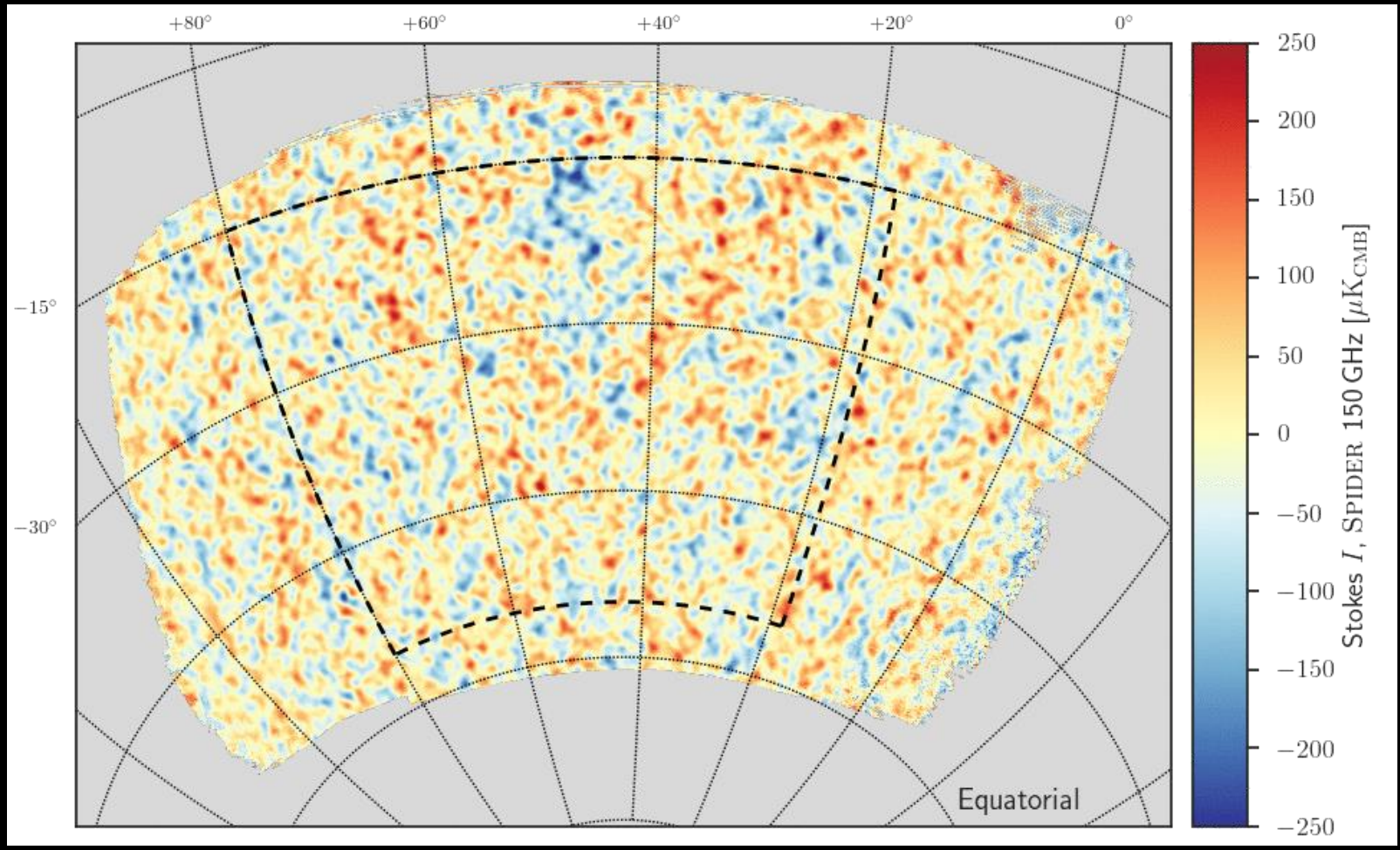
SPIDER



TRL: 6

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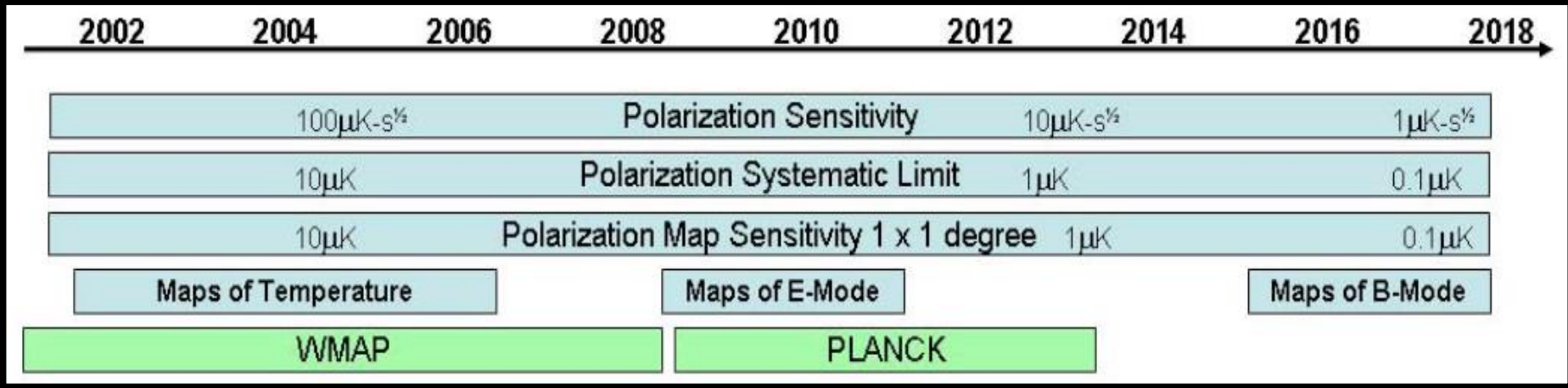
Where we are today

Task Force for CMB Research Weiss Report: Projected Timeline from 2005



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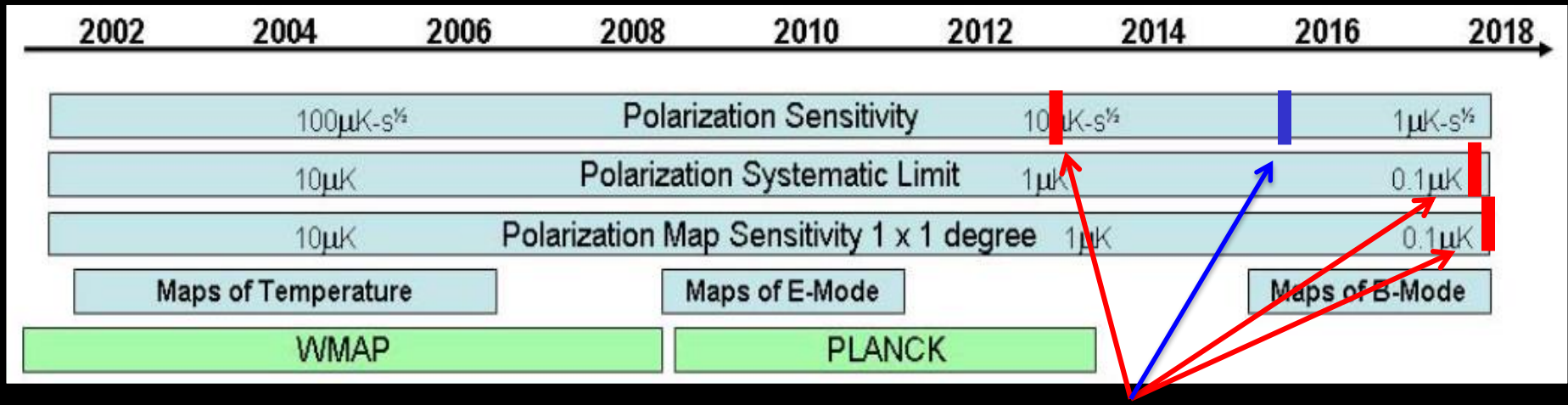

Where we are today in 2015 (Ground, Balloon)

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Where we are today

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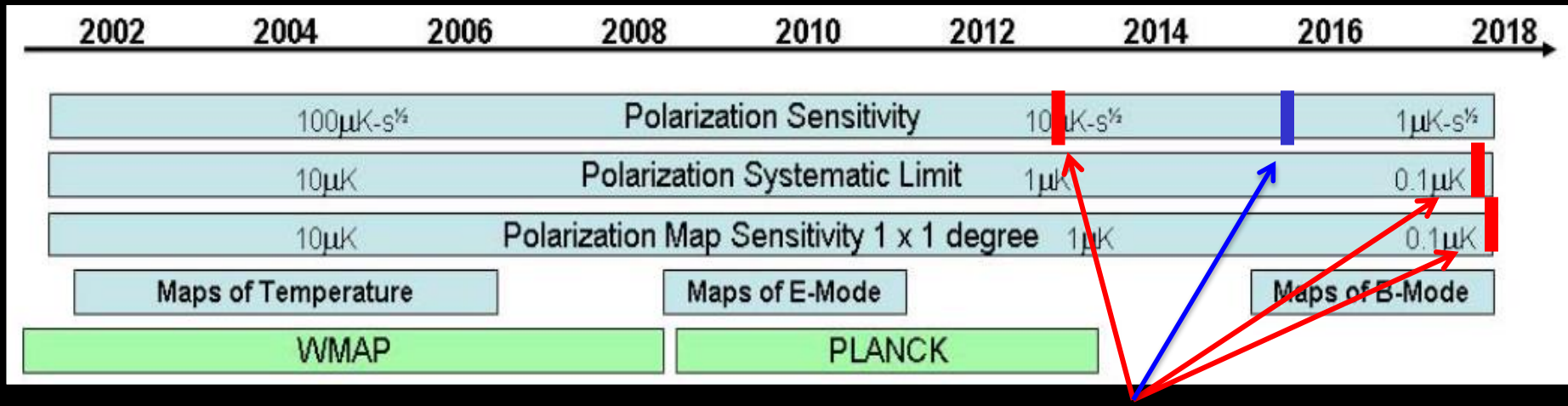

Where we are today in 2015 (Ground, Balloon)

Polarization Sensitivity: 9.5 uK √s (ground; Keck Array arXiv 15002.00643)
~4 uK √s (balloon; SPIDER priv. comm.)

Polarization Systematics: < 2σ instrument sensitivity $2(\Delta D_\ell)^{1/2}$ ~ 60 nK at ℓ = 100
(BICEP II/Keck arXiv 1510.09217)

Polarization Map Sensitivity: 50 nK-deg in 395 sq. deg.
(BICEP II/Keck arXiv 1510.09217)

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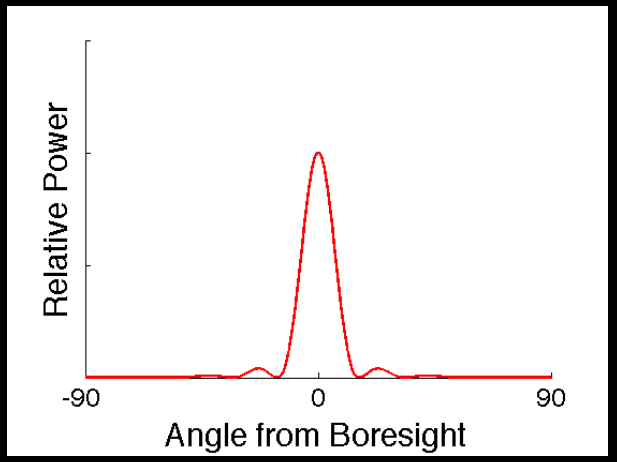
Illumination Patterns

- Top-hat:
  - BICEP2
  - Keck
  - SPIDER

Fourier Transform



Illumination Patterns

- Top-hat:
  - BICEP2
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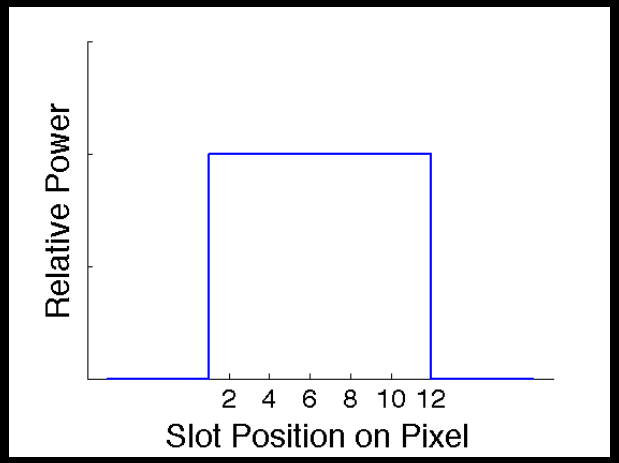
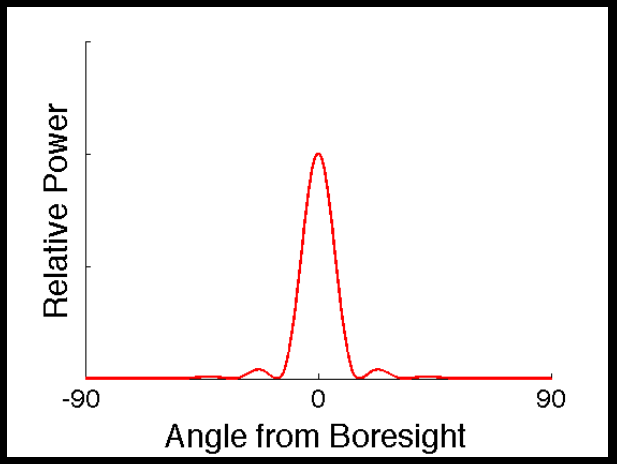
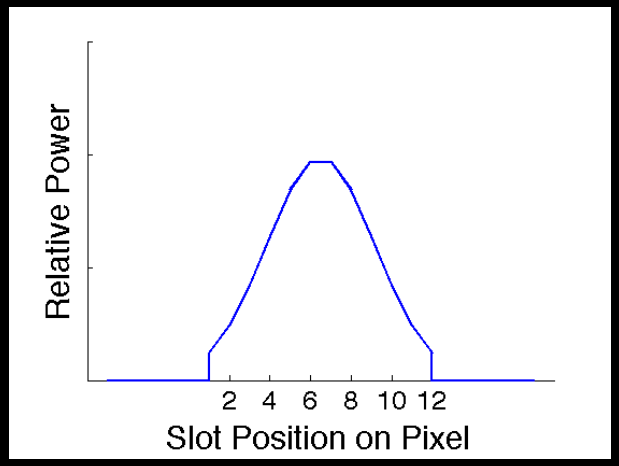
  - SPIDER



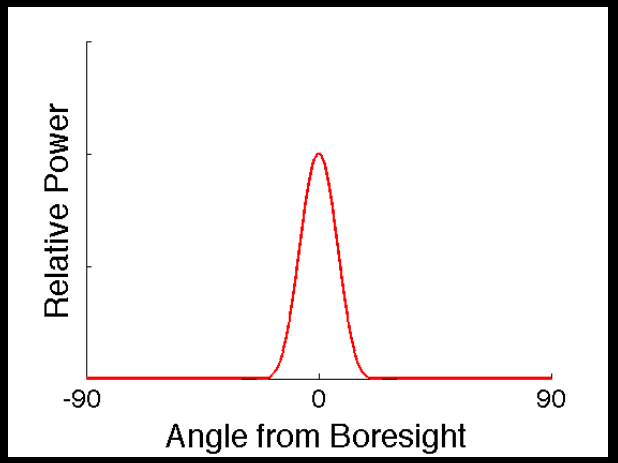
Fourier Transform →



- Gaussian:
  - BICEP3
  - BICEP Array



Fourier Transform →



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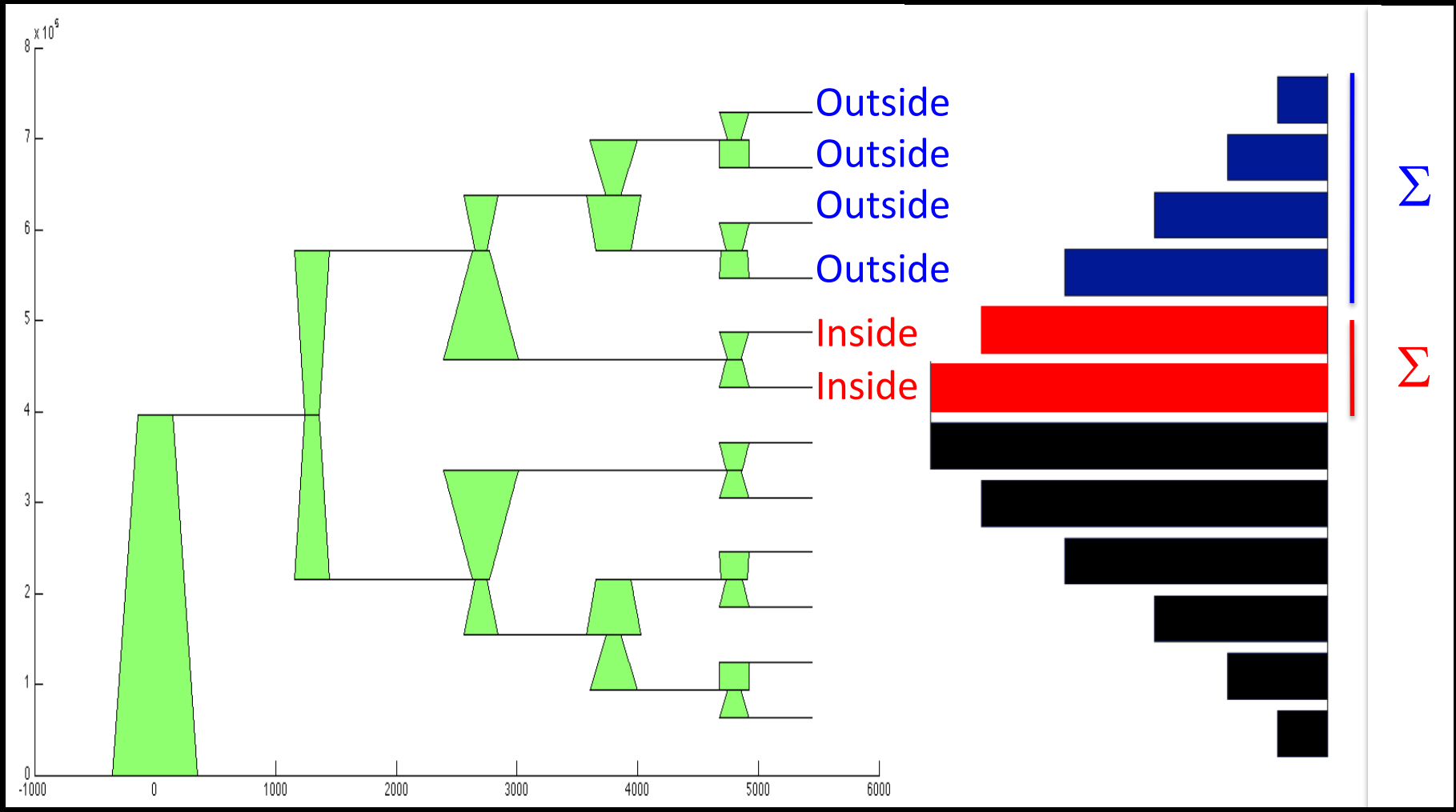
Illumination Patterns



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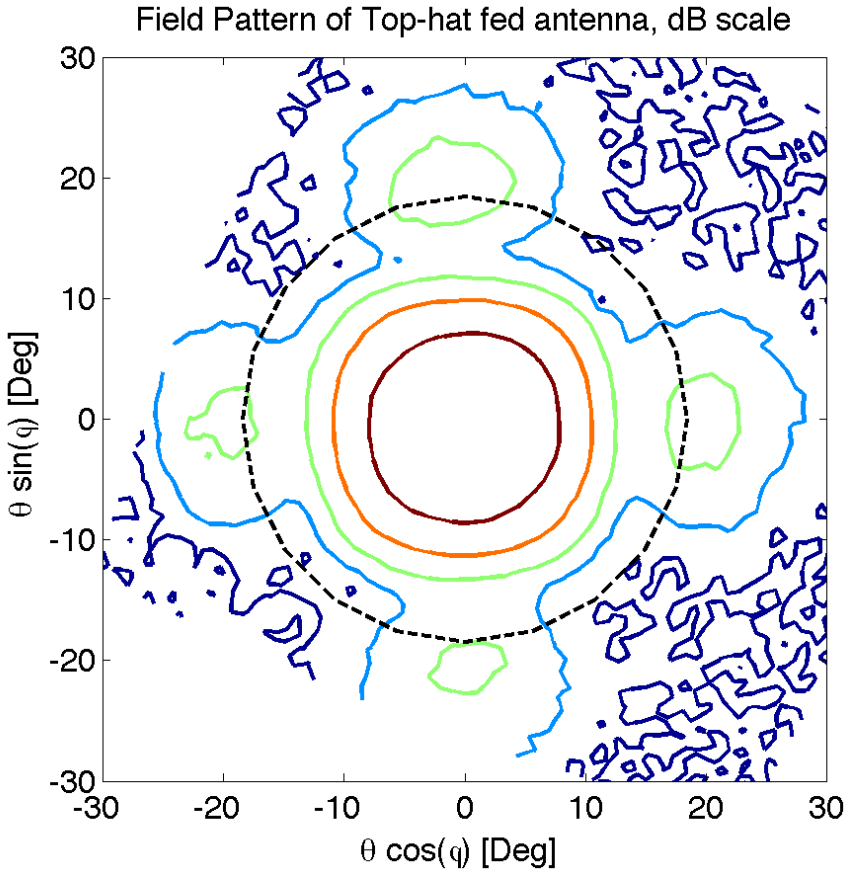
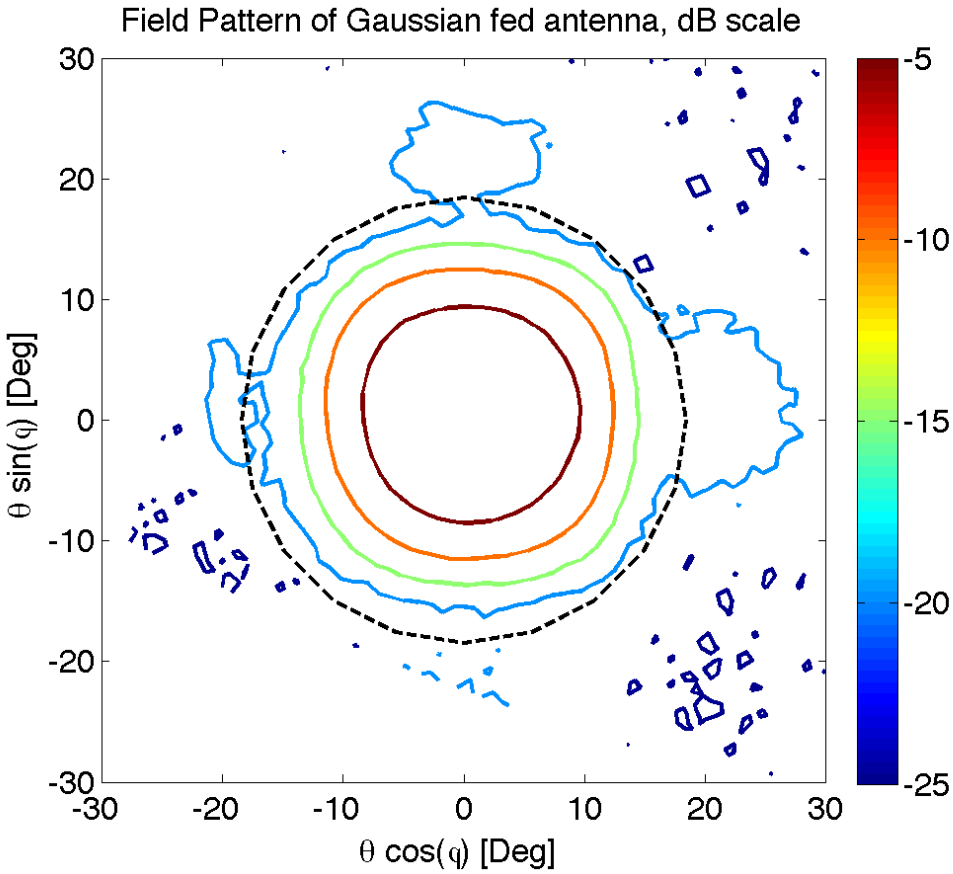
Patterns of Tophat & Gaussian Feeds





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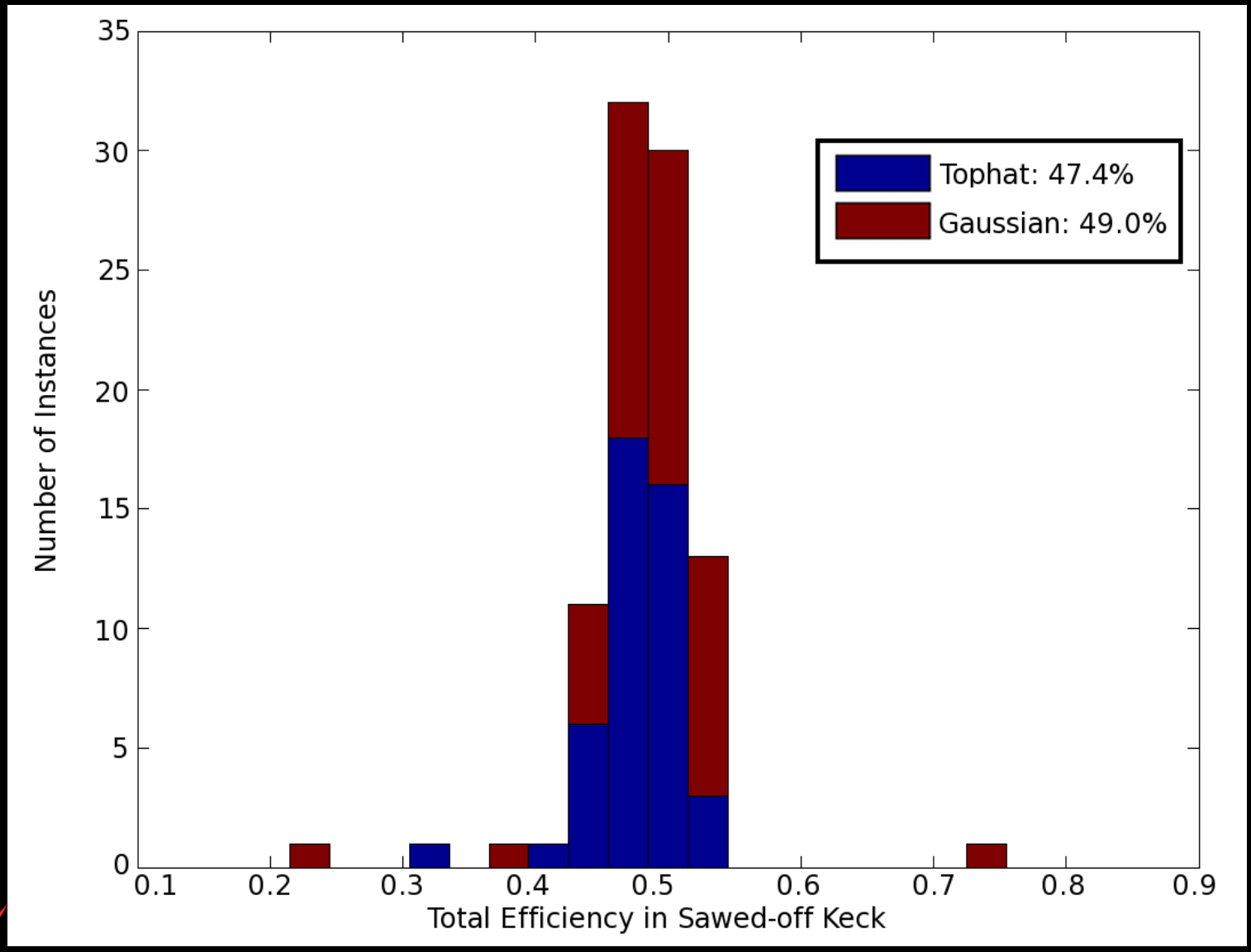
Optical Efficiency



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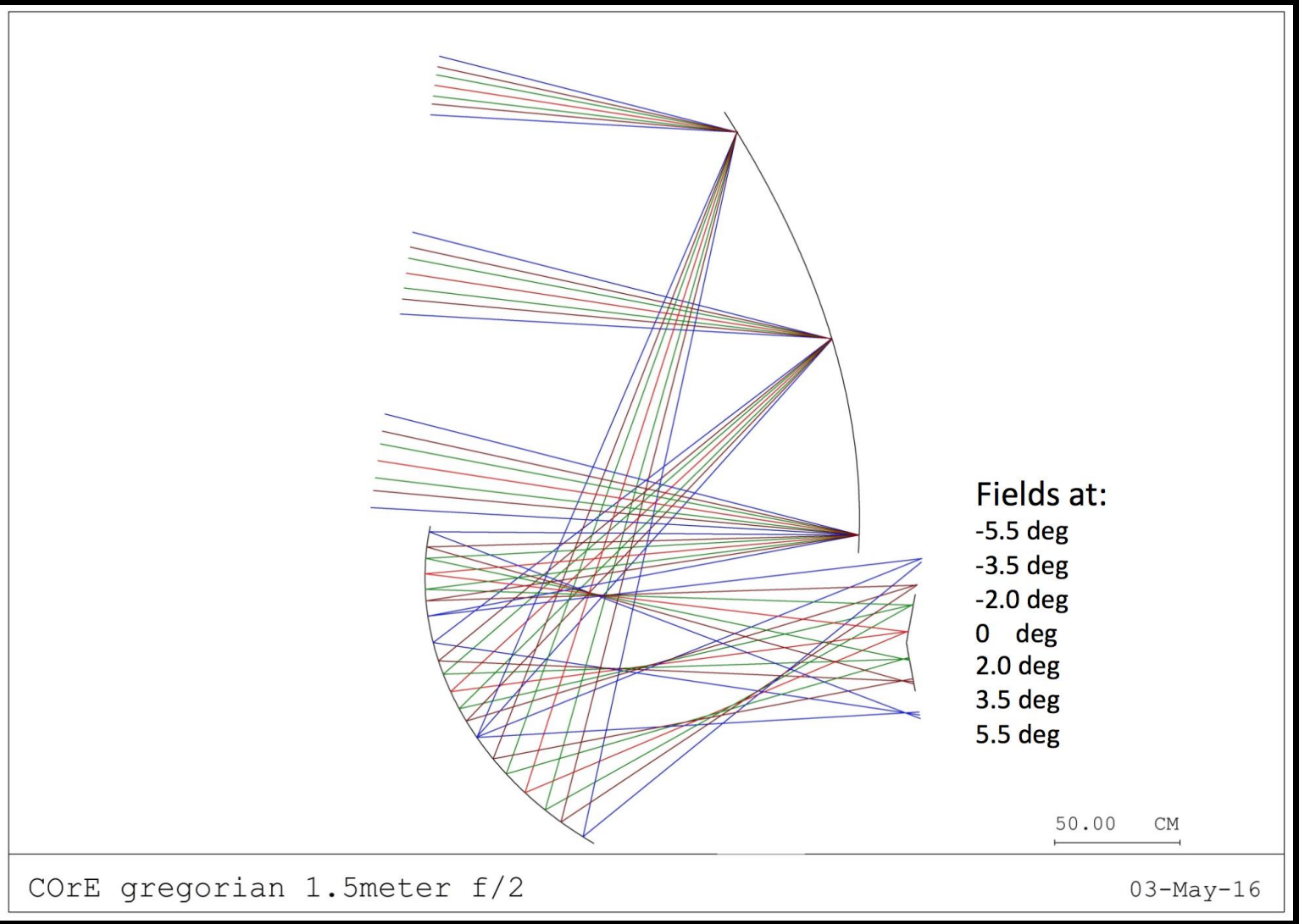
Baseline CORE+ Optics



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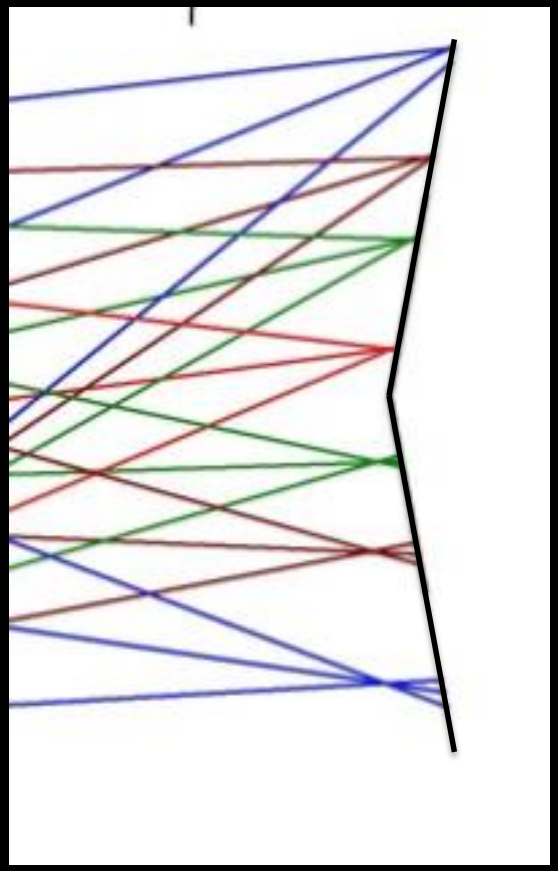
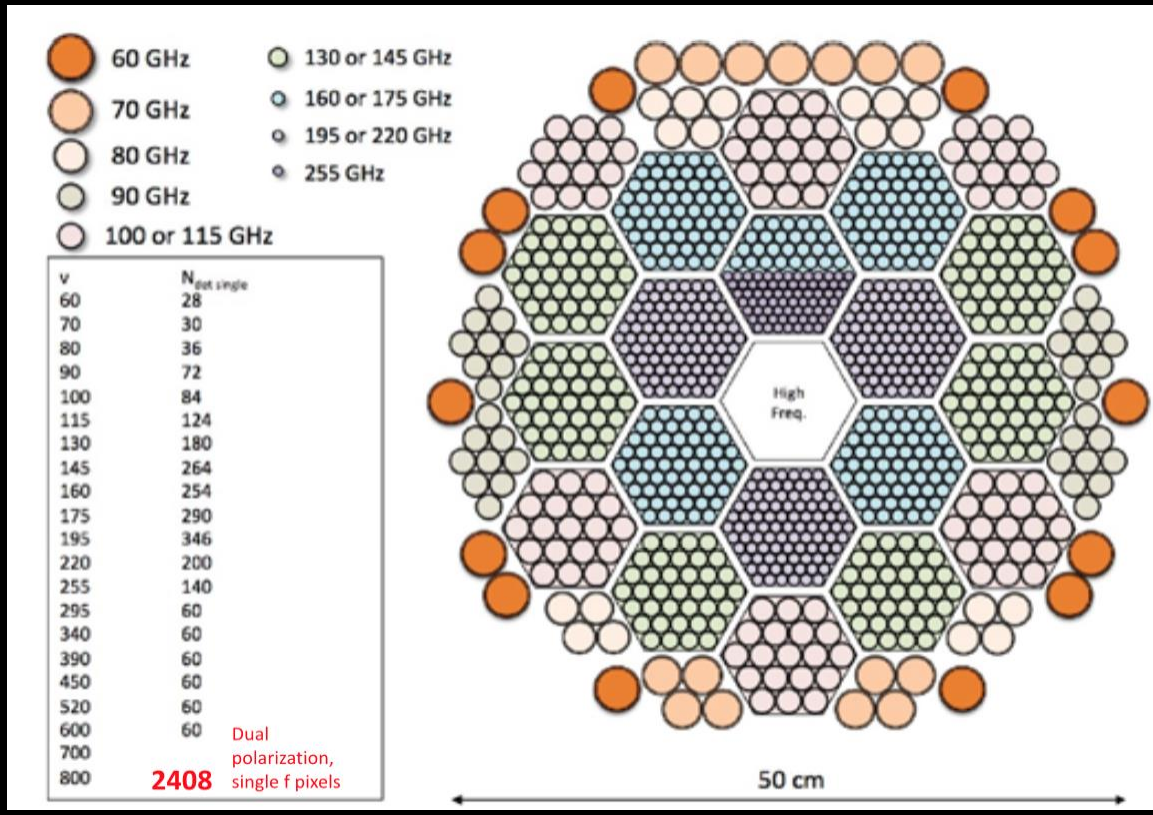
Baseline CORE+ Optics



No more than 30°



ν	$N_{det\ single}$
60	28
70	30
80	36
90	72
100	84
115	124
130	180
145	264
160	254
175	290
195	346
220	200
255	140
295	60
340	60
390	60
450	60
520	60
600	60
700	
800	**2408**

Dual polarization, single f pixels

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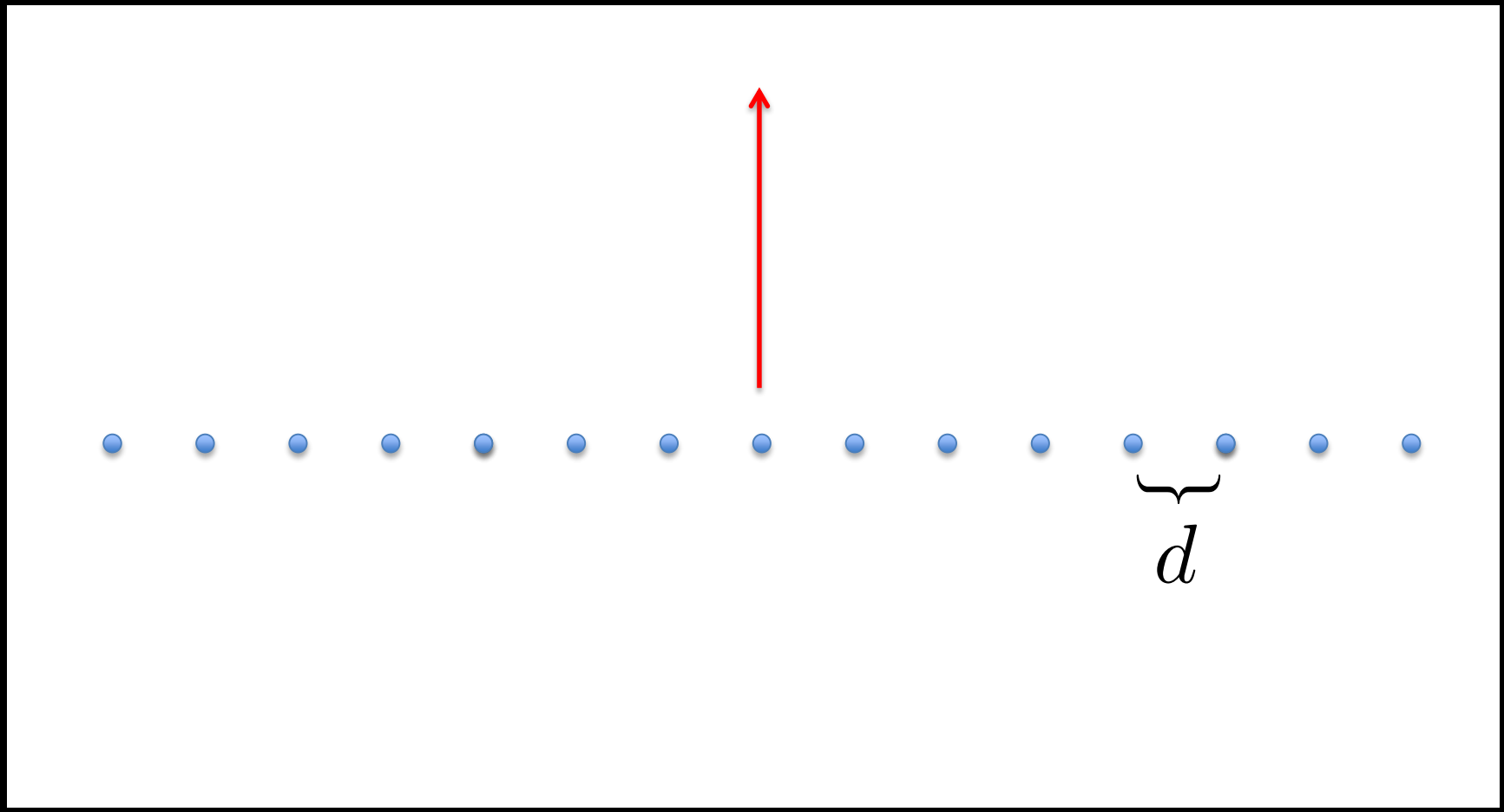
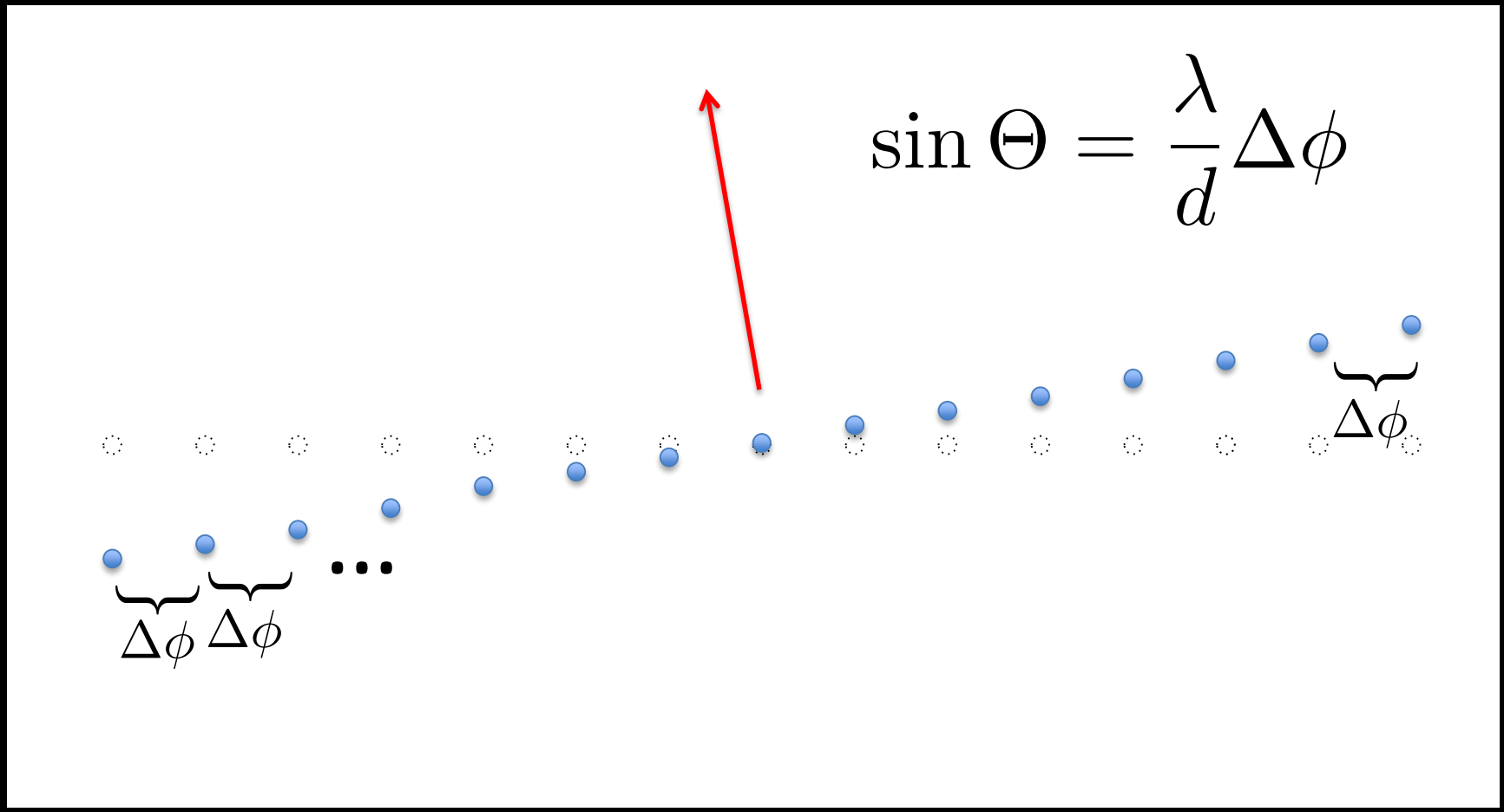
Linear Phase delays



Linear Phase delays

Linear Phase delays



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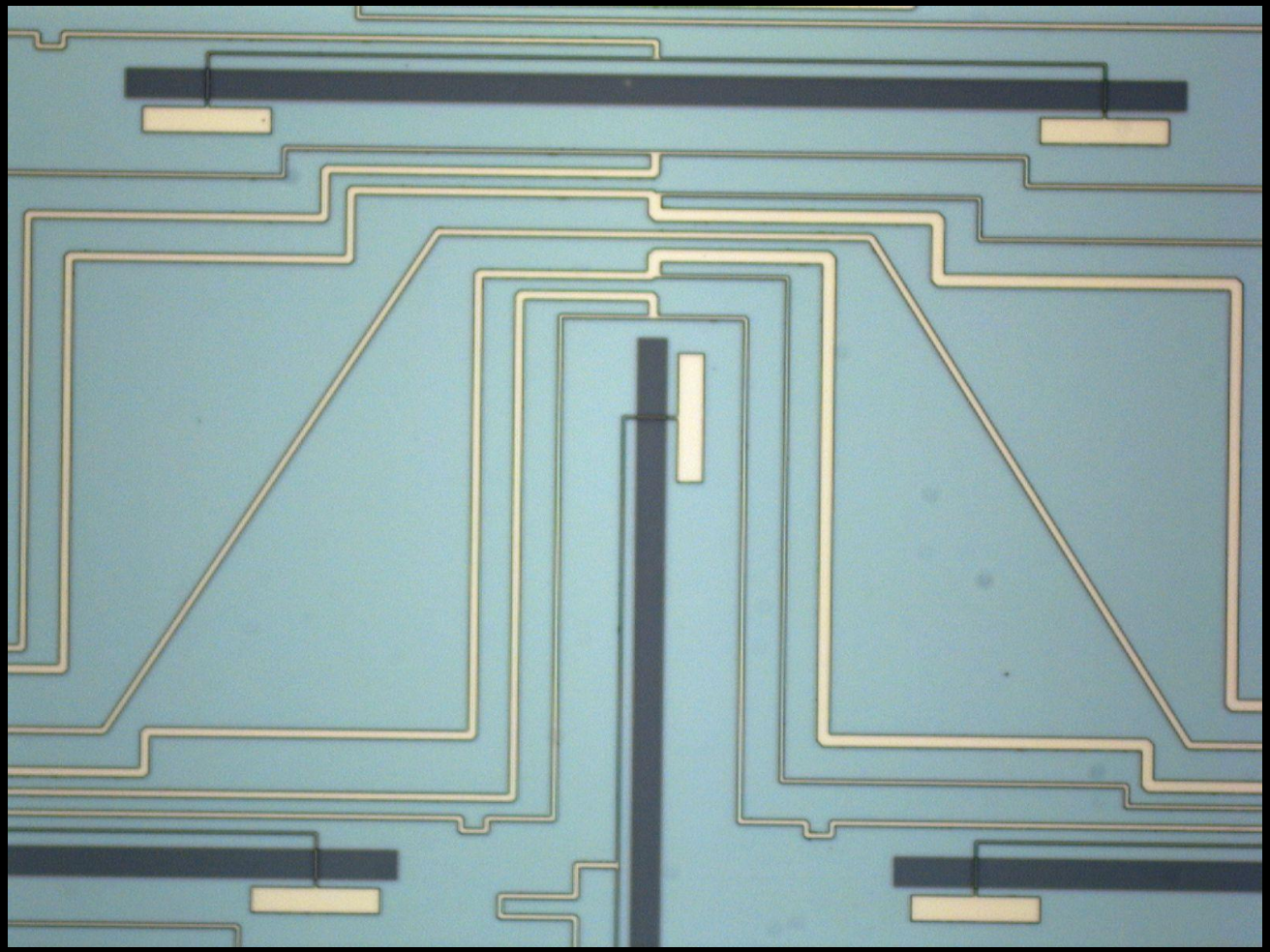
Phase Lags



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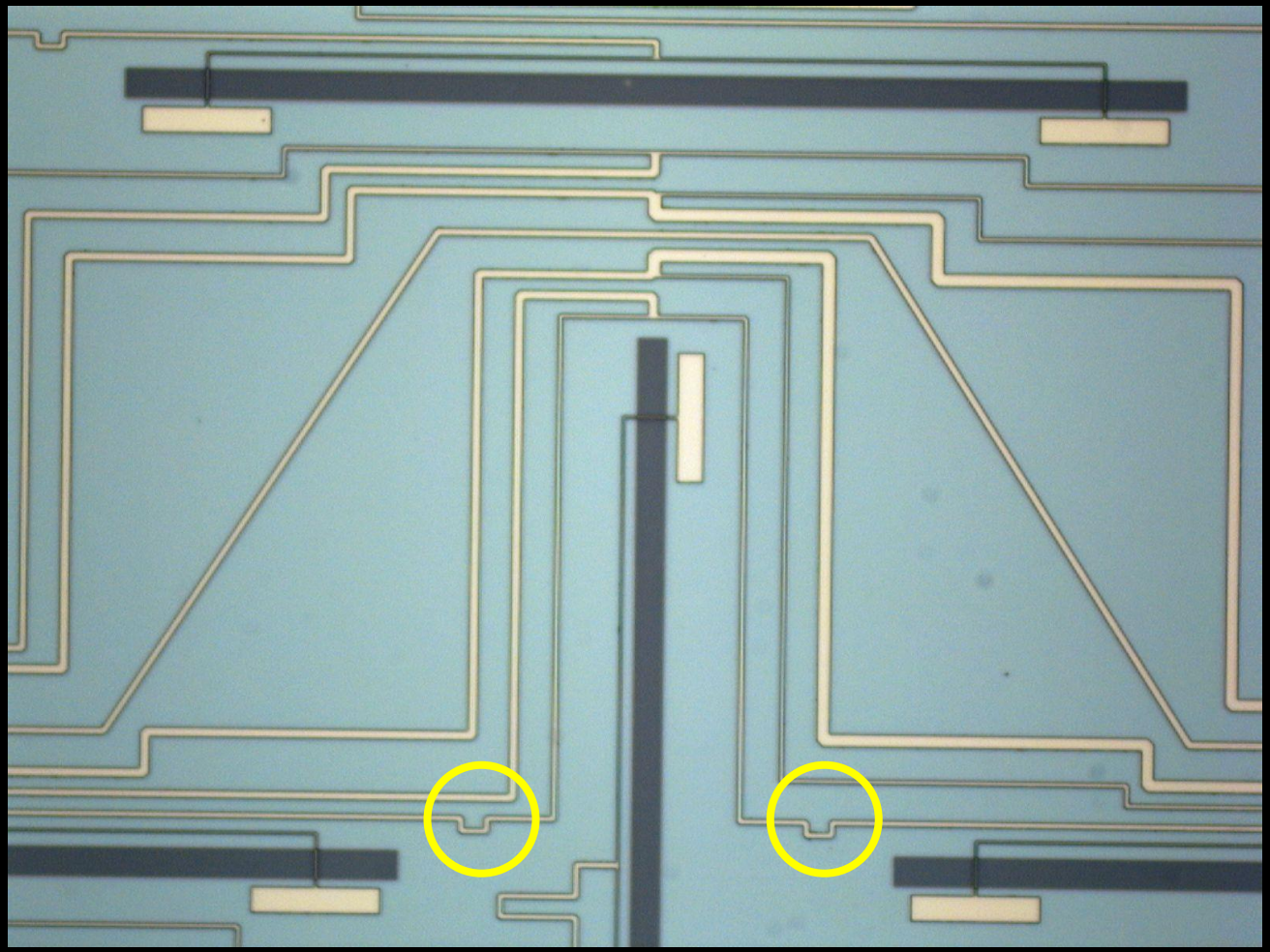
Phase Lags



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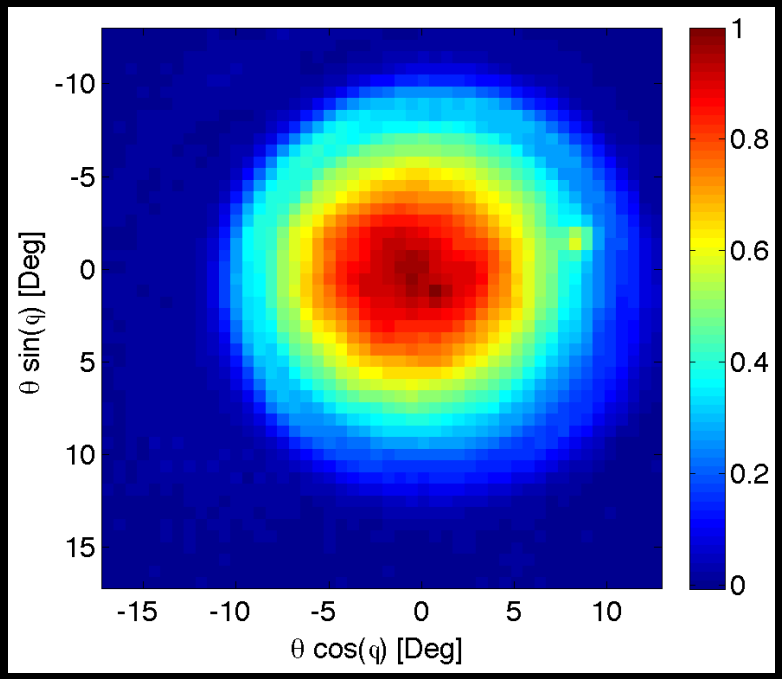
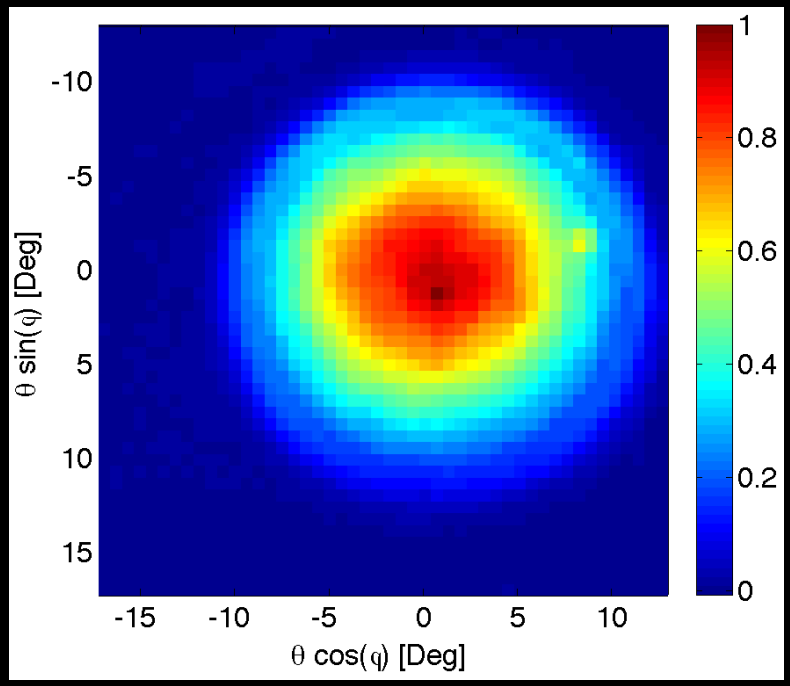
Beam Differences

Polarization A



Polarization B



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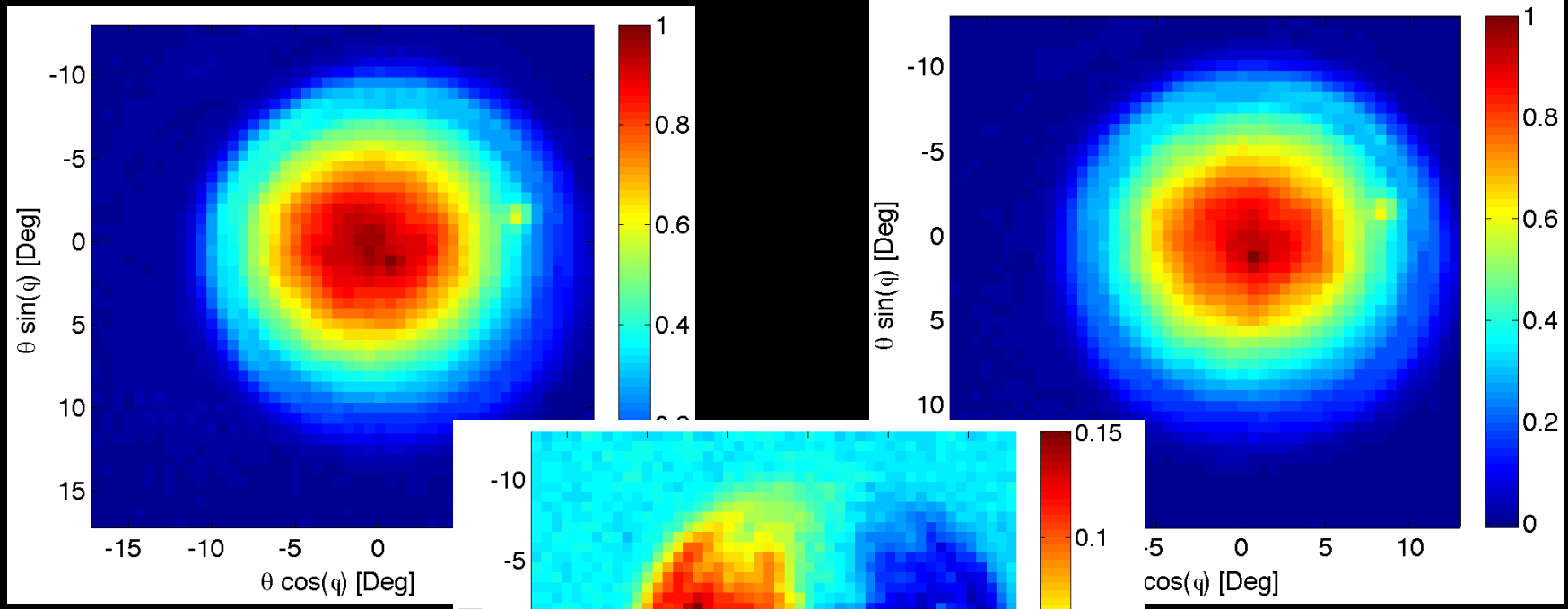
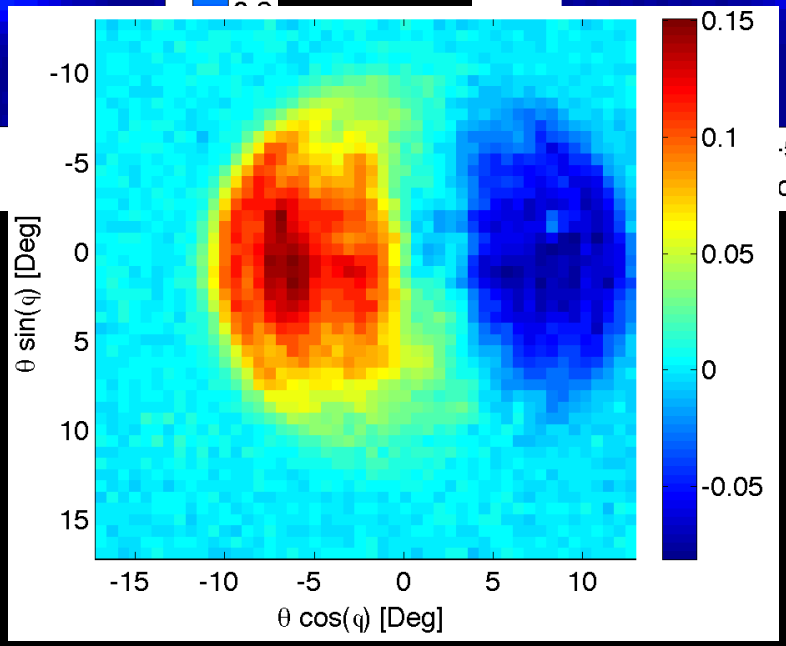
Beam Differences

Polarization A

Polarization B





Difference:
A-B

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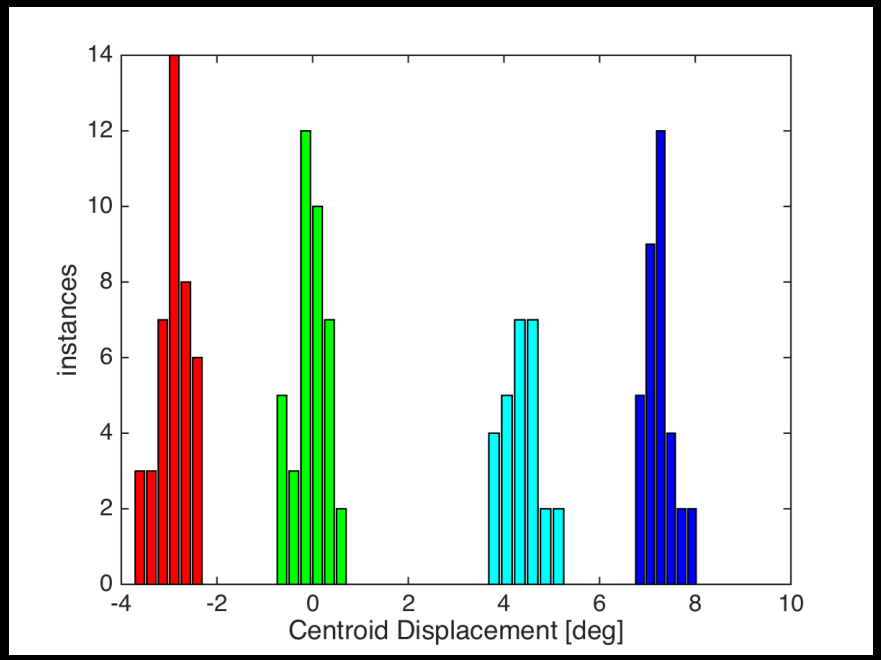
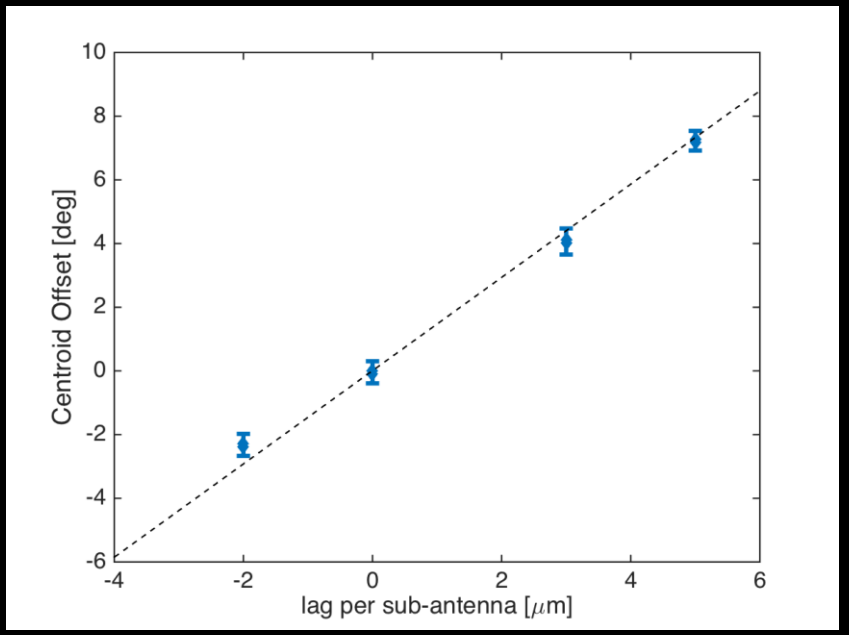
Centroid Differences





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Outline

- Mature Detectors
  - Overview of instruments
  - BICEP/Keck Program
  - SPIDER
- Flexible Technology
  - Tophat vs gaussian
  - Steerable beams

Thank you

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