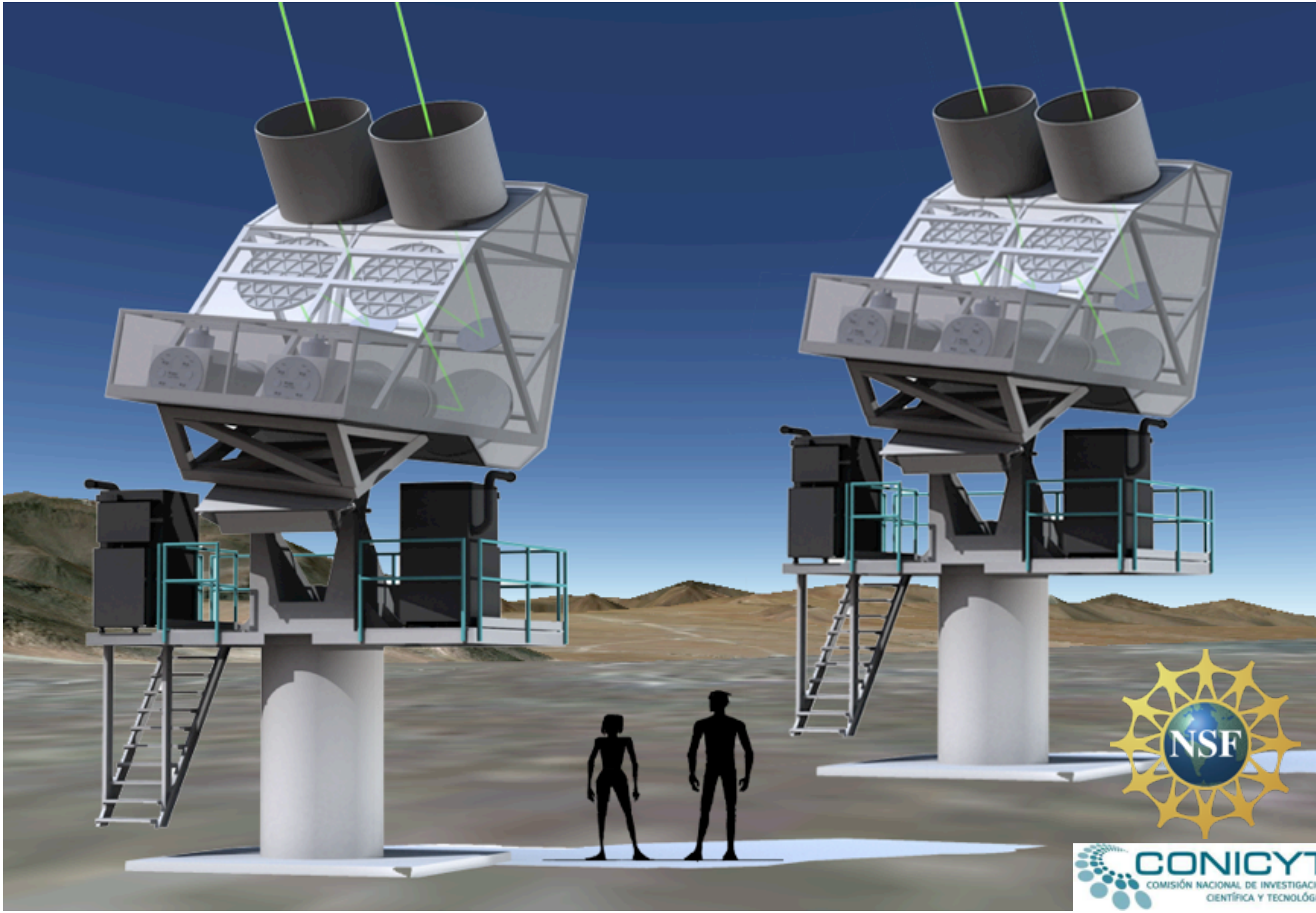
Cosmology Large Angular Scale Surveyor



T. Marriage for the CLASS Collaboration
U. Michigan — Cosmology After Planck — Sep 24, 2013

CLASS Collaborators

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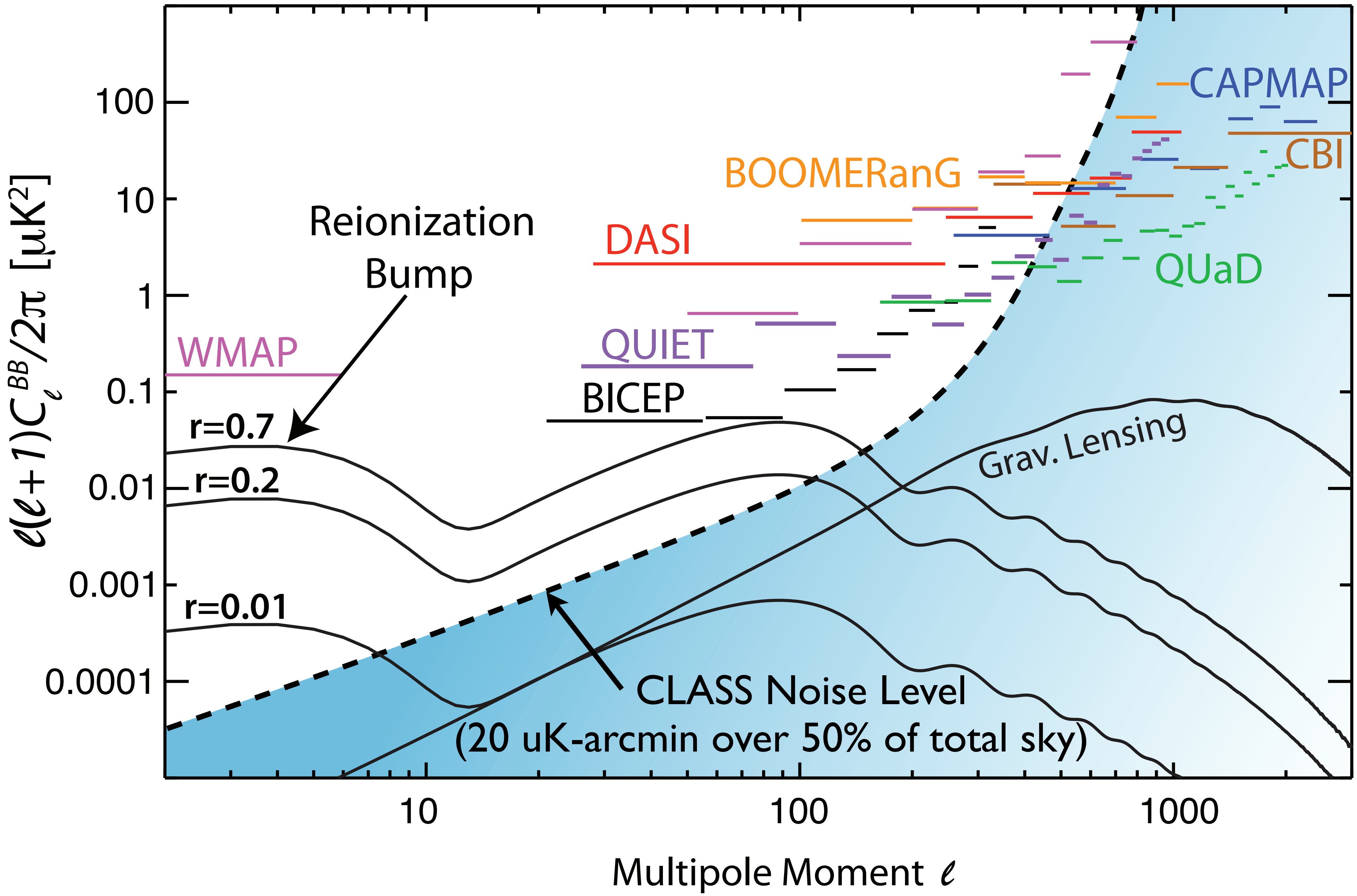
CLASS targets CMB **B-modes** at **large angles**.

1) **Recombination bump** packs a **lot of signal**.

2) **Avoids lensing B-modes**.

Also E-mode **Reionization** Constraints



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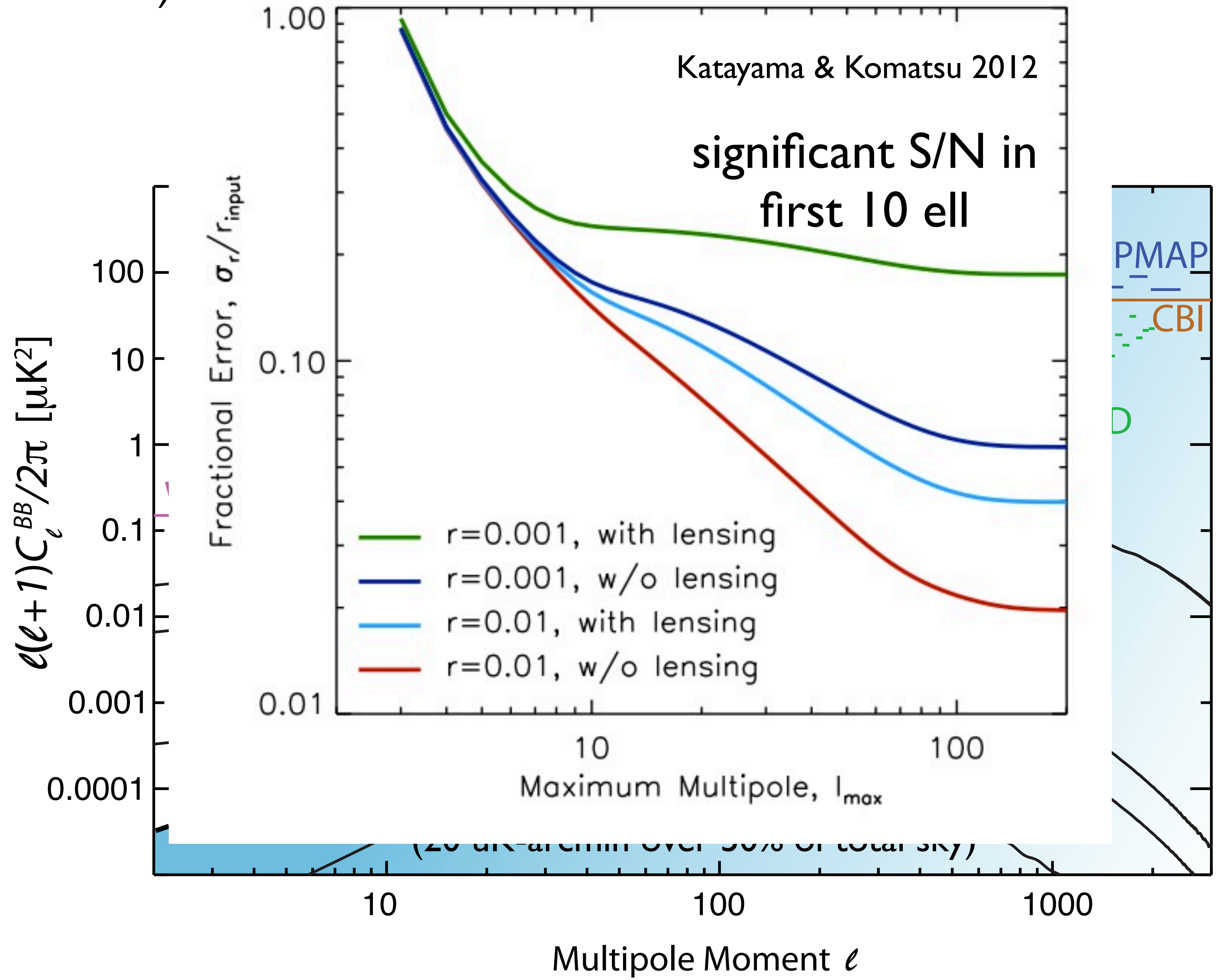

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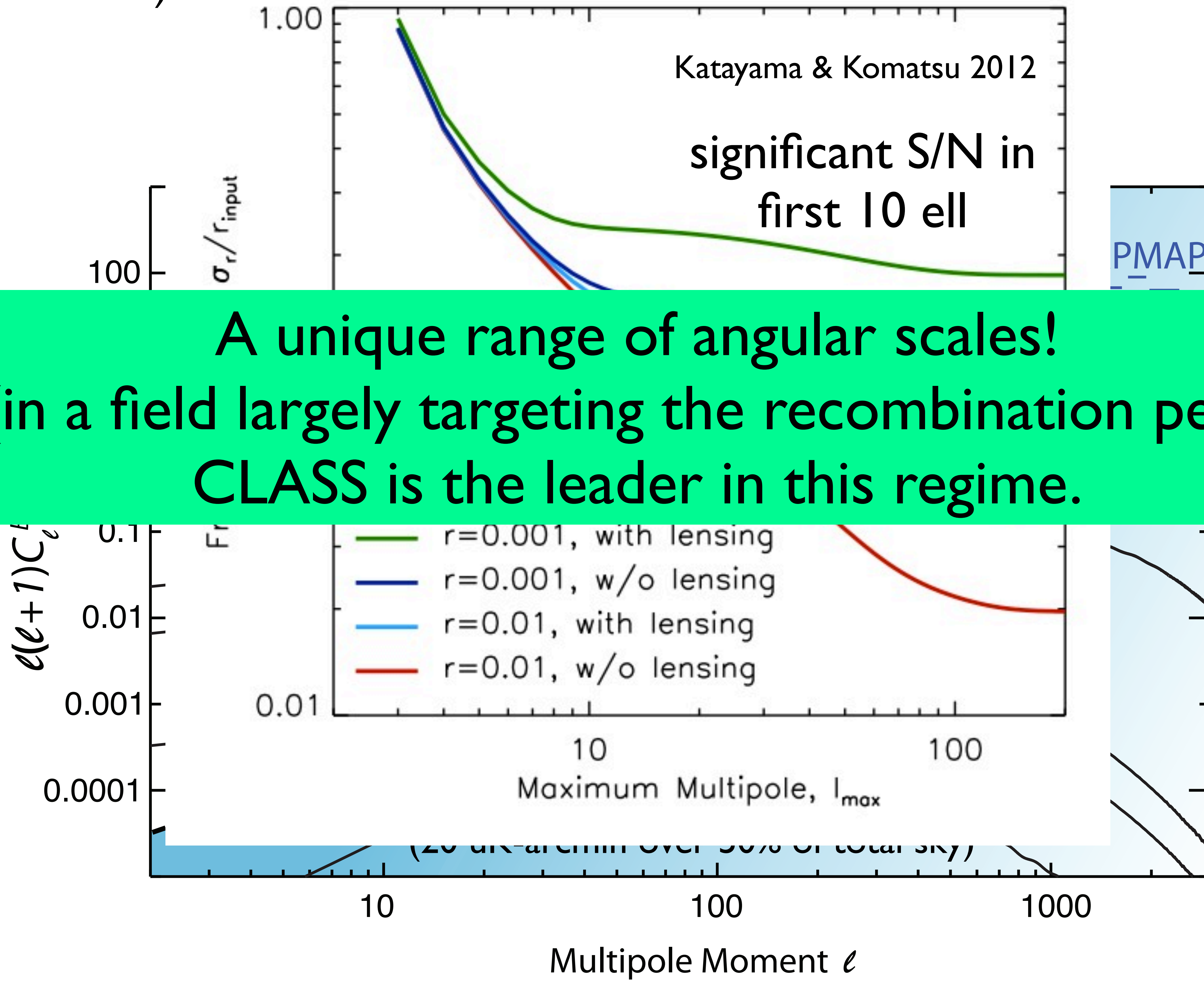
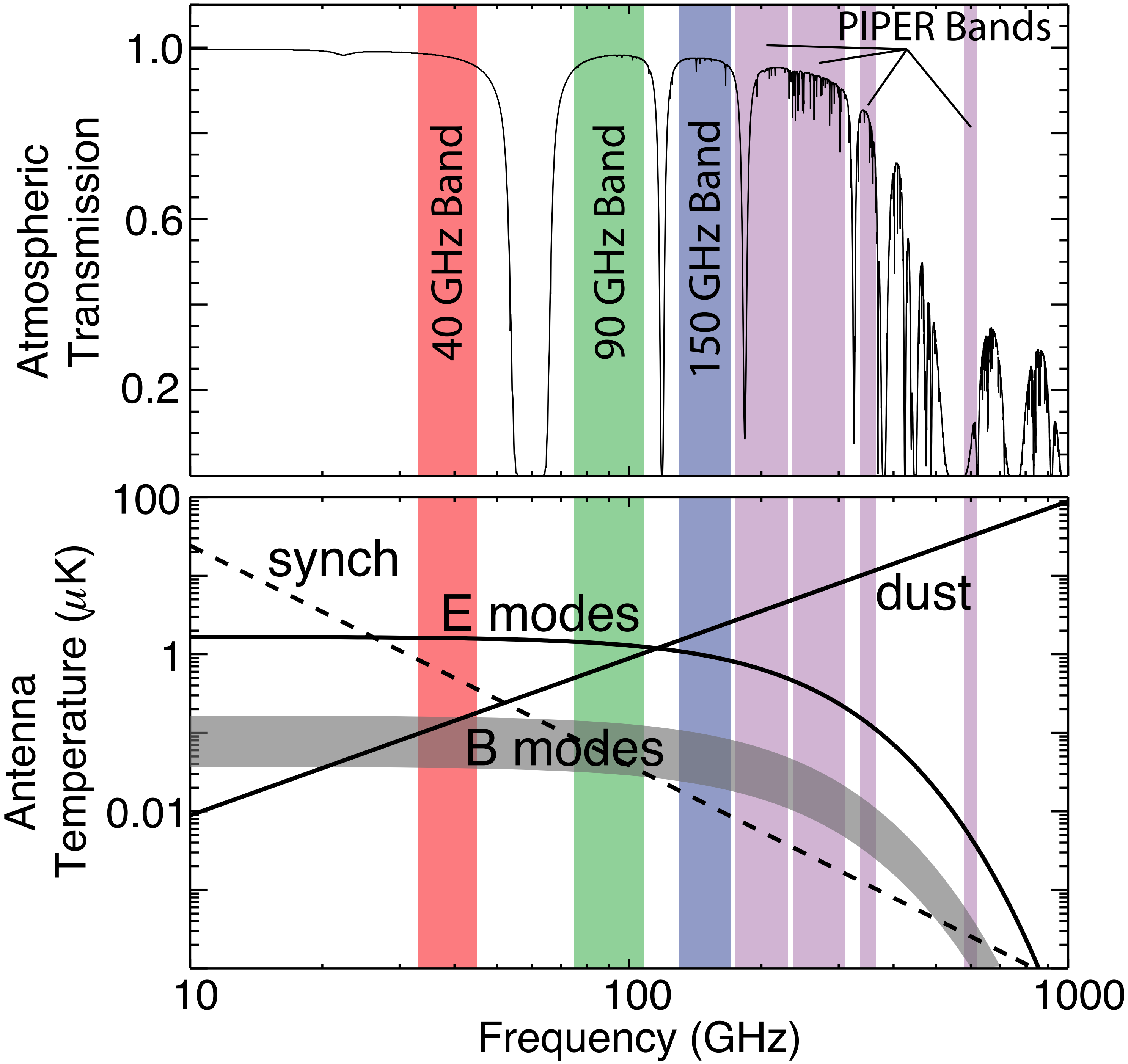


A unique range of angular scales!
(in a field largely targeting the recombination peak)
CLASS is the leader in this regime.



CLASS is an **array of 4 telescopes** operating at **three frequencies** that straddle the **foreground minimum**.

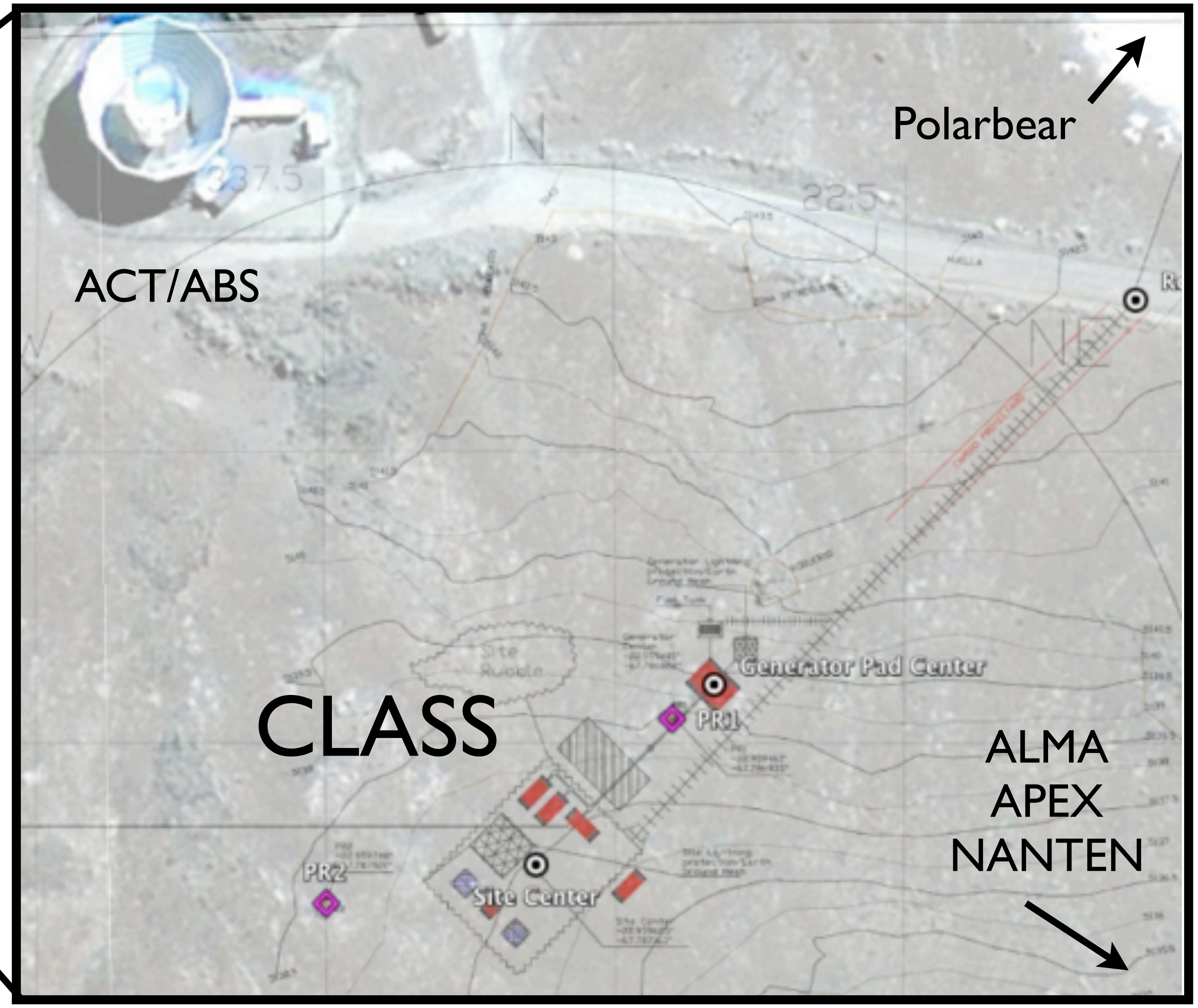
Additional foreground constraints from PIPER (200 GHz, 270 GHz) and Planck (217, 353 GHz)

CLASS Survey Design Parameters

Frequency	Detectors	Resolution
40 GHz	72	1.5°
90 GHz	1200	40'
150 GHz	120	24'

To detect **large-angle modes**, CLASS needs a **wide survey**.

The Atacama is the best site for large sky coverage.

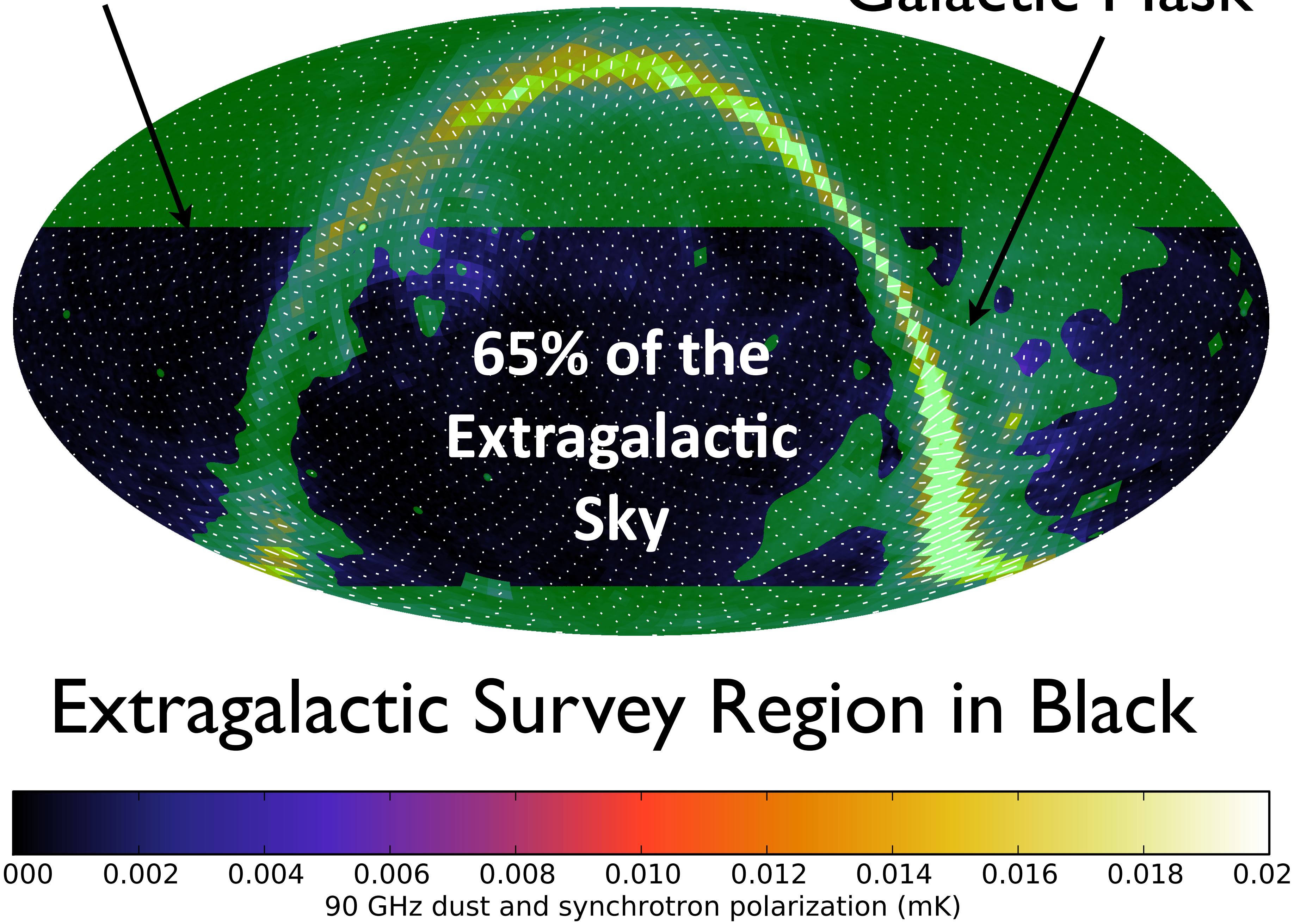


Site in Atacama Desert is not far from the equator: **most of sky** is surveyed at zenith angle 45 deg.

To detect **large-angle modes**, CLASS needs a **wide survey**.

CLASS Survey Boundary

Galactic Mask

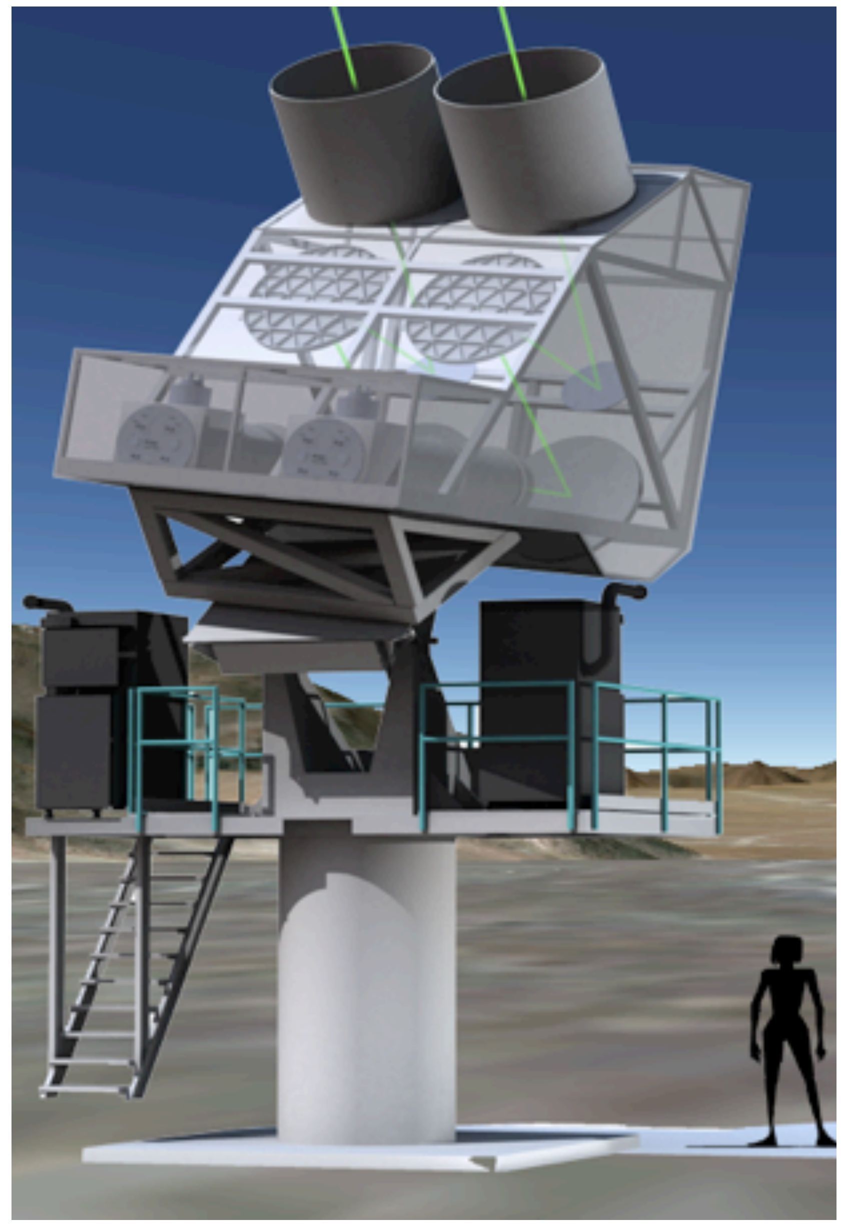


Extragalactic Survey Region in Black

Site in Atacama Desert is not far from the equator: **most of sky** is surveyed at zenith angle 45 deg.

To detect **large-angle modes**, CLASS needs a **wide survey**.

Multiple observing angles through **sky** and **deck rotation**



in the JHU highbay

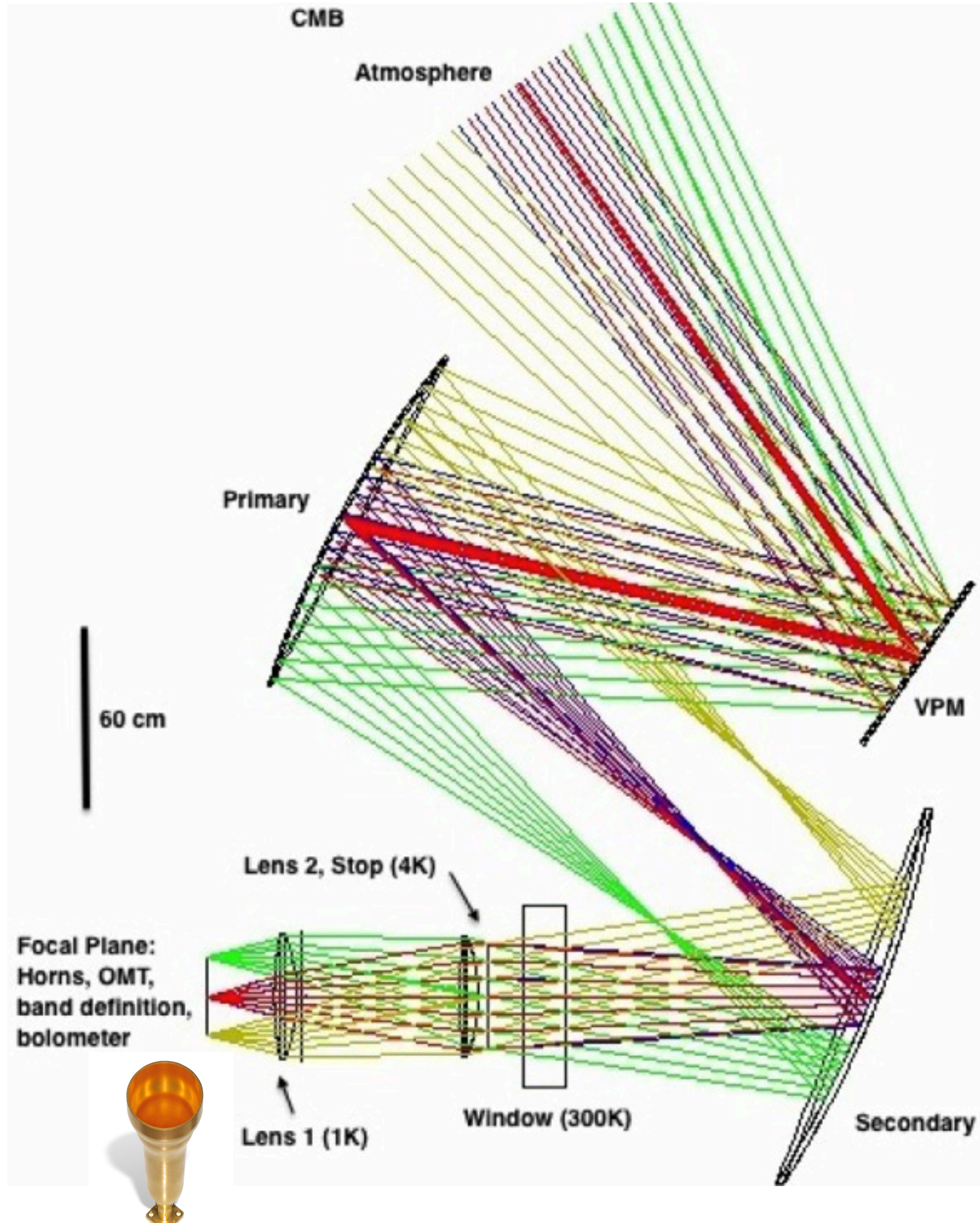
Site in Atacama Desert is not far from the equator: **most of sky** is surveyed at zenith angle 45 deg.

The CLASS Way

1. Systematics control with front end modulation.

2. Sensitivity with high efficiency optics and TES bolometers cooled to 150 mK.

3. Galactic foreground cleaning with multi-frequency telescope array.



The CLASS Way

1. Systematics control with front end modulation.

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Continuous Operation with 50 μW at 100 mK

One of the four CLASS receivers (PT+DR Cooler) undergoing tilt test.

The CLASS Way

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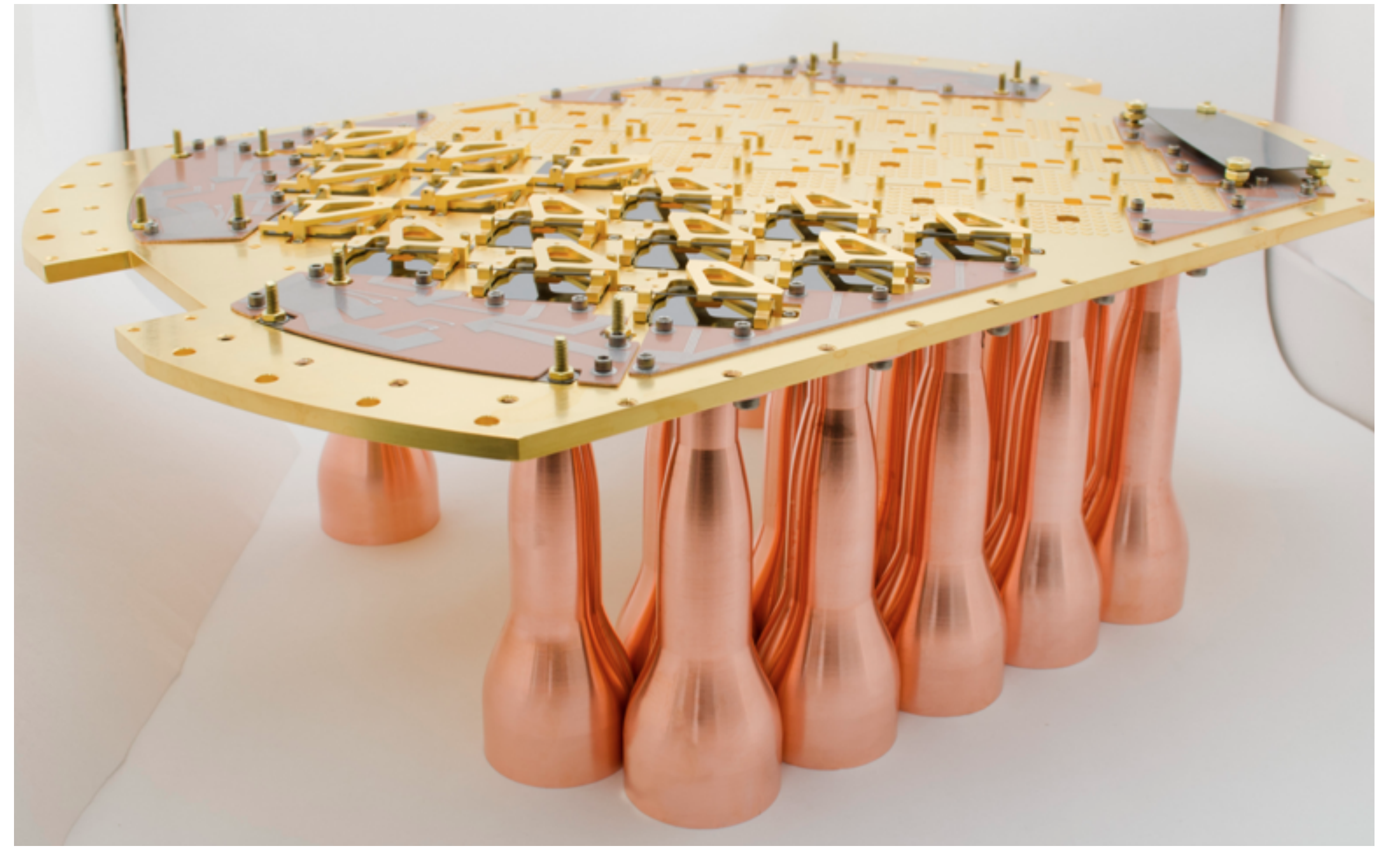


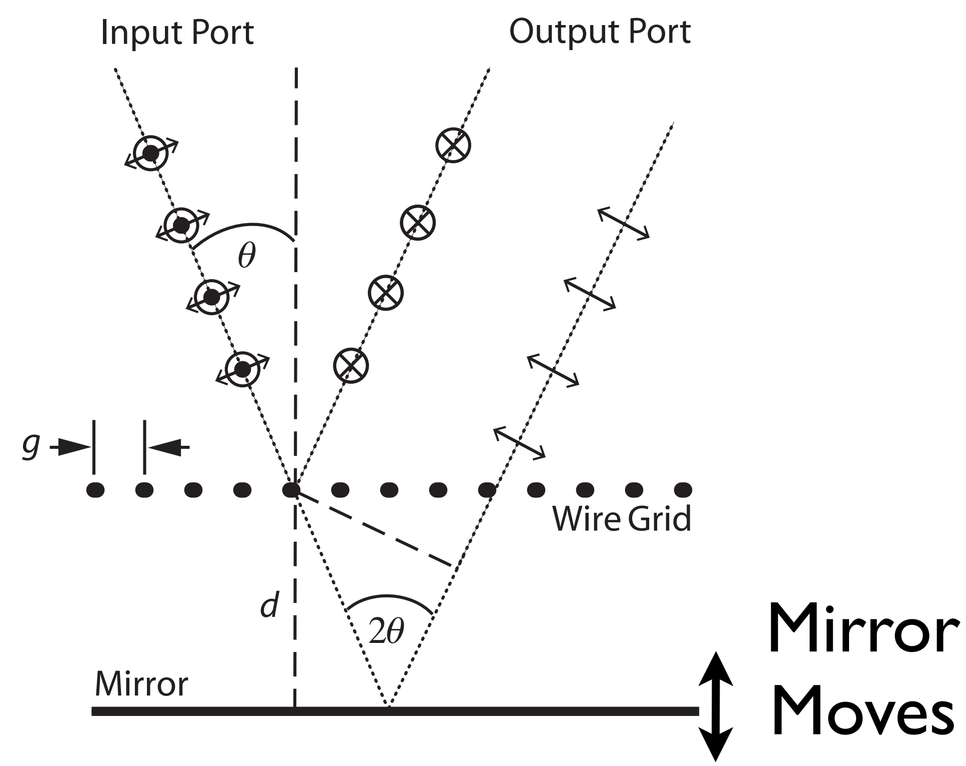
40 GHz Focal Plane Assembly.

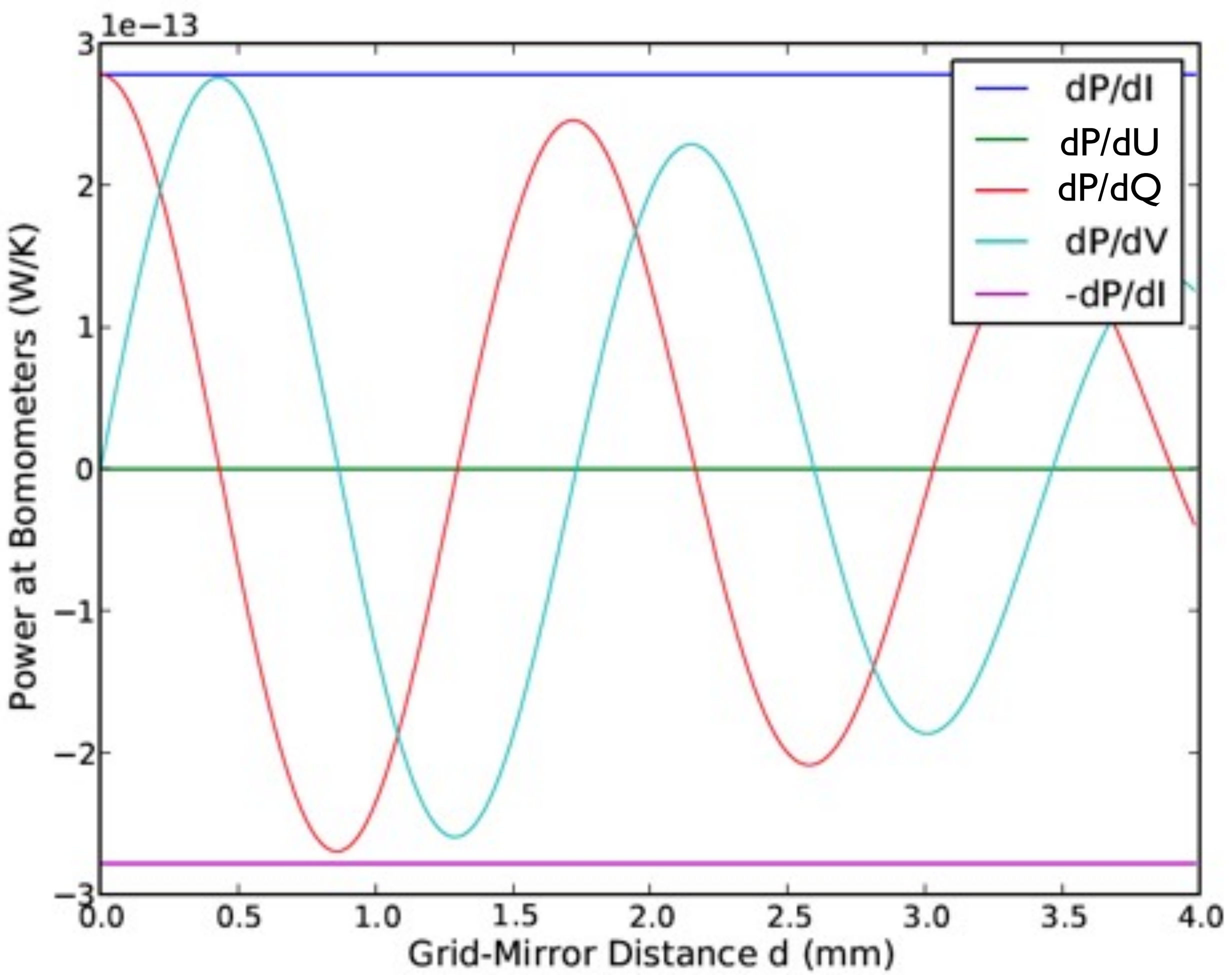
The CLASS Way #1: Systematics control with front end modulation

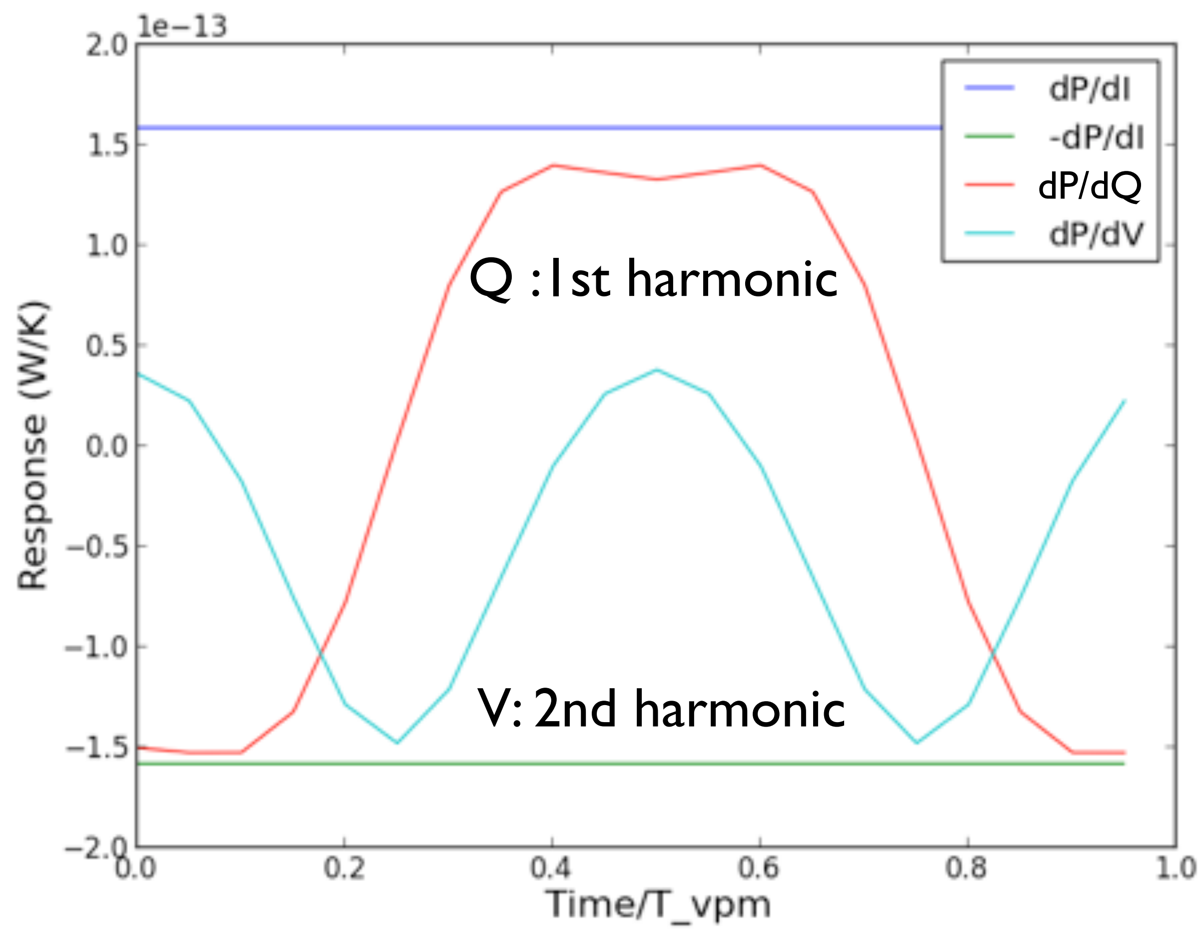
CLASS uses **modulation** to measure **large scales.**

A Variable-Delay Polarization Modulator (VPM) is the front-end optical element.

Modulates signal at **~5 Hz** to separate signal from the I-to-Q leakage of atmosphere and other instrument-related drift.



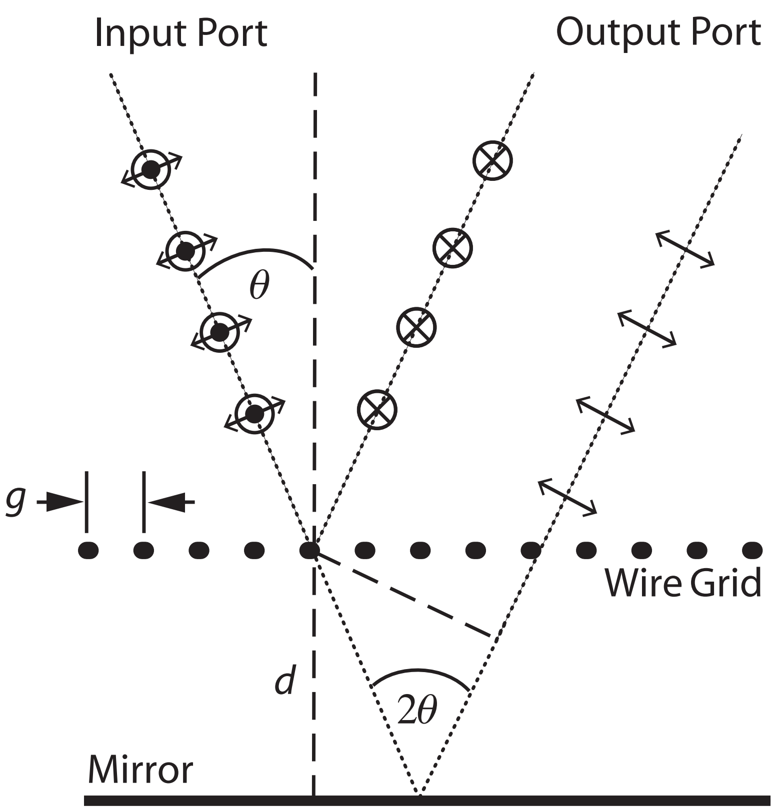


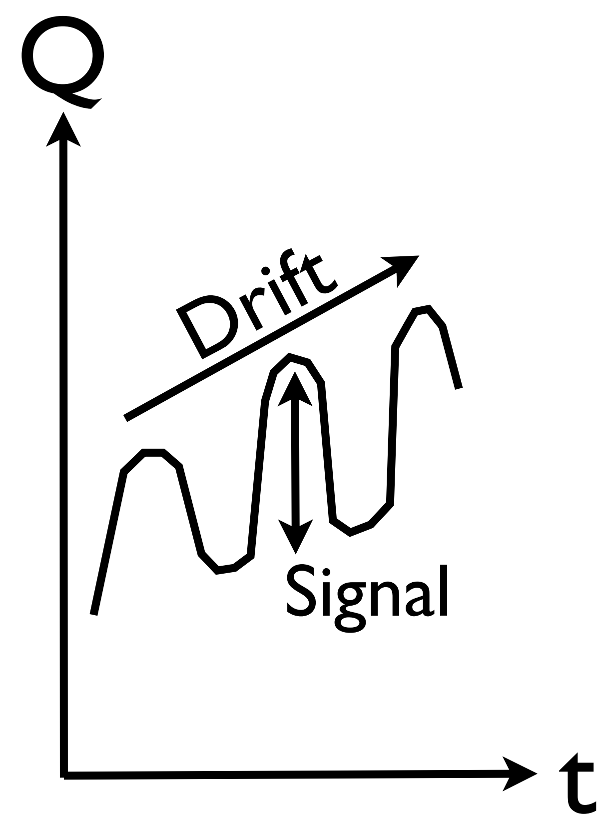


CLASS uses **modulation** to measure **large scales.**

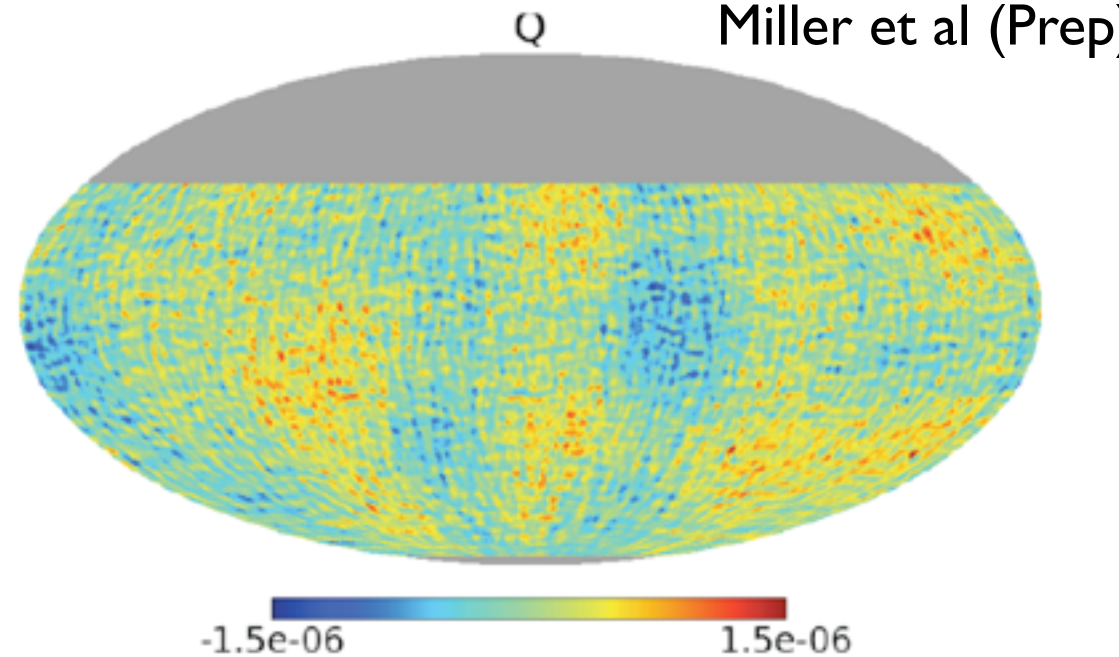
A Variable-Delay Polarization Modulator (VPM) is the front-end optical element.

Modulates signal at **5-10 Hz** to separate signal from the (unpolarized) atmosphere and other instrument-related drift.

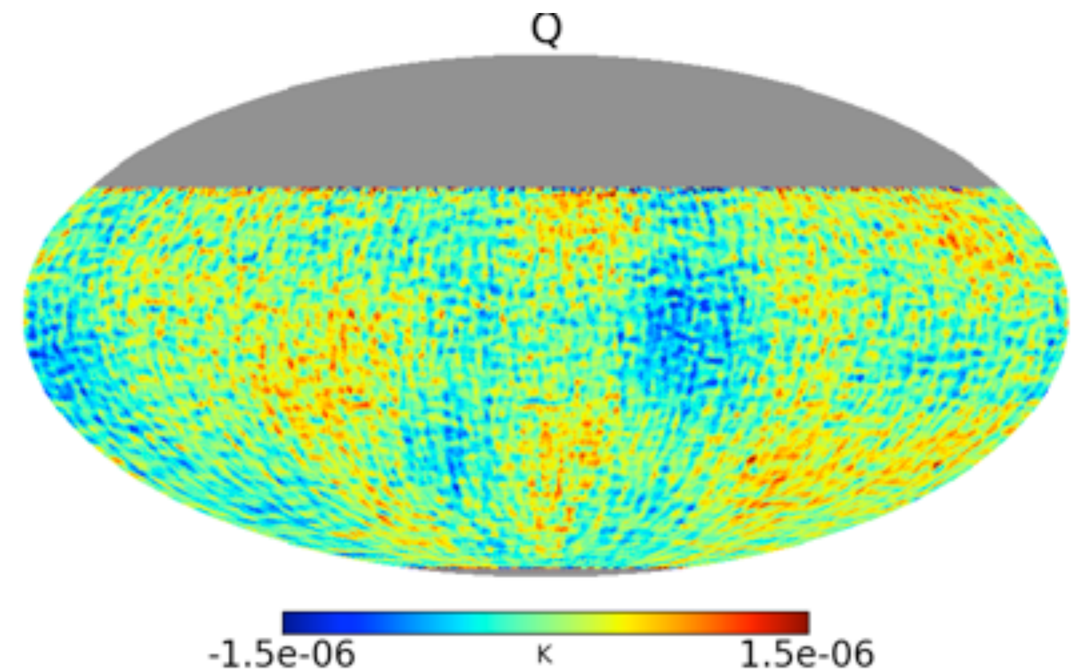




CMB Simulation



Recovery with Modulation and simple map-making



Atmosphere + Differential Gain*

*Both the atmosphere and gain time streams have $1/f^2$ power spectra. The atmosphere has an amplitude of 0.05 K at 0.1 Hz and the gain fluctuation has an amplitude of 0.5% at 0.005 Hz.

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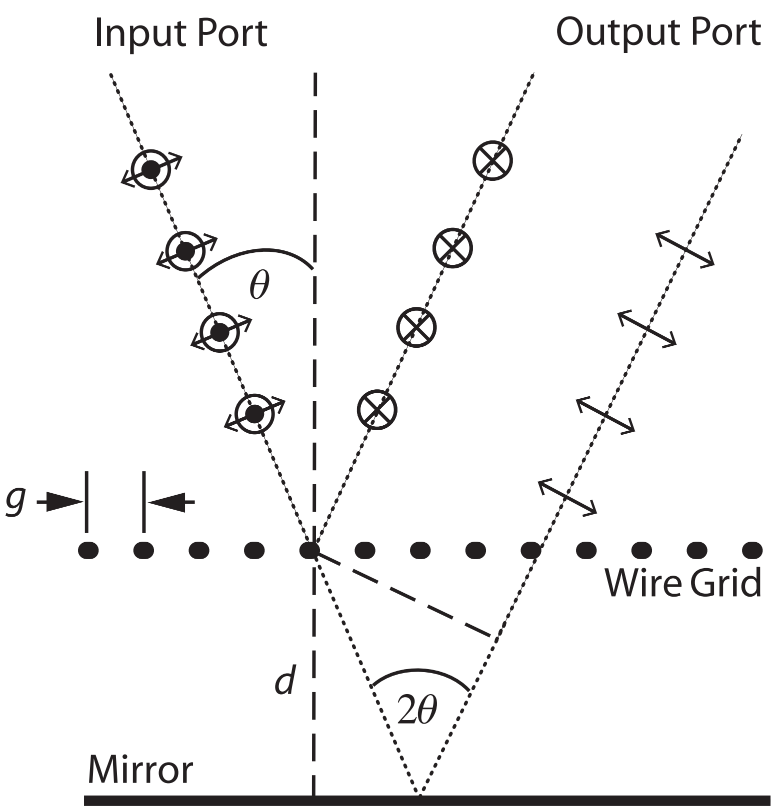
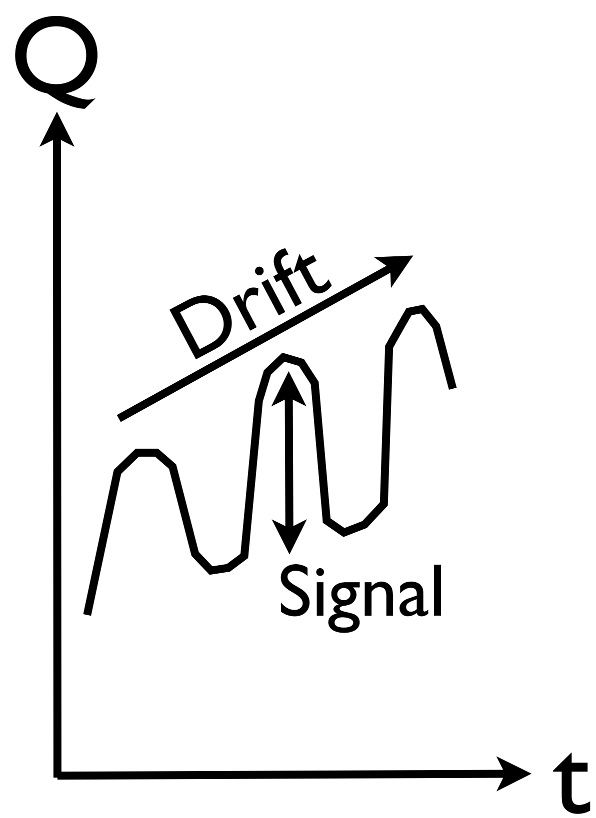
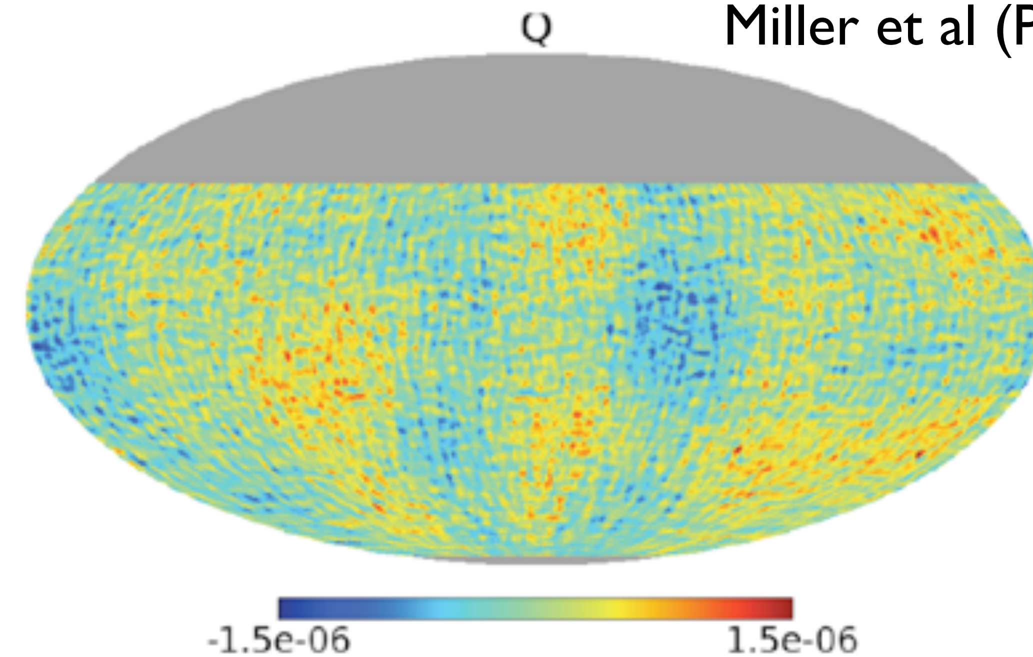


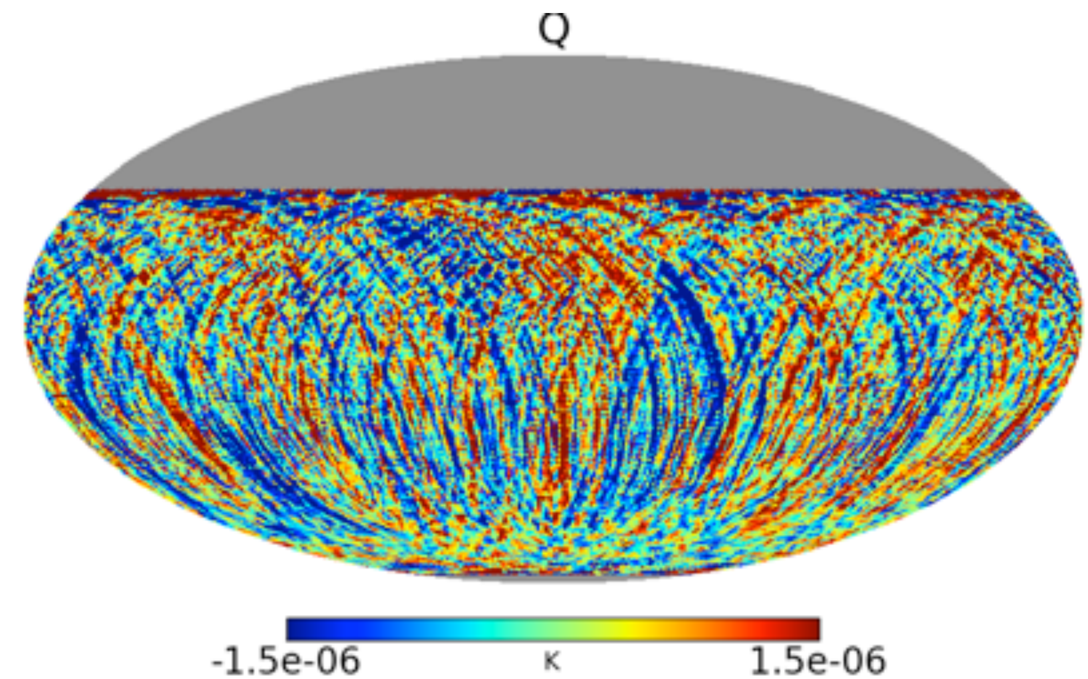


CMB Simulation

Miller et al (Prep)



Recovery without Modulation and simple map-making



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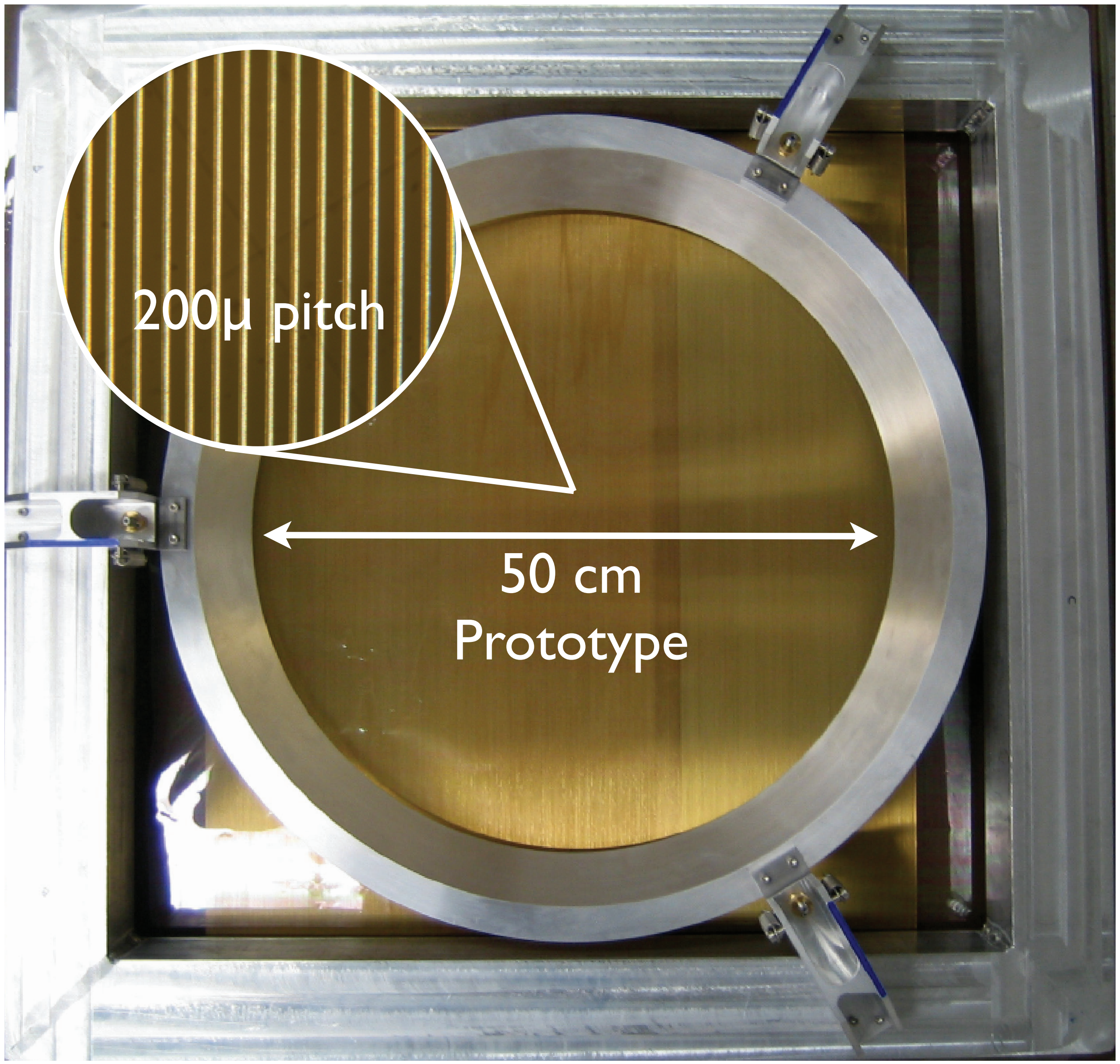

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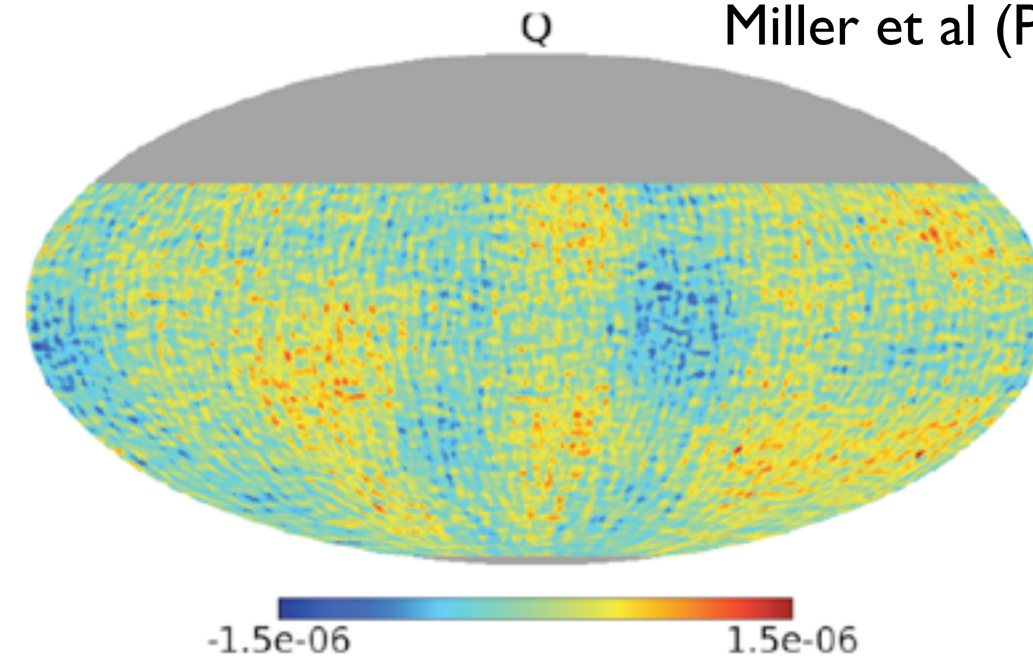

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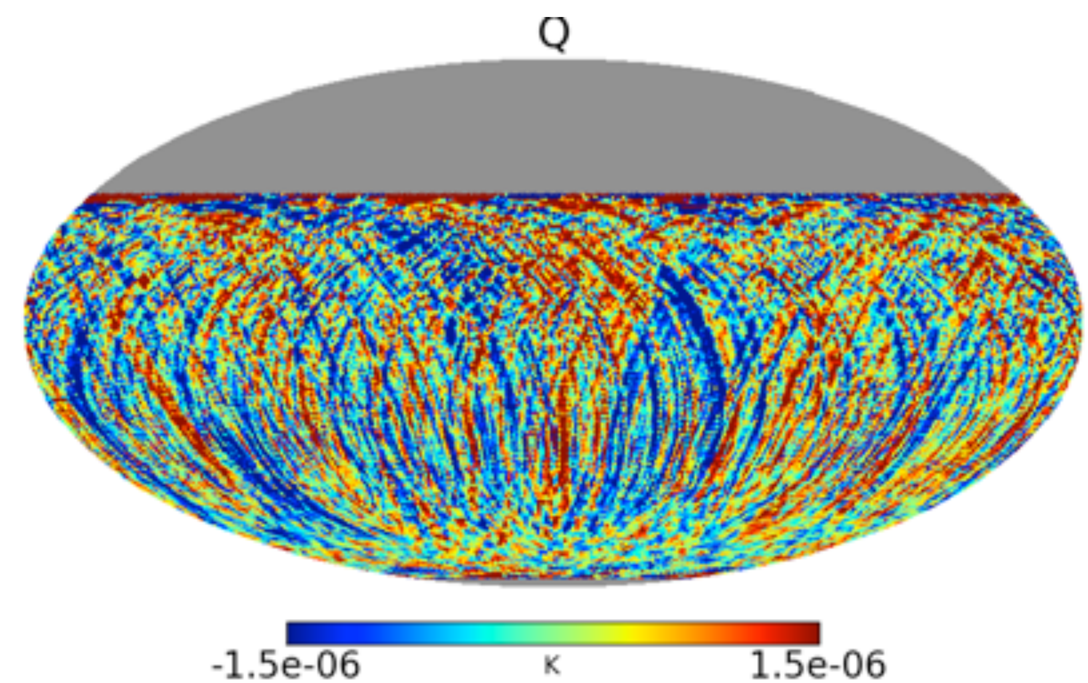

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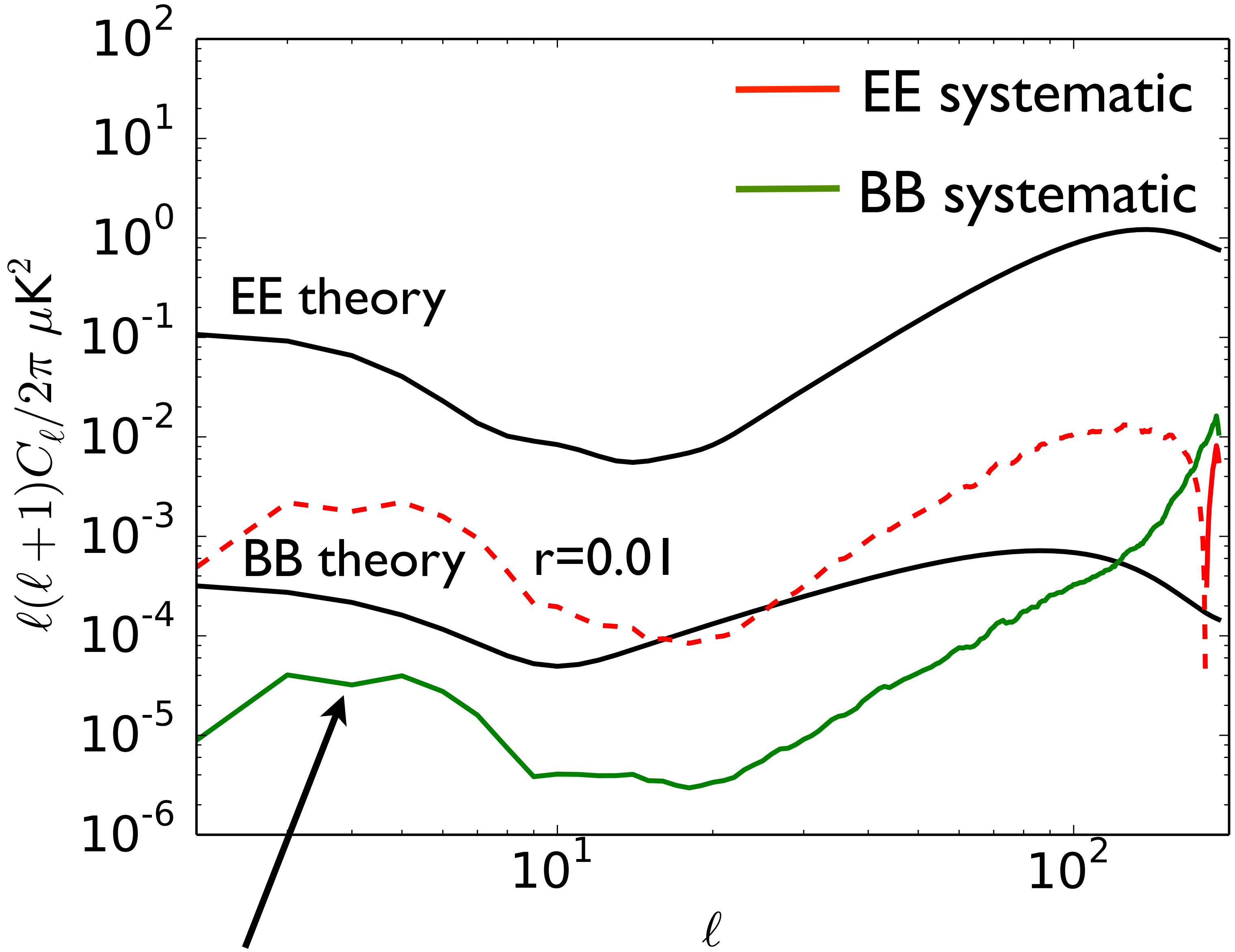
Preliminary Simulation Results

EE theory, r=0.01



Effects Included:

*Atmosphere

*VPM temperature drift + differential emissivity

*Detector pair differential gain fluctuation

*VPM-Detector misalignment (0.5 deg)

10% BB systematic due to VPM-Detector misalignment likely further reduced by adjusting angle so EB=0

Miller et al. (in prep)

The CLASS Way #2: Sensitivity with high efficiency optics and tweaked-up detectors cooled to 150 mK

CLASS Detectors : Design

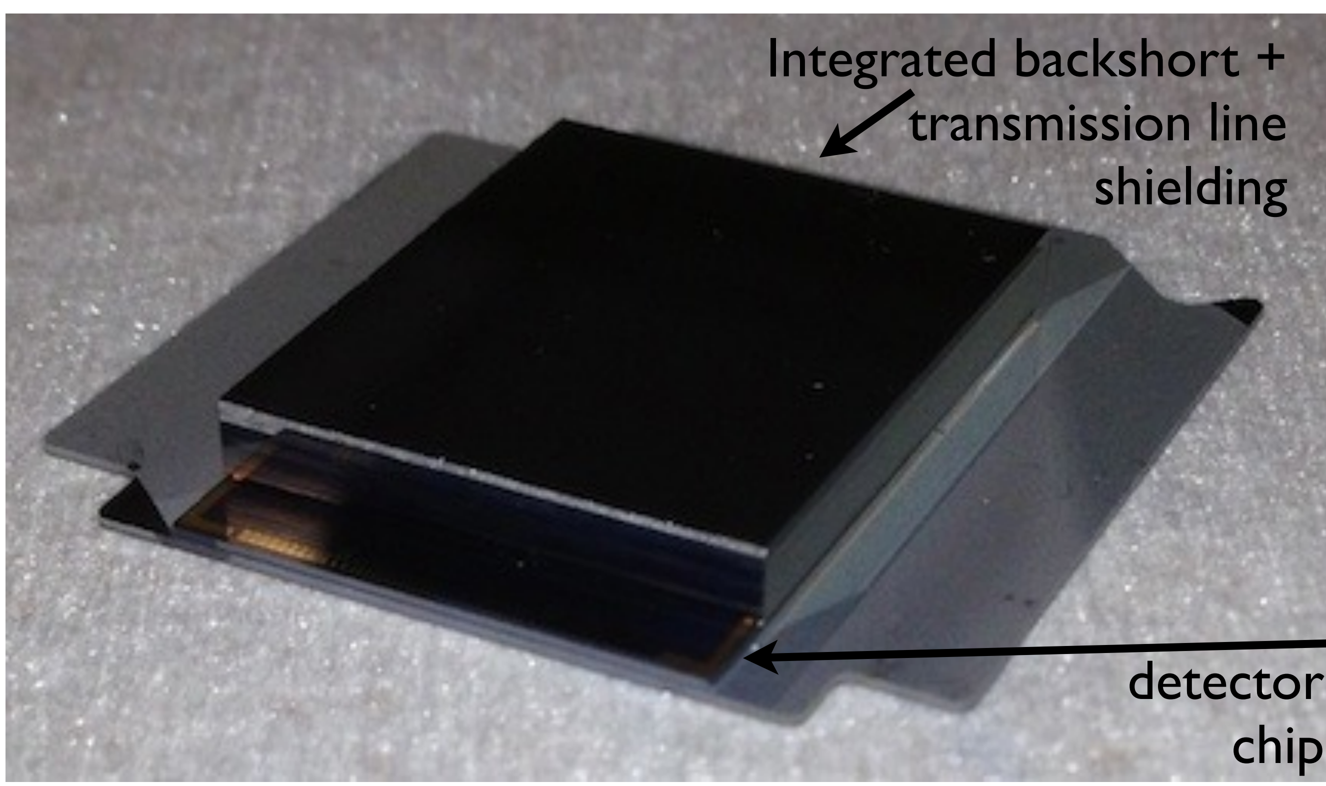
Designed and made by NASA

Horns and Planar OMT produce
simple single-moded beams.

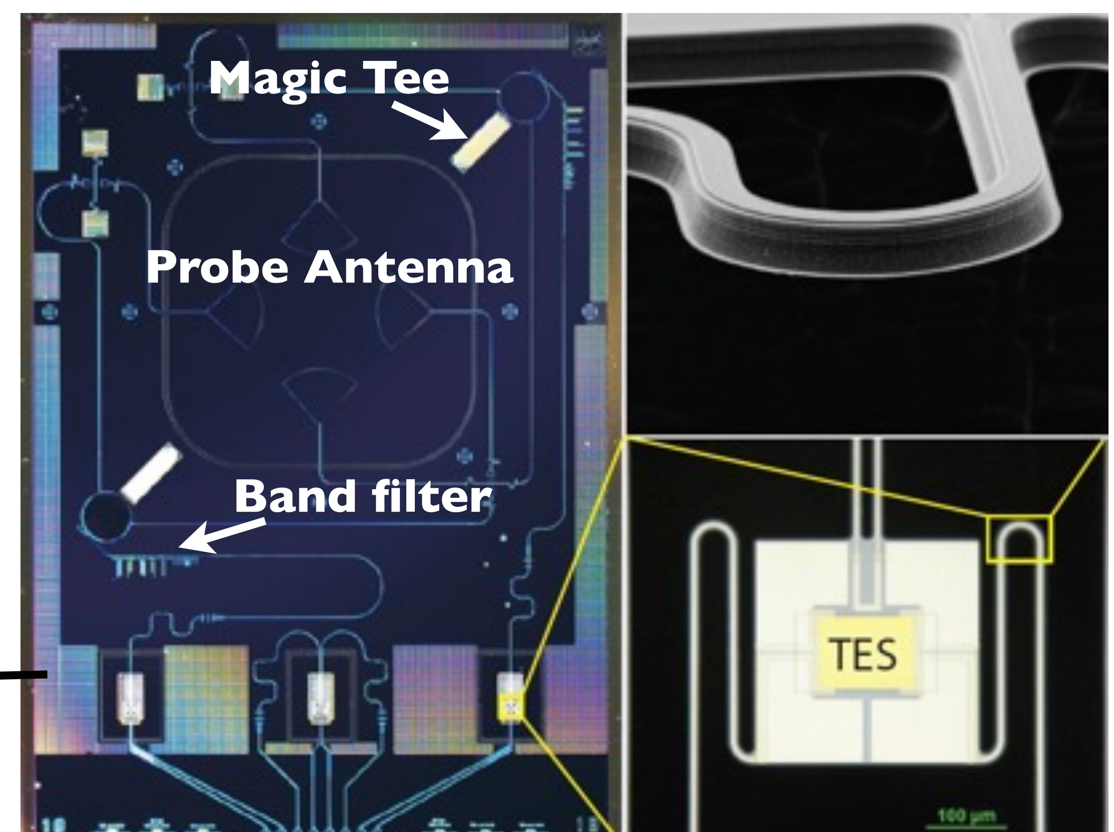
High-efficiency and **design repeatability** is achieved through use of monocrystalline silicon dielectric.

Intrinsic OMT design achieves **broad 50% fractional bandwidth**, which may be divided for multi-frequency operation.

On-chip transmission line filtering, shielding and niobium gap provide **well defined bandpass** and **stringent blue leak control**.

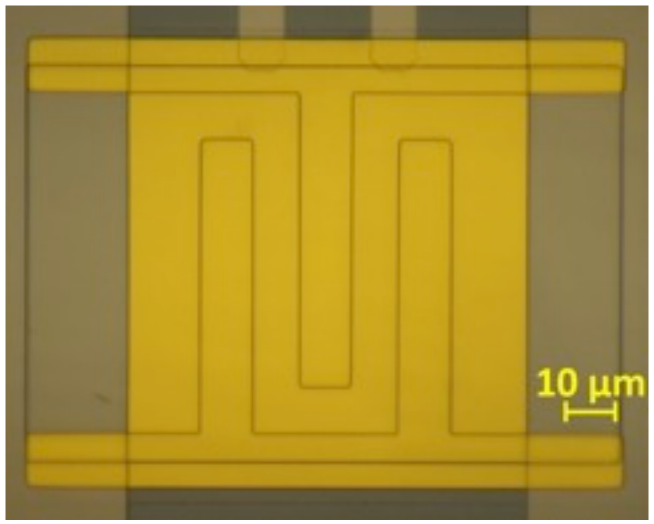


40 GHz Detector

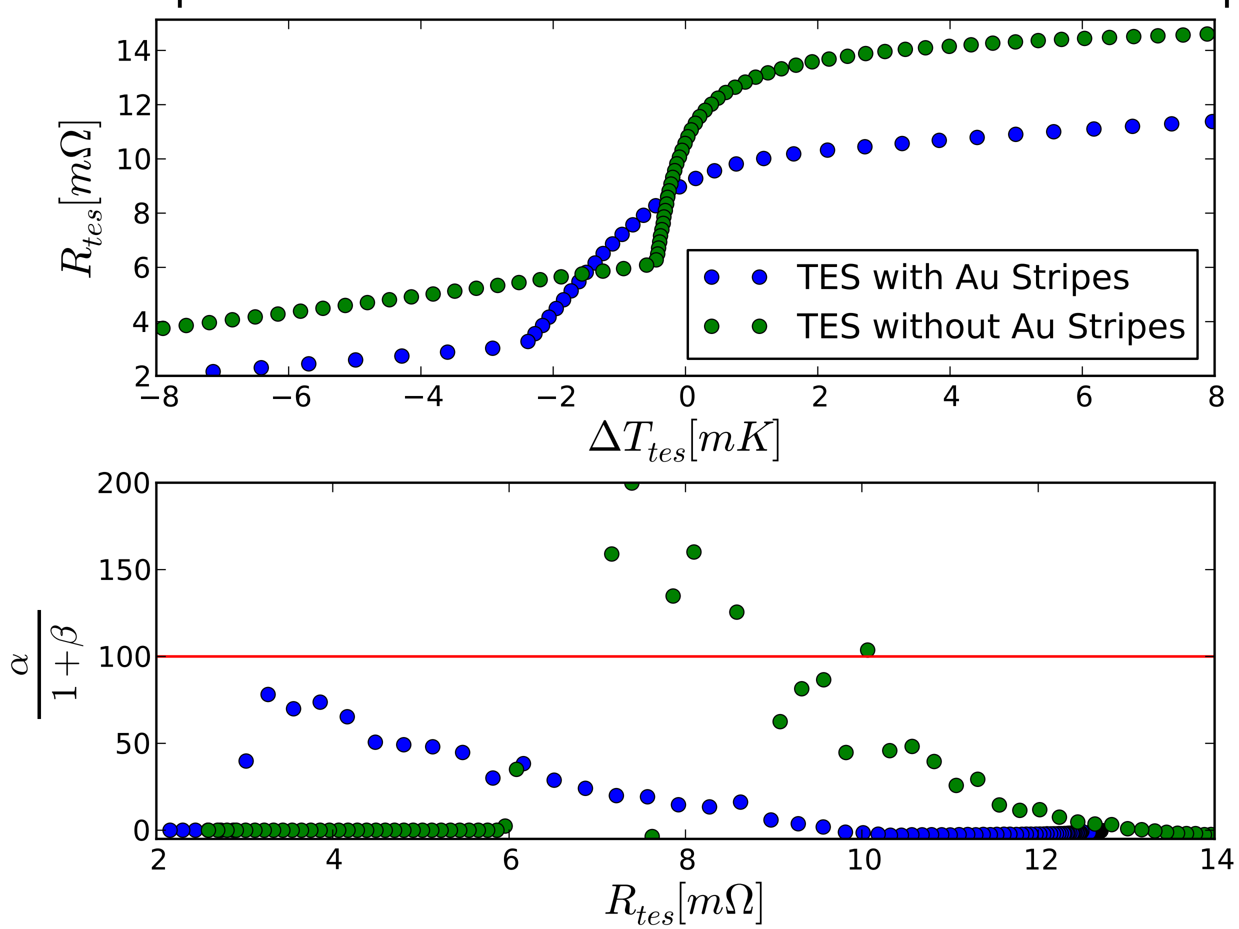


CLASS Detectors : Excellent Design; Excellent Tests

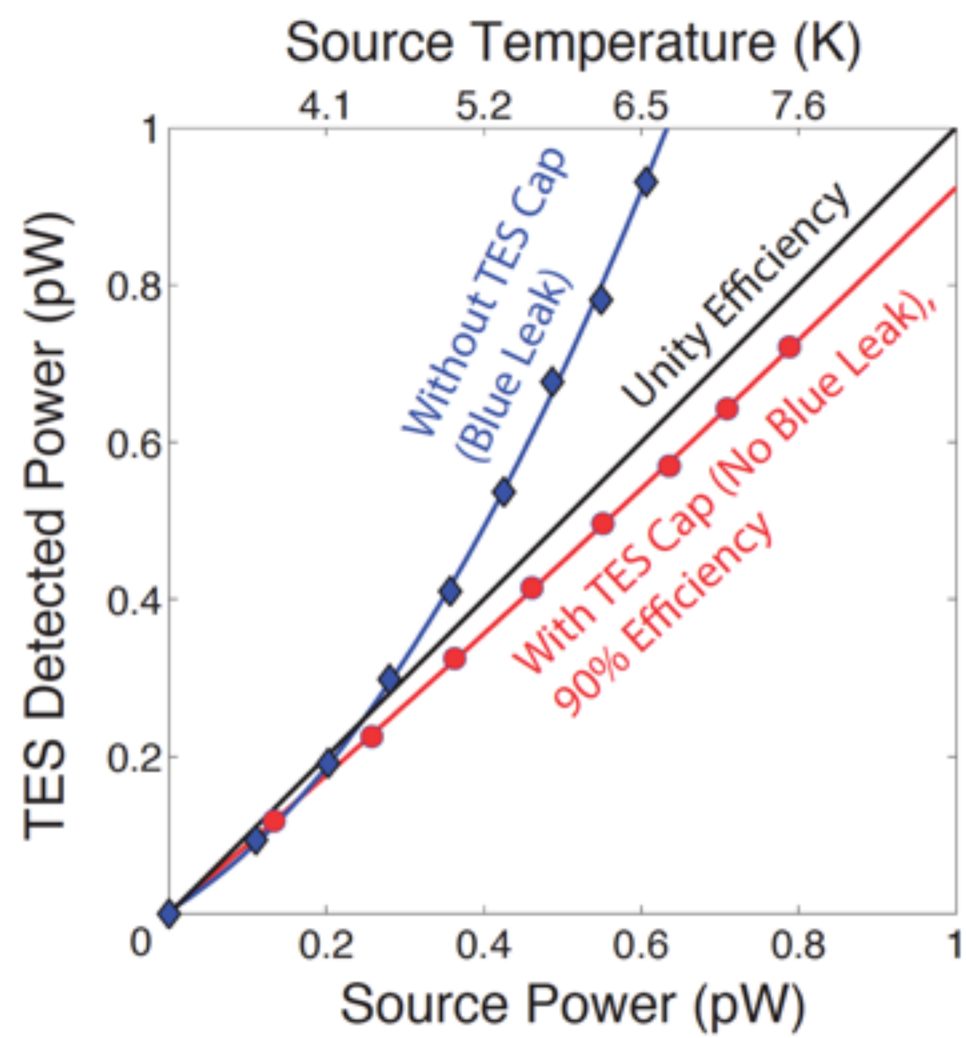
TESs with tuned transitions and thermal conductances



Comparison of TES transition with and without Au stripes



Detectors coupled to thermal source show 90% efficiency and no out of band leakage.

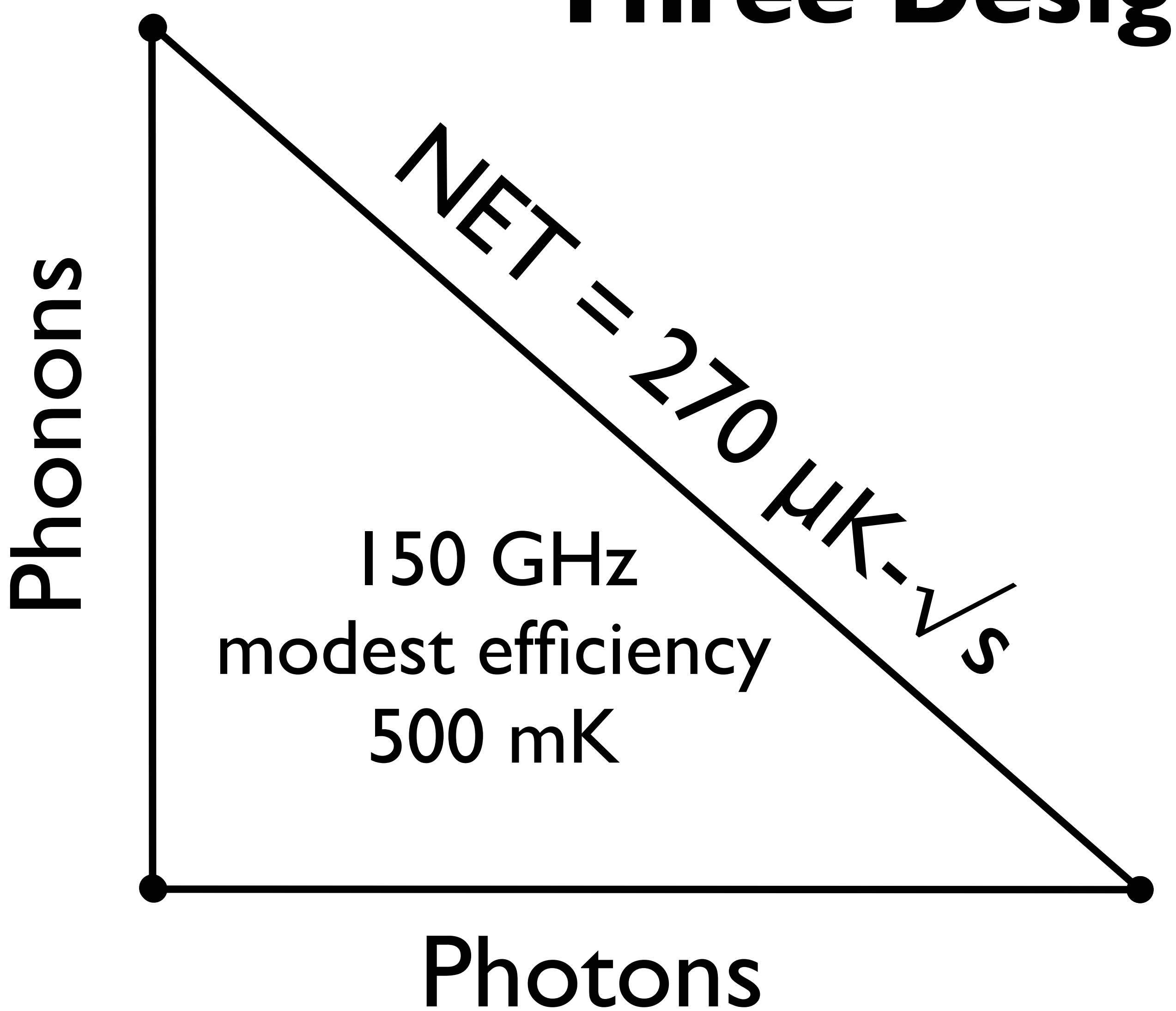


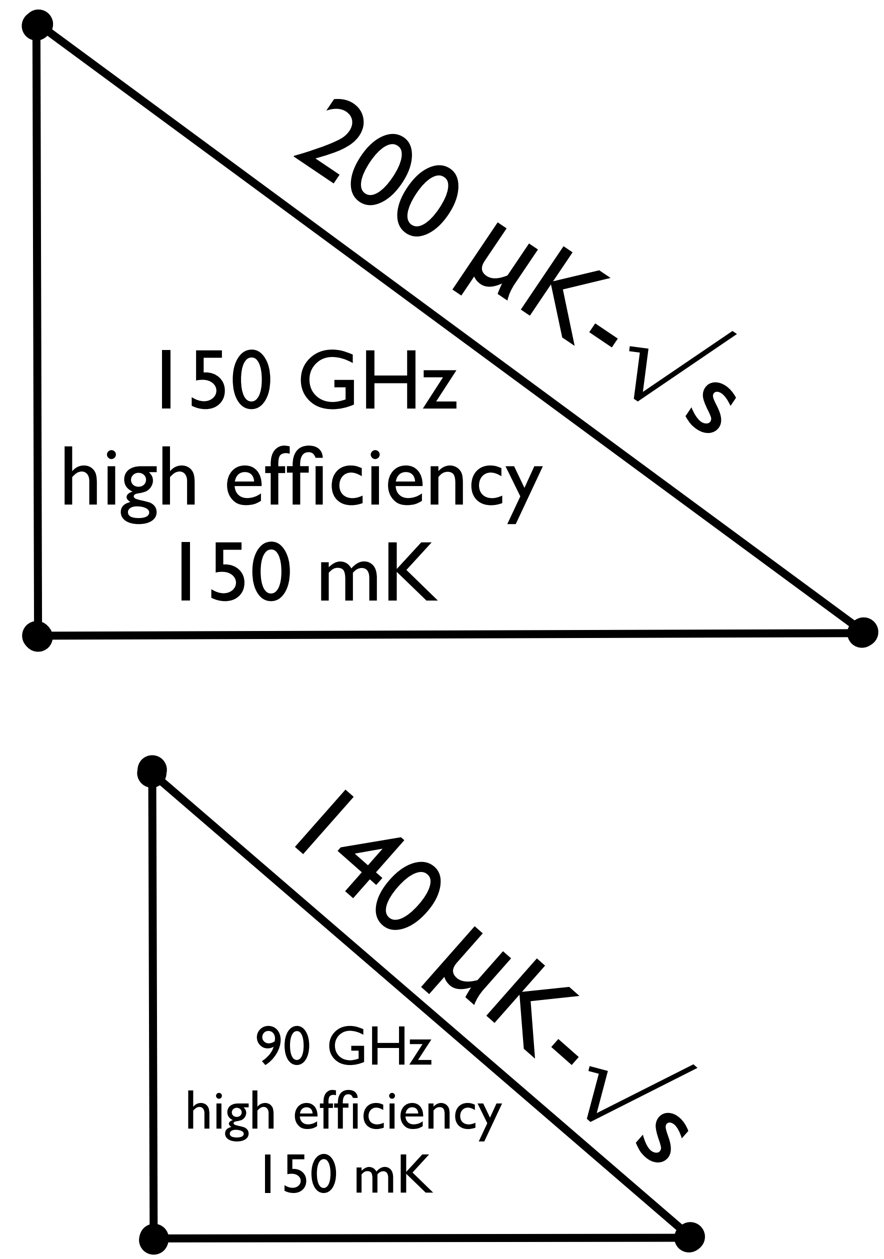
Wollack et al. (in prep)

CLASS Detectors : Sensitivity

(or how to detect B-modes with fewer than 10,000 detectors)

Three Designs*





*examples for argument; not exact; for instance need to add amplifier noise

Significant advances in SQUID amplifier noise over previous experiences.

CLASS Detectors : Sensitivity

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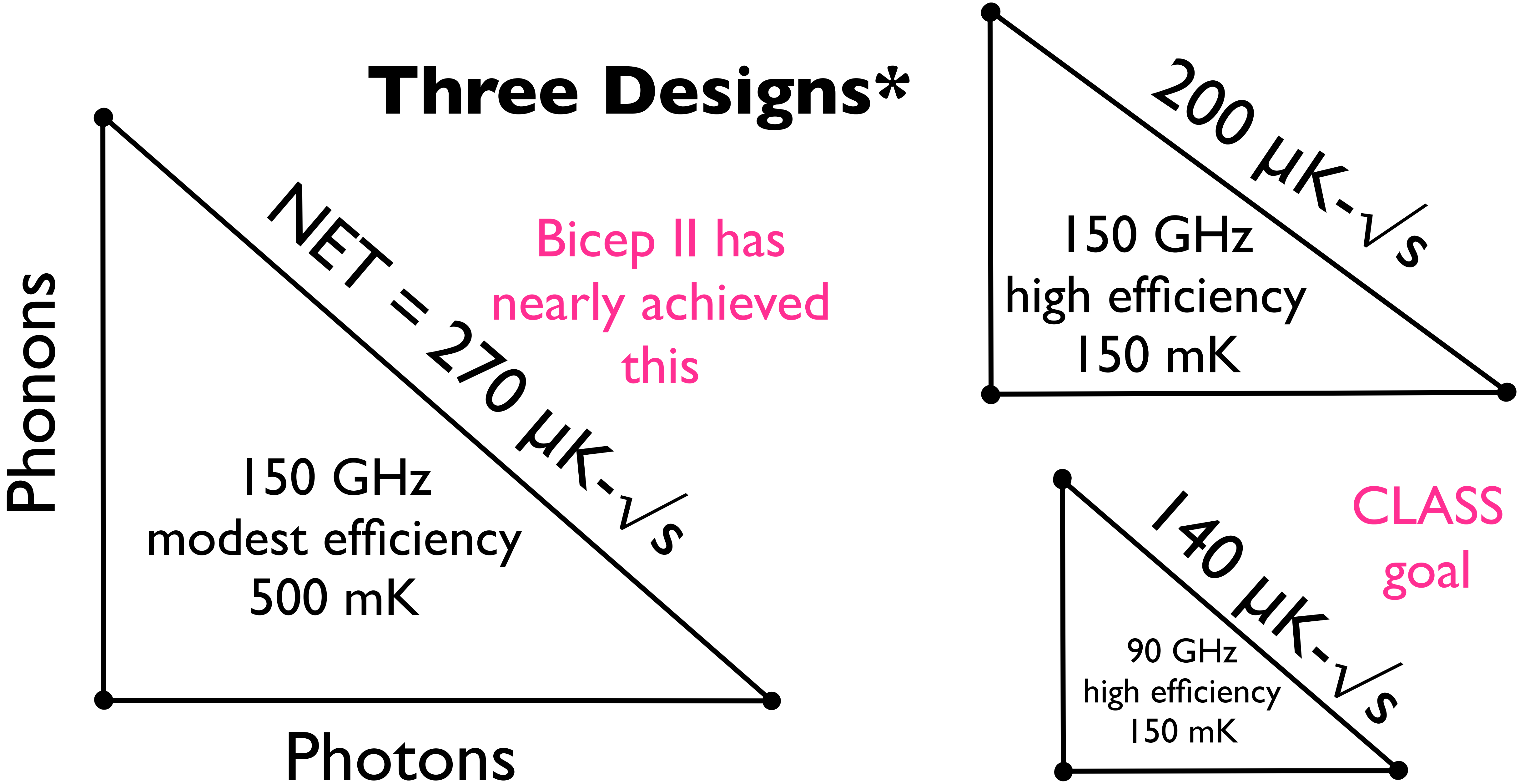

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Significant advances in SQUID amplifier noise over previous experiences.

The CLASS Way #3: Galactic foreground cleaning with multi-frequency telescope array

Template-based Likelihood for r, s, and Foregrounds

(Efstathiou et al. 2009; Katayama & Komatsu 2011)

$$\mathcal{L}(r, s, \alpha_i) \propto \frac{\exp\left[-\frac{1}{2}\boldsymbol{x}'(\alpha_i)^T \boldsymbol{C}^{-1}(r, s, \alpha_i)\boldsymbol{x}'(\alpha_i)\right]}{\sqrt{|\boldsymbol{C}(r, s, \alpha_i)|}}, \quad (9)$$

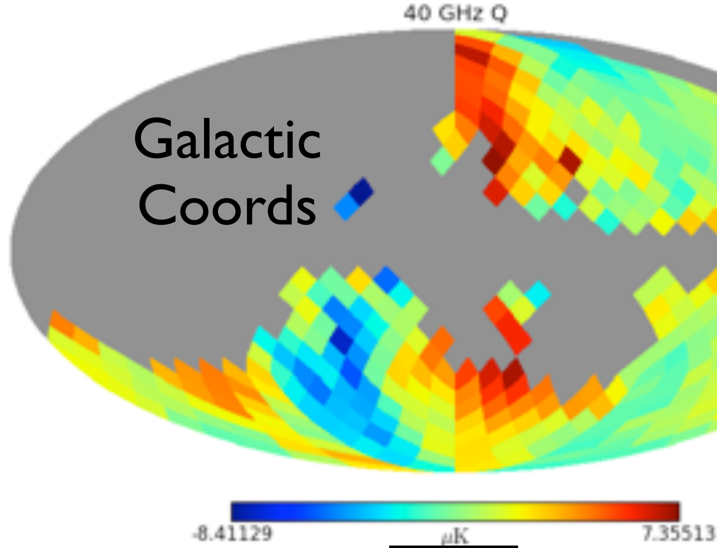
where

$$\boldsymbol{x}' = \frac{[Q, U](\nu) - \sum_i \alpha_i(\nu)[Q, U]\left(\nu_i^{\text{template}}\right)}{1 - \sum_i \alpha_i(\nu)} \quad (10)$$

$$\boldsymbol{C}(r, s, \alpha_i) = r\boldsymbol{c}^{\text{tensor}} + s\boldsymbol{c}^{\text{scalar}} + \frac{\boldsymbol{N}_1 + \boldsymbol{N}_2}{\left(1 - \sum_i \alpha_i\right)^2}, \quad (11)$$

Full likelihood is computationally feasible because we are probing large angles=fewer data with larger signal per-a_{lm}. Approach infeasible at smaller angles. Built-in handling of E-B mixing etc.

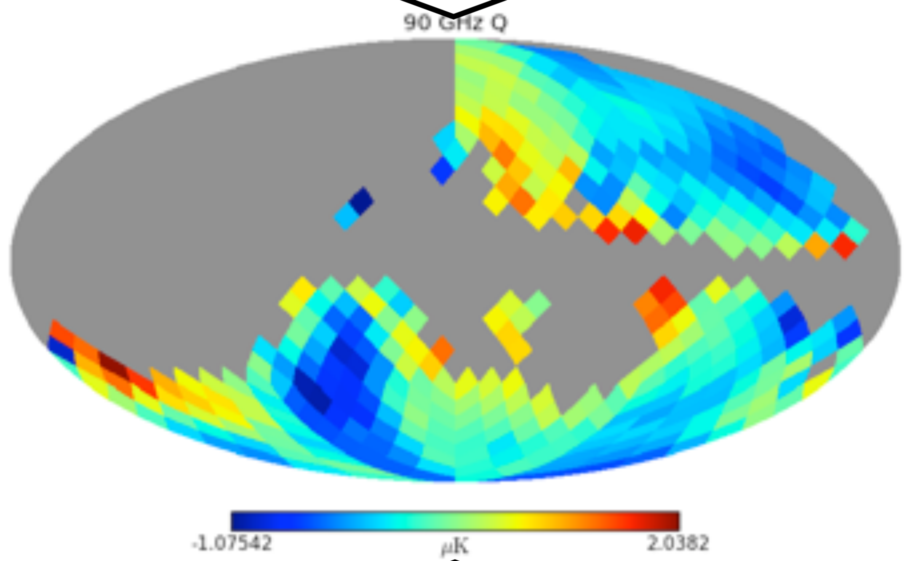
40 GHz

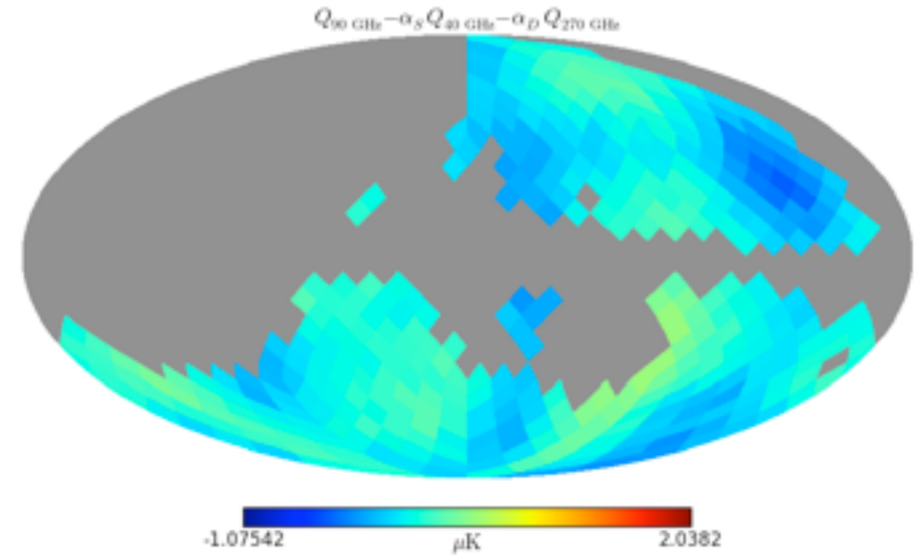


Template cleaned map

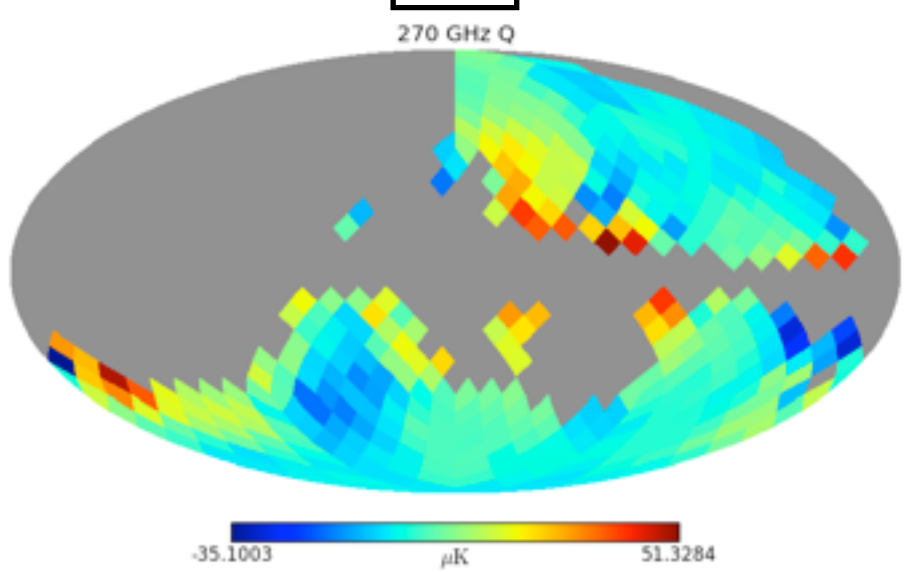
(Noise=11 μK-arcmin)

90 GHz





270 GHz (PIPER)



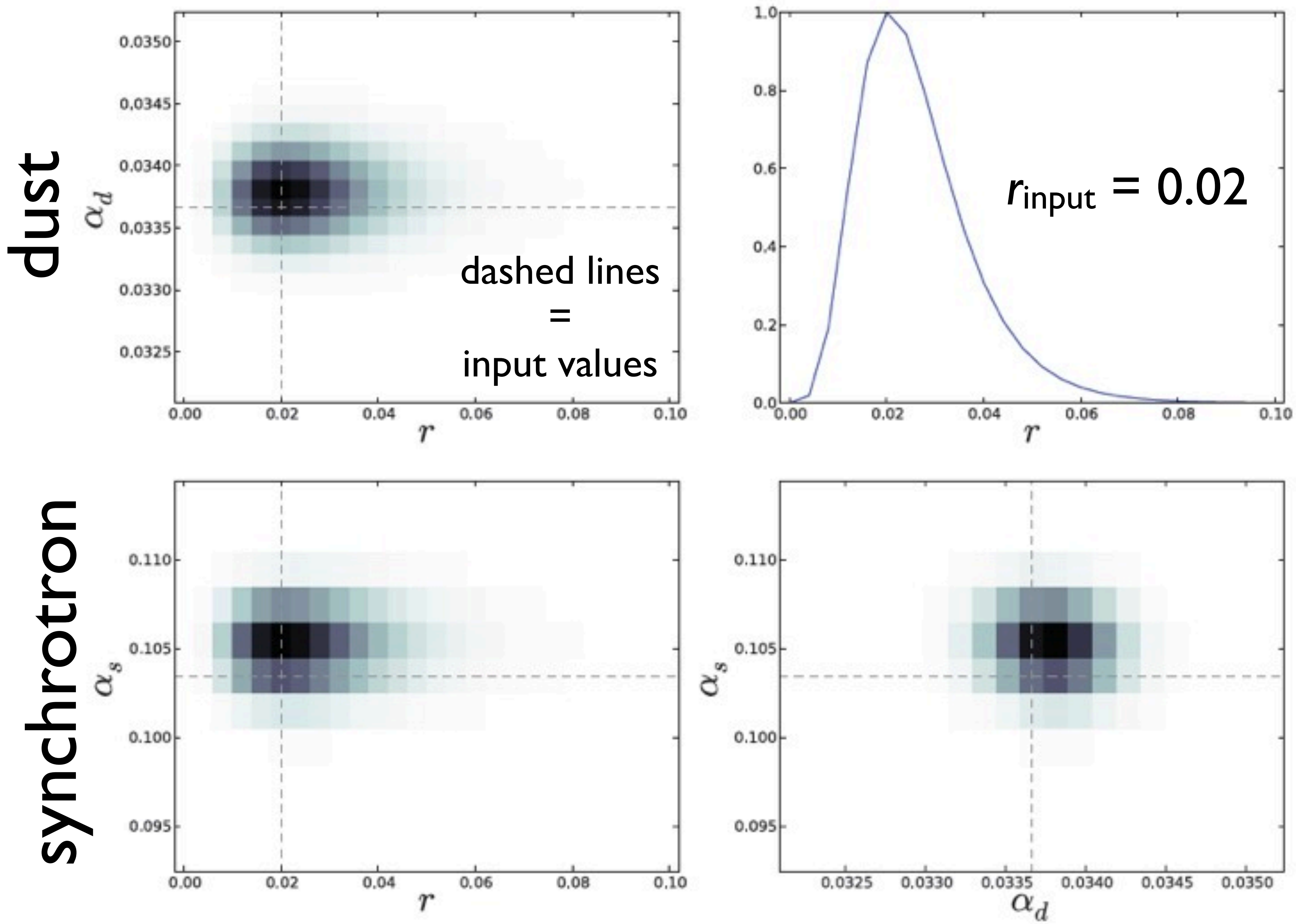
Residuals from CMB input map at 5nK level

15 μK-arcmin noise

Watts, Larson et al (in prep)

Exploring Constraints with Sky Cuts and Foregrounds

(Pixel-based likelihood as in Katayama & Komatsu 2011)



Note Non-Gaussian likelihood using large angular scales can yield a detection with tail to high *r*.

tensor-to-scalar ratio

Watts, Larson et al (in prep)

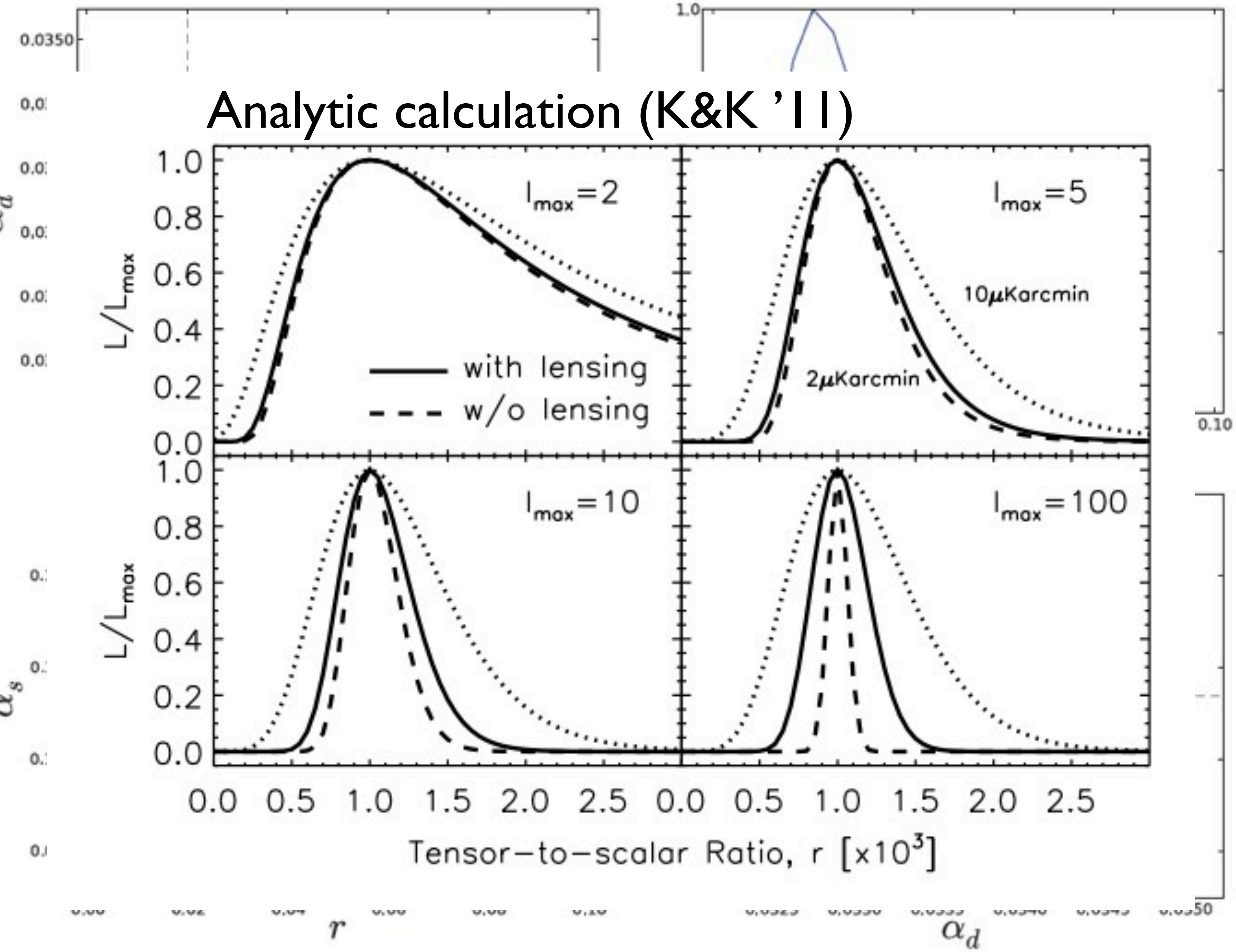
Preliminary!!! More work to be done.

Exploring Constraints with Sky Cuts and Foregrounds

(Pixel-based likelihood as in Katayama & Komatsu 2011)

dust

synchrotron



tensor-to-scalar ratio

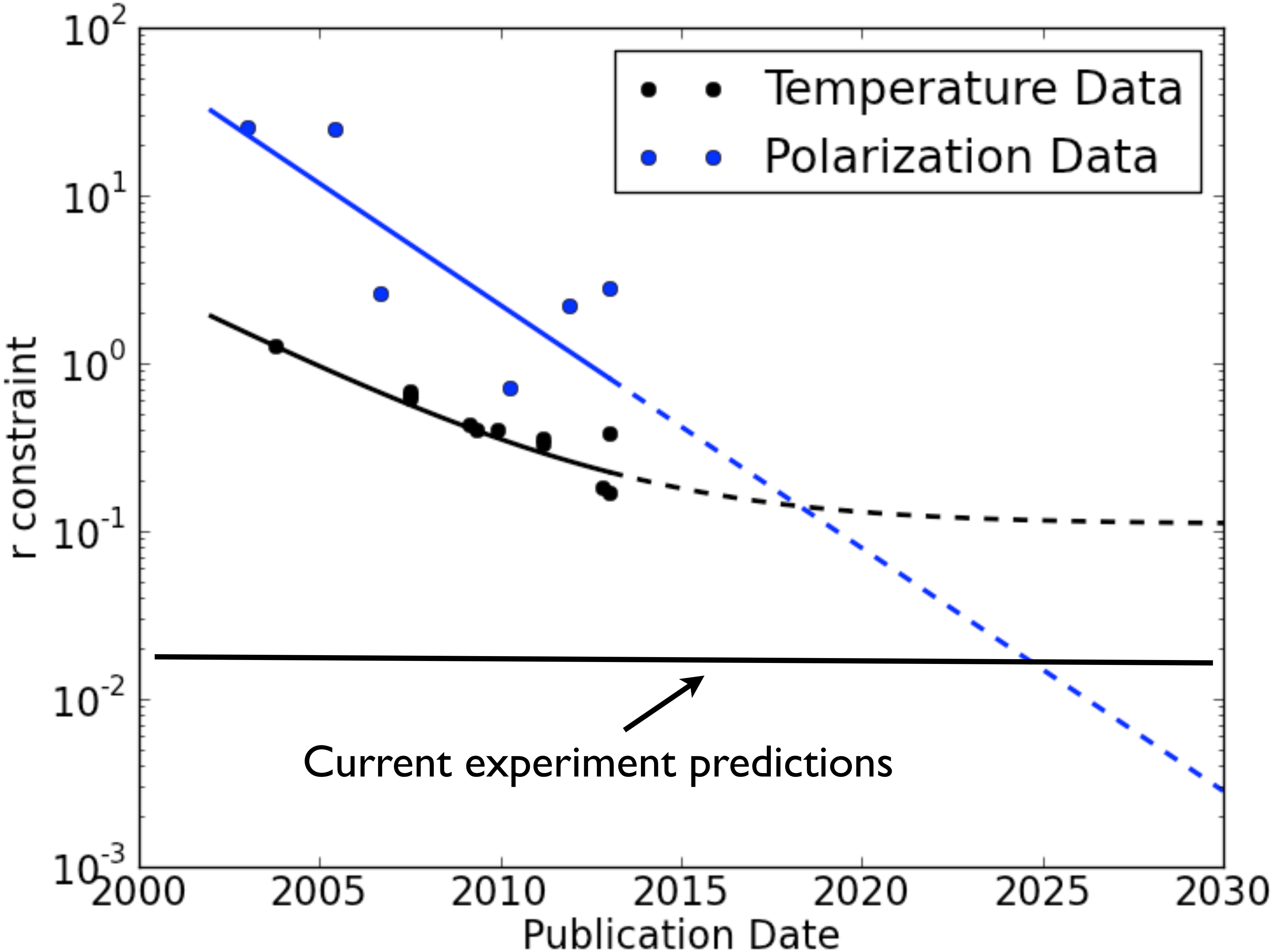
Note Non-Gaussian likelihood using large angular scales can yield a detection with tail to high *r*.

Watts, Larson et al (in prep)

Preliminary!!! More work to be done.

Outside View on r

(Upper
limits)



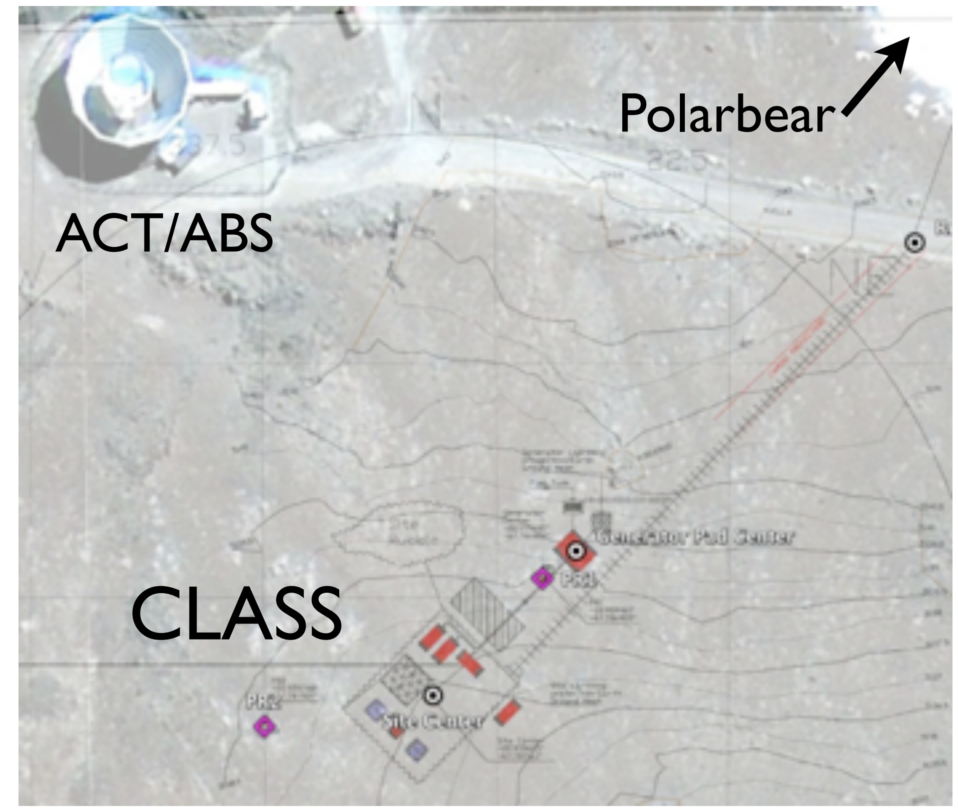
(trend ruled not just by shear
sensitivity but systematics etc)

Stay tuned! Deploying telescopes **2014-2015.**

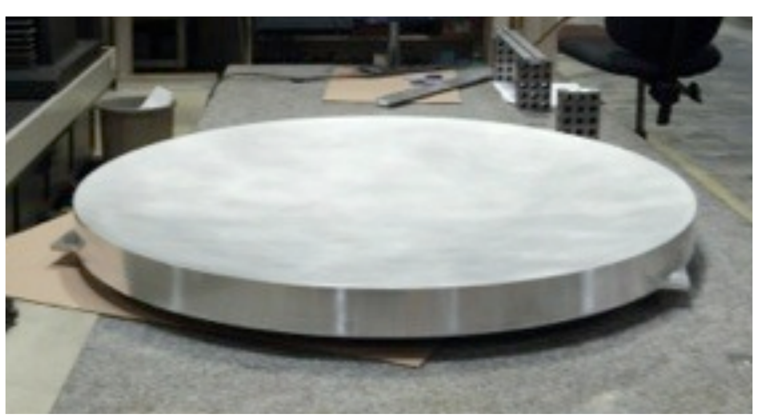
Mounts

Cryostats

Atacama Site Preparation

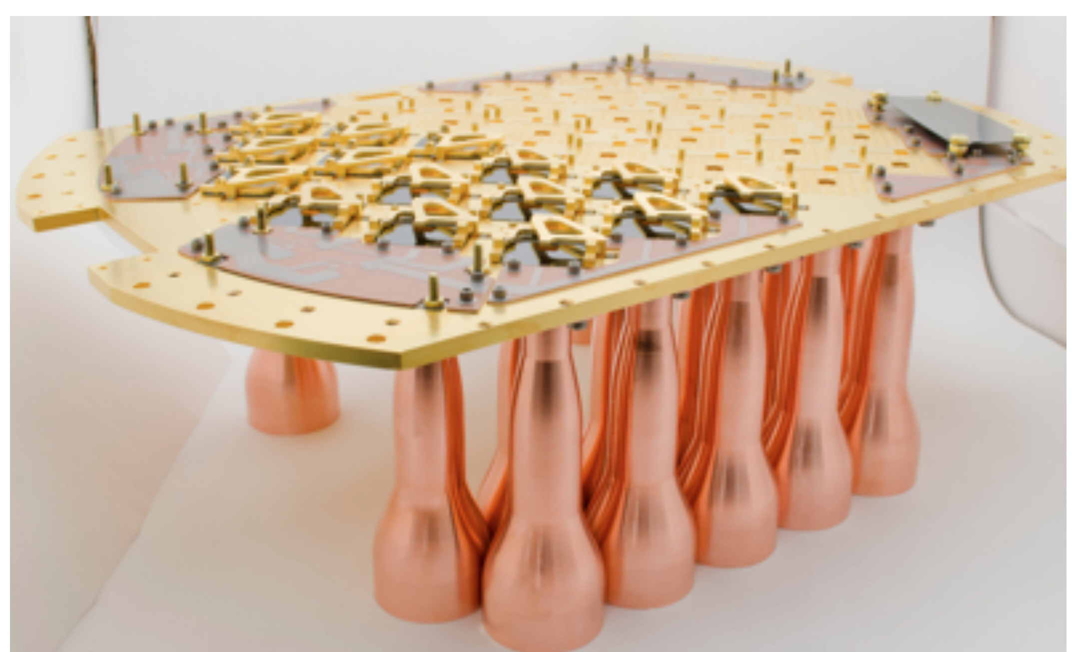


Optics



1.5 m

Focal Planes



VPMs