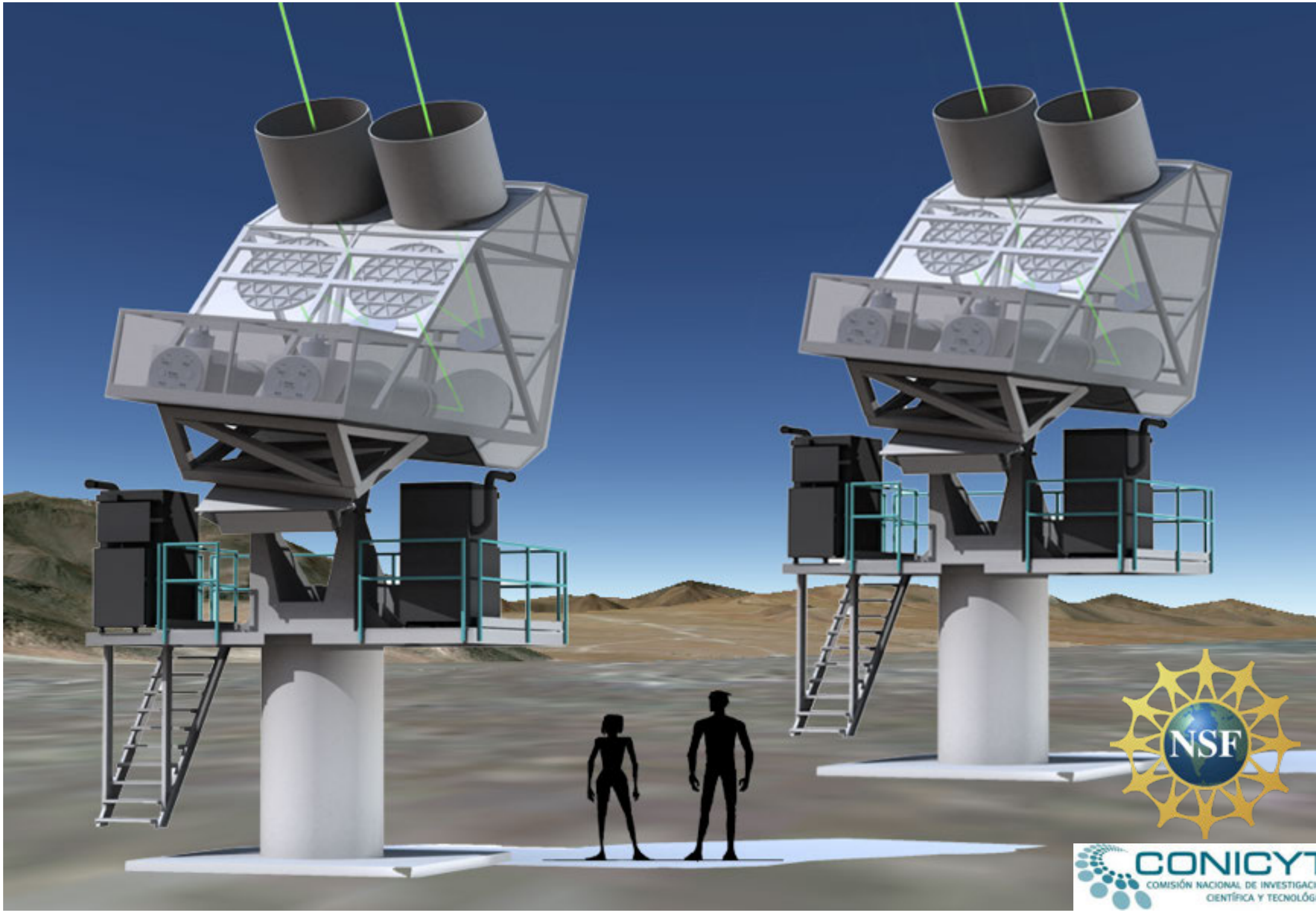
Cosmology Large Angular Scale Surveyor



Toby Marriage for the CLASS Collaboration
Okinawa — CMB2013 — June 13, 2013

CLASS Collaborators

CONICYT
COMISIÓN NACIONAL DE INVESTIGACIÓN CIENTÍFICA Y TECNOLÓGICA

<u>NASA GSFC</u>
D. Chuss
K. Denis
A. Kogut
N. Miller
H. Moseley
K. Rostem
E. Wollack

<u>UBC</u>
M. Amiri
M. Halpern
G. Hinshaw

<u>Northwestern</u>
G. Novak

<u>JHU</u>
A. Ali
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C. Bennett (PI)
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T. Essinger-Hileman
D. Gothe
K. Harrington
J. Karakla
D. Larson
T. Marriage
Z. Xu

Red=Present

<u>NIST</u>
H-M. Cho
K. Irwin
G. Hilton
C. Reintsema

<u>CfA-SAO</u>
L. Zeng

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<u>Columbia</u>
D. Araujo
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M. Limon
A. Miller

Columbia University

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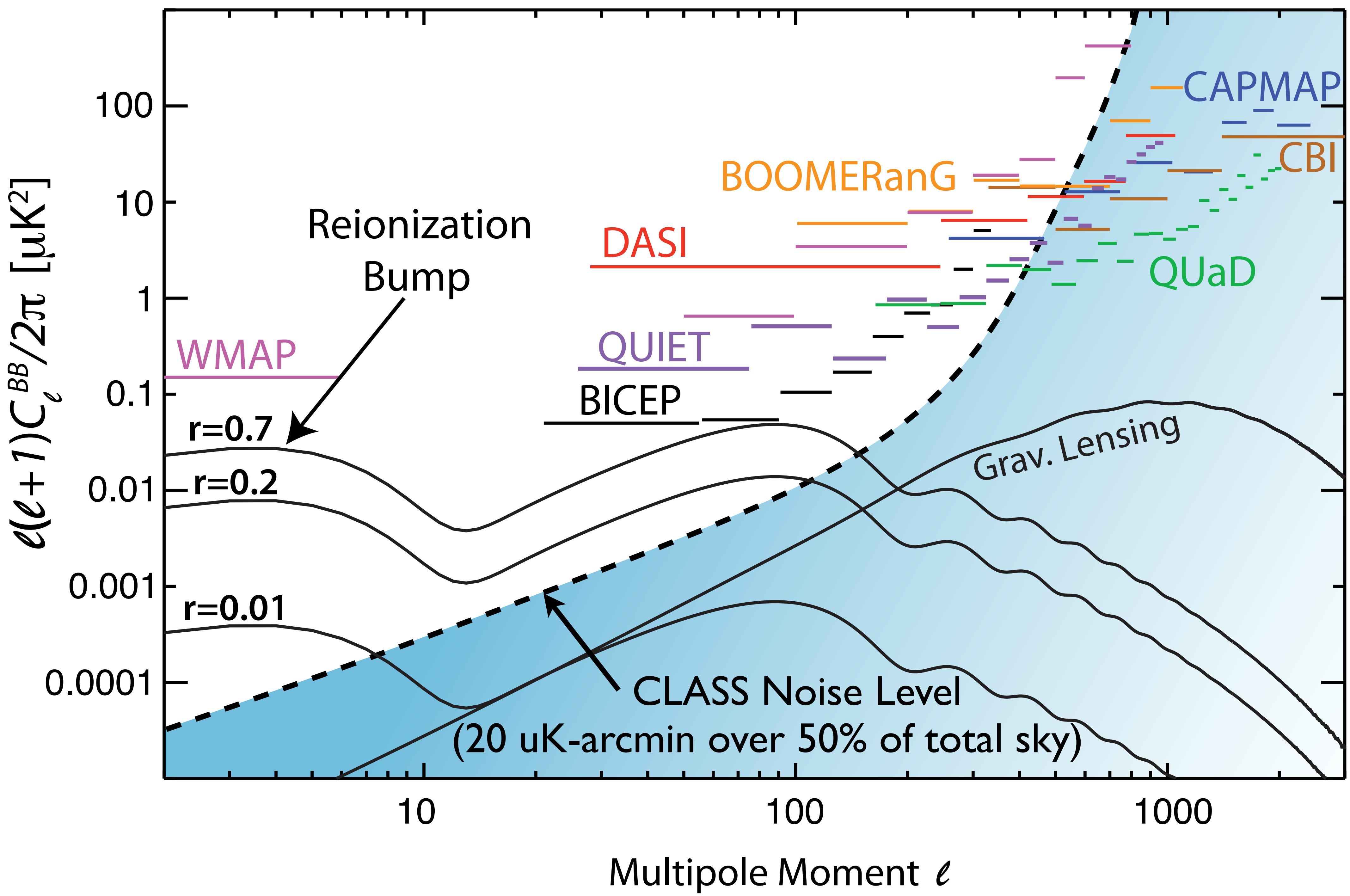
See **Joseph Eimer's** CLASS Poster for more information

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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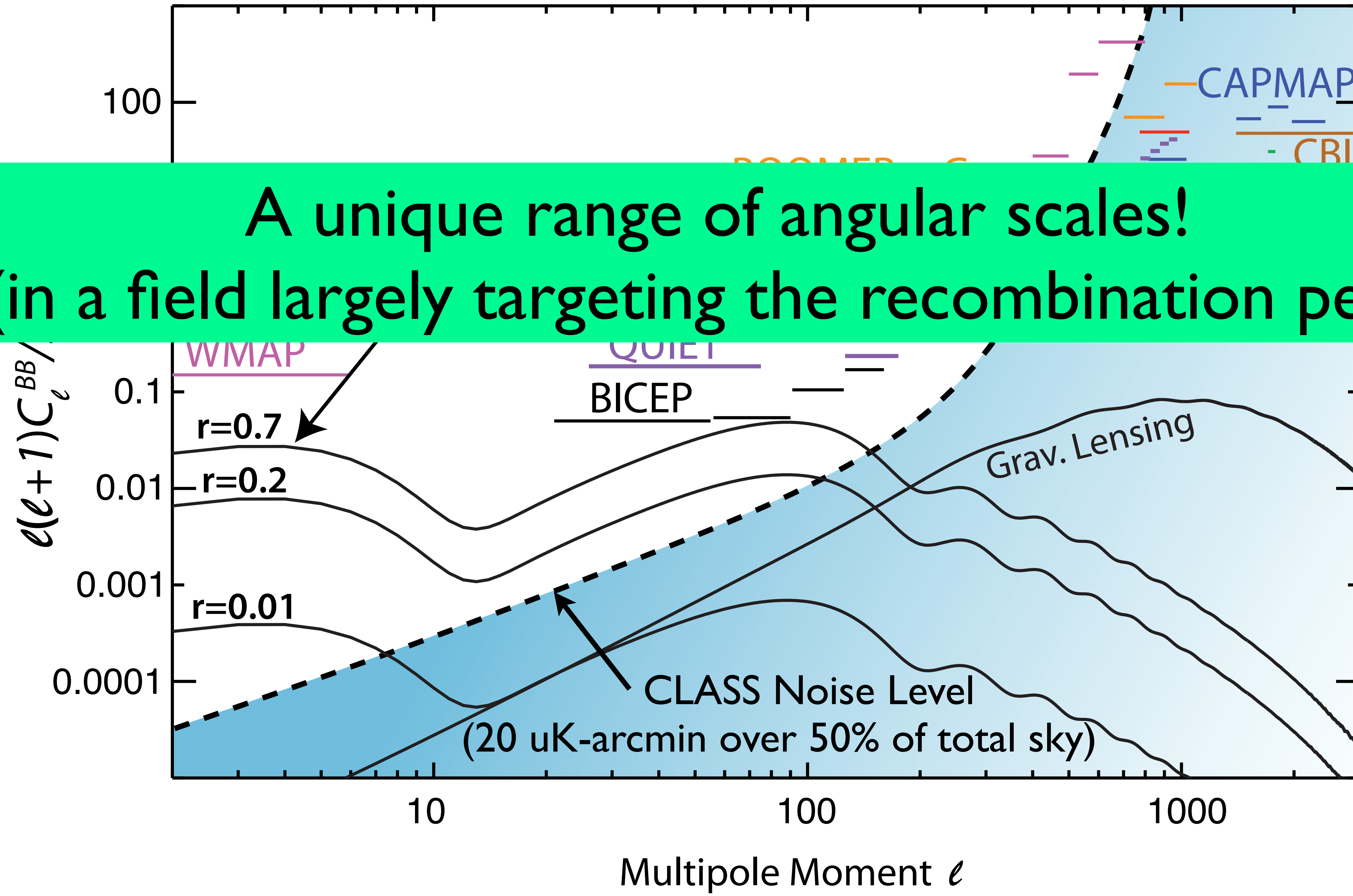
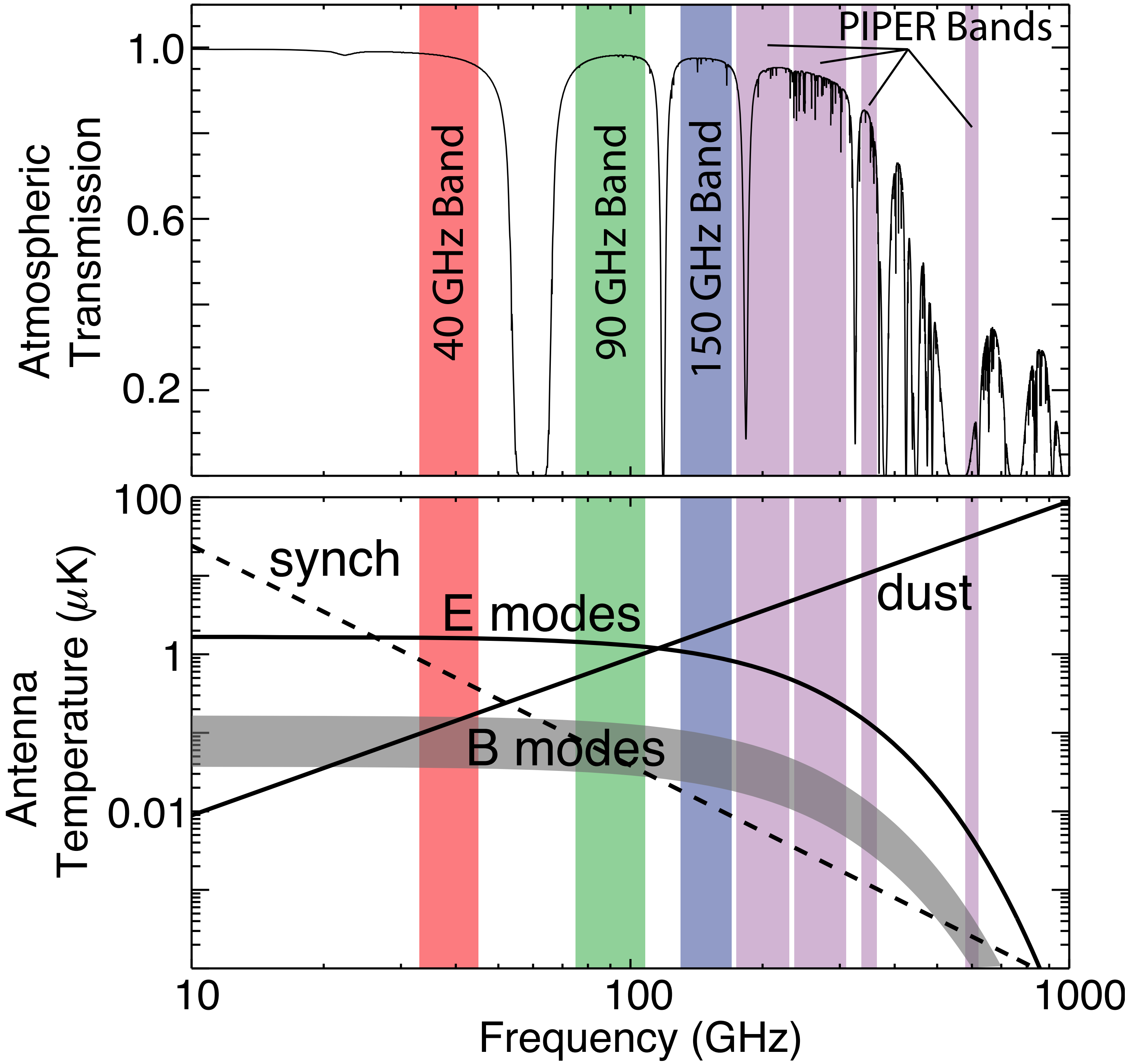


A unique range of angular scales!
(in a field largely targeting the recombination peak)



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

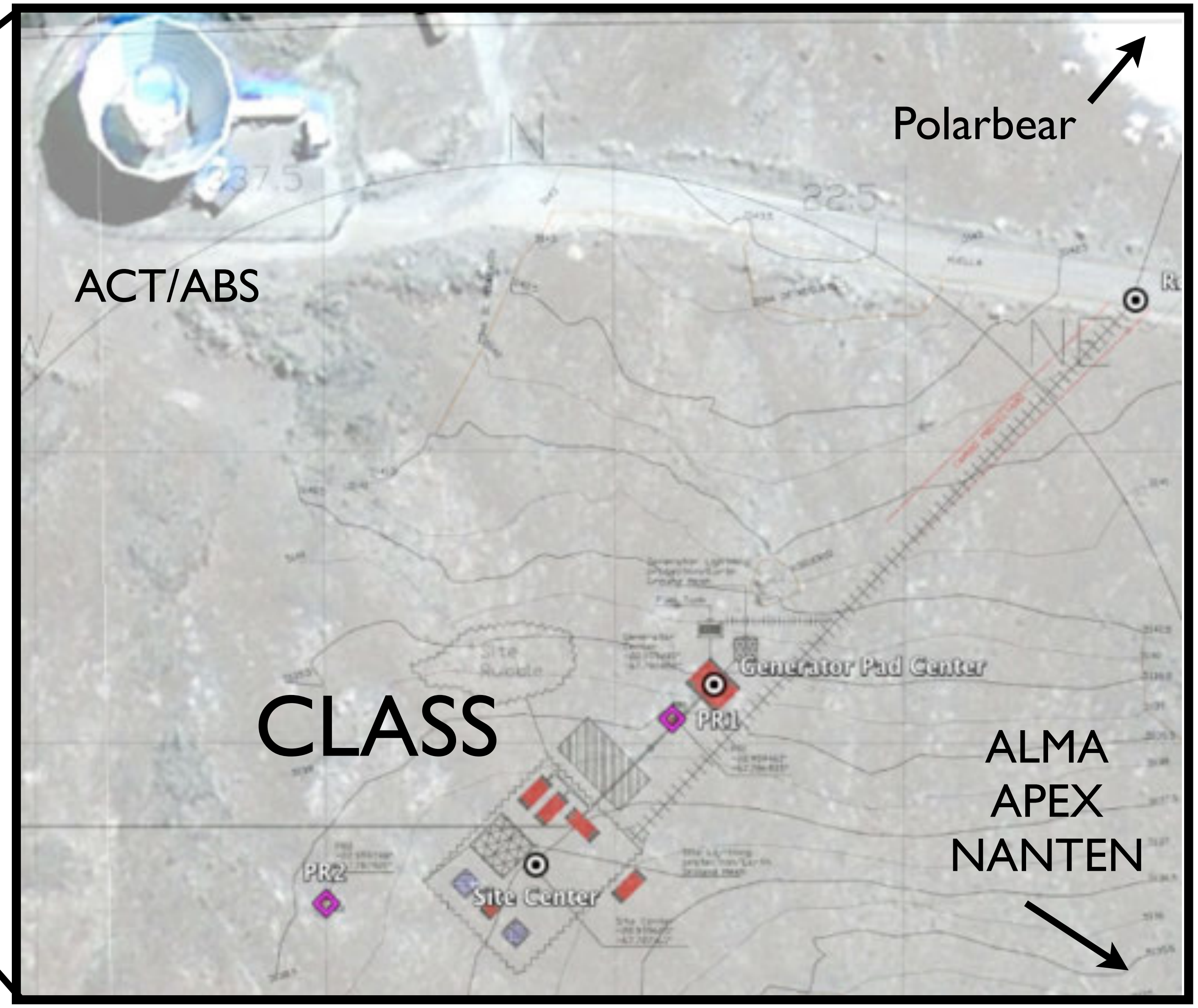
Additional foreground constraints from PIPER (200 GHz, 270 GHz) and Planck (217, 353 GHz)

CLASS Survey Design Parameters

Frequency	Detectors	Resolution
40 GHz	72	1.5°
90 GHz	600	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.

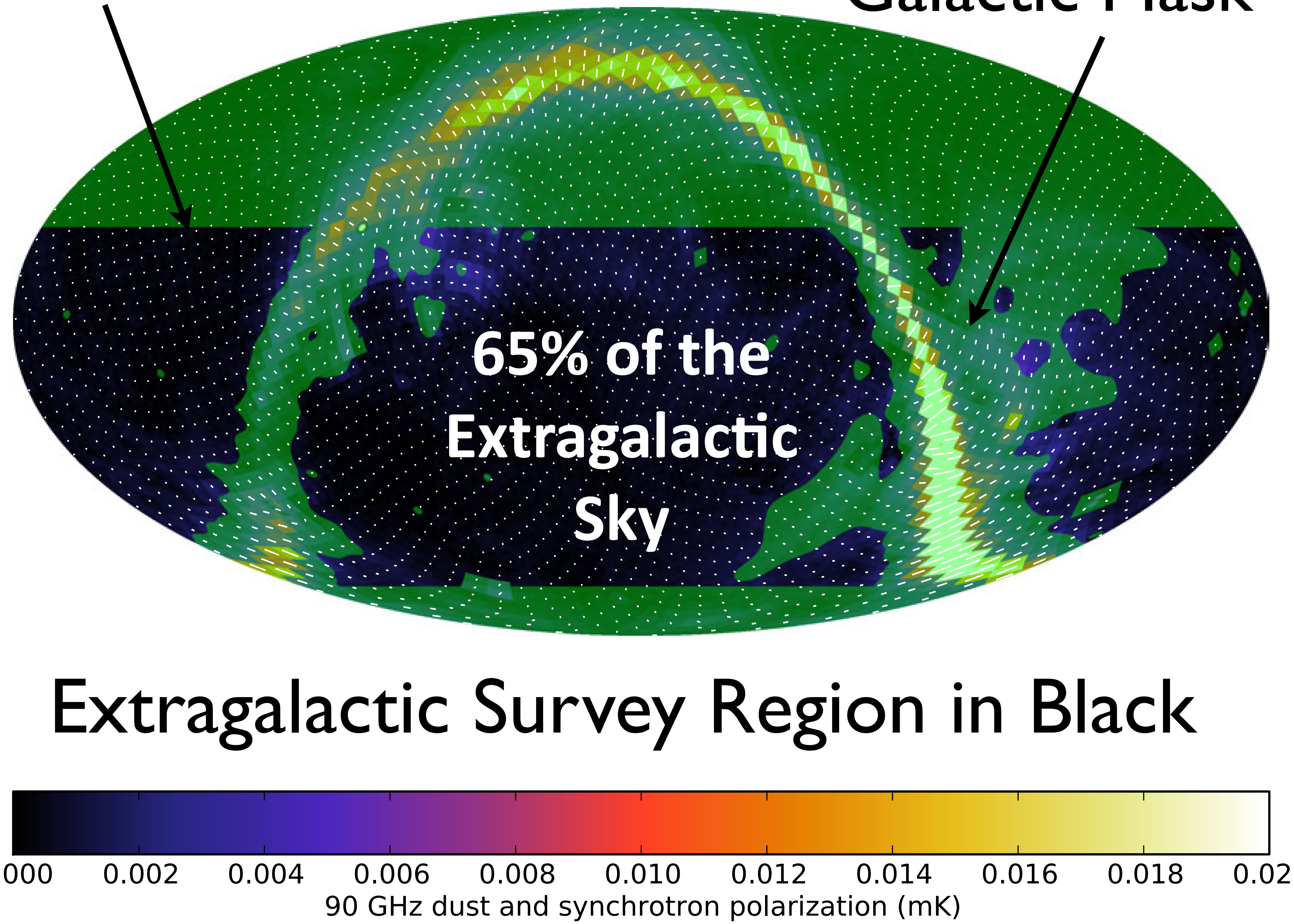


Site in Atacama Desert is not far from the equator: **most of sky** is surveyed at zenith angle 45 deg.

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

CLASS Survey Boundary

Galactic Mask

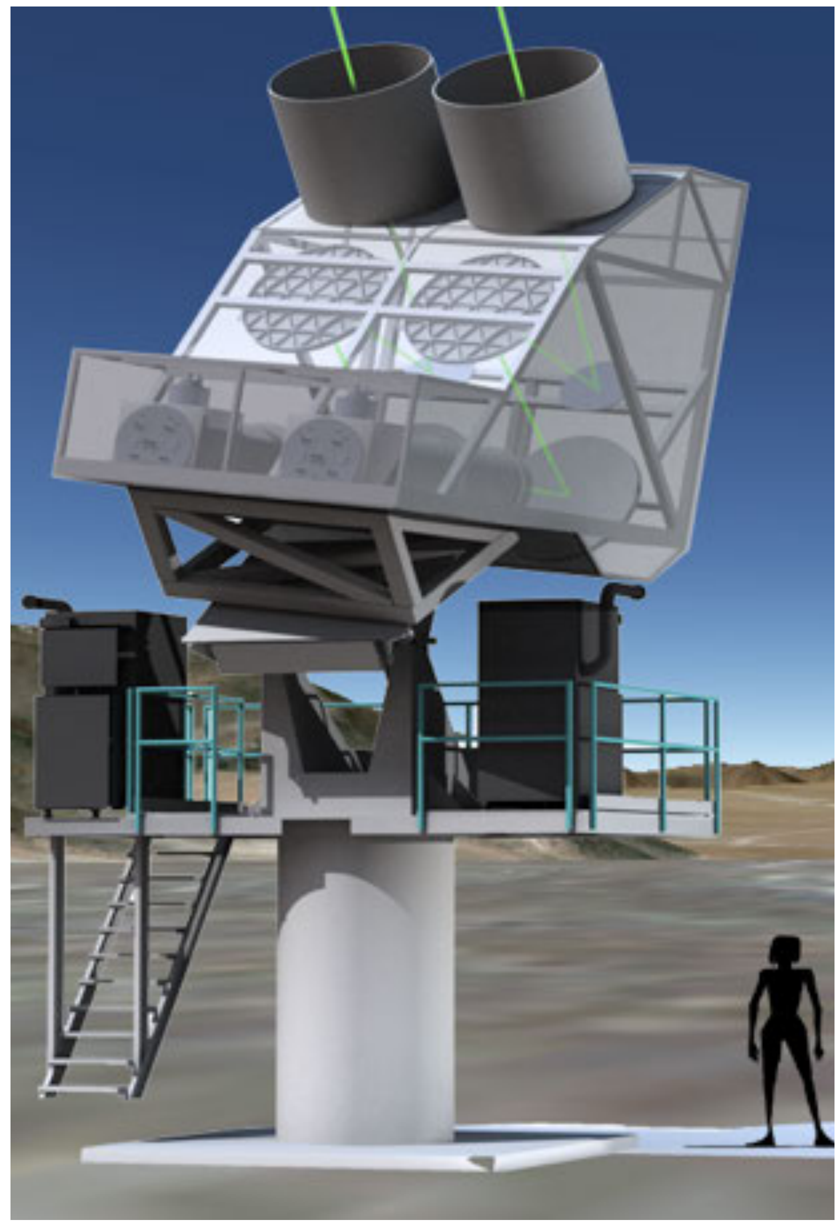


Extragalactic Survey Region in Black

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

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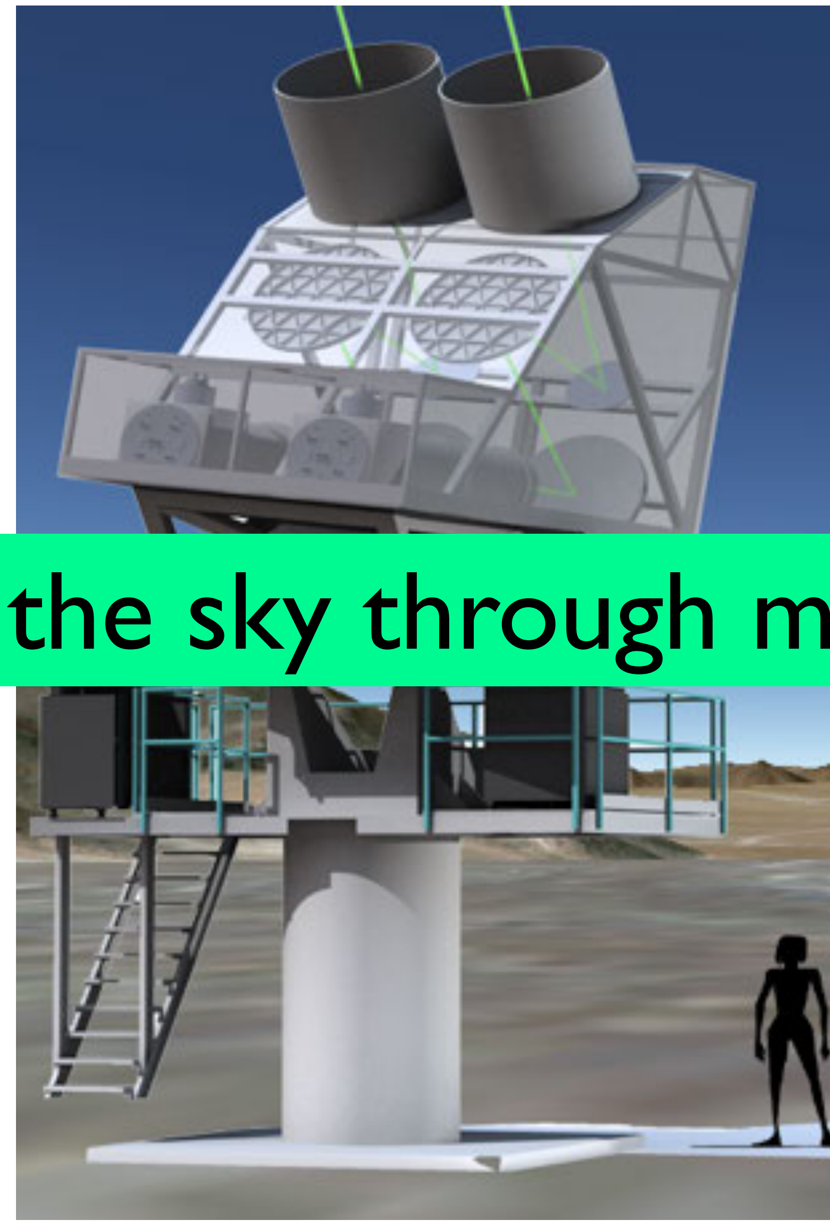


Viewing the sky through many angles.

in the JHU highbay

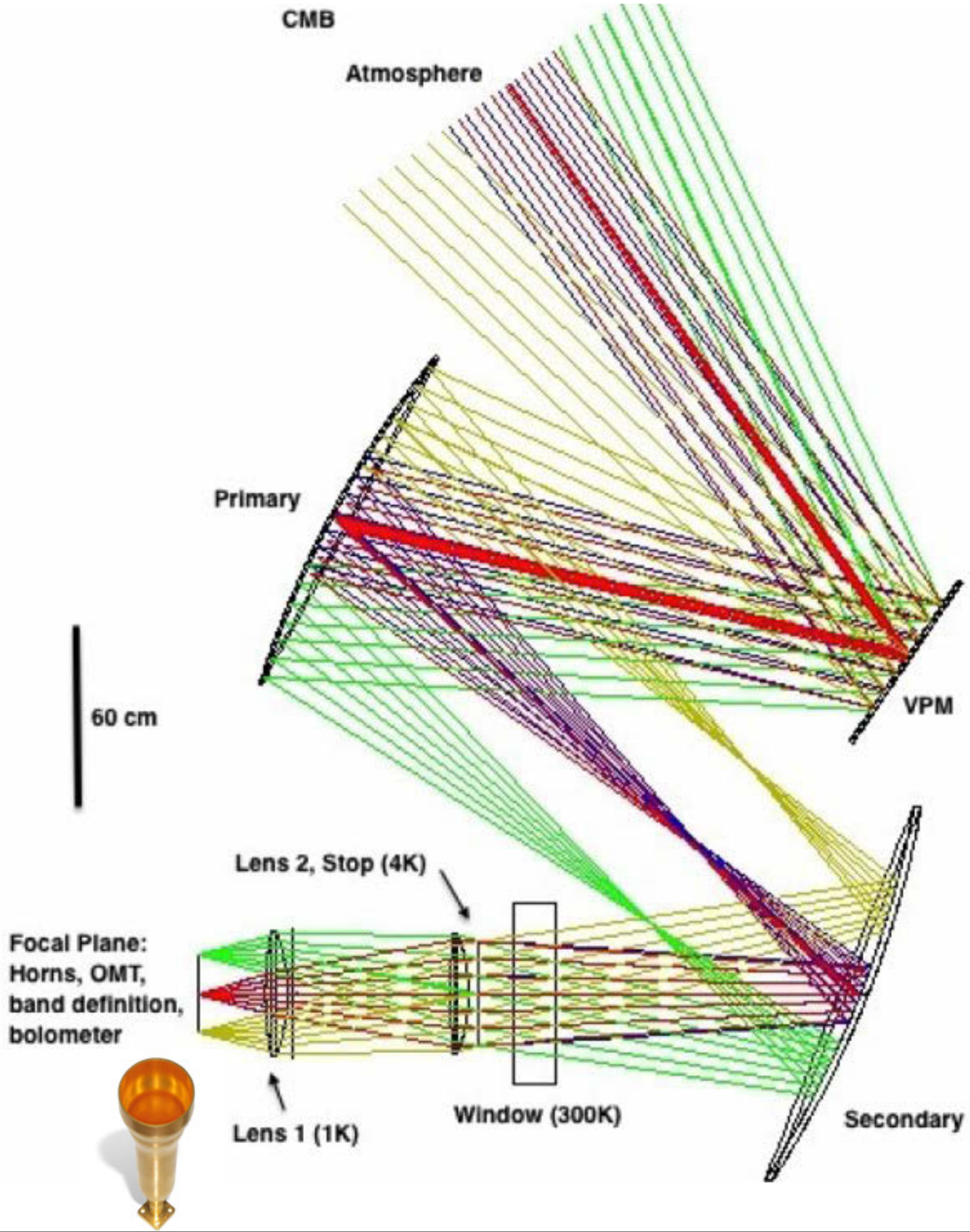
Site in Atacama Desert is not far from the equator: **most of sky** is surveyed at zenith angle 45 deg.

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.



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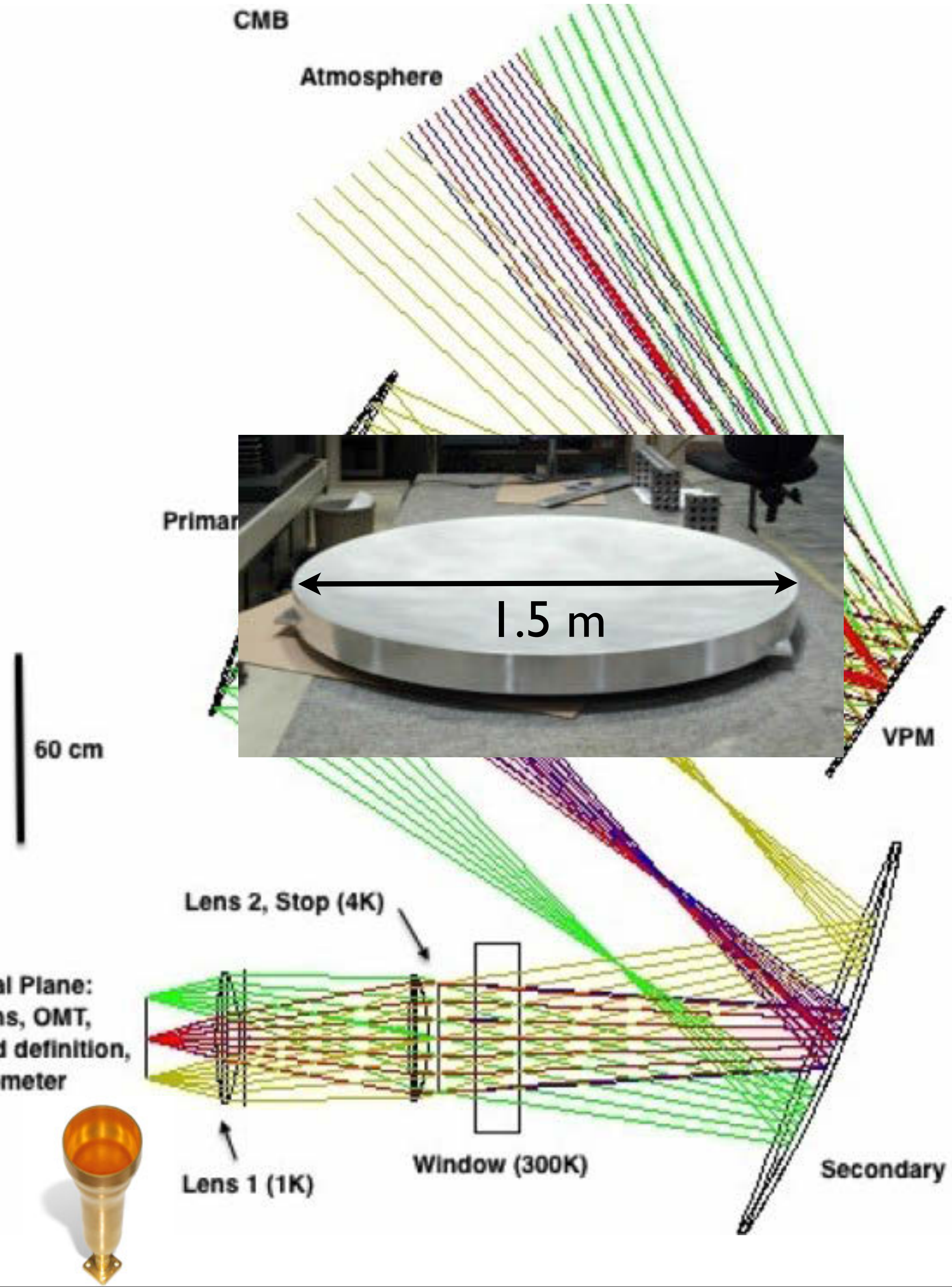

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Continuous Operation with 50 μW at 100 mK

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

The CLASS Way

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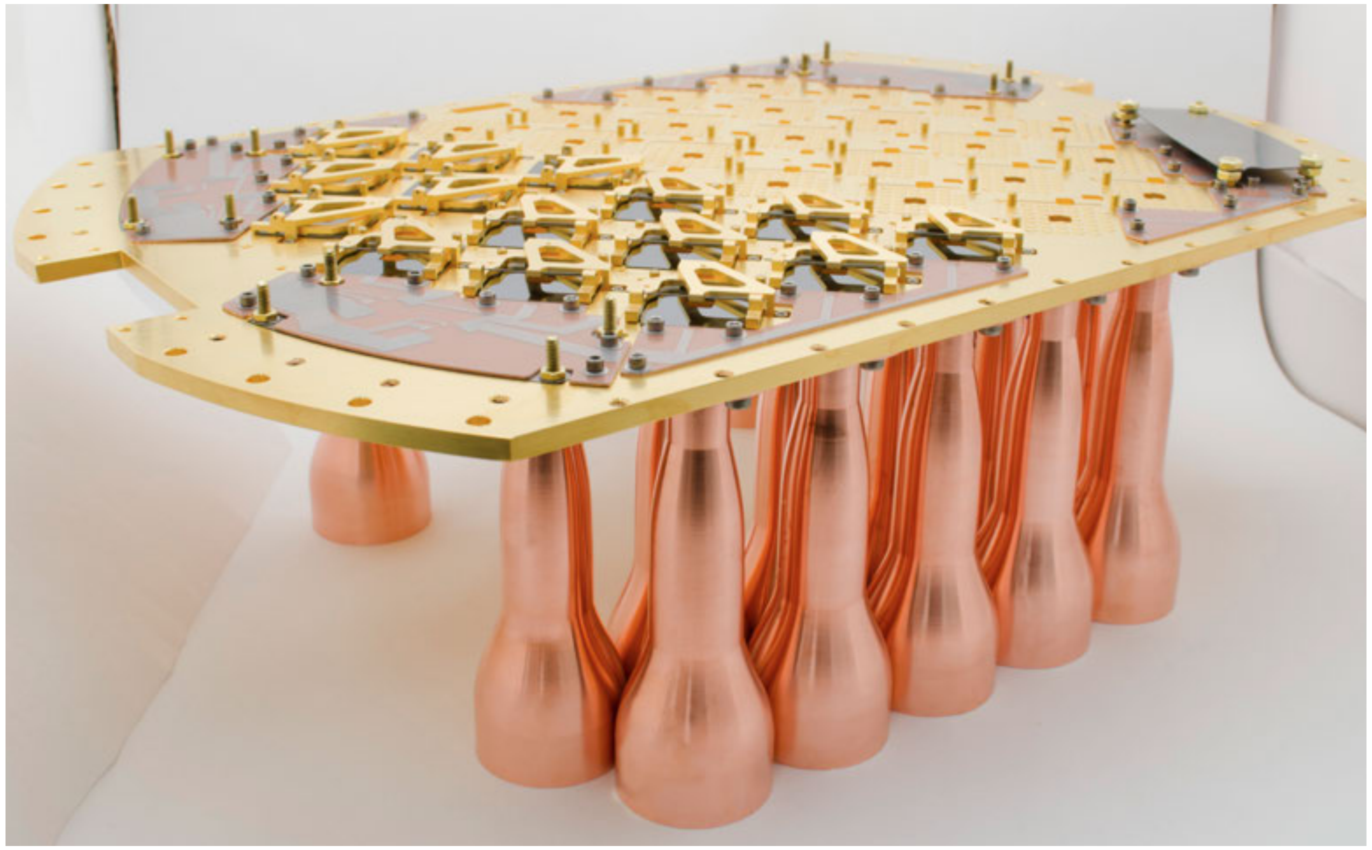
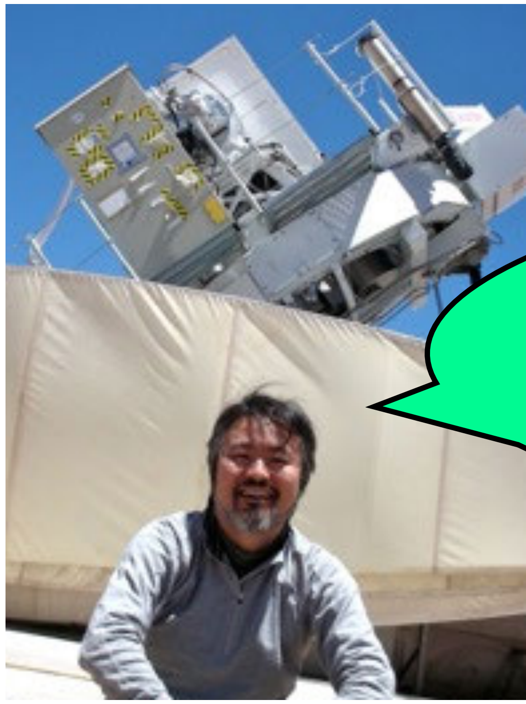


40 GHz Focal Plane Assembly.



M. Hazumi: You want to talk nitty gritty? You are welcome!

Sensitivity Discussion

Photons:

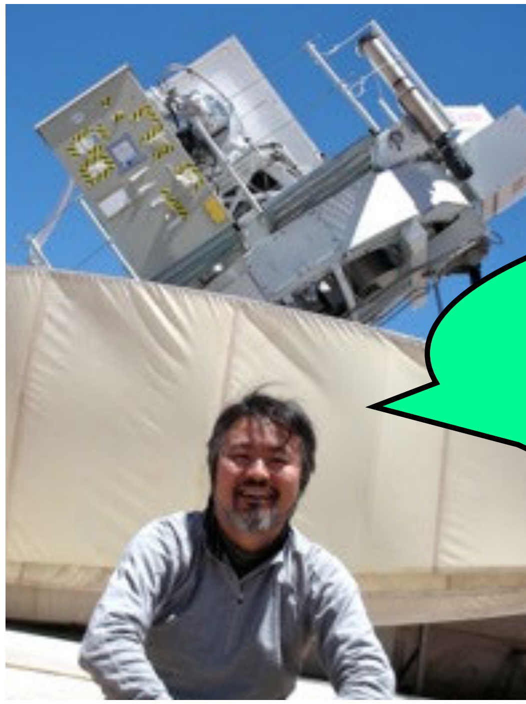
Photon shot noise NET ~$\eta^{-1/2}$

$$\sigma_P = \frac{h\nu\Delta\nu}{\eta\sqrt{\Delta\nu\tau}}\left[\eta n_0(1+\eta n_0)\right]^{1/2}$$

(Zmuidzinas 2003)

η=65% instead of η=40%: 25% less shot NET

ν=90 GHz instead of 150 GHz gives further reduction (generic ν dependence and higher atmosphere emissivity)



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Phonons:

$$\sigma_{Phonon}=\eta^{-1}\sqrt{4(GT)k_bT}$$
$$\sim\eta^{-1}\sqrt{4(\eta P)\,k_bT}$$
$$=\eta^{-1/2}\sqrt{4P\,k_bT}$$

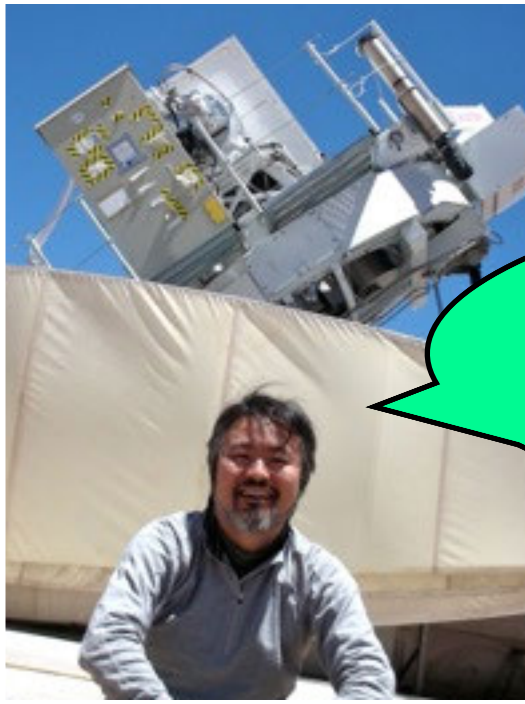
(P is total power from atm etc)

η=65% instead of η=40%: 25% less Phonon NET

T=150 mK instead of T=450 mK: 70% less Phonon NET

At 90 GHz, total power from atmosphere is lower.

While generally less than 50% of total power, phonon contribution is not far below that of photons.

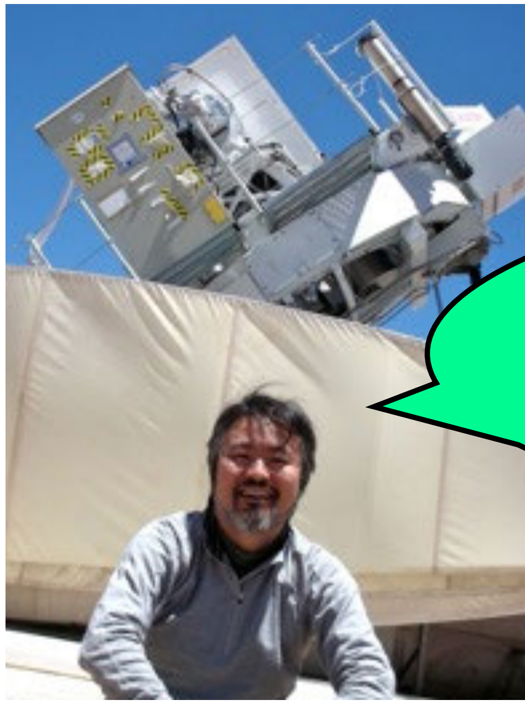


M. Hazumi: You want to talk nitty gritty? You are welcome!

Mitigate other practical effects that traditionally have caused problems (more grit):

Able to select best/most uniform detectors to give **better yield** (through fab and biasing)

Able to multiplex readout faster given current electronics options -- **less aliased readout noise**.



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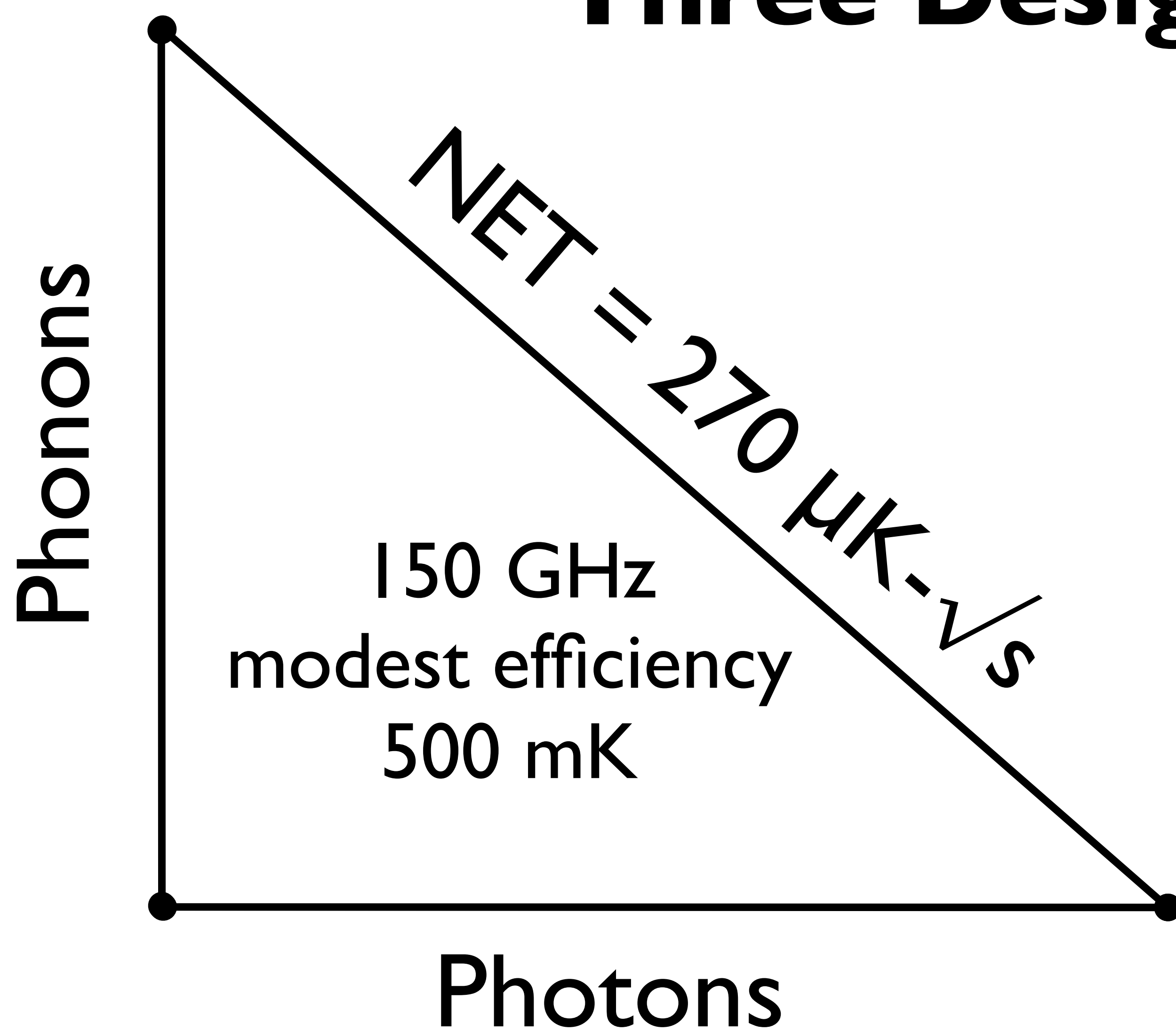
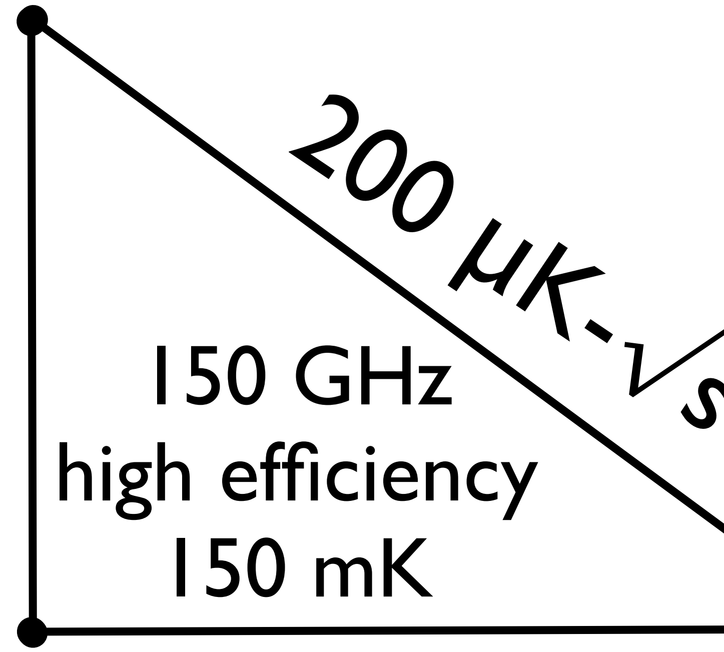
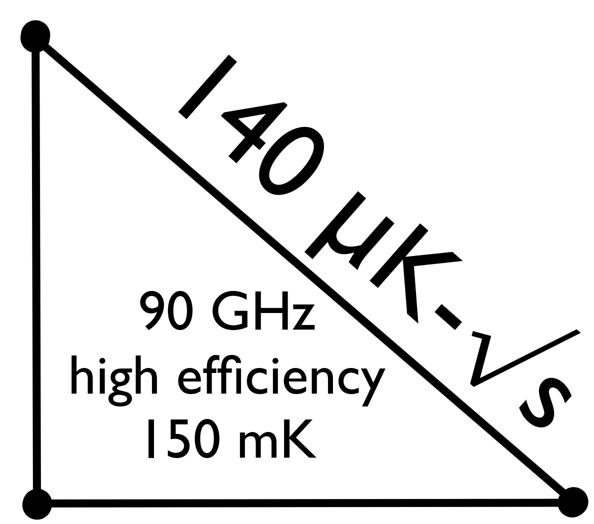
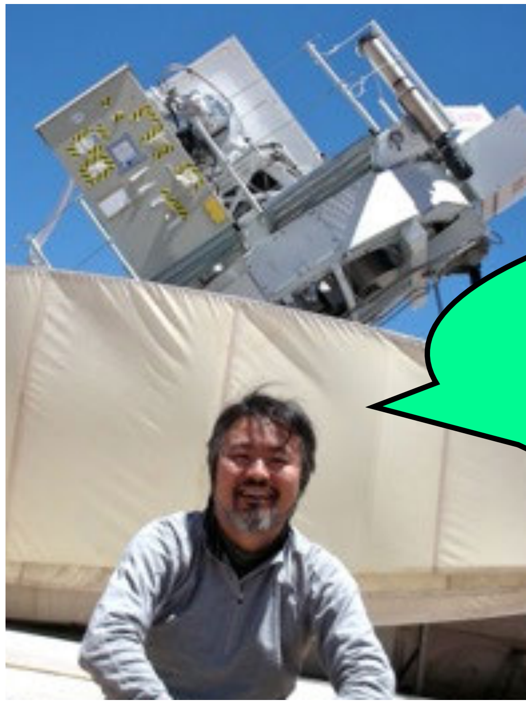
Three Designs*







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



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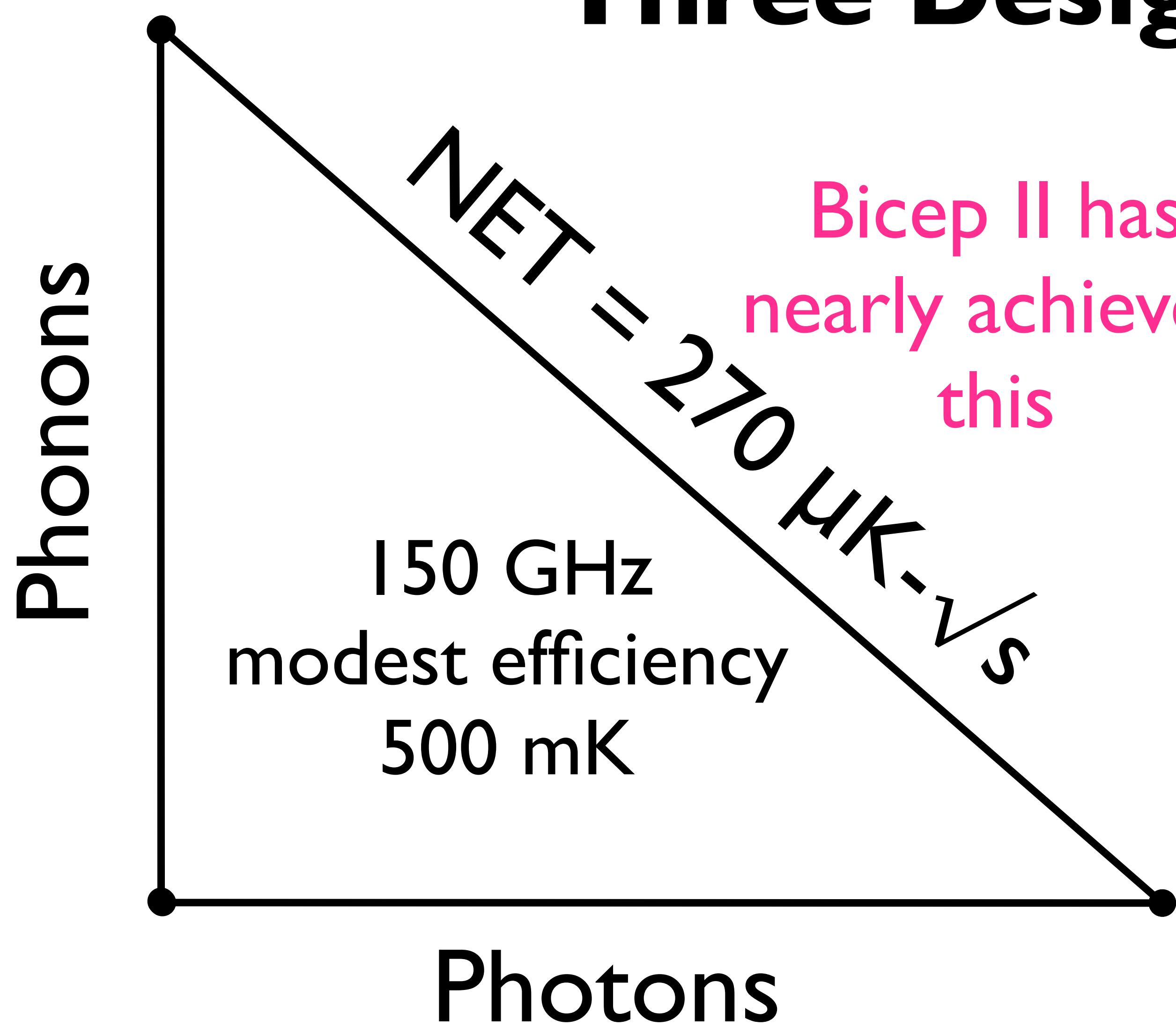
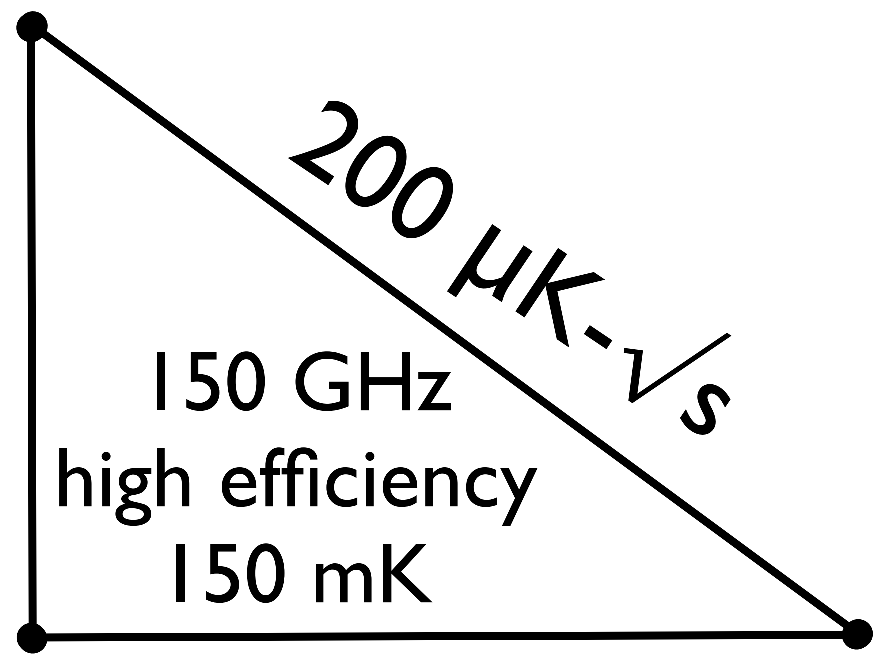
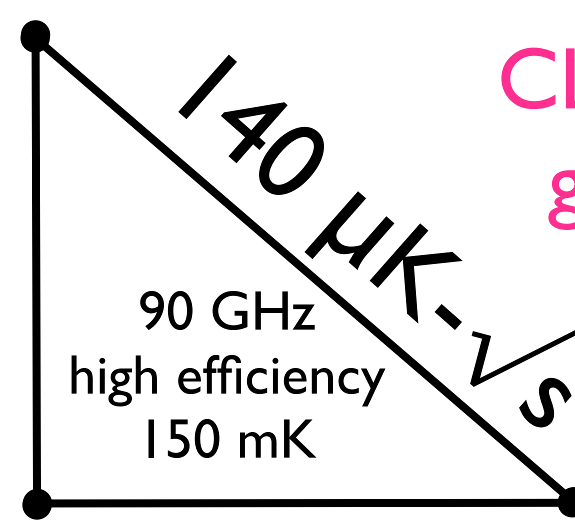


Bicep II has nearly achieved this

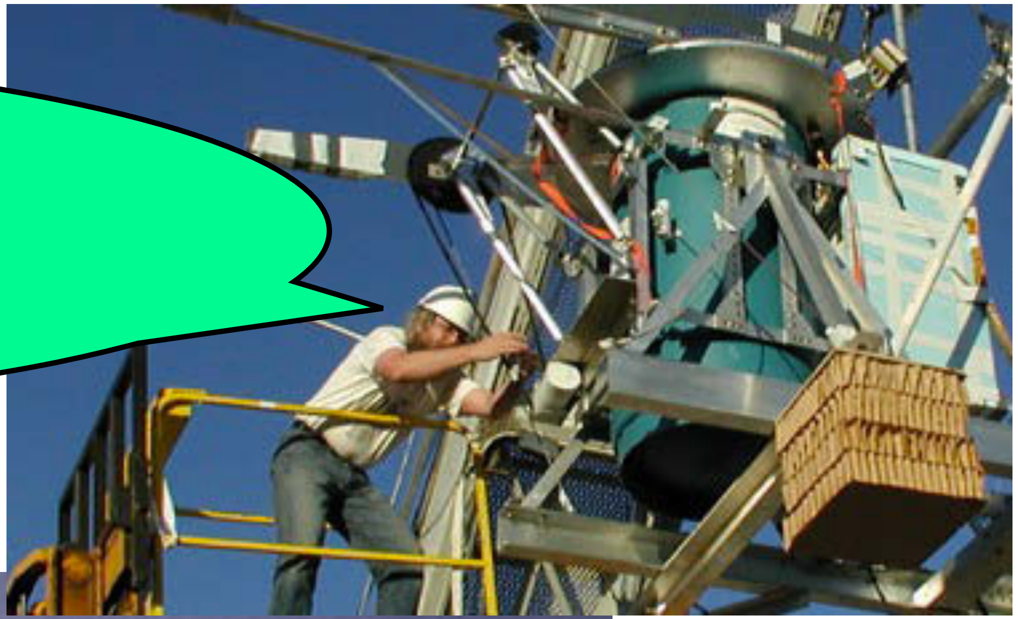




CLASS goal

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

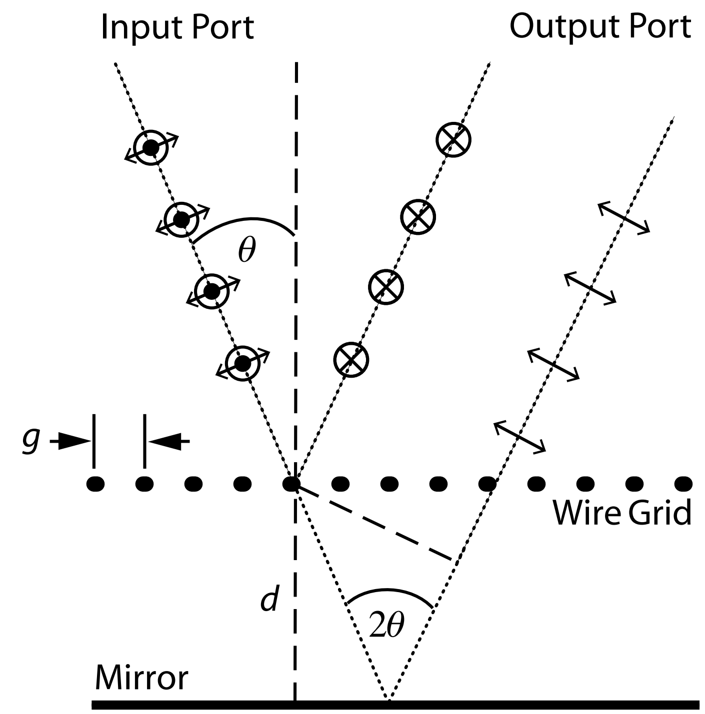
D.Fixsen: I feel like a ballerina on a football field.

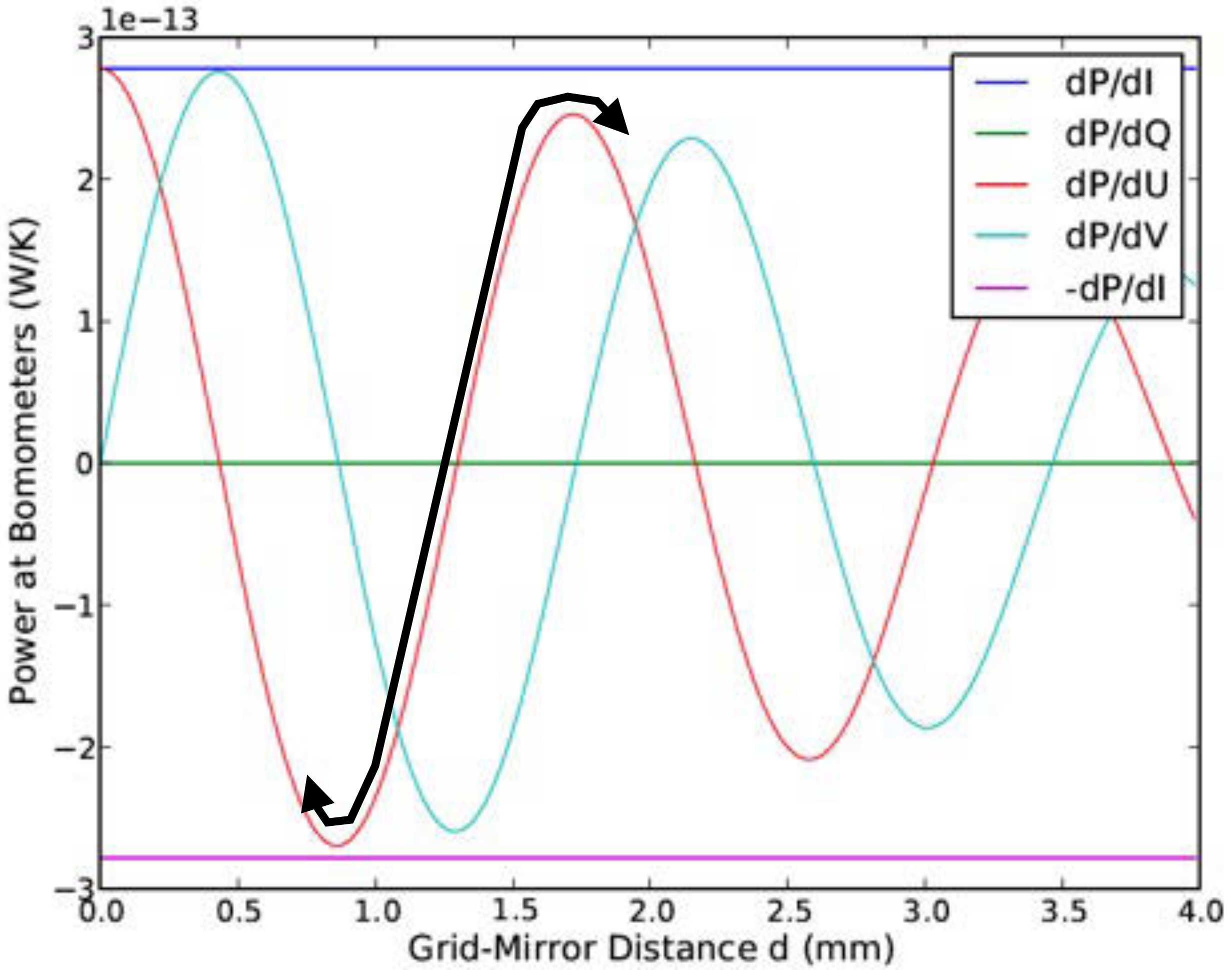


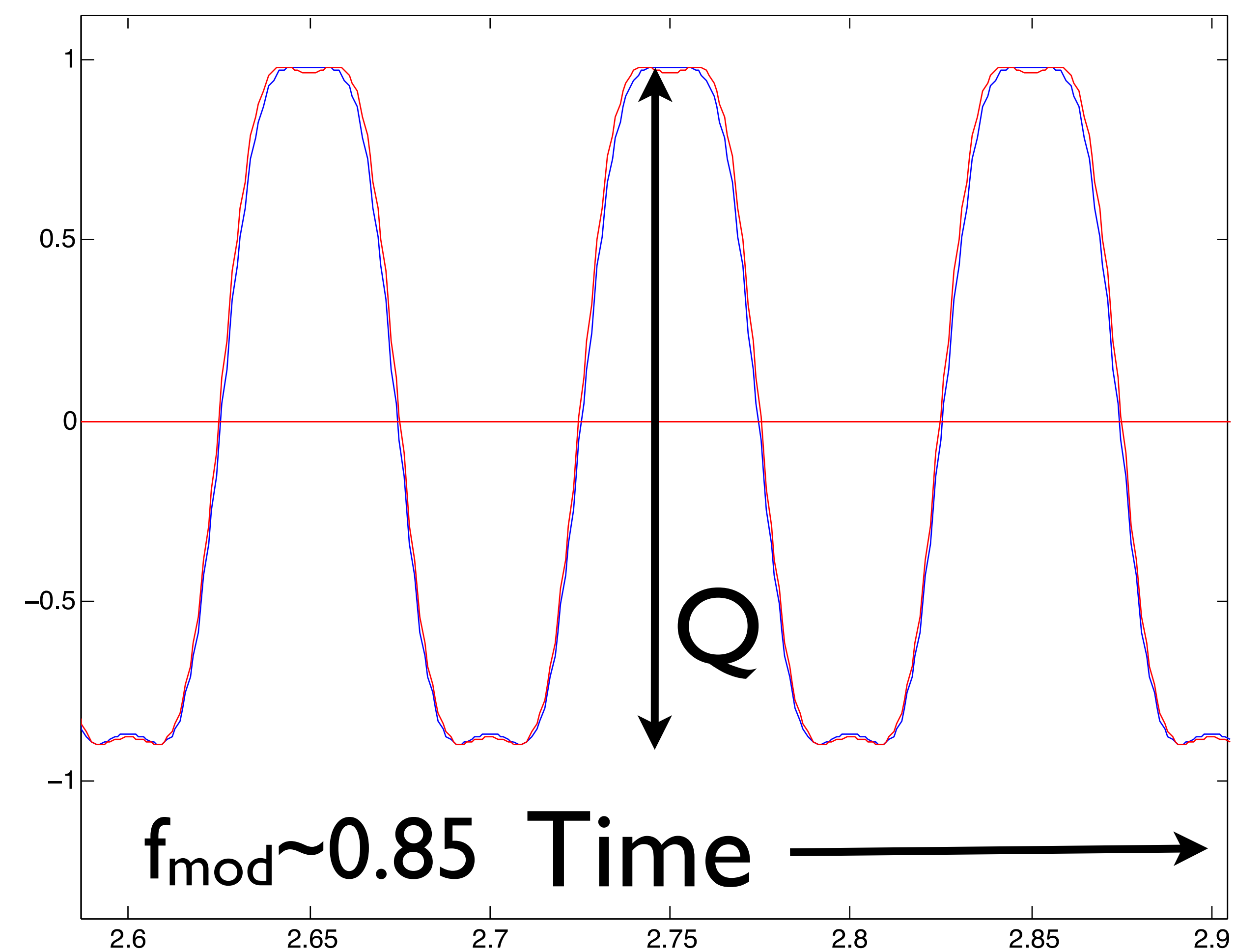
CLASS uses **modulation** to measure **large scales.**

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.







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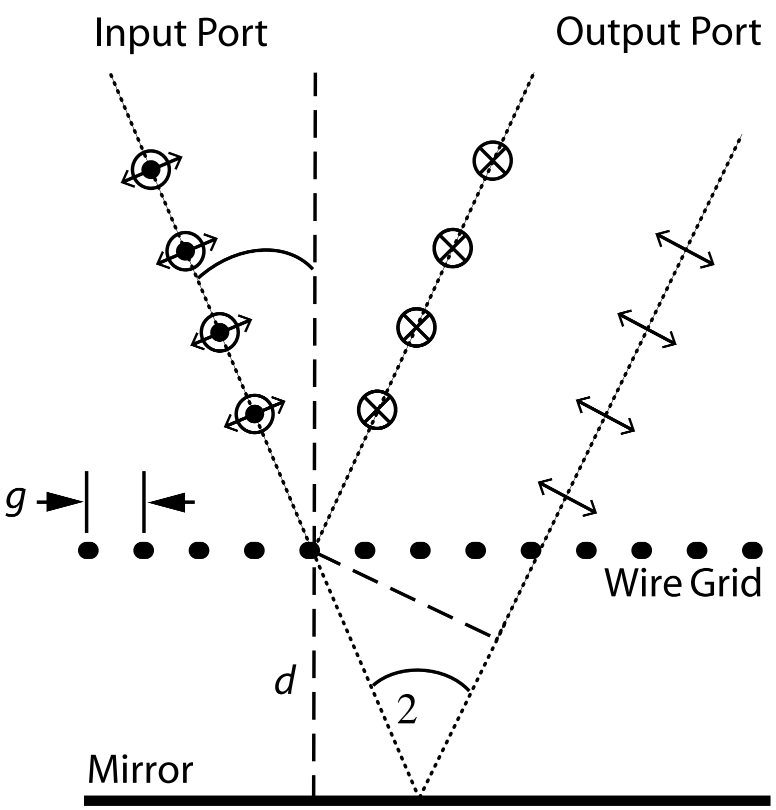
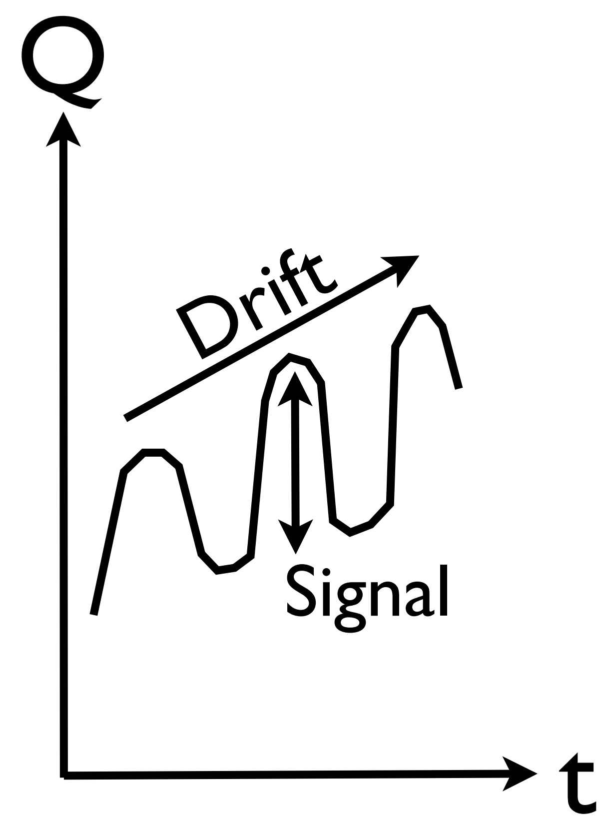
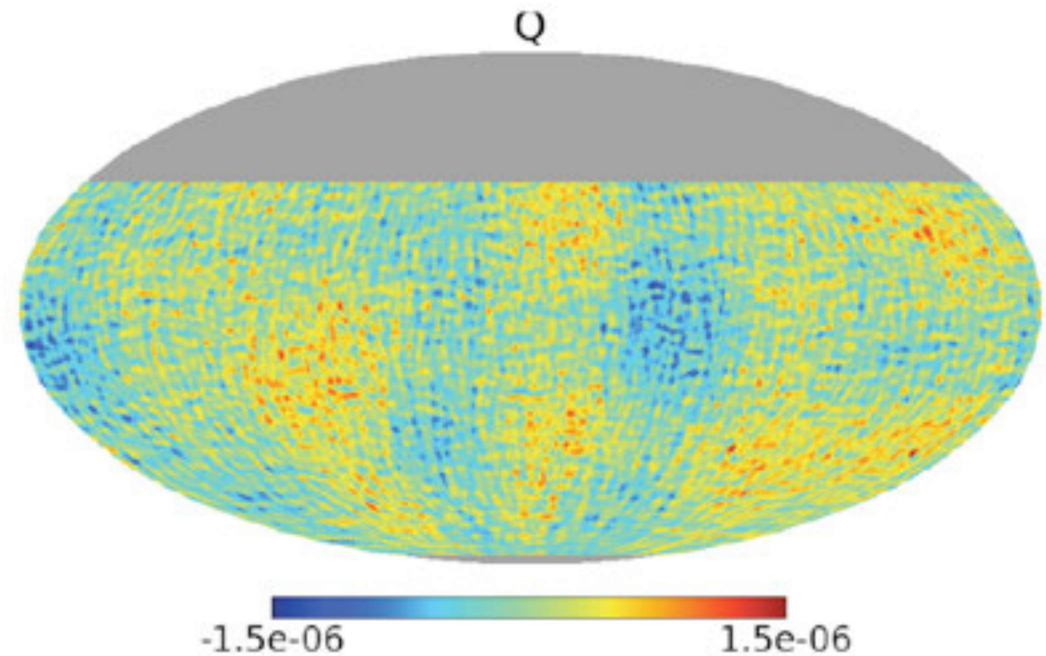
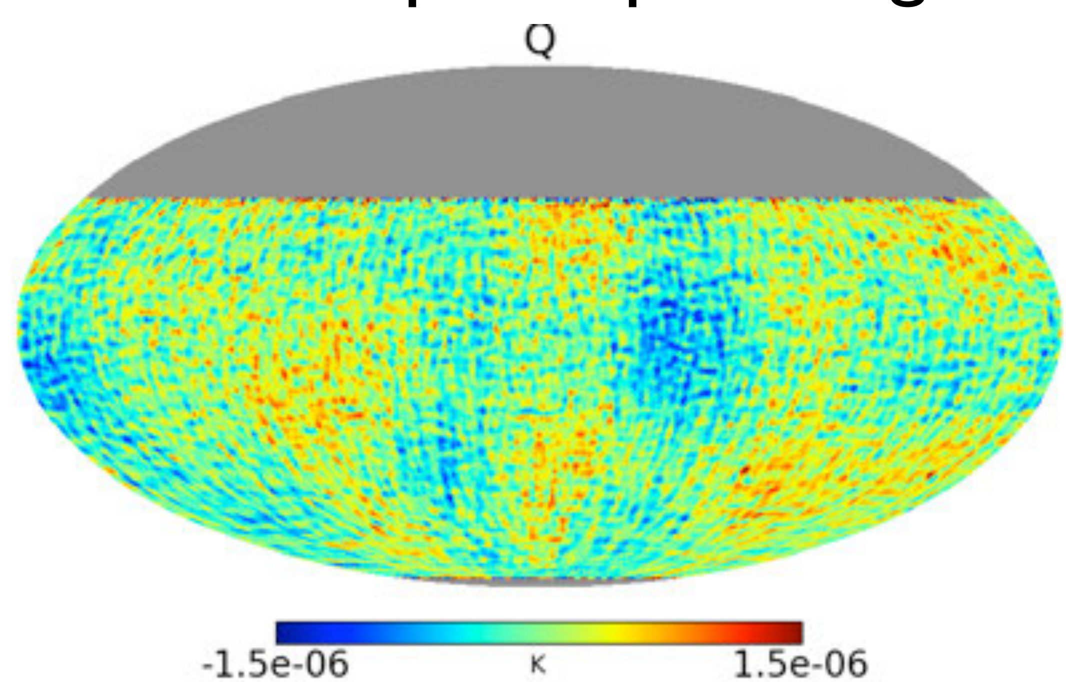




CMB Simulation



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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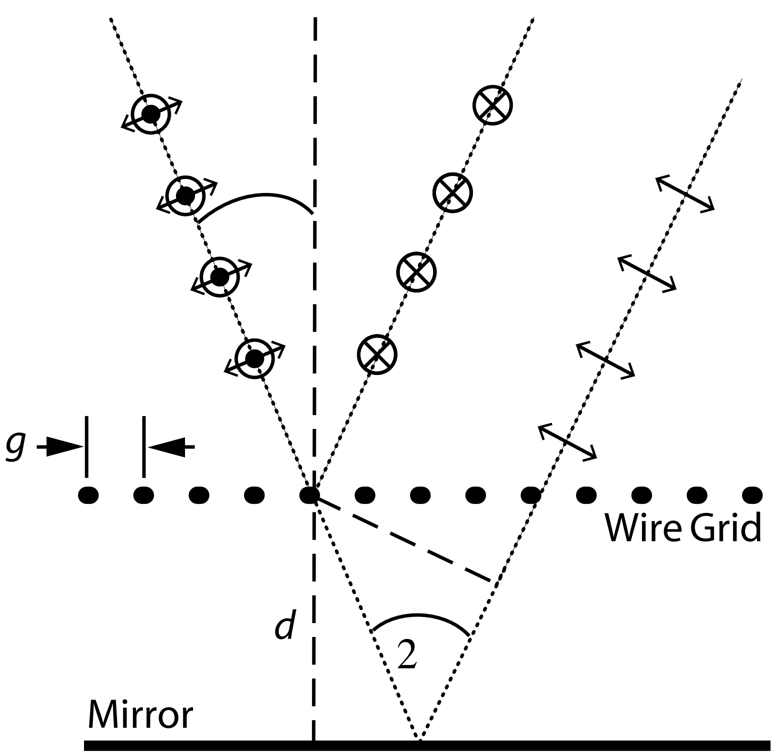

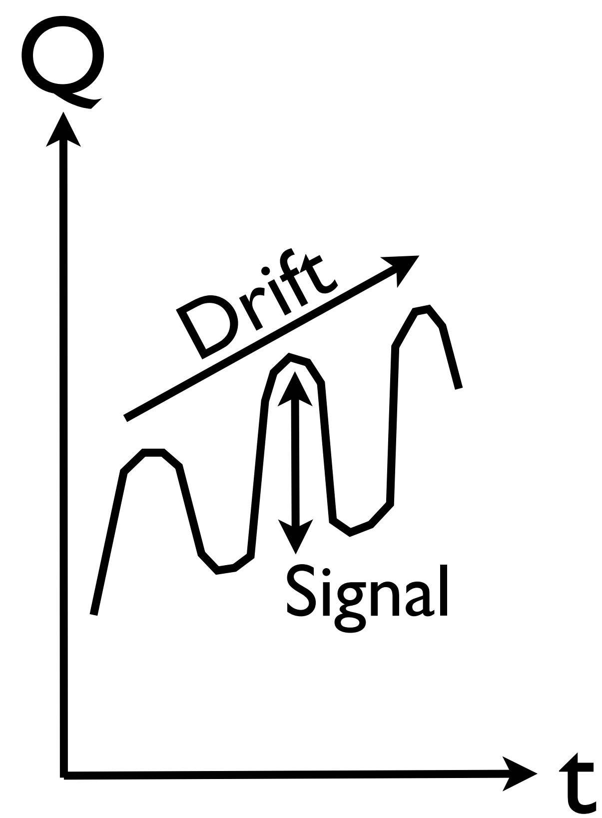

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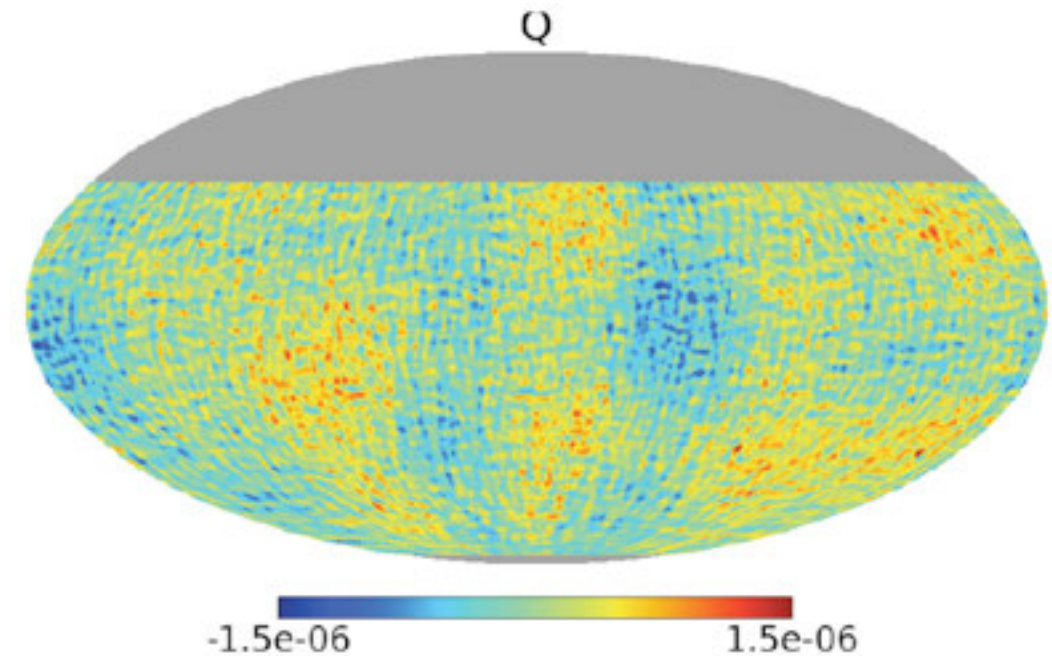
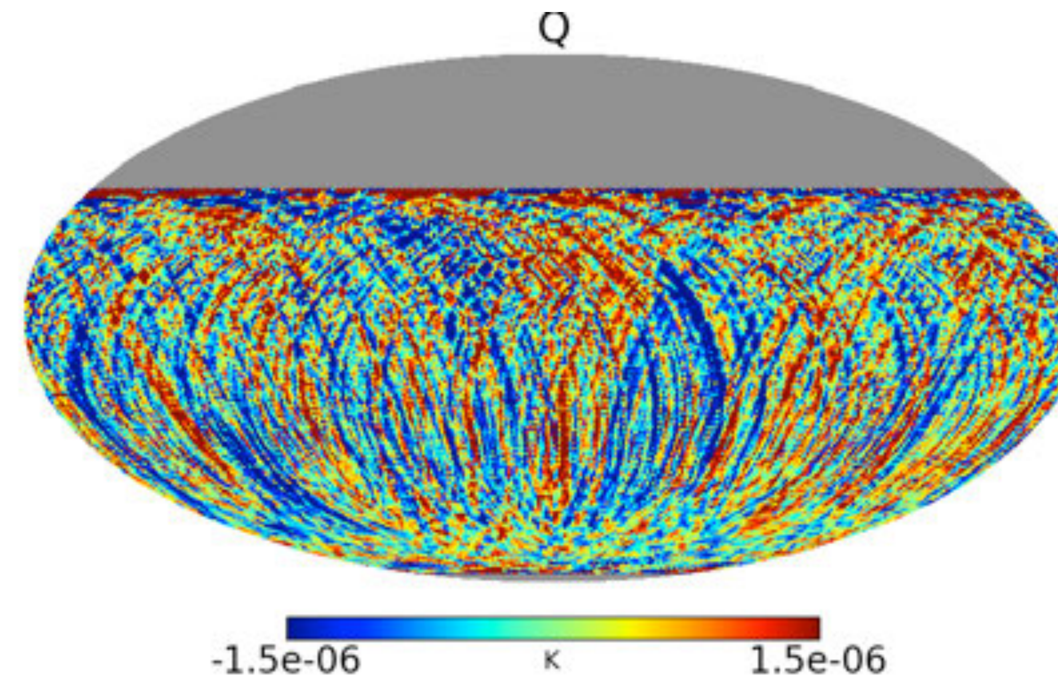


Recovery without Modulation and simple map-making



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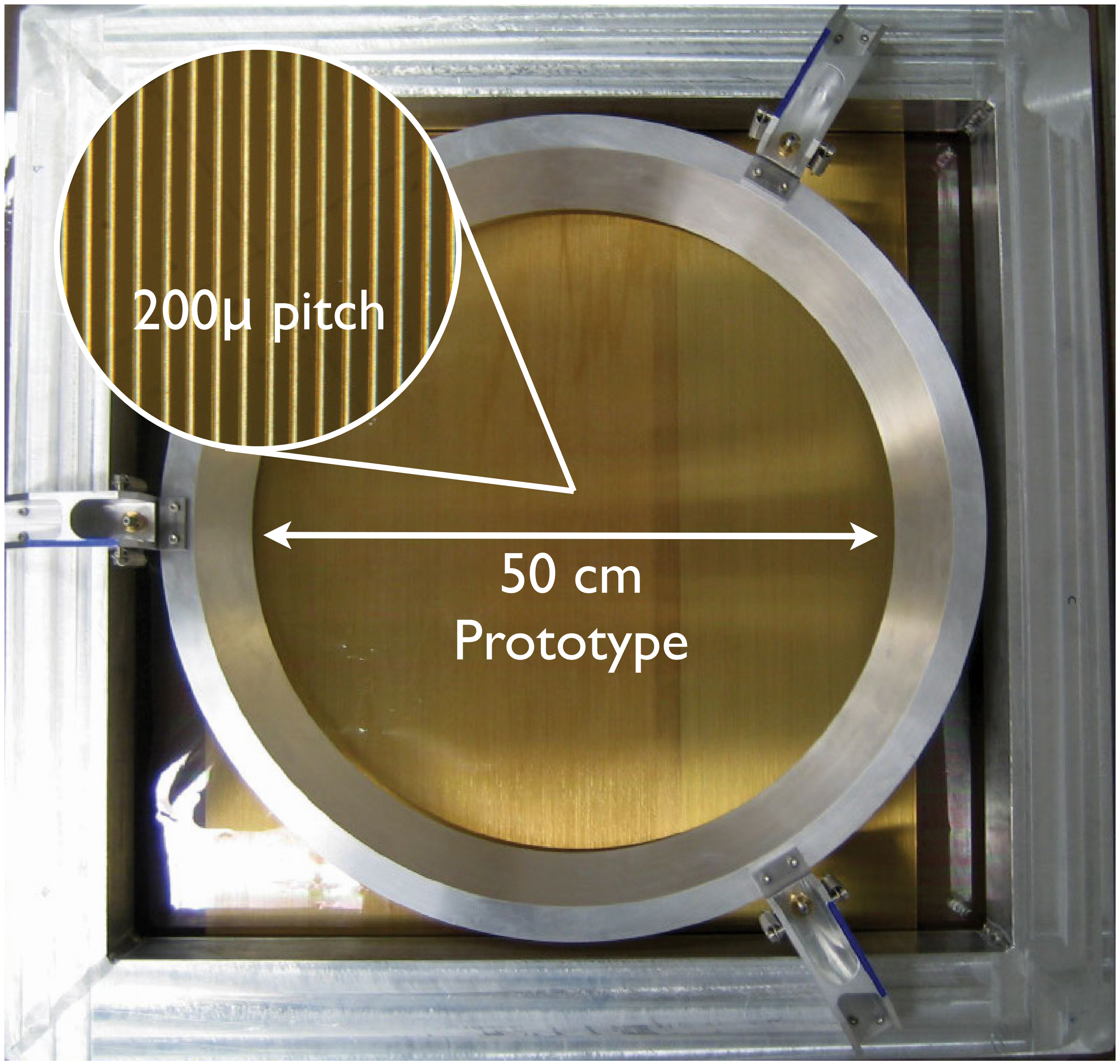

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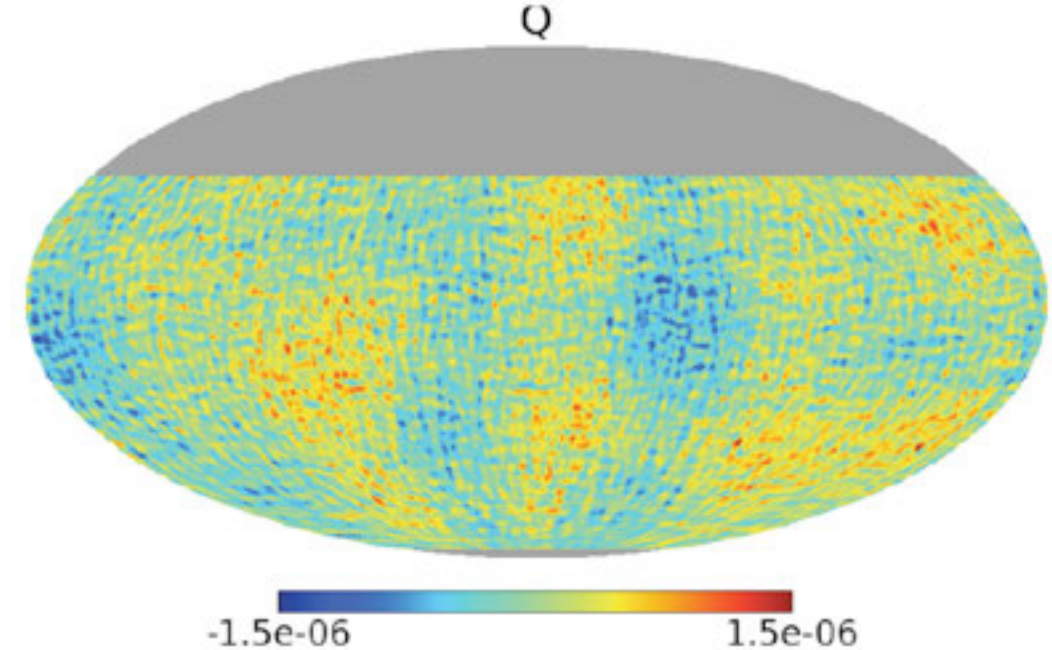

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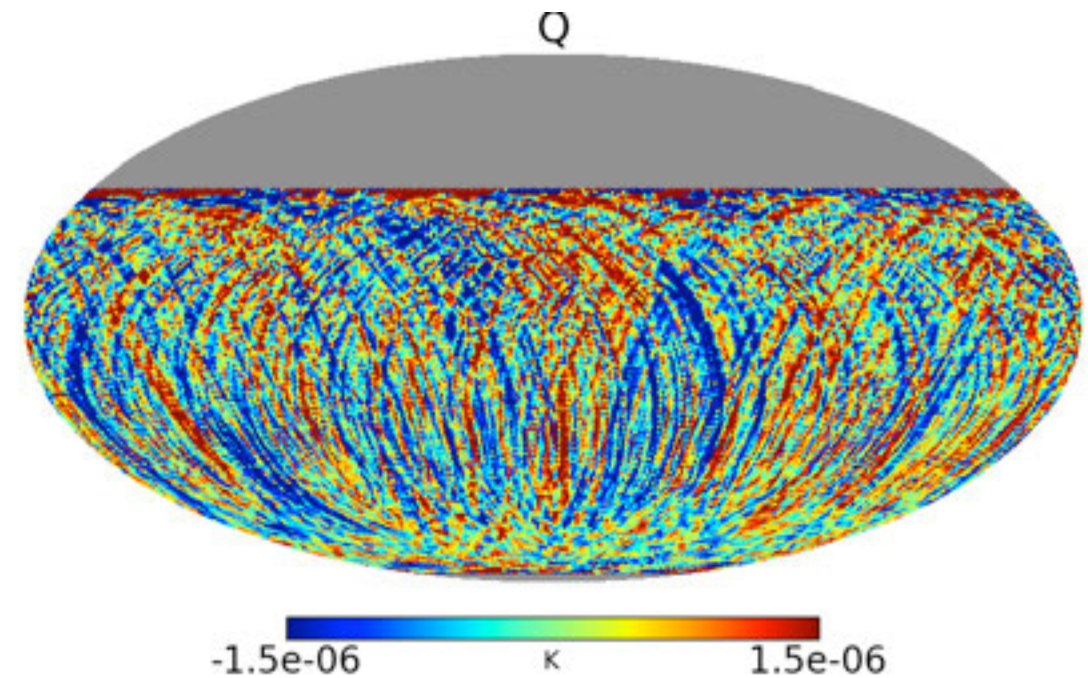

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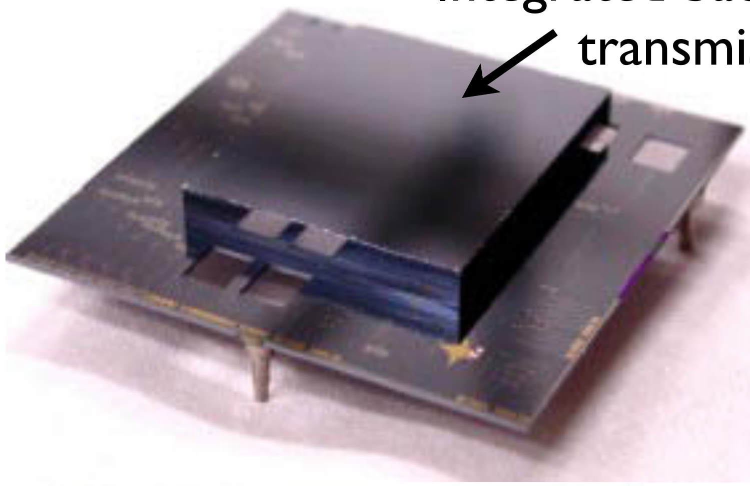
CLASS Detectors

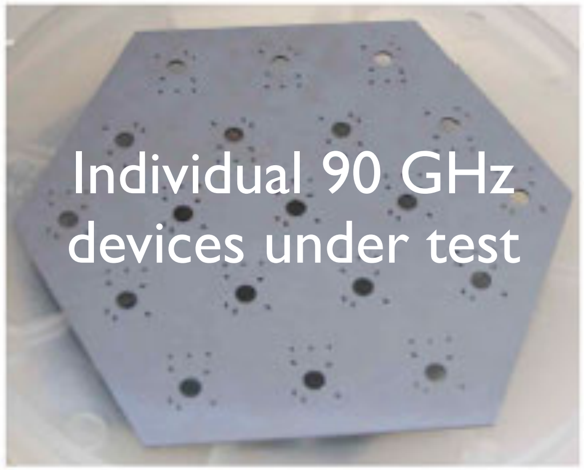


Horns and Planar OMT produce
simple single-moded beams.

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

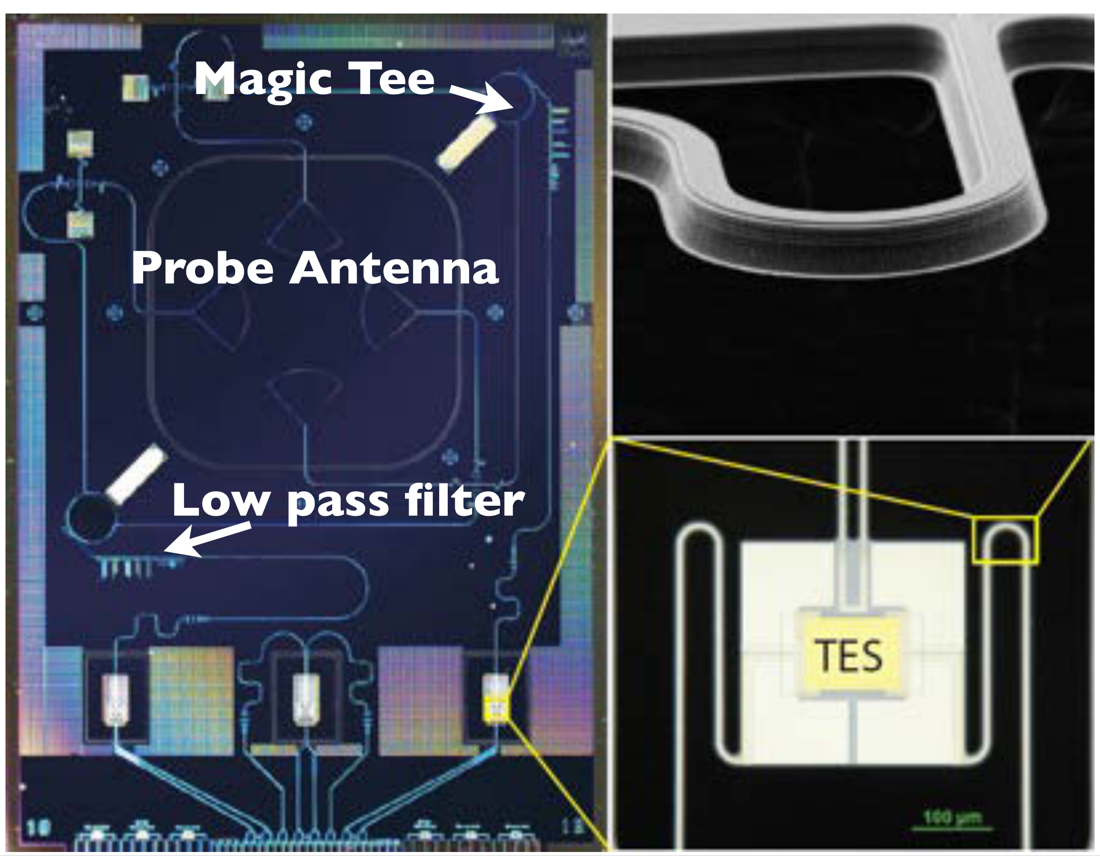
Intrinsic OMT design achieves **broad 50% fractional bandwidth**, which may be divided for multi-frequency operation.

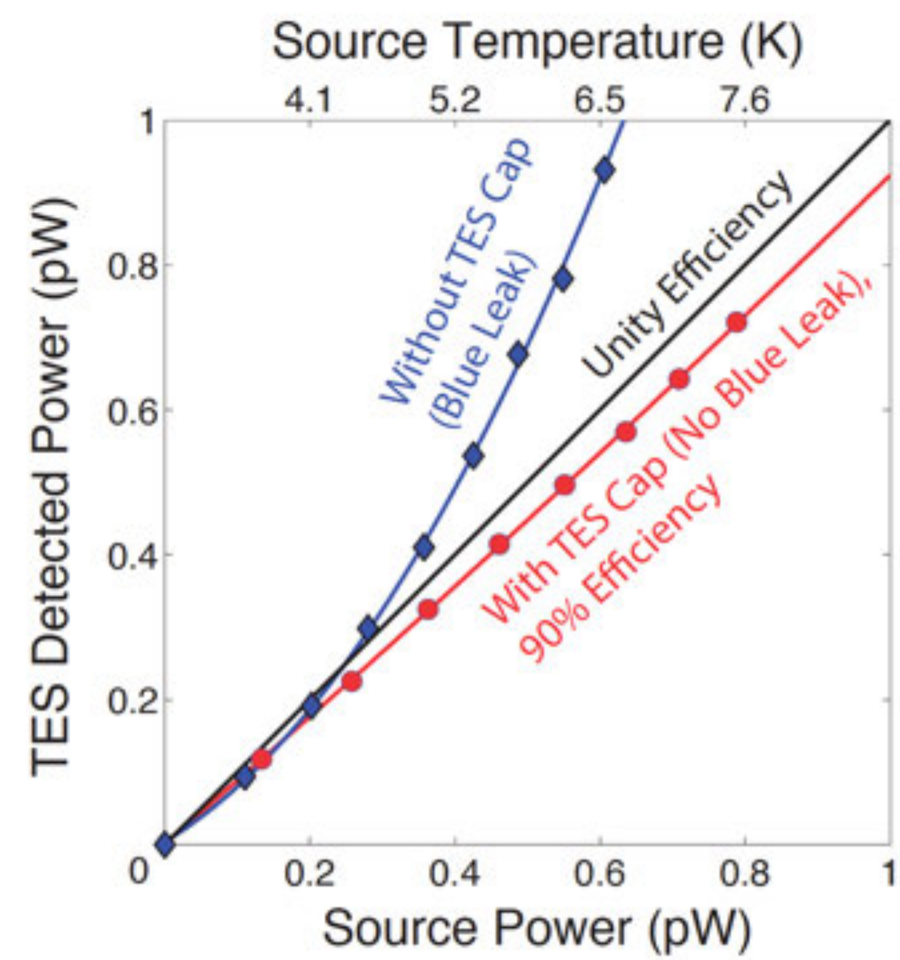
On-chip transmission line filtering, shielding and niobium gap provide **well defined bandpass** and **stringent blue leak control**.

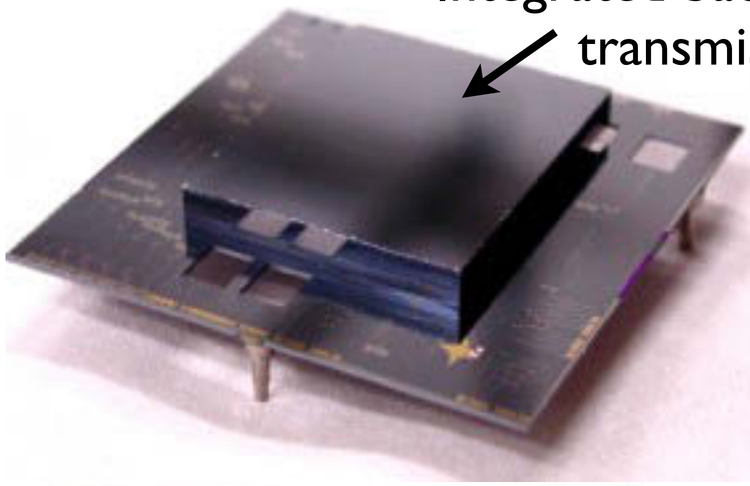


90 GHz Prototype wafer

40 GHz Detector







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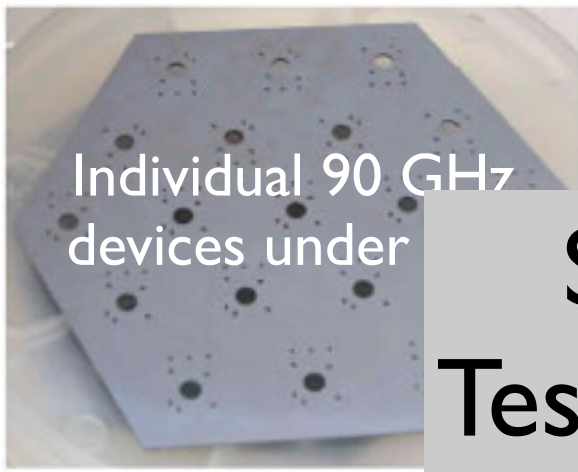
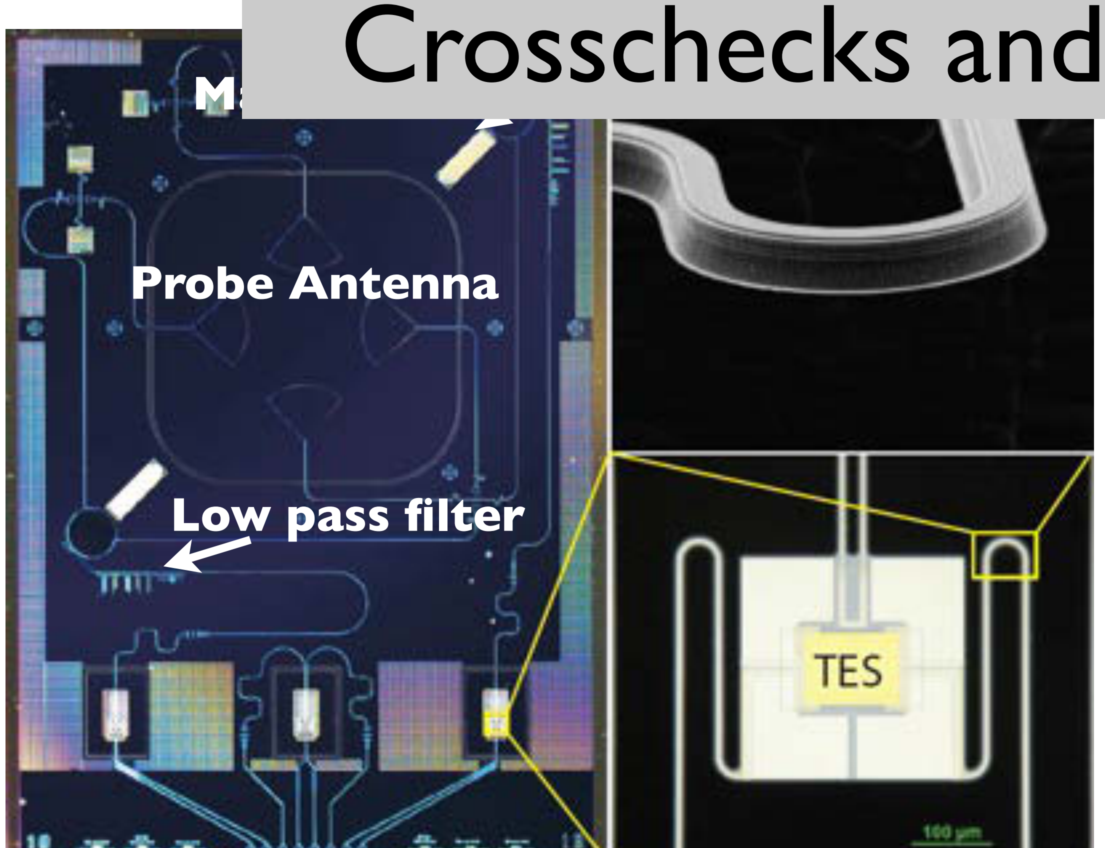
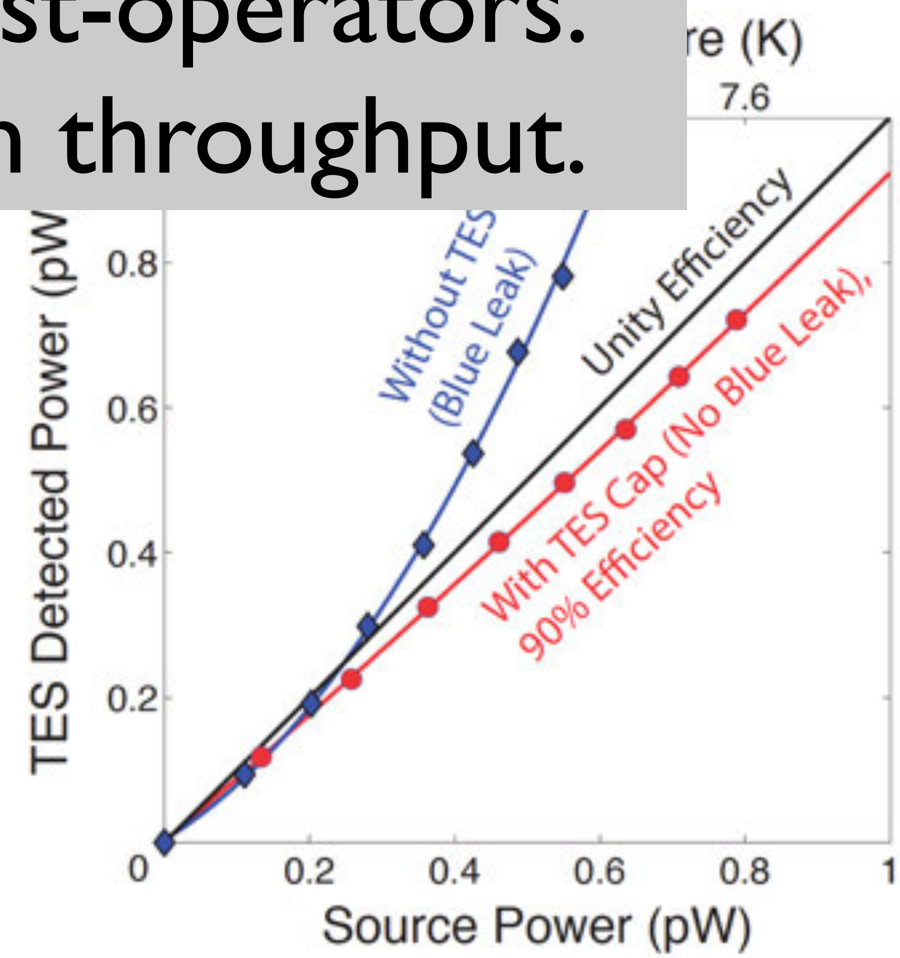


90 GHz Prototype v

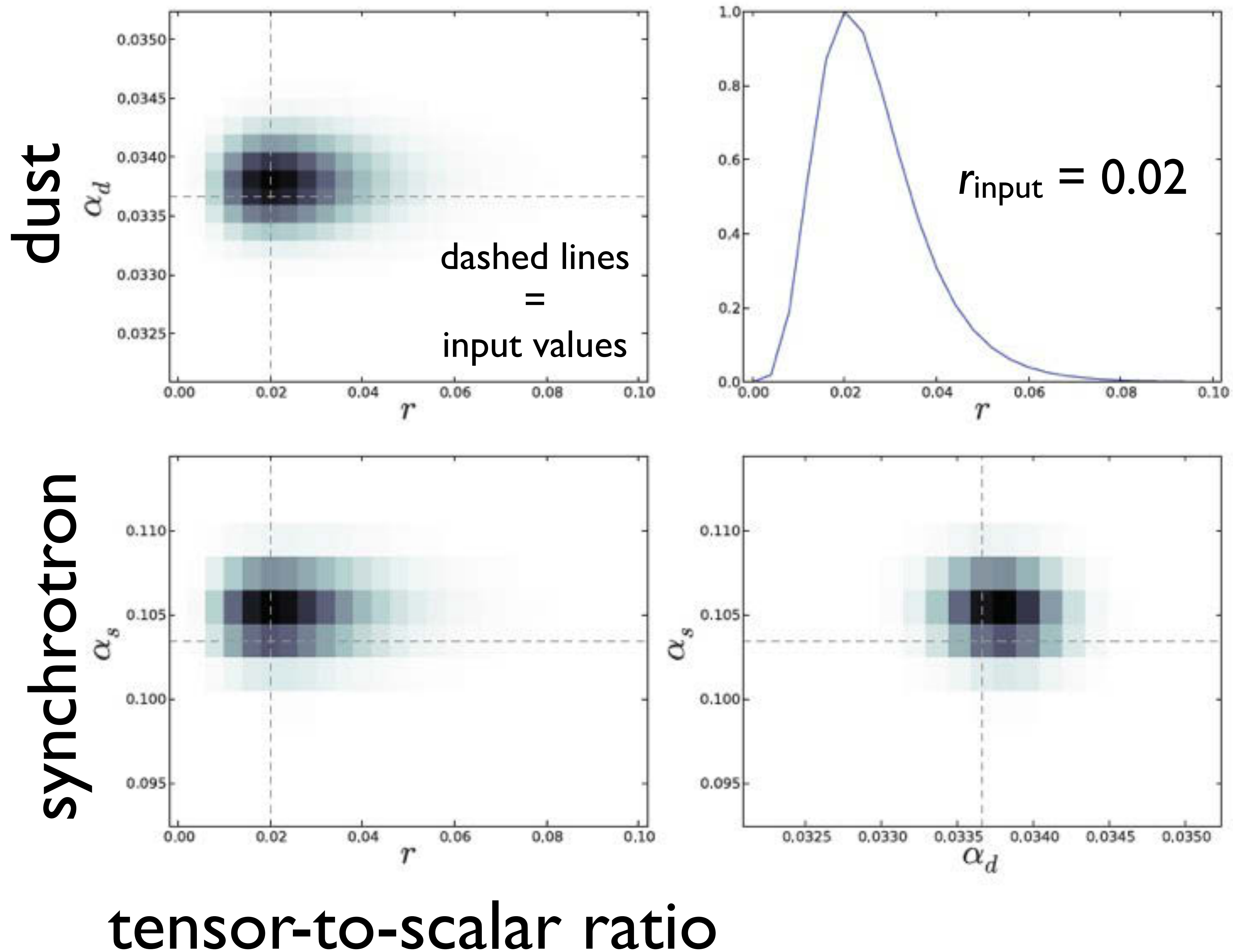
Significant testing infrastructure!
Testbeds at GSFC, JHU, and Columbia
with *dedicated* scientist-operators.
Crosschecks and high throughput.





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*.

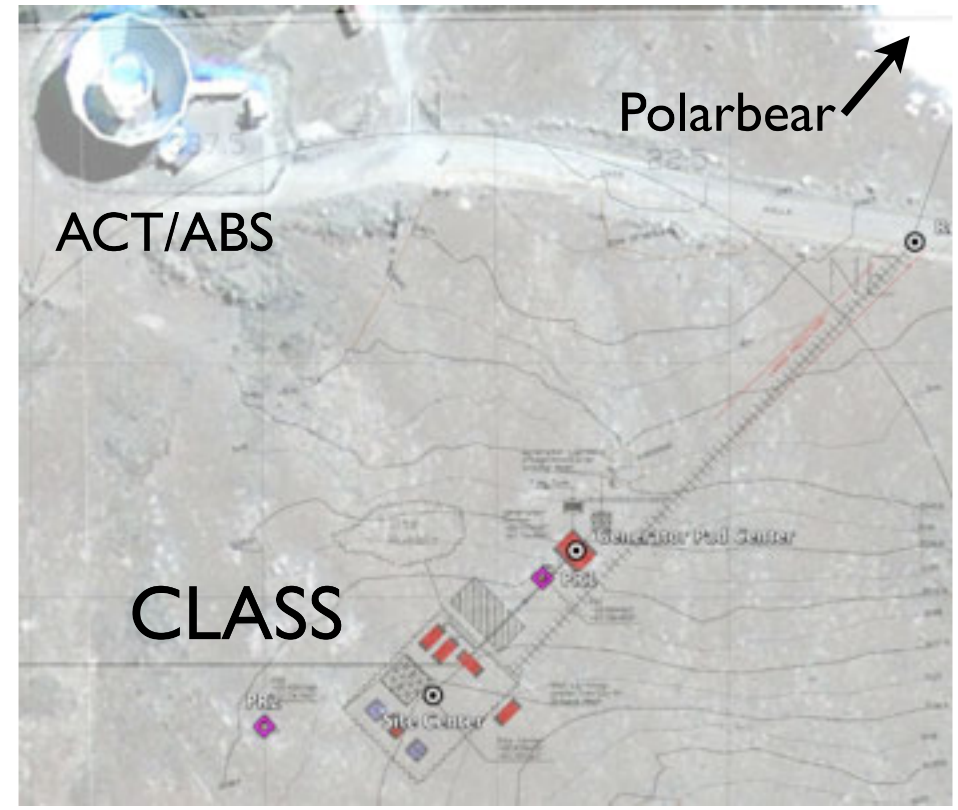
Preliminary!!! More work to be done.

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

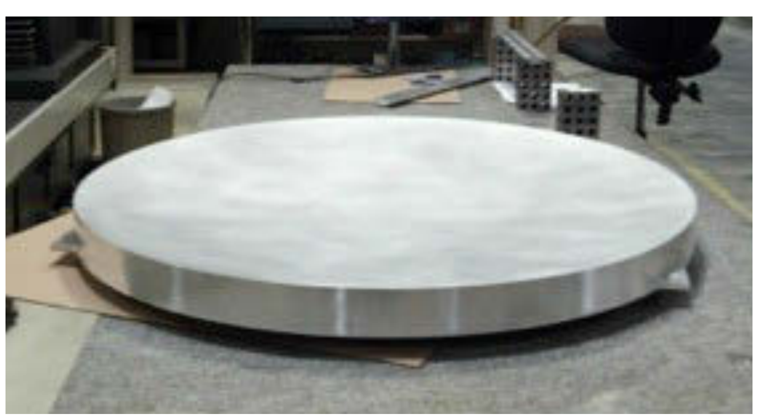
Mounts

Cryostats

Atacama Site Preparation

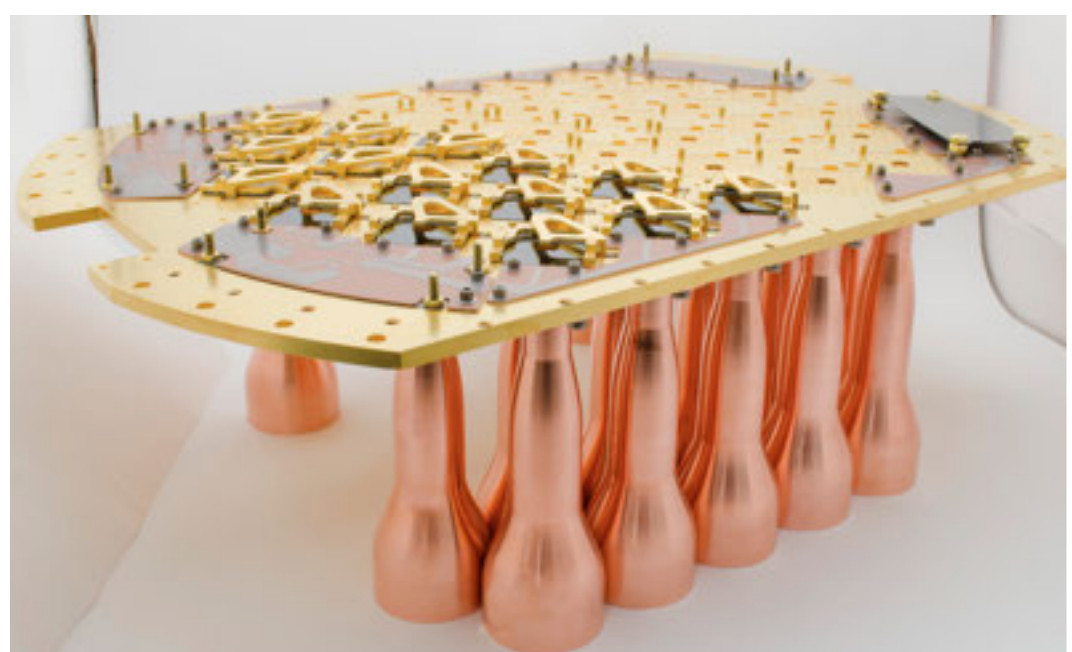


Optics



1.5 m

Focal Planes



VPMs