Cosmology Large Angular Scale Surveyor: CLASS

Joseph Eimer for the CLASS collaboration



Introduction

- CLASS is a new instrument designed to study the physics of the very early Universe.

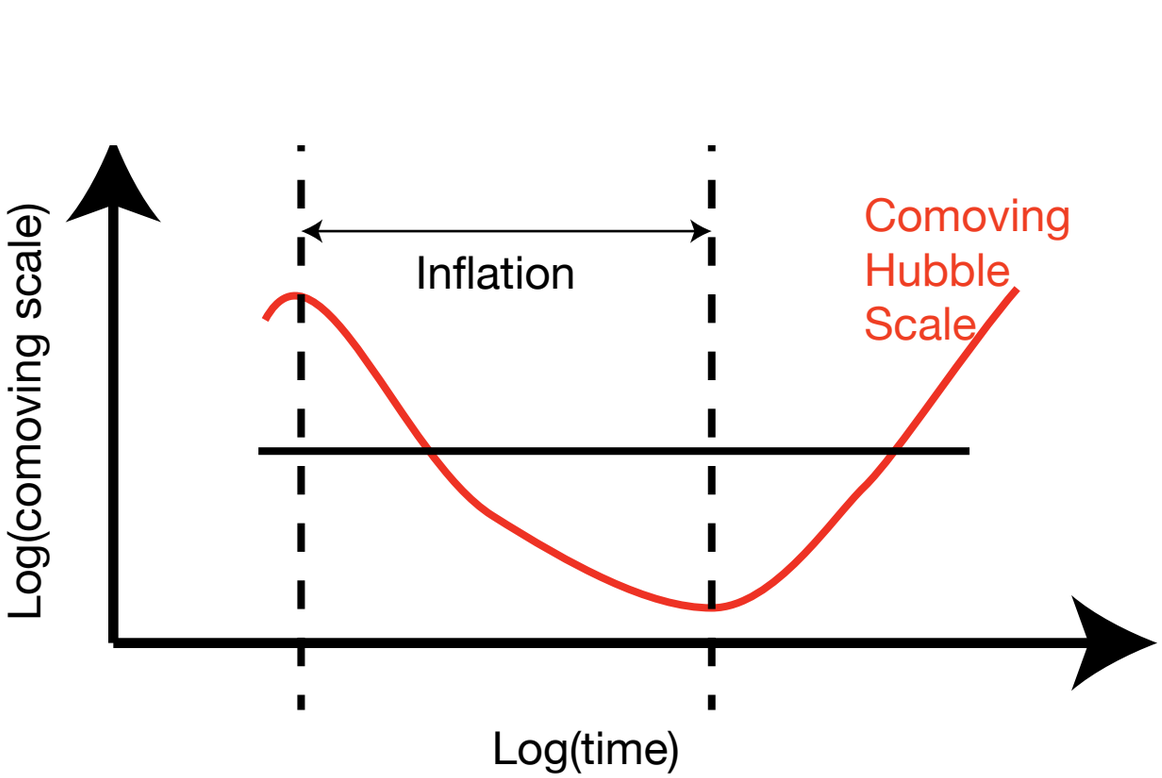
- The early Universe is believed to include an epoch of accelerating expansion called *inflation*.

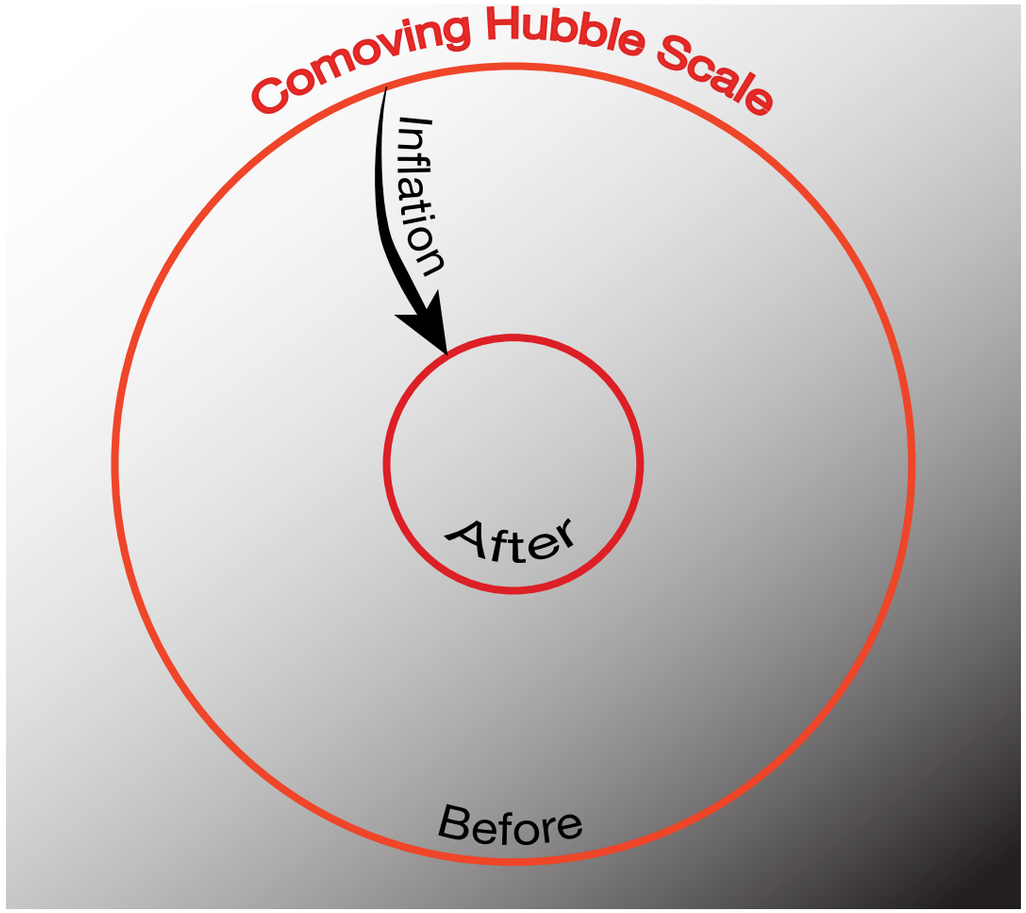
- Many models have been developed to describe inflation. These models are being constrained (even ruled out) by current measurements.

- Measurement of the polarization of the CMB is the ***only known way*** (in the near future) to probe the energy scale of inflation.

Definition of inflation

- Graphic description





Measurements of inflation

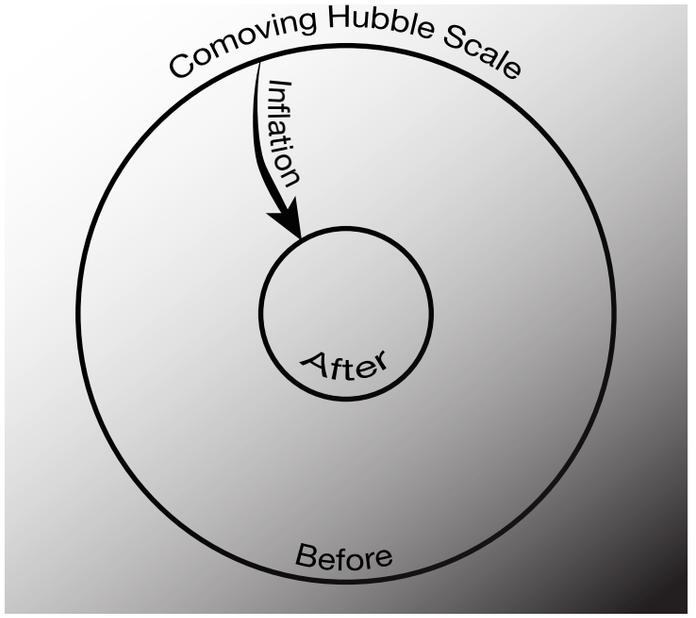
- Dilution of relics (historic motivation)

Monopoles

Topological defects

Massive super-partners

String theory exotica



- Flatness problem:

95 % CL

$$-0.0246 < \Omega_k < 0.0037$$

From LAMBDA web page

$$|\Omega_k(1\ \mathrm{sec})| < \boxed{10^{-16}}$$

Fine Tuned!

Measurements of inflation

- Horizon problem

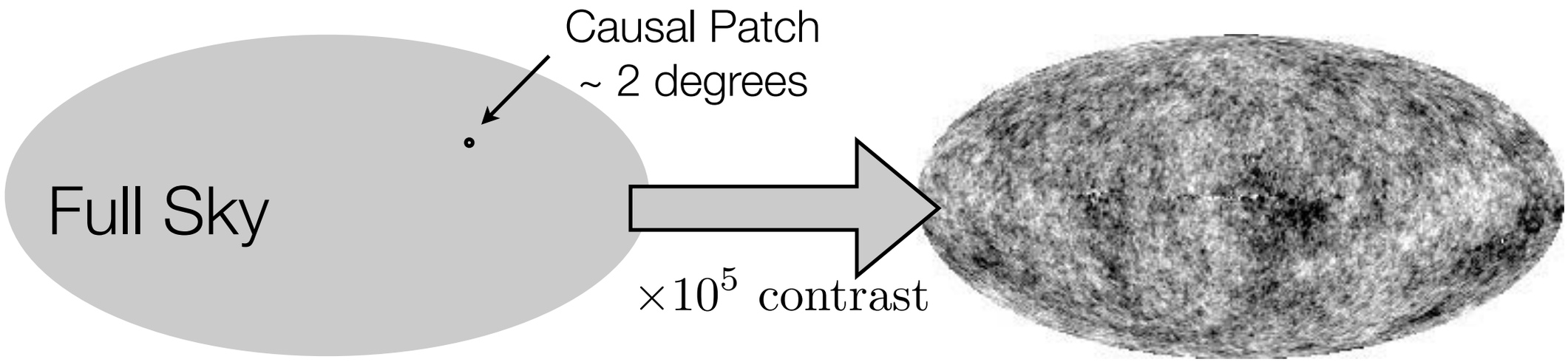
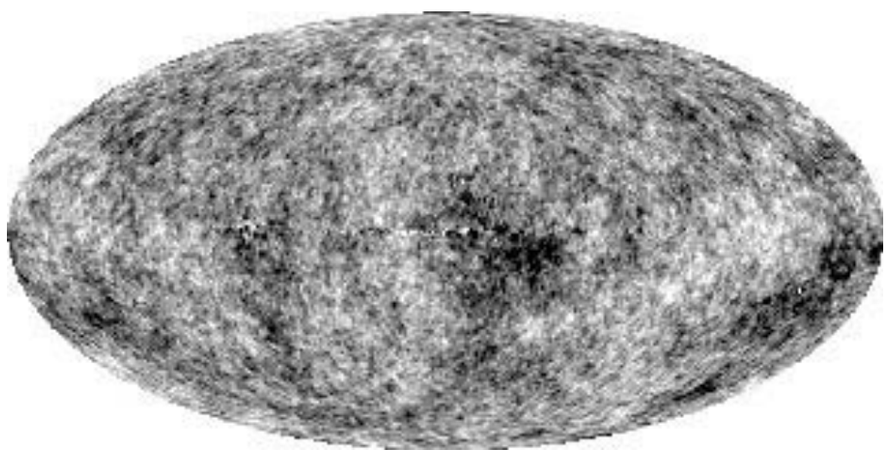
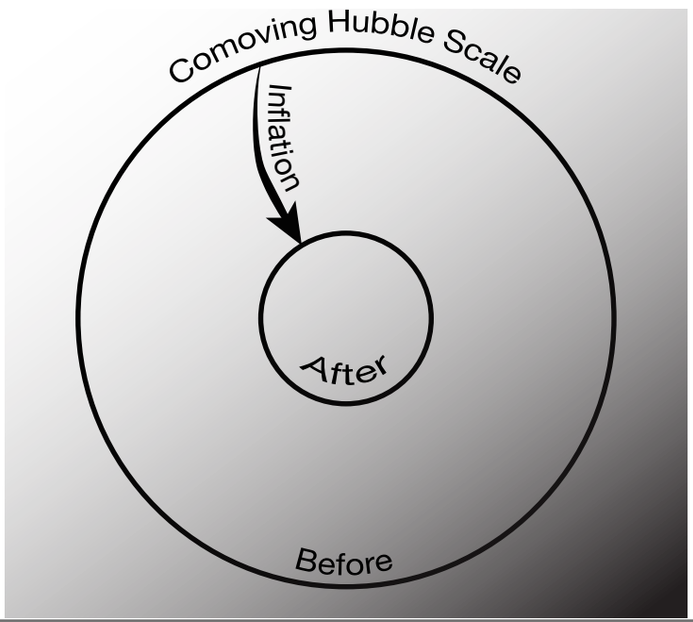


Image: map.gsfc.nasa.gov

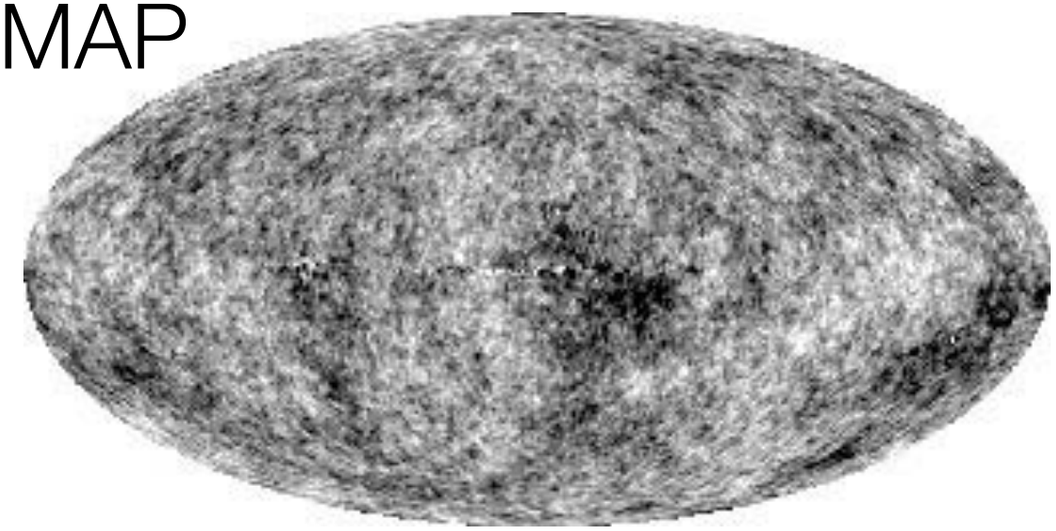
- Structure formation

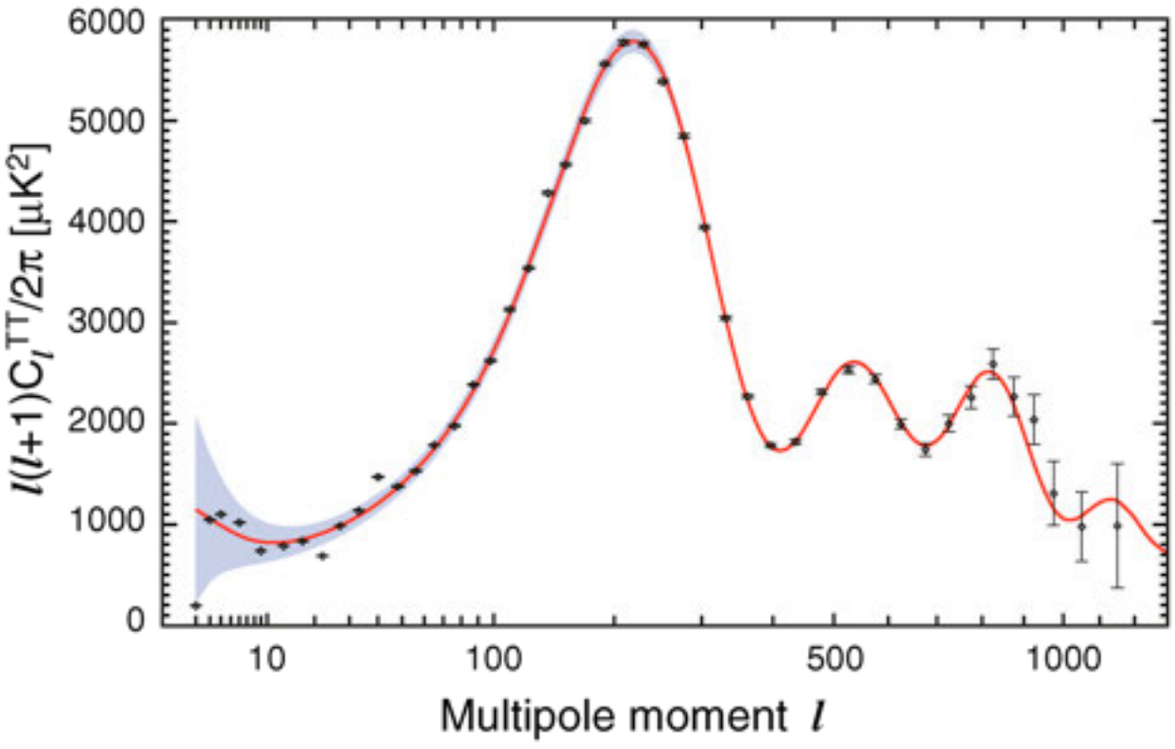




Measurements of inflation

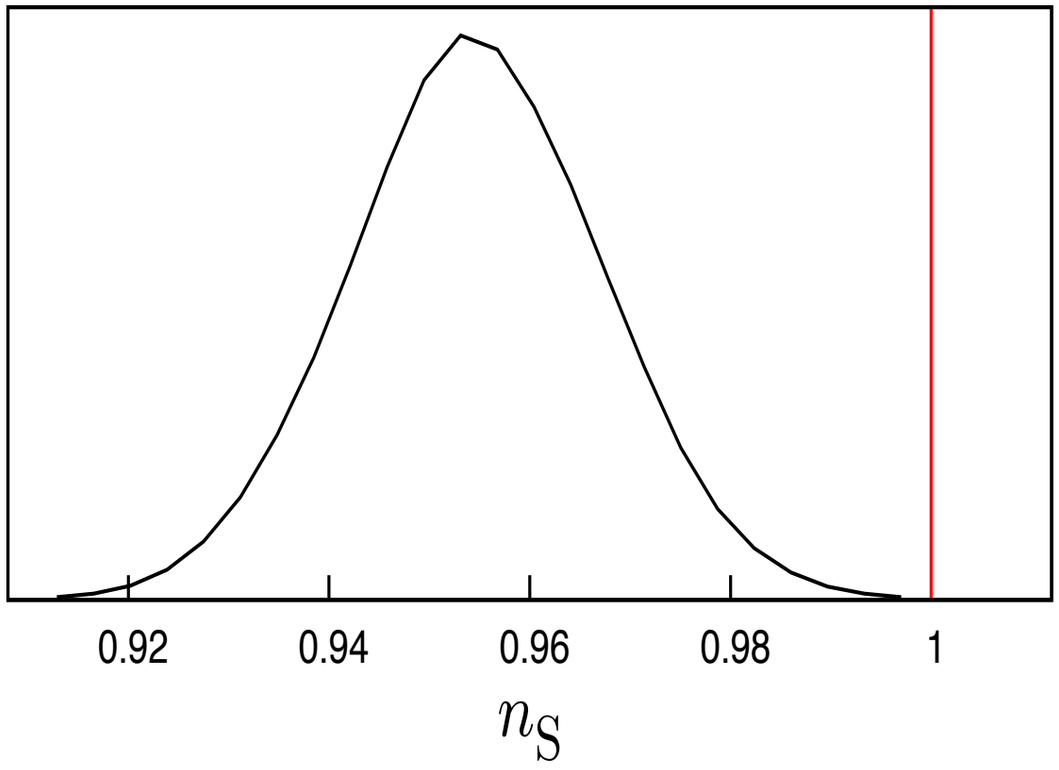
WMAP





Larson et al. WMAP7 2011

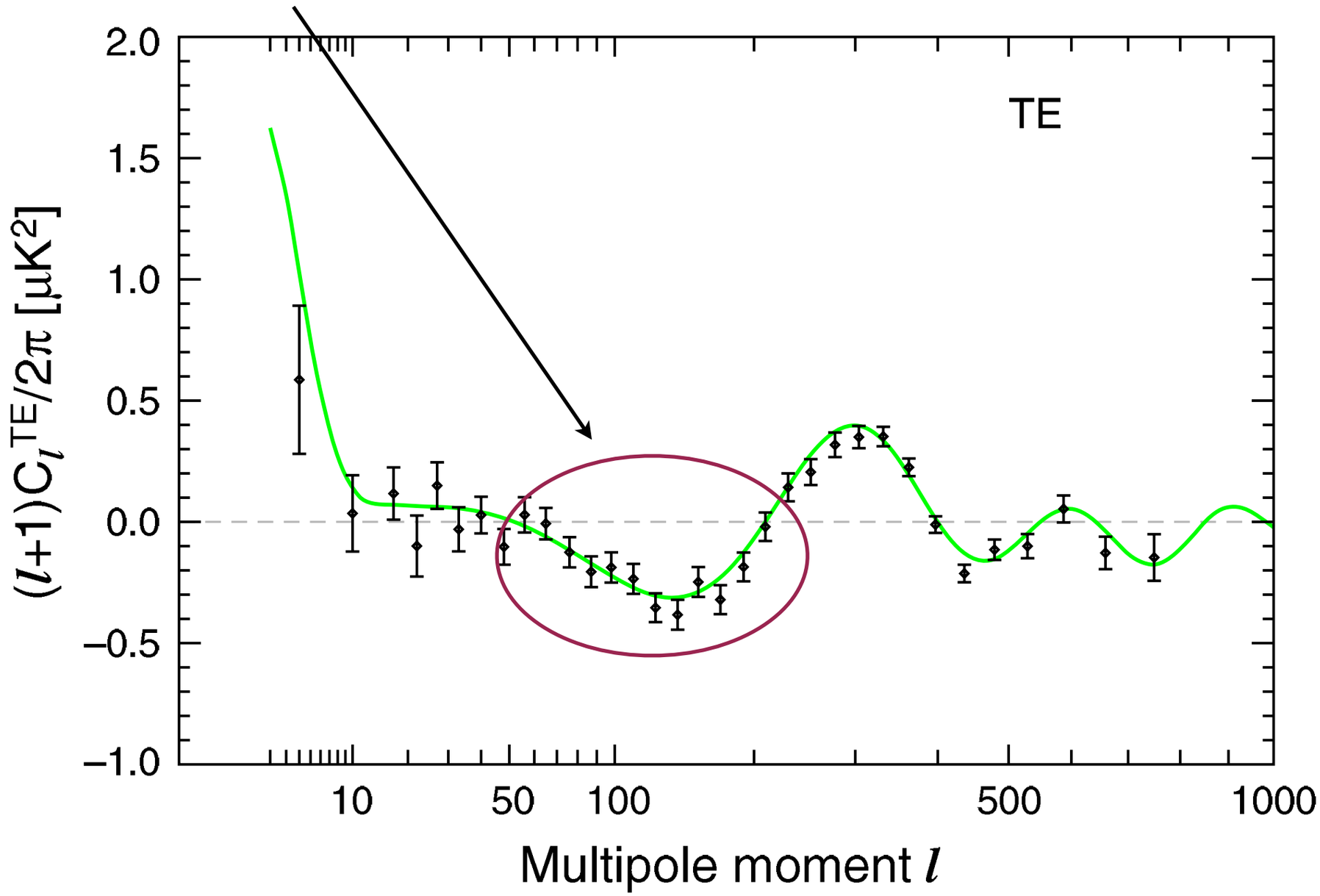
CMB+SDSS



Finelli et al. *Single-field inflation constraints from CMB and SDSS data*. Journal of Cosmology and Astroparticle Physics 2010

Measurements of inflation

- Super-horizon correlation. Model independent signature inflation.



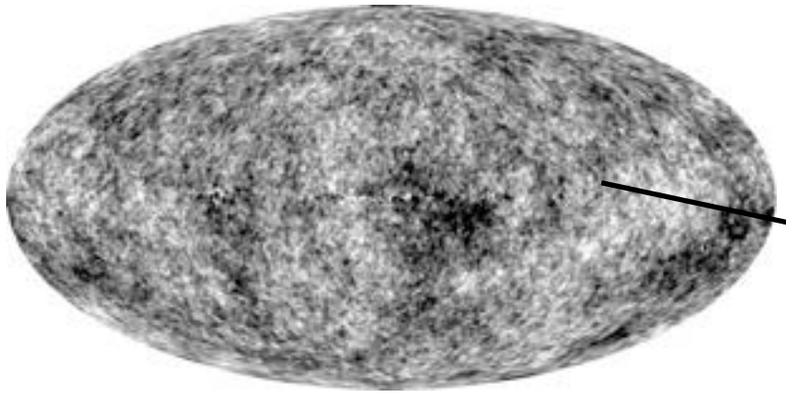
Larson et al. WMAP7 2011

Inflation report card

Lack of primordial relics	generic	✓
Flat Universe	generic	✓
Homogeneous and isotropic Universe	generic	✓
Existence of large scale structure	generic	✓
Super-horizon correlation in CMB	generic	✓
Gaussian random phases in the CMB	generic*	✓
Nearly scale invariant power spectrum	shape	✓
B-modes in the CMB polarization	scale	-

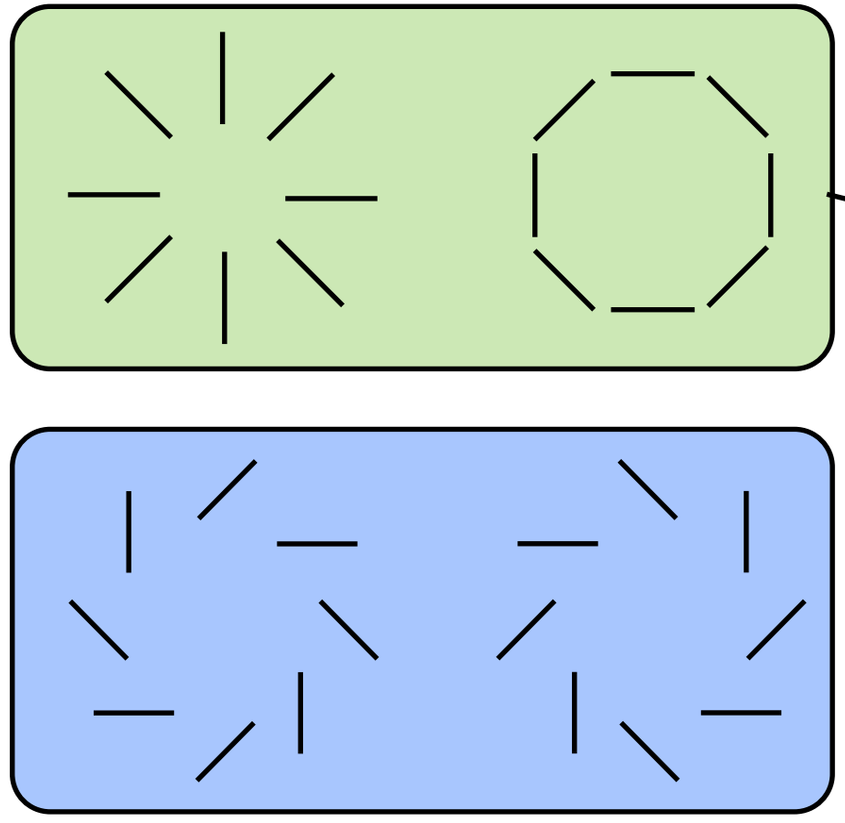
Measure the B-modes

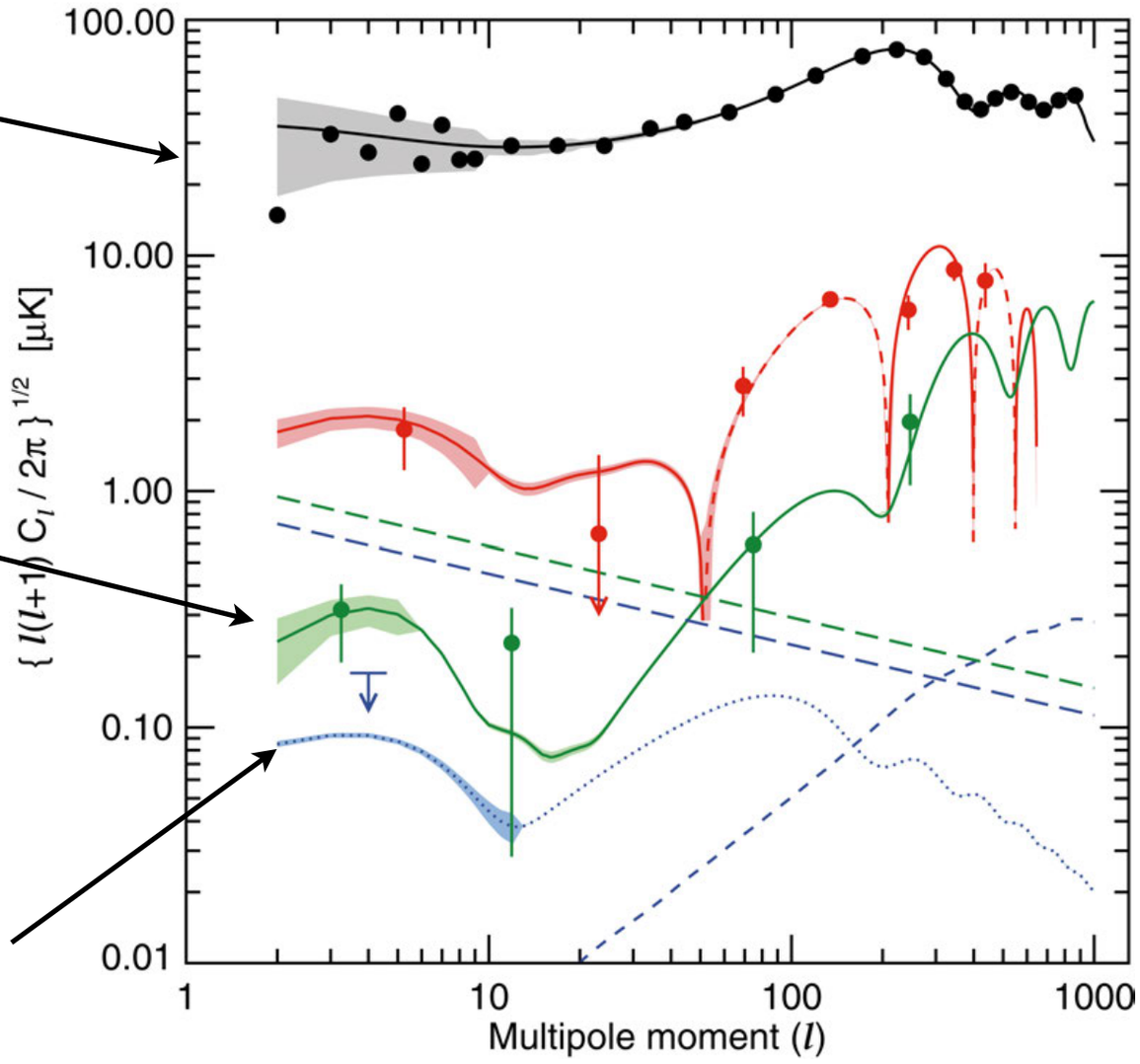
T



E

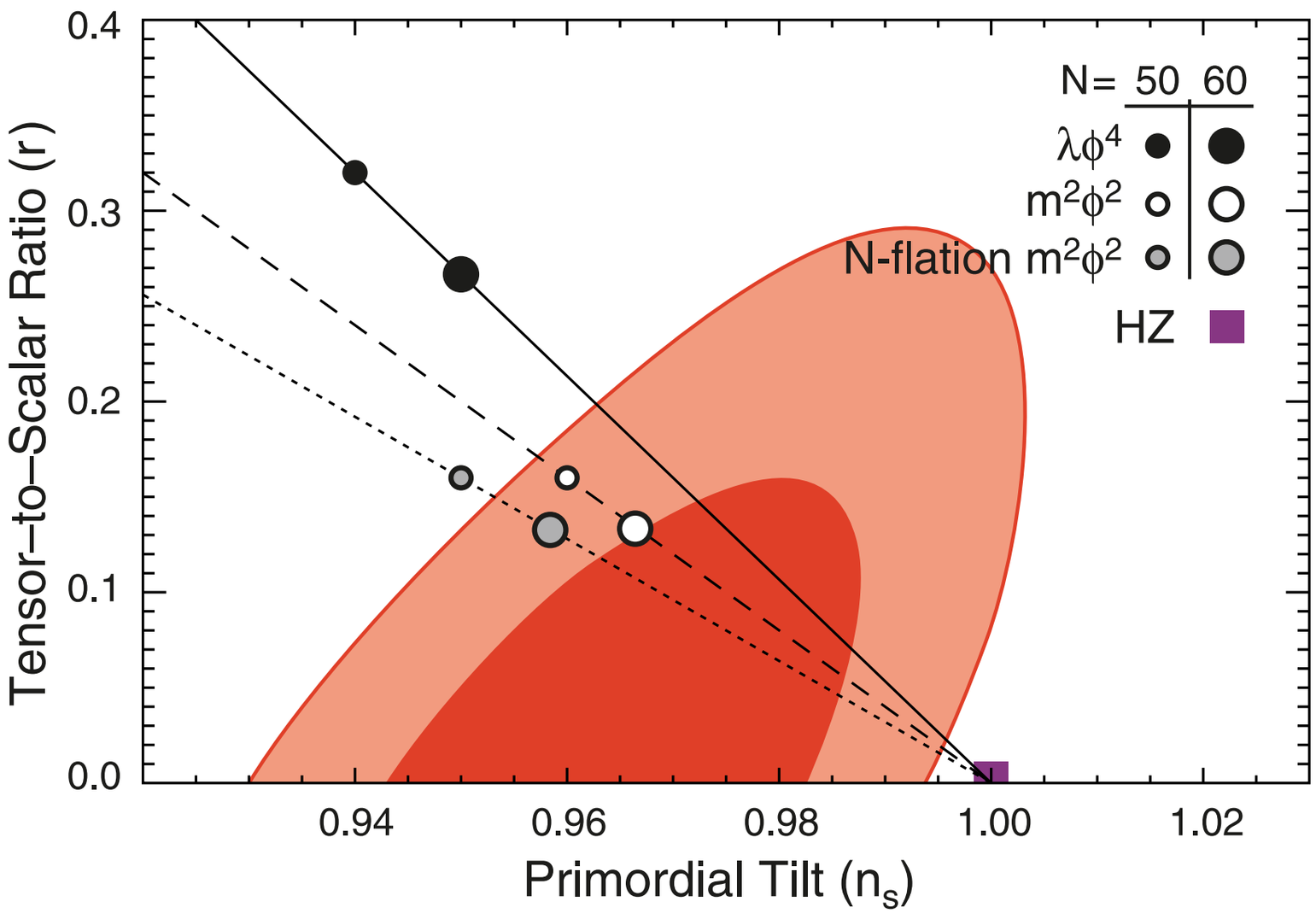
B





Page et al. WMAP3 2007

Measurements of inflation



Komatsu et al. WMAP7 2011

What about ‘r’?

- Only upper limits.

Keisler et. al. *A Measurement of the Damping Tail of the Cosmic Microwave Background Power Spectrum with the South Pole Telescope*. ApJ. Vol 743, Issue 1.

  - Upper limit from CMB only: $r < 0.21$.

  - Upper limit from CMB + SN + BAO: $r < 0.17$

- $r \sim 0.01$ would suggest GUT physics is relevant for inflation

  - lower limit on lifetime of protons

  - extreme extrapolation of gauge coupling (10 orders of magnitude!)

Design of an instrument to detect B-modes

Design of CMB B-mode search

Challenge	Requirement	CLASS solution
Faint signal	Sensitive detectors Systematic error control	
2.725 K Blackbody	Look where the signal is strong	
70 μK Anisotropy	Many background limited detectors	
300 nK Polarization	Fast front-end polarization modulation	
? 30 nK B-modes	Symmetric beams with good polarization purity	

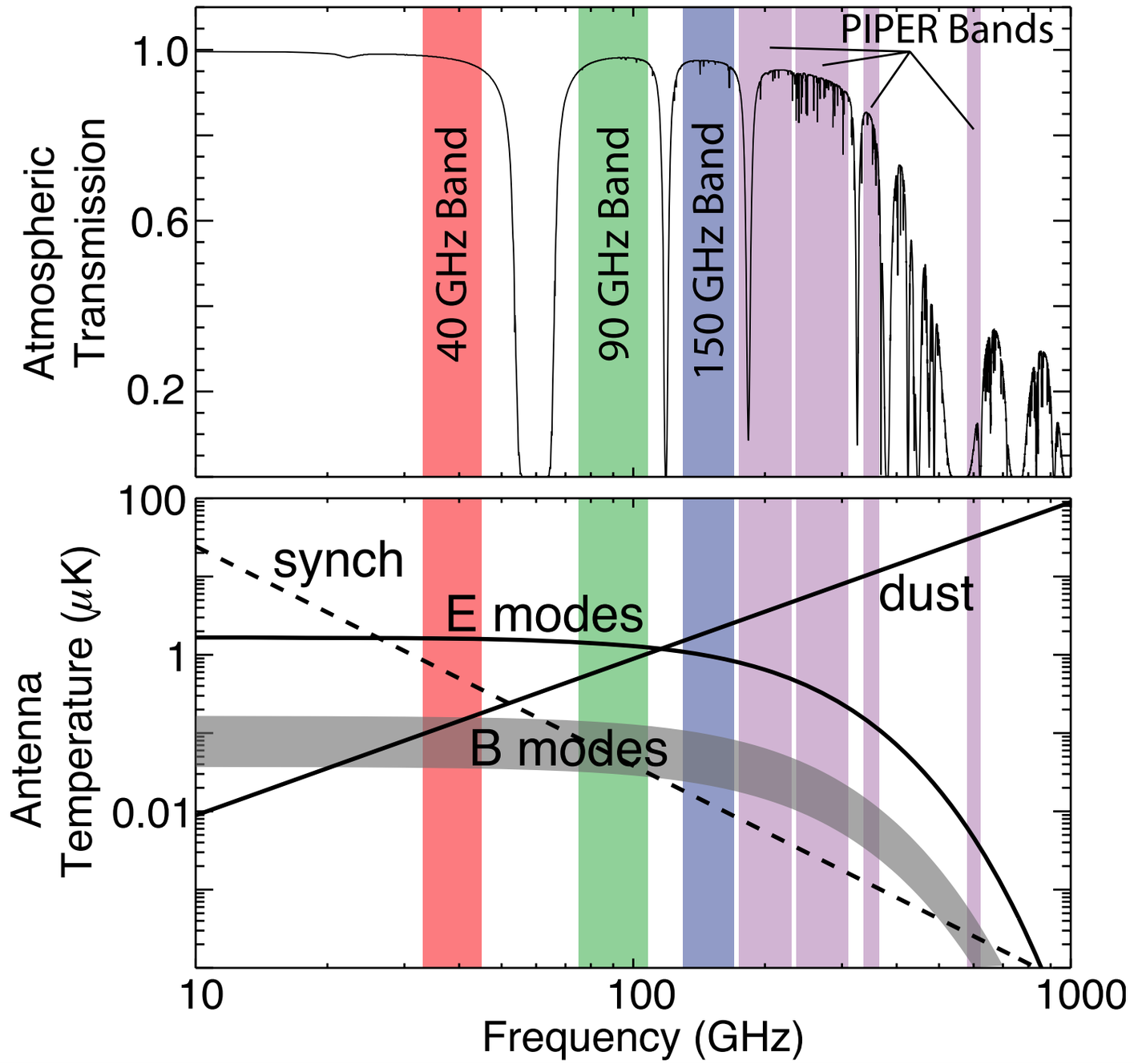
Design of CMB B-mode search

Challenge	Requirement	CLASS solution
Foreground contamination	Multi-frequency observation	

Atmosphere

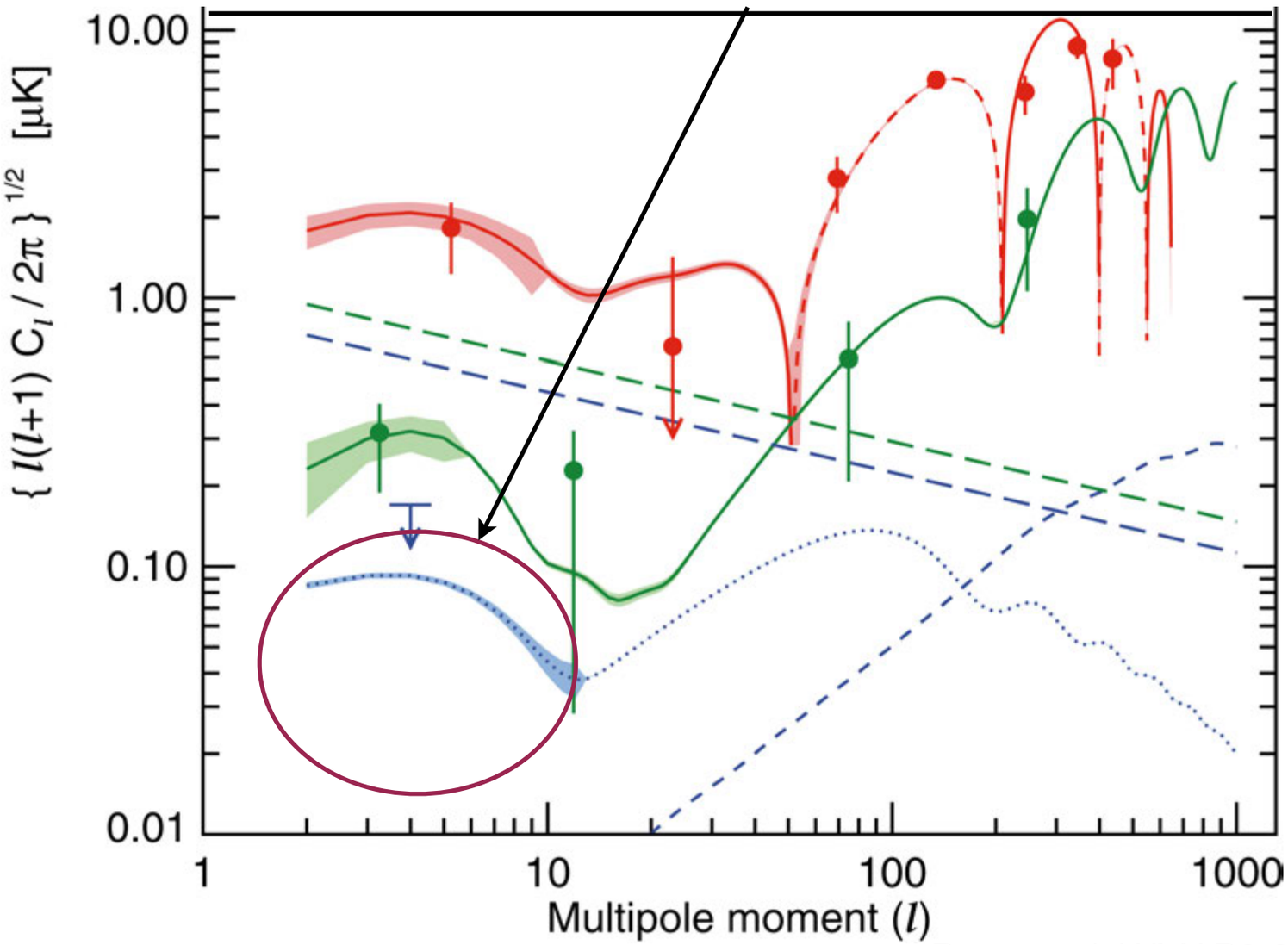
Synchrotron radiation

Dust emission



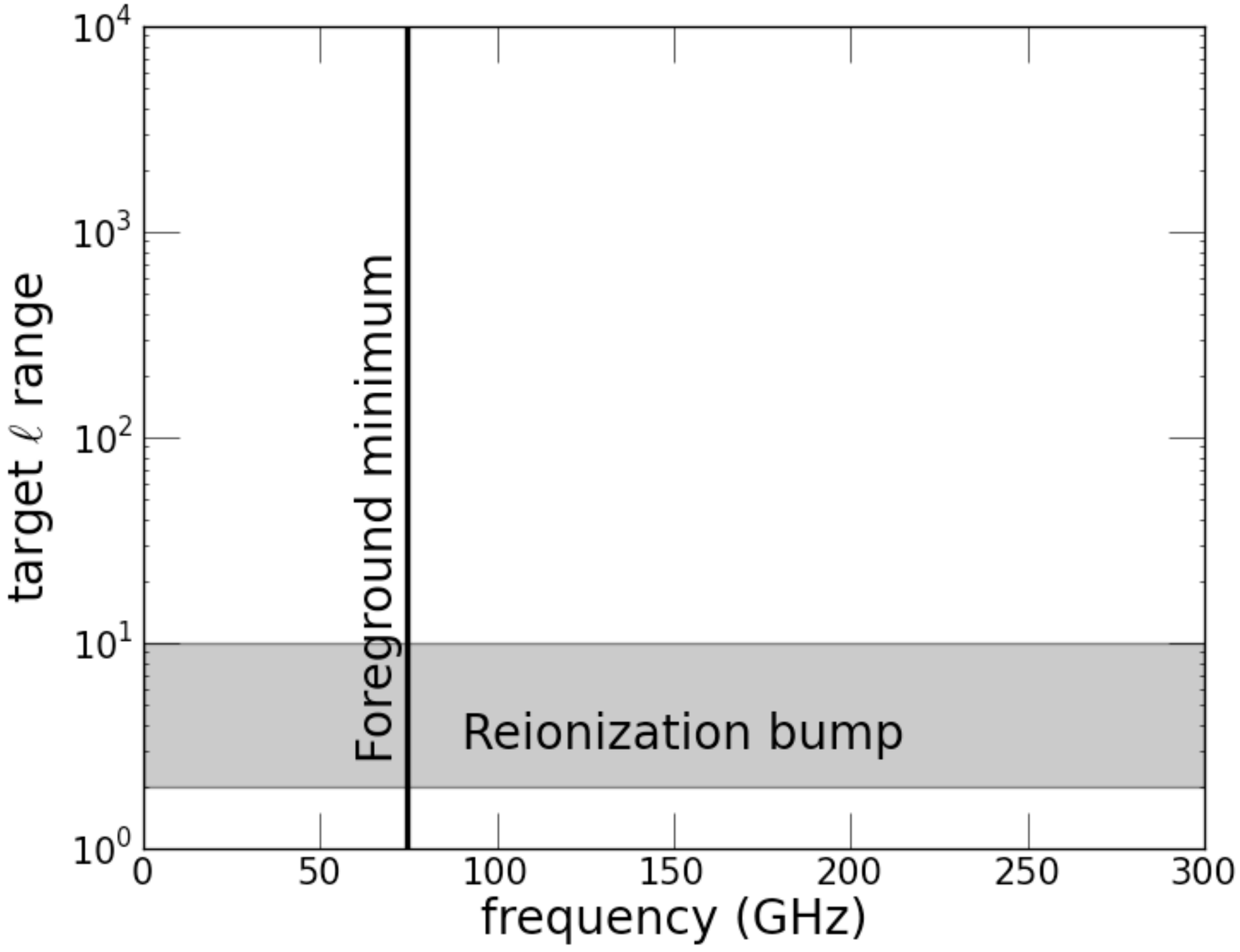
Design of CMB B-mode search

Challenge	Requirement	CLASS solution
Gravitational Lensing B-modes	Avoid or delens	Focus on reionization bump

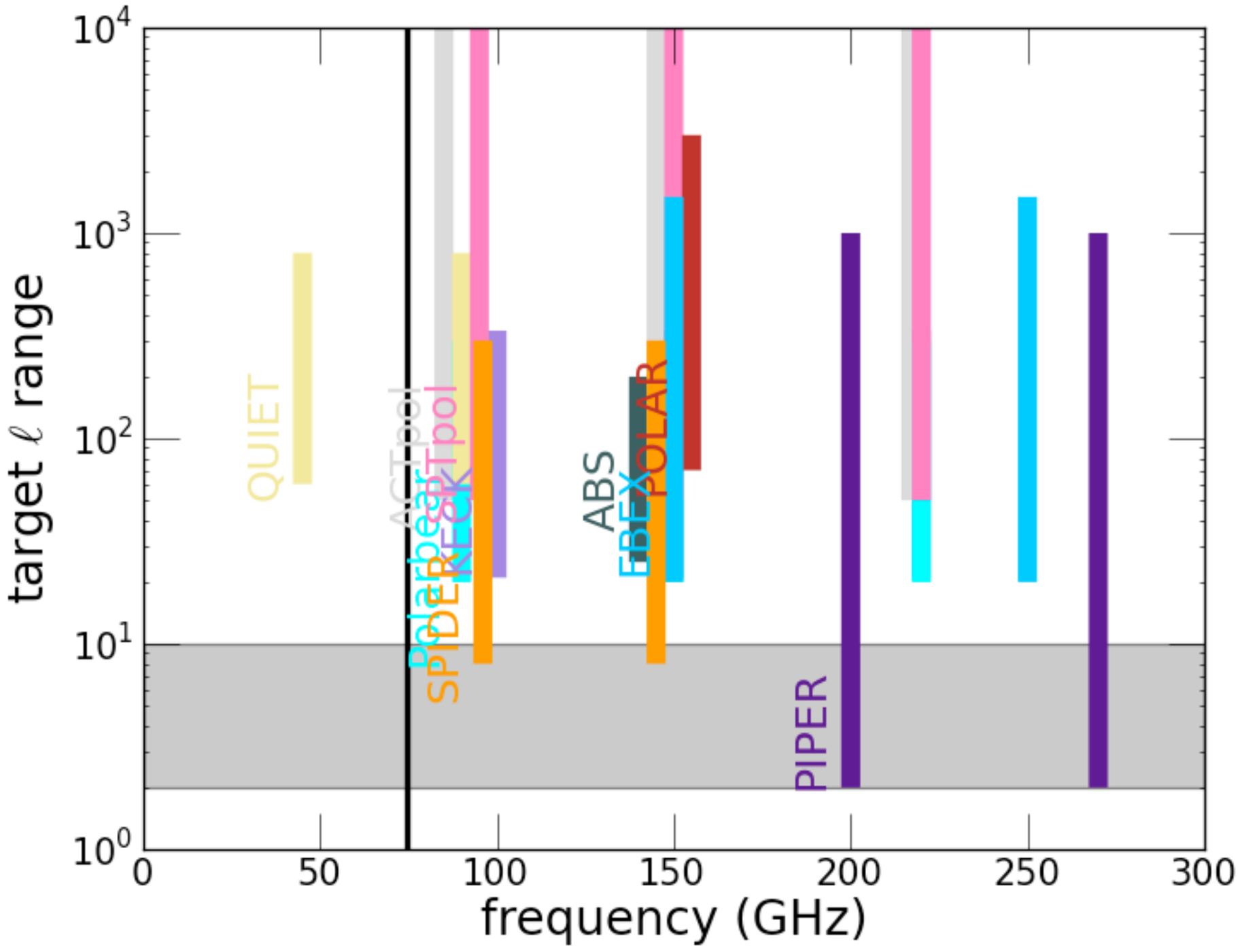


Page et al. WMAP3 2007

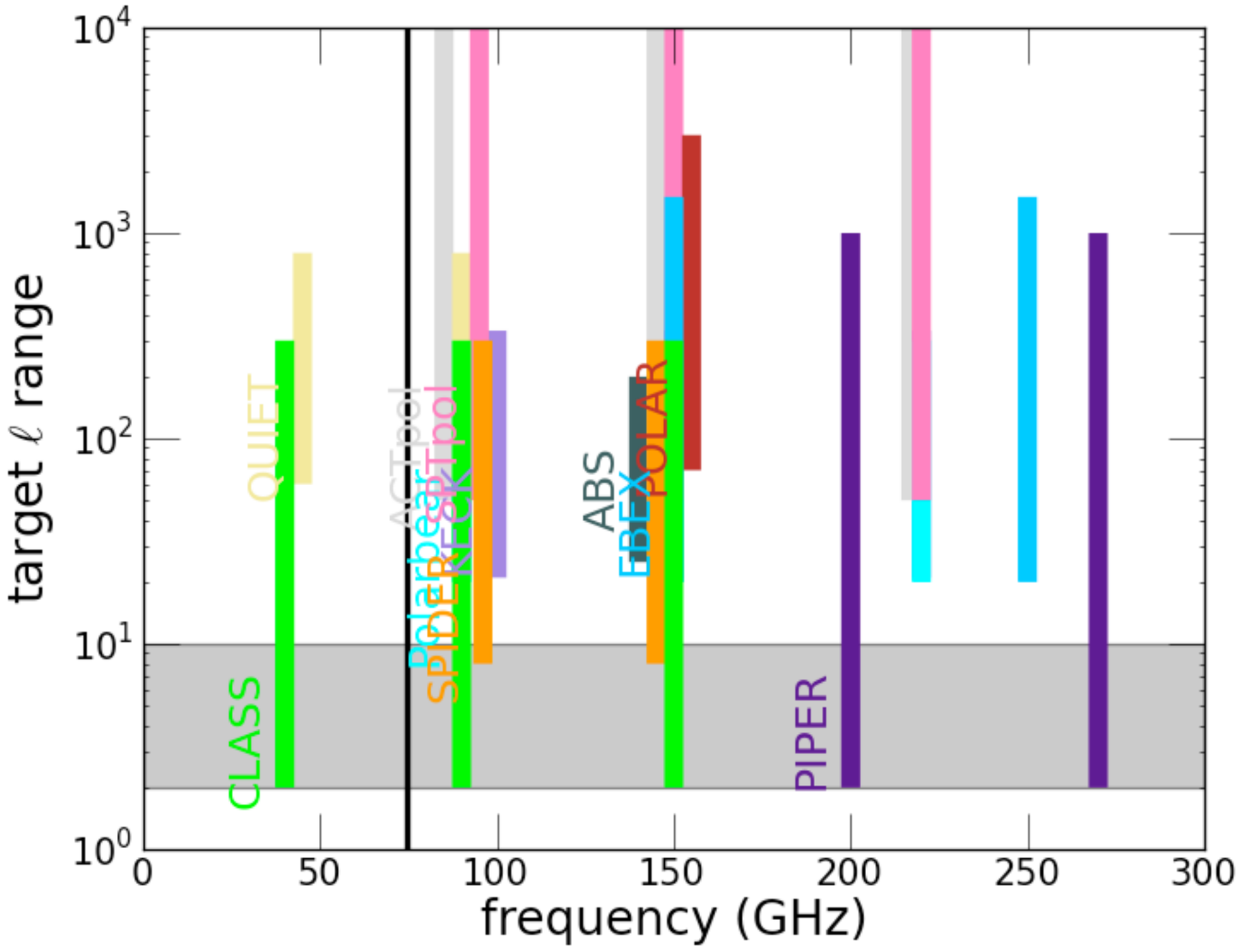
State of the field



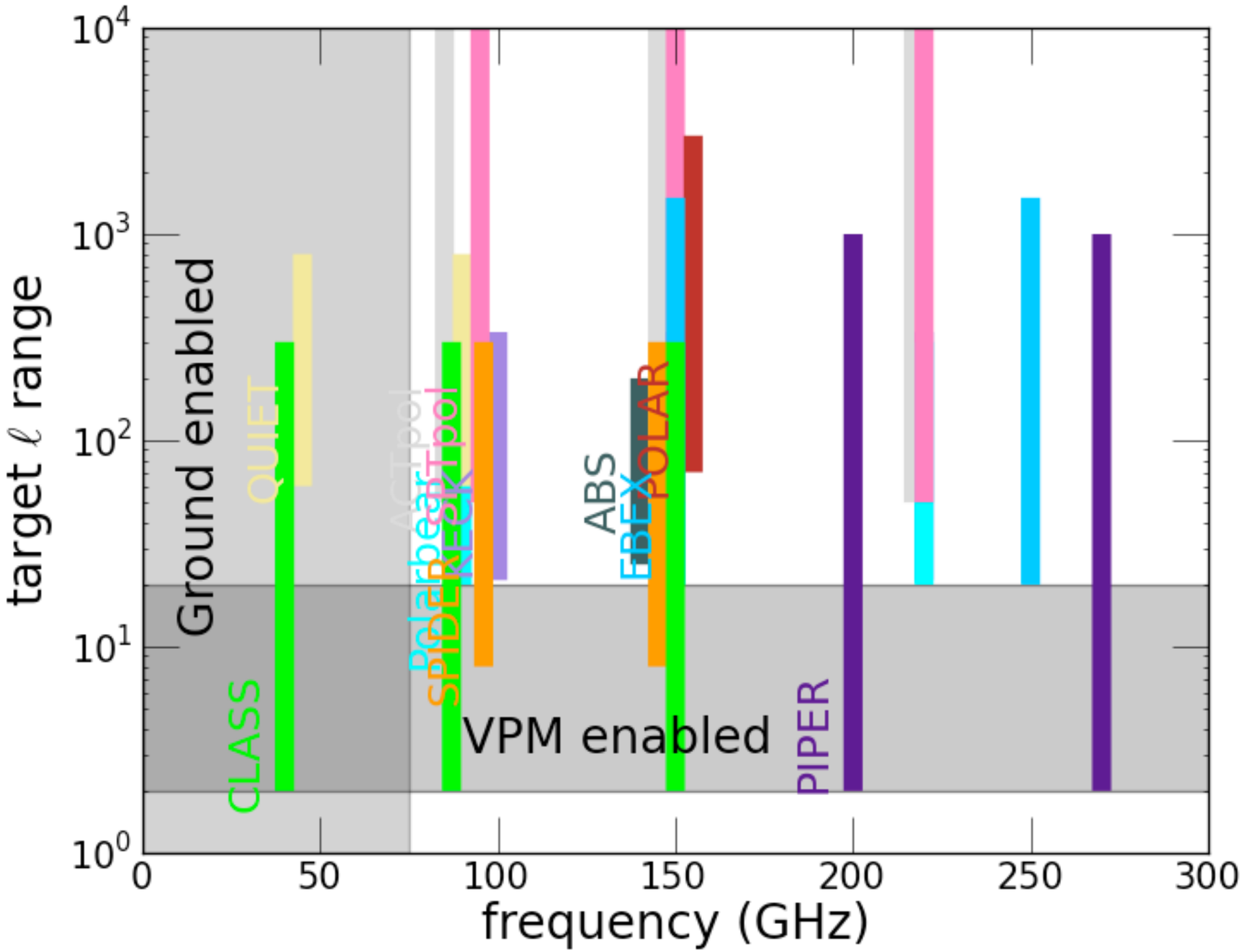
State of the field



State of the field



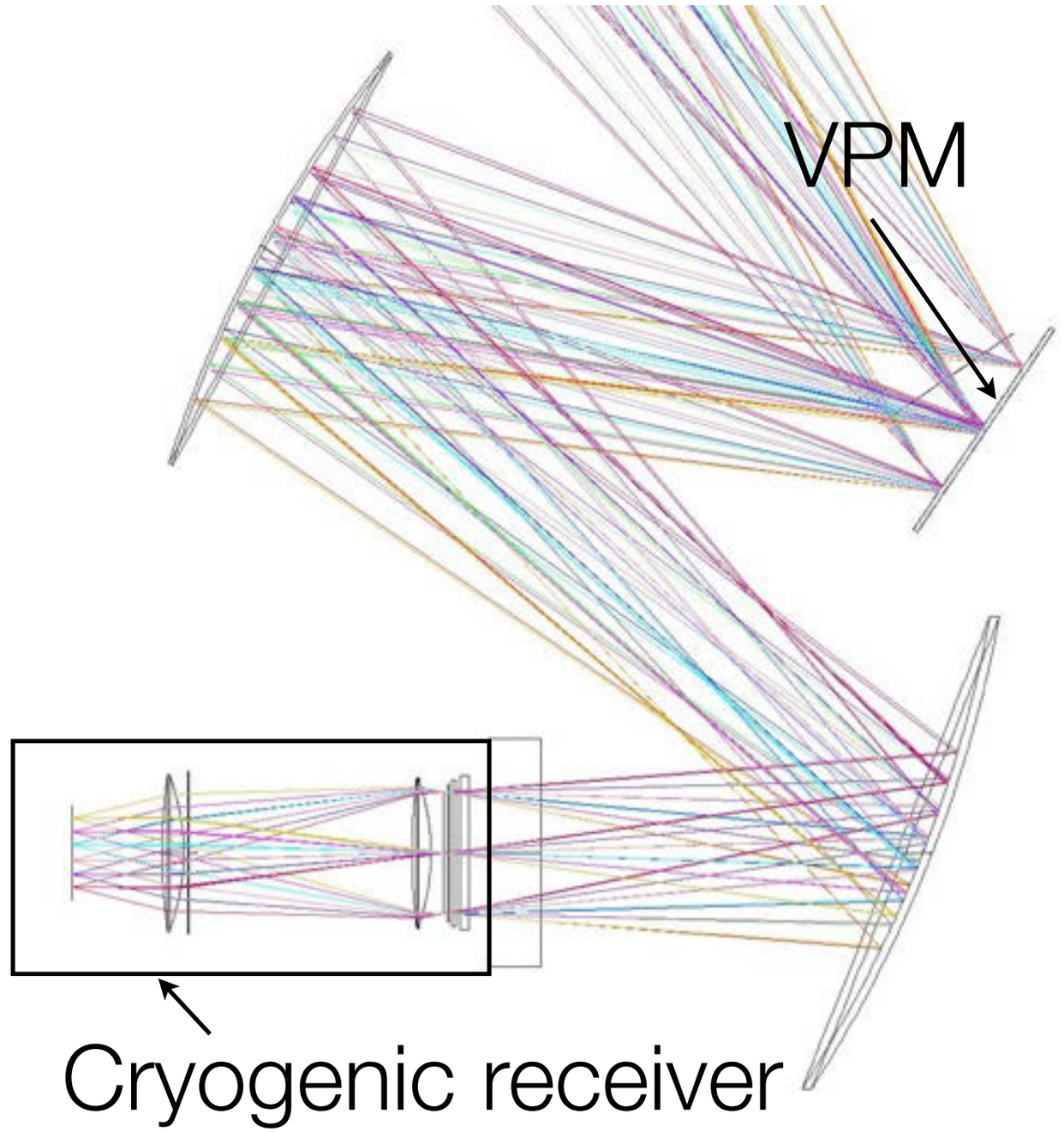
State of the field



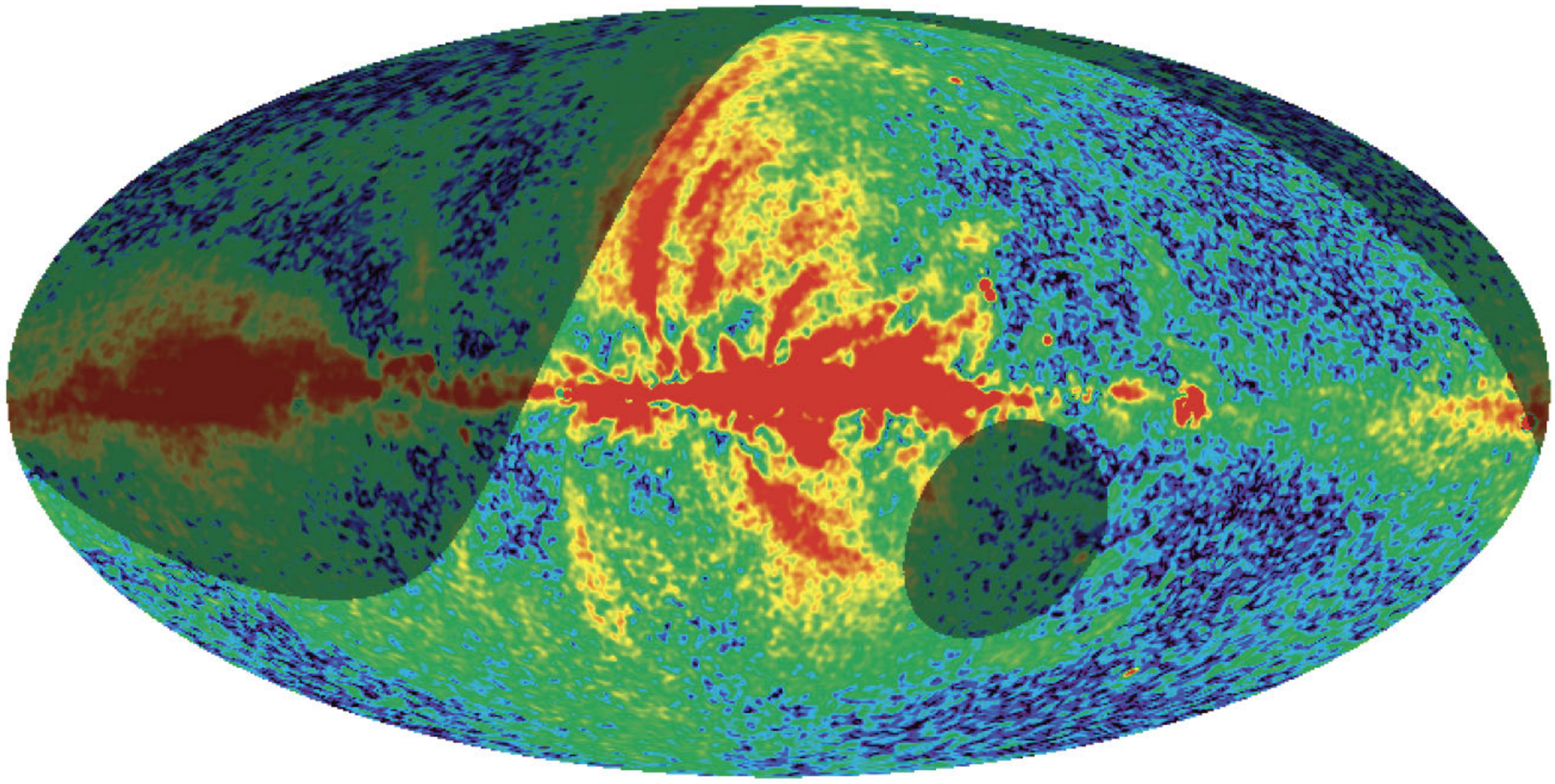
CLASS overview

Frequency	Detectors	telescopes	Resolution
40 GHz	36 pairs	1	1.5°
90 GHz	300 pairs	2	40’
150 GHz	60 pairs	1	24’

- **Front-end rapid polarization modulation**
- Combine clean coherent techniques with bolometric sensitivities. Detectors operate at 100 mK.
- Low cross-polarization and symmetric beams
- Observe over 65% of the sky.



Sky coverage

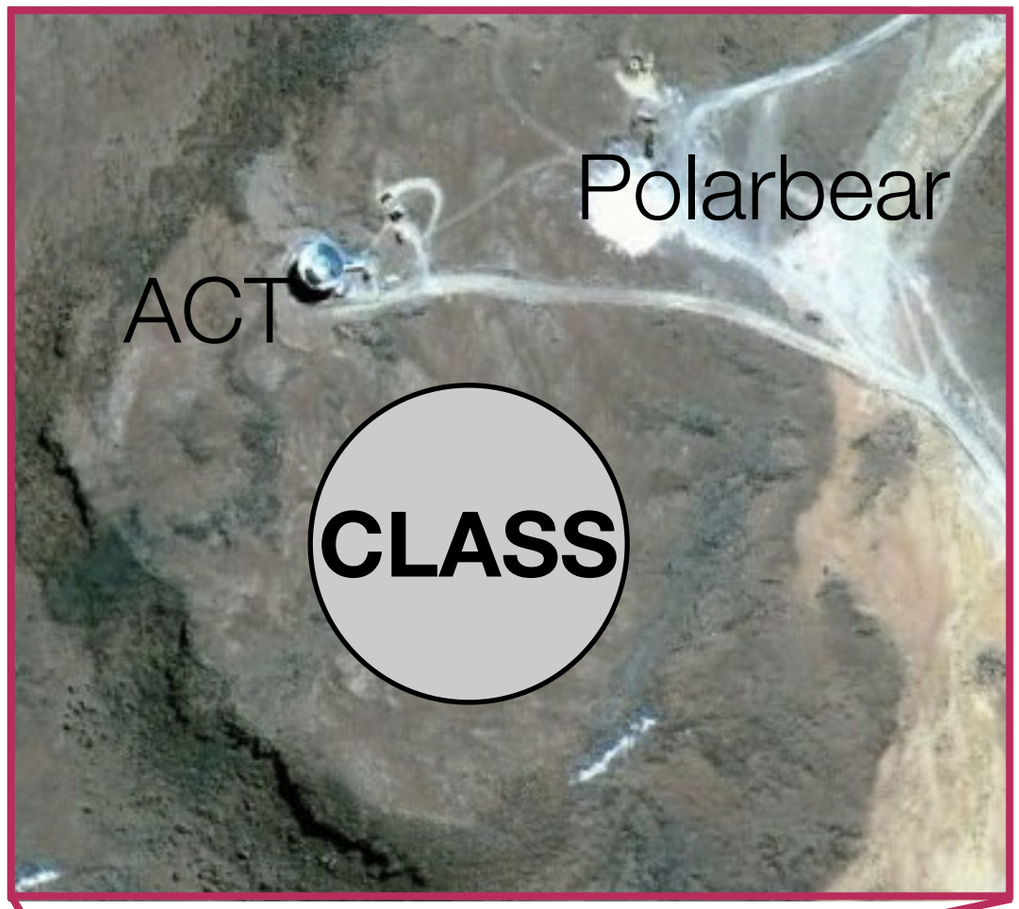


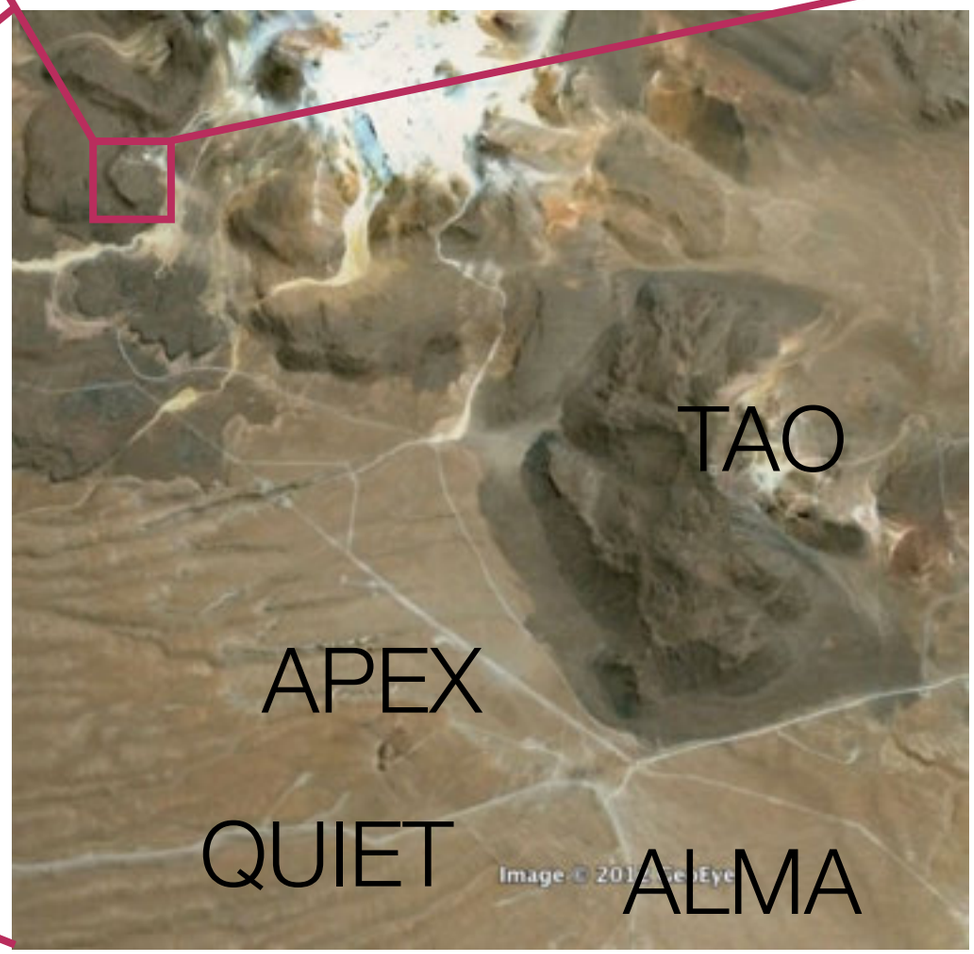
65 % of the sky is visible above 45° zenith angle.

Figure from David Larson

Location

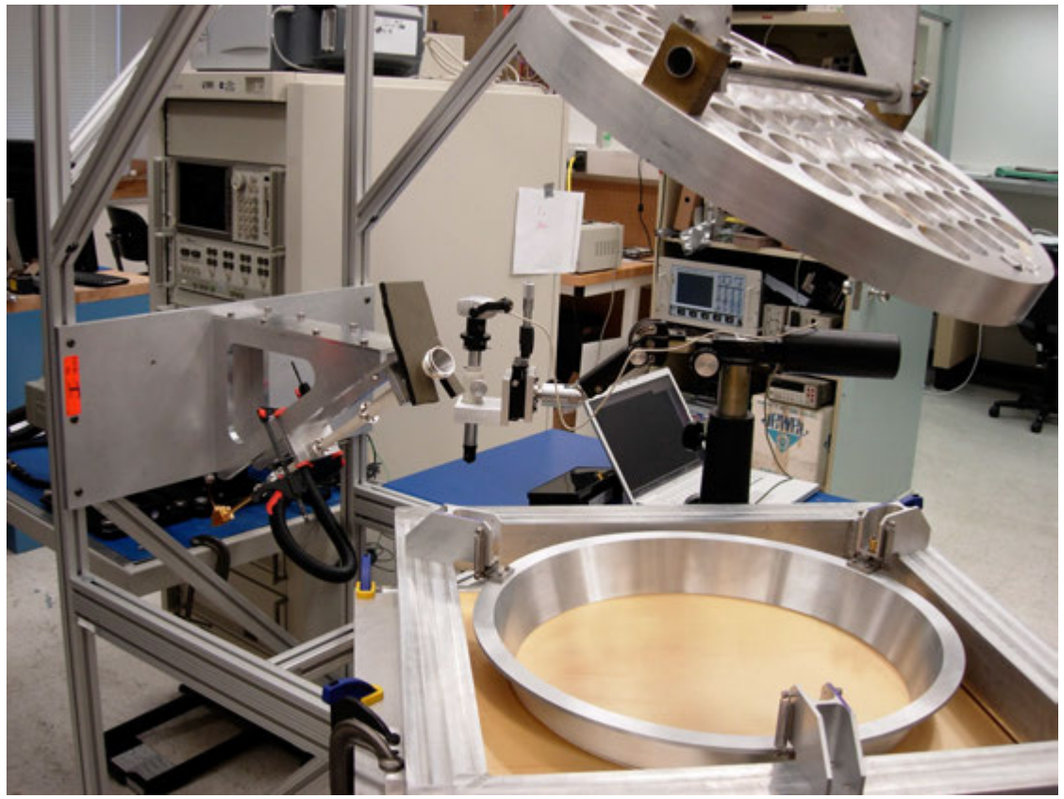
- Atacama desert in northern Chile.
- Altitude = 5180 m (16,995 ft)
- Atmospheric moisture content around 1 mm PWV. (typical global value ~25 mm)

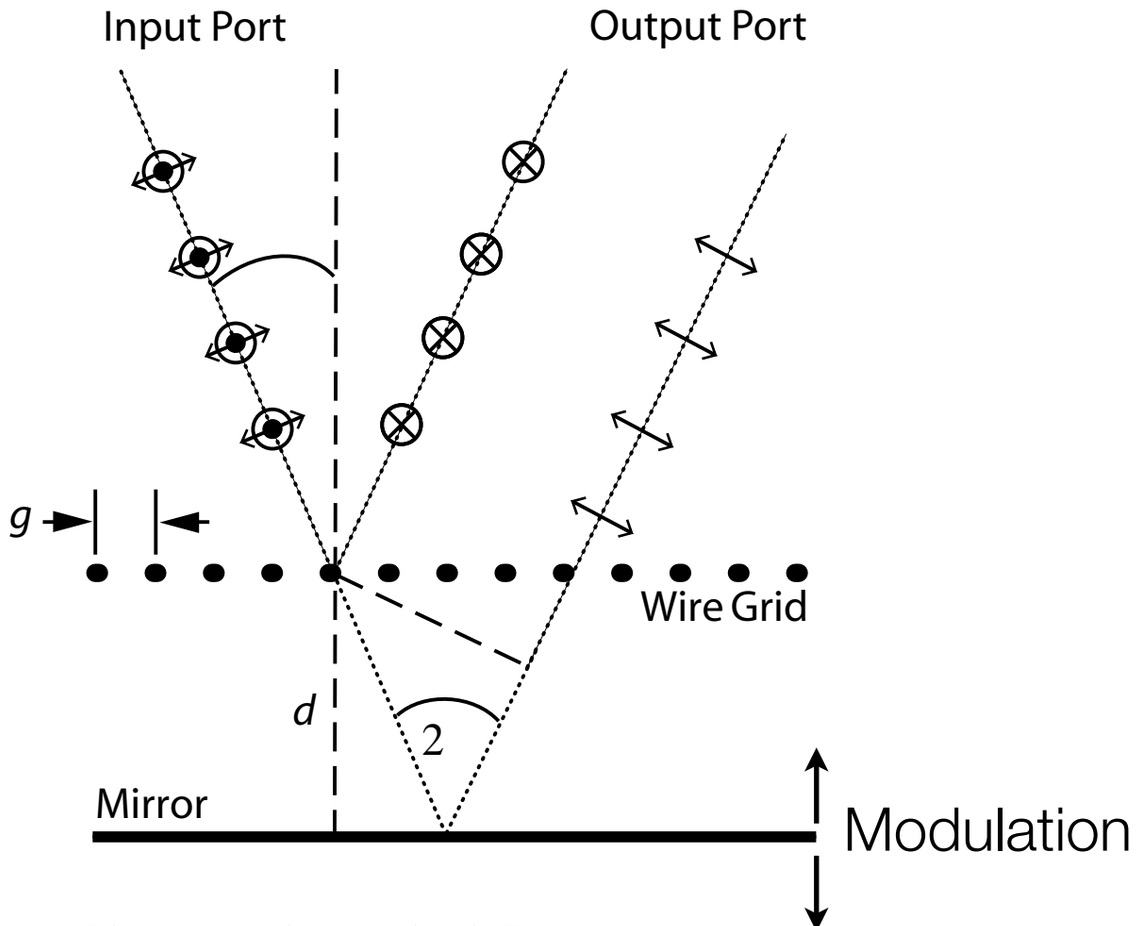




Modulator Technology

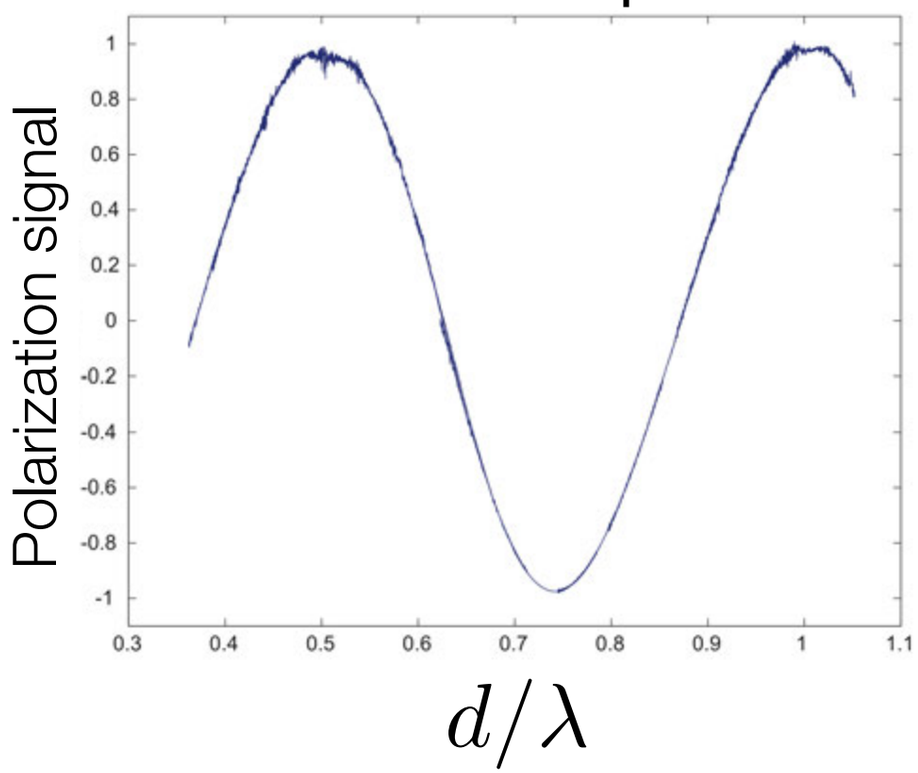
- 50 cm diameter prototype grid constructed.
- Electromagnetic performance verified.





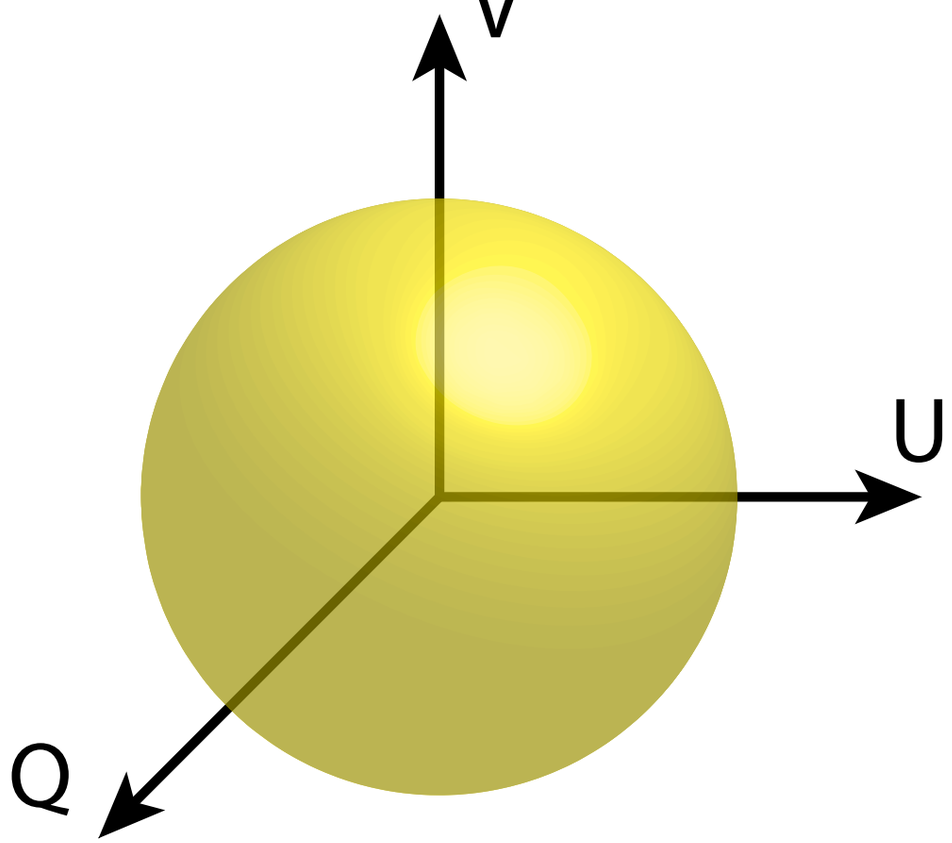
Chuss et. al. Applied Optics 2011.

Measured response

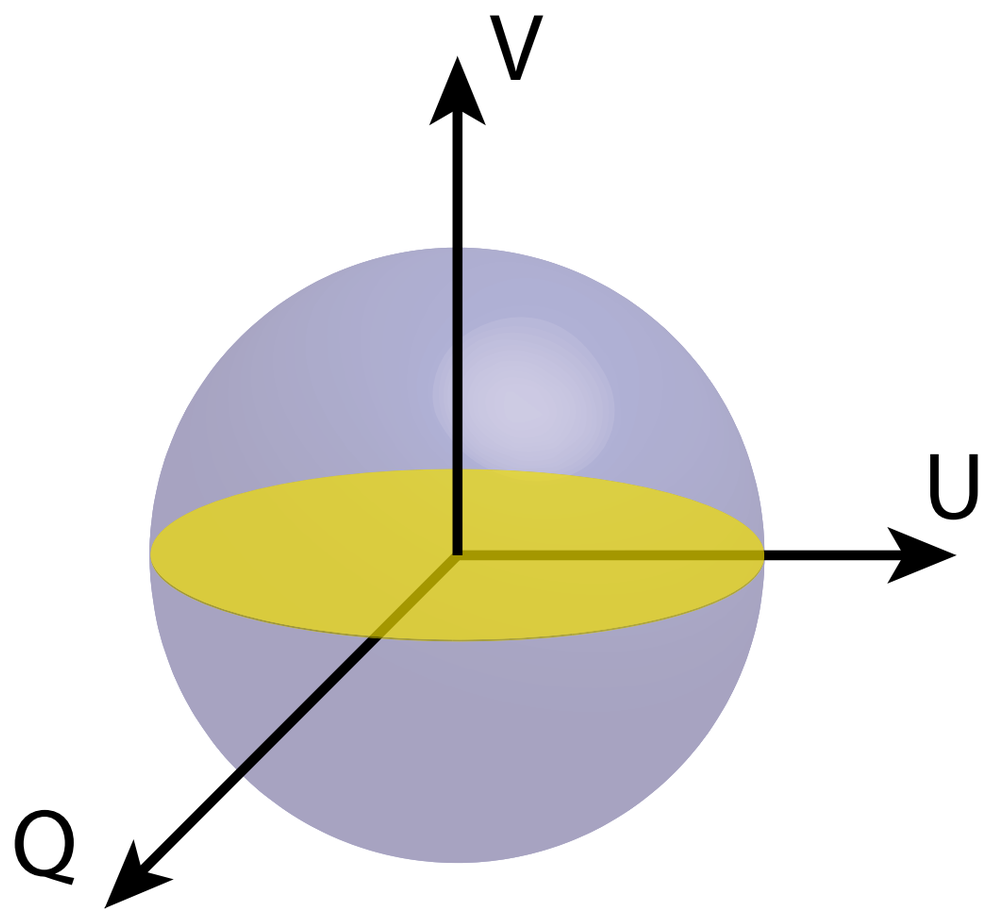


Modulator Technology

VPM

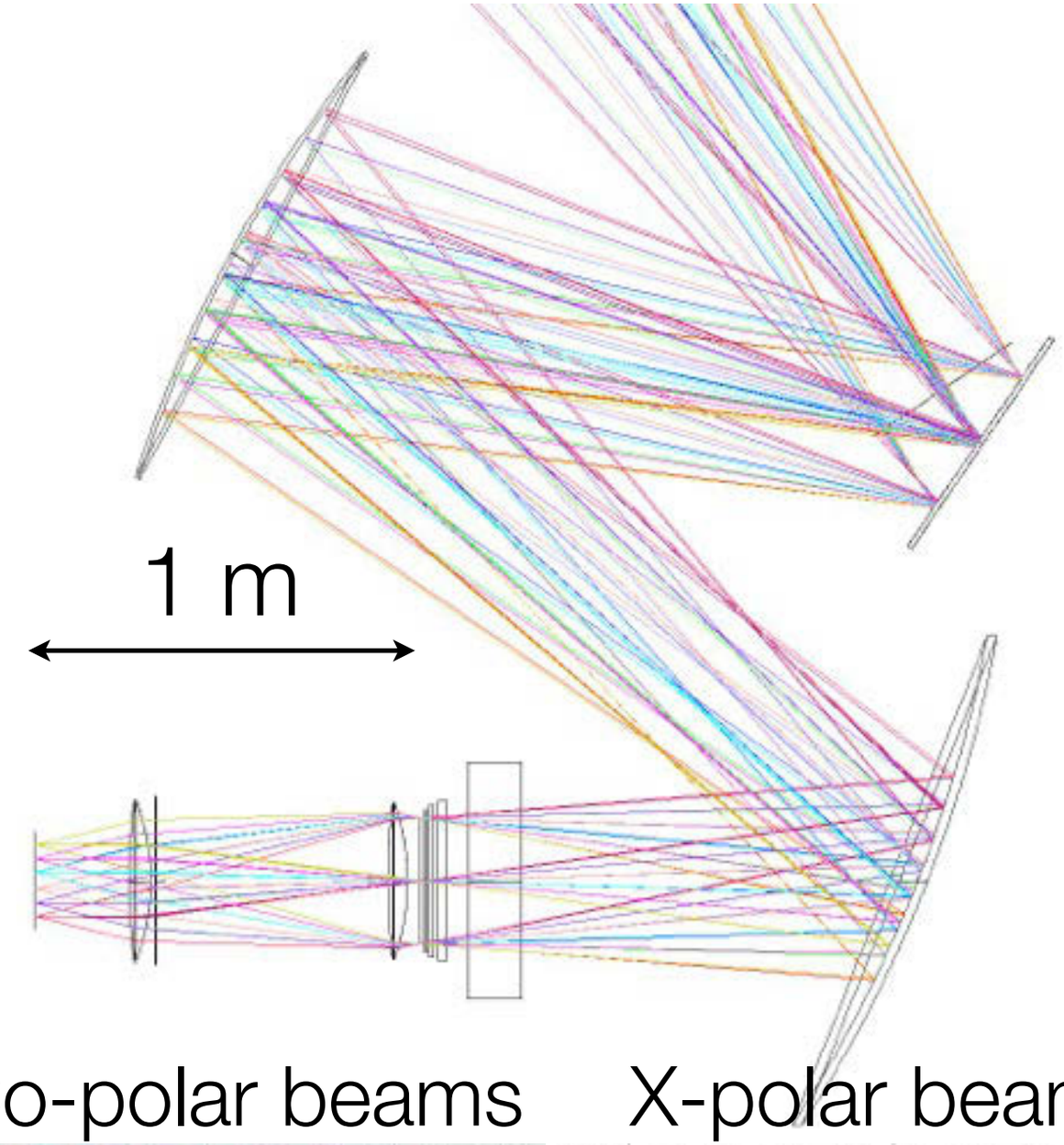


other methods

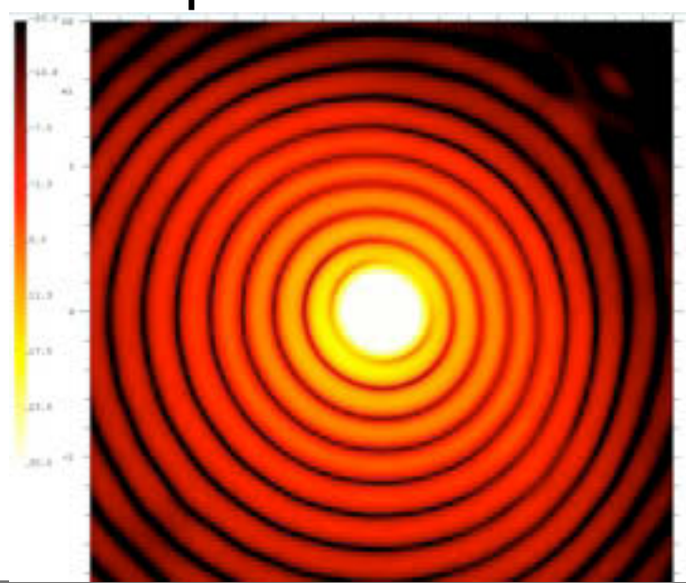


Optical design for 40 and 90 GHz

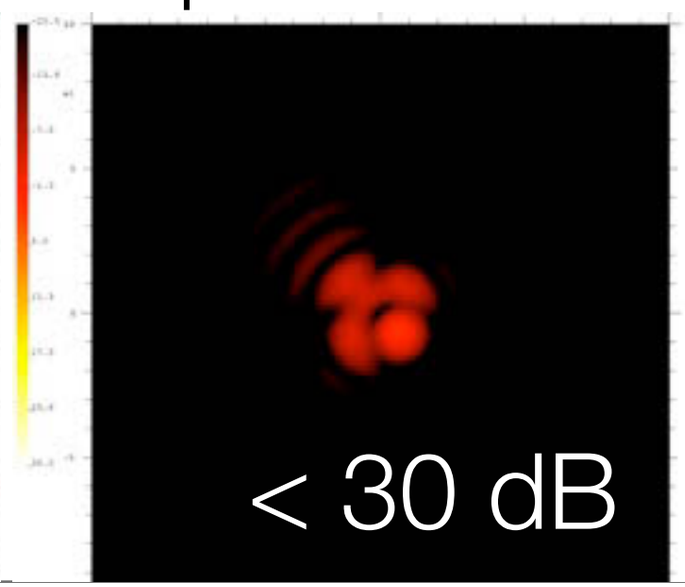
- Catadioptric architecture
- Entrance pupil located at front-end VPM.
- Warm mirrors
- 4 K HDPE lenses
- 18º diameter field-of-view
- Strehl ratio > 0.99



Co-polar beams



X-polar beams



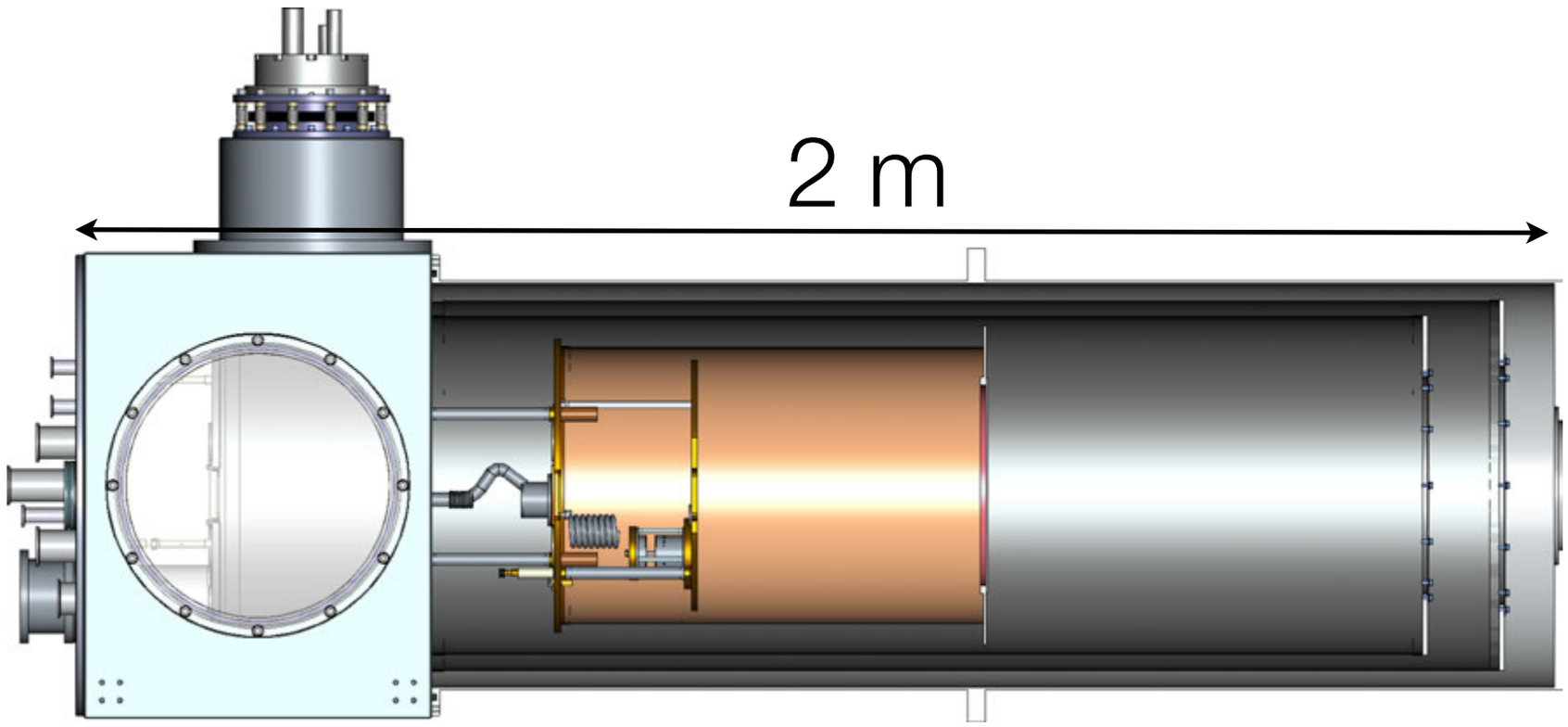
Telescope mount

- Designed by Antedo
- 2’ pointing repeatability
- +/- 200º azimuth rotation
- 0º-90º elevation drive
- 2 degrees/sec azimuth scan

Cryogenic Receiver Design

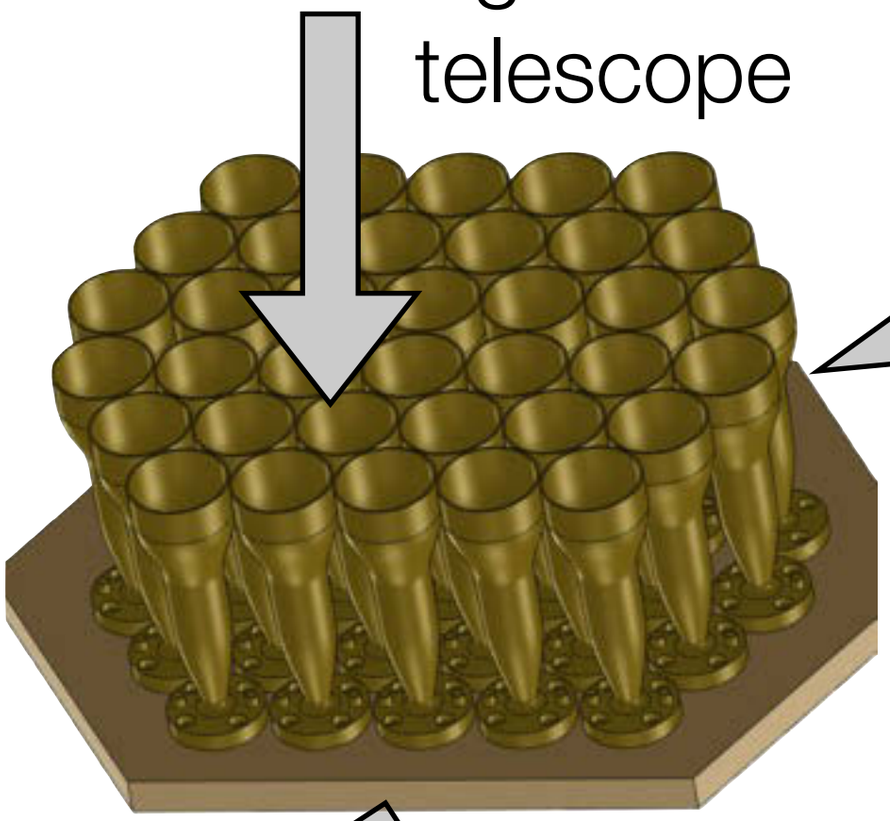
BlueFors CRYOGENICS

- Designed and built by BlueFors cryogenics.
- Pulse-tube cooler backed horizontal dilution refrigerator.
- 50 μW of cooling power at 100 mK.

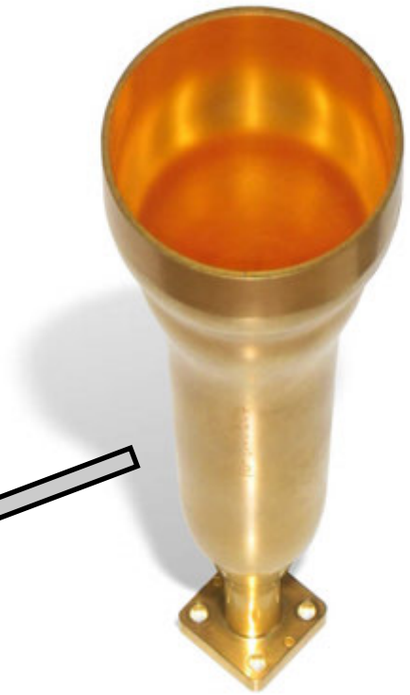


40 GHz Focal Plane

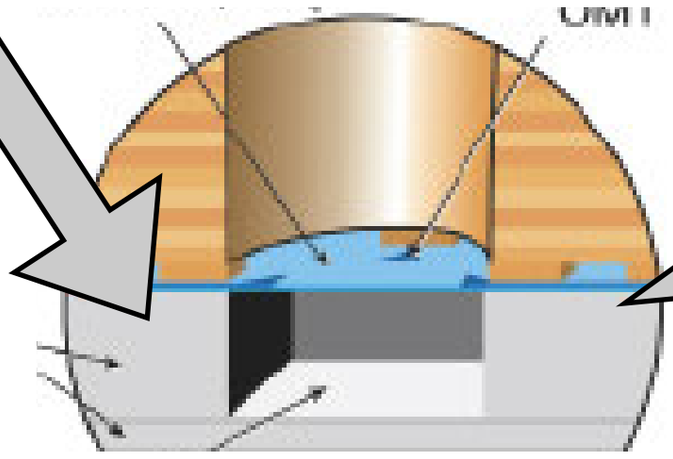
Light from telescope



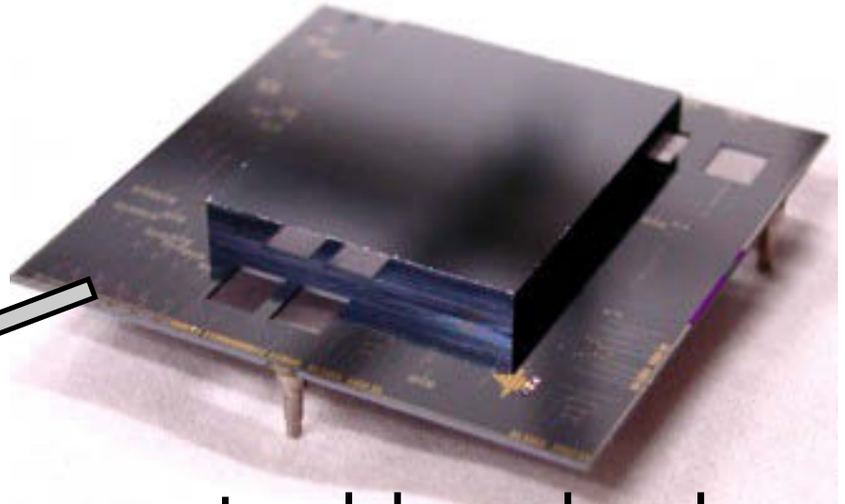
Smooth-walled feed horns



Focused onto detectors



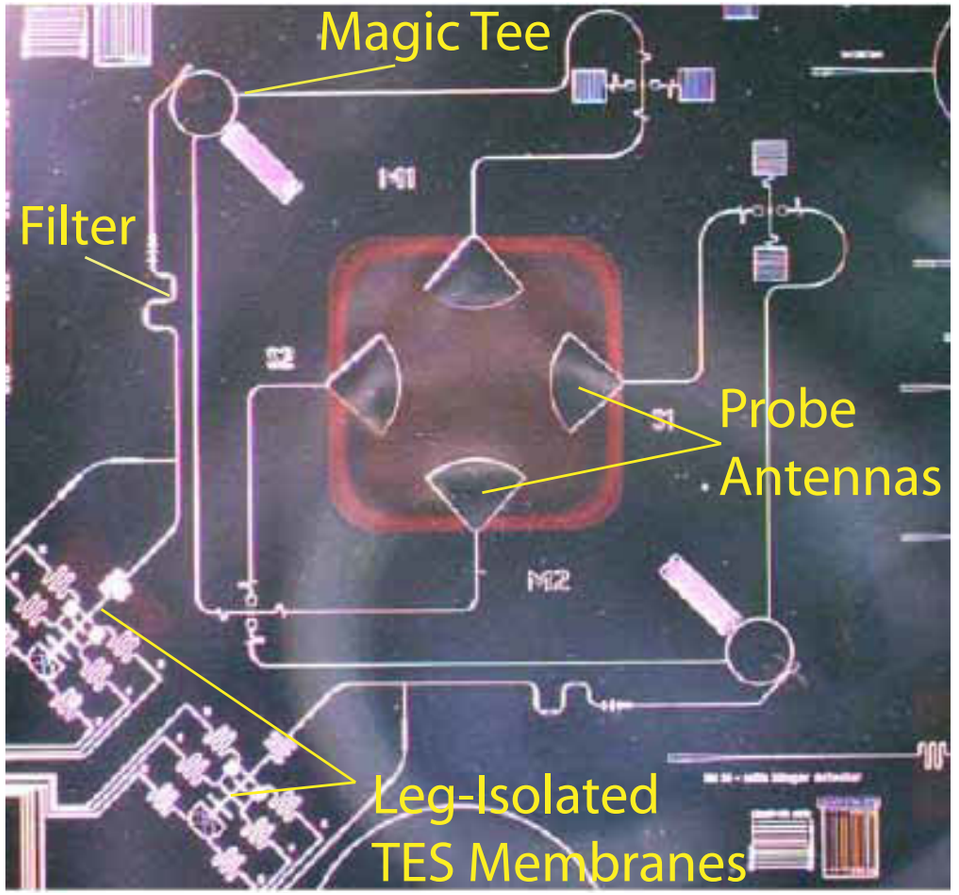
Integrated back short



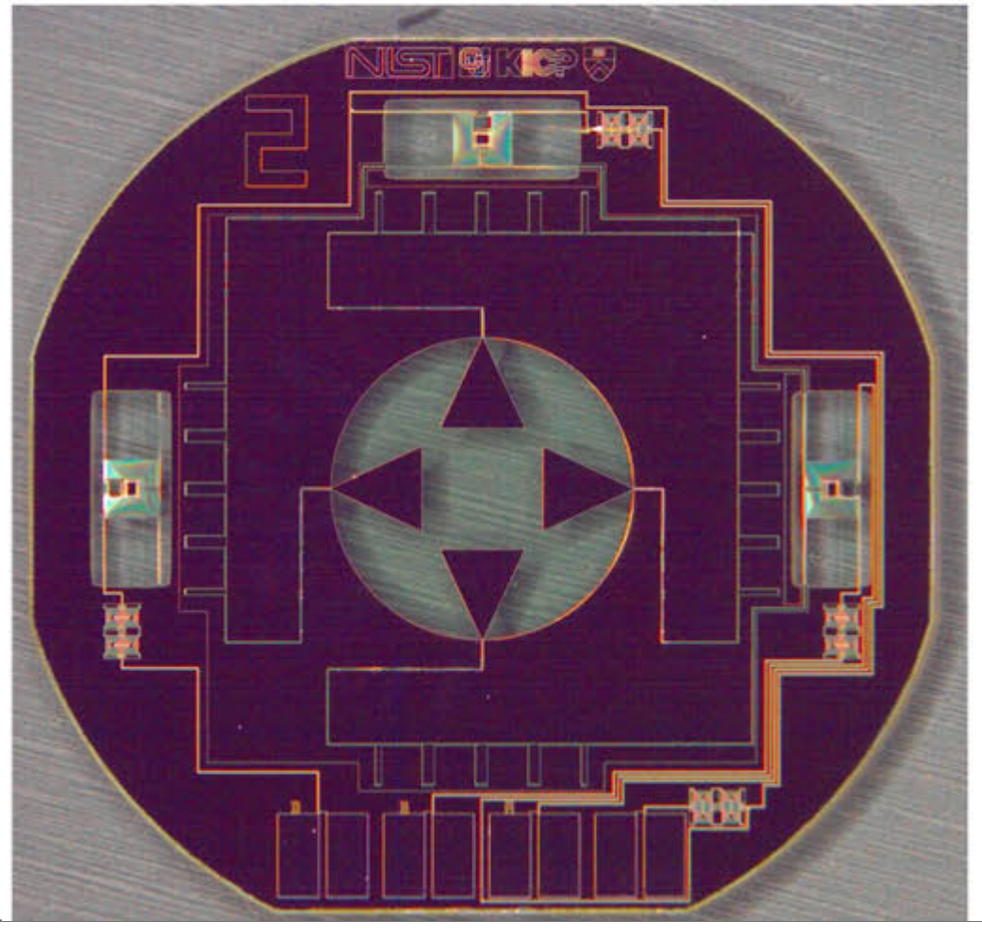
Detector technology

- Symmetric architecture preserves polarization purity.
- Hybrid of coherent - bolometric technology.
- Transition-edge-sensor (TES) bolometers. T_c =150 mK
- On-chip band defining filters.

NASA GSFC 40/90

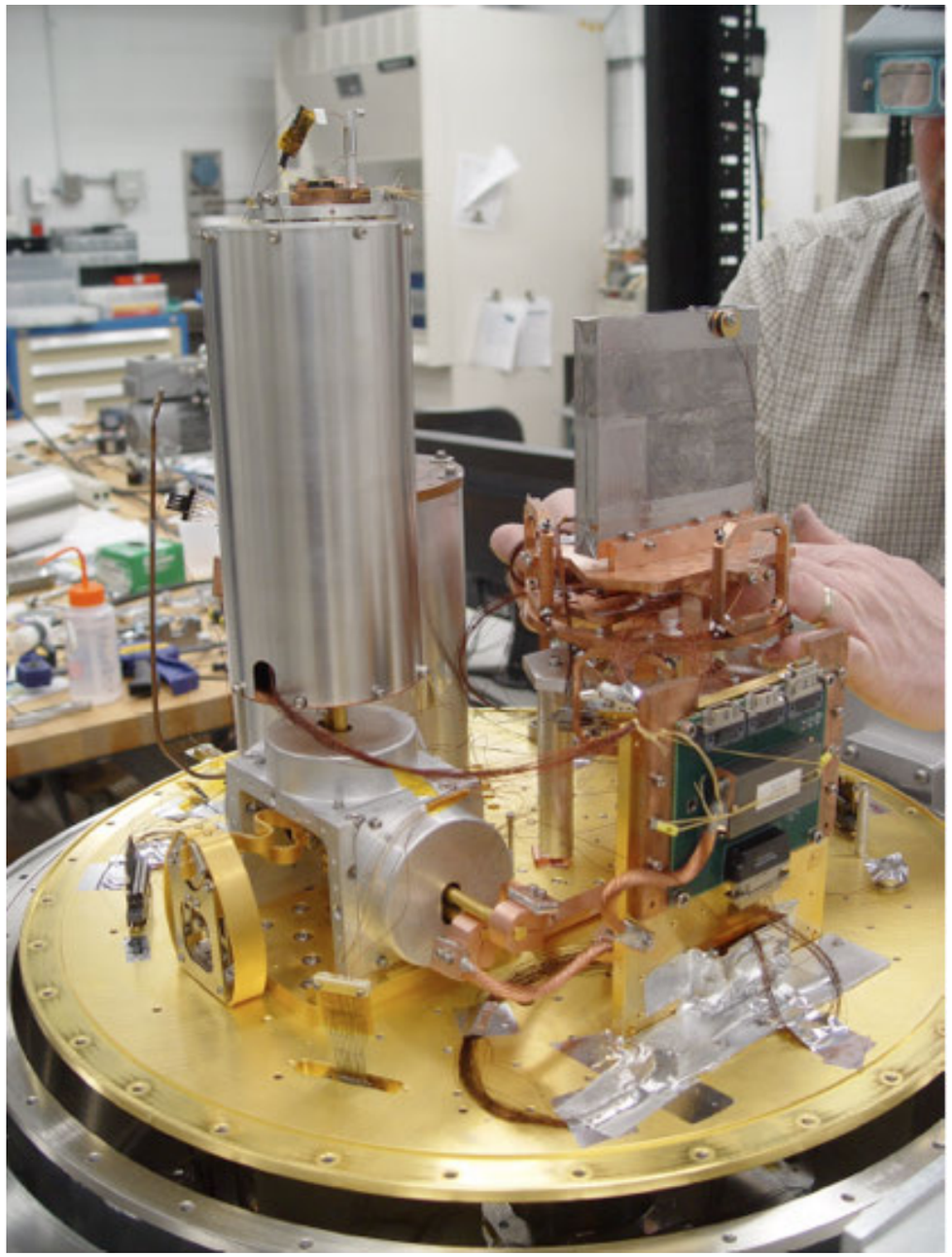


NIST 150

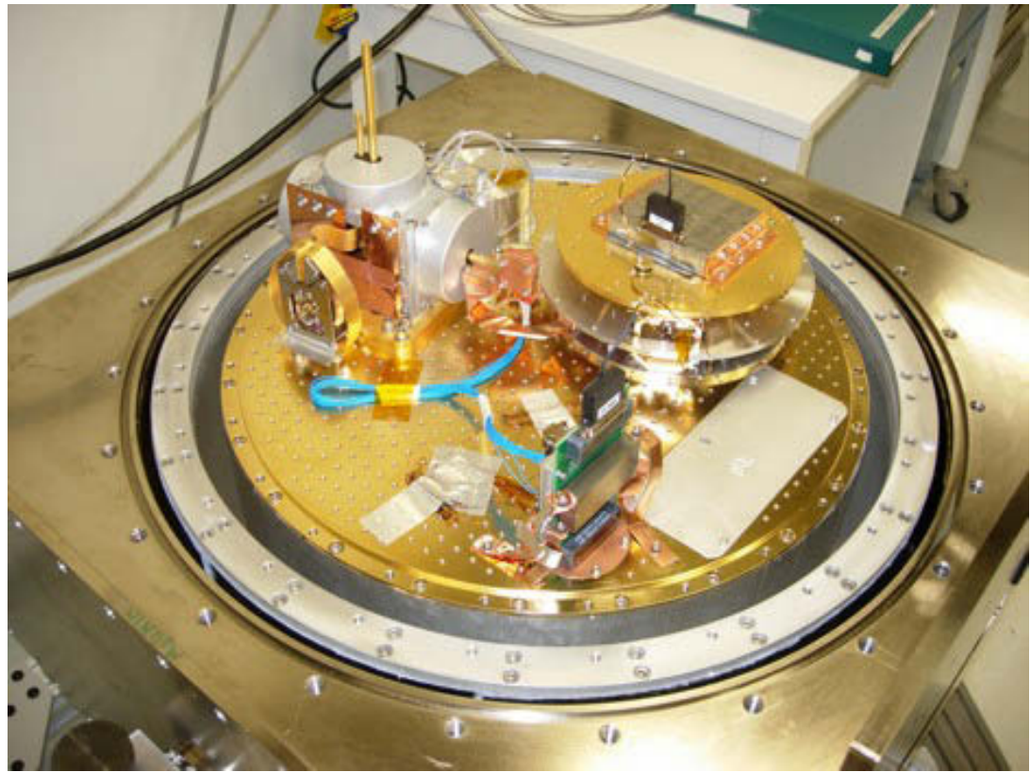


Detector testing

JHU

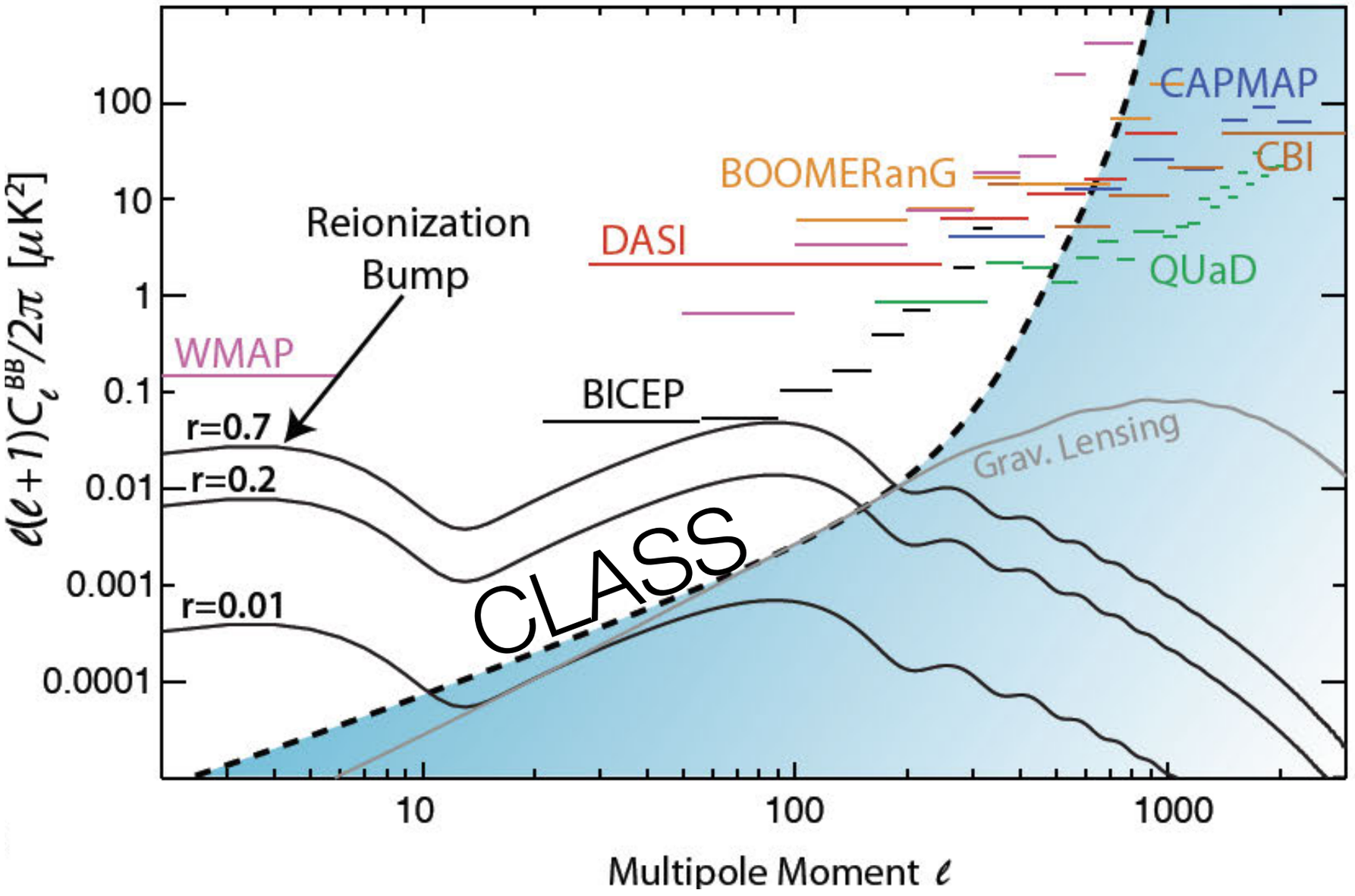


Goddard



Columbia

Raw Sensitivity



First light in the Austral summer of 2013-2014

CLASS

- Inflation naturally explains many otherwise strange observations of the Universe.

- Inflation resides at the intersection of gravity and quantum mechanics - one of the few accessible ways to probe this overlap.

- The B-mode signal, combined with CMB temperature anisotropy, is an measure of the energy scale of inflation.

- Through innovative technology and careful design, CLASS will perform a powerful search for the B-modes.

- With our anticipated sensitivity, CLASS will either detect or rule-out single field GUT inflation.

Thank you.

Simple models of inflation

- Single scalar field, slow-roll models

$$\mathcal{L} = \frac{1}{2}(\partial\phi)^2 - V(\ \ )$$

Inflation theories are distinguished here

- Klein-Gordon equation (interpreted through the lens of the continuity equation) gives density and pressure in terms of the field and its potential.

- Quantum fluctuations, interpreted as perturbations, can be Fourier expanded.

- The power spectrum of these fluctuations, subject to the transfer function, is the observable quantity.

Generation of B-modes

- Single field, slow-roll models

$$\mathcal{L} = \frac{1}{2}(\partial\phi)^2 - V(\ \ )$$

B-modes

$$n_s \left(\frac{V'}{V}, \frac{V''}{V}\right)$$

Shape of potential

r

V

Energy Scale of Inflation!