

Ground Based CMB Polarization Experiments

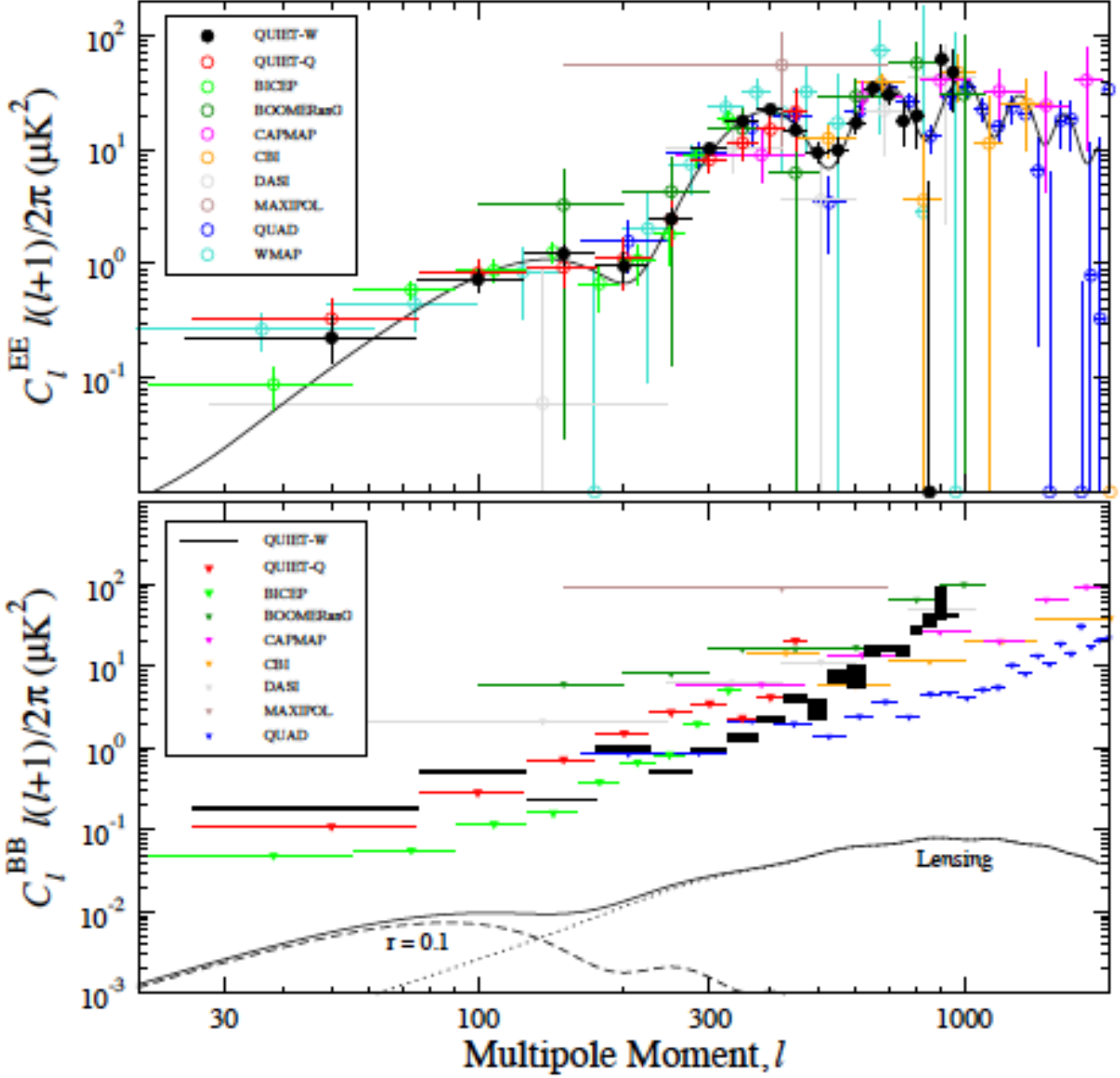
Adrian T. Lee

NASA IPSAG Meeting

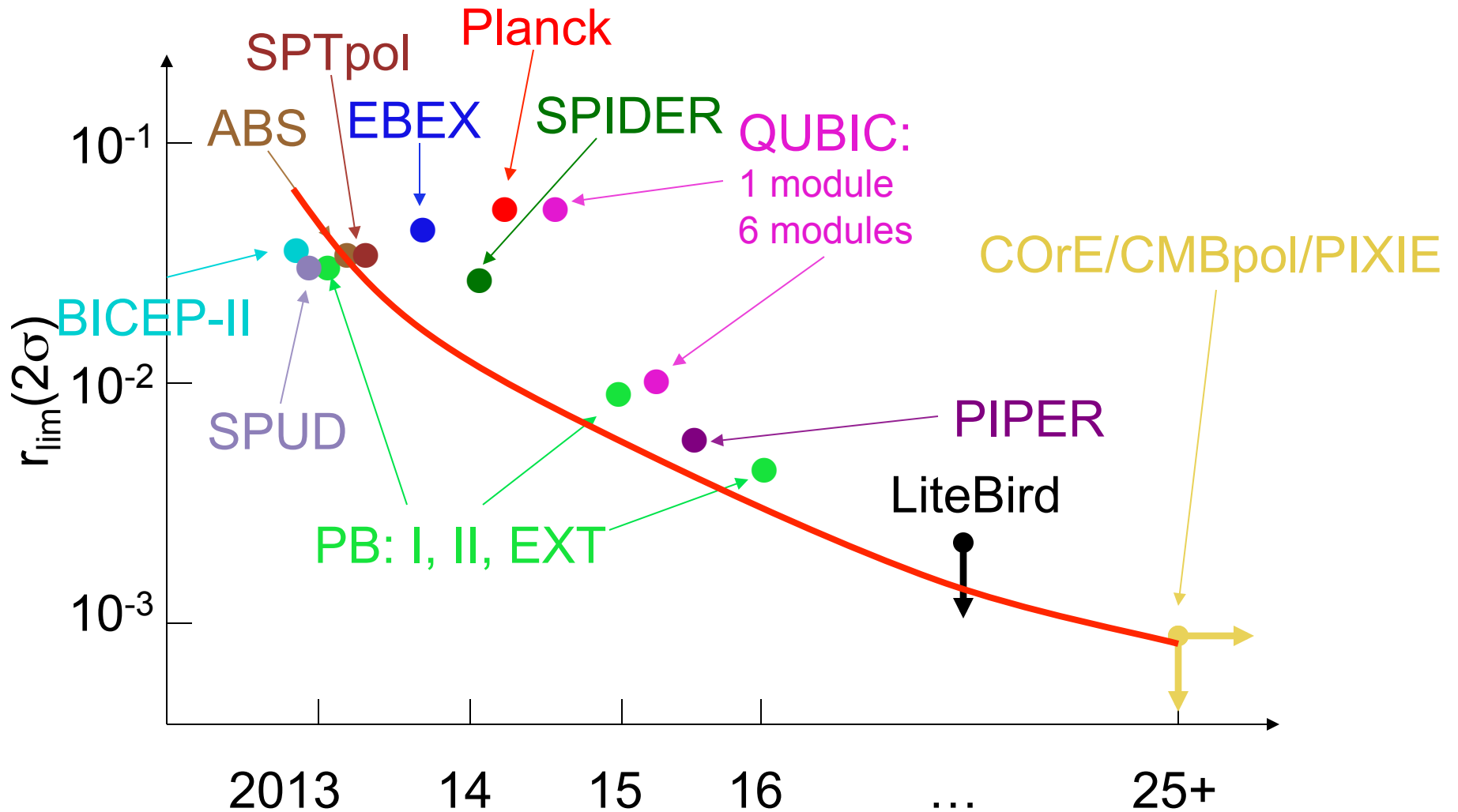
Ground Observations and NASA

- Technology Development
 - First step tests of technology for space
- Guiding Science Results
 - Ground (and balloon) results -> mission design
 - Both Cosmology and Foregrounds
- Complementary Data
 - Angular Scales (Smallest scales from ground)
 - Frequency Range (Lowest frequencies from ground)

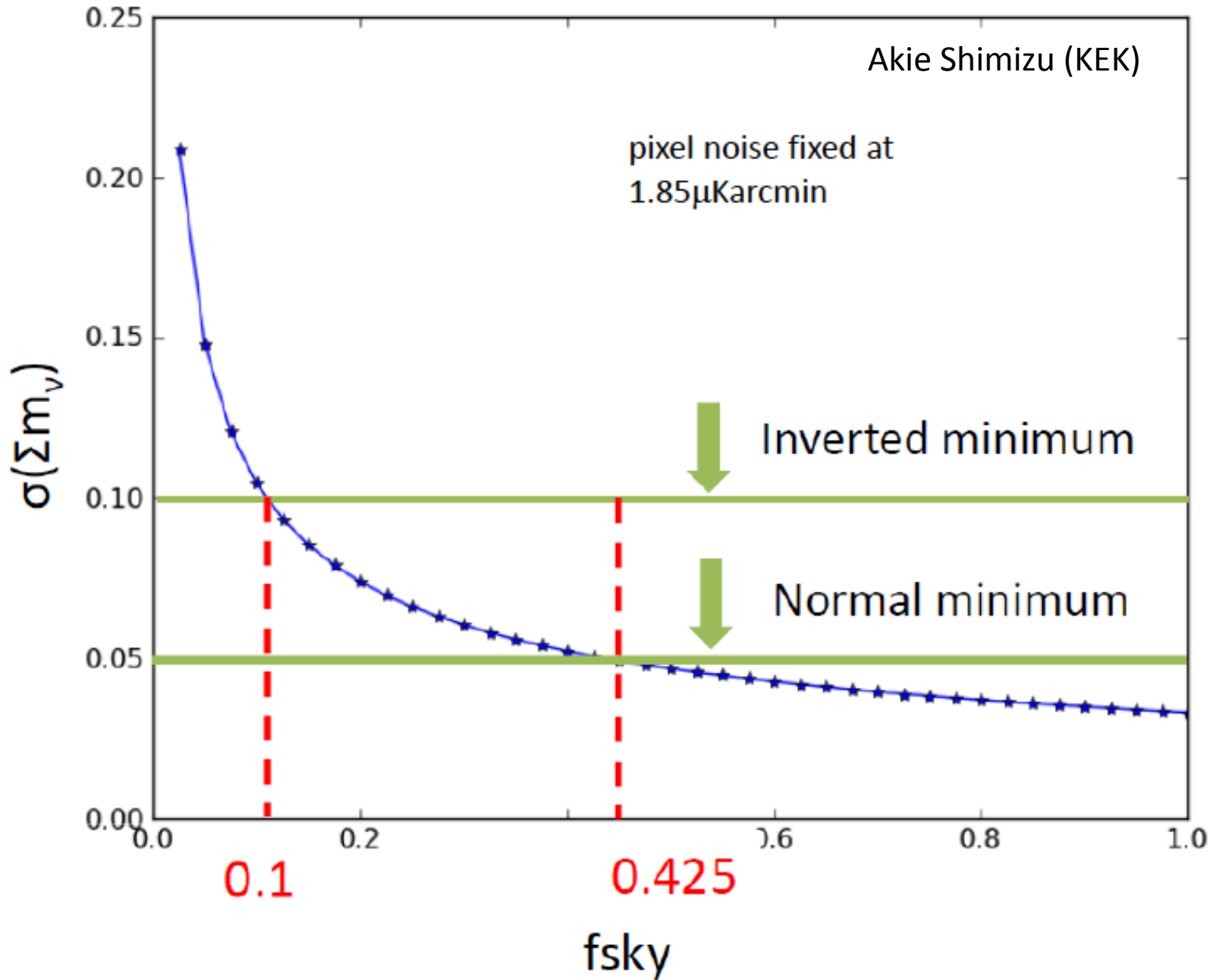
CMB B-mode experiments (2012)



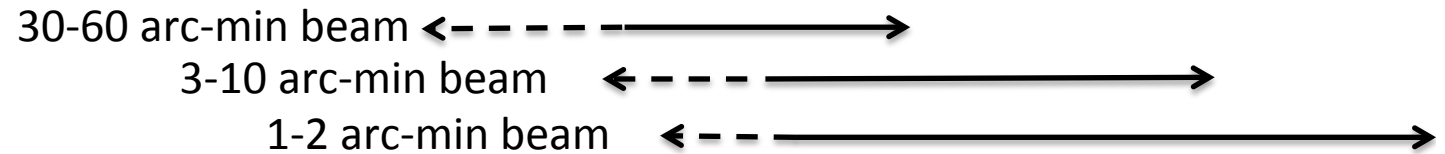
Sensitivity - constraints on r



Sum of Neutrino Masses from Gravitational Lensing



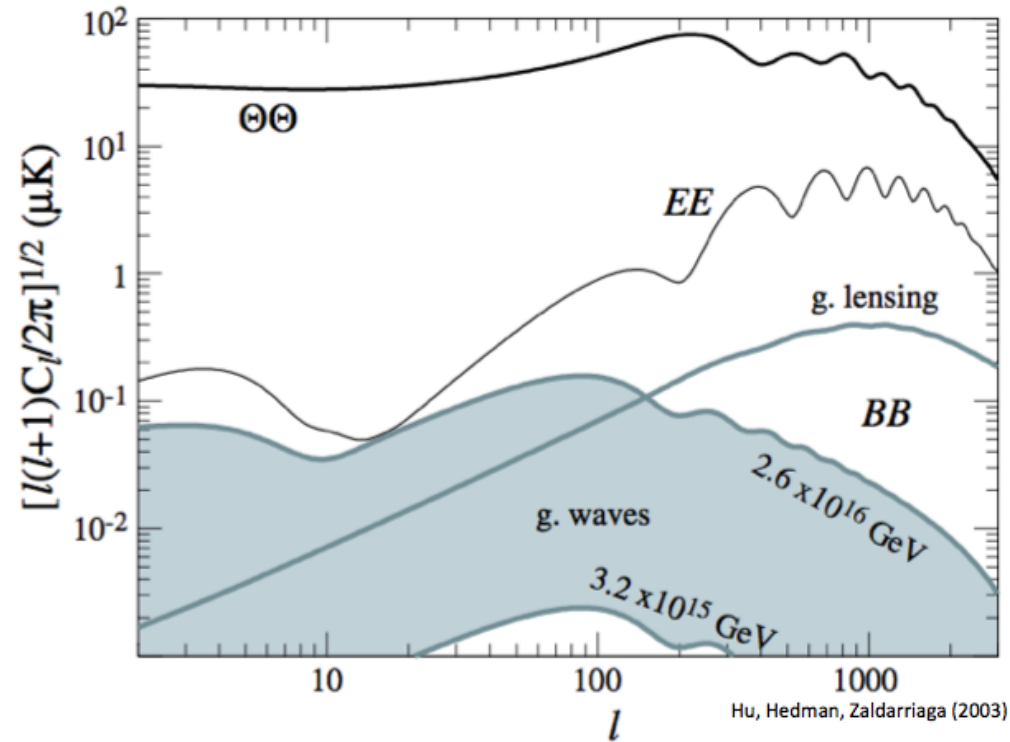
Resolution and l range



- 30-60 arc-min beam:
 - ABS, BICEP, CLASS, GroundBIRD, KECK/SPUD

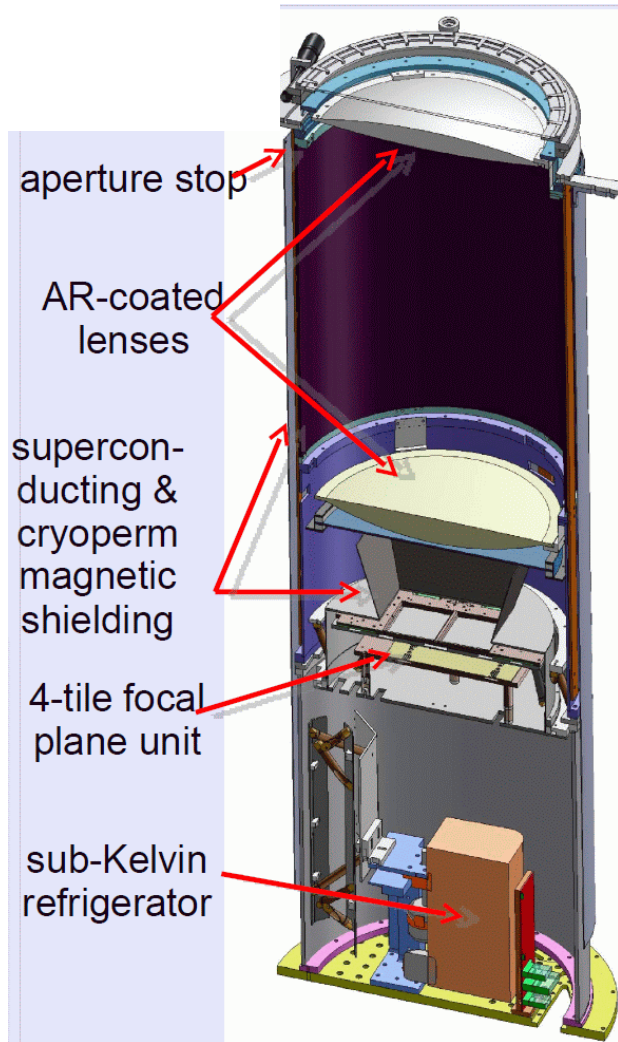
- 3-10 arc-min beam:
 - POLARBEAR;
 - POLAR Array.

- 1-2 arc-min beam:
 - ACTpol;
 - SPTpol.

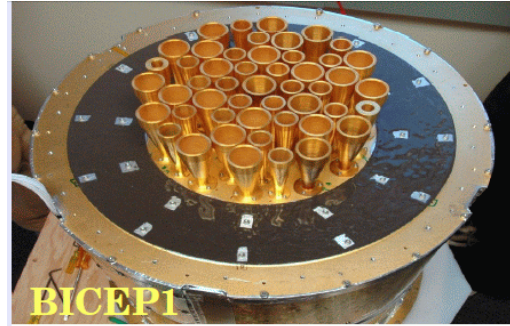


0.5 – 1 degree resolution experiments

BICEP1/BICEP2/Keck Array

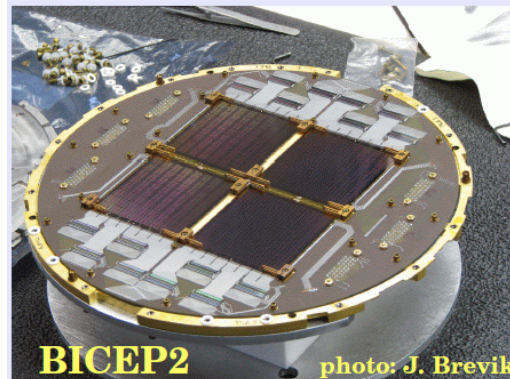


* All with small refract
(25cm) ;
@ South Pole



90/150GHz
25/24 elements
2005-2008

Provided best limit
on tensor: $r < 0.72$



150GHz
256 elements
Since 2009
5x survey
speed than
BICEP1

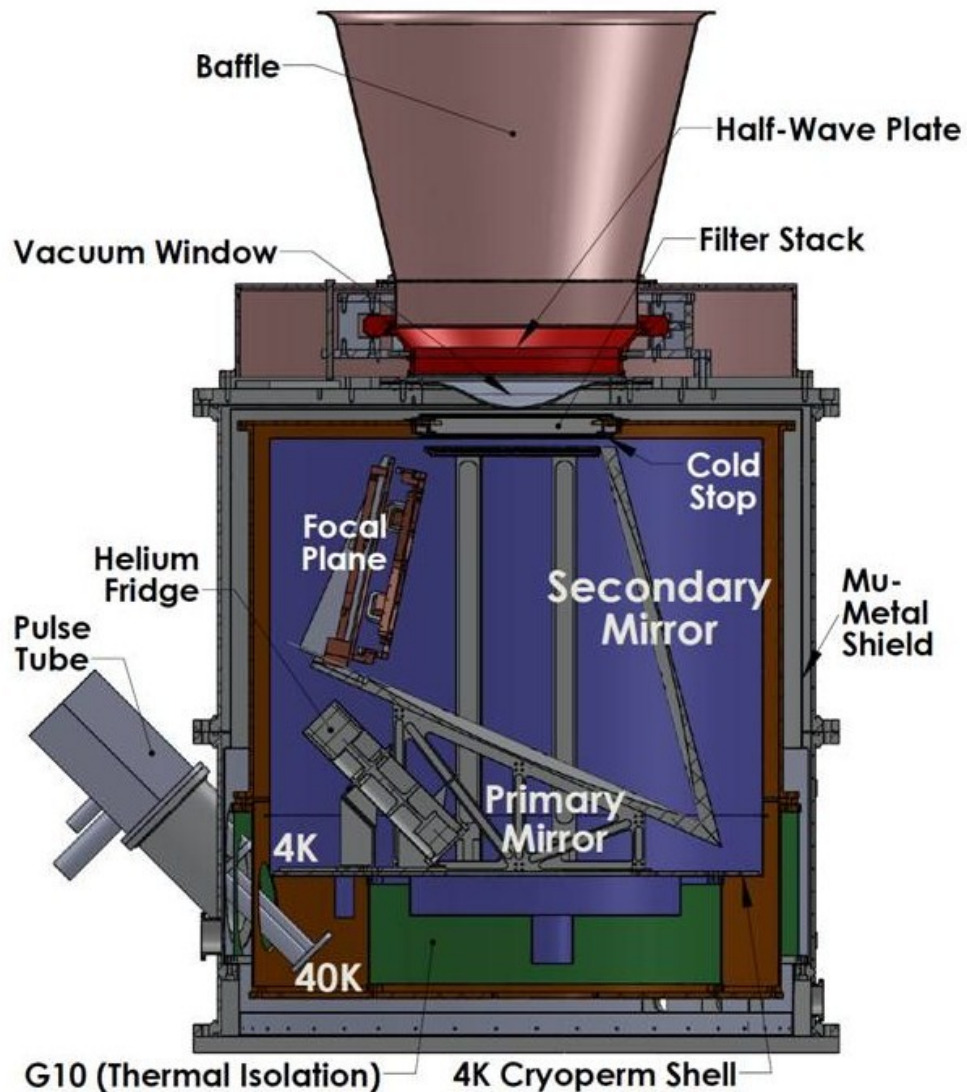
Analysis in
advanced stage,
First publication
exp. late 2012



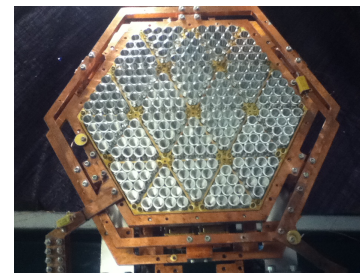
150GHz
256x5 elements
Since 2010
Target is **5x**
BICEP2

Instr. verification;
currently
making pretty maps

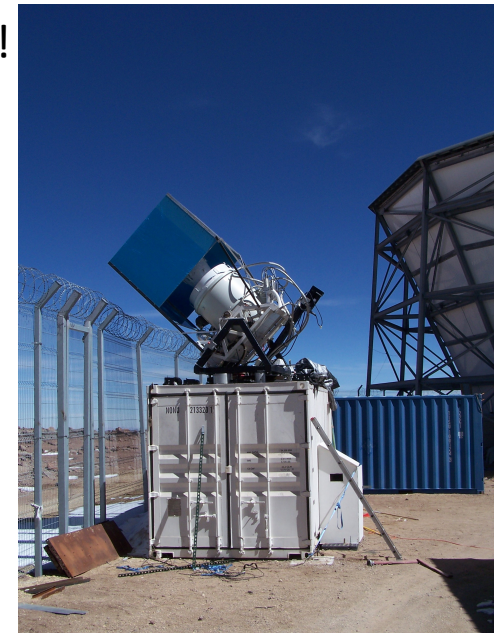
ABS: Atacama B-mode Search



- 240 150-GHz feedhorns
- 480 TES bolometers at 300 mK
- Low foreground parts of sky
- ~ 35 microK rt(s)
- Cold mirrors
- Warm continuously rotating HWP
- Atacama desert: 5100 m elevation
- Target $r < 0.03$
- Status: taking data!



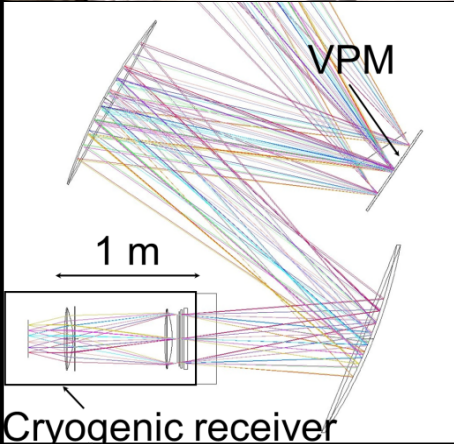
FOCAL PLANE



COSMOLOGY LARGE ANGULAR SCALE SURVEYOR



Modulator & Optics



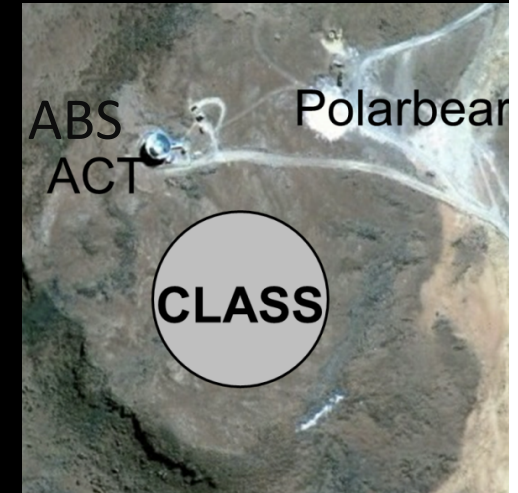
Search for B-mode inflation signature from primordial gravitational radiation at $>2^\circ$ scales with projected sensitivity to detect tensor-to-scalar ratios below 0.01, even when including foreground and systematic errors.

Use demonstrated front-end wire grid polarization modulator (VPM) at 10 Hz (above atmospheric noise).

Take advantage of enhanced signal of reionization "bump" and avoid lensing B-mode signal.

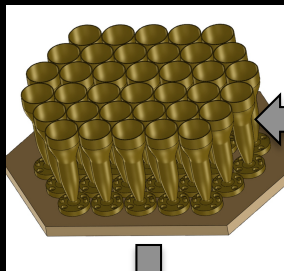
Survey large fraction (65%) of sky observable from Atacama Desert at frequencies (40, 90, 150 GHz) where the full-sky CMB-to-foreground ratio is maximized.

Atacama Site

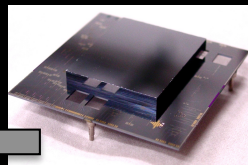
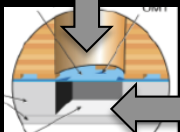


Cerro Toco, 5200 m, 65% of sky observable above elev 45°

Focal Plane



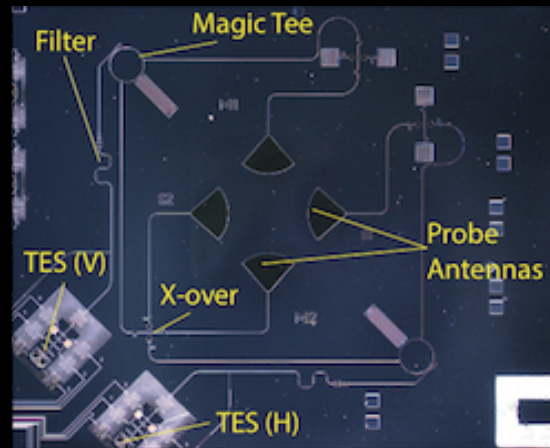
Smooth-walled Feedhorns (Patent!)



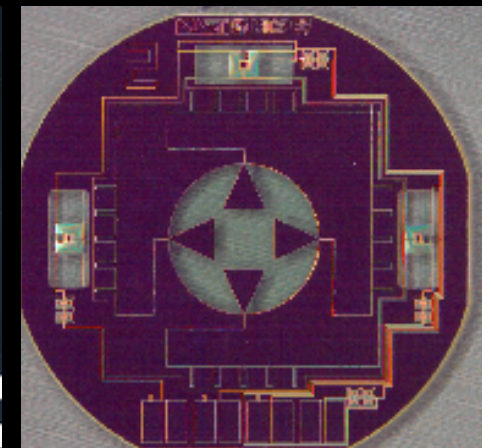
Horn Coupled Detectors

Integrated Backshort

Polarization Sensitive Bolometric Detectors



NASA/GSFC 40 & 90 GHz



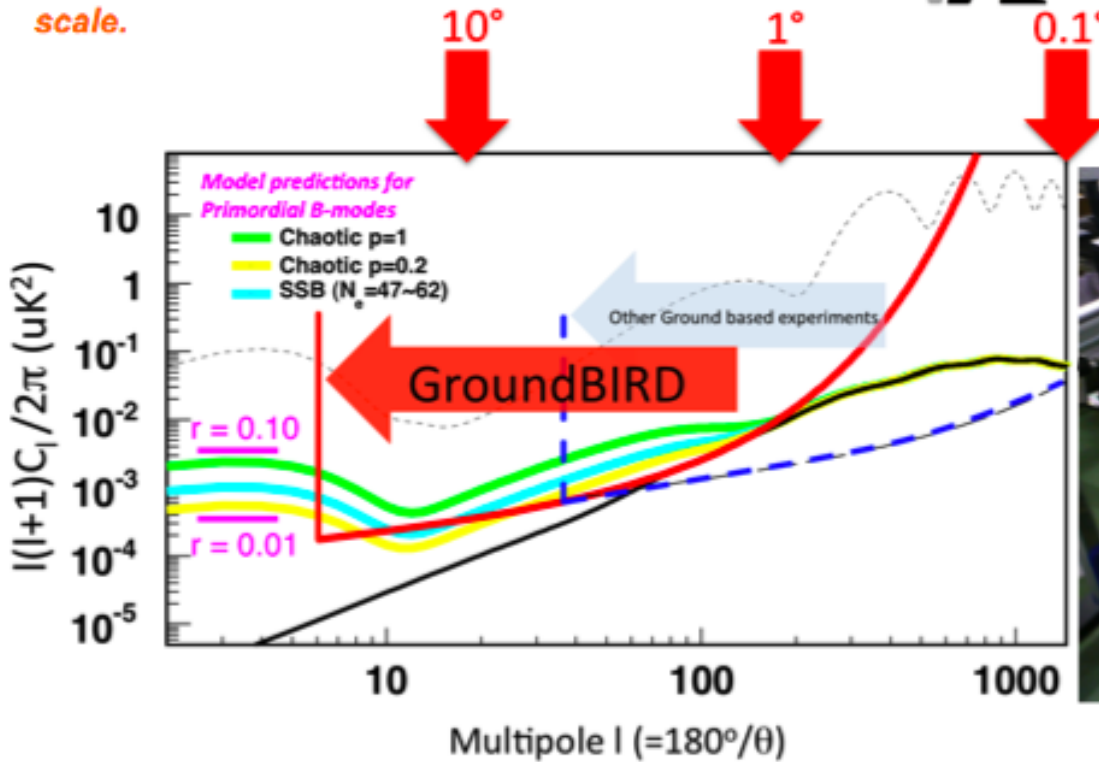
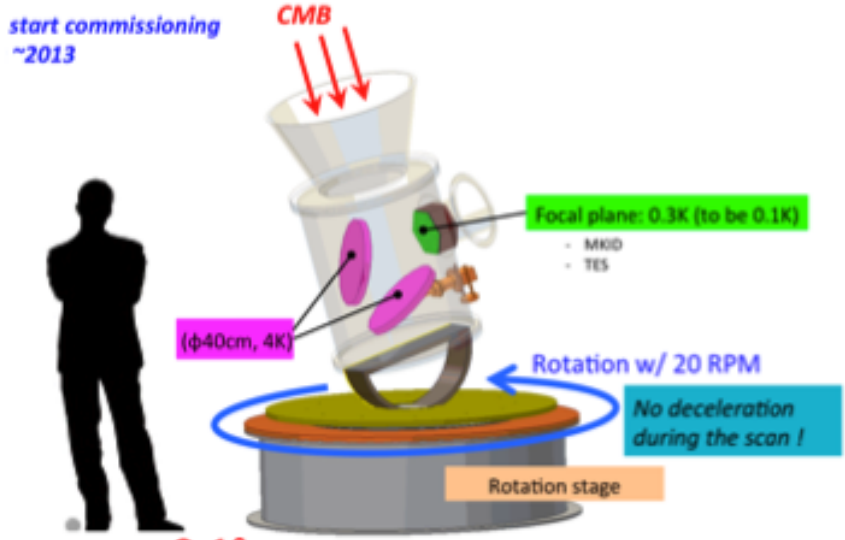
NIST 150 GHz

3-10 arc-minute resolution experiments

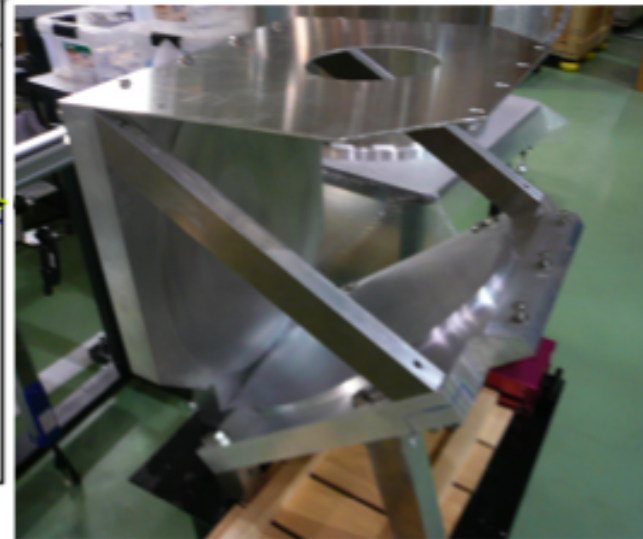
GroundBIRD

◆ Measurements of the primordial B-modes at a large angular scale directly constrain inflation models !!

Large area of observation allows us to measure the B-mode power at a large angular scale.



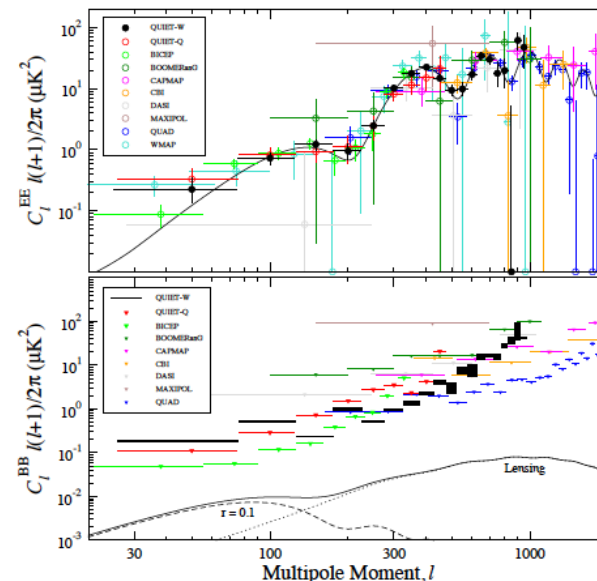
◆ Mirrors



From KEK O. Tajima

QUIET - Q and U Imaging Experiment

- Only B-mode HEMT radiometer at this time (see STRIP);
- Uses “radiometer on chip” technology;
- Operates from Atacama.
- QUIET:
 - 19 Q-band detectors (43GHz) (2008-09);
 - 91 W-band detectors (90GHz) (2009-10).
- QUIET-II (awaiting funding):
 - 500 detectors;
 - 3 bands: 30, 37, 95 GHz
 - Coverage from $l = 25 - 1000$
 - Lensing B-mode $\sim 20\sigma$ detection
 - $r \sim 0.01$
- Followed by FOCUS (if funded):
 - Synchrotron mapping experiment



Caltech, Chicago (KICP), Columbia, Fermilab, JPL, KEK, Manchester, Miami, MPI-Bonn, Oslo, Oxford, Princeton, Stanford (KIPAC)

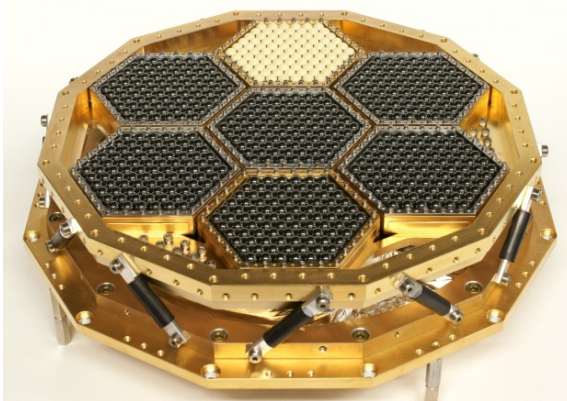
POLARBEAR

APC (Paris), Berkeley, Cardiff, Colorado, Dalhousie, Imperial, KEK, LBNL, McGill, San Diego,



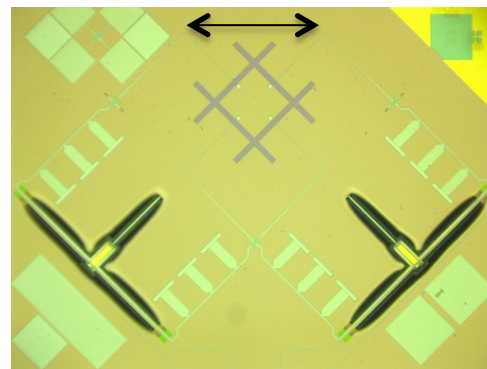
- Dual goals: Inflation + Lensing
- Phased Deployment
 - PB-1: 1,274 bolos, Observing!
 - PB-2: 7,588 bolos, multichroic pixels
 - PB-Extended: 3 x PB-2
- Test for NASA Technology
 - Baseline detectors for LiteBIRD
- LiteBIRD+PB-X: $3 < \ell < 3000$

← 20 cm →

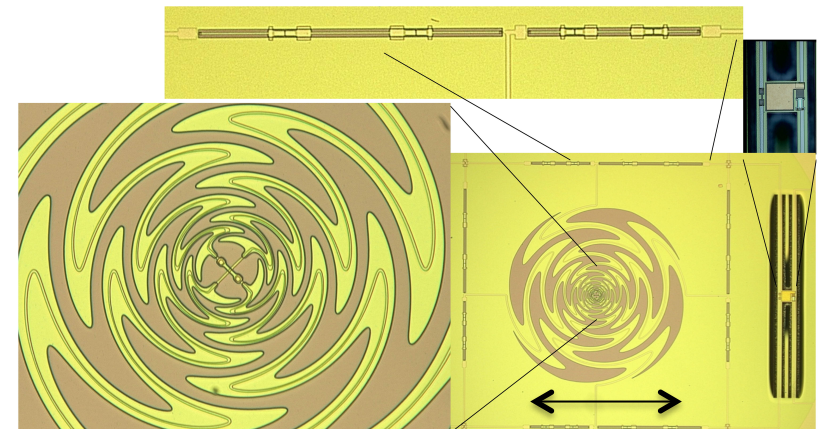


PB-1 Focal Plane: 1274 bolometers

1 mm



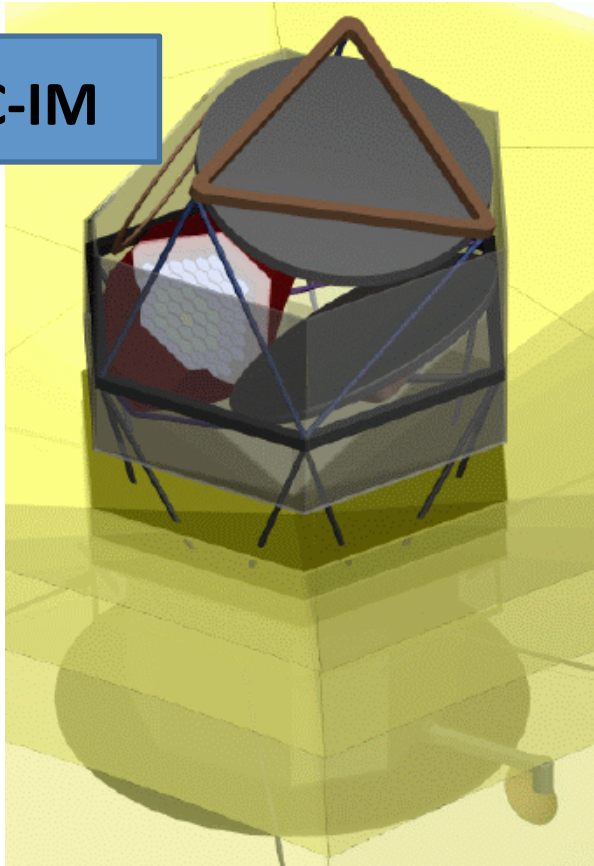
PB-1 antenna coupled bolometer



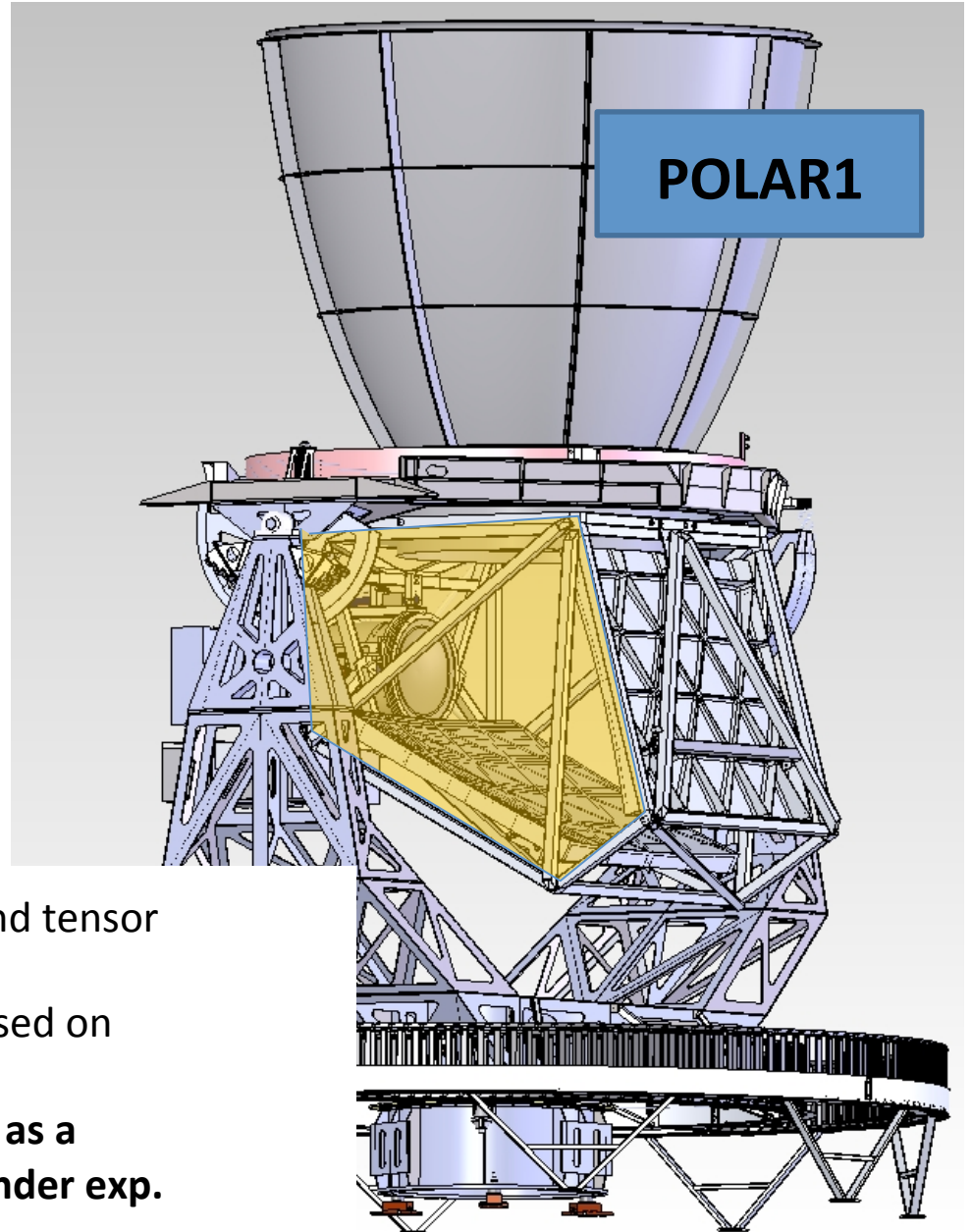
PB-2: 90/150 GHz pixel (also 90/150/220)

EPIC-IM and Its Ground-Based Pathfinder **POLAR1**

EPIC-IM



POLAR1

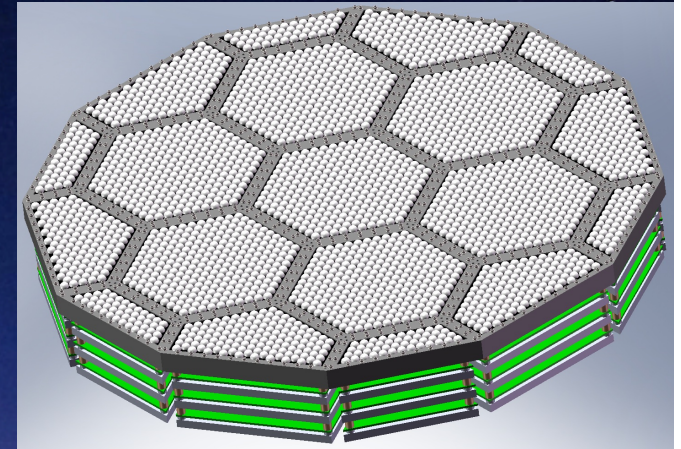
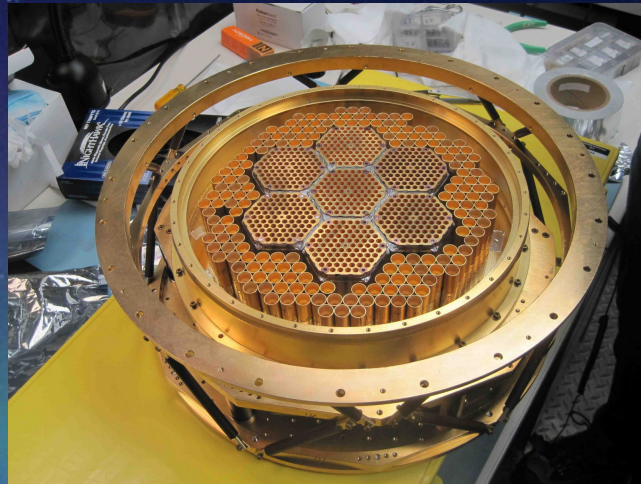
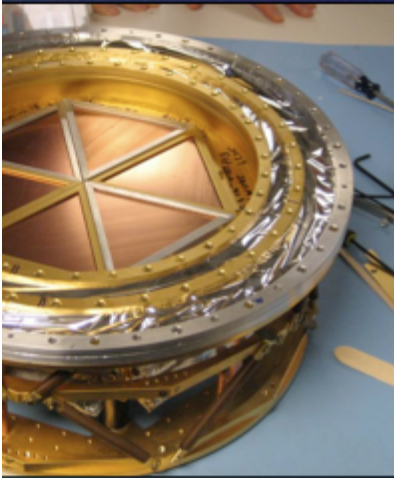


- EPIC-IM targets both lensing (arcmin-scale) and tensor
- EPIC-IM is a 1.4m **crossed-Dragone** telescope
- POLAR1 is a 1.6m **crossed-Dragone**, largely based on EPIC-IM optical design
- * **After completion in 2013, POLAR1 will serve as a technology testbed for EPIC-IM, and a pathfinder exp. for a ground-based array “POLAR Array”**

1-2 arc-minute resolution experiments

SPTSZ, SPTPOL, and Beyond

o, Berkeley, Harvard, Case Western, McGill, Boulder, Caltech, Munich, Michigan, Arizona, ANL, NIST



SPTPOL



SPT3G (Multichroic Sinuous Pixels)

1 arcmin resolution at 150GHz;

polarization sensitive pixels

150GHz channels

started in Jan, 2012.

180 degrees observed for 3 years;

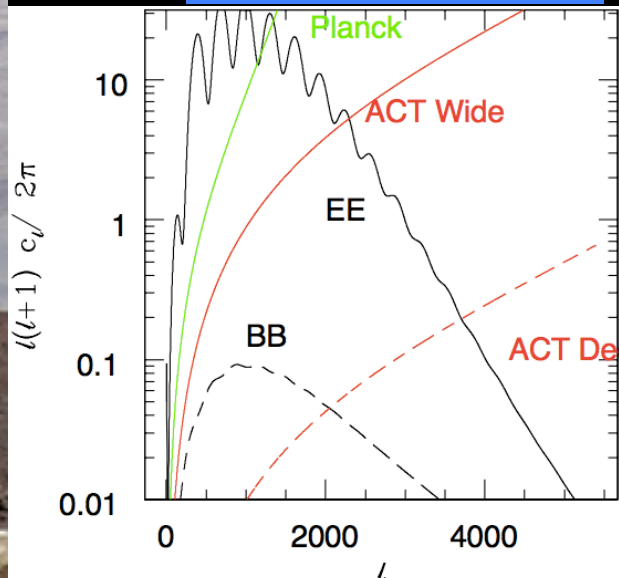
recovery of lensing B-mode



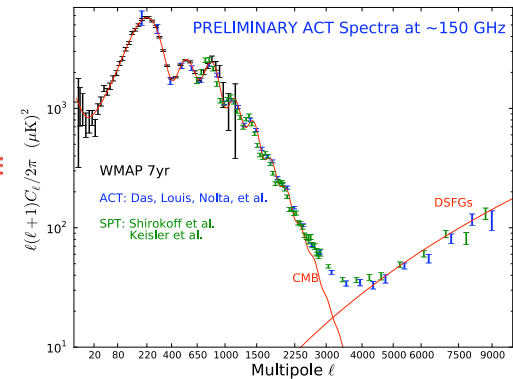
ACTP



ACTPol projections



ACT achievements:
Low to high multipoles!



- New receiver on the 6m ACT
- 16x mapping speed of ACT, plus polarization sensitivity
- First deployment in Atacama for 2012-13
- First goals: gravitational lensing with rich cross-correlation science (neutrino mass sum, early dark energy, and more)



Conclusions

- Ground-based experiments:
 - Possible first detection of inflationary B-modes
 - Excellent constraints on lensing (neutrinos, early dark energy)
- Space Mission
 - Factor 10 deeper search for inflationary B-modes
 - If detected -> characterization of signal
 - Lensing depends on Aperture
 - ~ 30 cm => complement with ground (balloon) based
 - ~ 1.5 m => ultimate CMB lensing measurement
- Ground-based experiments good for testing NASA detector technology