Measuring the CMB Polarization

Advances in Theoretical Cosmology in Light of Data

Nordita, July 2017

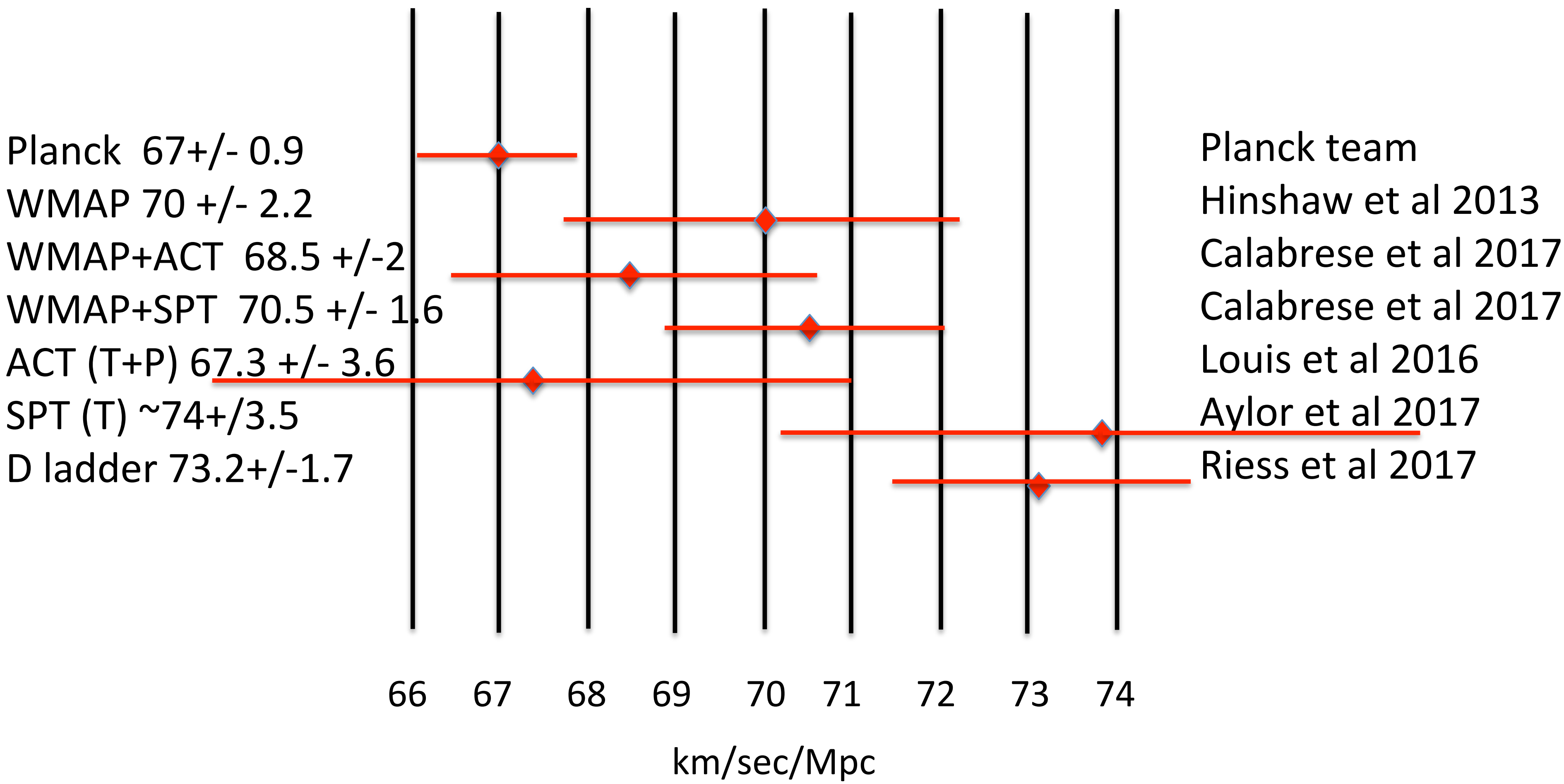
L. Page

Why do it?

Polarization Smörgåsbord

- Primordial B-modes: gravity acting on quantum scales.
- Independent assessment of cosmological parameters
- H_0
- Isocurvature modes from EE; the lowest hanging fruit?
- Testing GR through the growth of structure.
- Calibrating LSST lensing and other surveys.
- Mass bias for quasars, radio sources, through lensing…
- Halo masses through stacking and lensing.
- Cosmic ionization history.
- Axion gauge-field/gravitational leptogenesis (?!)
- …..
- **Something new!**

per Silvia (!)



Just CMB + LCDM to “powerpoint” accuracy.

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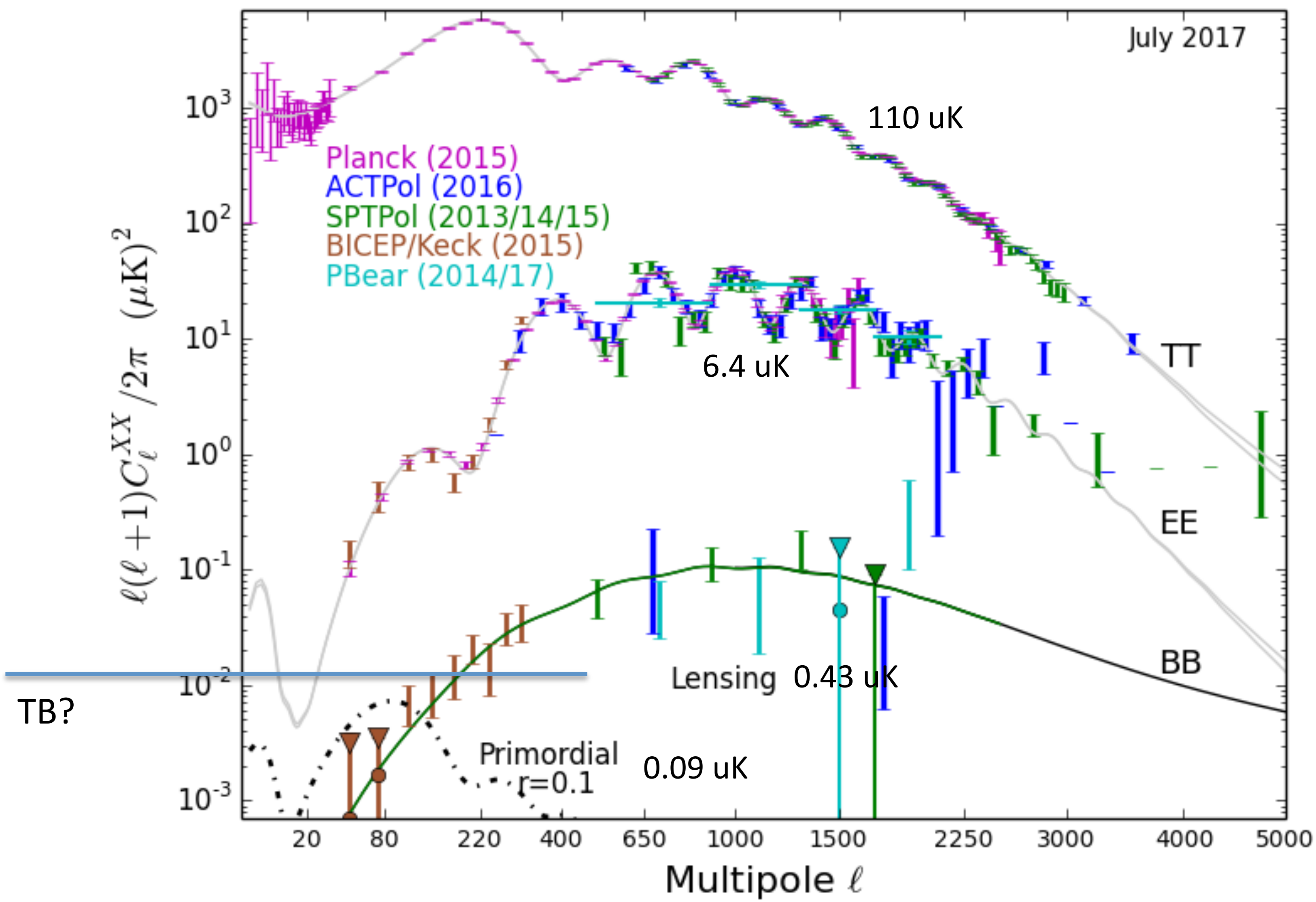
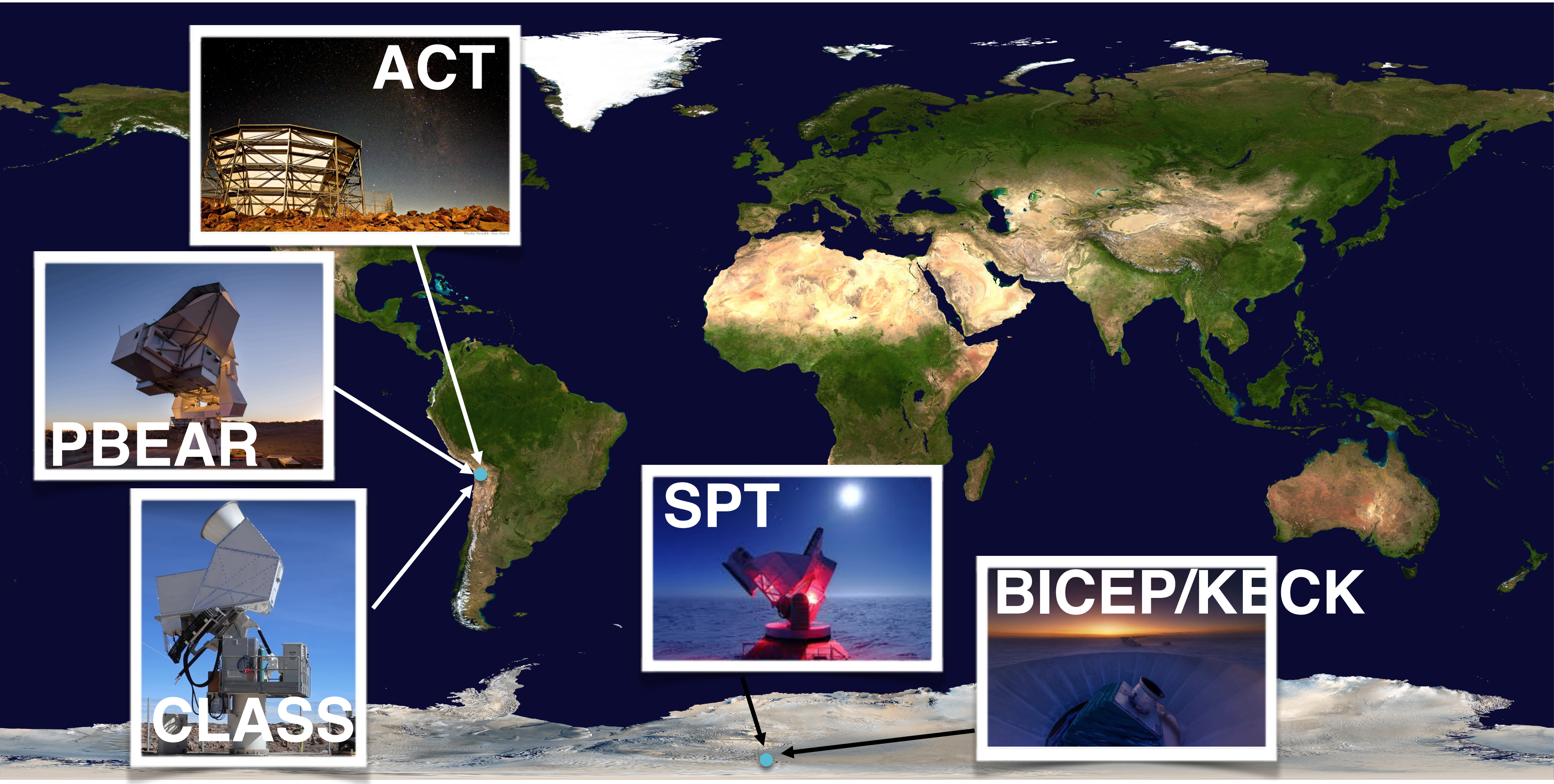
Lots of progress in the past few years



Fielded ground-based experiments in the process of/ or exceeding Planck sensitivity.



Satellite: PIXIE, LiteBIRD, CORE-f
Balloons: SPIDER, EBEX10K, PIPER, LSPE
Ground: QUBIC, ABS, QUIJOTE, B-machine, GroundBIRD, GreenPol

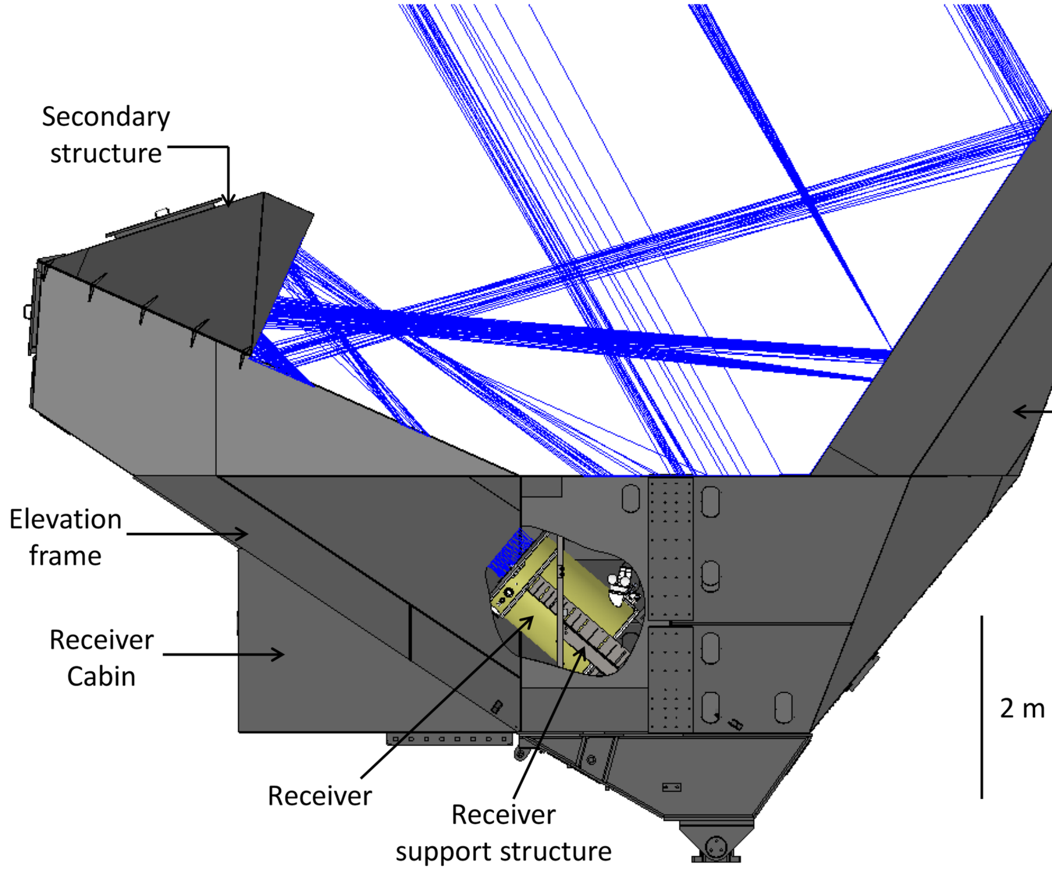
From Patty Ho

ACT/SO neighborhood

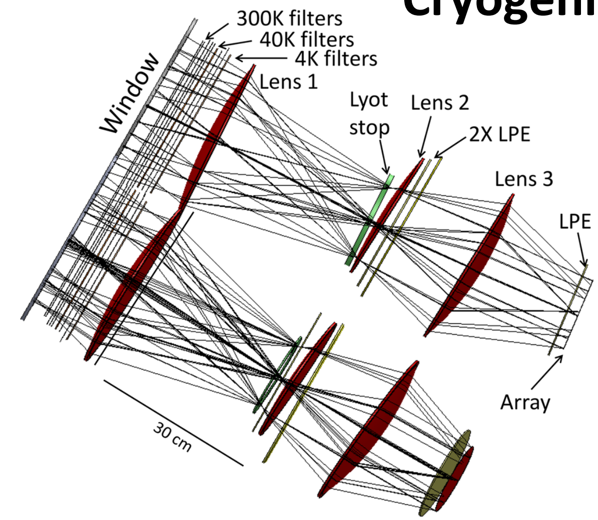
Movie proprietary

Credit: Simons Foundation, Director Debra Kellner, Image Yvan Neault
AdvACT: Suzanne Staggs PI, Mark Devlin co-director
SO Spokesperson: Mark Devlin > Adrian Lee> Suzanne Staggs

ACT Optics



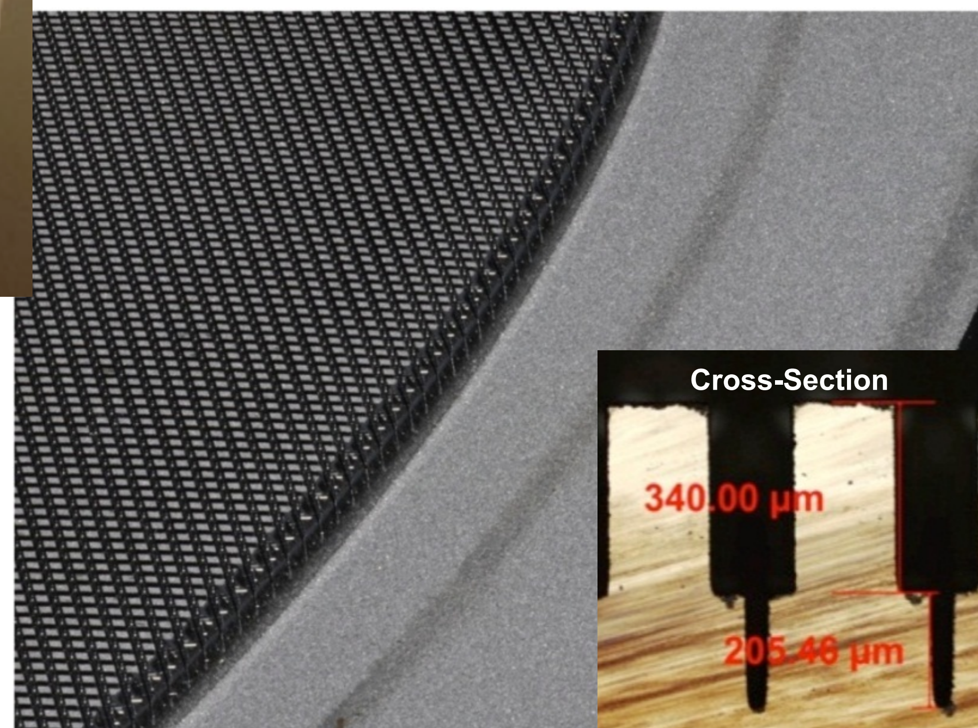
Cryogenic optics



Detectors

From Thornton et al. (2016)

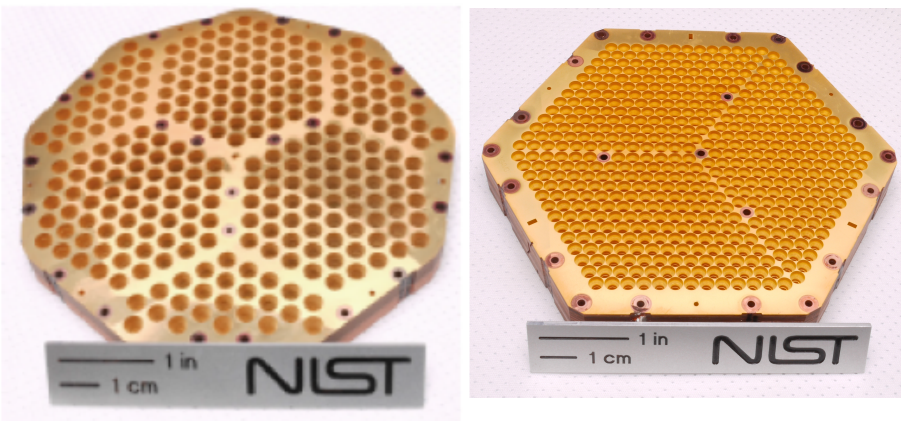
New anti-reflection coated silicon optics and HWPs in the field.

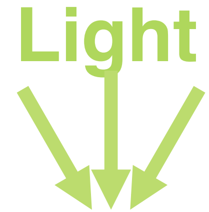


Jeff McMahon’s group at U. Michigan.

Dutta et al. 2014

Feedhorn





NIST proprietary pictures removed

WIP

Detector wafer

BS cavity

Backshort (BS)

Wafer stack

AdvACT detector Wafer PA4

NIST proprietary pictures removed

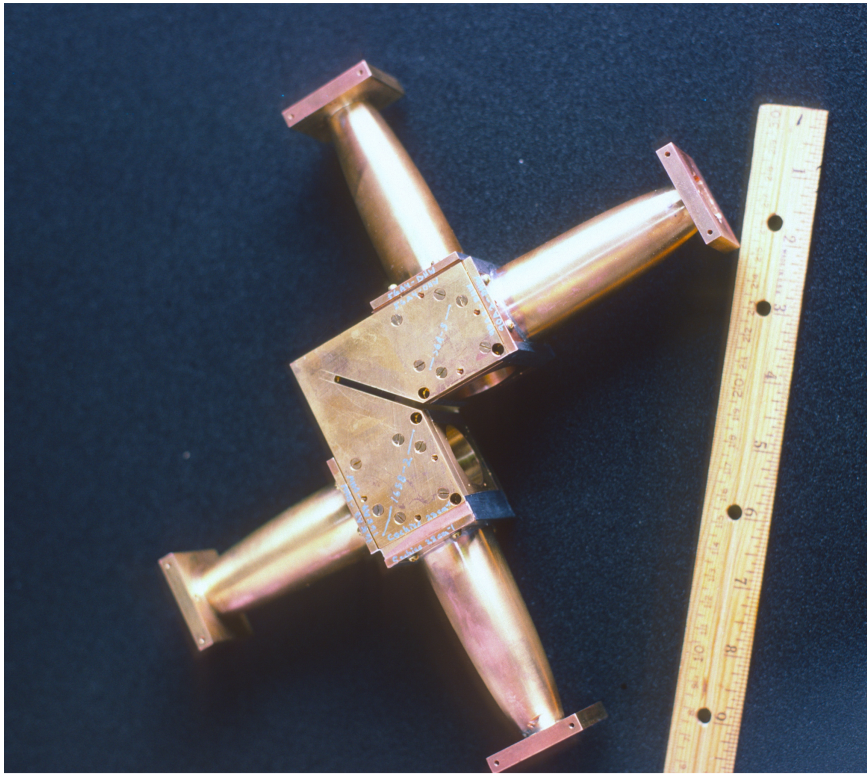
1.3 mm

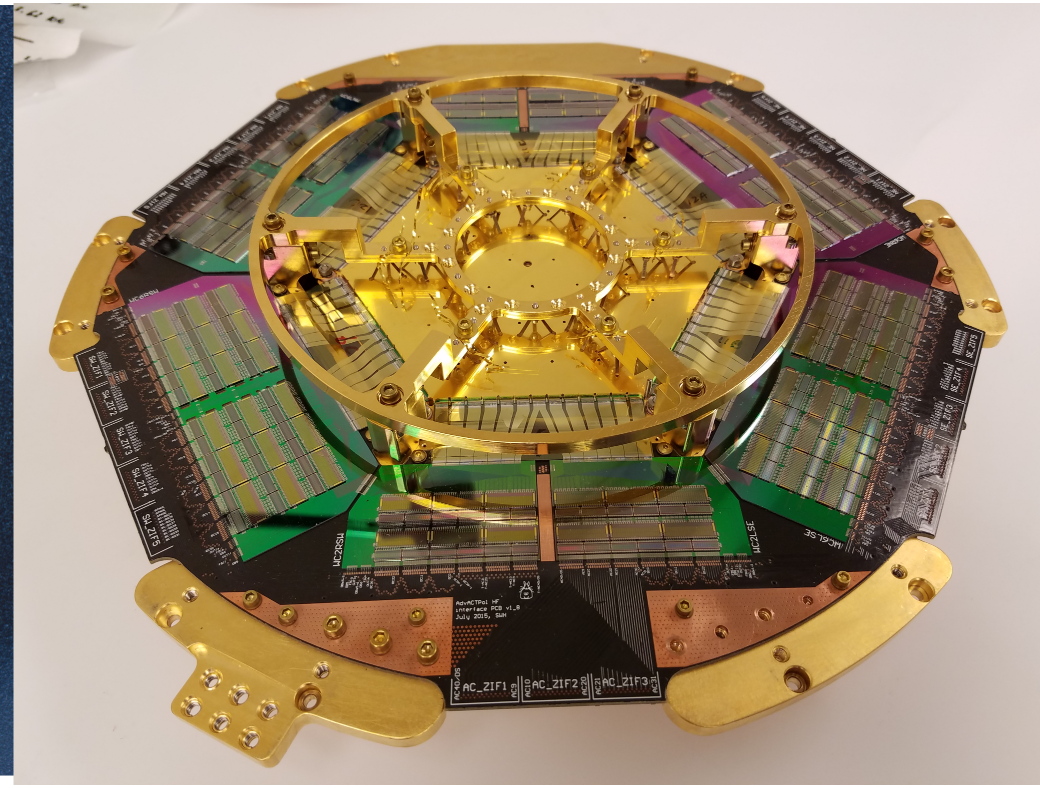
- **506 pixels / 503 horns**
- **2024 TES detectors**
  (1012 each at 150 and 220 GHz)

150 mm

Figures courtesy of NIST

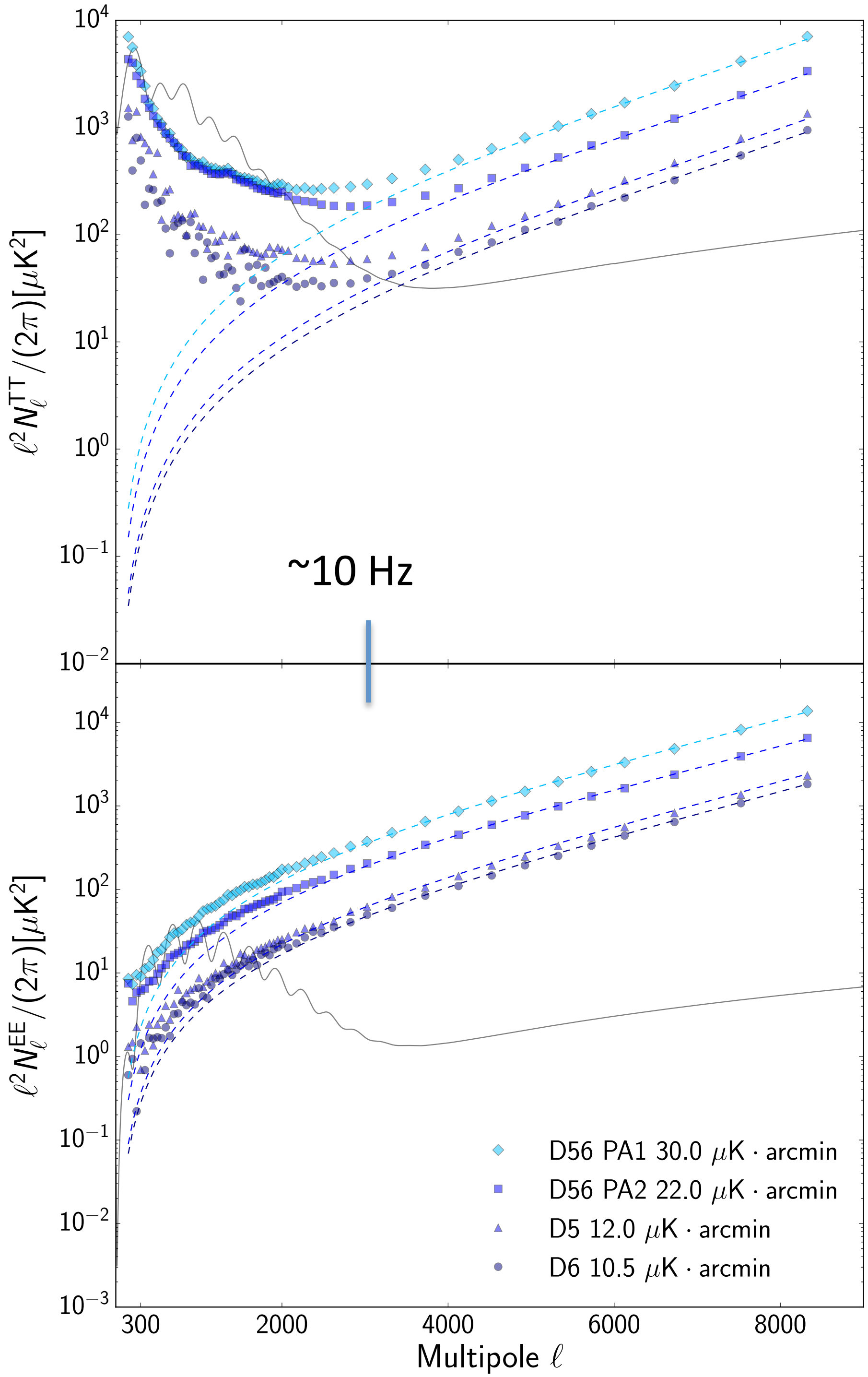
30 years of receiver development





FIRS. First detection of CMB with bolometers. (PI Steve Meyer)

One of three AdvACT array of ~500 feeds. Combination is 3x as sensitive as Planck



ACT Noise curves

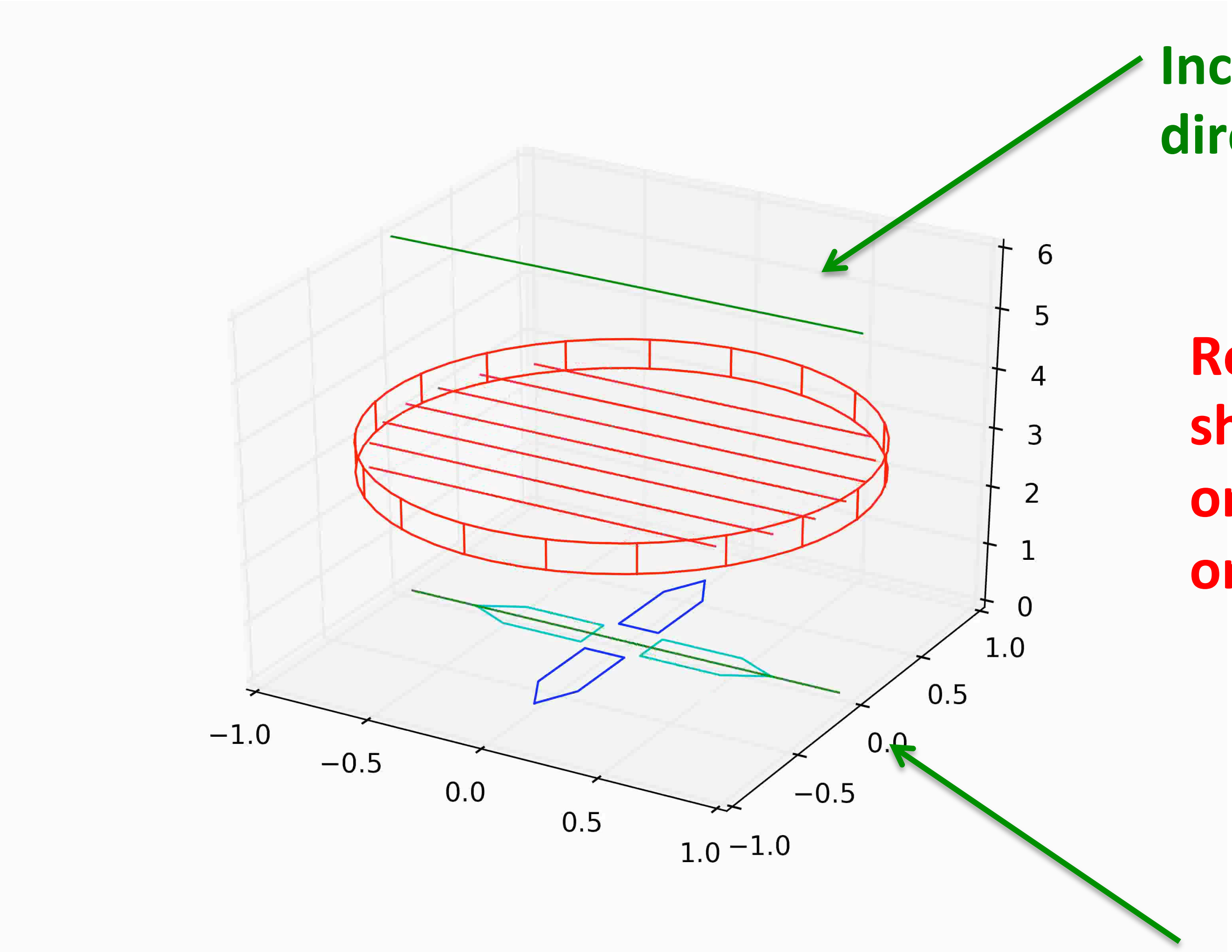
White noise, $C_l \sim l^2$

Atmospheric signal adds low frequency (low ell) noise.

Polarization signal does not follow the white noise. Need better gain modeling...etc.

From Louis et al. 2017

One solution: fast HWP rotation



Incident polarization direction. Fixed

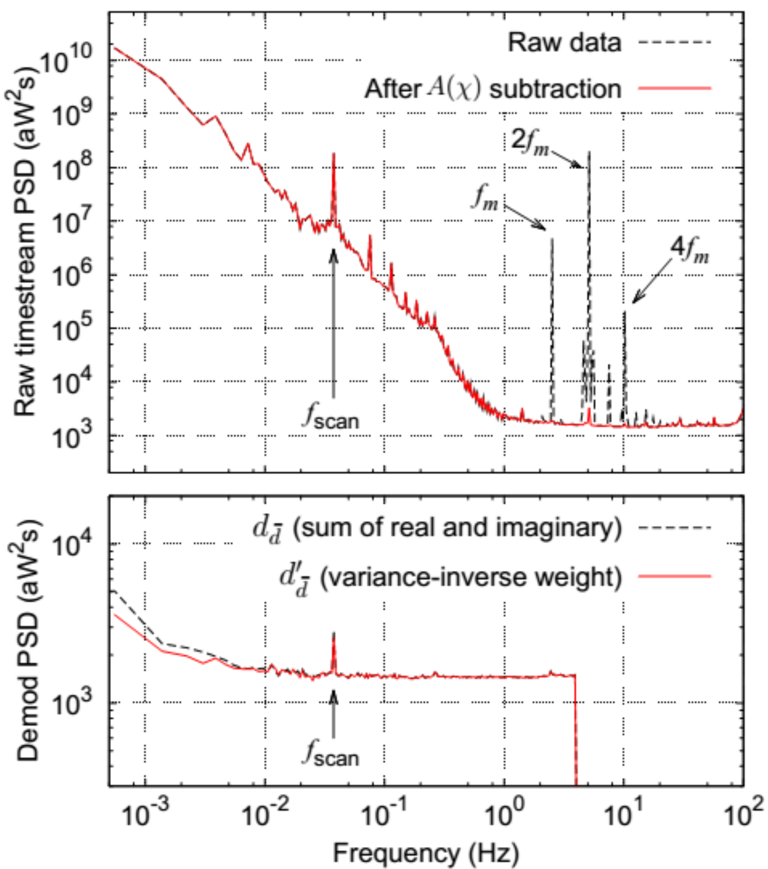
Rotating HWP. Red shows direction of ordinary axis during one rotation.

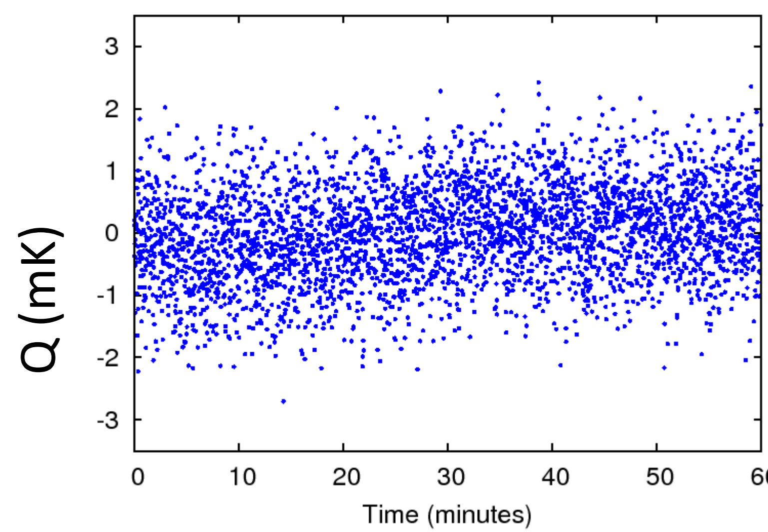
Output polarization direction and polarization sensitive detectors.

Rapid modulation of incident polarization signal.

Demonstrated for CMB by ABS & PBear/SA, used by AdvACT CLASS.

Akito's plot





Data stable on time scales of 500-1000 seconds (1-2 mHz)

Kusaka et al, RSI 85, 024501 (2014)

HWP cont.

- Why not just pair difference?
  A pair cannot be matched well enough so there is residual
- ABS T->P leakage 0.013% [Essinger-Hileman et al. RSI 87:4503, 2016]
- HWP buys immunity to beam systematics because it samples all polarization orientations for one pointing.
- Note: “even” the LiteBIRD satellite baselines a HWP!
- As sensitivity improves, HWP ever more attractive.
- An open question: Can a large aperture telescope measure to low ell?

Ultimate limits

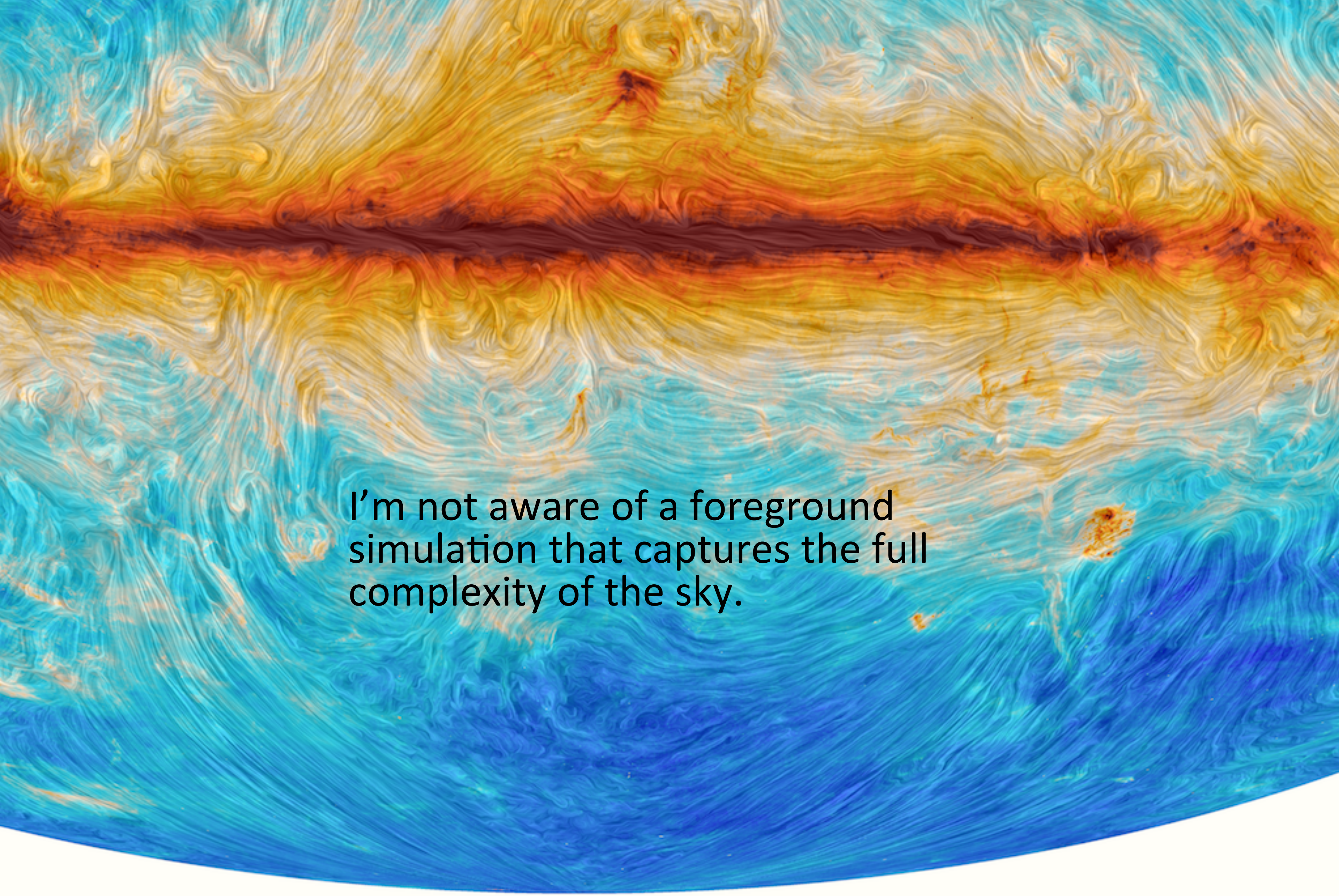
Sensitivity, always important and gains can be made.

For the ground:

Frequency	30 GHz	40 GHz	90 GHz	150 GHz	220 GHz	270 GHz
Achieved (μK $s^{1/2}$)	[320]	[420]good!	250	260	780	1100
"Best" possible	…	120	100-120	170	500	1000

Single detector, single polarization. From J. Gudmundsson & LP

We will ultimately be limited by foreground emission *plus* low-level systematic effects.



I’m not aware of a foreground simulation that captures the full complexity of the sky.

Planck’s 353 GHz dust map

Coverage

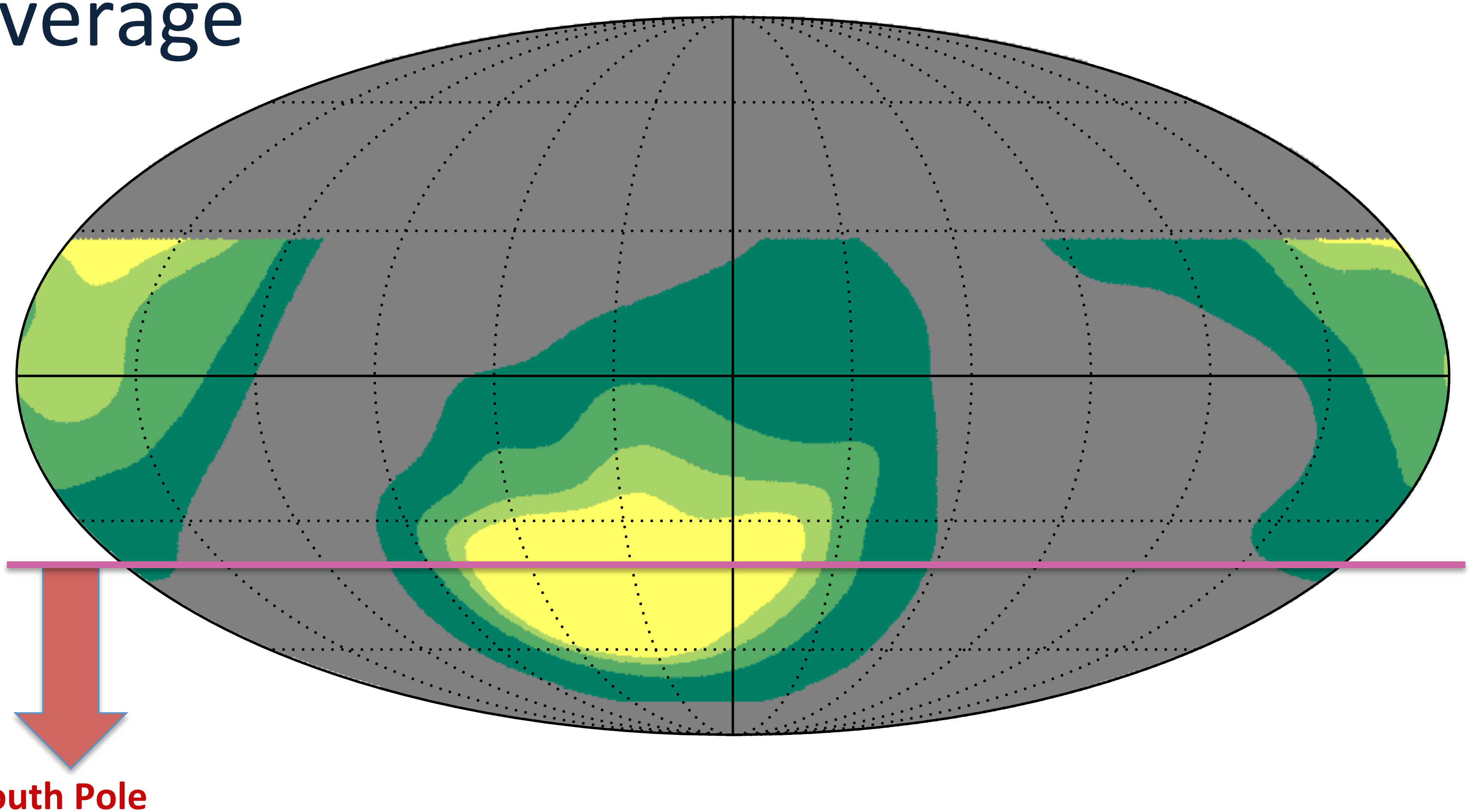


FIG. 3: Sky masks used in the analysis, corresponding to the cleanest 2000, 4000, 8000 and 16000 deg^2 of the sky accessible from Chile in terms of foreground contamination.

Accessible from Chile

David Alonso, Oxford

Coverage

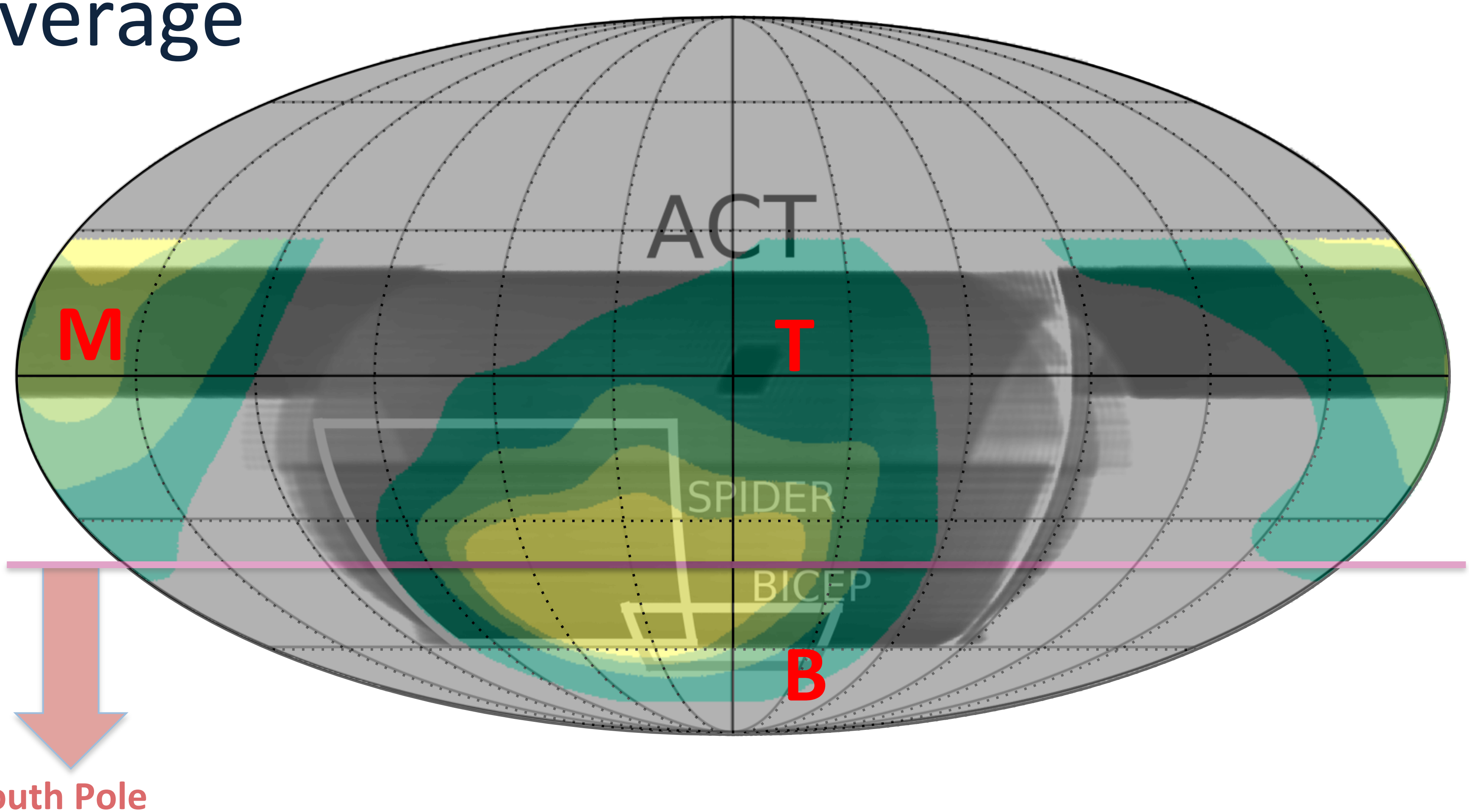
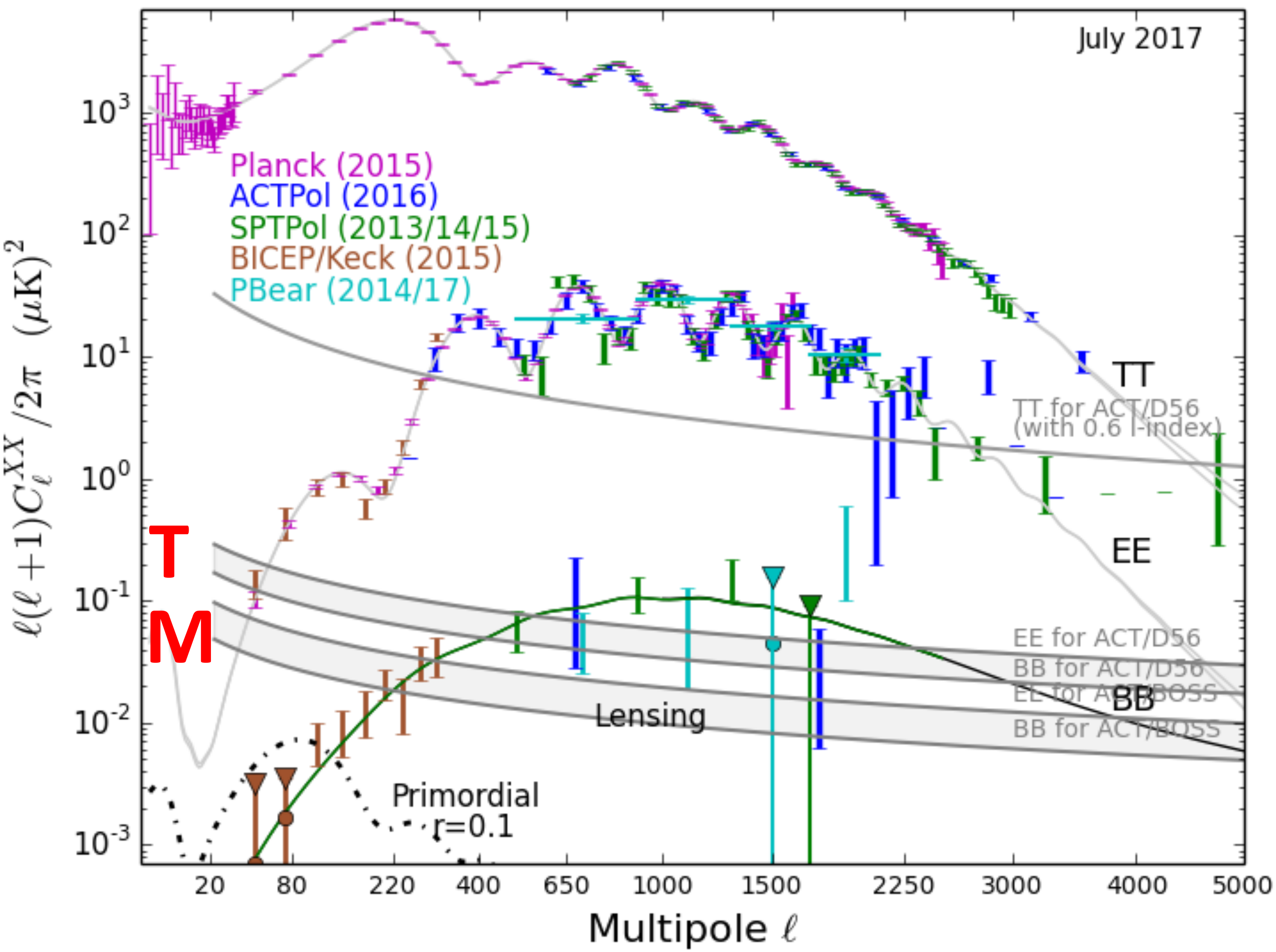


FIG. 3: Sky masks used in the analysis, corresponding to the cleanest 2000, 4000, 8000 and 16000 $\deg^2$ of the sky accessible from Chile in terms of foreground contamination.

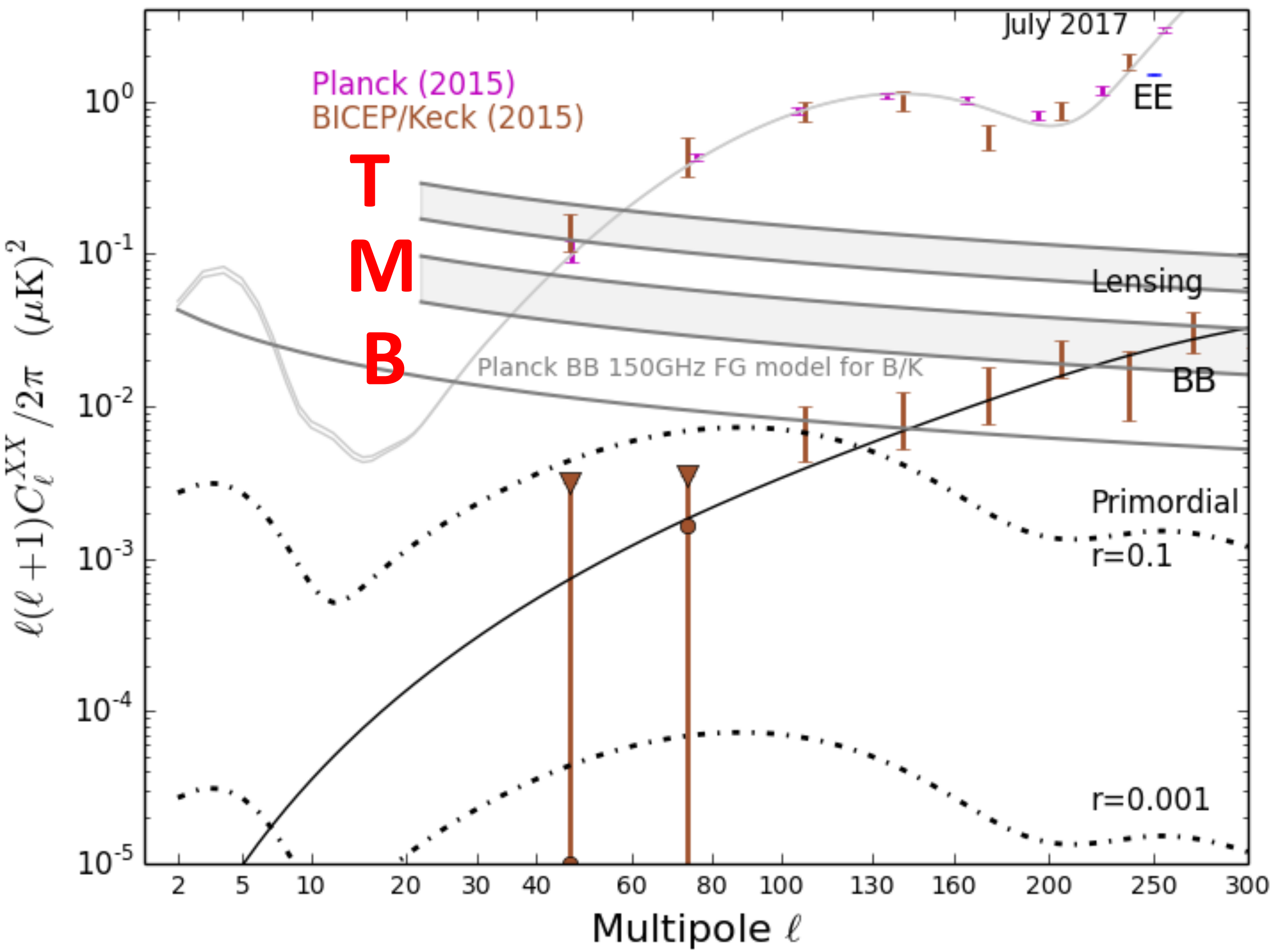
David Alonso, Oxford

At 150 GHz



July 2017
Planck (2015)
ACTPol (2016)
SPTPol (2013/14/15)
BICEP/Keck (2015)
PBear (2014/17)
TT
TT for ACT/D56
(with 0.6 l-index)
EE
EE for ACT/D56
BB for ACT/D56
EE for ACT/BOSS
BB
BB for ACT/BOSS
Lensing
Primordial
r=0.1
T
M
$\ell(\ell+1)C_\ell^{XX}/2\pi \quad (\mu K)^2$
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
20
80
220
400
650
1000
1500
2250
3000
4000
5000
Multipole ℓ

At 150 GHz



July 2017
Planck (2015)
BICEP/Keck (2015)
EE
T
M
B
Lensing
Planck BB 150GHz FG model for B/K
BB
Primordial
r=0.1
r=0.001
$\ell(\ell+1)C_\ell^{XX}/2\pi \quad (\mu K)^2$
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
2 5 10 20 30 40 60 80 100 130 160 200 250 300
Multipole ℓ

For a convincing detection of primordial B-modes I think you will want:

1) Independent detections with independent instruments (e.g., ATLAS and CMS) at the ~5-sigma level.
2) Measurements in multiple regions of sky.
3) An unambiguous frequency spectrum.

Large aperture telescopes will be helpful for foreground cleaning at <90 GHz. To achieve ½ degree resolution at 30 GHz requires a 1.5 meter aperture.