Simons Array

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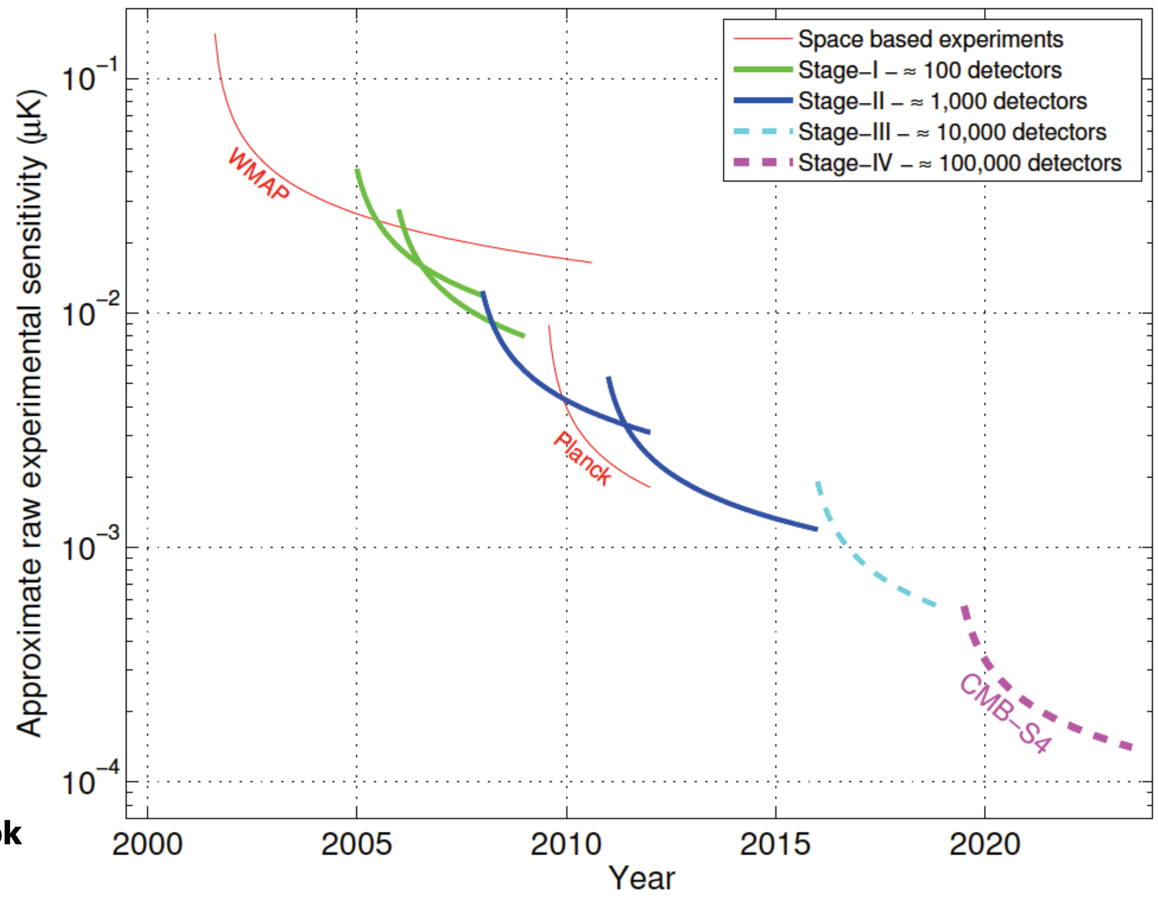
University of California, Berkeley

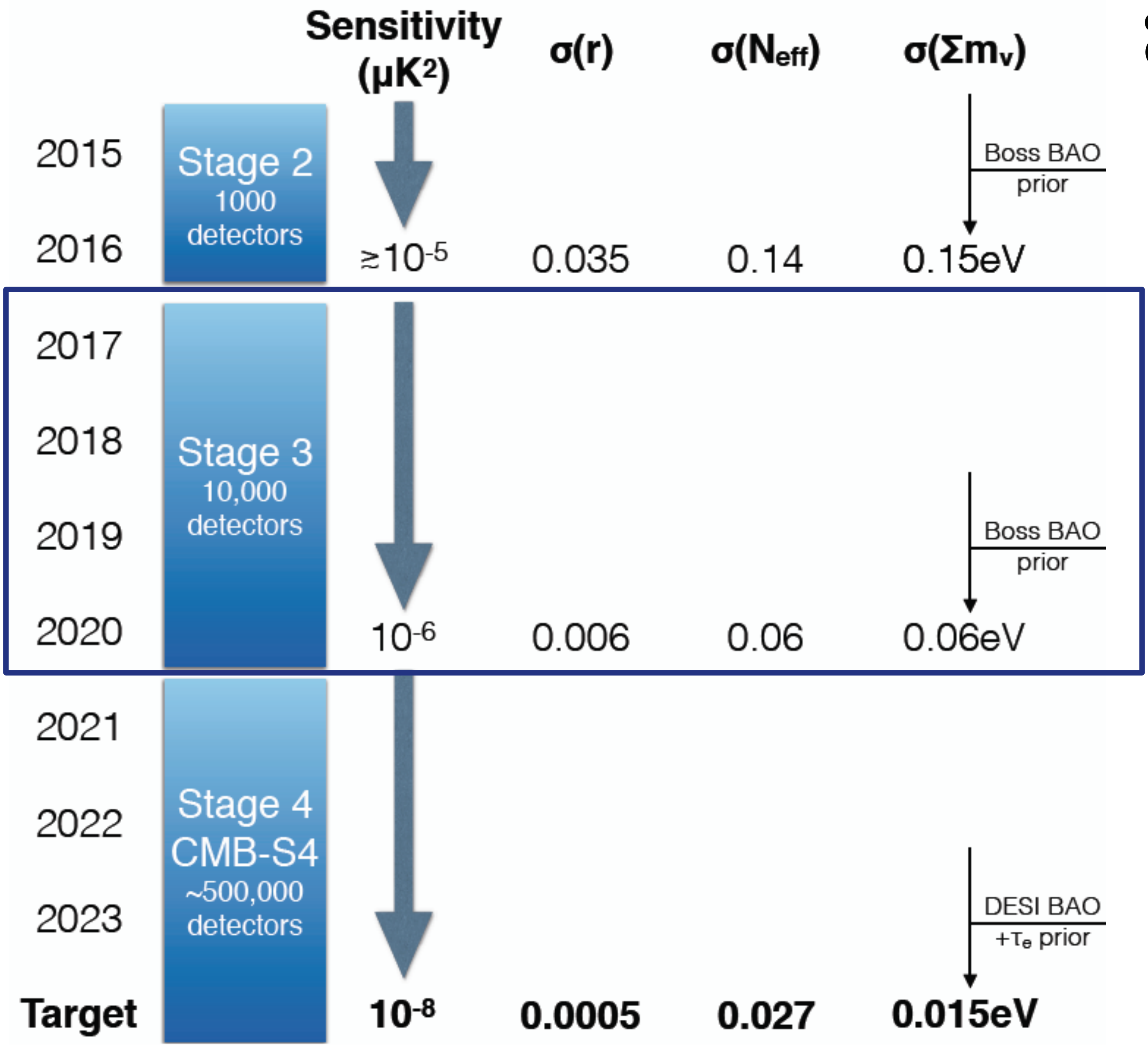
Kavli IPMU

11:10-11:40; 8th March

Simons Array is a "Stage 3" CMB experiment



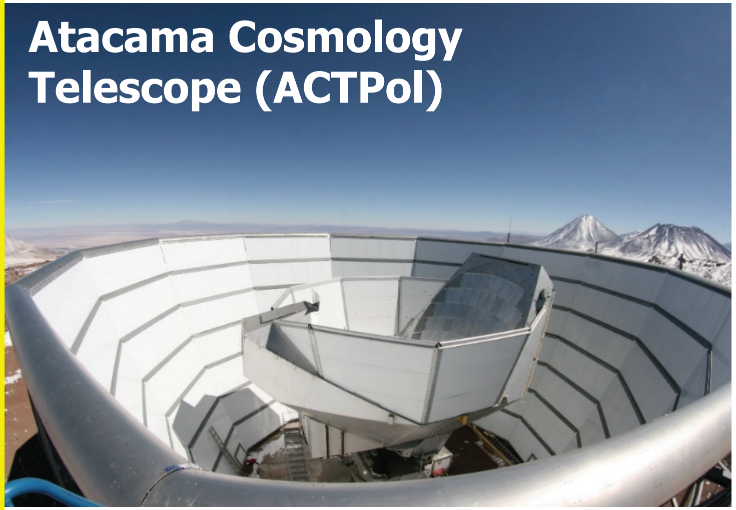
CMB-S4 Science Book (arXiv:1610.02743)

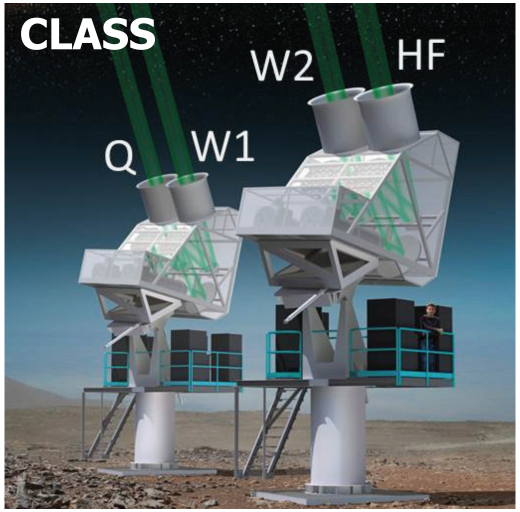


CMB-S4 Science Book
(arXiv:1610.02743)

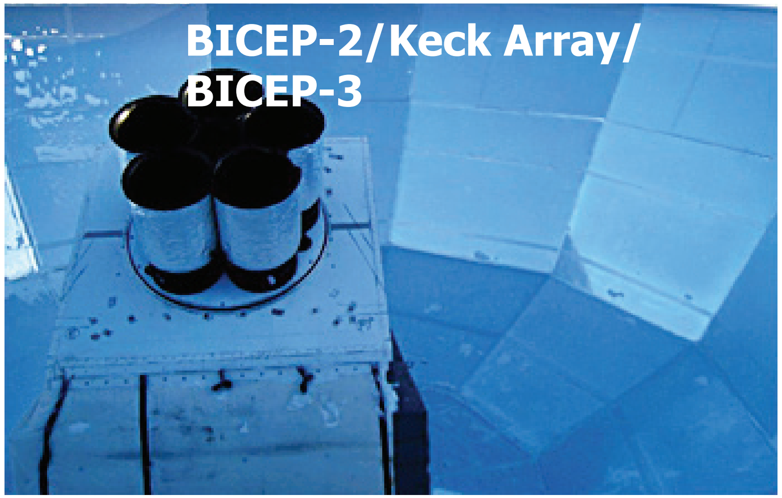
Stage 2 = Current Ground-Based Experiments

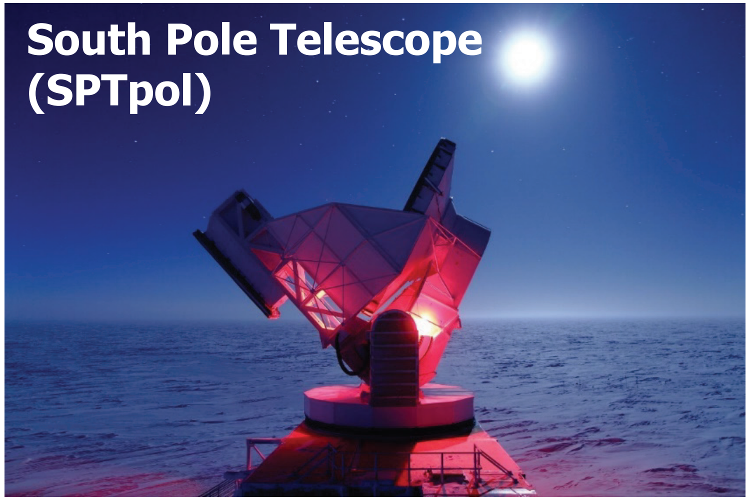
Chile, Atacama





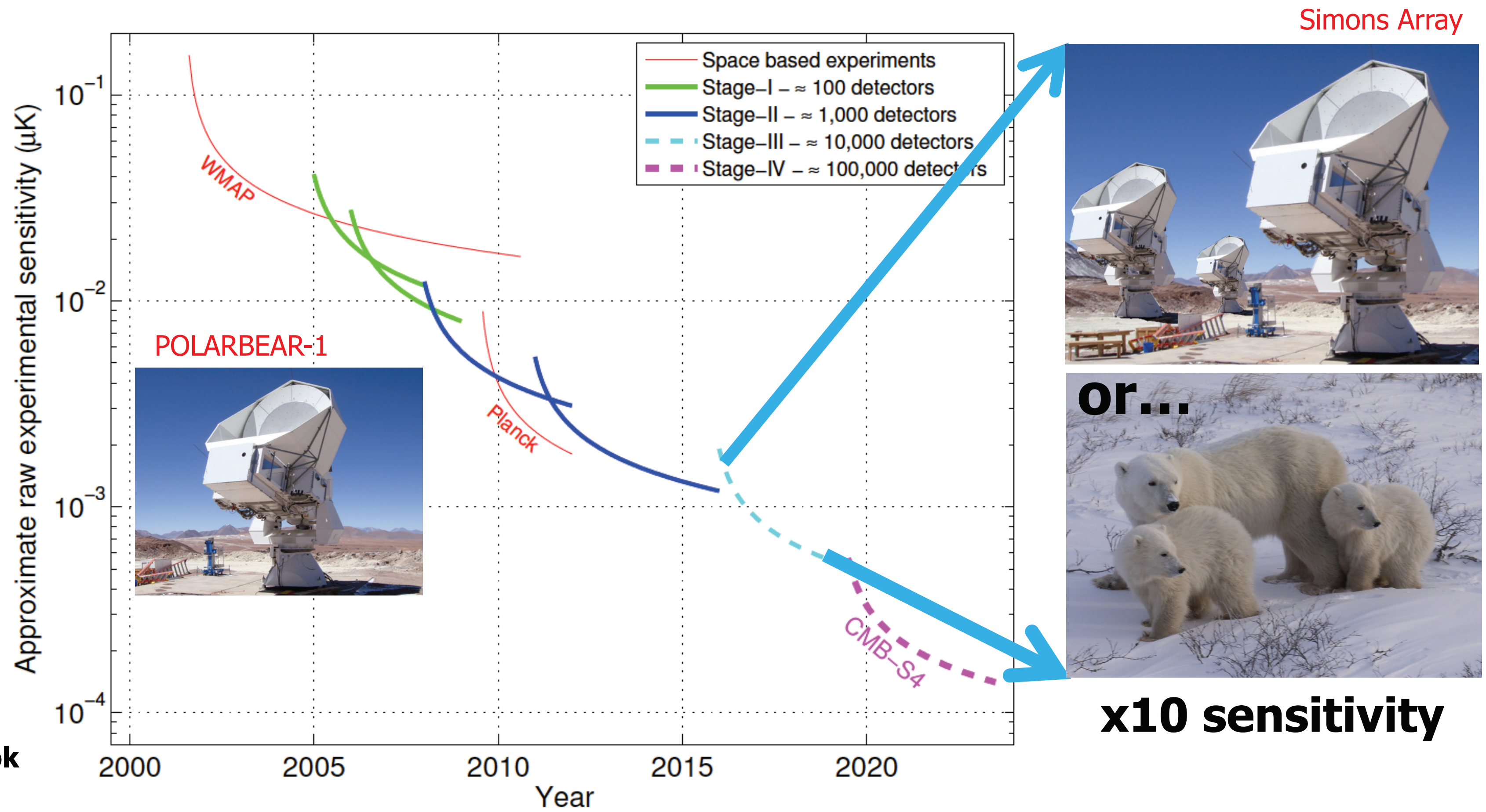
South Pole





Simons Array is a "Stage 3" CMB experiment

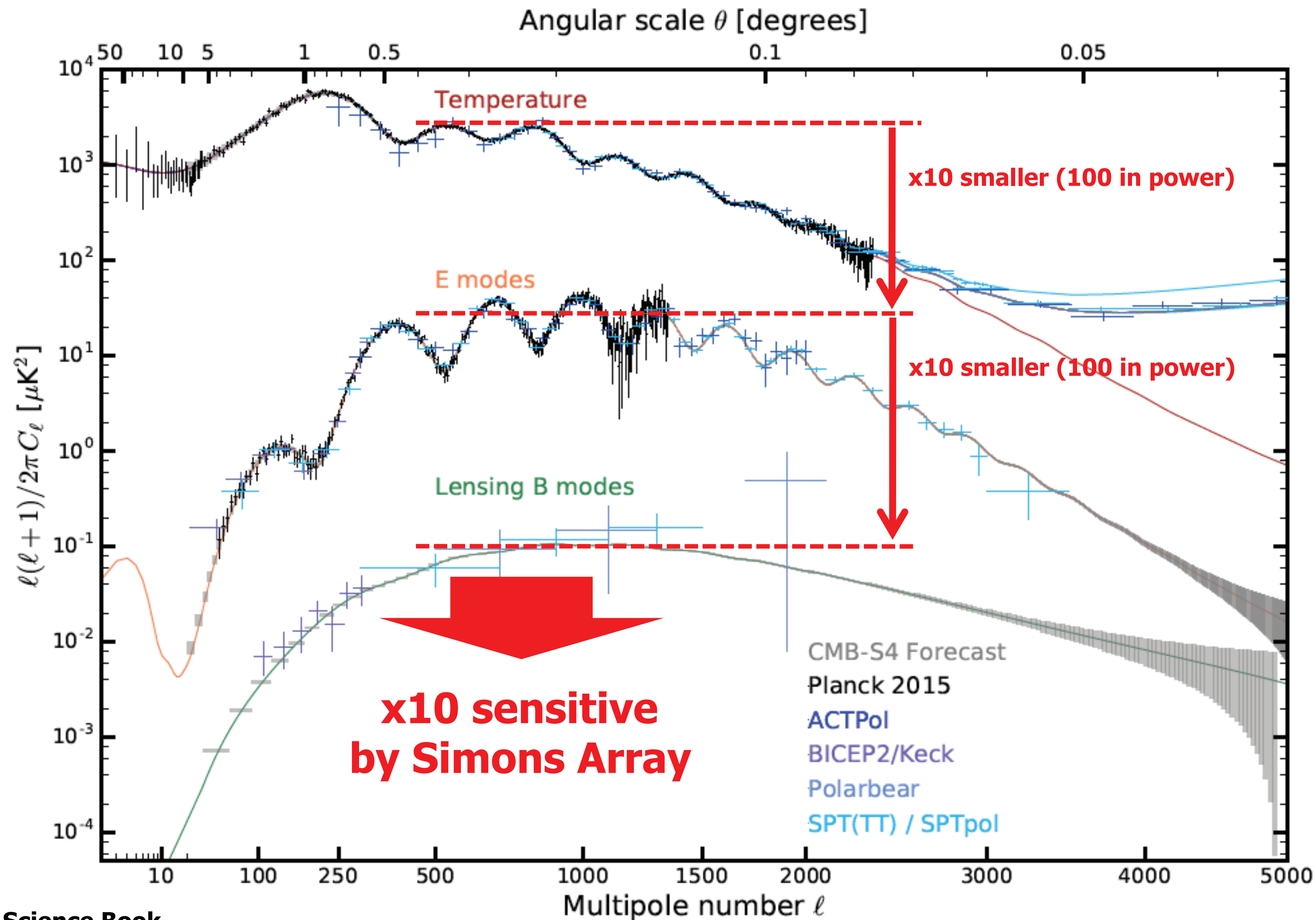
upgraded from POLARBEAR



x10 sensitivity

CMB-S4 Science Book (arXiv:1610.02743)

CMB Power Spectrum & Sensitivity Today



CMB-S4 Science Book
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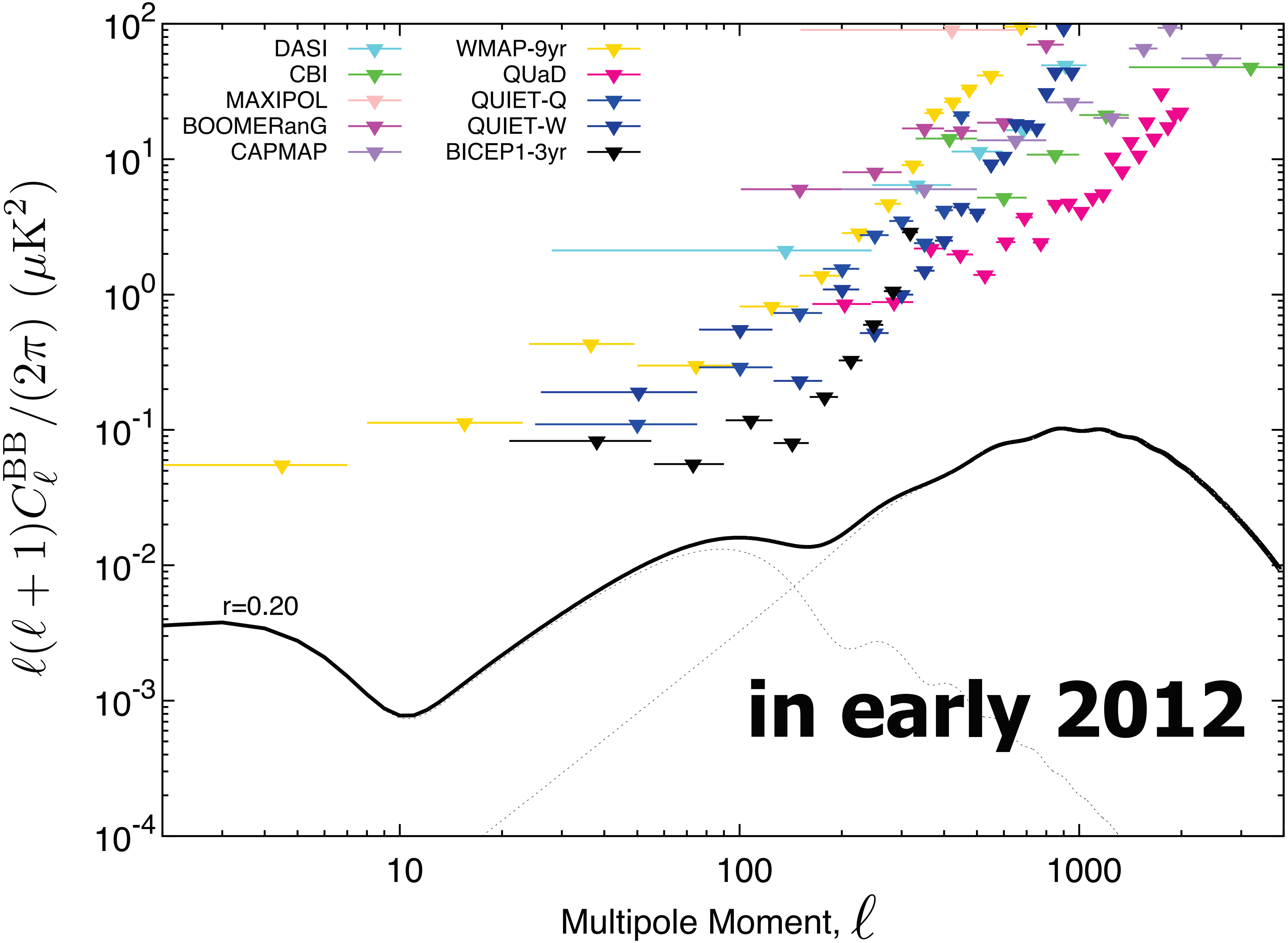
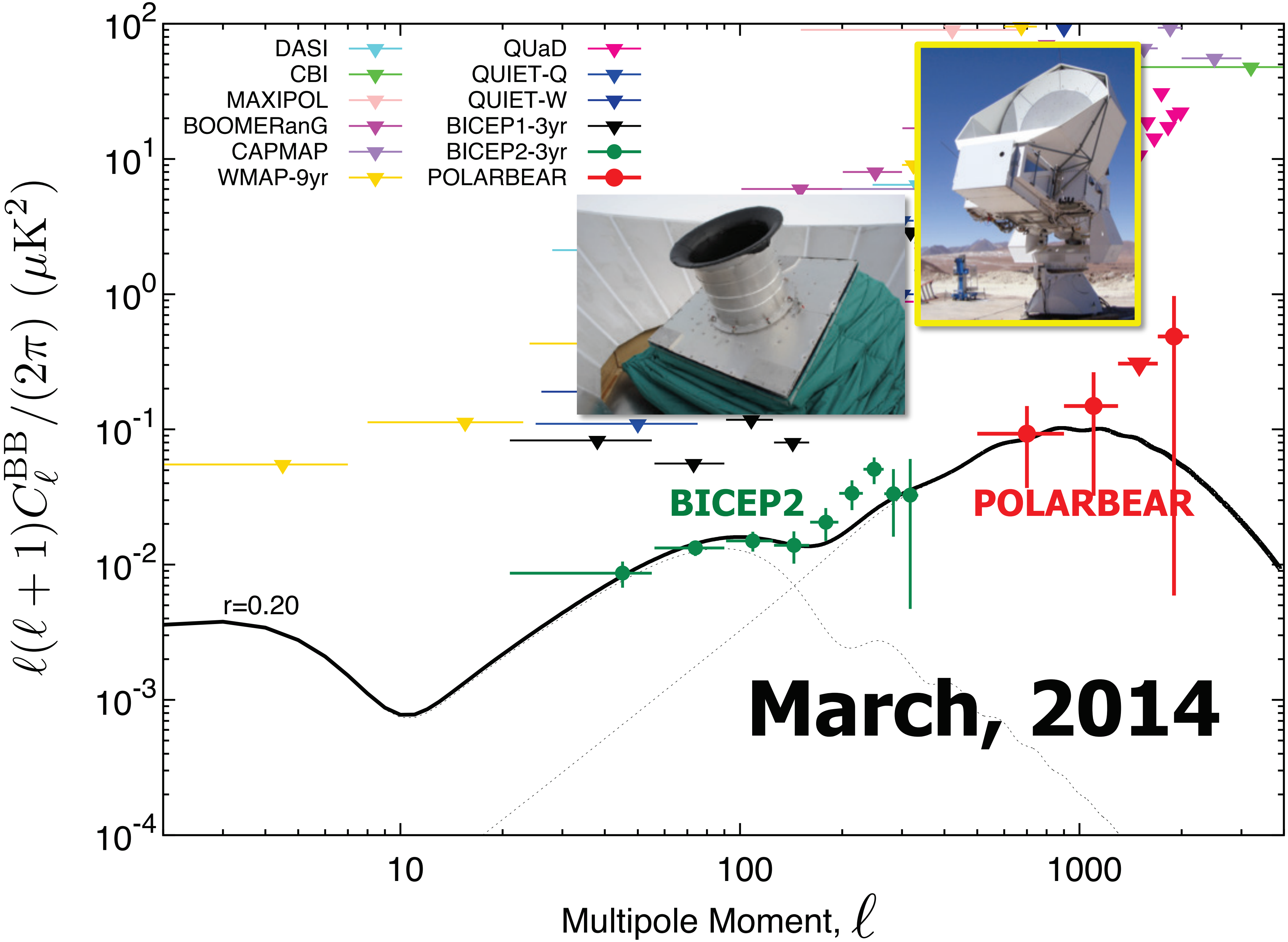
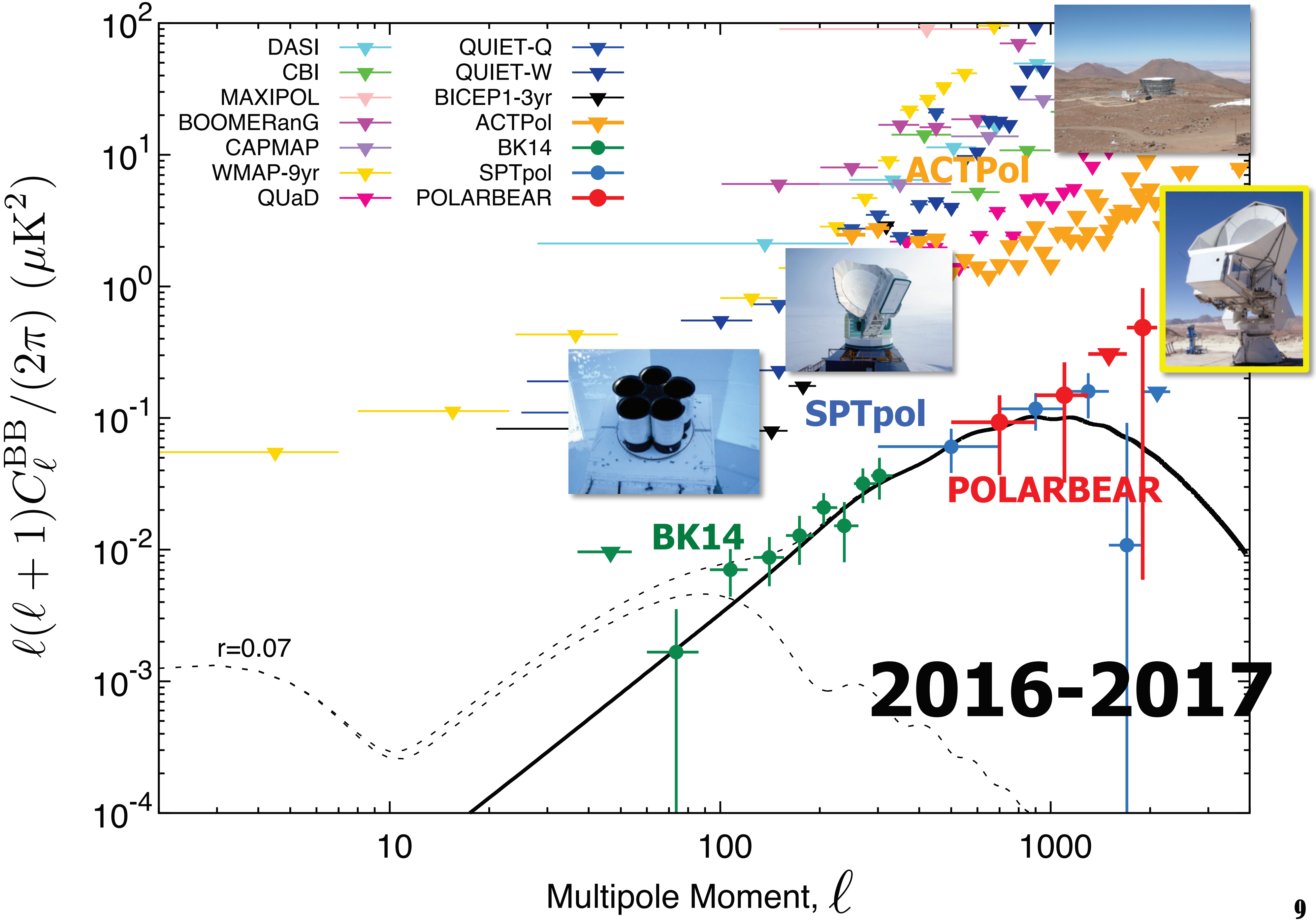
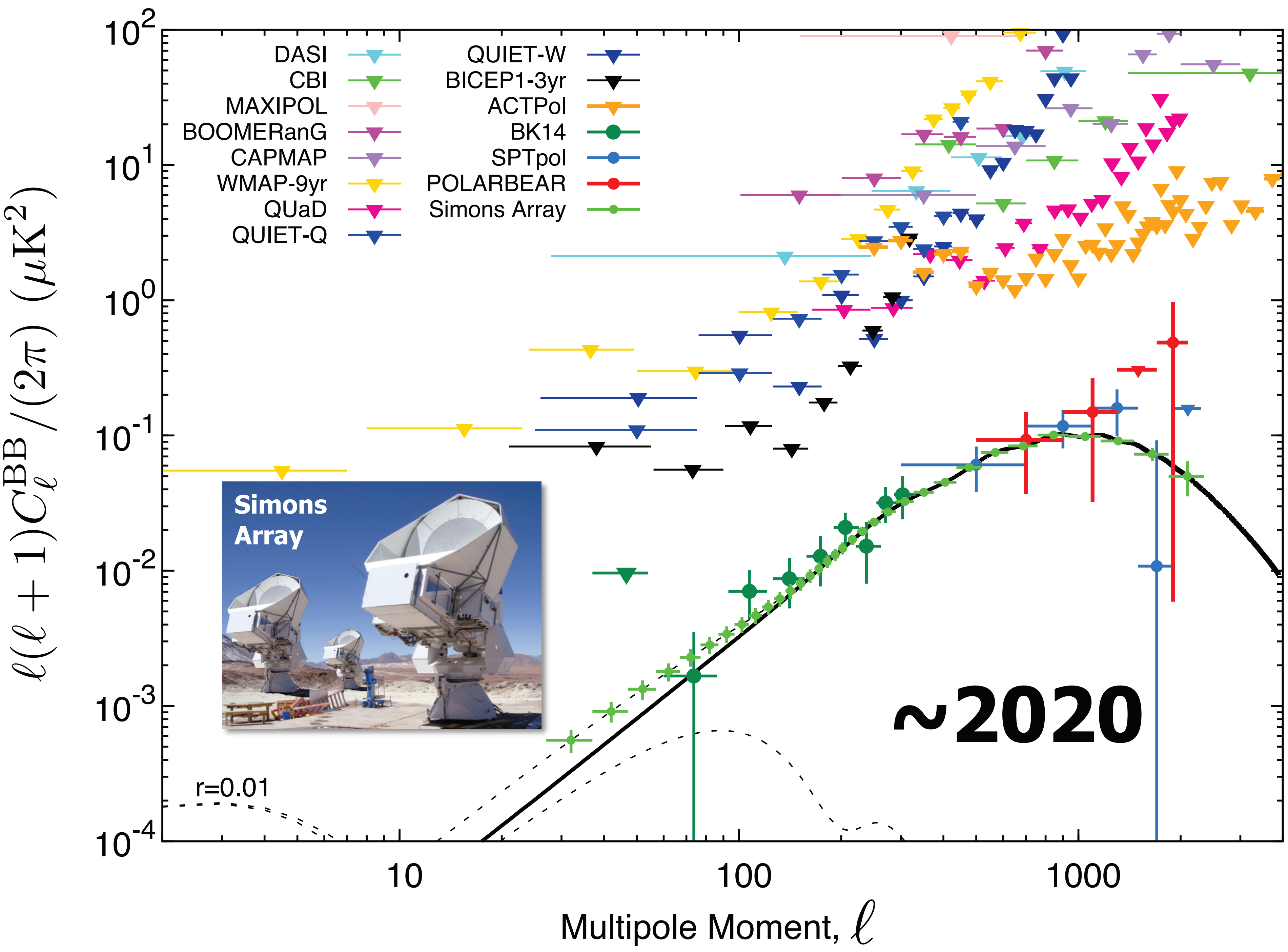


DASI
CBI
MAXIPOL
BOOMERanG
CAPMAP
WMAP-9yr
QUaD
QUIET-Q
QUIET-W
BICEP1-3yr
r=0.20
in early 2012
$\ell(\ell+1)C_\ell^{\mathrm{BB}}/(2\pi)$ $(\mu\mathrm{K}^2)$
Multipole Moment, ℓ
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10
100
1000



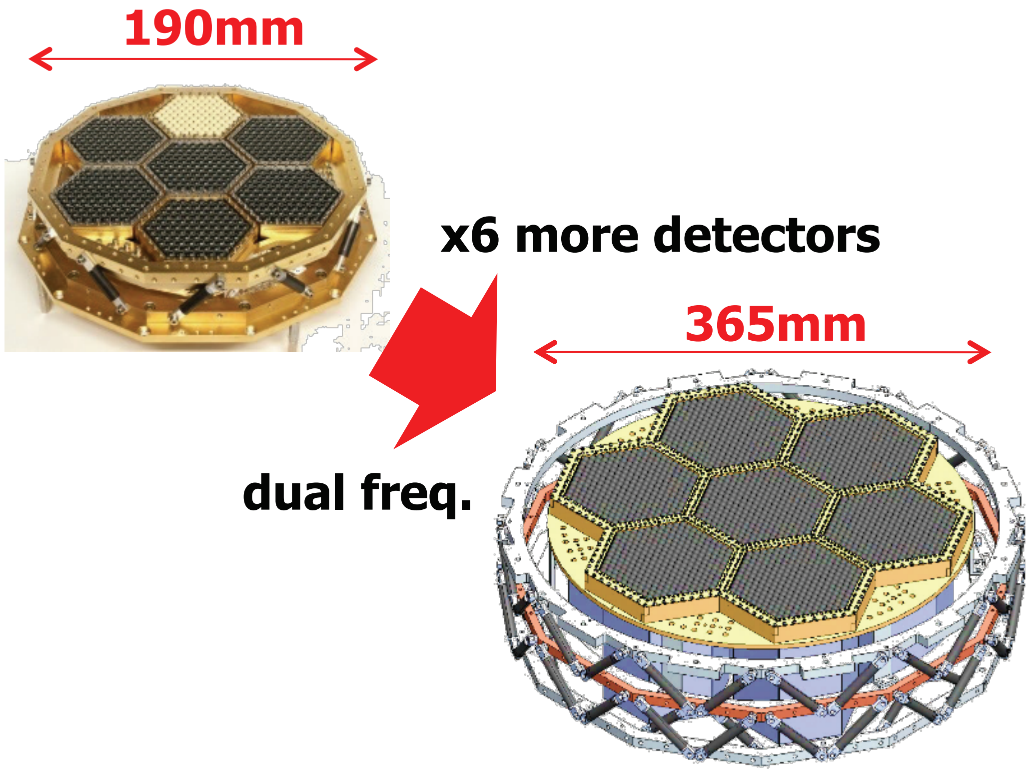
DASI
CBI
MAXIPOL
BOOMERanG
CAPMAP
WMAP-9yr
QUaD
QUIET-Q
QUIET-W
BICEP1-3yr
BICEP2-3yr
POLARBEAR
BICEP2
POLARBEAR
r=0.20
March, 2014
$\ell(\ell+1)C_\ell^{BB}/(2\pi)$ (μK^2)
Multipole Moment, ℓ

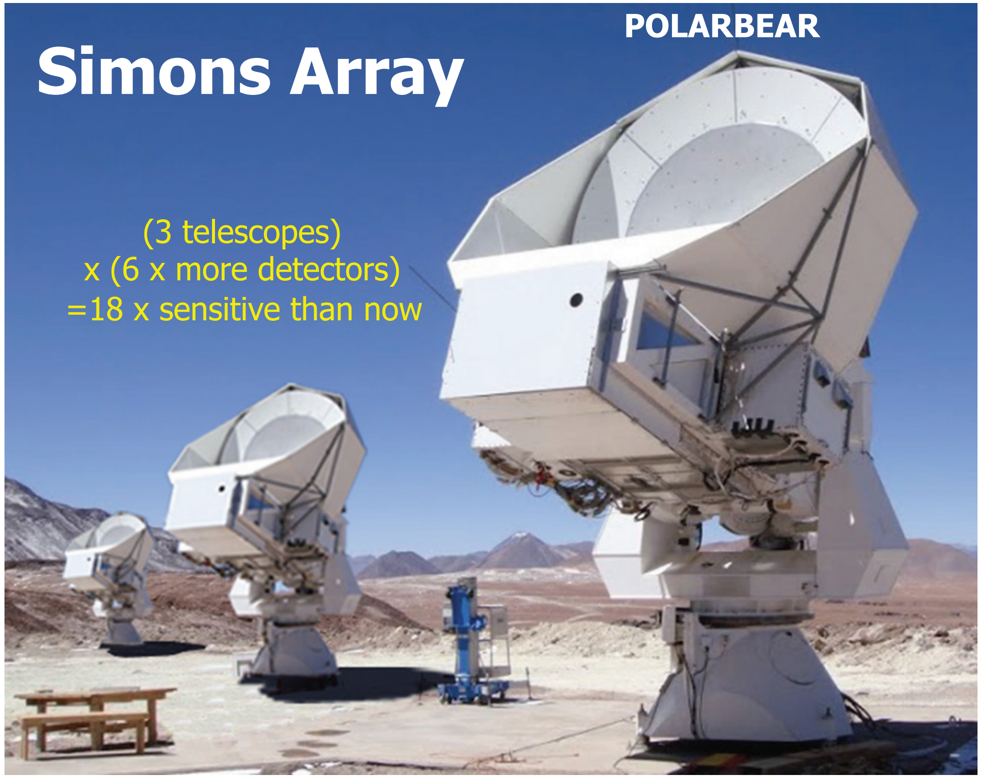

DASI
CBI
MAXIPOL
BOOMERanG
CAPMAP
WMAP-9yr
QUaD
QUIET-Q
QUIET-W
BICEP1-3yr
ACTPol
BK14
SPTpol
POLARBEAR
ACTPol
SPTpol
POLARBEAR
BK14
r=0.07
2016-2017
$\ell(\ell+1)C_\ell^{BB}/(2\pi)$ (μK^2)
Multipole Moment, ℓ


DASI
CBI
MAXIPOL
BOOMERanG
CAPMAP
WMAP-9yr
QUaD
QUIET-Q
QUIET-W
BICEP1-3yr
ACTPol
BK14
SPTpol
POLARBEAR
Simons Array
Simons Array
~2020
r=0.01
$\ell(\ell+1)C_\ell^{\mathrm{BB}}/(2\pi)\ (\mu\mathrm{K}^2)$
Multipole Moment, ℓ

Simons Array

Simons Arrays

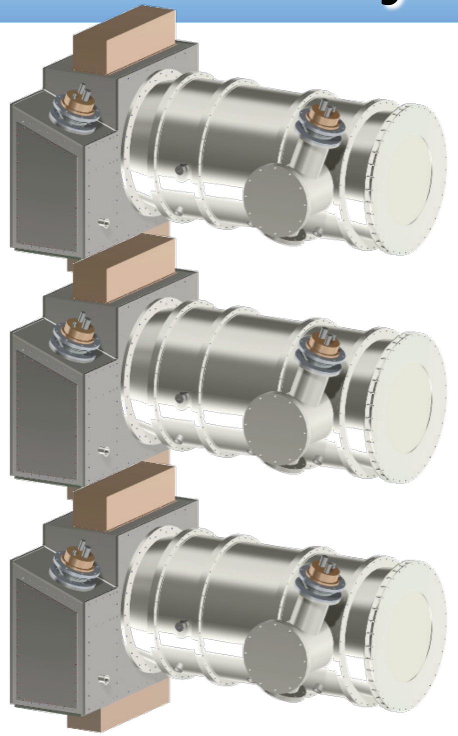




- 7,588 bolometers per receiver, factor of **6** increase from current receiver
- **Three telescopes** (two new telescopes + one current one)
- **→ (3 telescopes) x (6 x more detectors) = 18 x sensitive than now**

Simons Arrays

@KEK



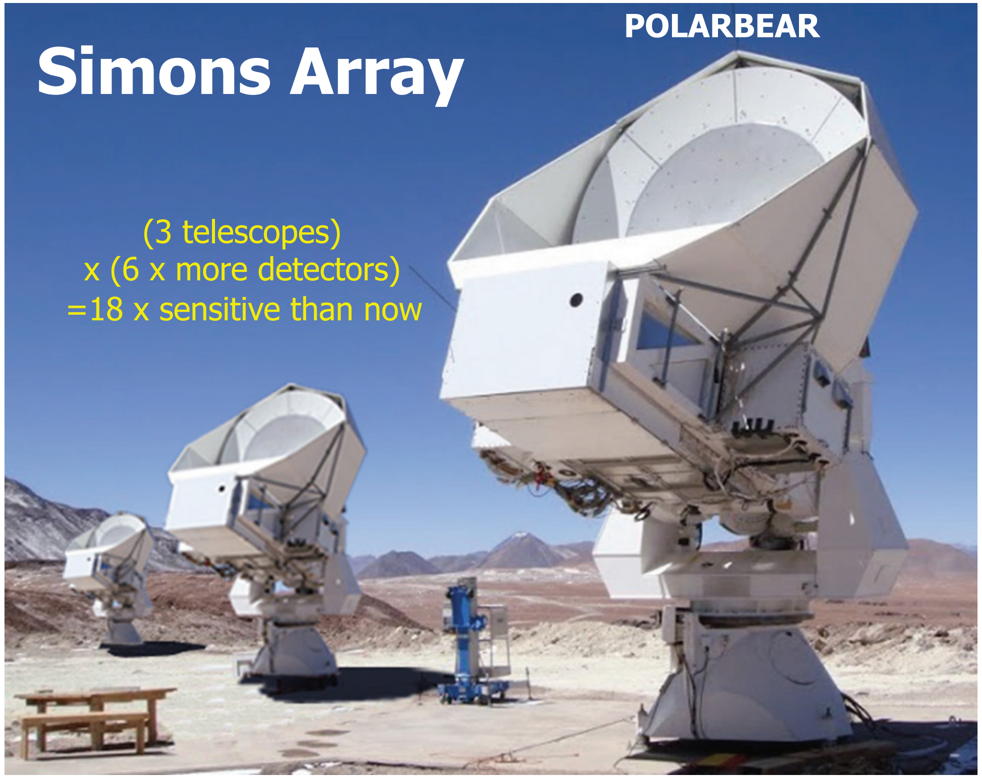
POLARBEAR-2A
95/150 GHz

POLARBEAR-2B
95/150 GHz

@UCB
& UCSD

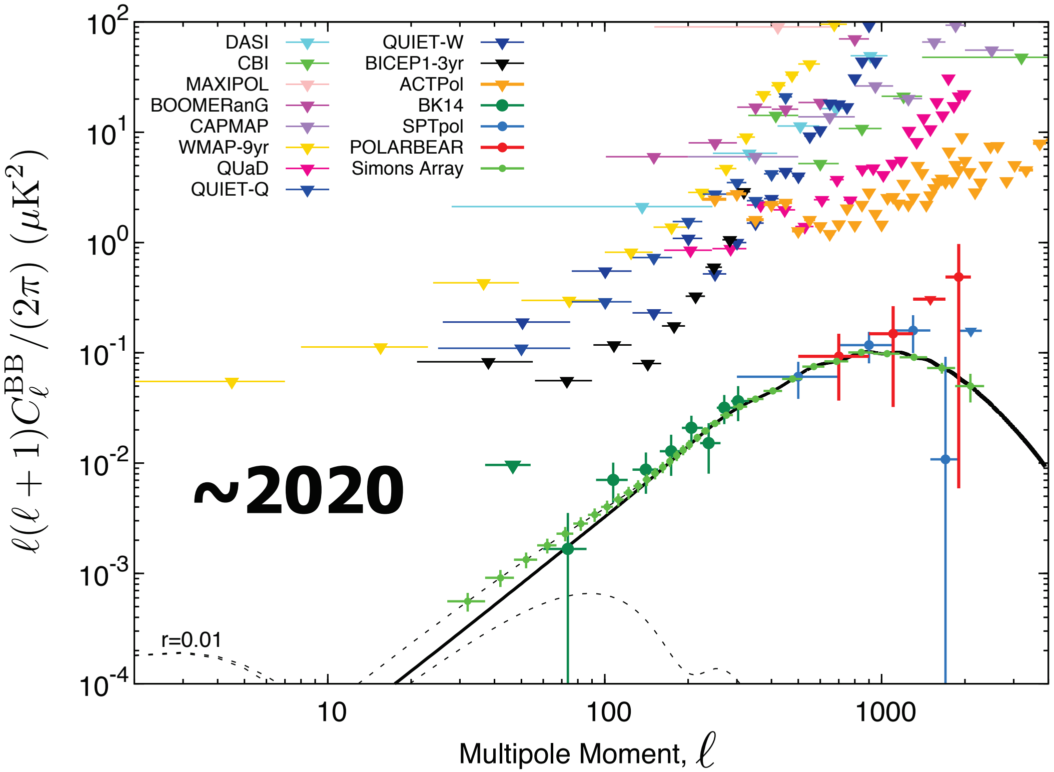
POLARBEAR-2C
220/270 GHz

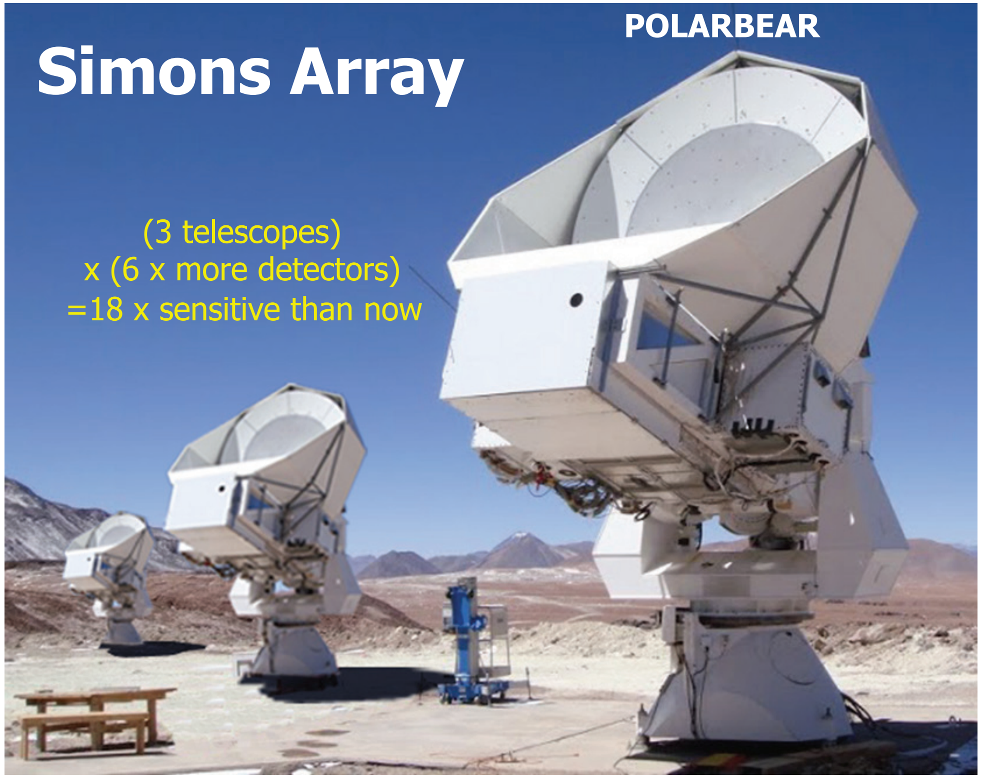
POLARBEAR-2 Receiver Frequency Plan



- 7,588 bolometers per receiver, factor of **6** increase from current receiver
- **Three telescopes** (two new telescopes + one current one)
- **→ (3 telescopes) x (6 x more detectors) = 18 x sensitive than now**
- Expand frequency coverage for foreground removal (**95/150/220/270 GHz**)
- Deploy first receiver (PB2A) in **2017** (this summer!!!)
- Deploy two more receivers (PB2B, PB2C) in **2018**

Simons Arrays



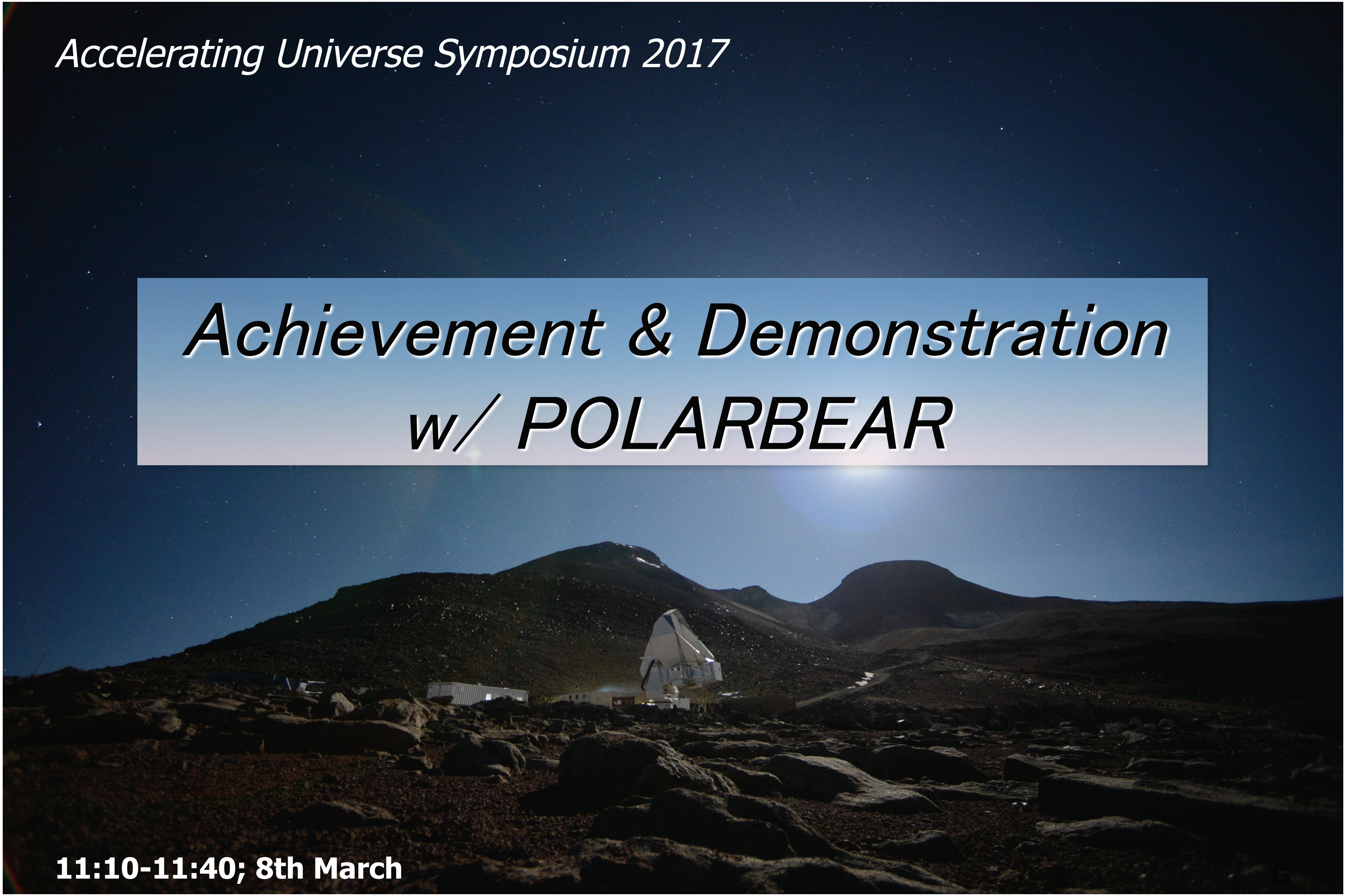


- **Inflation: σ(r=0.1) = 6×10^{-3} (4×10^{-3} stat.)**
- **Neutrino mass: σ(Σmν) = 40 meV (19 meV stat.)** **w/ BAO from DESI**
- **Light relic: σ(N_{eff}) = 0.04**

Demonstration of telescope, detectors, & analysis w/ on-going experiment is necessary

Accelerating Universe Symposium 2017

Achievement & Demonstration w/ POLARBEAR



11:10-11:40; 8th March

POLARBEAR/Simons Array Collaboration

many contributions from JAPAN!

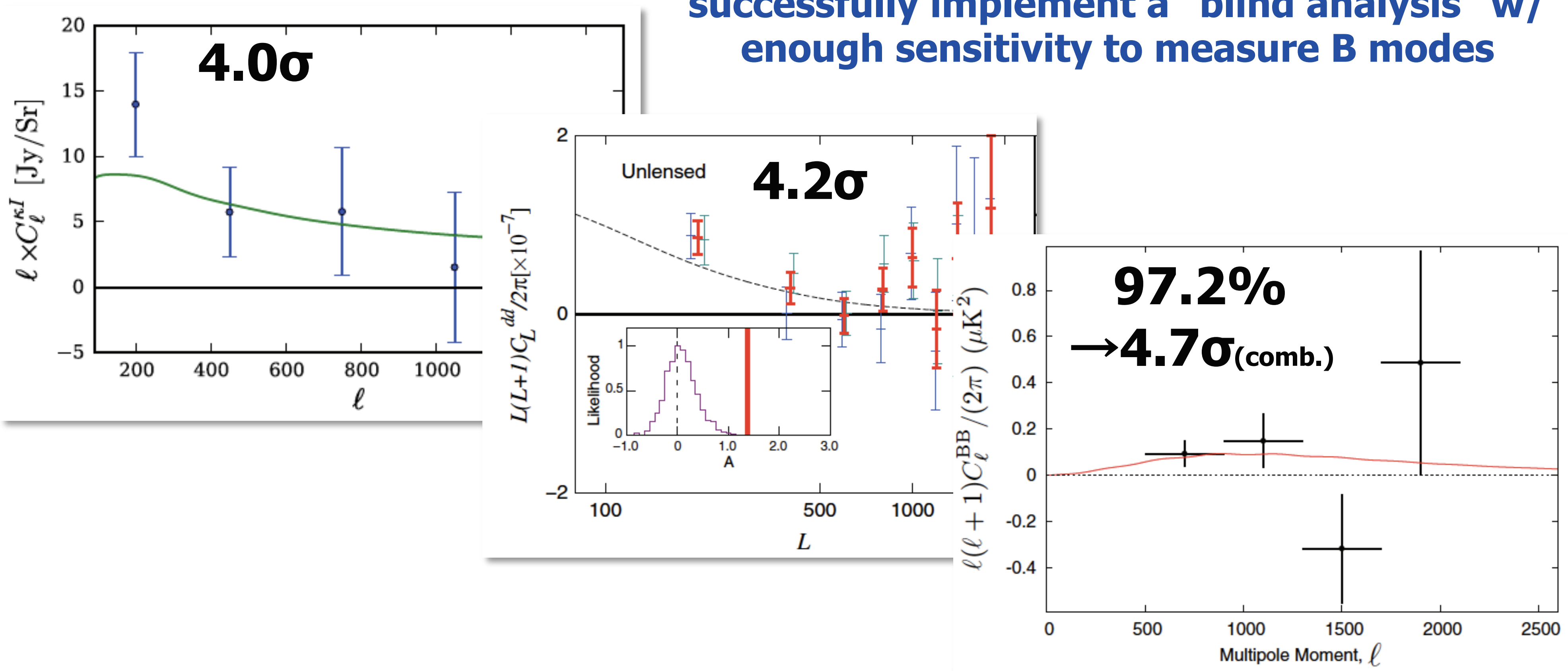
97 collaborators, 8 countries, 20 institutions

POLARBEAR since 2012 (deployed in 2011)

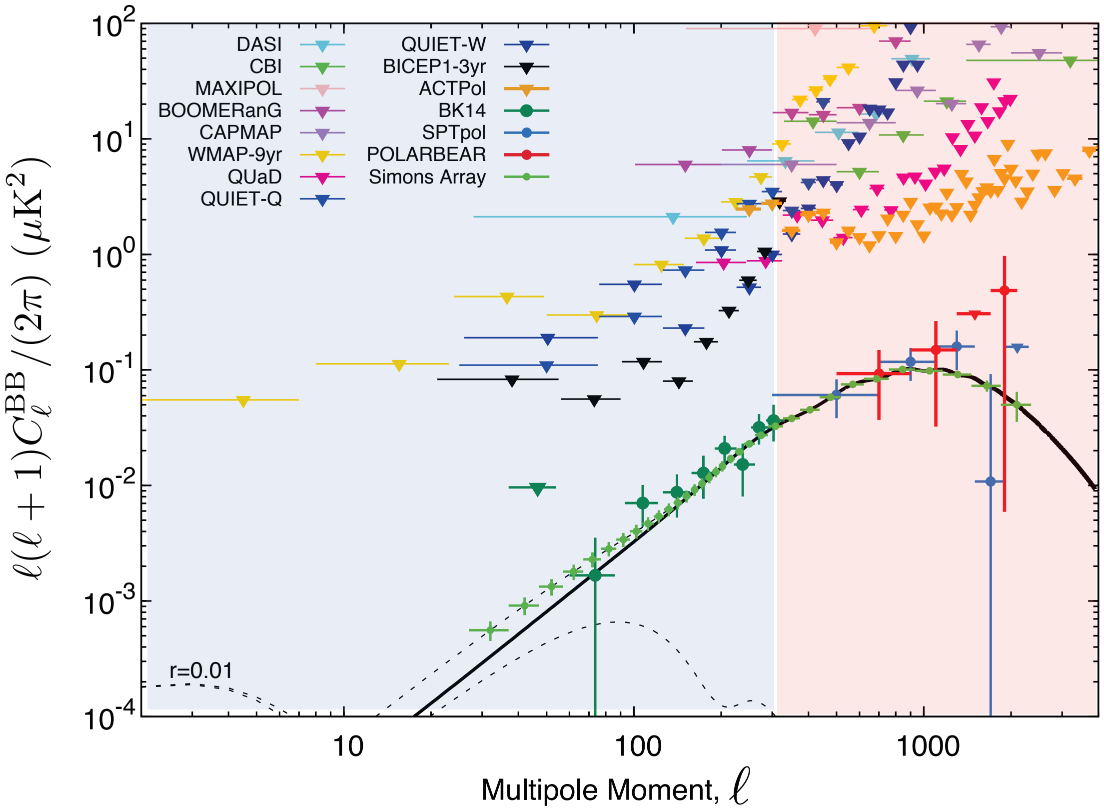
Science Results

- **23rd Dec, 2013: Detection of lensing by POLARBEAR x CIB**
- **23rd Dec, 2013: Detection of lensing by POLARBEAR w/ 4pt**
- **10th Mar, 2014: Measurement of lensing B modes by POLARBEAR w/ 2pt**
- 9th Sep, 2015: Constraint on Cosmic birefringence & Primordial magnetic field by **POLARBEAR**

POLARBEAR is the first experiment to successfully implement a "blind analysis" w/ enough sensitivity to measure B modes



Success & Concern



- POLARBEAR successfully measured B modes @ high ell (small angular scales)
- How about low ell (large angular scales) for inflationary B modes?
  - Actually satellite or only small telescope have measured large angular scales
- Must demonstrate a large telescope can also measure large angular scales ⇨ demonstration of "1/f noise" mitigation by POLARBEAR!

Accelerating Universe Symposium 2017

Demonstration of 1/f Noise Mitigation w/ POLARBEAR

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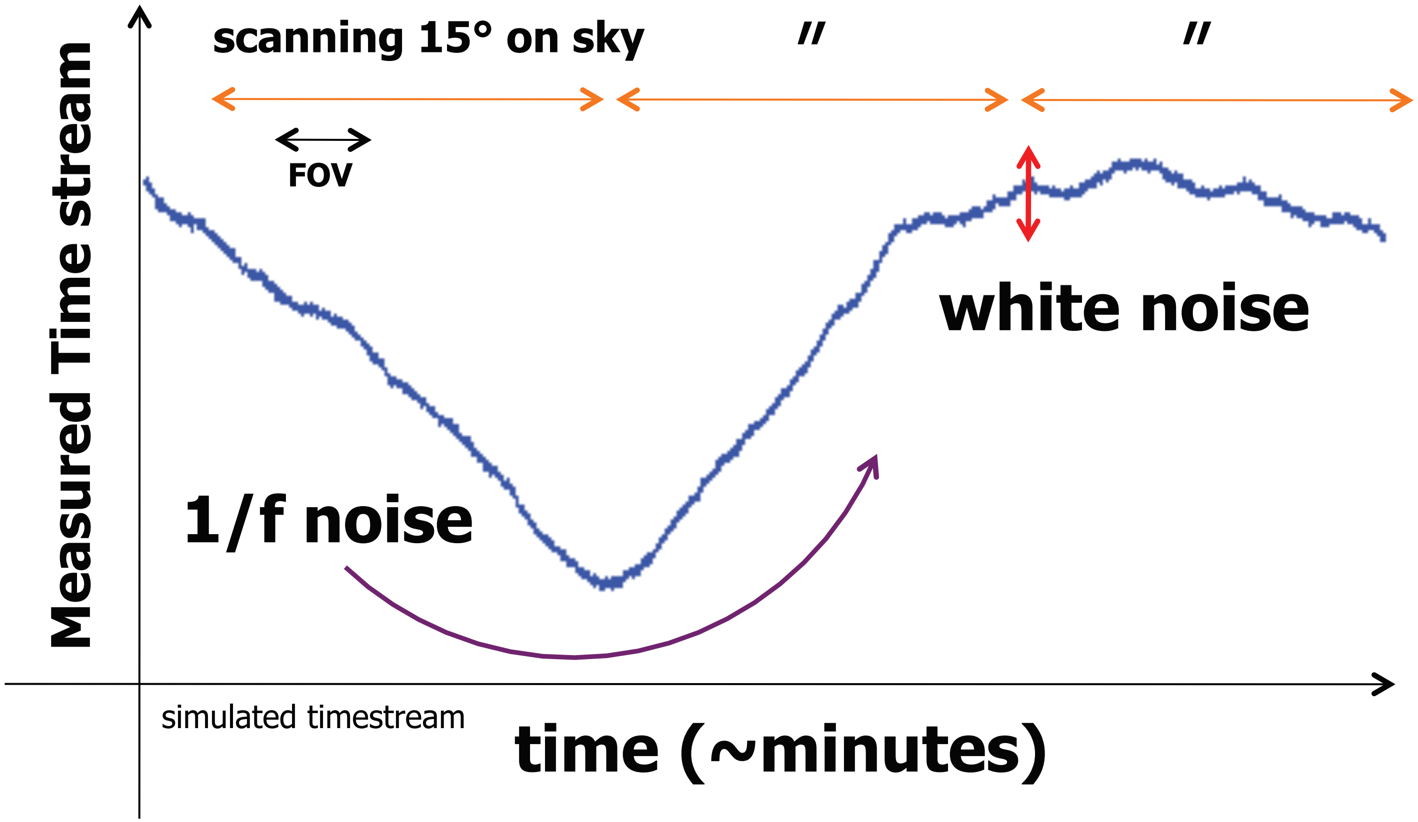
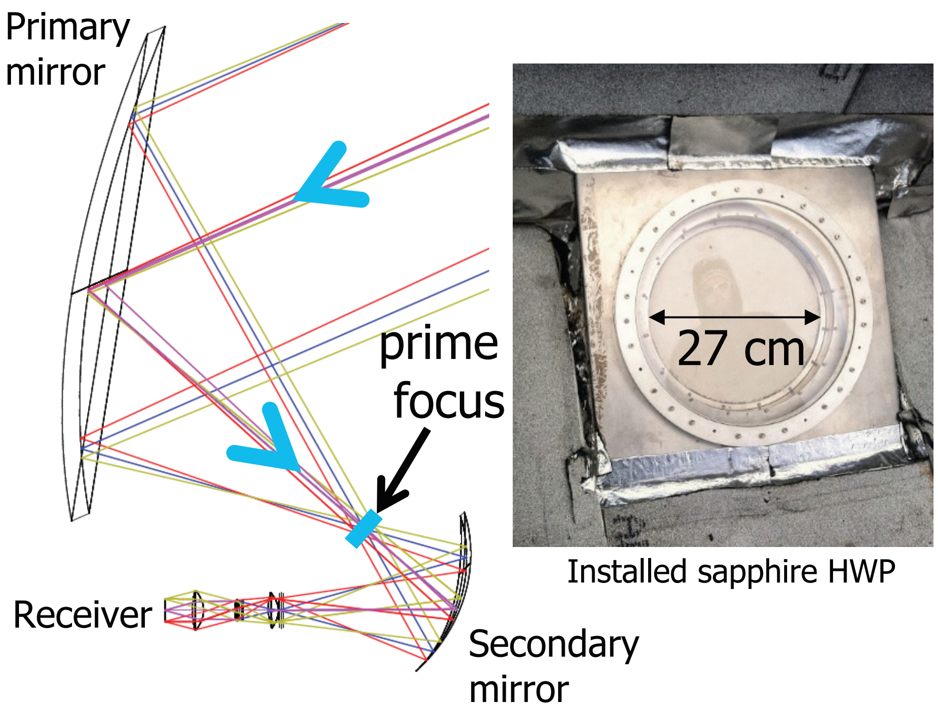
Atmospheric 1/f Noise



- Measured data @ large angular scales are dominated by atmospheric 1/f noise, which is not suppressed by averaging
- Make it difficult to measure inflationary B modes

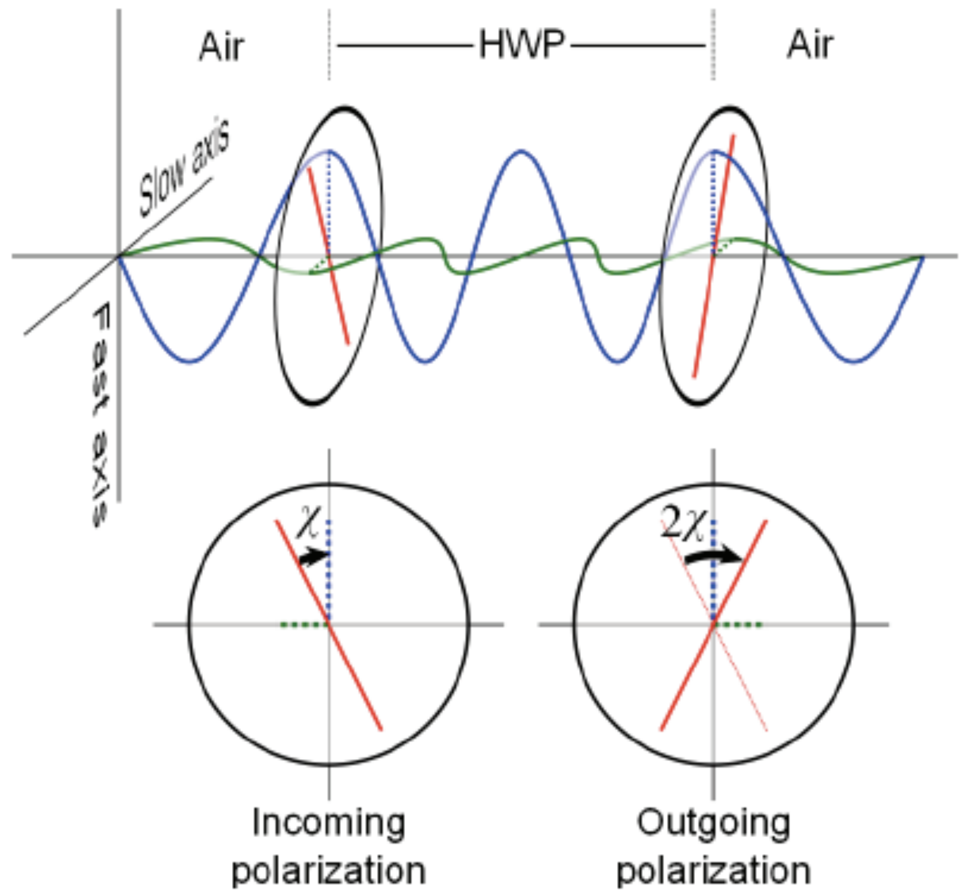
Modulation by Continuously Rotating Half-wave Plate

HWP is optical element made of a birefringent material whose thickness is set to make the path difference between birefringent axes half of a wave length.



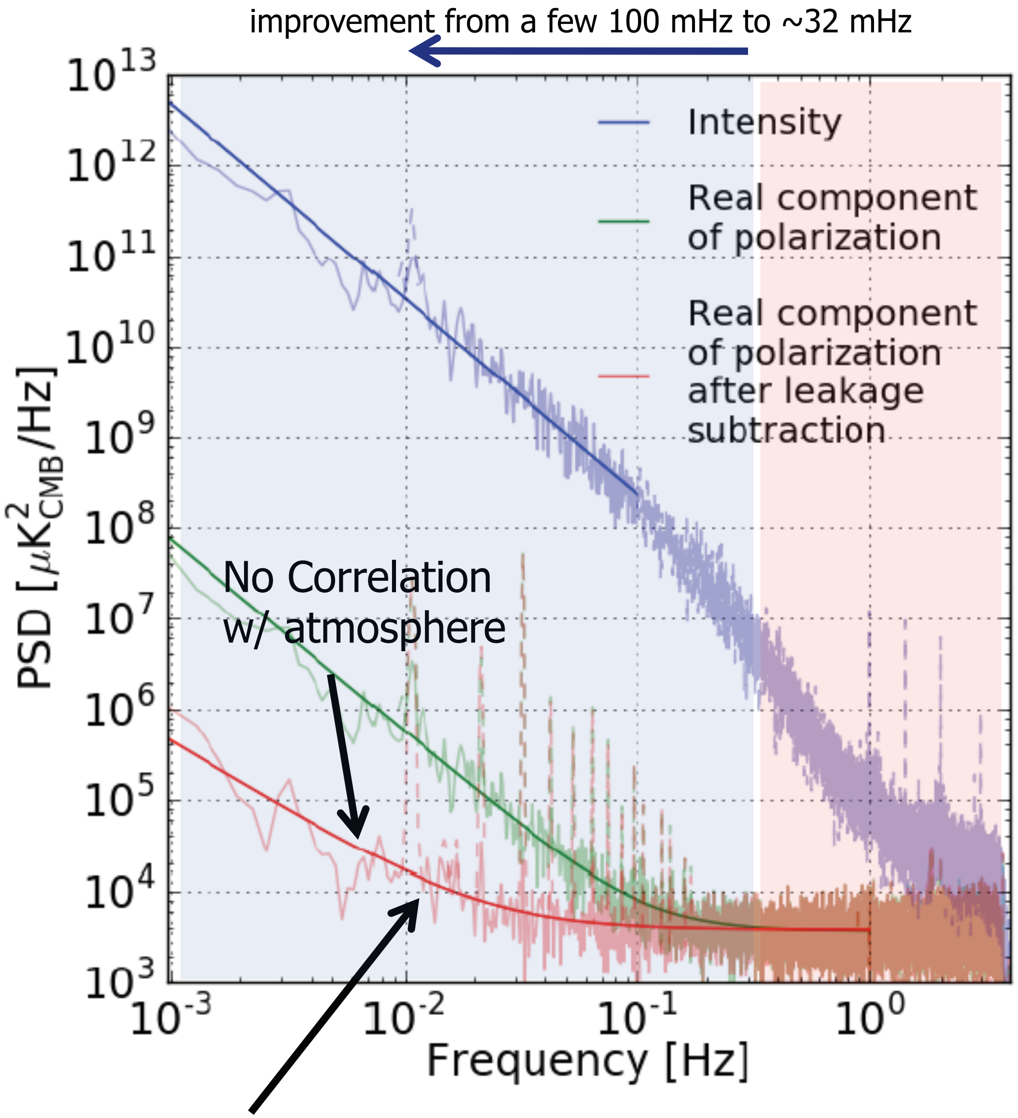
Installed sapphire HWP

Kusaka et. al (2014)



- HWP can rotate incoming polarization signal as we want
  - given an angle between HWP axis & incoming polarization of χ, outgoing polarization angle will be 2χ
- By rotating HWP, we can modulate incoming signal as we want!

Demonstration of Low-Frequency Polarization Noise

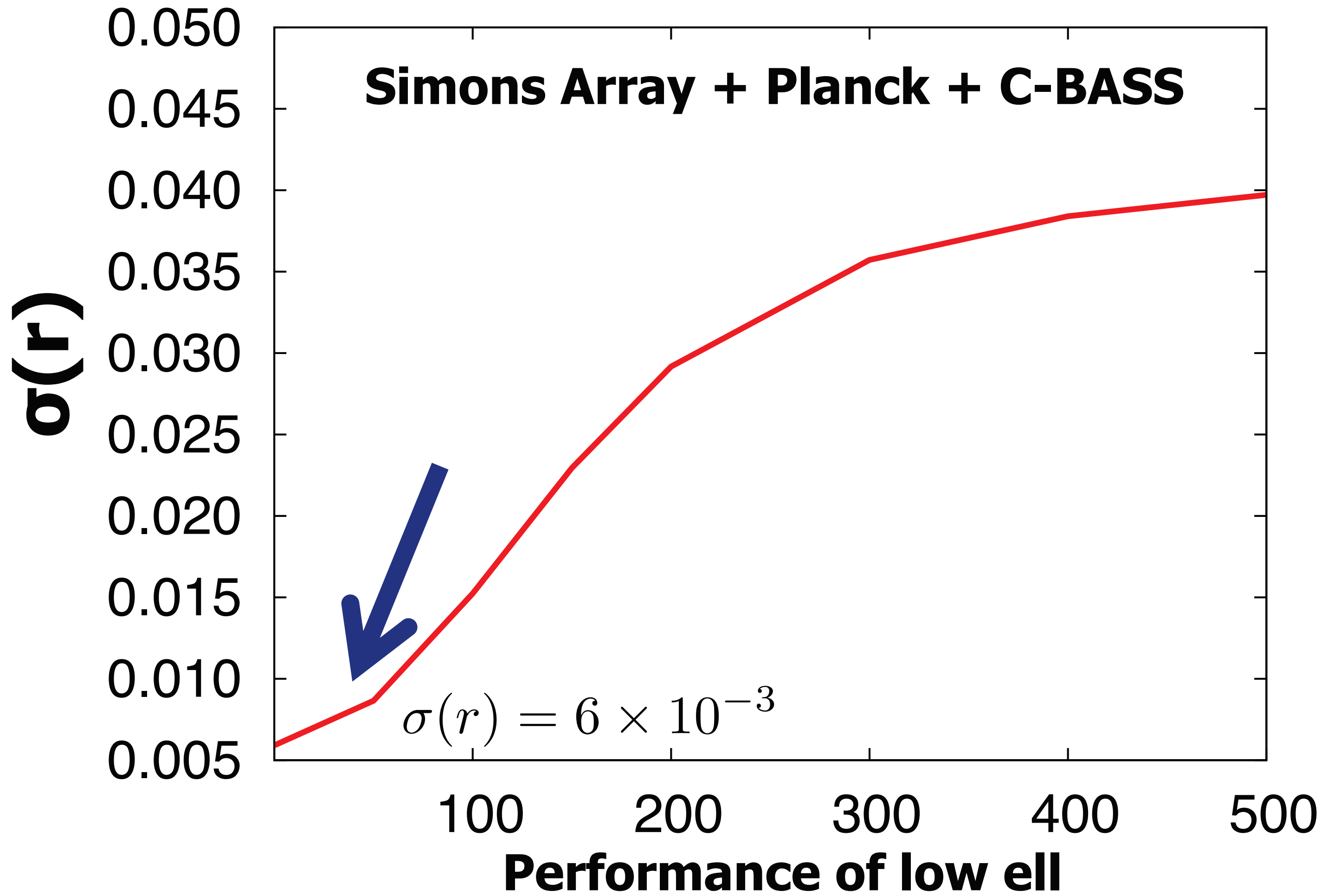


knee=32 mHz (l~39)

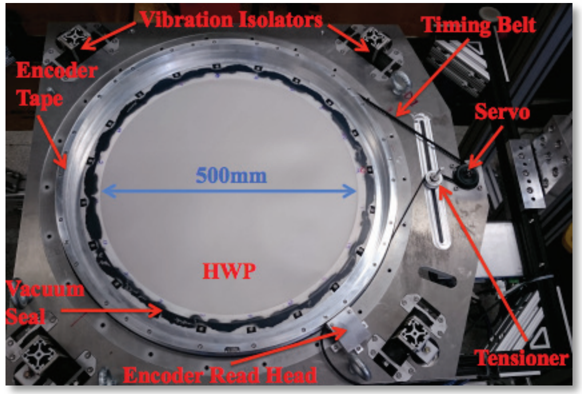
- Successfully removed atmospheric correlated signal
  - tiny residual NOT atmosphere BUT from temperature variations
- Validated modulation by HWP would be able to mitigate 1/f noise **& the residual would be level of r<0.01**

arXiv:1702.07111
S. Takakura et. al. (PB Collab.)

Application to Simons Array



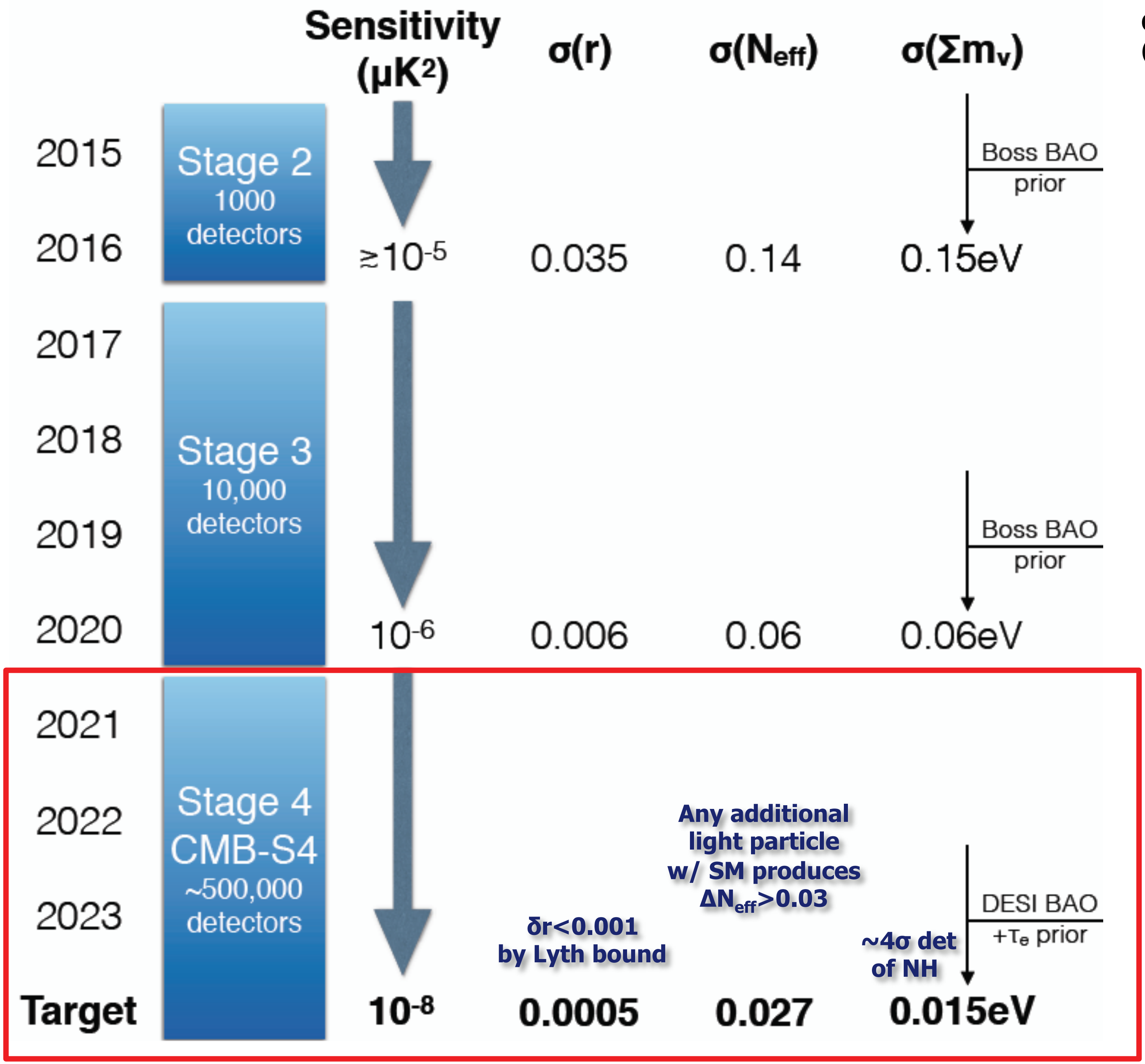
arXiv:1607.07399; CA Hill, S Beckman, Y. Chinone et. al.



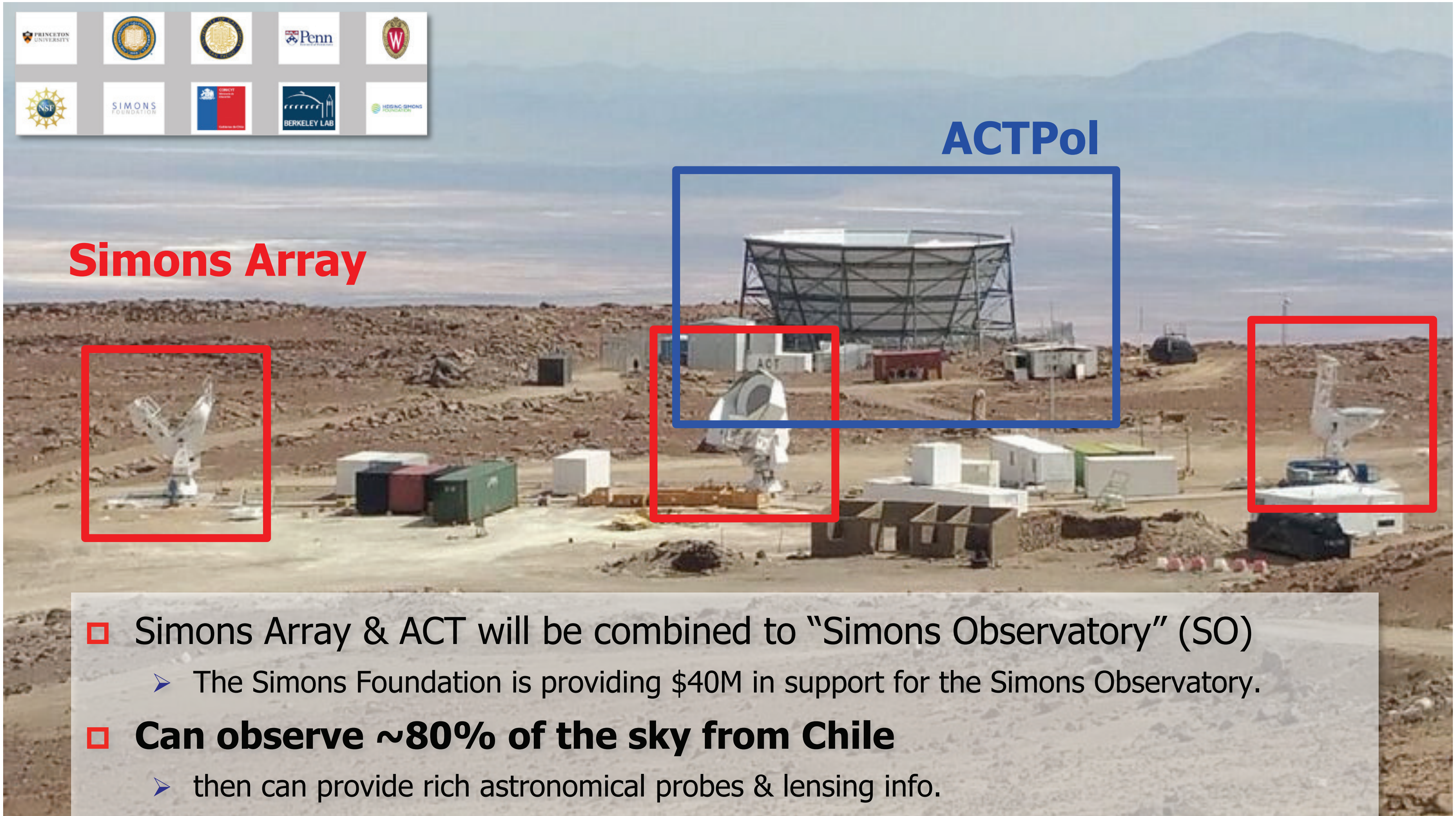
& Cold HWP
by CA Hill & A. Kusaka

- HWP is necessary to achieve the best performance of Simons Array; HWPs are developed @ UC Berkeley/LBNL

CMB-S4 Science Book (arXiv:1610.02743)



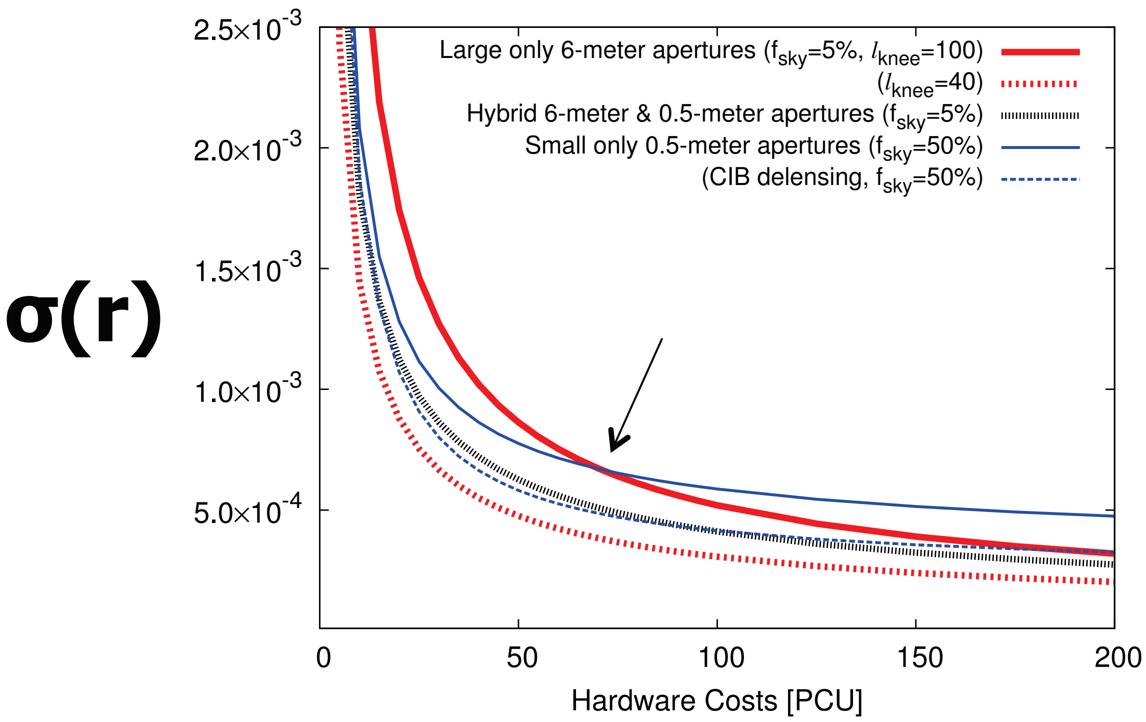
Simons Array to Simons Observatory



- **Simons Array & ACT will be combined to "Simons Observatory" (SO)**
  - The Simons Foundation is providing $40M in support for the Simons Observatory.
- **Can observe ~80% of the sky from Chile**
  - then can provide rich astronomical probes & lensing info.
- **SO is designed to be an important step toward CMB S4**

Optimization for Experiment Configurations of S4

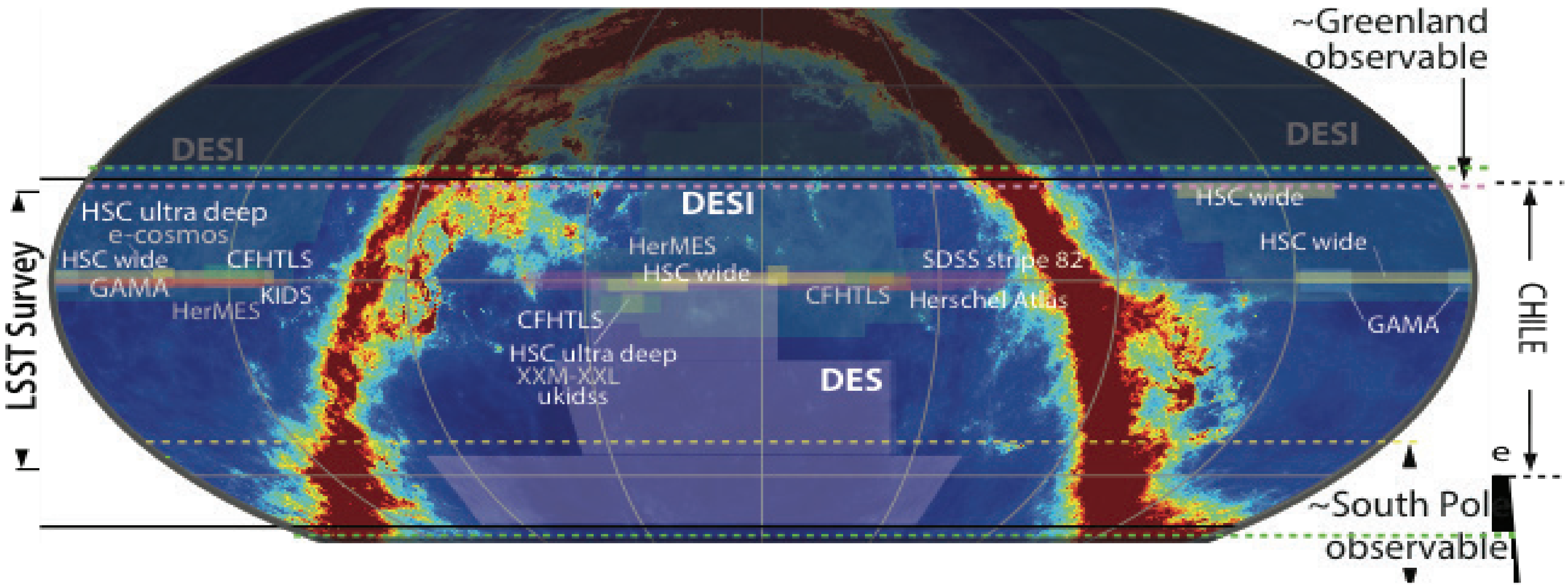
arXiv:1702.07467
Darcy Barron, Yuji Chinone, Akito Kusaka et. al.



- To maximize science outputs (w/ limited budge & time), accurate optimization for "realistic" experimental configuration is necessary
  - telescope size for delensing/high-ell/inflationary B modes
  - frequency distribution for foreground removal
  - sky fraction for CV & foreground mitigation & overlap w/ other surveys

Why CMB Observations From Chile? Large Survey!

Foreground + optical survey coverage map



- Access to large low foreground regions for inflation and lensing
  - 80% of the sky is accessible from Chile; only 30% from South Pole
- Overlap with optical surveys, e.g. LSST, DESI, HSC,PSF, DES, SDSS, and so on, to maximize impact of large-scale structure measurements for neutrinos, dark energy, dark matter, and astrophysics

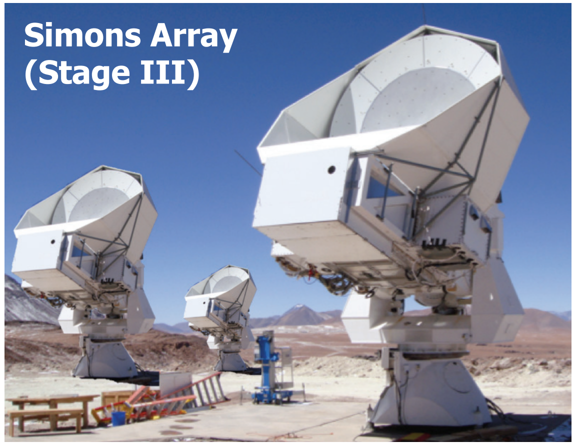
Summary

- Simons Array is a "stage 3" CMB experiment upgraded from POLARBEAR experiment; Many contributions from Japan!
  - POLARBEAR successfully achieved measurement of lensing B modes & validated low frequency performance for inflationary B modes by HWP
- Simons Array & ACT will be combined to "Simons Observatory", which is designed to be an important step toward "CMB S4"

Now

$\sigma(r)<0.1$

2017~



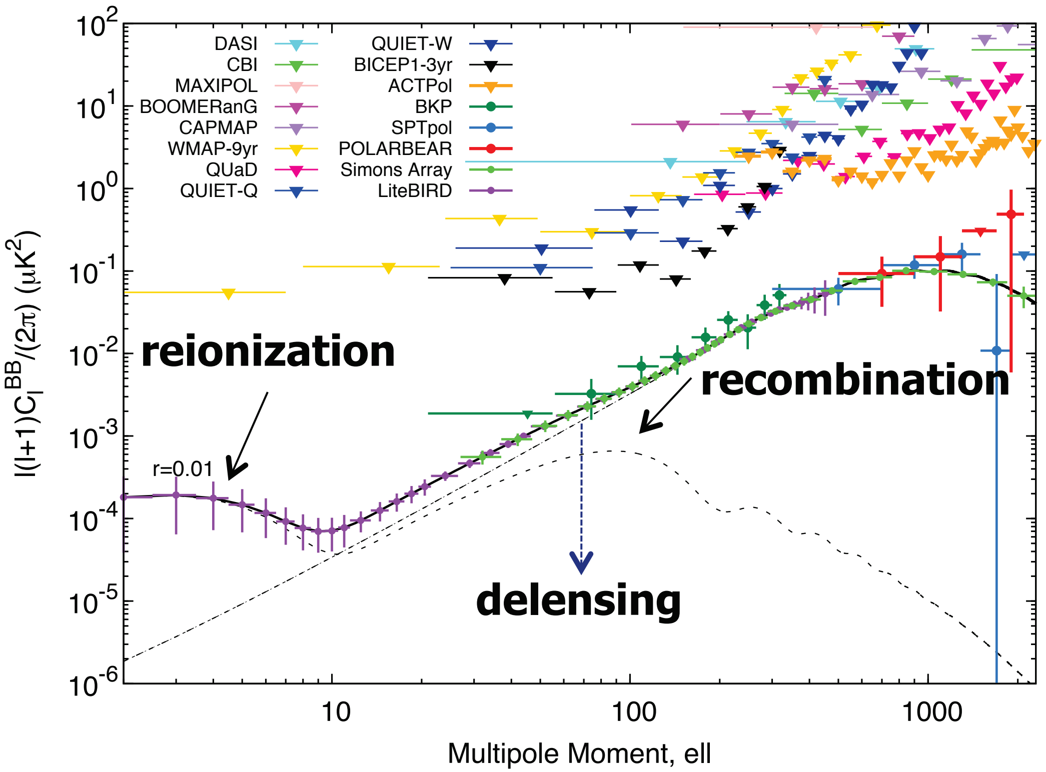
$\sigma(r)<0.01$; $\sigma(\Sigma m_\nu)\sim 40$ meV

2020~

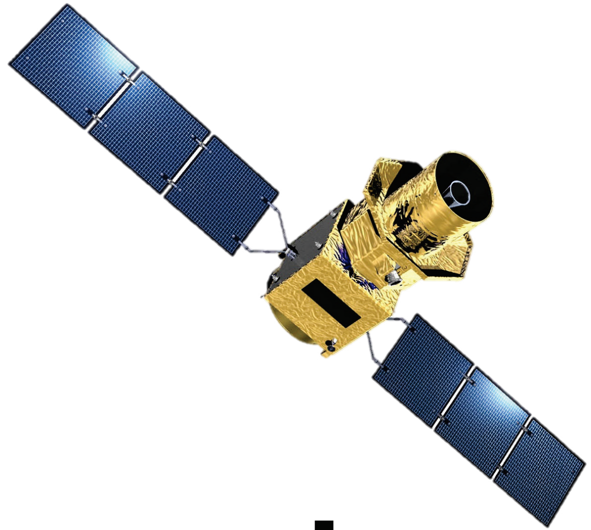
$\sigma(r)<0.001$; $\sigma(\Sigma m_\nu)\sim 15$ meV

Final Remarks

- Synergy BTW **CMB S4** & **LiteBIRD** is quite important
  - **CMB S4** can "**delens**" for LiteBIRD, which can make LiteBIRD (several times?) more sensitive on inflationary B modes
  - **LiteBIRD** can access **the full sky** & **reionization** bump. Both detection of recombination & reionization peaks would provide firm evidence of inflation
- **Continuous contribution to ground-based exps. from JAPAN could make us (me?) happy!**



2025?~



+

2020~