Status and Science Goals of the Simons Array

Kevin T. Crowley (UC Berkeley)
for Simons Array Collaboration

APS DPF Meeting

July 31st, 2019

Overview

- Microwave Background Polarization
- Intro to the Simons Array (SA)
- SA Science Goals
  - POLARBEAR-1 Heritage
- Status of Simons Array Receivers
- What's next

UC Berkeley
Shawn Beckman
Yuji Chinone
Kevin T. Crowley
Ari Cukierman
Tijmen de Haan
Neil Goeckner-Wald
John Groh
Charles Hill
William Holzapfel
Oliver Jeong
Adrian Lee
Dick Plambeck
Chris Raum
Paul Richards
Ben Westbrook
Nathan Whitehorn

CU Boulder
Nils Halverson
Greg Jaehnig
Hayley Roberts

Católica (PUC)
David Boettger
Rolando Dunner

U. New Mexico
Darcy Barron

U Chile
Mario Faundez

UC San Diego
Kam Arnold
Kevin D. Crowley
Tucker Elleflot
George Fuller
Nicholas Galitzki
Logan Howe
Brian Keating
David Leon
Lindsay Lowry
Martin Navaroli
Gabriel Rebeiz
Max Silva-Feaver
Praween Siritanasak
Grant Teply
Calvin Tsai
Alex Zahn

Laboratoire Astroparticule & Cosmologie
Dominic Beck
Josquin Errard
Maude Le Jeune
Radek Stompor

U of Sussex
Julien Peloton

KEK
Yoshiki Akiba
Takaho Hamada
Masaya Hasegawa
Masashi Hazumi
Yuto Minami
Yuuko Segawa
Sayuri Takatori
Daiki Tanabe

U. Melbourne
Christian Reichardt
Federico Bianchini
Anh Pham

SISSA
Carlo Baccigalupi
Nicoletta Krachmalnicoff
Davide Poletti
Giuseppe Puglisi

U Tokyo
Haruki Nishino

Kyoto U
Osamu Tajima
Shunsuke Adachi
Tomofumi Abe

And many more in years past...

MEXT
SIMONS FOUNDATION

McGill University
Matt Dobbs
Adam Gilbert
Josh Montgomery

Dalhousie
Scott Chapman
Colin Ross
Kaja Rotermund
Alexei Tikhomirov

Lawrence Berkeley NL
Julian Borrill
Reijo Keskitalo
Theodore Kisner
Akito Kusaka
Eric Linder
Alex Madurowicz
Blake Sherwin
Aritoki Suzuki

Kavli IPMU
Daisuke Kaneko
Nobuhiko Katayama
Tomotake Matsumura
Frederick Matsuda
Satoru Takakura

Institute D'Astrophysique Spatiale
Giulio Fabbian

U Manchester
Gabriele Coppi
Andrew May
Lucio Piccirillo

UIUC
Chang Feng

Cardiff University
Peter Ade

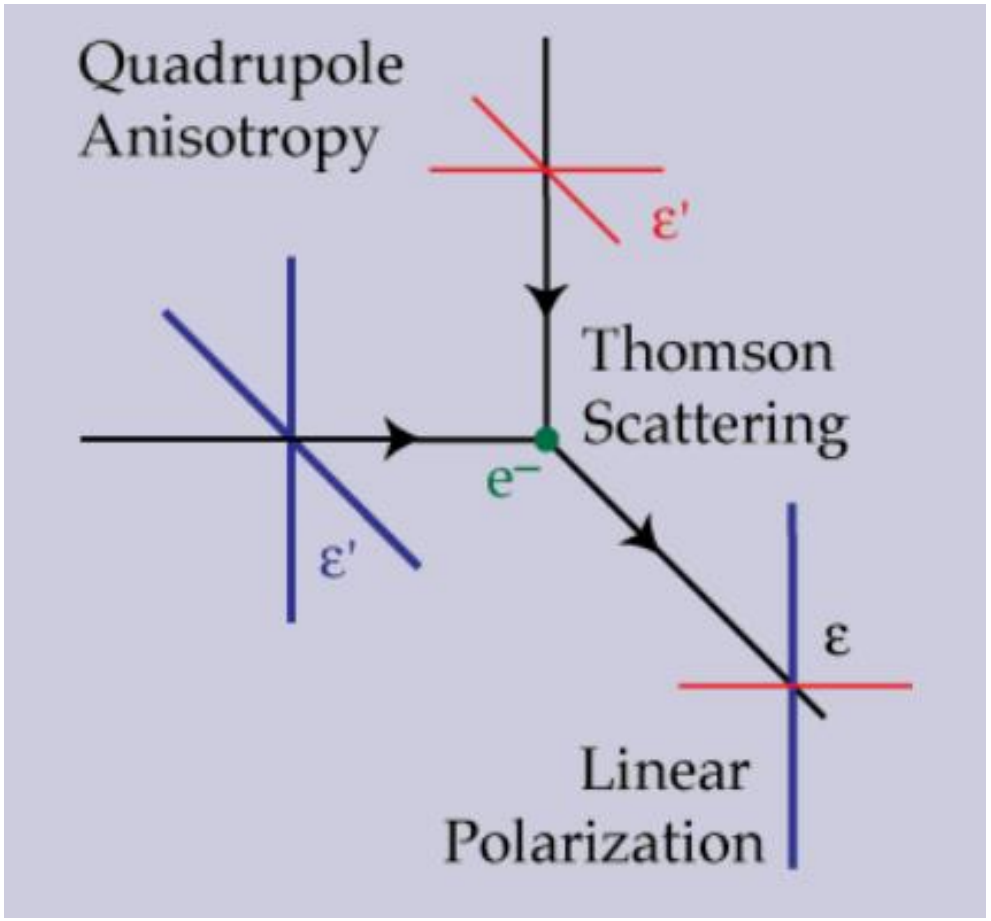
NASA Goddard
Nathan Miller

Argonne NL
Amy Bender

Imperial College
Andrew Jaffe
Daisy Mak

C Computational Astrophysics
Stephen Feeney

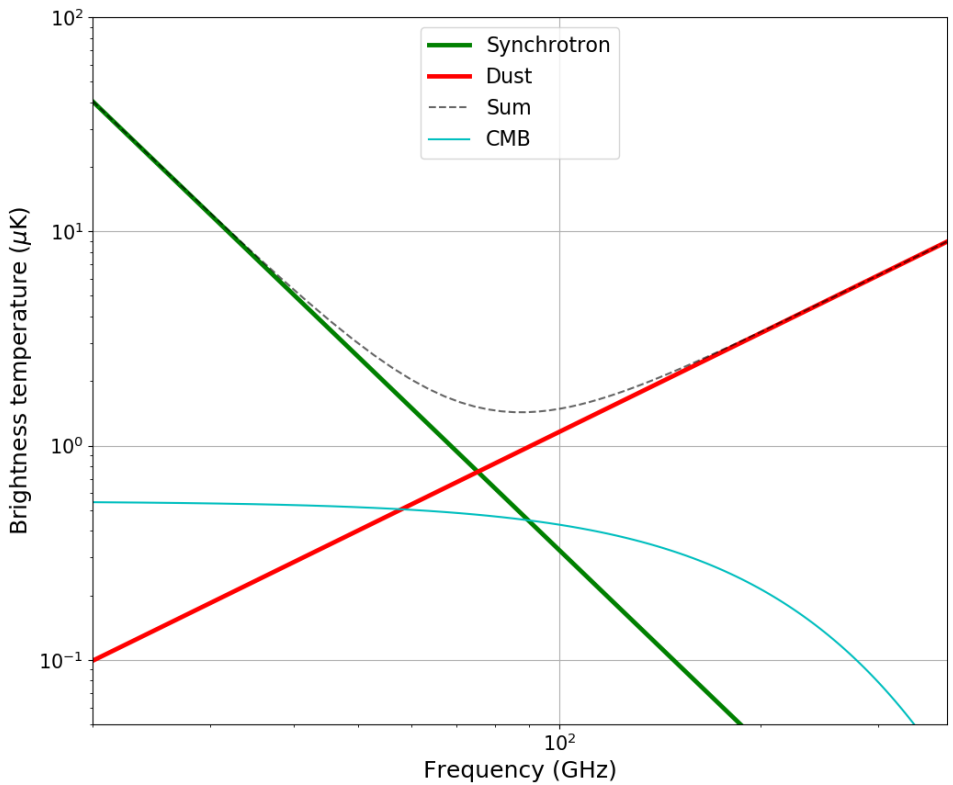
Polarization Anisotropies



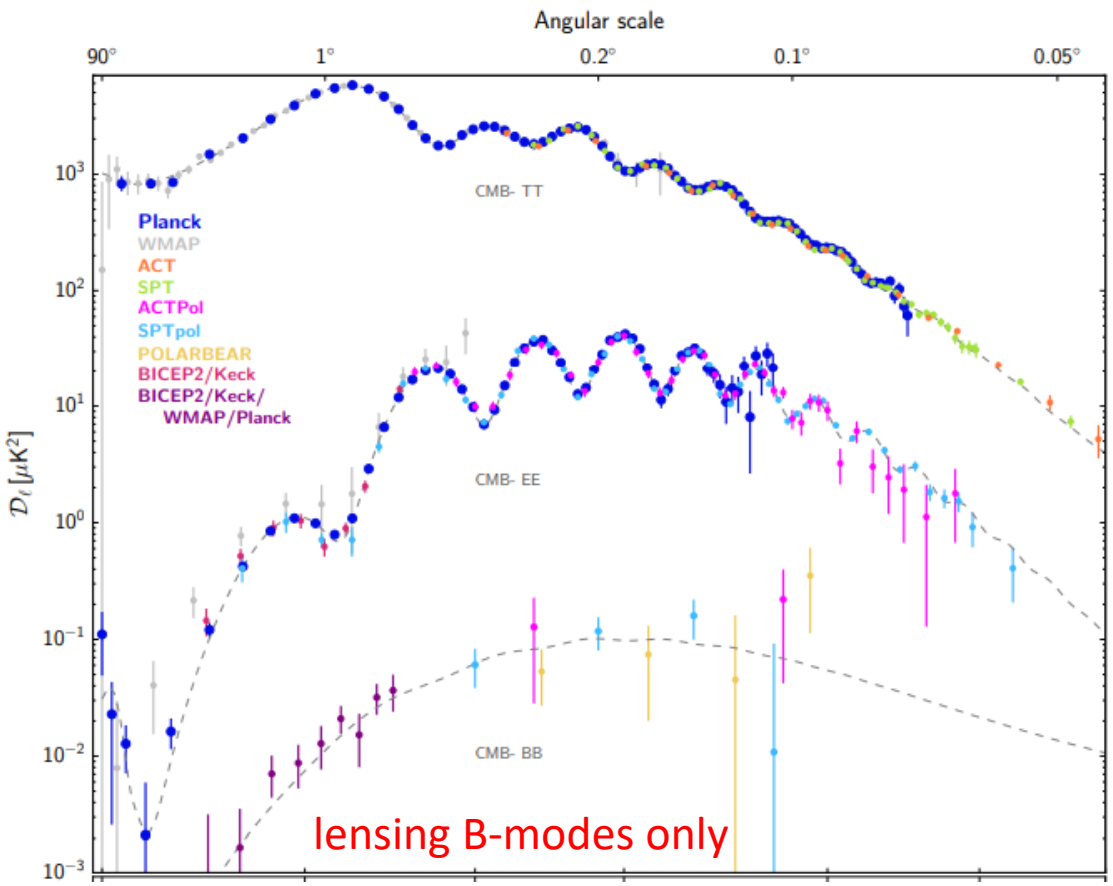
Hu, W. and M. White. New Astronomy 2(323) 1997.

- Primary: Thomson scattering → linear polarization
  - Describe with scalar E (curl-free) & B (divergence-free) modes
  - E – sourced by both scalar (all scales) and tensor perturbations (PGW) (subdominant)
  - B – sourced **only** by tensors; peak on degree scales
- Secondary: E modes distorted by weak lensing from LSS → B modes at sub-degree scales

Challenges for CMB Polarization



- Galactic foregrounds (degree-scale)
- Low amplitude of B-modes

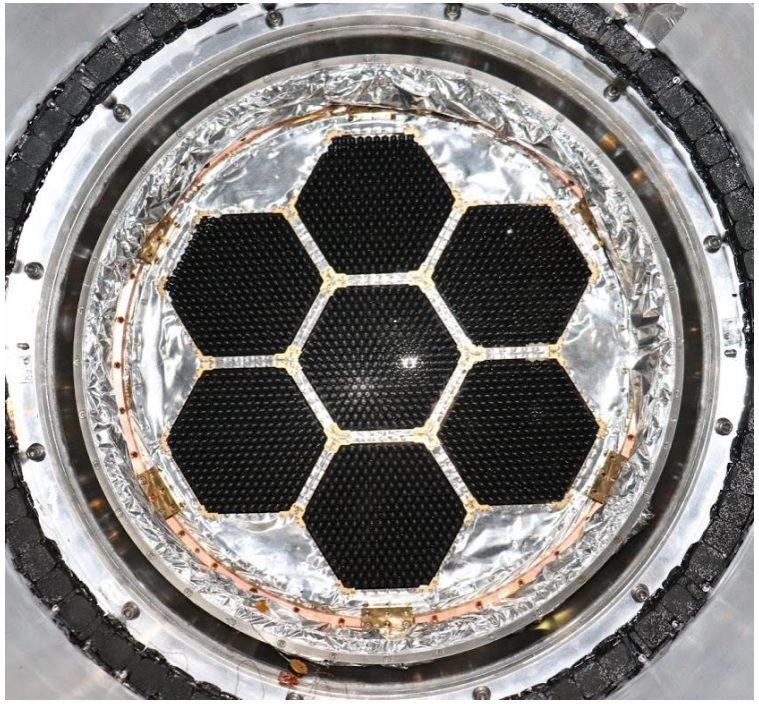


Planck 2018: I arxiv:1807.06205

- Systematic error mitigation

Simons Array Big Picture

- Three 2.5 m off-axis Gregorian telescopes
- 1,897 dichroic pixels in each focal plane
  - 7,588 bolometers per receiver *Westbrook et al. JLTP 2018*
  - Lenslet-coupled sinuous antennae *Bender et al. arXiv:1407.3161*
  - 40x frequency-division multiplexing of TES bolometers
- Continuously-rotating half-wave plate (CRHWP) for polarization modulation *Hill, Beckman arxiv:1607.07399* *Hill arxiv:1805.10403*
  - PB-2a: warm; PB-2b & c: cryogenic



Receiver POLARBEAR	Band(GHz) /Detectors	Beam Size (arcmin)
2a	95/3794 150/3794	5.2 3.5
2b	95/3794 150/3794	5.2 3.5
2c	220/3794 270/3794	2.7 2.2

Simons Array Big Picture

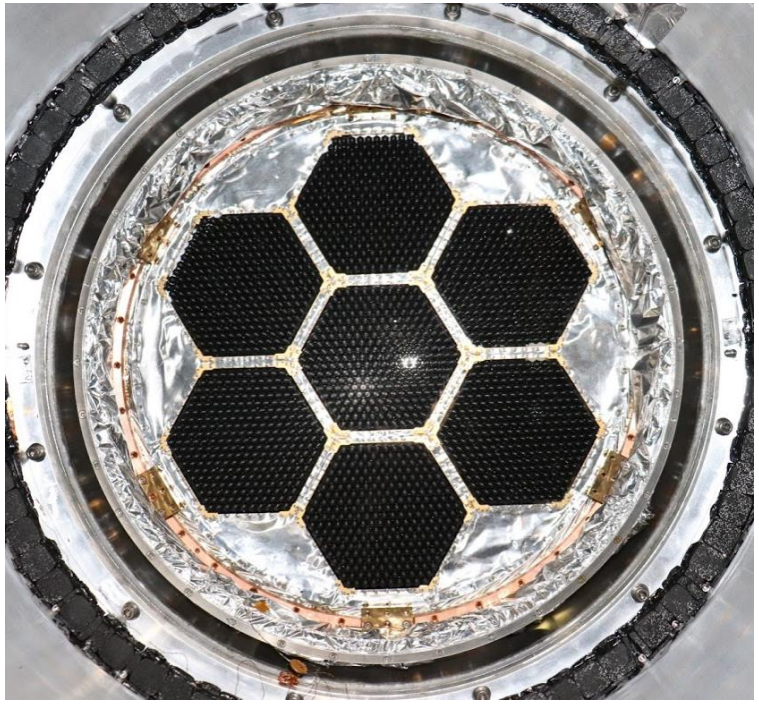
- Three 2.5 m off-axis Gregorian telescopes
- 1,897 dichroic pixels in each focal plane
  - 7,588 bolometers per receiver
  - Lenslet-coupled sinuous antennae
  - 40x frequency-division multiplexing of TES bolometers

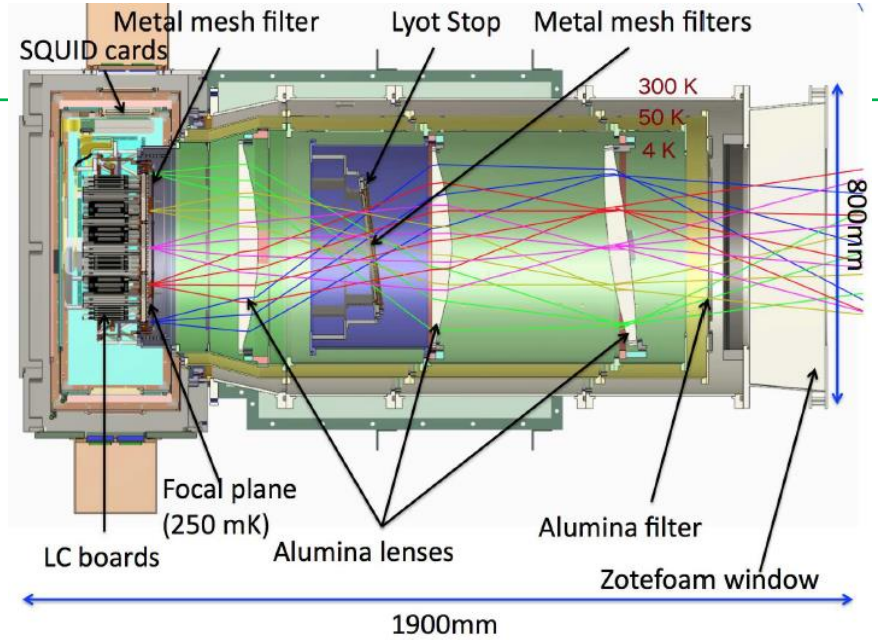
SENSITIVITY

- Continuously-rotating half-wave plate (CRHWP)

SYSTEMATICS

FOREGROUNDS

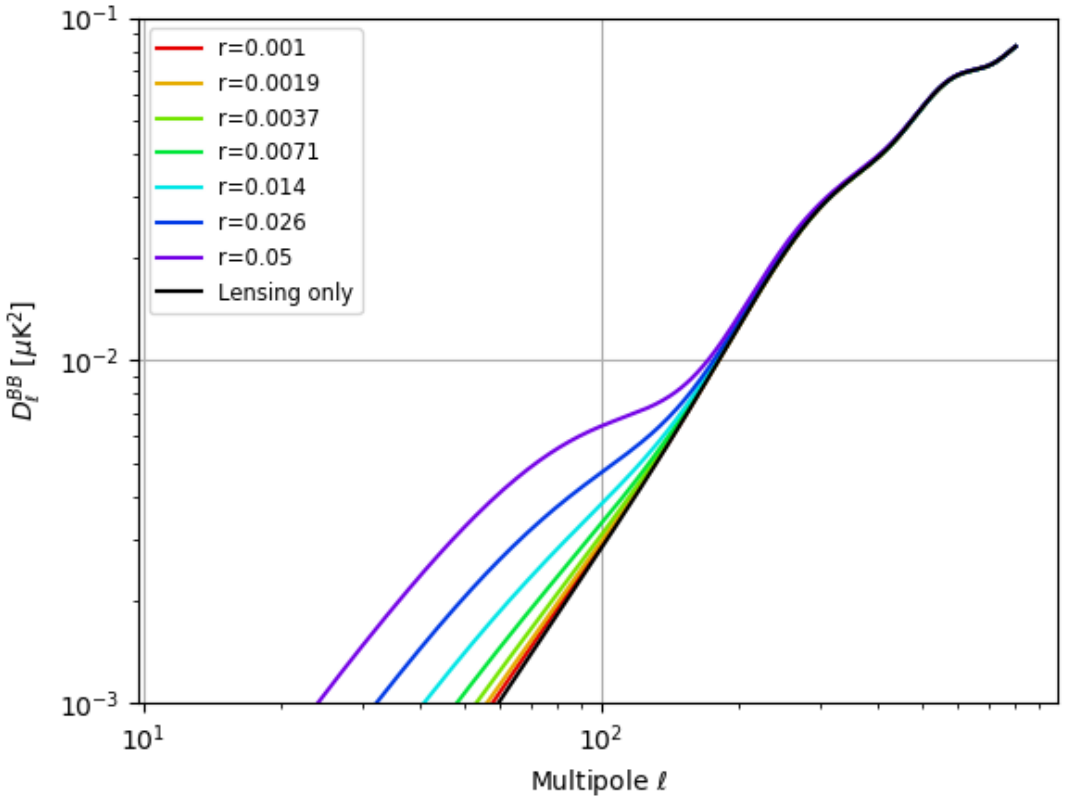




PB2a receiver model

Receiver POLARBEAR	Band(GHz) /Detectors	Beam Size (arcmin)
2a	95/3794 150/3794	5.2 3.5
2b	95/3794 150/3794	5.2 3.5
2c	220/3794 270/3794	2.8 2.2

Tensor Perturbations & Inflation



- Inflation: period of accelerating expansion in early universe
- Generically predicts primordial tensor perturbations
  - Parametrize as tensor-to-scalar ratio r
- Non-zero r measurement strongly supports inflation
  - Current 95% CL constraint of $r_{0.05} < 0.06$ (Planck T + BK B)
  - Pursuing small values of r: foregrounds, delensing

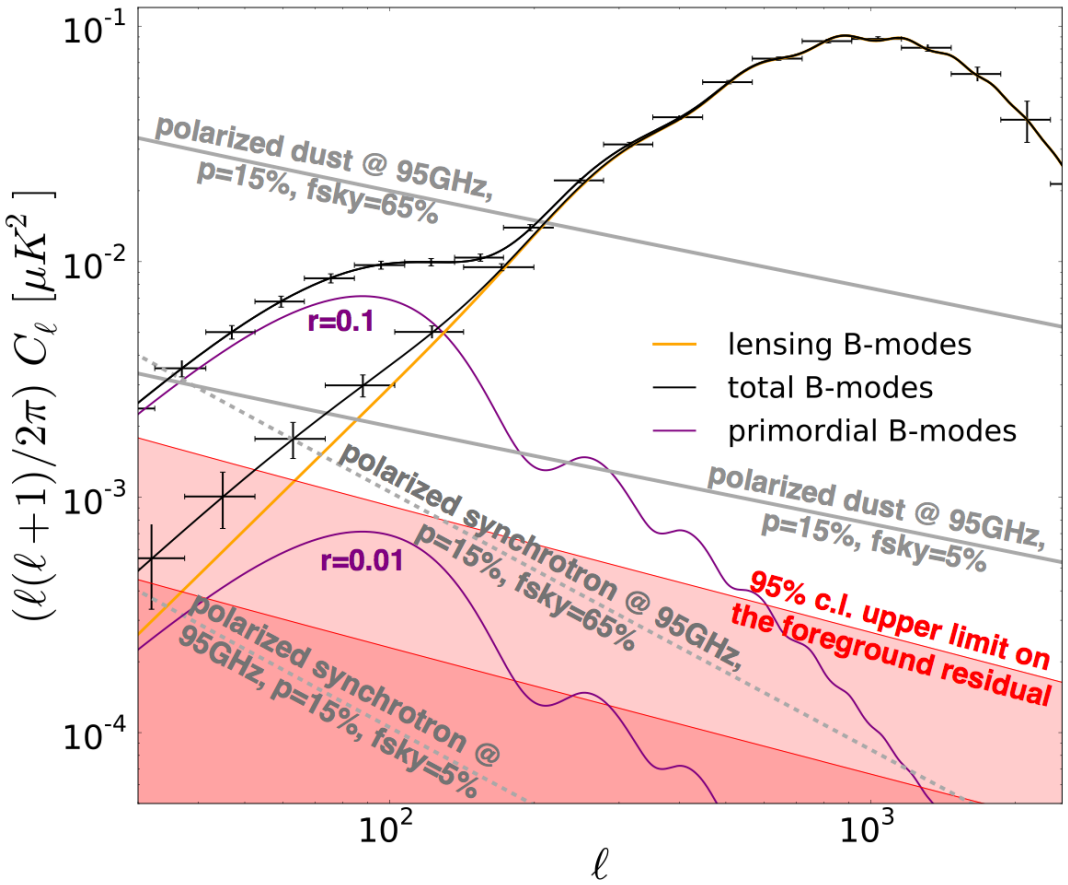
Studying Inflation with Simons Array

- Add'l dust constraints w/ 220/270 channels
- After component separation*:

$$\sigma\,(r = 0.1) = 0.006$$

w/ Planck 353 GHz (dust) and C-BASS (sync)

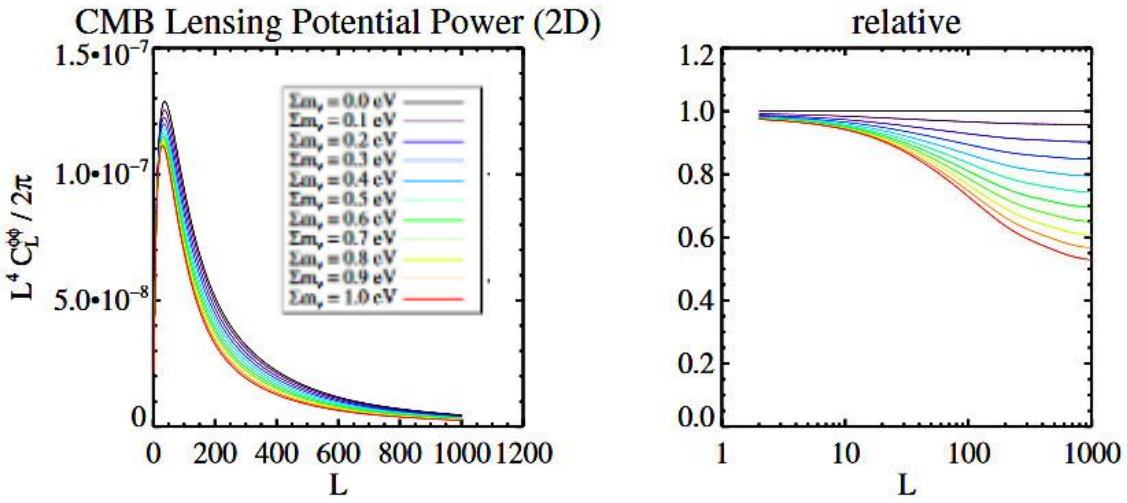
- Improving forecast with:
  - Observing strategy changes
  - Input from receiver commissioning



Stebor et al. SPIE 2016

**Errard et al. arxiv:1509.06770*

Lensing B-modes and Neutrinos for SA



CMB-S4 Science book arxiv:1610.02743

- Non-zero neutrino mass reduces structure growth at small scales
- Primordial perturbations from CMB power spectra & lensing signal
- Σm_ν from CMB → NH vs. IH

- SA will use pol measurements for lensing, primordial perturbations
  - Include external data (e.g. DESI BAO) to break parameter degeneracy

- After cross-correlation with DESI galaxy survey:

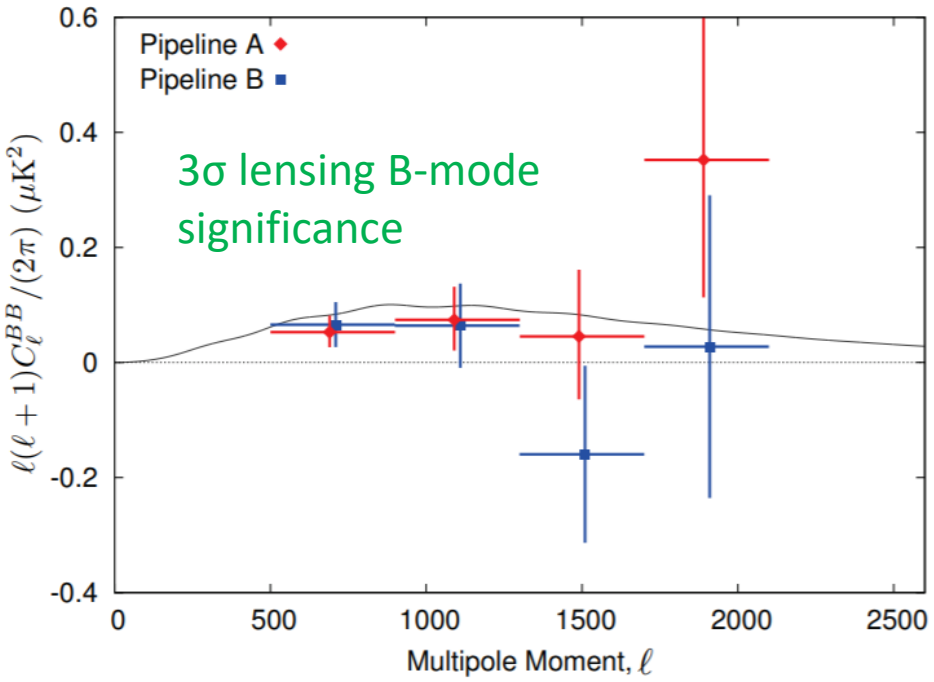
  σ (NH) = 40 meV

Stebor et al. SPIE 2016

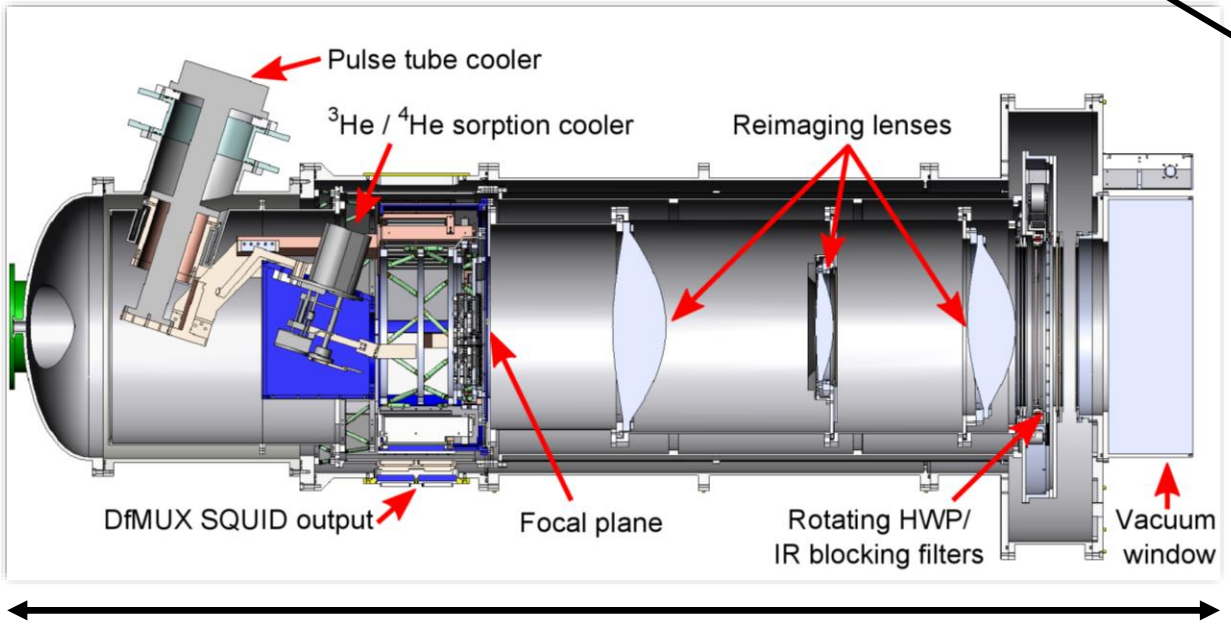
POLARBEAR-1

- Gregorian design
  - 3.5 arcmin beam at 150 GHz
- 637 dual-polarization pixels
- CMB observations in 2 stages
  - 3 deep fields ~ 9 deg^2
  - Wide field with CRHWP ~ 700 deg^2

+ 4 σ 4-pt lensing significance; cross-correlation; birefringence



POLARBEAR ApJ 2017



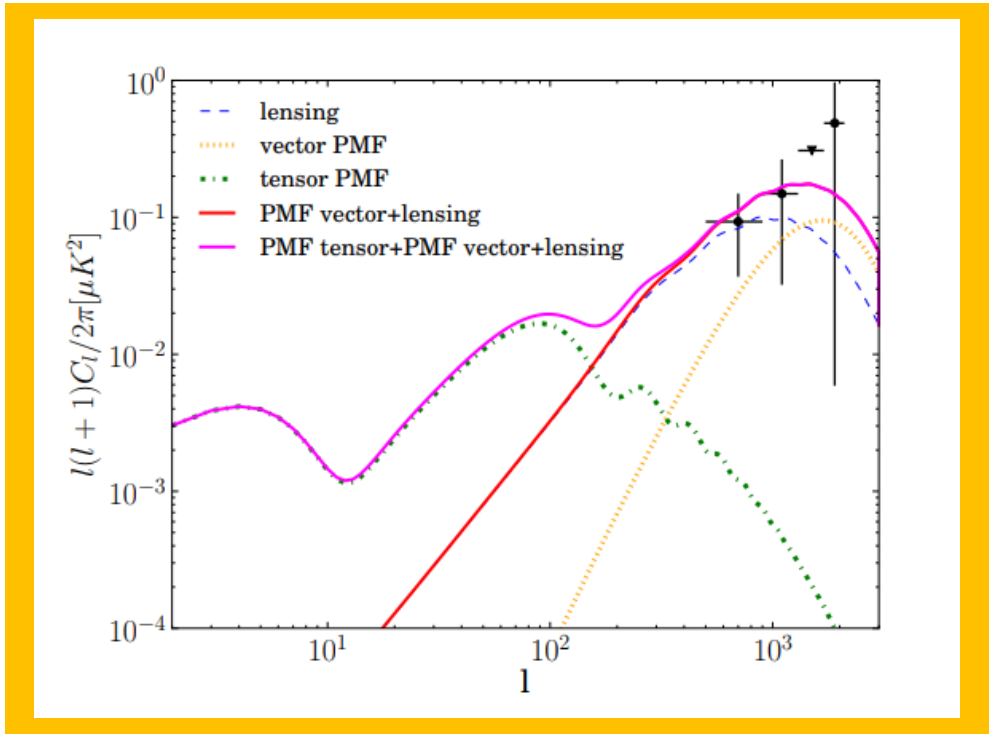
2 meters

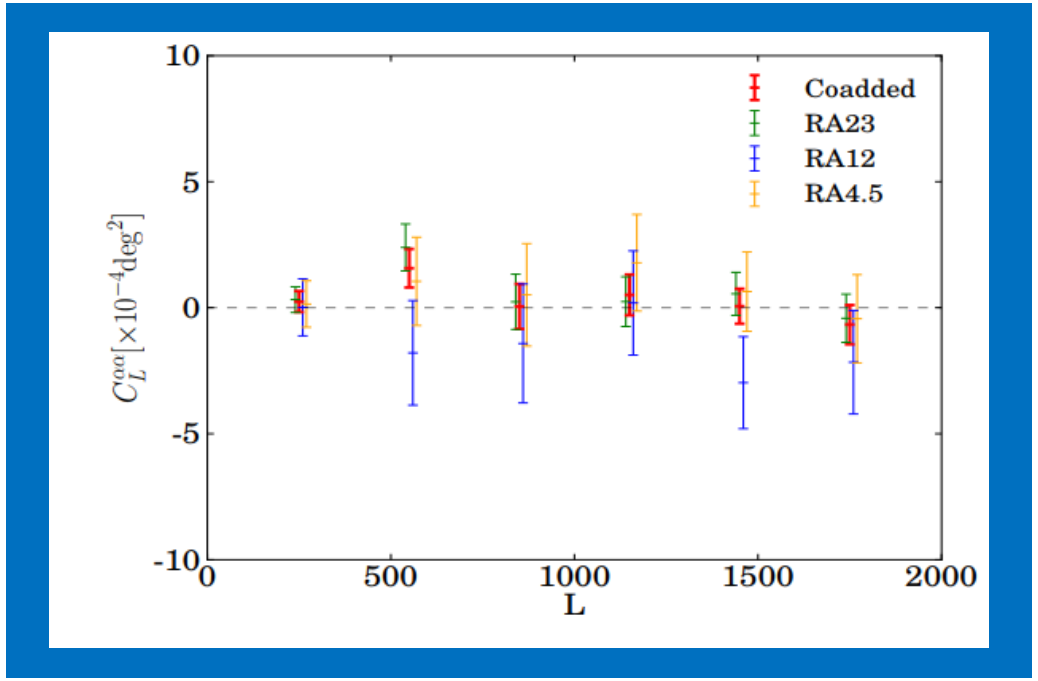
Large-scale B-modes result in prep
$50 \leq \ell \leq 600$
Results coming soon!

4-pt lensing studies also in the pipe

Studying Cosmic Birefringence w/ Simons Array

- Beyond Standard Model extensions interact with CMB photon polarizations differently
  - Pseudoscalar fields coupling to photons
- Faraday rotation of & signals in CMB pol from primordial magnetic fields (PMF)



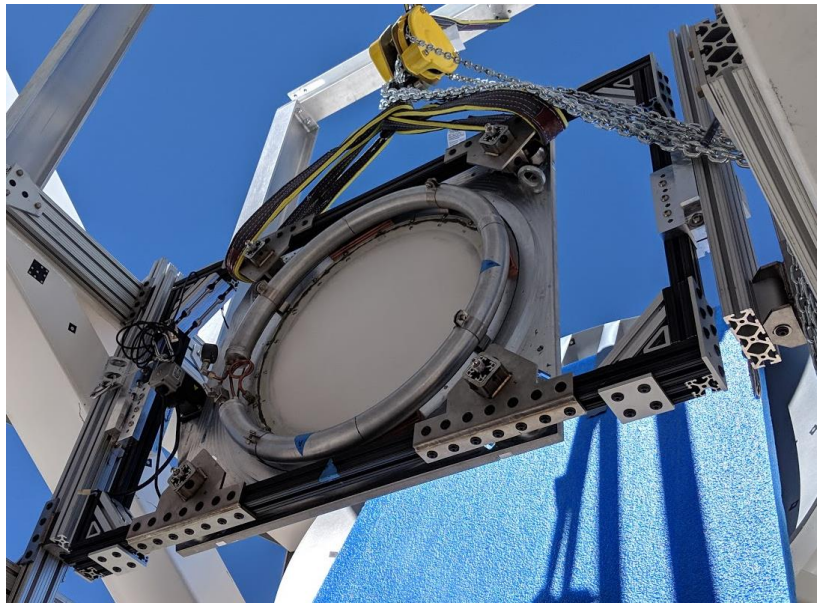


- POLARBEAR-1 bound (deep fields):
  - <~ 93 nG on PMF @ 95% CL (4-pt)
  - <~ 4 nG on PMF (C_l^{BB})
- SA will follow up

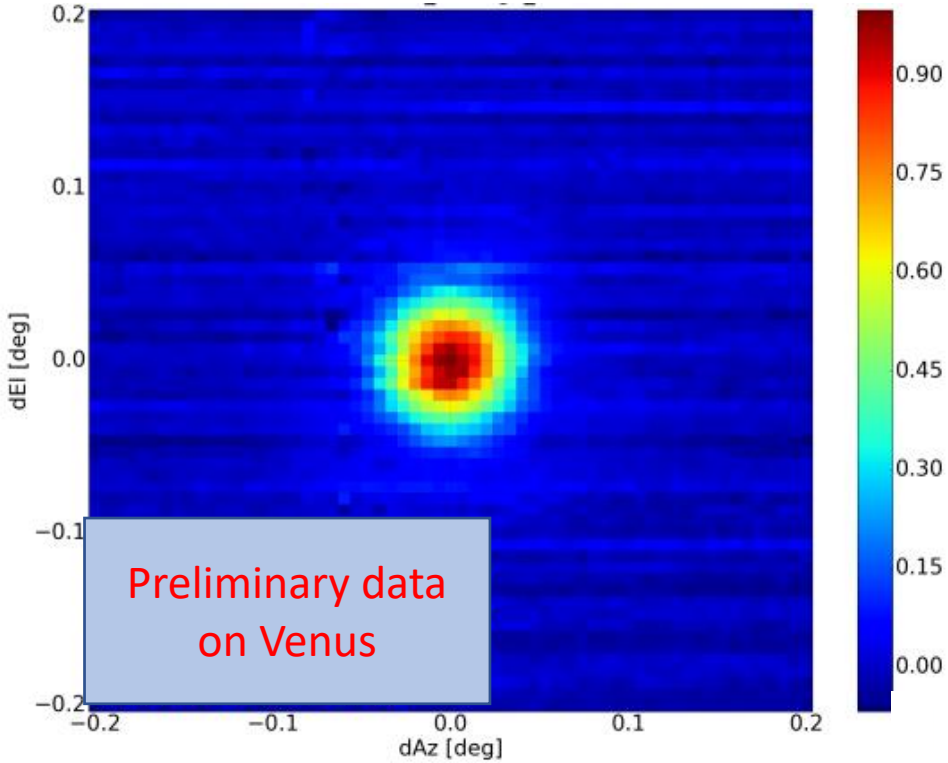
POLARBEAR PRD 92:123509 (2015)

SA Status: POLARBEAR-2a

- Integration/ commissioning at KEK Japan
- Deployment to Chile fall 2018
- First light Jan 5, 2019
- Commissioning in field ongoing
  - Enclosure complete
  - Receiver focusing + final HWP install
  - Science scans to begin soon

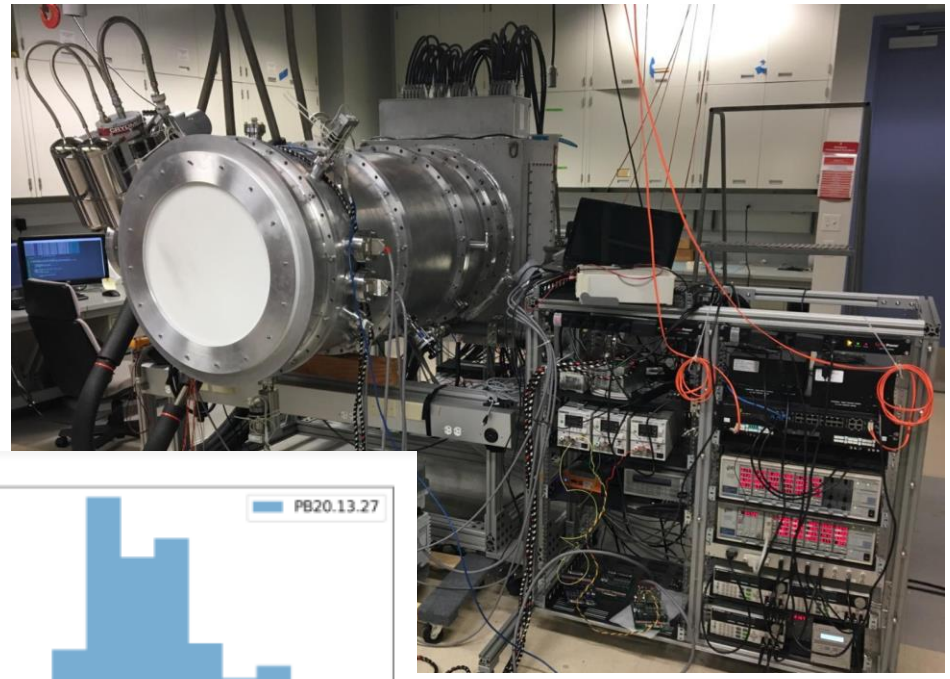


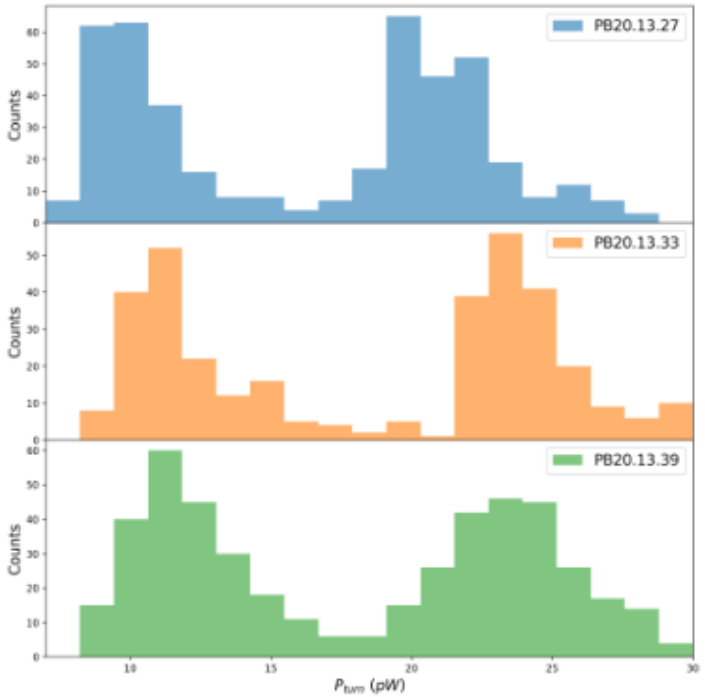
HWP test hoist 11/2018



SA Status: POLARBEAR-2b

2b integrated Spring 2019



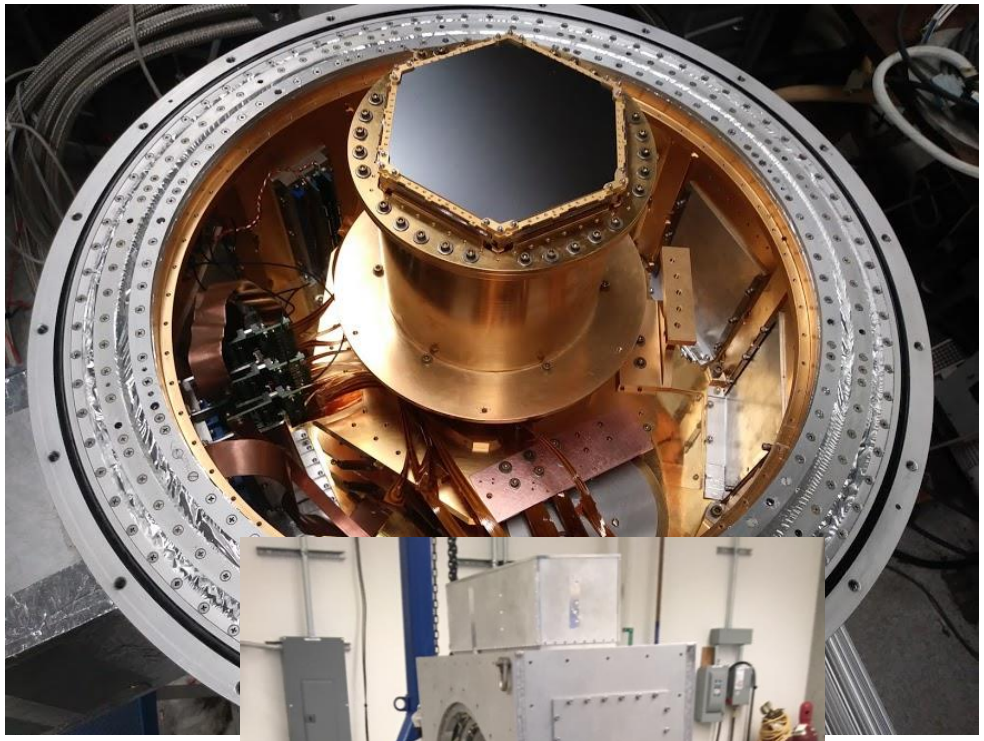


Dark bolometer parameters
See T. Elleflot JLTP, forthcoming

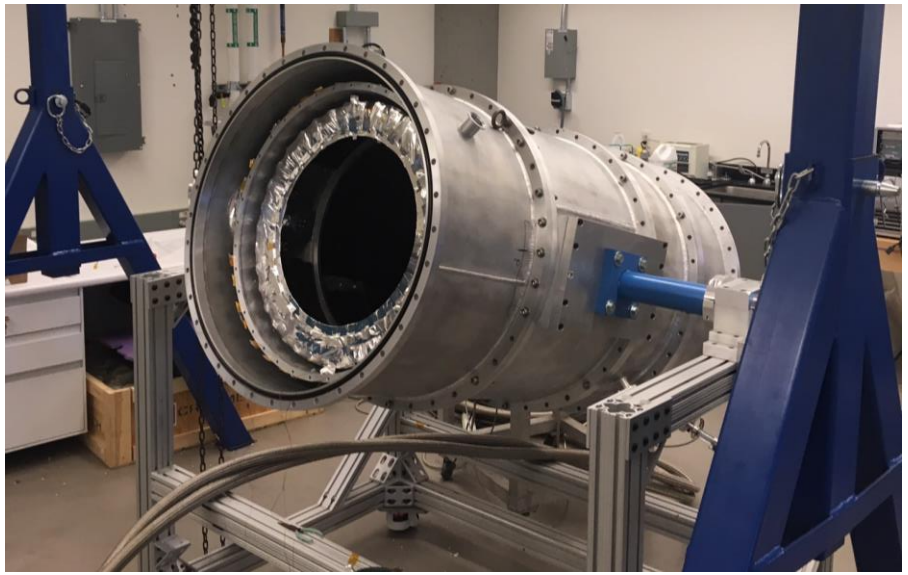
- Integration/ commissioning at UC San Diego
- Deployment this year
- Add'l cooling power from distinct fridge design *Howe arxiv:1806.05576*
- Laboratory studies
  - Receiver cryogenic performance
  - Detector response and noise performance
  - Optics alignment confirmation

SA Status: POLARBEAR-2c

- Integration/commissioning at UC Berkeley
- Wafer testing campaign ongoing
- Receiver components in validation
- Building from 2b experience/design
- Deployment & first light in 2020



220/270 dichroic wafer ready for dark test



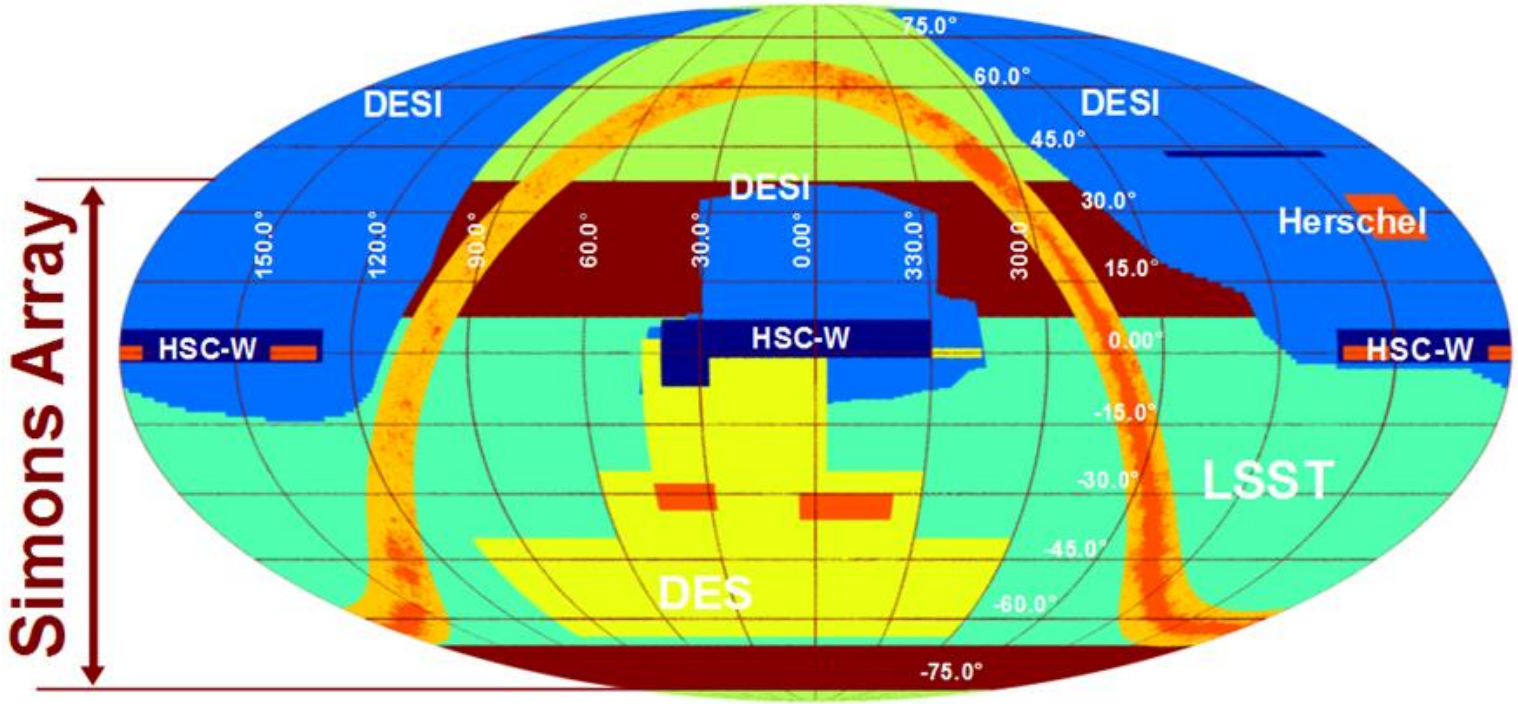
Optics assembly after first cooldown, July 2019

Assembly for first run of detector & readout cryostat, July 2019

Next steps

- Simons Array fully deployed in 2020
- Observe for 3 years each telescope

- Sky coverage scheme being finalized
  - Large sky fraction accessible
  - Cross-correlation with galaxy surveys
- Add'l reach: foreground cleaning (220/270) and delensing power for Simons Observatory (2021-)
  - Forecasting ongoing



Conclusion

- Simons Array pursuing:
  - r, Σm_ν, cosmic pol rotation
  - Growth of structure with cross-correlations to galaxy surveys

- Three telescopes + receivers observe from mid-latitude site
- Full SA observations begin 2020

POLARBEAR-
2a DEPLOYED
2b FINAL TESTING
2c INTEGRATION

Photo: Debra Kellner Simons Foundation