Multichroic Dual-Polarization Bolometric Detector for studies of the Cosmic Microwave Background

Aritoki Suzuki
University of California, Berkeley
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Collaborators

University of California, Berkeley

Kam Arnold
Gregory Engargiola
Adnan Ghribi
William Holzapfel
Adrian Lee
Xiao Fan Meng
Mike Myers
Erin Quealy
Paul Richards
Darin Rosen
Aritoki Suzuki

California Institude of Technology

Roger O'Brient

University of California, San Diego

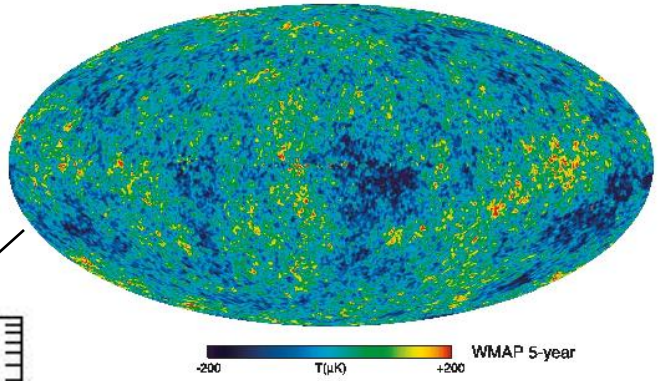
Jennifer Edwards
Gabriel Rebeiz

NASA grant NNG06GJ08G

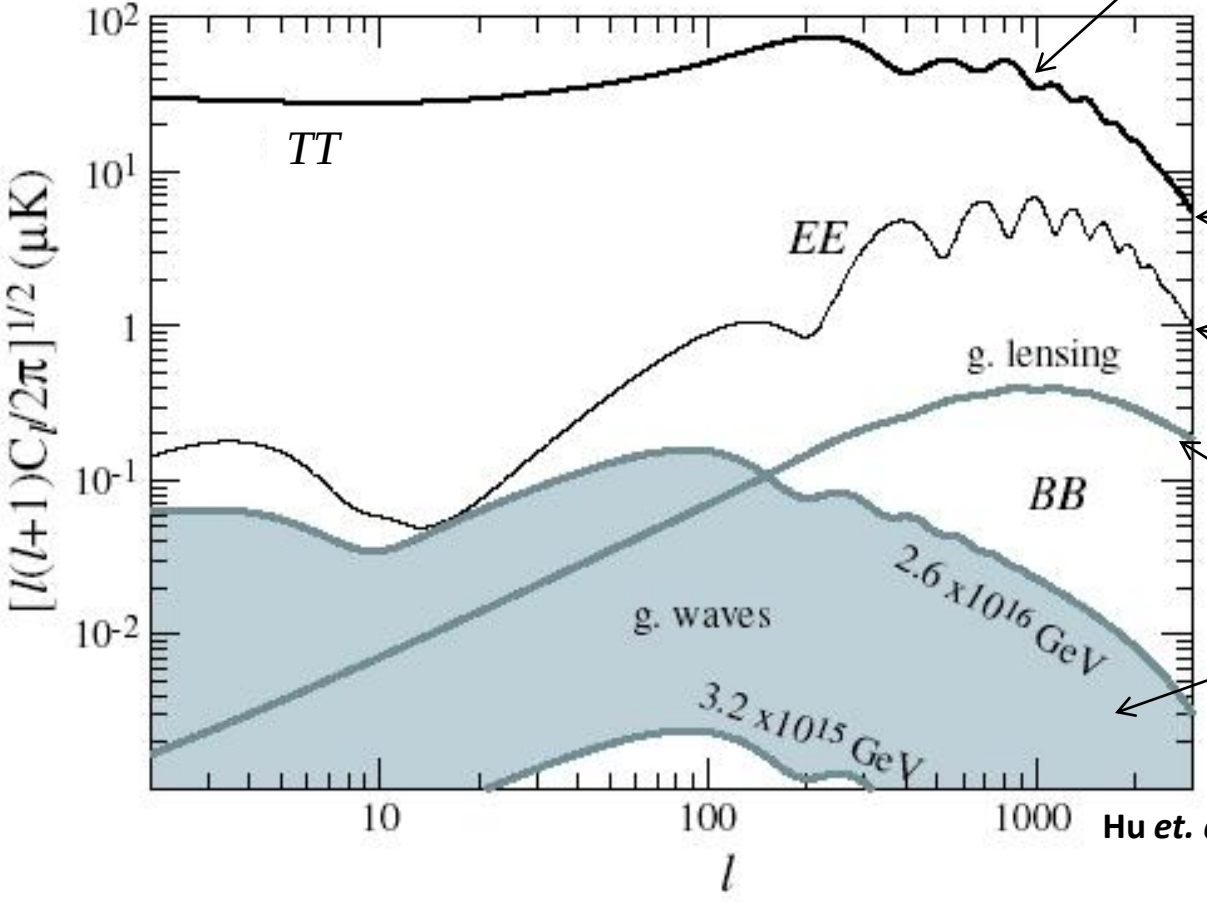
Outline

- Science Motivation
- Design
- Performance
- Detector Array

We are after B-mode polarization of CMB



Credit: WMAP



T Spectrum

E-mode Spectrum

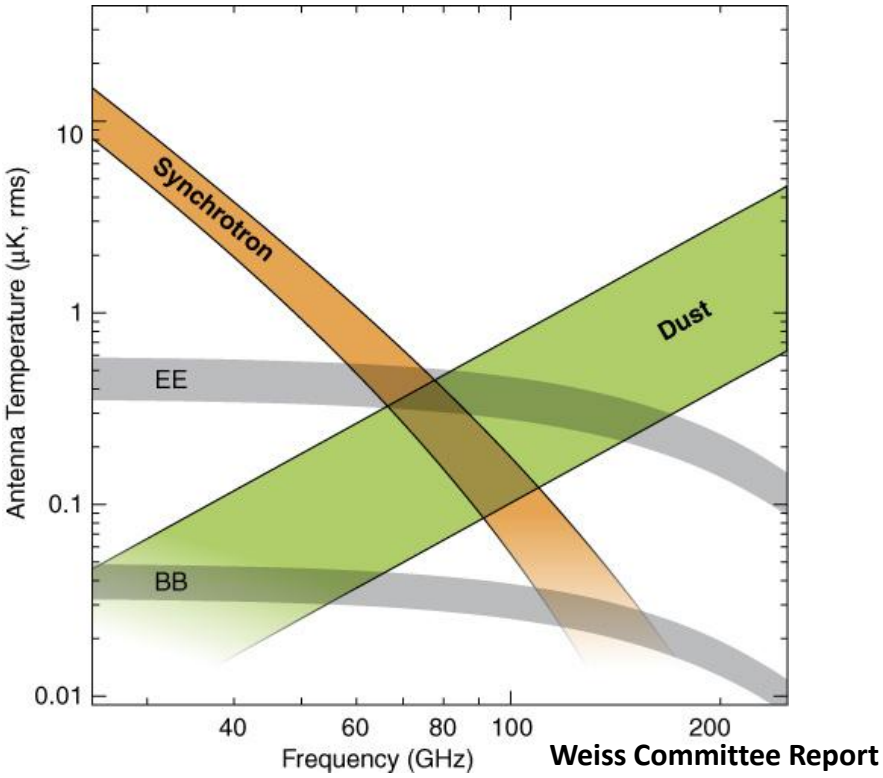
B-mode Spectrum

Lensing

Gravitational Wave

Hu *et. al.*, (2003)

Multiple Frequency Detection is Needed

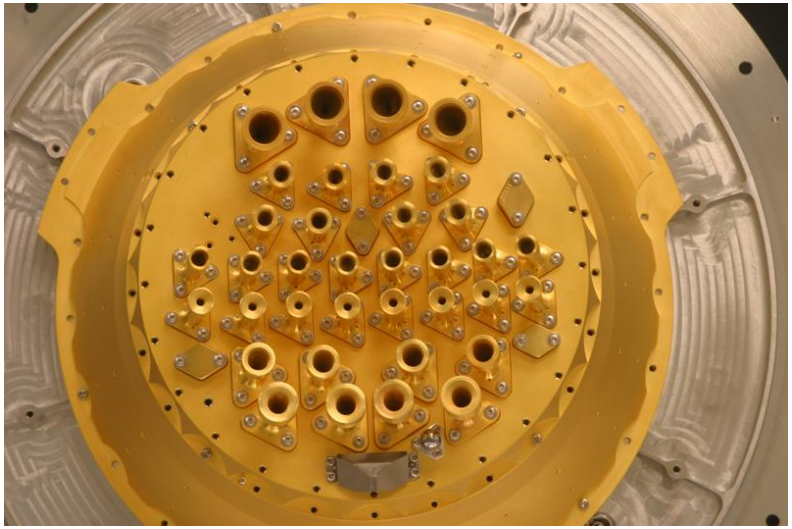


Weiss Committee Report

- Detect more photons → higher sensitivity
- Observe and remove foreground (dust, sync radiation)

Next Generation Focal Plane

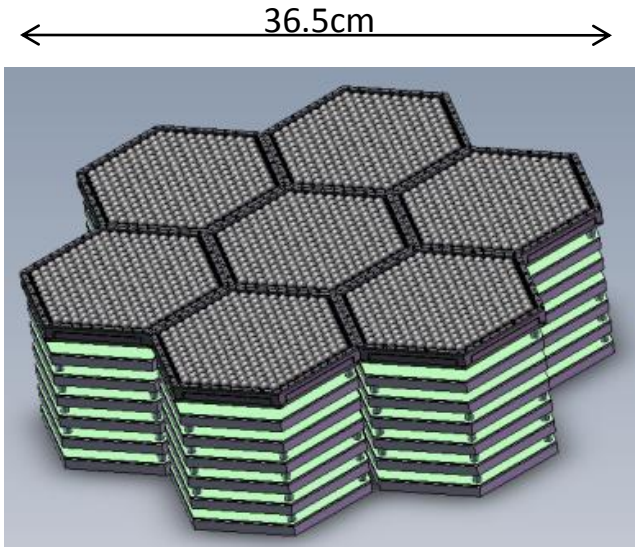
Traditional Focal Plane



Planck HFI Focal Plane. Photo Credit: ESA

- **One frequency band per horn**
- More space is needed for more frequency bands

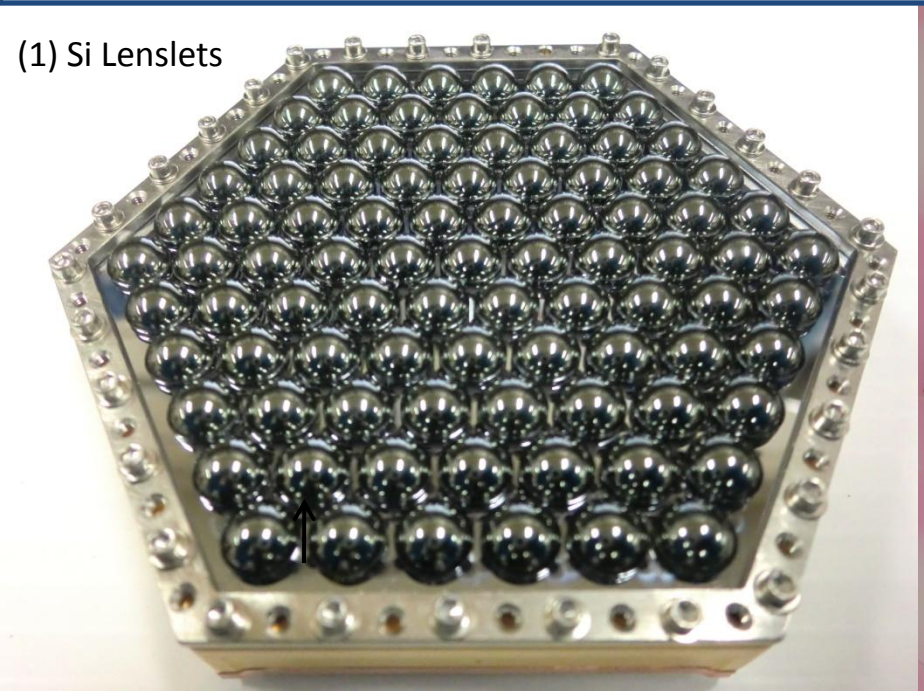
Next Generation Focal Plane

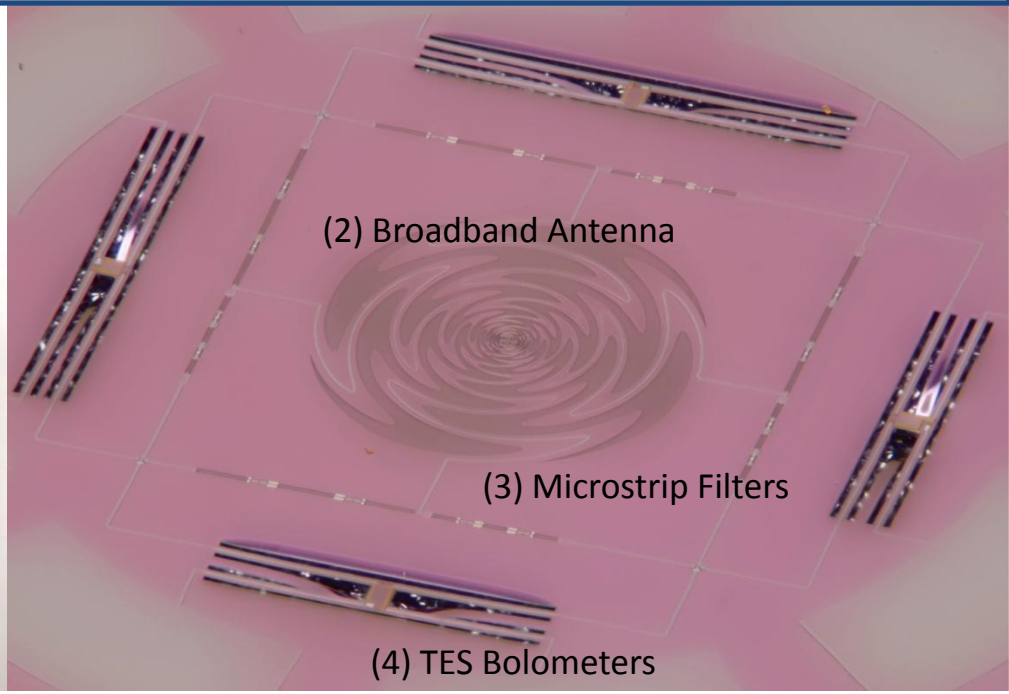


POLARBEAR-2 Focal Plane CAD drawing

- **Multiple frequency bands per pixel**
- No space, weight, & cryogenic cost to increase number of frequency bands

How Multi-Chroic Pixel Operates





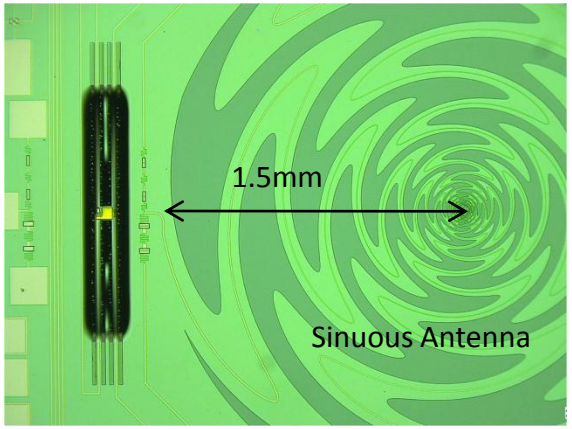
1. Silicon lens focuses beam to antenna
2. Broadband antenna collects photon
3. On chip microstrip filter splits signal into frequency bands
4. TES bolometers detect signal

Components of Multi-Chroic Pixel

1) Lenslet (6mm diameter)

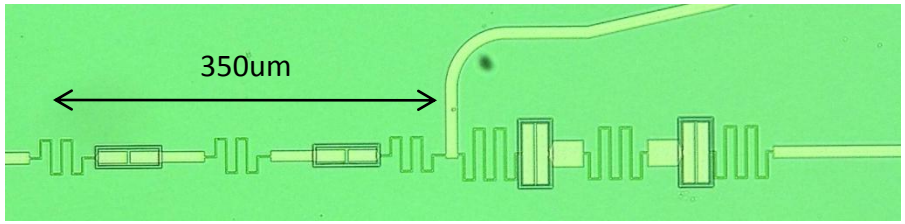
- Broadband anti reflection coated

2) Sinuous Antenna



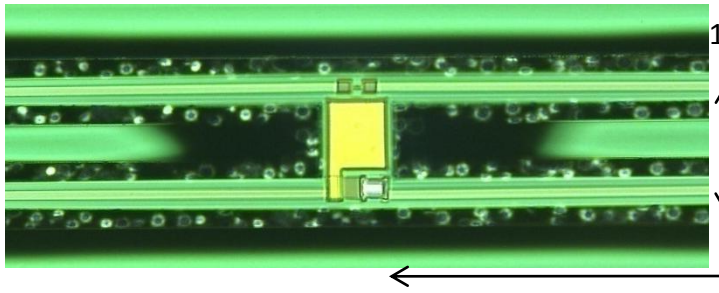
- Over octave bandwidth
- Sensitive to 2 linear polarizations

3) Microstrip Filter



- Splits signal into desired bands
- Lumped elements

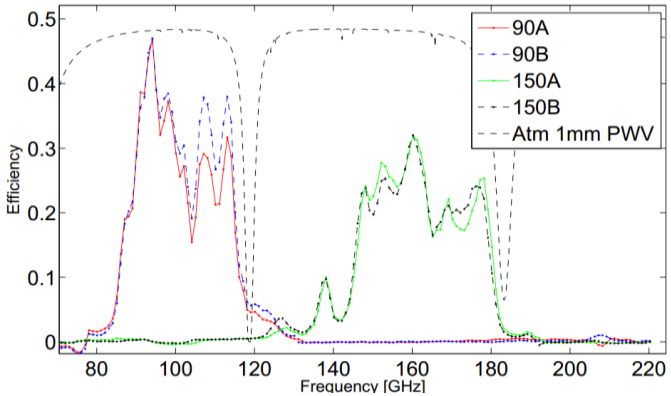
4) TES Bolometer

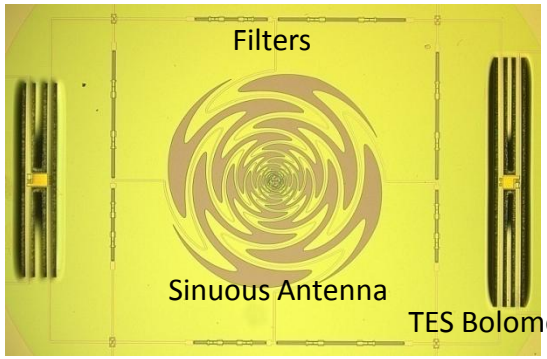


- Operates @ 250mK bath temp
- Background Noise Limited

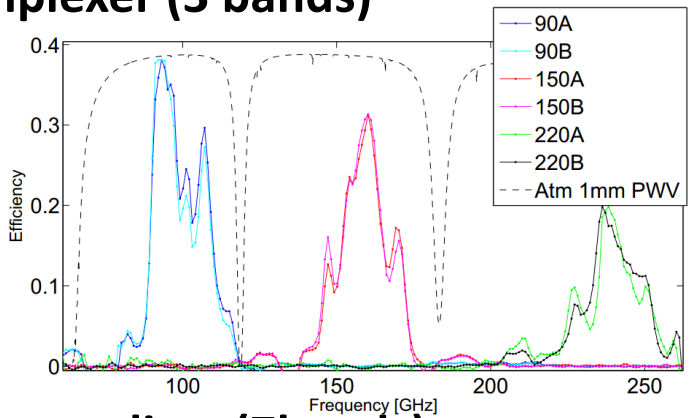
Spectra

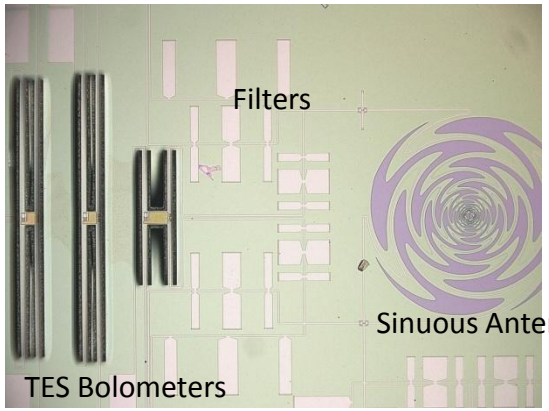
Diplexer (2 bands)



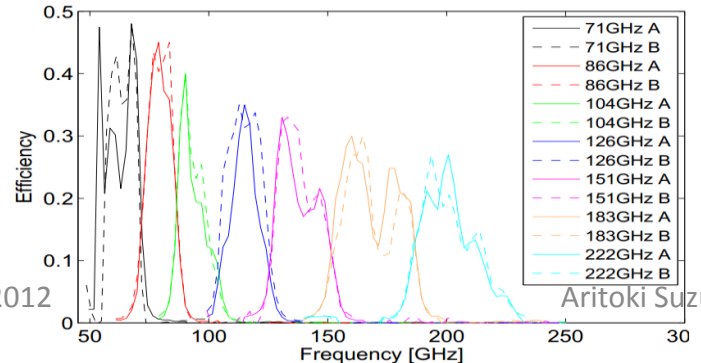


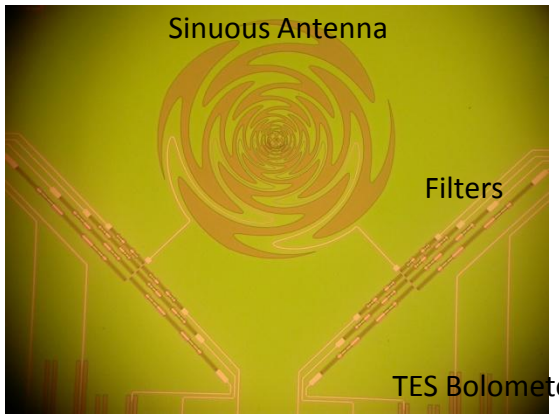
Triplexer (3 bands)





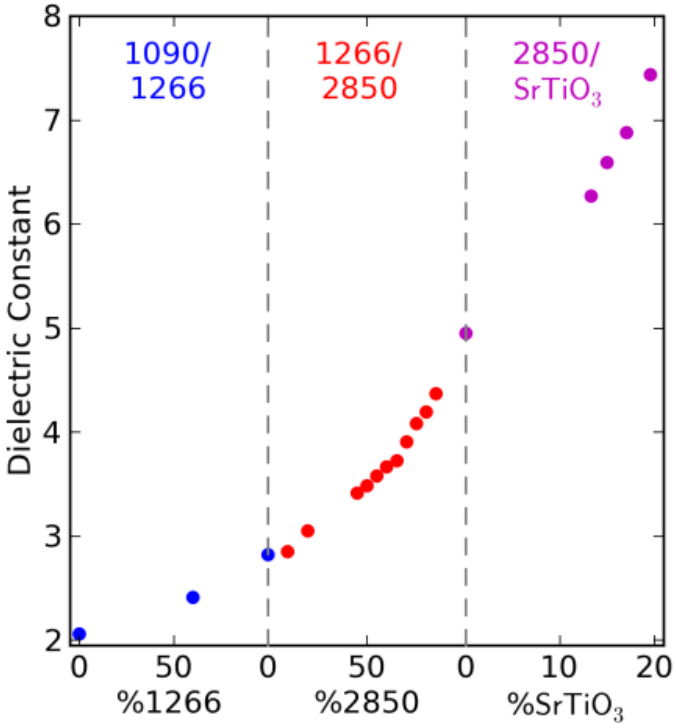
Channelizer (7bands)

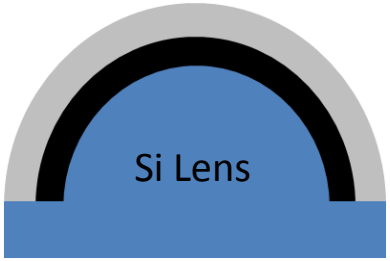




Broadband Anti Reflection Coating

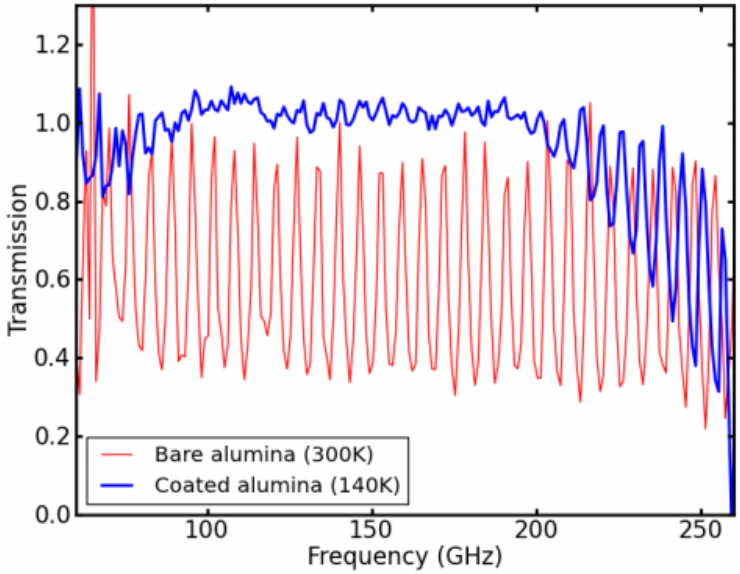
Diel. Const. Control





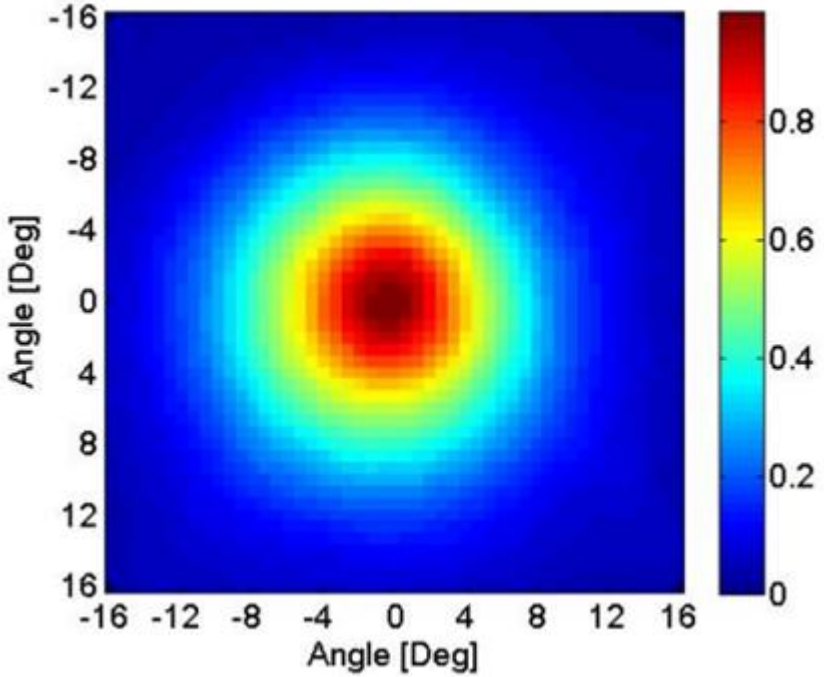
AR Coated Lens

Transmission measurement

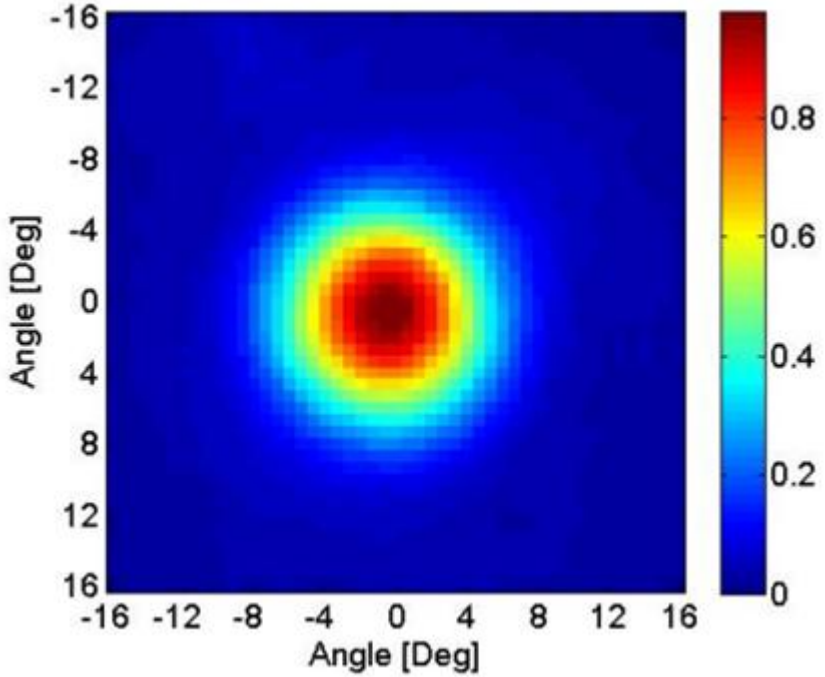


- Silicon lenslet needs broadband anti reflection (AR) coating
- Ability to control index of material by mixing different epoxy + filler
- Successfully made broadband AR using multiple layers of epoxies
- Thermally cycles OK
- Good transmission over broadband

Beam Maps



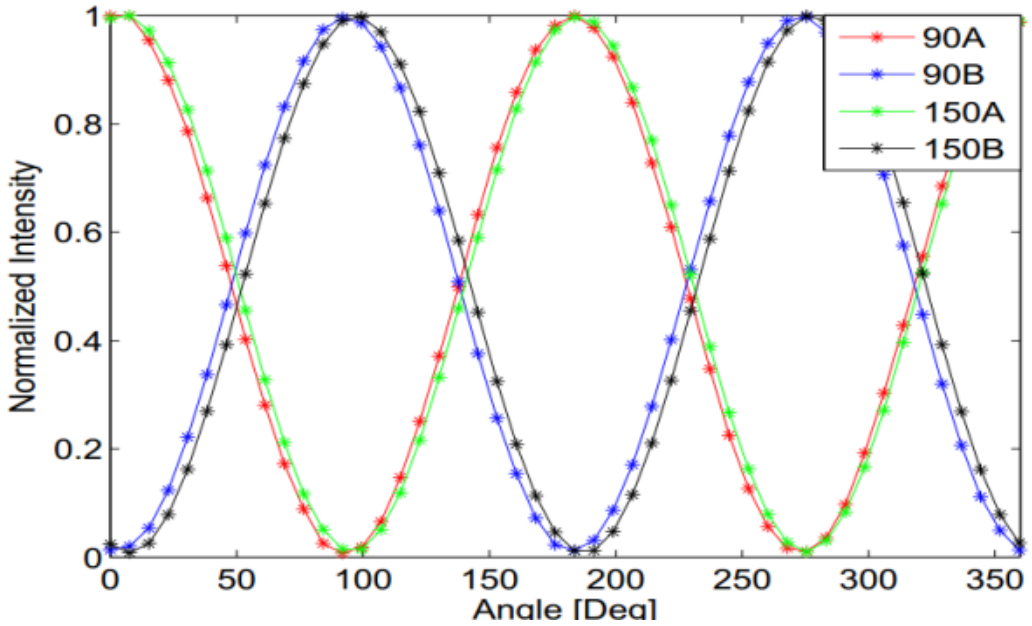
90GHz: Ellipticity 1.6%



150GHz: Ellipticity 1.3%

- Sinuous antenna & lenslet produced round beam
- Measurement uncertainty ~1%

Polarizations



Cross-Pol :

90GHz	0.3%
150GHz	1.3%

- Sinuous antenna & lenslet had low cross-pol level
- Measurement uncertainty ~ 1%

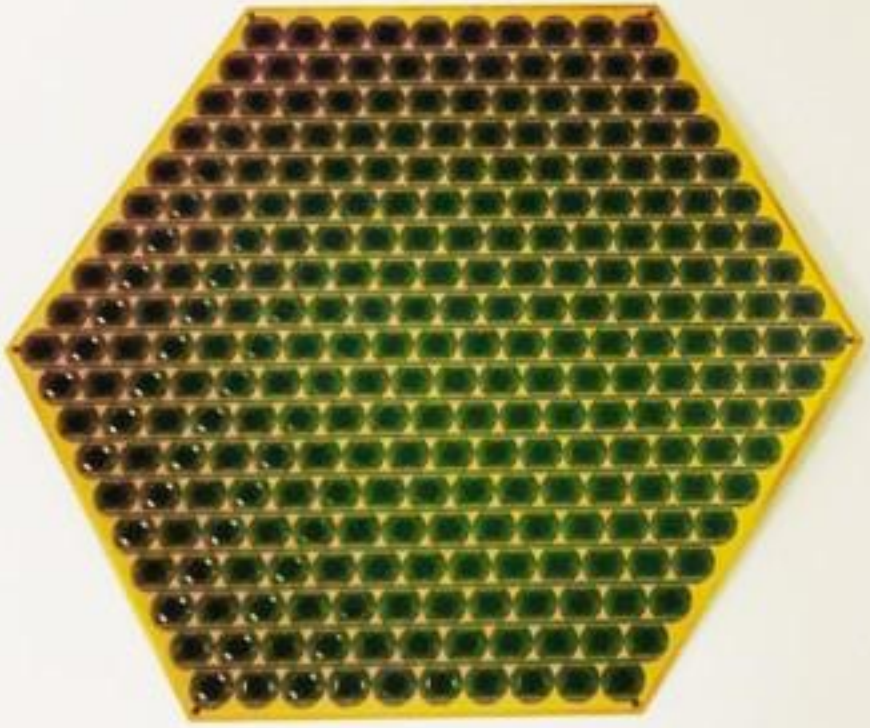
Pixel Array Photo

POLARBEAR-2 Focal Plane:

271 pixels x 2polarizations x 2 frequencies x 7 wafers

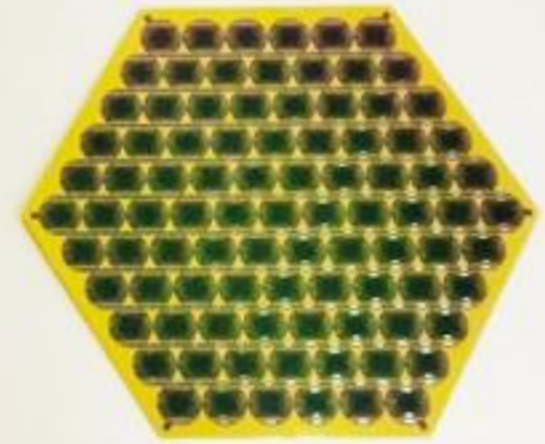
= 7588 bolometers!!

13 cm



271 pixels, 1084 bolometers
90Ghz & 150 Ghz Dipliexer

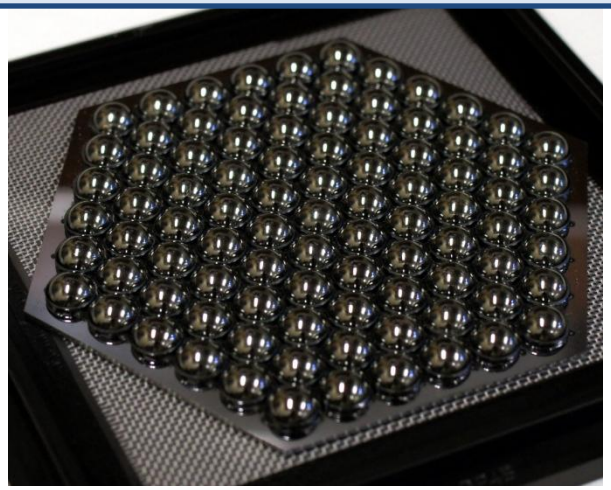
8 cm



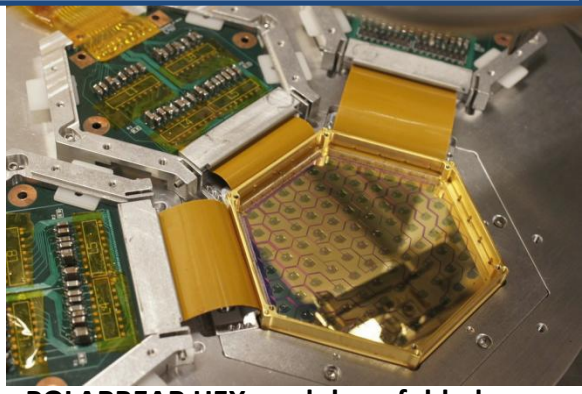
91 pixel, 364 Blometers
90Ghz & 150 Ghz Diplexer

25 cent

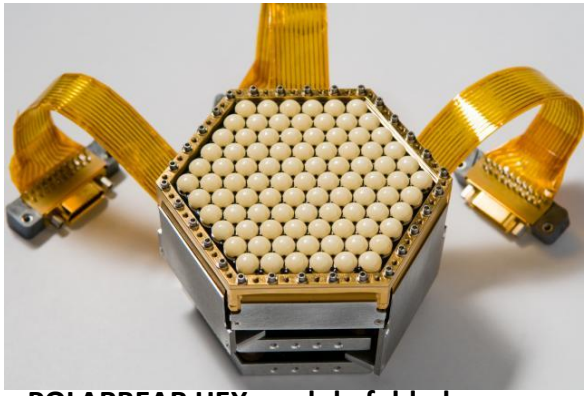
Assembly Process



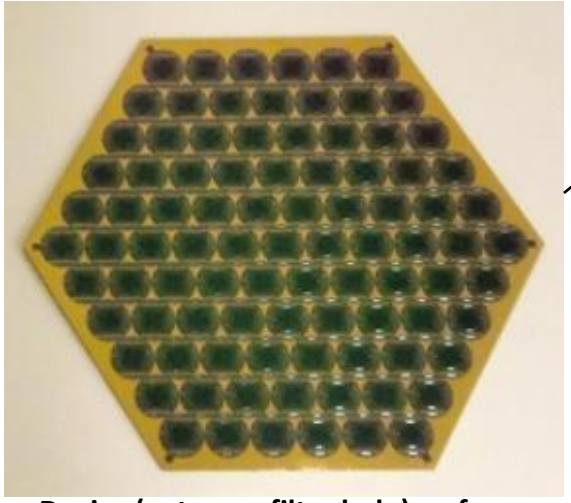
AR coated lens in silicon wafer "seat"



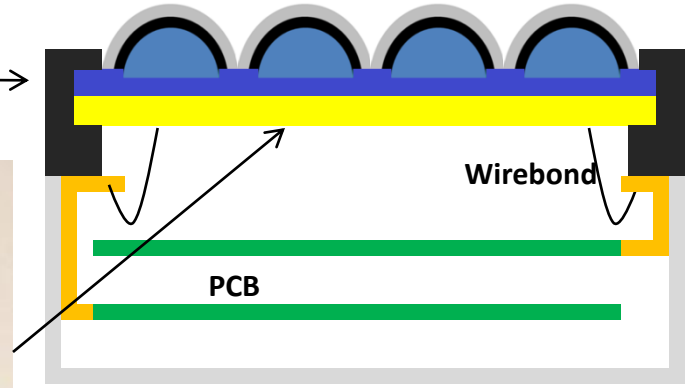
POLARBEAR HEX module unfolded



POLARBEAR HEX module folded



Device (antenna, filter bolo) wafer



Hex Module

POLARBEAR focal plane assembled

Wire bonding

Current Gen Wirebonding

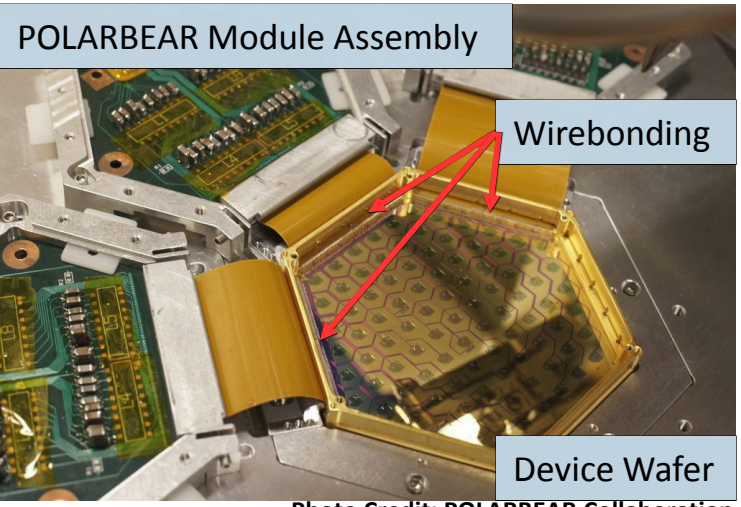
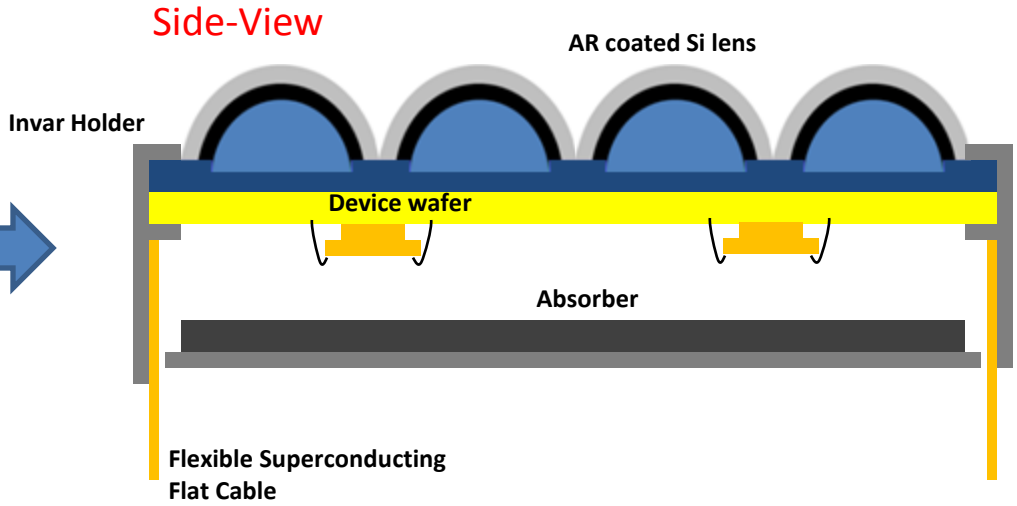


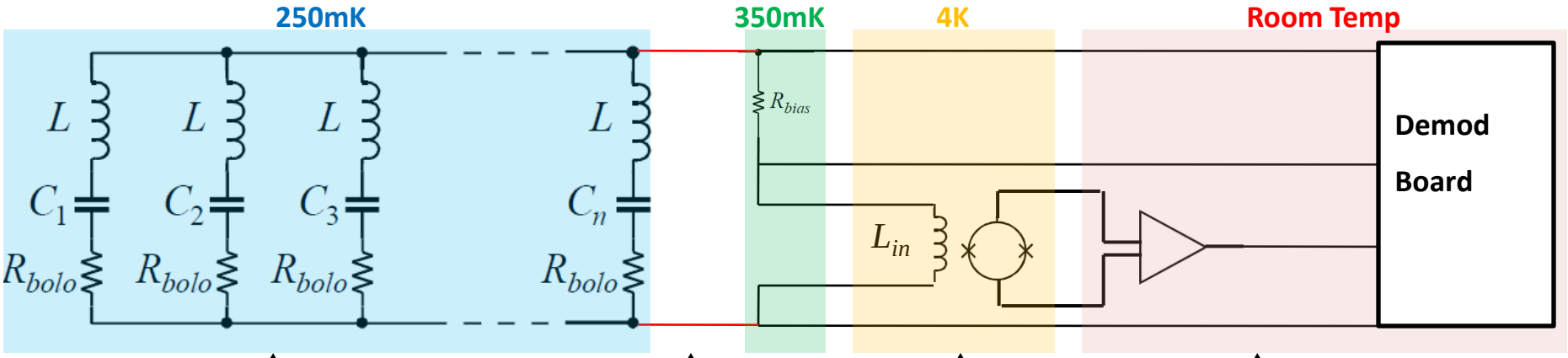
Photo Credit: POLARBEAR Collaboration

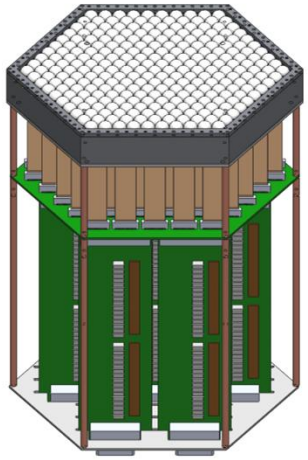
Next Gen Wirebonding ?



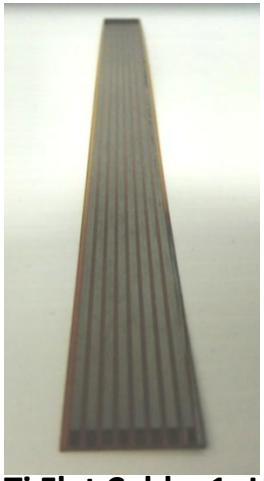
- High bolometer count new wire bonding solution
- Multi-layer Flexible PCB to run between wafers?

Digital Active Nulling Frequency MUX Readout



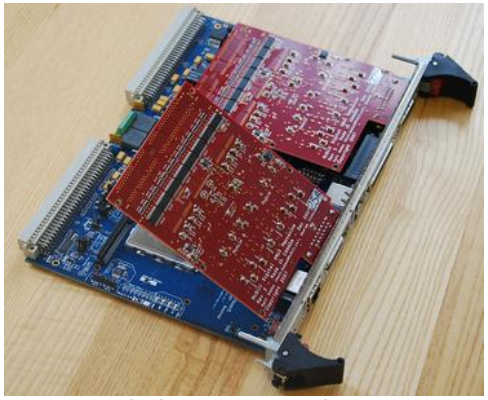


Bolometer + LC board



NbTi Flat Cable, 1nH/cm

NIST SQUID



Demodulator Board

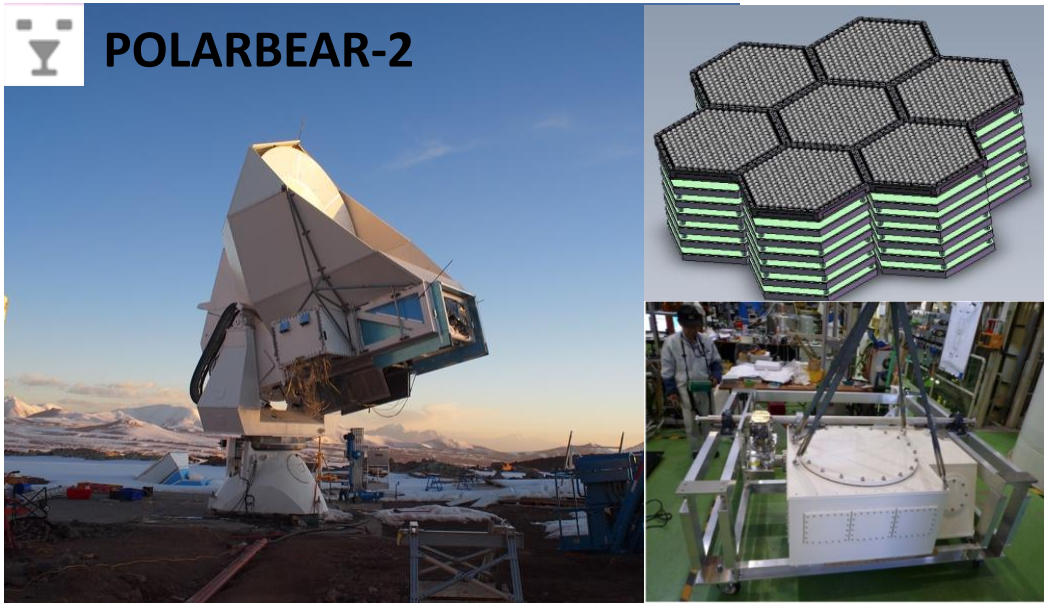
- Reduces number of wiring to mK stage
- x32 MUX readout baseline, 240 SQUIDs
- Total readout bandwidth 3MHz

McGill: Matt Dobbs, Jean-Francois Cliche, Graeme Smecher , Amy Bender, Tijmen de Haan, Adam Gilbert

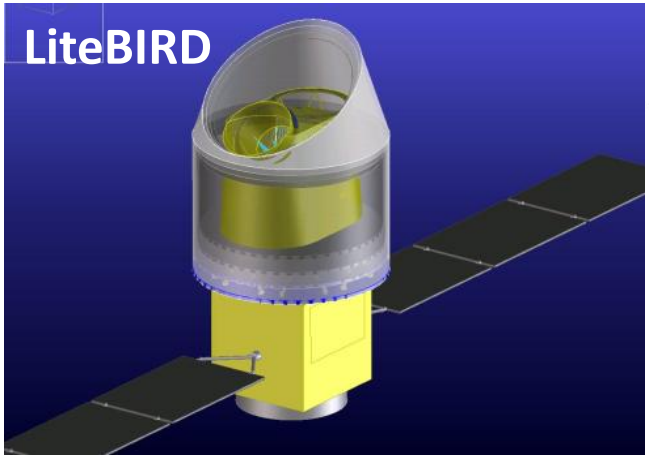
UCB: Nick Harrington

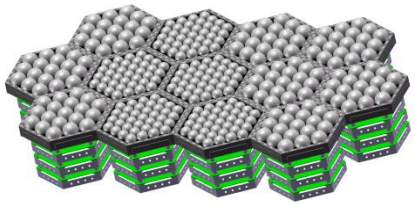
KEK: Kaori Hattori

Where Multichroic Detectors Will be Used



- Atacama, Chile
- 2014~
- 90 & 150 Ghz observation
- **7588** bolometers
- r < 0.01





- Satellite (LEO or L2)
- 2020~
- 50~270Ghz, 6 bands
- **1914** bolometers
- r < 0.002

Conclusion & Summary

Multi-chroic detector provides high sensitivity focal plane efficiently

- We successfully achieved
  - 2,3, and 7 bands pixel
  - Round beam
  - Low cross pol
  - Broadband AR coating
  - Fabrication of large array of pixels
- Reading out this many detectors will be very challenging