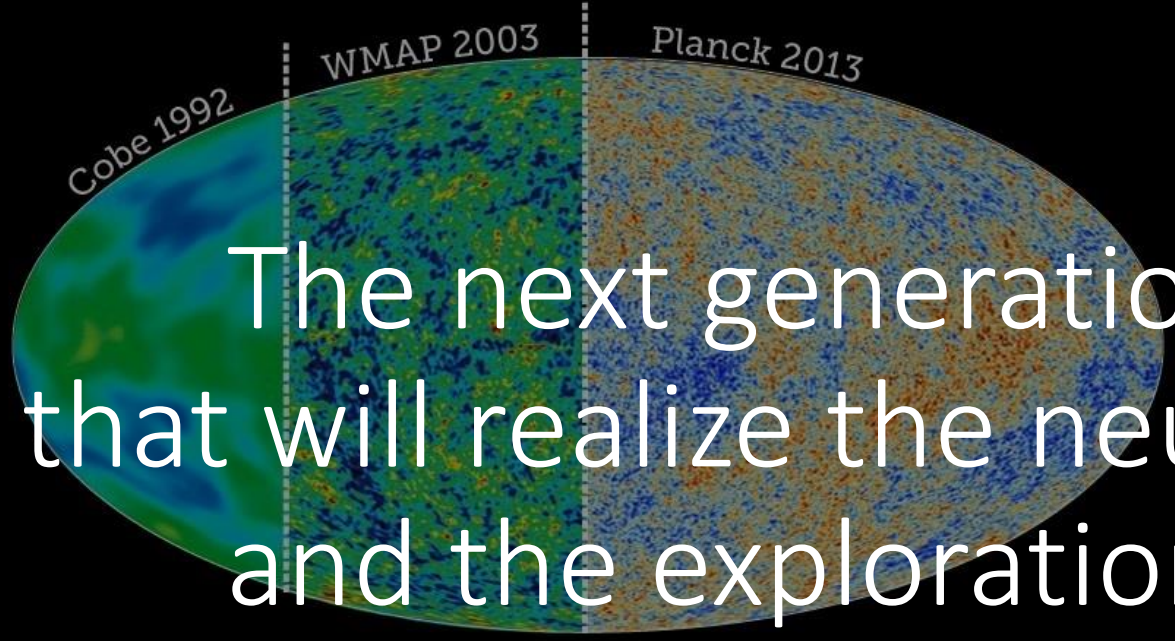


The next generation of CMB observation that will realize the neutrino mass measurement and the exploration of super-TeV physics

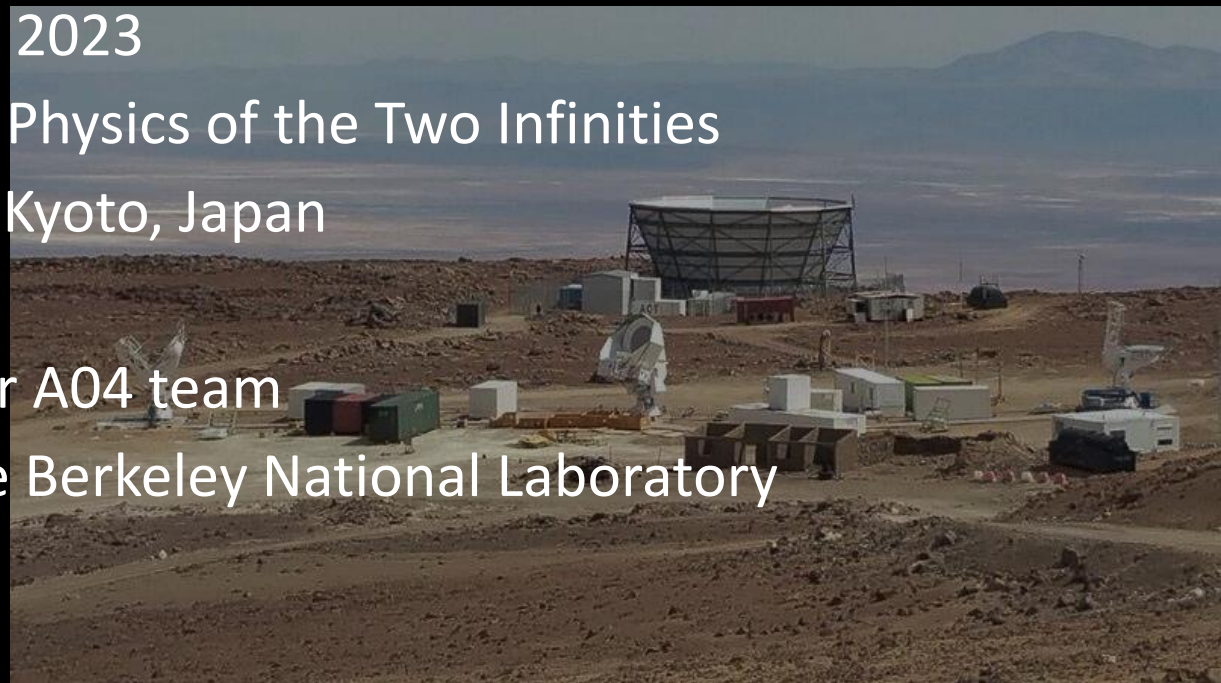
March 29, 2023

International Conference on the Physics of the Two Infinities

Kyoto University, Kyoto, Japan

Akito Kusaka for A04 team

The University of Tokyo / Lawrence Berkeley National Laboratory



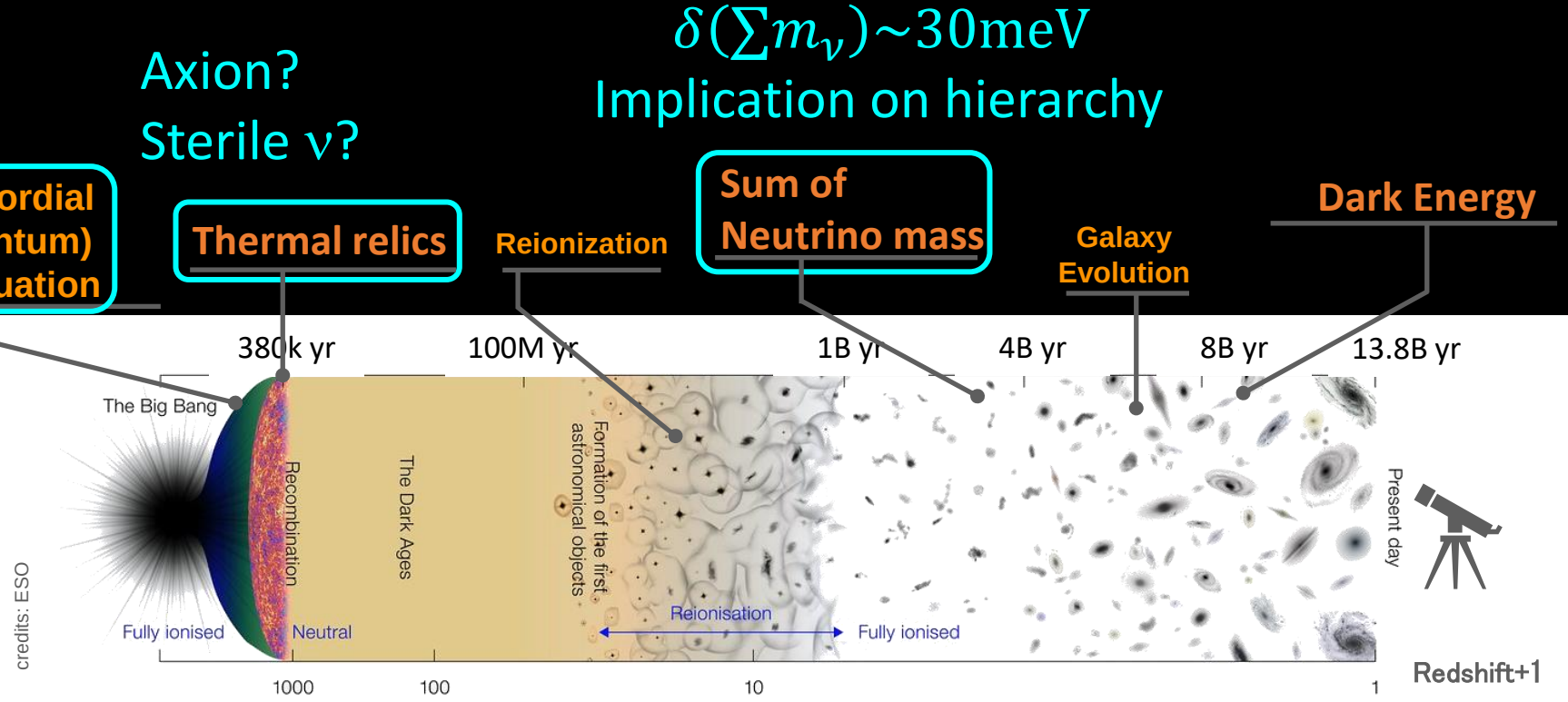
CMB: “backlight” shedding on cosmic evolution

A huge HEP laboratory

Inflation?

Axion?
Sterile ν?

$\delta(\sum m_\nu) \sim 30\text{meV}$
Implication on hierarchy



Order ~1 improvement by next-generation instruments → Leap in cosmology and HEP.

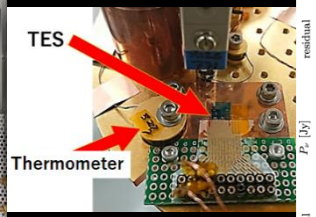
Goals (that we set five years ago)

Technology R&D
Data Analysis

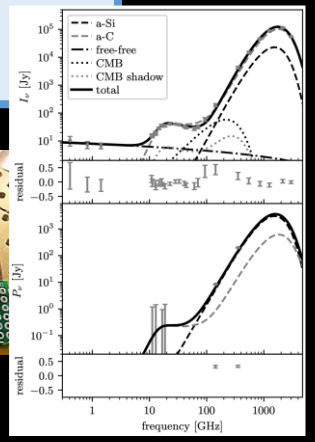
Science w/
Ongoing projects

Community
activities

Readout

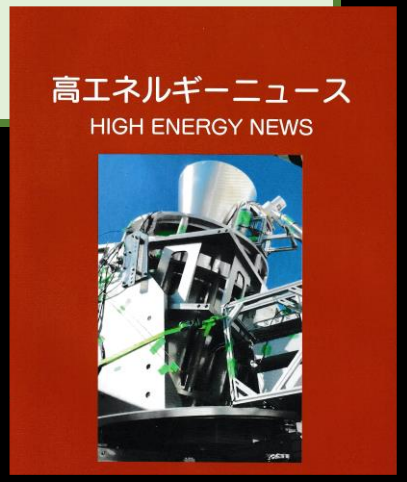


Supercon.
Detectors



Foregrounds

Simons Array



GroundBIRD

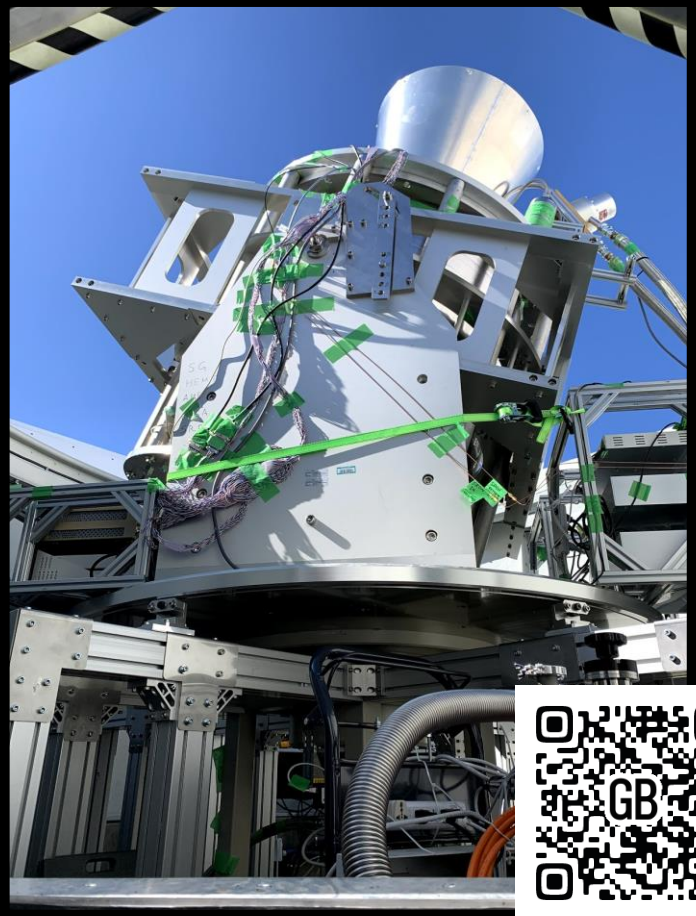
Workshops

Constraints on Inflation and Neutrino Mass through CMB

Establishing “Team Japan” toward the next-generation projects such as CMB-S4

GroundBIRD

Compact telescope for large scale CMB-polarization observations



https://photos.app.goo.gl/ivjrHVkWJcSDzaHNA

Continuous azimuth rotation at 20RPM

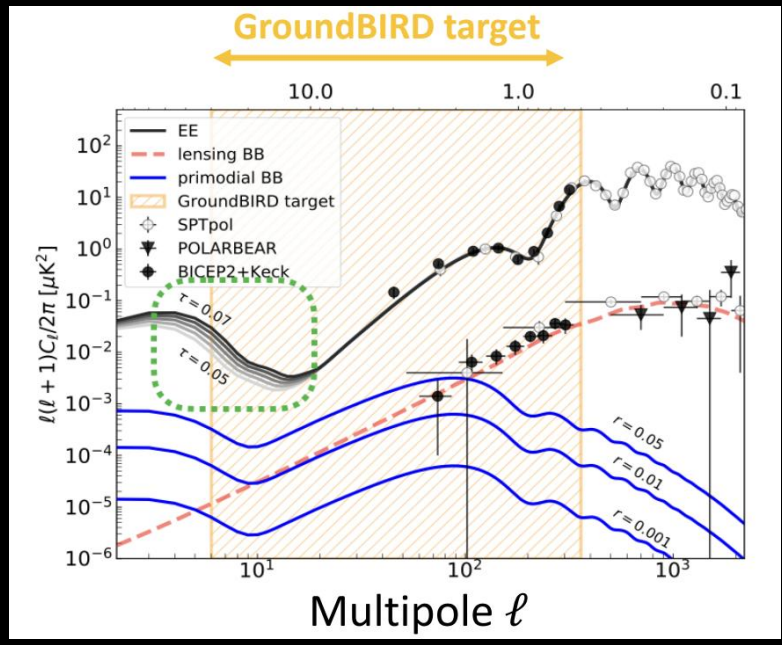
mitigating effects of atmospheric fluctuation

→ Cutting out any 1/f on timescales longer than 3 seconds

Superconducting detector "MKIDs"

faster time response than sampling rate of 1ksps

*two observational frequency bands = **145GHz and 220GHz***

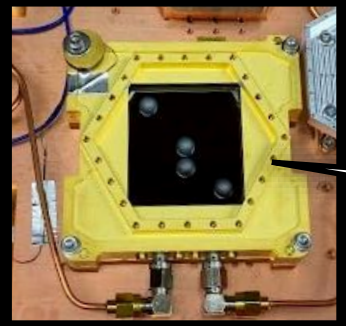


7 MKID modules in focalplane
(23pixels /module)

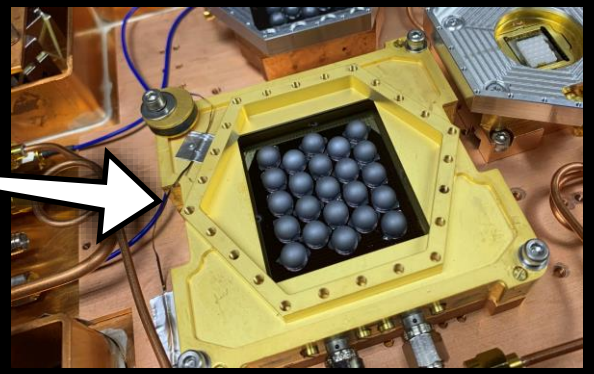
GroundBIRD

- **Performances have been evaluated**
- **with 23 pixels in a test MKID chip**

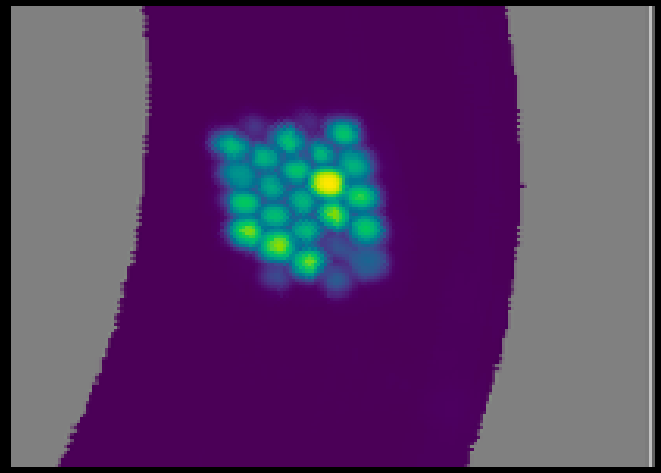
cooling run 2021.07 —



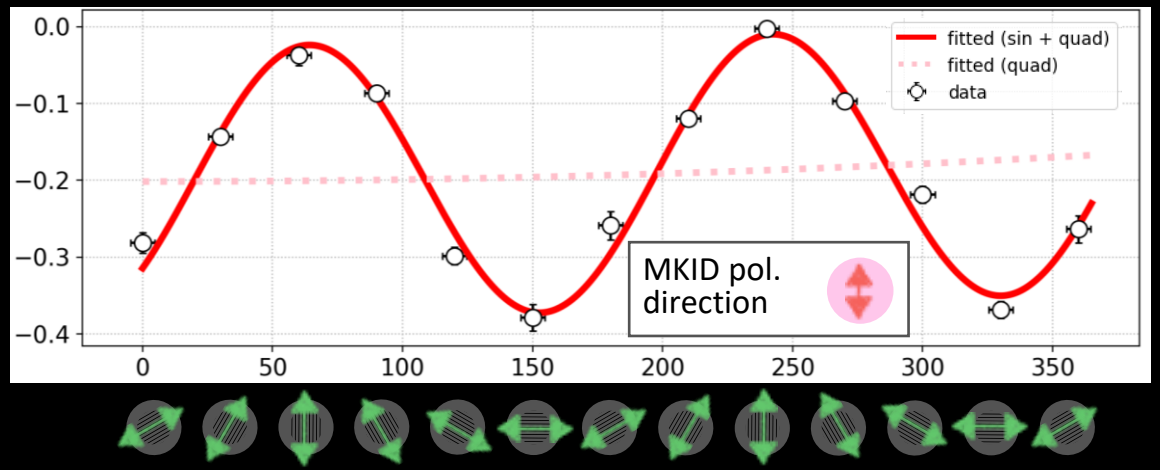
cooling run 2021.12 —



Moon observation

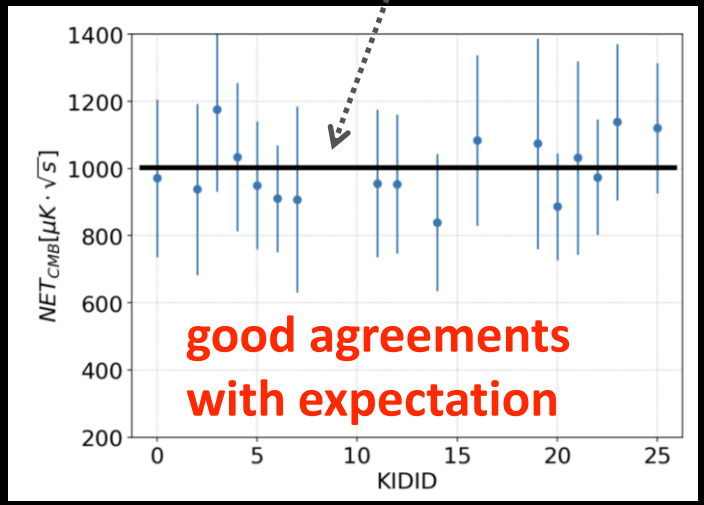


Polarization responses



Sensitivity

prototype expectation at PWV=4mm

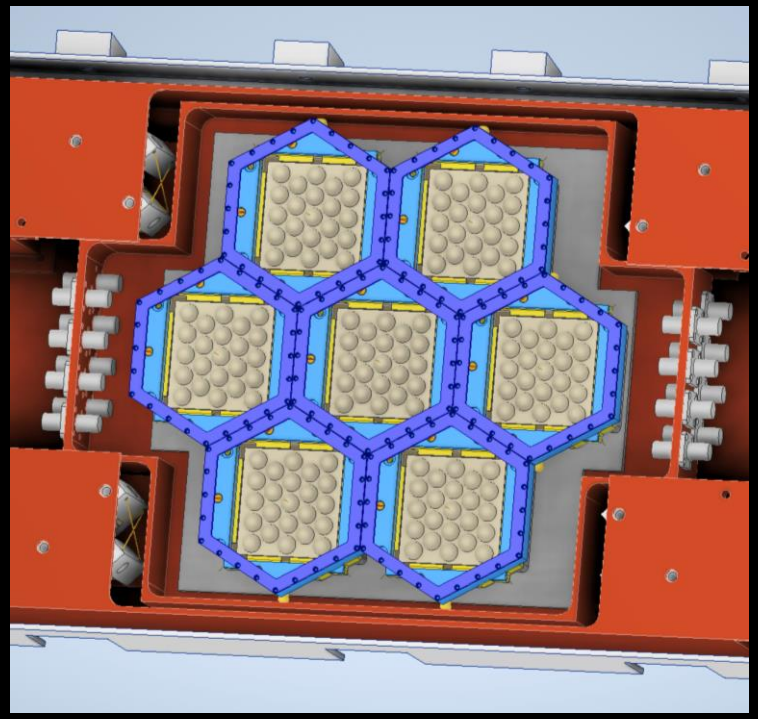


GroundBIRD

Other components also to be upgraded for 7 chip readout!

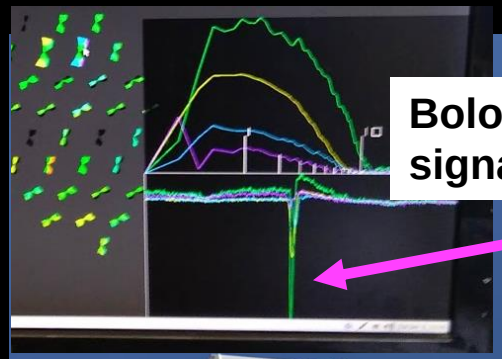
- Lee, Kyungmin et al. “A Forecast of the Sensitivity on the Measurement of the Optical Depth to Reionization with the GroundBIRD Experiment”, Astrophysical Journal, Volume 915, Number 2, 2021
- Sueno, Yoshinori et al. “Characterization of two-level system noise for microwave kinetic inductance detector comprising niobium film on silicon substrate”, Progress of Theoretical and Experimental Physics, ptac023, 2022
- Kutsuma, Hiroki et al. “A method to measure superconducting transition temperature of microwave kinetic inductance detector by changing power of readout microwaves”, AIP Advance 10, 095320 2020
- Honda, Shunsuke et al. “On-site performance of GroundBIRD, a CMB polarization telescope for large angular scale observations”, Proc. SPIE 11445, Ground-based and Airborne Telescopes VIII, 114457Q
- Lee, Kyungmin, et al. "GroundBIRD: A CMB polarization experiment with MKID arrays." Journal of Low Temperature Physics 200 (2020): 384-391.
- Kutsuma, Hiroki, et al. "Optimization of Geomagnetic Shielding for MKIDs Mounted on a Rotating Cryostat." Journal of Low Temperature Physics 193 (2018): 203-208.

cooling run 2023.05 —

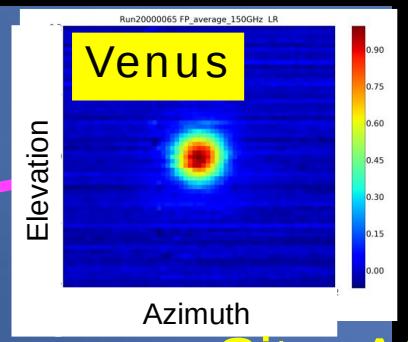


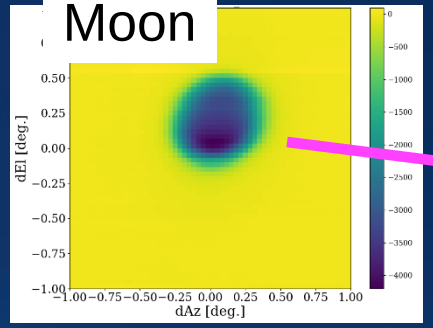
Operation with full MKID arrays will start from June 2023!

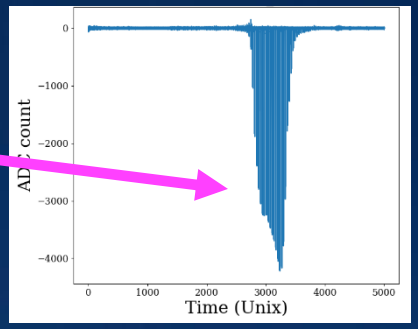
POLARBEAR / Simons Array



Bolometer signal

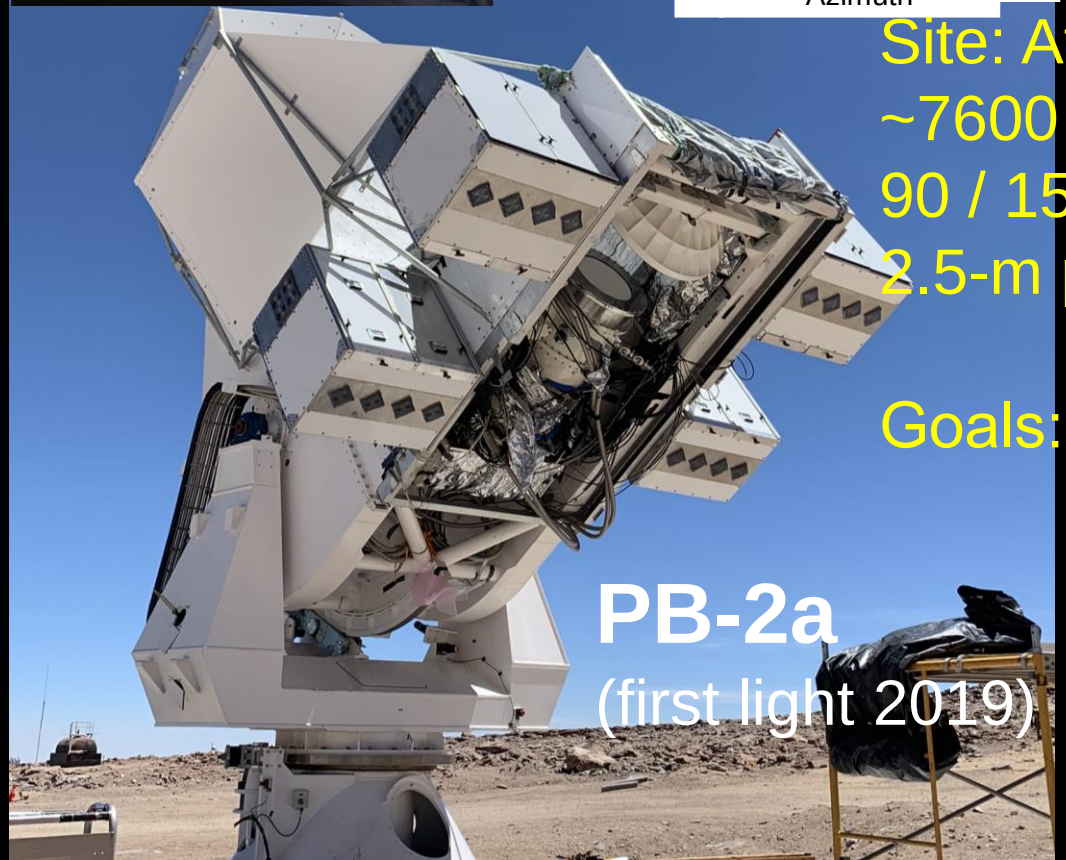






Bolometer signal

Site: Atacama, Chile
~7600 detectors per telescope
90 / 150 GHz dual frequency
2.5-m primary aperture
3~5 arcmin resolution
Goals: Inflation / Neutrino, ...



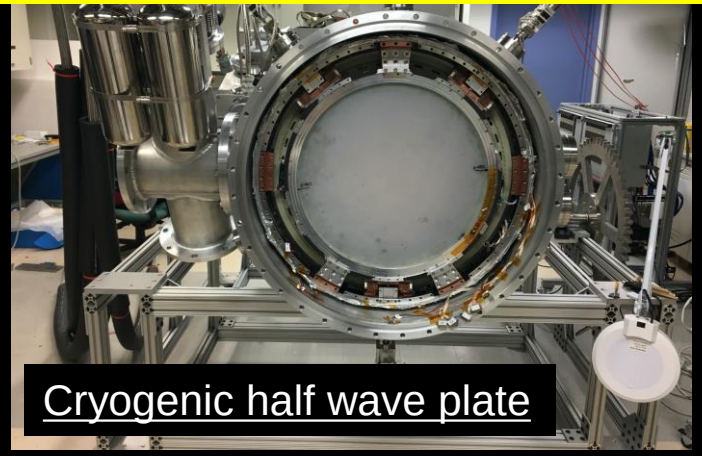
PB-2a
(first light 2019)

PB-2b
(first light 2022)

POLARBEAR / Simons Array

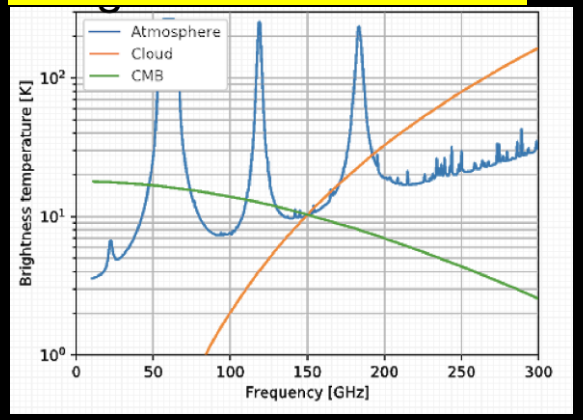
Analysis framework well in progress

Modulators
Instrumental systematics & low frequency noise mitigation

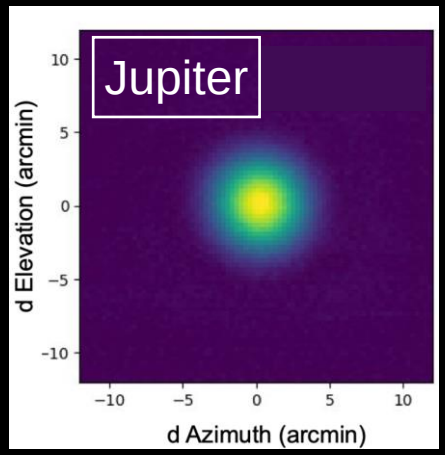


Cryogenic half wave plate

Study of a new noise/syst. source
Ice Cloud polarization

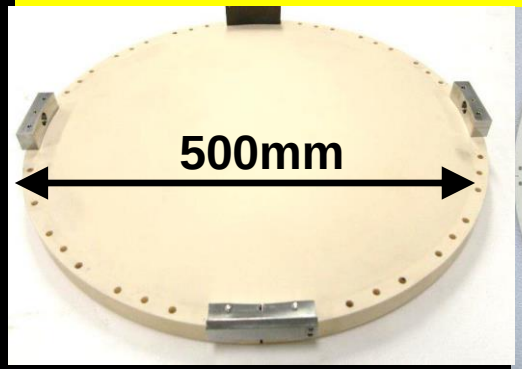


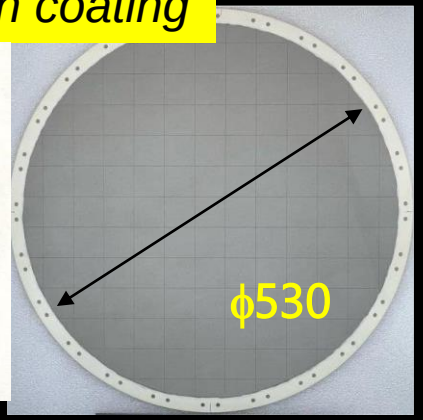
Calibration



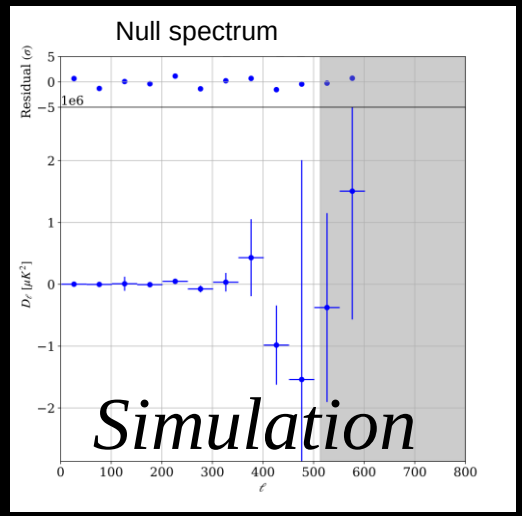
Beam :
150 GHz … 3.3 arcmin
90 GHz … 5 arcmin
Gain accuracy : ~0.3%
Angle accuracy : ~0.2 deg.

Large optical element
Alumina, Anti-reflection coating





Established key technologies to SA and the next (SO, CMB-S4 & LiteBIRD)



Null test

Bias evaluation w/o looking at signal

POLARBEAR / Simons Array

Topic	Journal
Cross correlation of lensing deflection with Cosmic Infrared Background	PRL 112, 131302 (2014) Editor's suggestion
Lensing deflection power spectrum	PRL 113. 021301 (2014) Editor's suggestion
CMB B-mode auto power spectrum (1^{st} year)	ApJ 794, 2 (2014)
Modeling of atmospheric emission	ApJ 809, 63 (2015)
Cosmic Birefringence and Primordial Magnetic Field	PRD 92, 123509 (2015) Editor's suggestion
Map-making algorithm	A&A 600, A60 (2017)
Performance of continuously HWP	JCAP 05 008 (2017)
B-mode auto power spectrum (1^{st}+2^{nd} year)	APJ 848, 2 (2017)
Ice cloud	APJ 870, 2 (2019)
POLARBEAR x Herschel-ATLAS	ApJ 886, 38 (2019)
POLARBEAR x HSC	ApJ 882, 62 (2019)

Topic	Journal
FTS Calibrator	RSI 90, 115115 (2019)
Lensing power spectrum	ApJ 893, 85 (2019)
Delensing	PRL 124, 131301 (2020)
Degree scale CMB B-mode spectrum	ApJ, 897, 55 (2020)
E-mode power spectrum	ApJ 904 65 (2020)
Warm temperature monitoring	JATIS 8, 036003 (2022)
Improved degree scale CMB B-mode spectrum	ApJ, 931, 101 (2022)
Blackbody absorber	Appl. Optics 62, 1419 (2023)

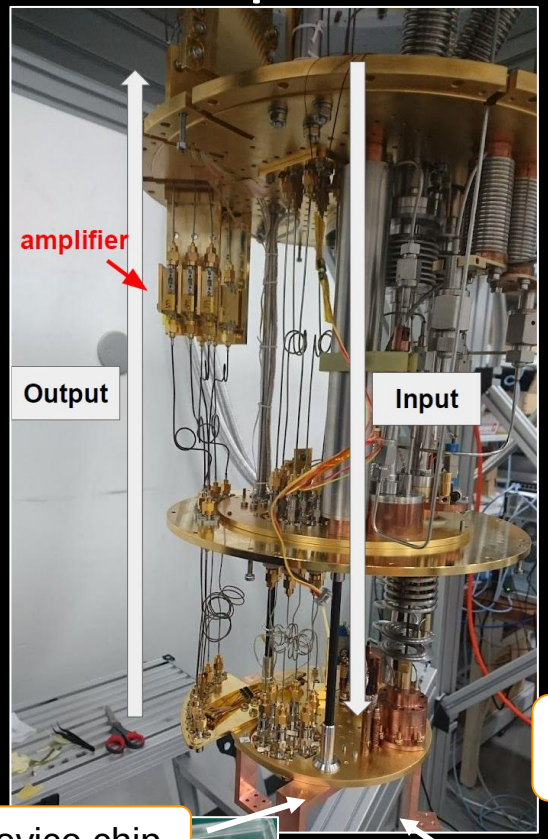
Best *r* limit from Chile

Constraints on axion-like polarization oscillations in the cosmic microwave background with POLARBEAR

ArXiv:2303.08410 (2023)
Submitted to PRD

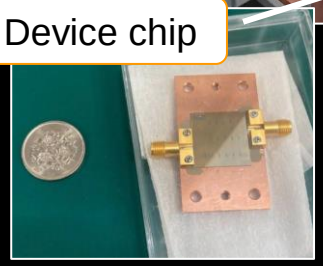
New!

Technology/Analysis R&D
Superconducting device test & readout

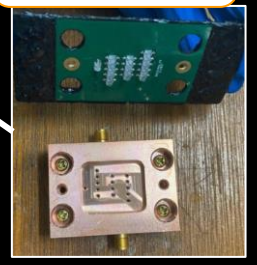


- Base temperature 50 mK
  - Approx. 48h for 300K to 50mK
- RF measurement equipment
  - VNA: Frequency sweep
  - SMuRF: RF TES & MKIDs
  - GB readout: MKIDs
- Device characterization equipment
  - e.g., AC resistance bridge
- 6 RF devices in one cooling run
- Dark and/or Optical
- Fully remote measurement

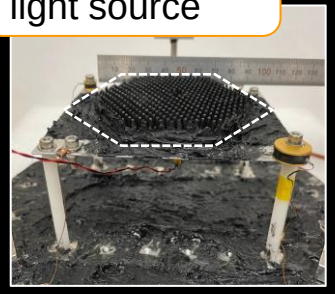
Device chip

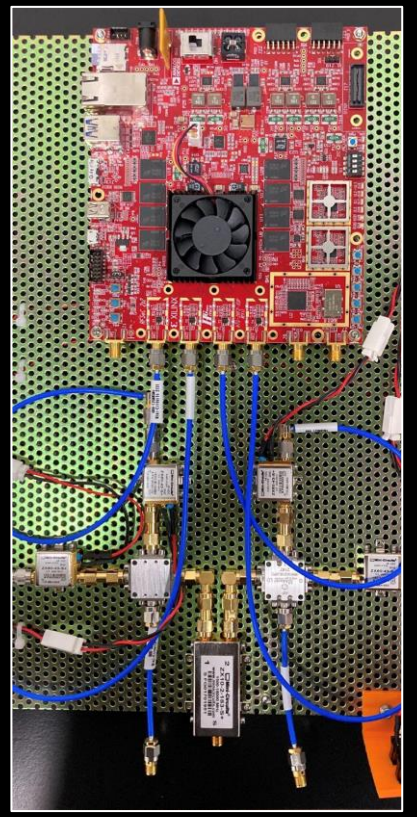


LED IR light source

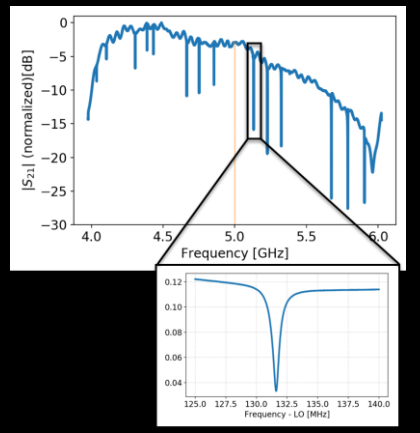


Blackbody mm light source





Superconducting resonator (MKIDs)
Read out by developed readout system



Development of microwave multiplexing readout using RFSoC.

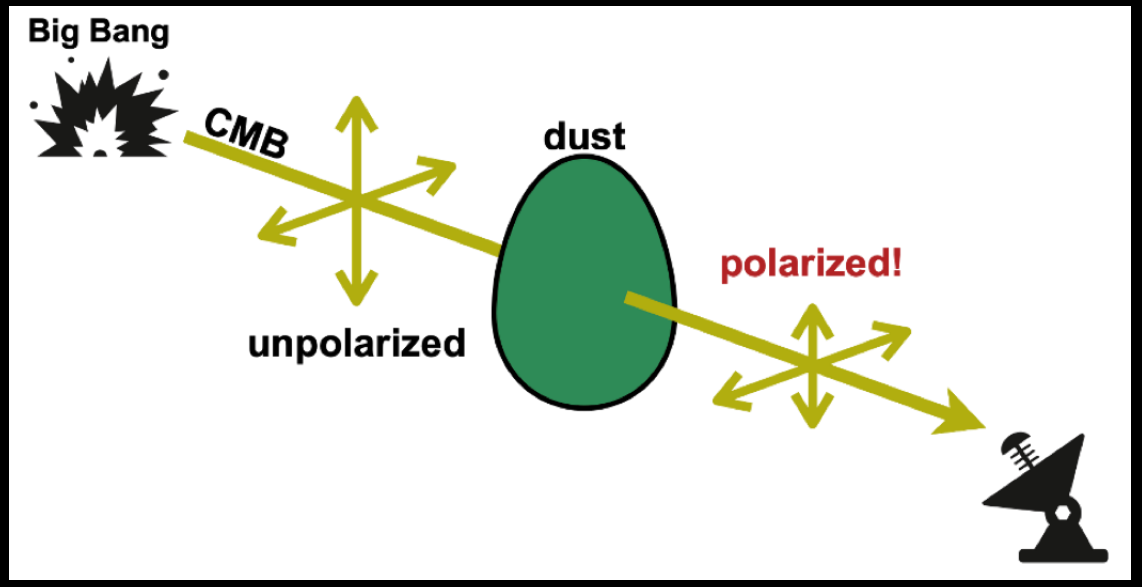
- Higher MUX factor
- Lower cost

Investigation on DAQ integrated into telescope systems.[10]

Technology/Analysis R&D
Deeper understanding of foregrounds

CMB shadow!

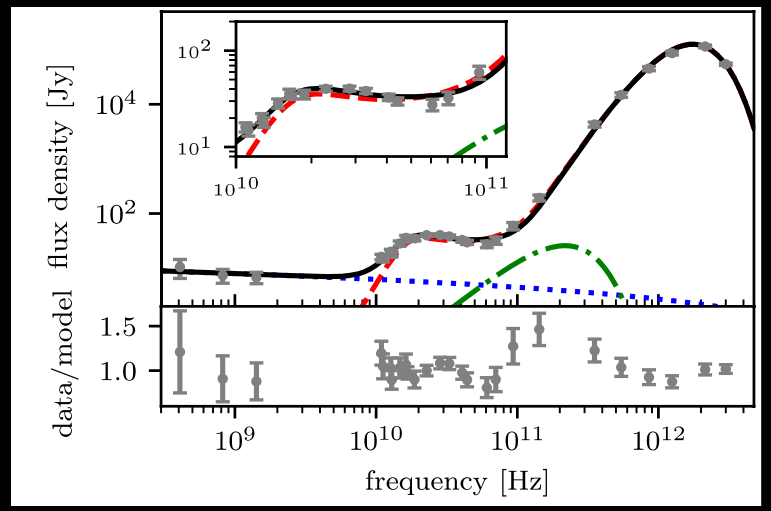
Foregrounds: not only emission, but absorption.

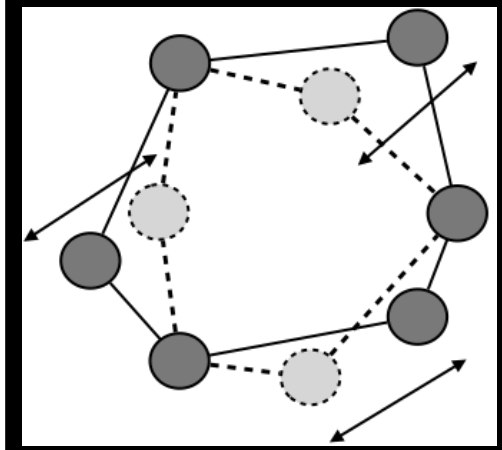


"CMB Shadows …", M.Nashimoto, M.Hattori, Y.Chinone, ApJ Letters, 895, id.L21, 5pp (2020)
"Map-based studies on how the CMB shadow degrades …", T.Murokoshi, Y.Chinone, M.Nashimoto, K.Ichiki, M.hattori, submitted to ApJ Letters (2023)

Dust emission

Understanding physical process of the dust emission





"Thermal emission from the amorphous dust: …", M.Nashimoto, M.Hattori, R.T.Genova-Santos, F.Poidevin, PASJ, 72, id.8 (2020)
"Cosmic Amorphous Dust model as the origin of anomalous microwave emission", M.Nashimoto, M.Hattori, F.Poidevin, R.T.Genova-Santos, ApJ Letters, 900, id.L40, 7pp (2020)

Summary

Three goals in the exploration of inflation and cosmic neutrinos:

- Execution of on-going projects: Simons Array and GroundBIRD
  - Both project making solid progress.
  - Simons Array / POLARBEAR set the tightest constraint on *r* from Chile.
  - GroundBIRD up for making unique constraint at LARGE angular scales.
- Development toward future CMB projects
  - Unique capability: device testing facilities and readout.
  - Deeper understanding of the foregrounds emission.
  - On-going projects contributed to this area as well.
- Supporting Japanese CMB community
  - Stimulating young forces in this area.
  - This program seeded even a larger initiative: JSPS core-to-core program.