GroundBIRD

CMB polarization observation with continuously high-speed rotation

Shunsuke Honda (U Tsukuba) on behalf of GroundBIRD Collaboration

Outline

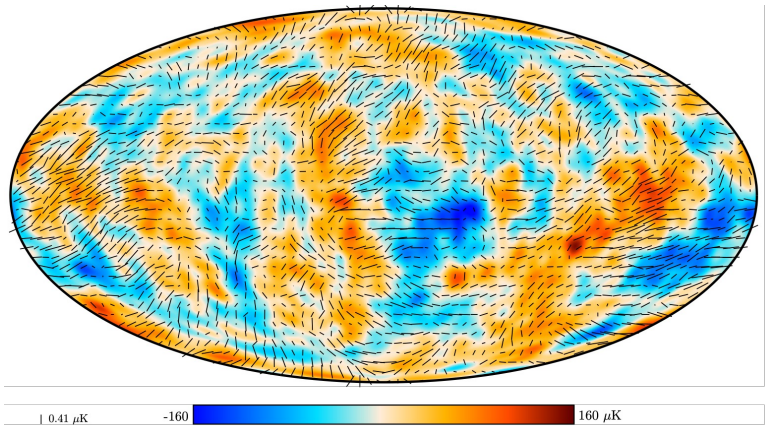
- Introduction of CMB polarization
- GroundBIRD overview and first-light
- Instrumental features
- Current status

CMB Polarization Observation

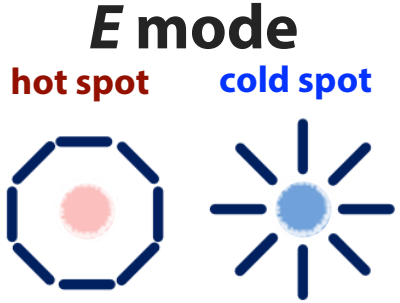
maps taken from "A&A Volume 641, September 2020, Planck 2018 results"

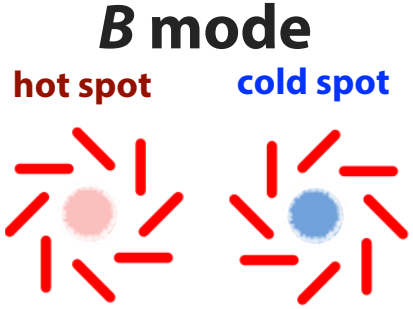
CMB polarization power = O(0.1–1) μK

linear polarization measured with two orthogonal components



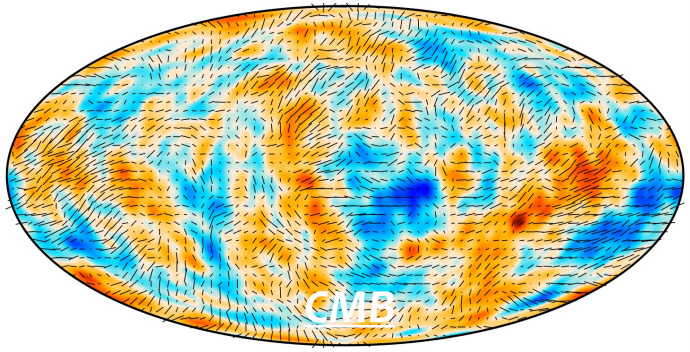
color: intensity *rods: pol. ampl. and direc.*

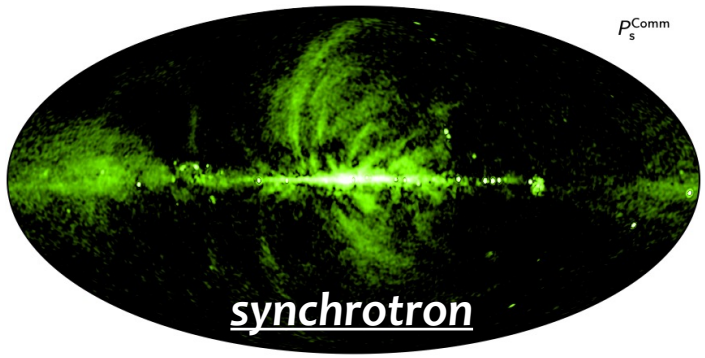


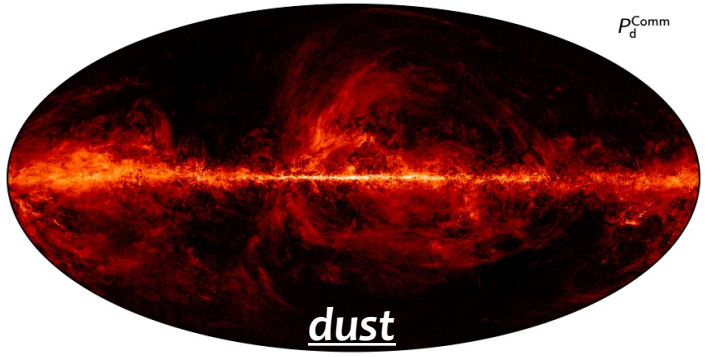


To measure weak CMB polarization precisely, foreground and atmospheric components should be carefully removed from the data.

Atmosphere and Foreground



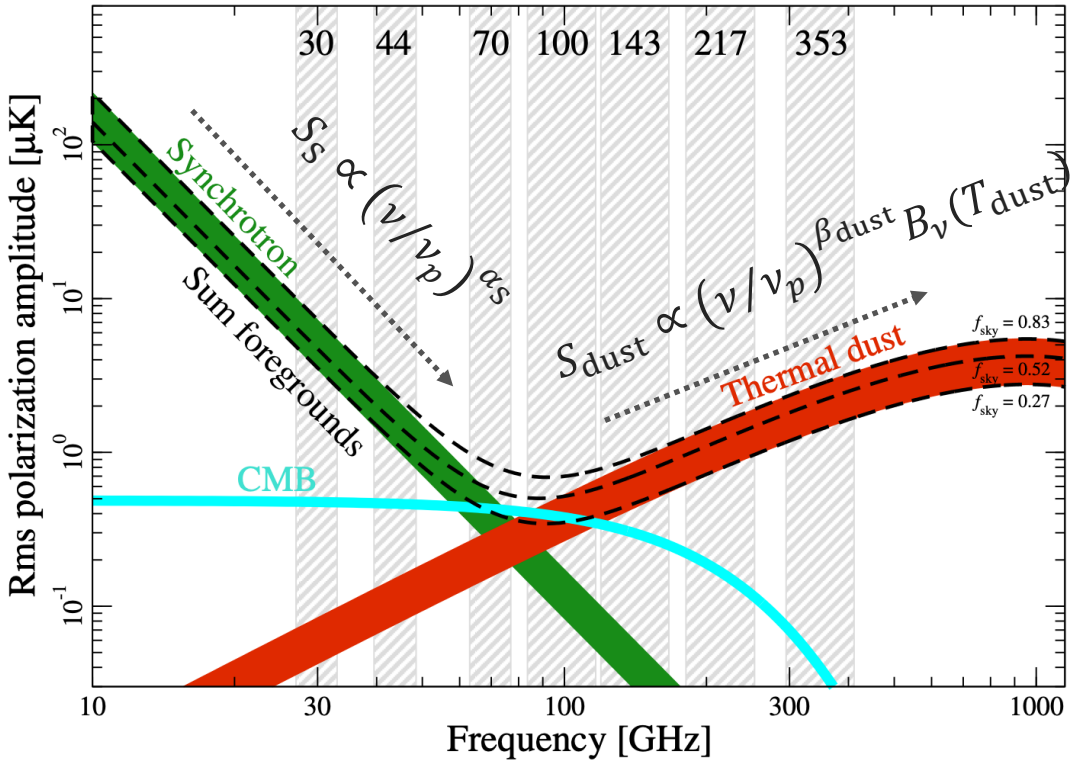




https://www.cosmos.esa.int/web/planck/picture-gallery

① foreground emissions

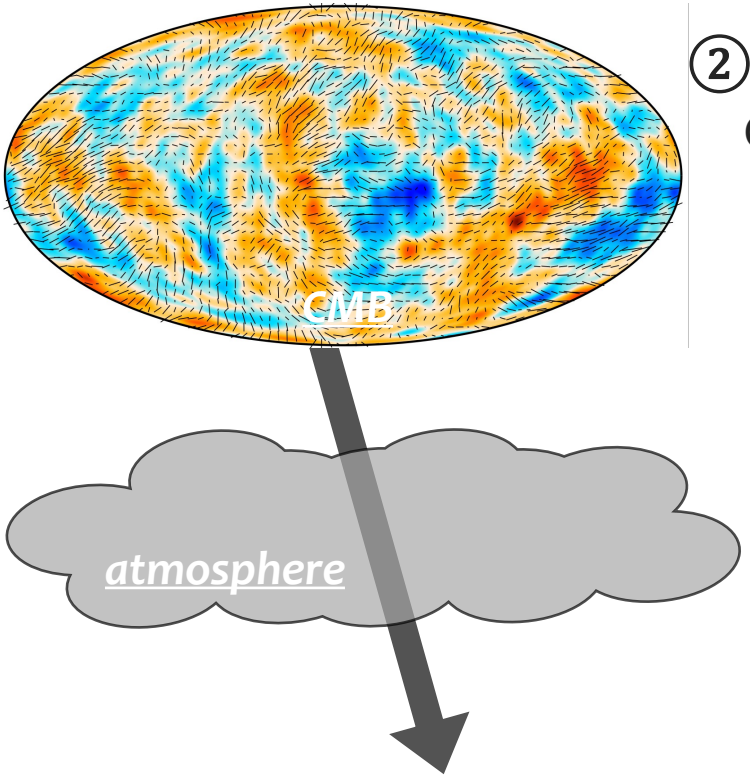
having different frequency scalabilities

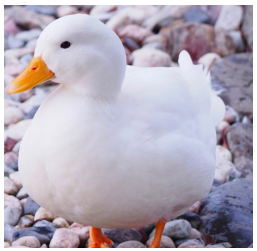


https://www.cosmos.esa.int/web/planck/picture-gallery

multiple observational freq. bands
are essential to estimate each component

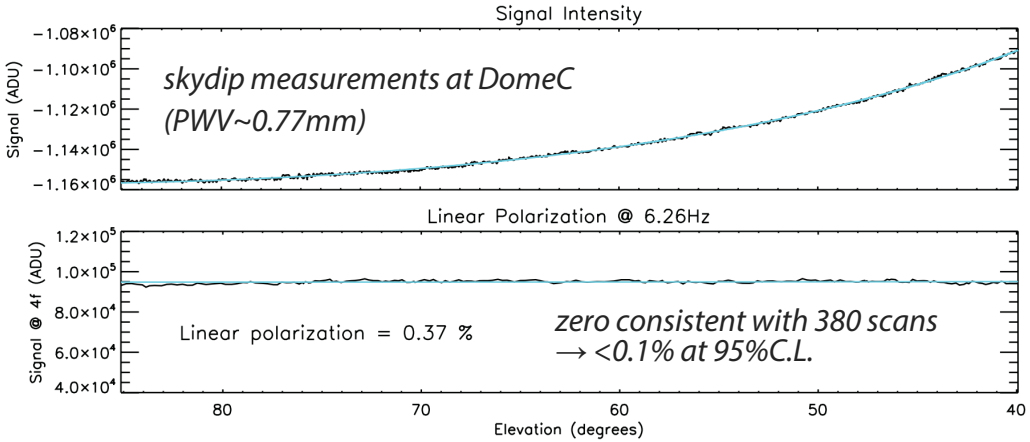
Atmosphere and Foreground





② atmosphere contributions: non-pol in principle

O(10) sec. scale fluctuations with leakage from non-pol



E.S. Battistelli, Monthly Notices of the Royal Astronomical Society, Volume 423, Issue 2, June 2012, Pages 1293–1299

three options to mitigate this effect

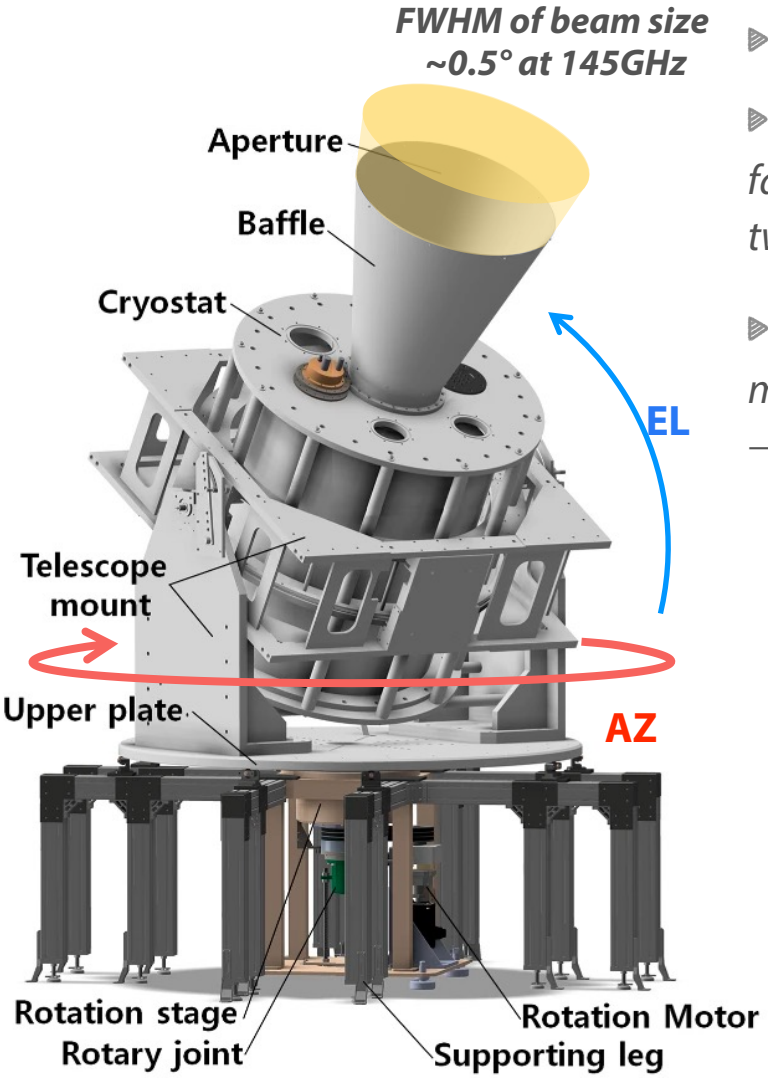
- Satelite observations
- Precise observations in small angular patches
- **observations with High-speed rotation**

https://www.cosmos.esa.int/web/planck/picture-gallery

GroundBIRD Telescope (GB)

Compact telescope for large scale CMB-polarization observations

Installed at the observatory in 2019 and achieved the first light with moon



- **Elevation from 60° to 90°**
- **Superconducting detector "MKIDs"**

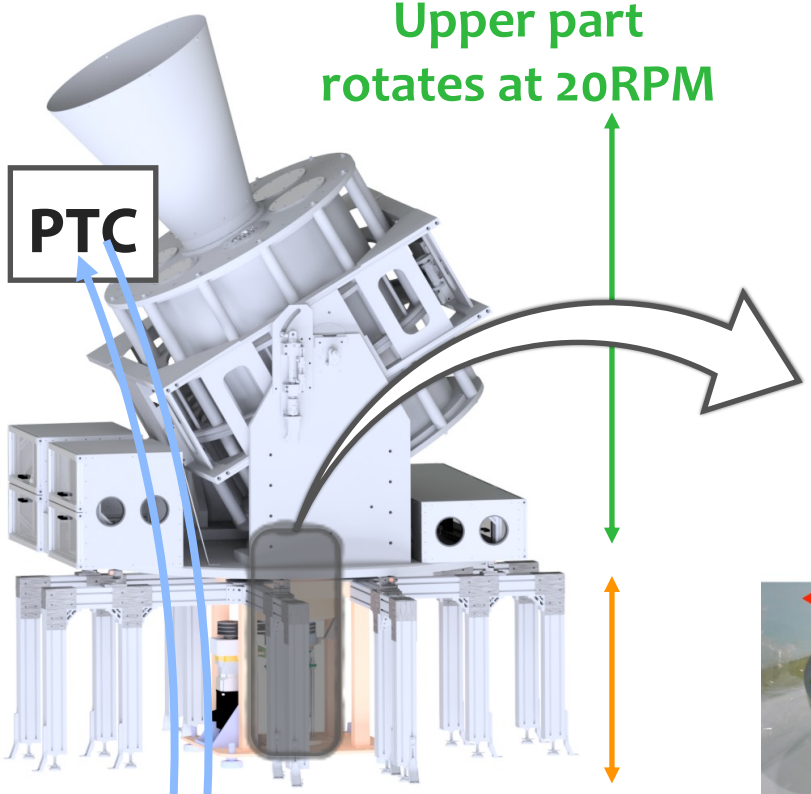
faster time response than sampling rate of 1ksps
*two observational frequency bands = **145GHz and 220GHz***

- **Continuous azimuth rotation at 20RPM**

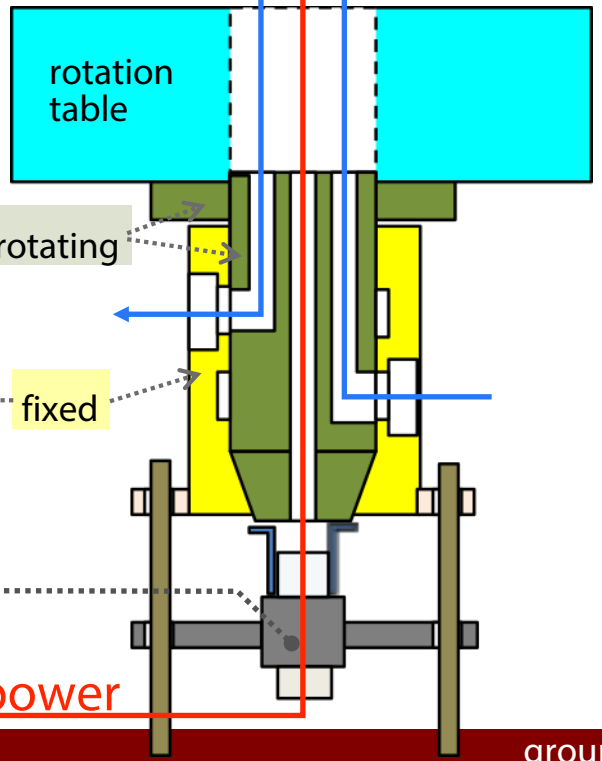
mitigating effects of atmospheric fluctuation
→ Cutting out any 1/f on timescales longer than 3 seconds

Installation site: Teide Observatory at 2400m altitude

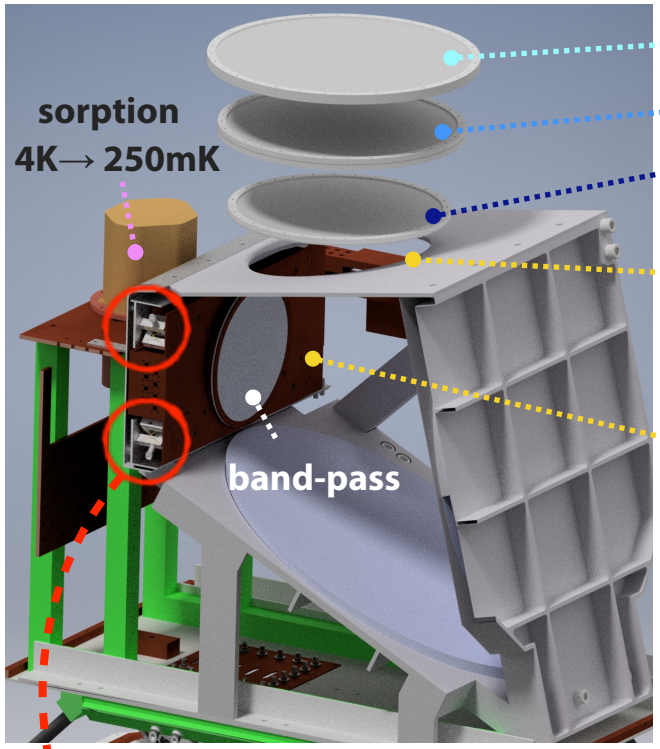
Telescope property: rotary joint



PTC
helium

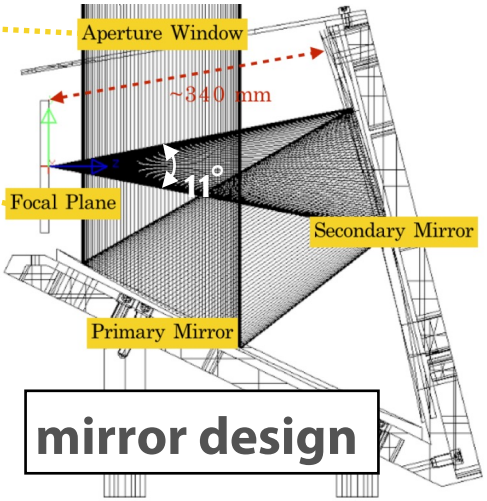


8 Telescope property: cold mirror and focal plane



300K vac. window
40K low-pass filter
4K low-pass filter

cooled down with PTC

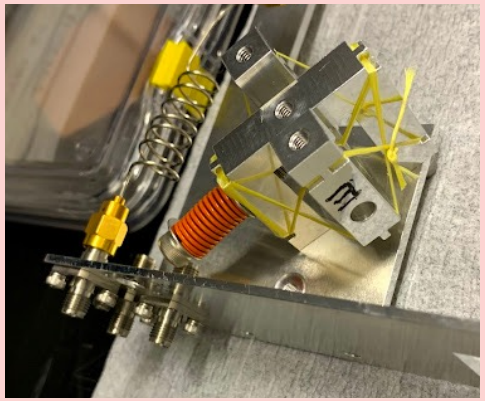


mirror design

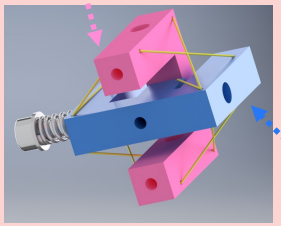
7 wafers on the focal plane operated at 250mK

- 138 pix. with 145GHz for CMB
- 23 pix. with 220GHz for dust

Kevlar small jigs for thermal isolation

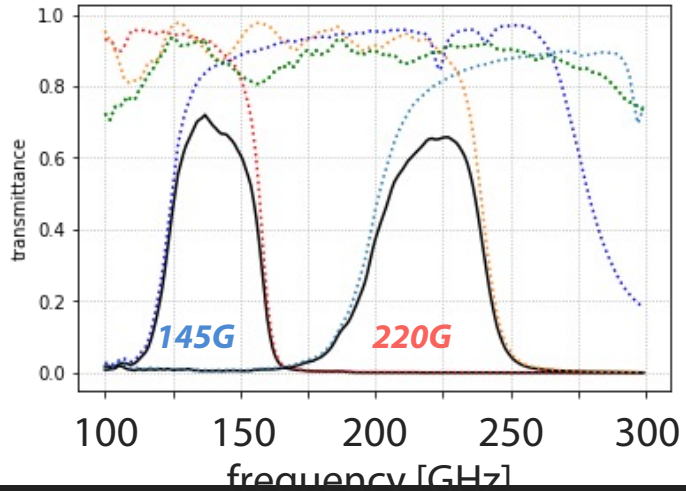


Thermal isolation well achieved by tensions of Kevlar wires



thermal conductivity
~ 0.0064 [mW/K]

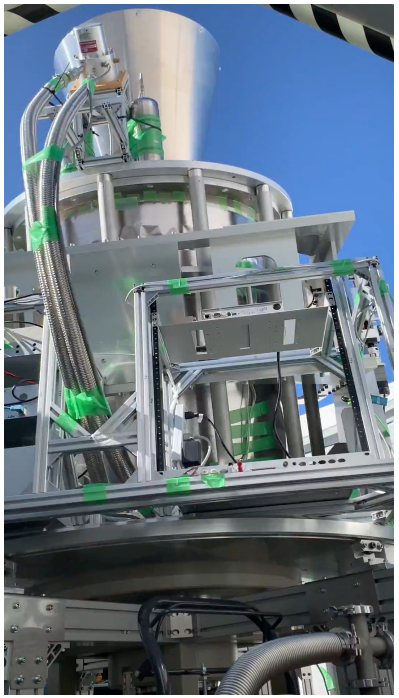
spec. of optical filters at focal plane



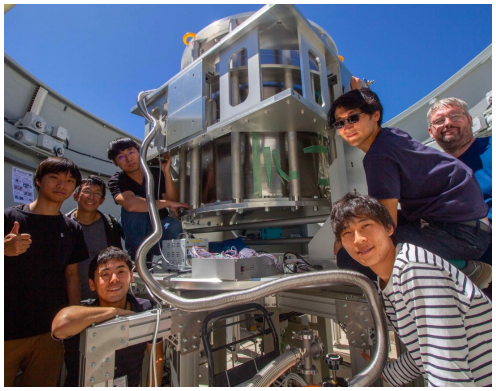
Telescope Installation and First Light

S.Honda et al. (2020) Proc. SPIE

Deployment at Teide Observatory (TO) - *2400m alt. in Tenerife*



Demonstration of high-speed-rotation scan at 20RPM

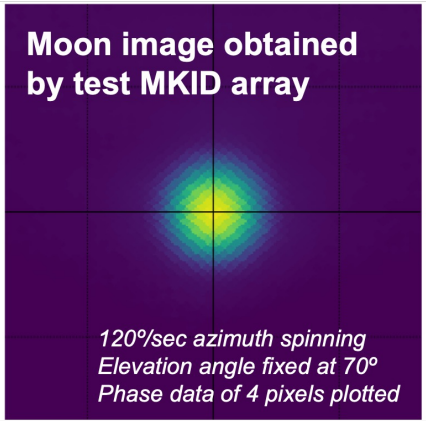


First light (Moon) Sep. 2019

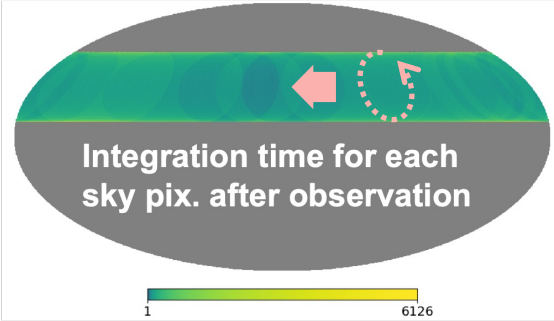
→ Confirmation of optical design

Demonstration of large-sky coverage

→ End-to-end function test



Integration time [ms] indicating how much data was taken at each sky pixel. Test MKID array took data during several days with 120°/sec continuous rotation.



∗ *Test MKID for the first-light campaign was borrowed from SRON.*

More Frequency Bands with QUIJOTE

The QUIJOTE experiment

(Q-U-I JOint Tenerife Experiment, http://research.iac.es/project/quijote)

RADIO FOREGROUNDS

QT-1 and QT-2: Crossed-Dragone telescopes, 2.25m primary, 1.9m secondary.

QT-1. Instruments: MFI, MFI2.
11, 13, 17, 19 GHz.
FWHM=0.93º-0.62º
MFI: 2012-18.
MFI2: 2023-

QT-2. Instruments: TGI & FGI
30 and 40 GHz.
FWHM=0.37º-0.28º
Commissioning 2018.
Observations re-started 2021.

UNIÓN EUROPEA
Ref. de la ayuda: ICTS-2019-03-IAC-12

More Frequency Bands with QUIJOTE

The QUIJOTE experiment

(Q-U-I JOint Tenerife Experiment, http://research.iac.es/project/quijote)

RADIO FOREGROUNDS

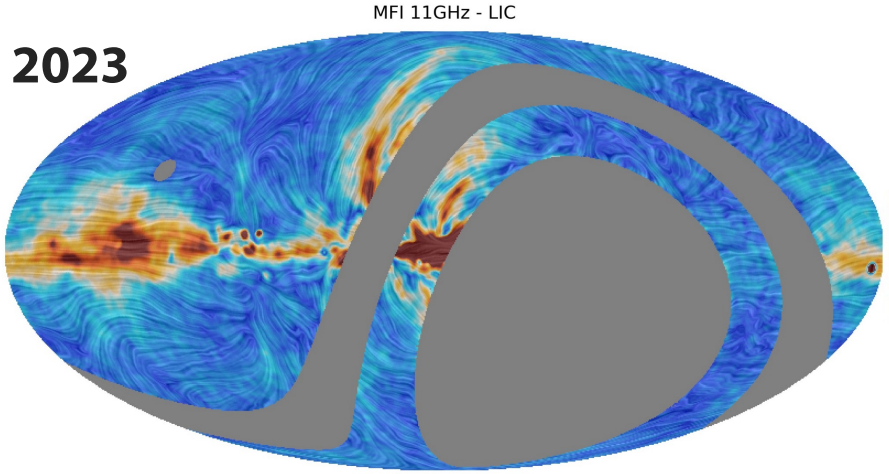
- **very close to GroundBIRD, just a few meters away**
- **same observation strategy: continuous azimuth rotation at <10rpm**

1st observation data released in Mar 2023

with 11,13,17,19 GHz

(sensitivities ~ 700-800 μK/√Hz)

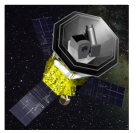
30 and 40 GHz observations being commissioned

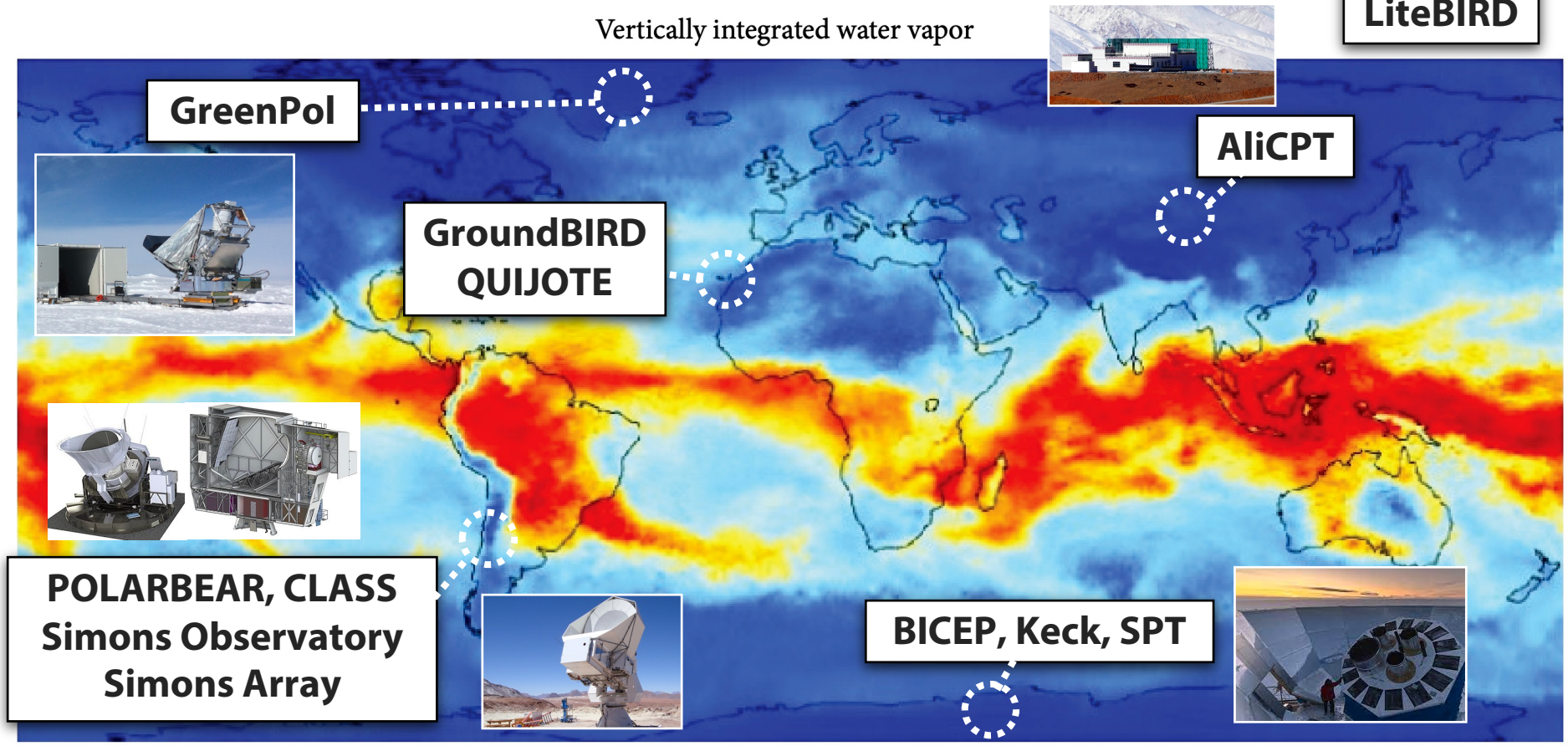


Installation Site for CMB Observations

Most CMB telescopes in the South hemisphere (Chile and Antarctica)

→ comprehensive observation by addition of Nouth telescopes!





Q. Zhang, et al, 2018

CMB Observation Experiments (observation bands)

Most CMB telescopes in the South hemisphere (Chile and Antarctica)

→ comprehensive observation by addition of Nouth telescopes!

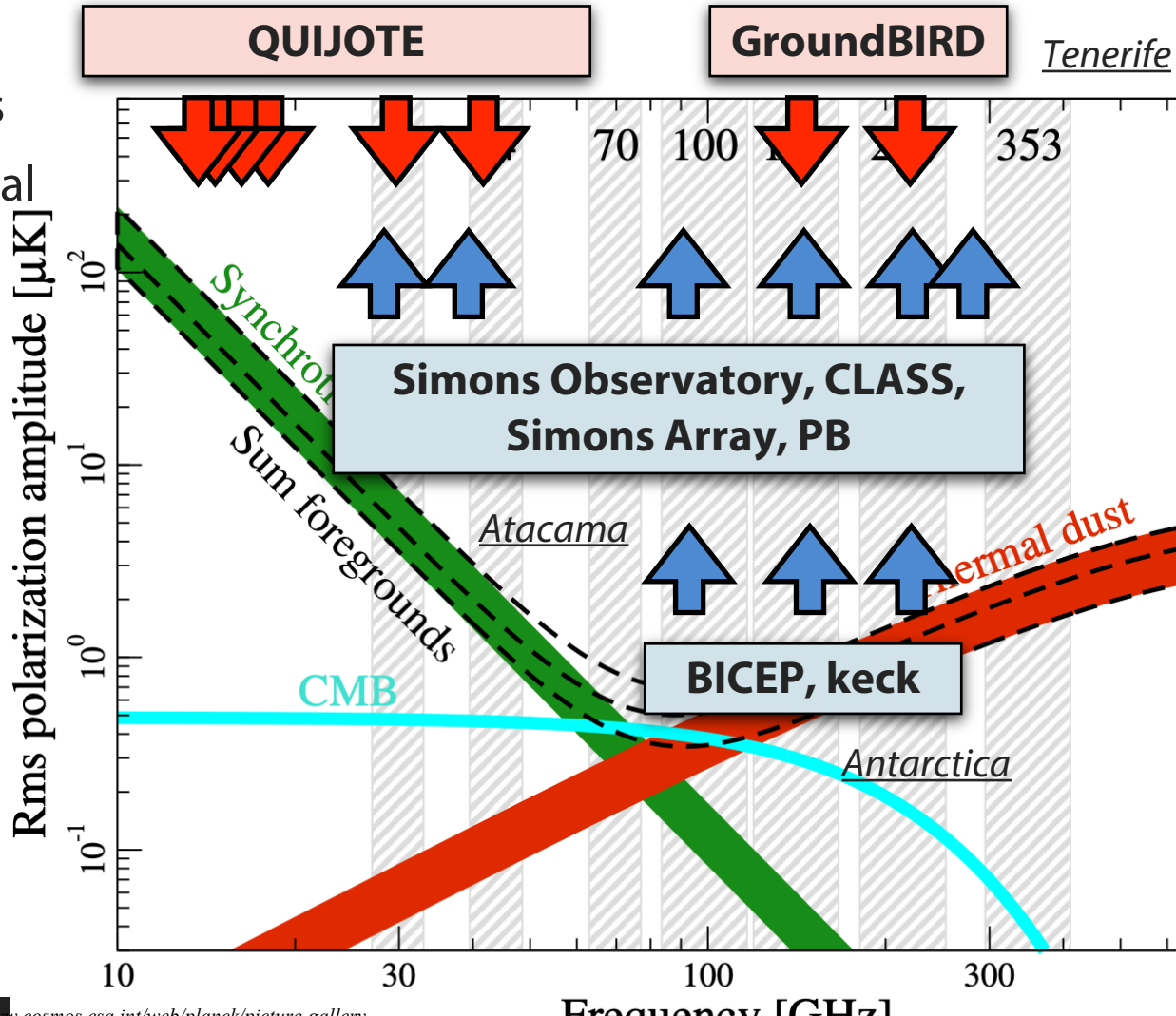
wide coverage of

observation frequency bands

→ precise foreground removal

validation of foreground estimation

by comparisons btw north and south

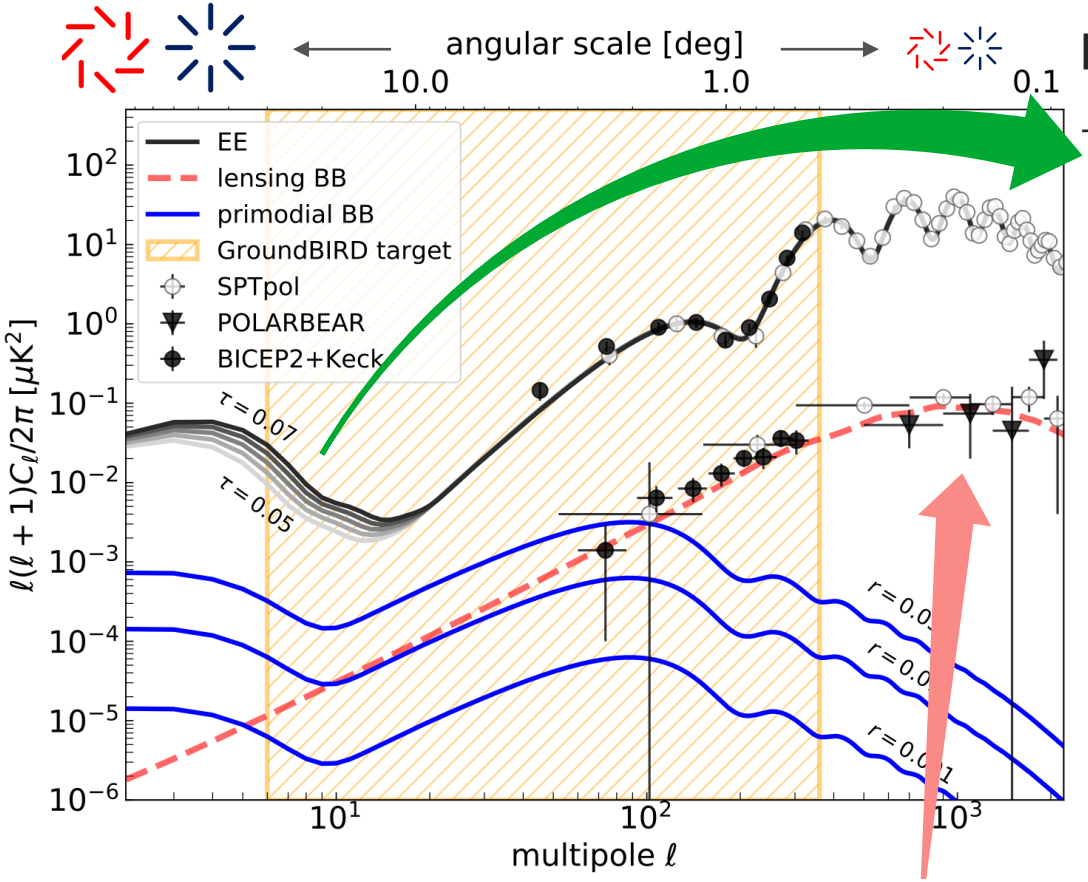


https://www.cosmos.esa.int/web/planck/picture-gallery

Science Targets with High-Speed Rotation

High-speed rotation can provide sensitivities to large angular scale regions!

GroundBIRD target: E-mode measurements at large angular-scale polarizations



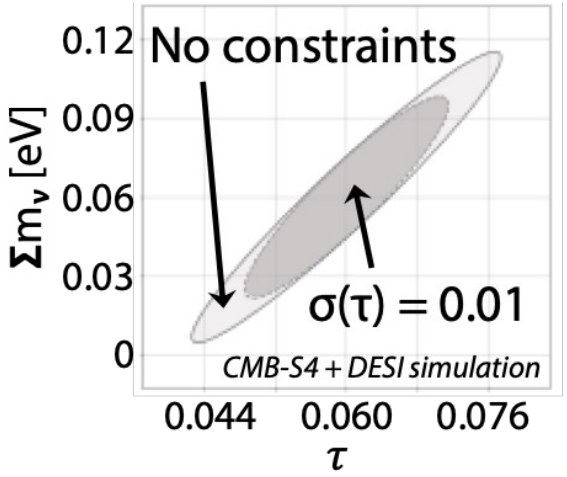
E-mode at large angular scale

→ constraint on "**τ**"

optical depth of reionization

neutrino mass measurement

unfolding correlations : Σmν ⇔ τ



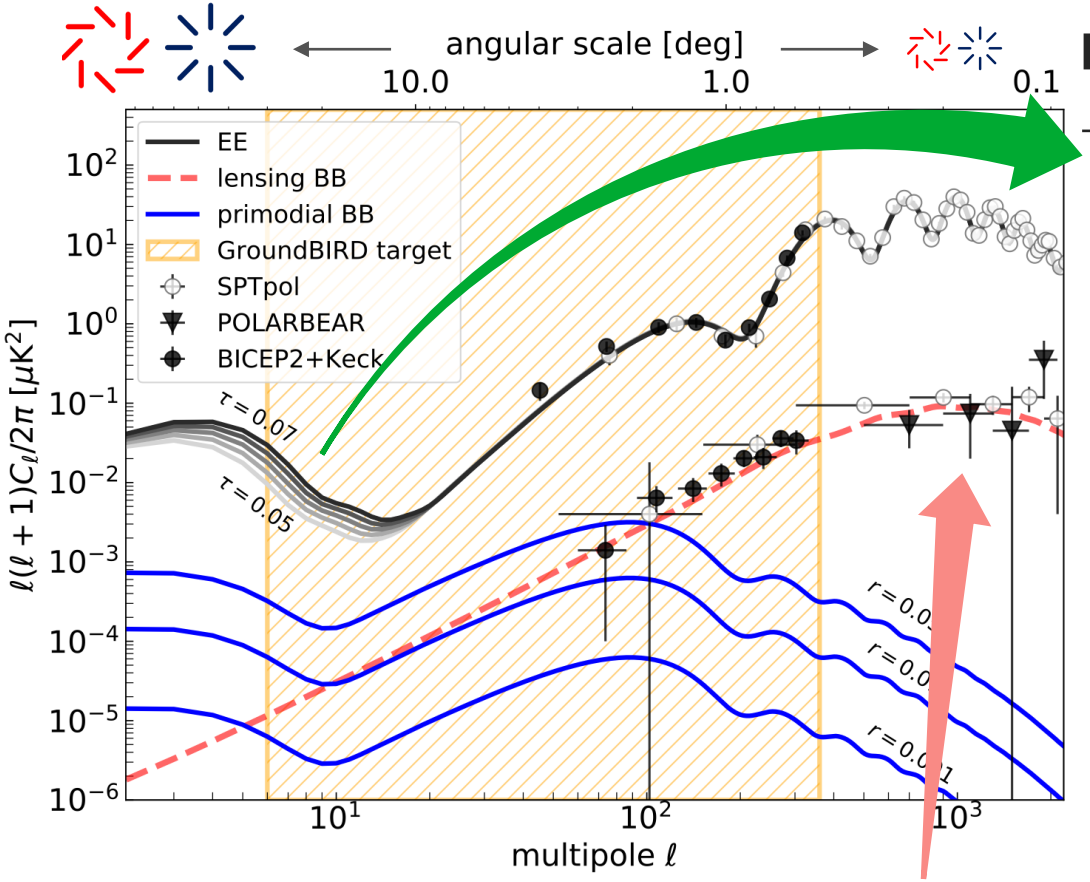
neutrino mass measured as Σmν * τ

by measuring lensing-*BB*

Science Targets with High-Speed Rotation

High-speed rotation can provide sensitivities to large angular scale regions!

GroundBIRD target: E-mode measurements at large angular-scale polarizations



E-mode at large angular scale

→ constraint on **"τ"**

σ(τ) ~ 0.01 *K. Lee et al 2021 ApJ **915** 88*

by GroundBIRD + QUIJOTE

- 3-year observation
- O(10) degree scale measurements
- north hemisphere obsevation
- 8 bands from 11GHz to 220GHz
- noise level (NET):
  820μK/√s for 145GHz band

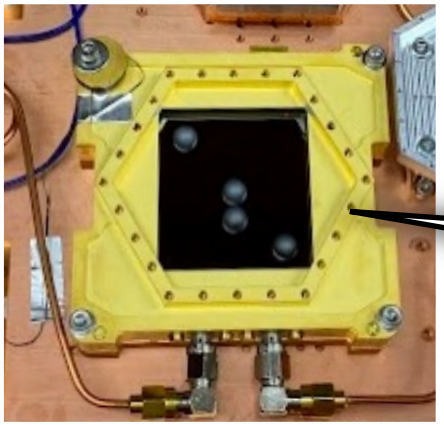
neutrino mass measured as Σmν * τ by measuring lensing-*BB*

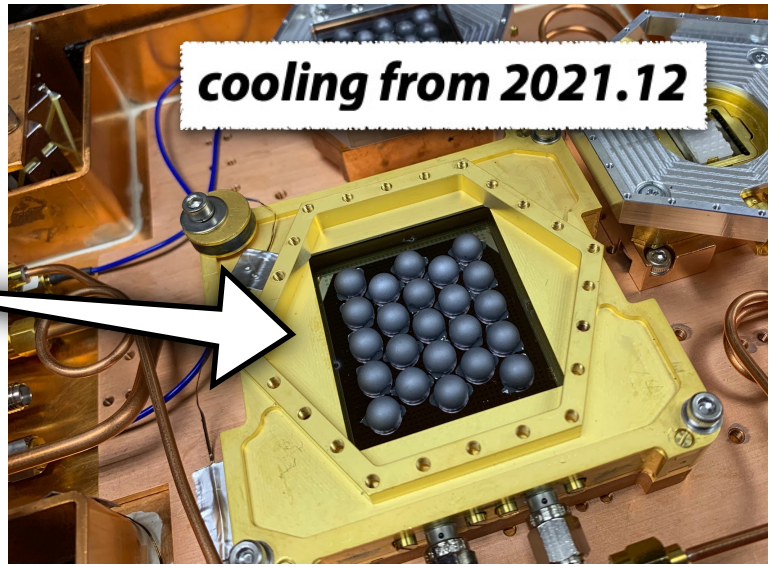
Current Status of GroundBIRD

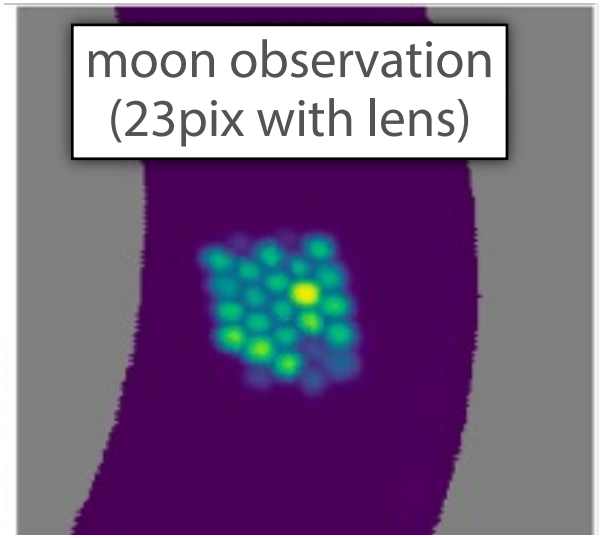
After installation and first-light, commissioning observations were performed for instrumental evaluations.

Proto-type sensor chip fabricated by SRON / TU Delft
→ Performance check for all pixels in 2022

cooling from 2021.07



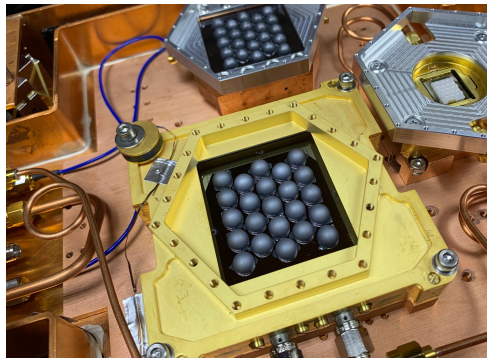


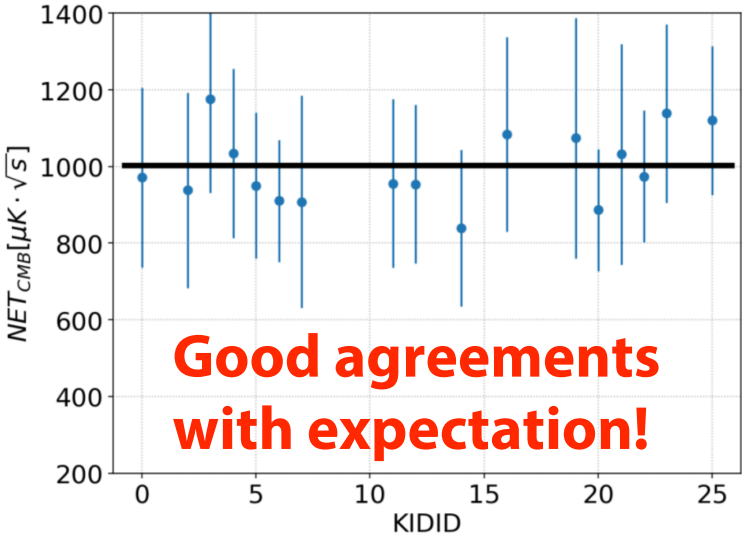


Commissioning Observation

Sensitivity of prototype detector calculated

Y.Sueno JPS, 2022.09





prototype expectation at PWV=4mm

improvements

optimization of antenna geometry, …

Spec. of final fabrication being evaluated now

c.f. Planck 150GHz : 1.96μK deg → 70μK arcmin

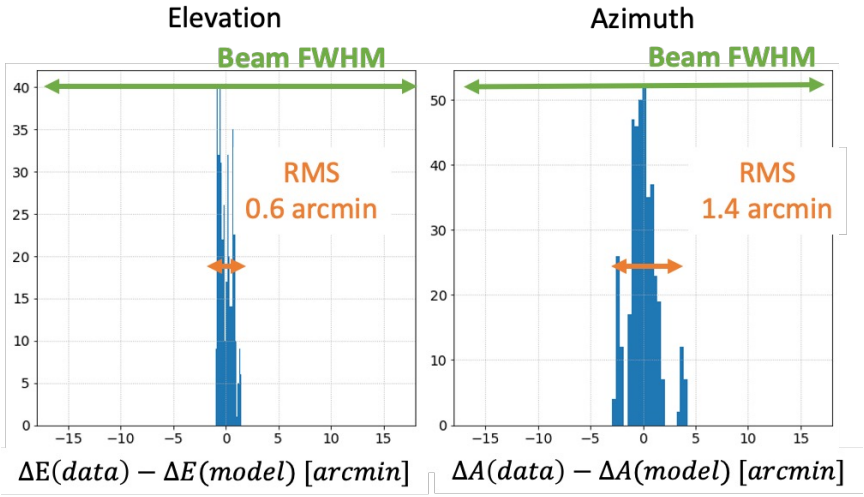
GroundBIRD 150GHz: ~100μK arcmin expected

Pointing calibration

Good consistencies between data and model

→ < 1/10 of the beam width (FWHM~36 arcmin)

c.f. POLARBEAR : RMS ~ 0.5 arcmin, ~ 1/7 of the beam width

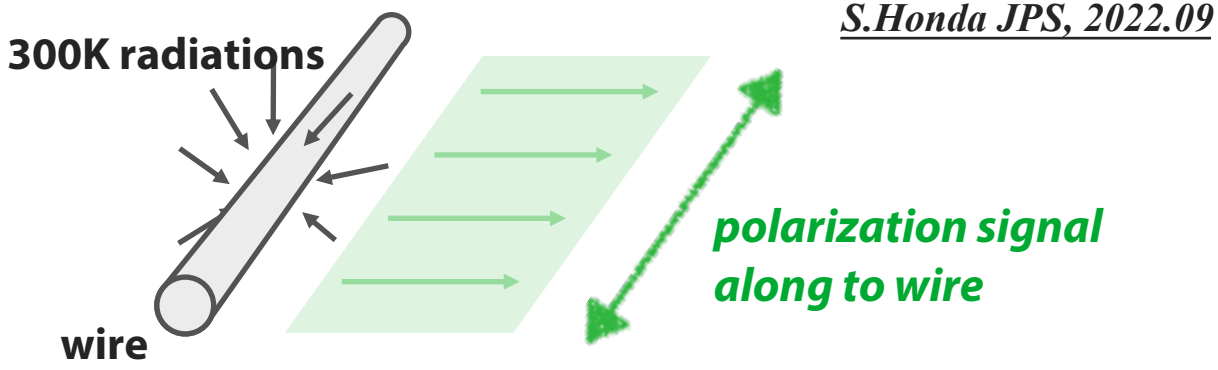


Polarization Signal from Wires

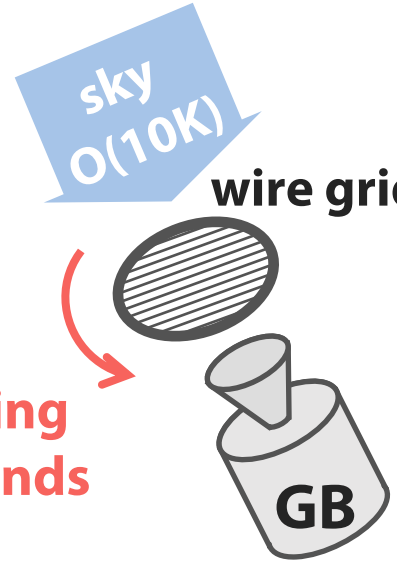
Wires used for evaluation of pol. responses.

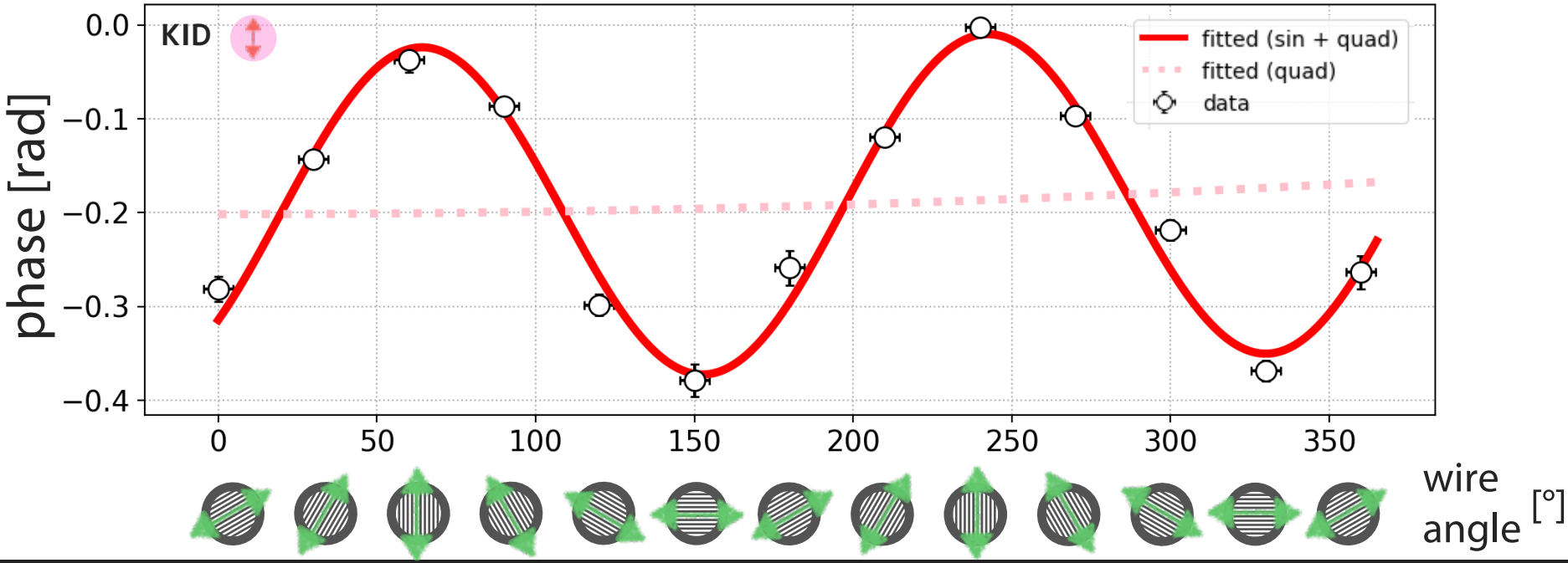
The first trial to see wire signals with GB-KIIDs.

S.Honda JPS, 2022.09



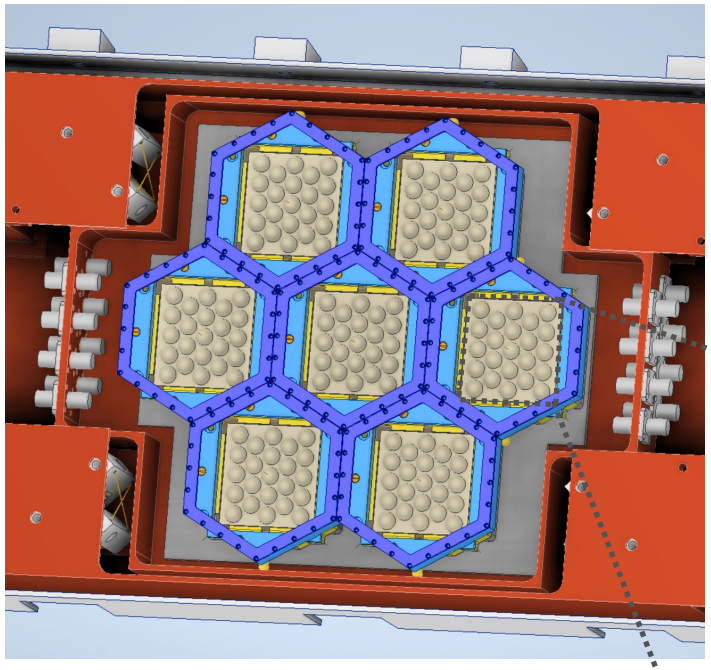
measurement setup





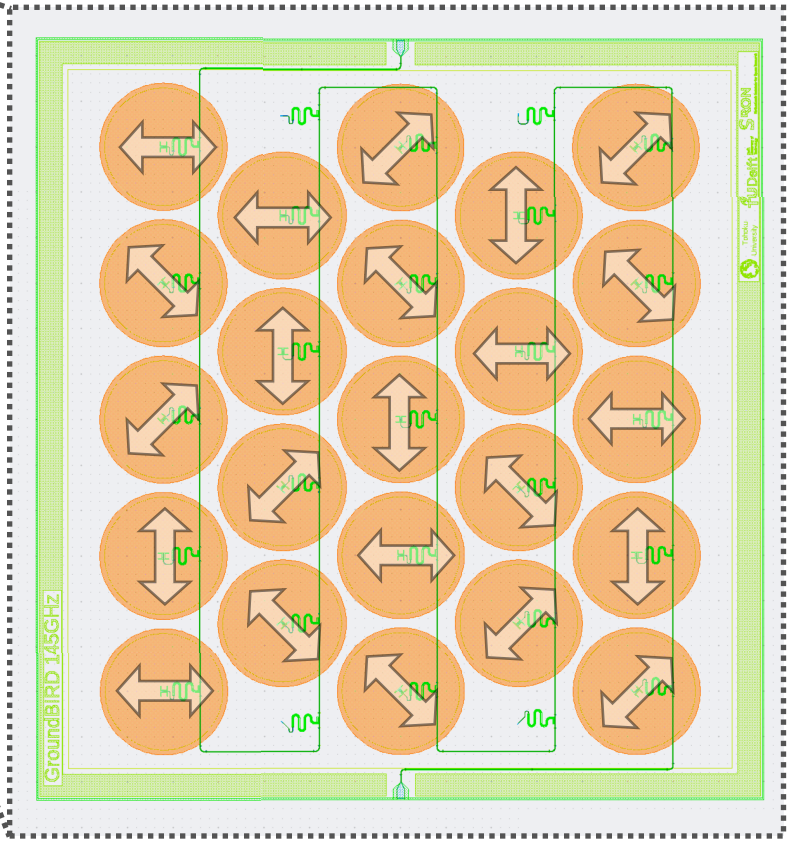
Full-array Detector Design/Fabrication

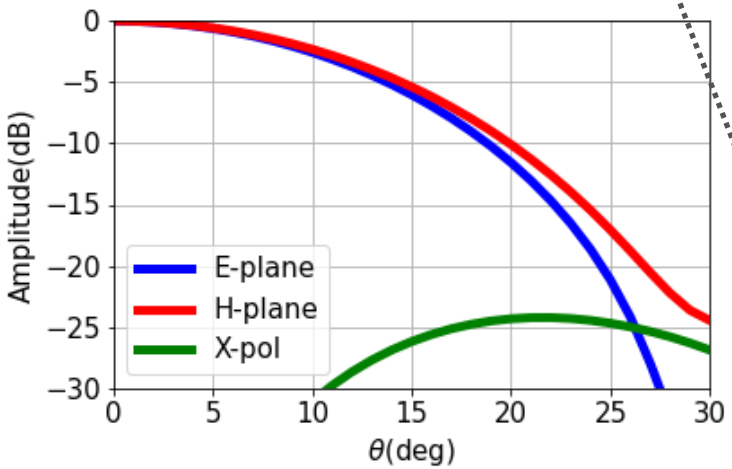
T.Tanaka



Full-array detector design

- 23 pixels+lenslets in compact chip size
- antennas with 4 directions for polarization
- fabrication on-going by SRON





The simulation developed by TUDelft for beam pattern w/ lens.

Summary

GroundBIRD is the compact telescope for large-scale CMB-polarization observations

- Continuous azimuth rotation at 20RPM (3sec per rotation) mitigates atmospheric fluctuations.
- By combined analysis with QUIJOTE, the wide frequency range of 11-220GHz is covered for foreground estimation.
- The optical depth of reionization (τ) will be measured as σ (τ) ~ 0.01 with 3 years observation

Commissioning observations performed for instrumental evaluations using the proto-type detector

→ Performances are very nice.

→ Fabrication of the full-array detector is ongoing by SRON/TUDelft.

Science observation with full-array detector will start in this year!