The GroundBIRD experiment

an experiment to measure the large-scale CMB polarisation from the ground

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on behalf of the GroundBIRD collaboration

B-mode from space
December 16-19, 2019
Max-Planck-Institut für Astrophysik

Outline

★ Site. Teide Observatory

- Current and previous CMB Telescopes
- Atmospheric conditions and PWV statistics

★ GroundBIRD collaboration

★ GroundBIRD overview

- Scanning strategy
- Cryogenics, optics, detectors, calibration strategy
- Science goals

★ First light

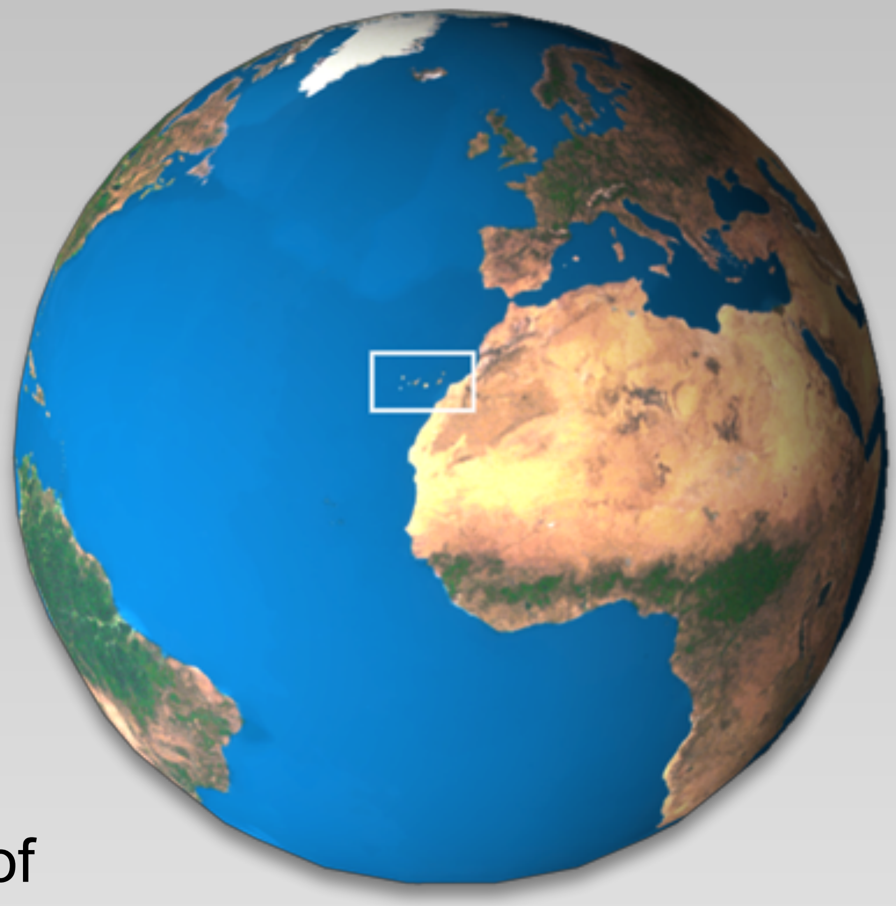
- Installation at the observatory
- First light on the Moon and preliminary analyses

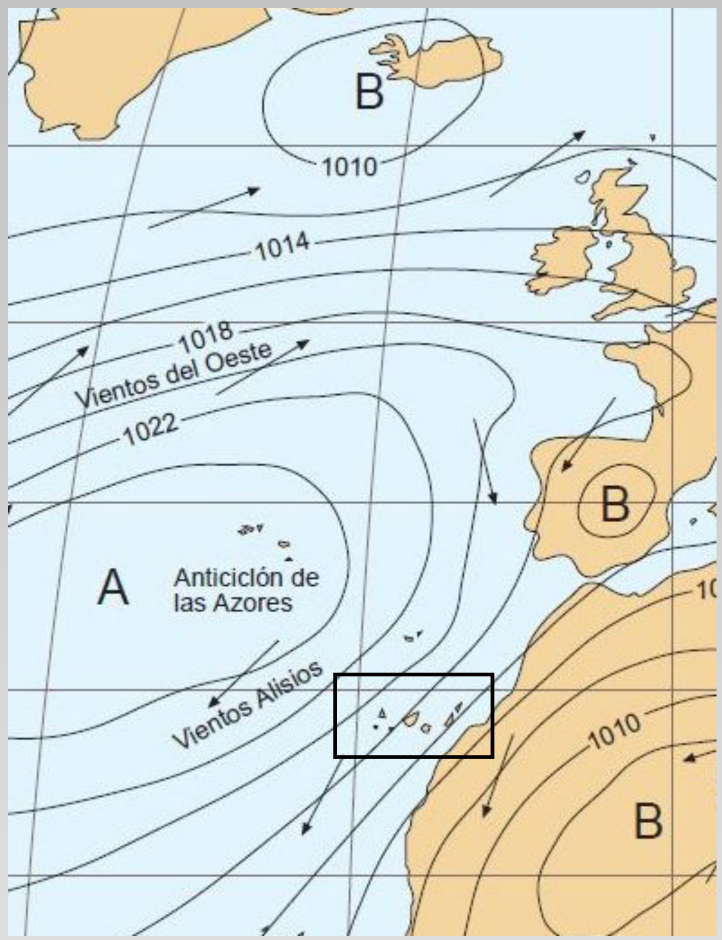
★ Summary

The Teide Observatory

★ Geography:

- Lat. 28º18' N, Long. 16º30' S
- Sky visibility: full northern hemisphere and part of the south
- Far from tropical storms





★ Climate:

- Dominated by a persistent area of high pressure in the North Atlantic (Azores anticyclone)
- Persistent inversion temperature layer at 1500 m

★ Altitude:

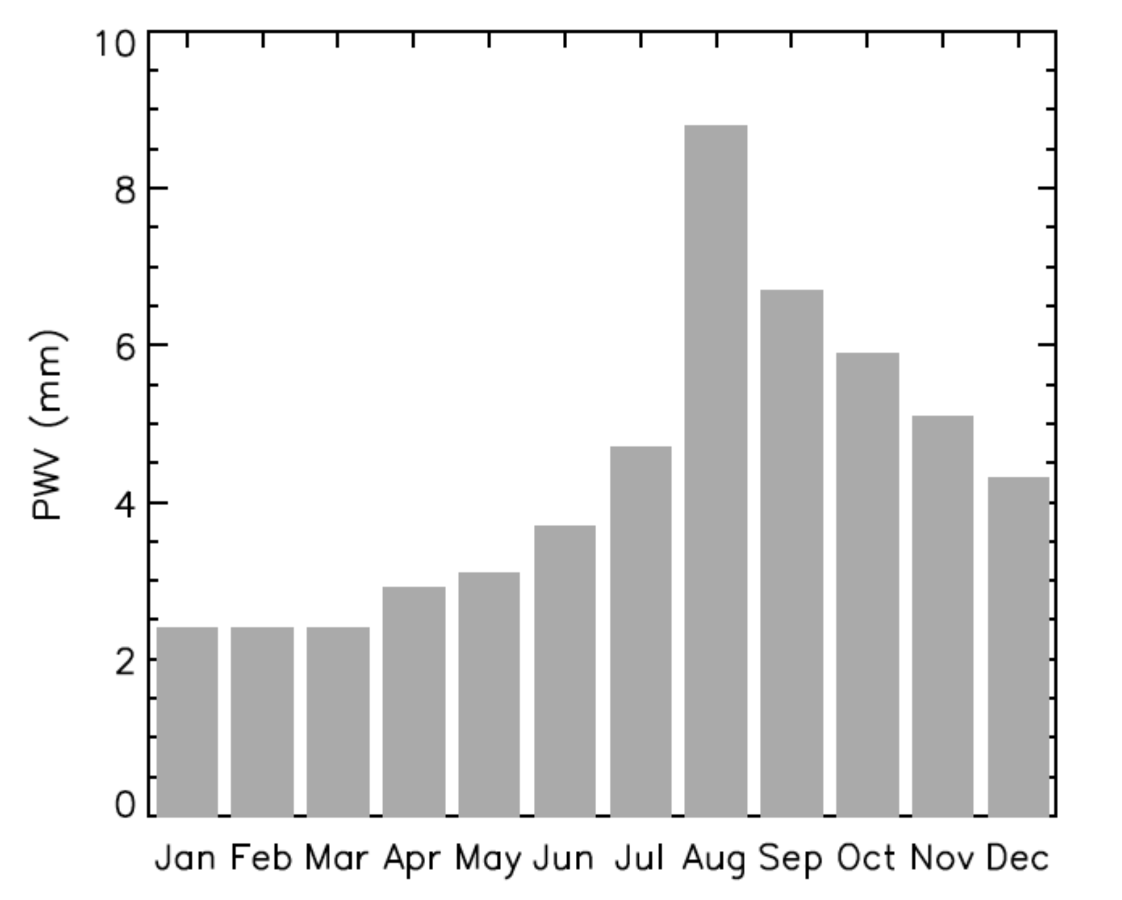
- 2400m
- Above the cloud layer
- Transparent and very stable atmosphere

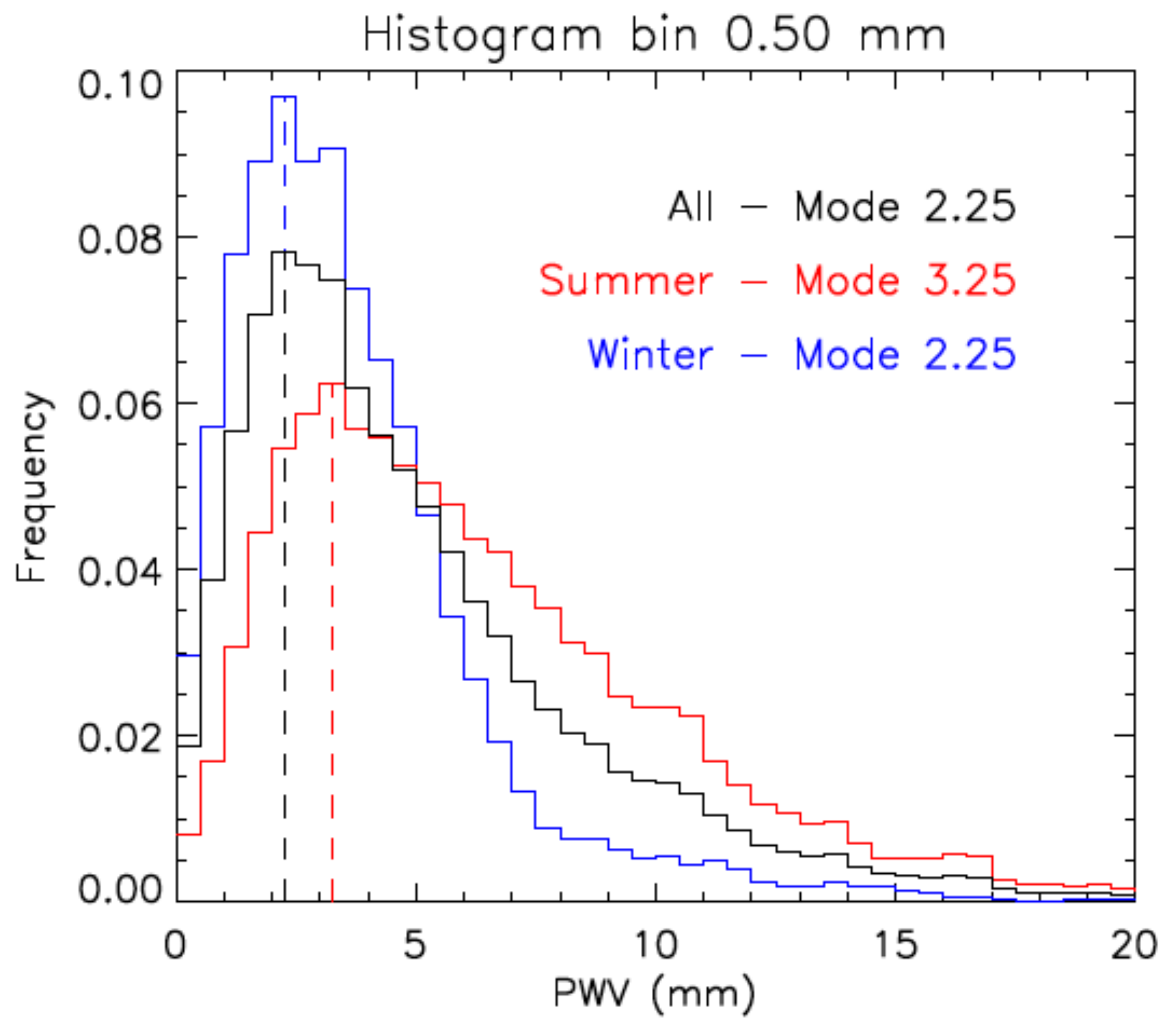
The Teide Observatory - PWV

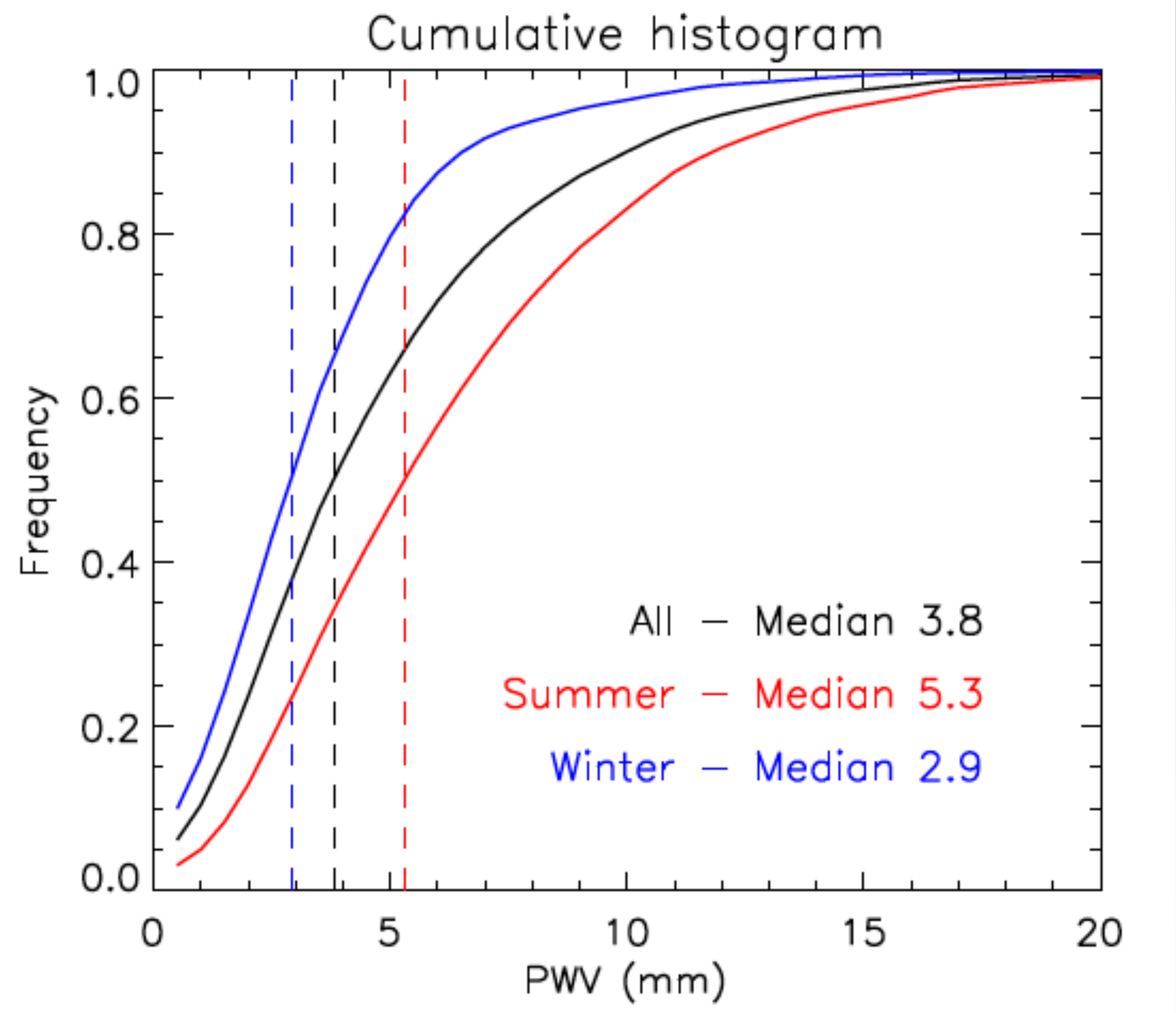
★ Median PWV= 3.8 mm (García-Lorenzo et al. 2010)

★ Stable atmosphere

★ 86% of available time (no rain, RH<90%, WV<45km/h, dust<0.025 m^{-3})

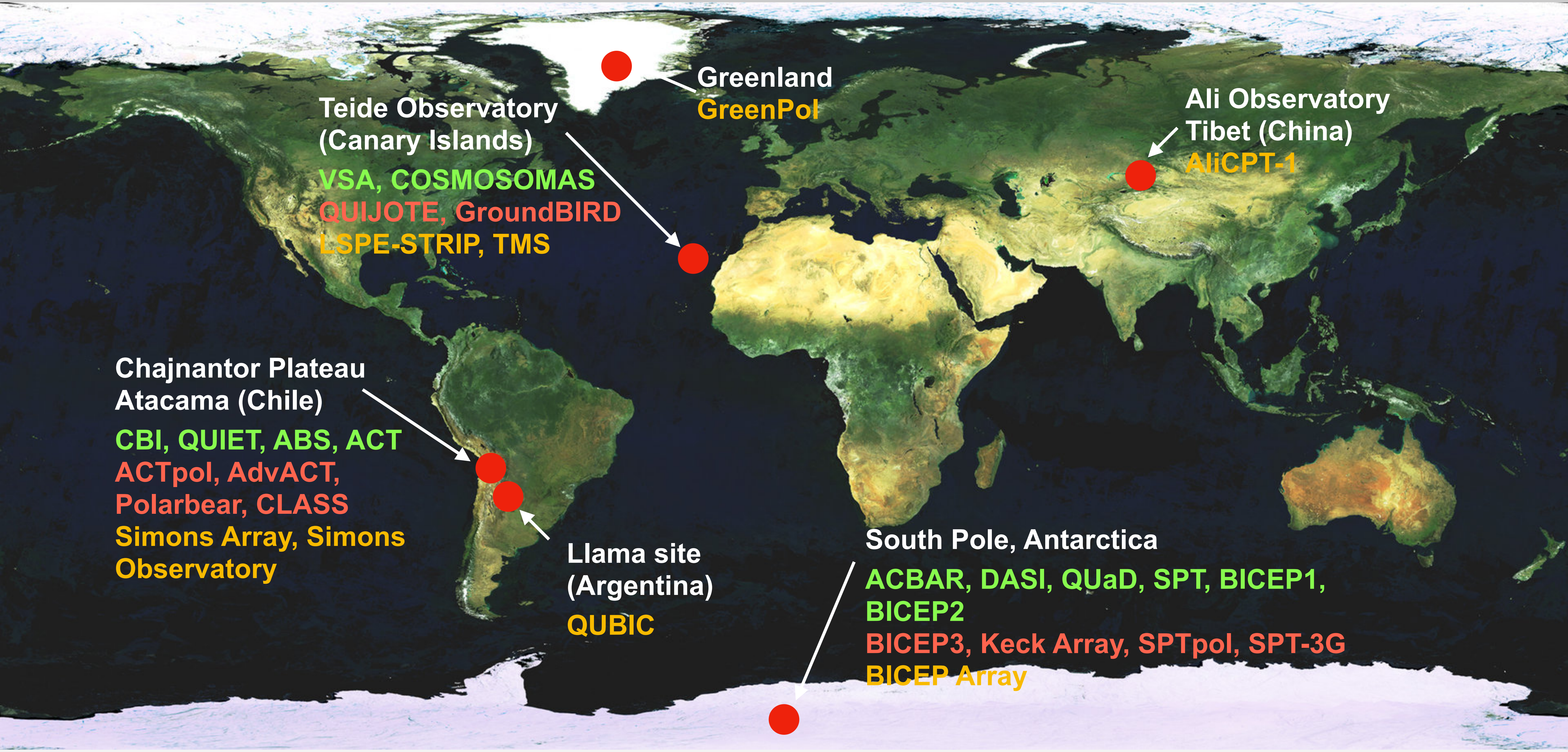






CMB observatories - last decade

Past, Current, Future



★ Most of current CMB observatories are located in the Southern hemisphere

★ The **Teide Observatory** is the only observatory in the North hosting ongoing experiments

★ North observations provides important complementary to the South. Also important for foreground characterisation for LiteBIRD

The Teide Observatory: previous CMB experiments

CMB experiments at Teide Observatory

Same sky area from the North Hemisphere
10 frequencies from 10 to 240 GHz
Redundancy, cross-correlation

Previous talk (José Alberto Rubiño-Martín)

See talk by Silvia Masi tomorrow

GroundBIRD collaboration

RIKEN Satoru Mima, Shugo Oguri, Chiko Otani (PI), Taketo Nagasaki

Kyoto University Shunsuke Honda, Takuji Ikemitsu, Junta Komine, Junya Suzuki, Yoshinori Sueno, Osamu Tajima

KEK Masashi Hazumi, Hikaru Ishituka, Tomohisa Uchida, Mitsuhiro Yoshida

NAOJ Makoto Nagai, Yutaro Sekimoto (now at JAXA)

Tohoku university Makoto Hattori, Fumiyasu Kanno, Hiroki Kutsuma, Tomoka Okada

University of Tokyo Kenji Kiuchi, Makoto Minowa, Nozomu Tomita

Saitama University Ryo Koyano, Masato Naruse, Munehisa Semoto, Toru Taino

Korea University Yonggil Jo, Kyungmin Lee, Joonhyeok Moon, Eunil Won

KASI Jihoon Choi

SRON Kenichi Karatsu

IAC Ricardo Génova-Santos, Mike Peel, Rafael Rebolo, José Alberto Rubiño-Martín

Japan, Spain, Korea,
The Netherlands

Overview of GroundBIRD

★ **Site:** Teide Observatory (altitude: 2400 m, latitude: 28º), Spain

★ **Observability:** EL=30º, -32º<Dec.<88º (f_{sky} ~0.76)

★ **Frequencies:** **145** and **220 GHz**

★ **Angular res.:** **0.5°** @145GHz, **0.3°** @220GHz

★ **Optics:** cross-Dragone, FOV=±10°

★ **Detectors:** lens-antenna-filter coupled **MKIDs**

★ **Temperature:** 250 mK, with cold optics 4 K

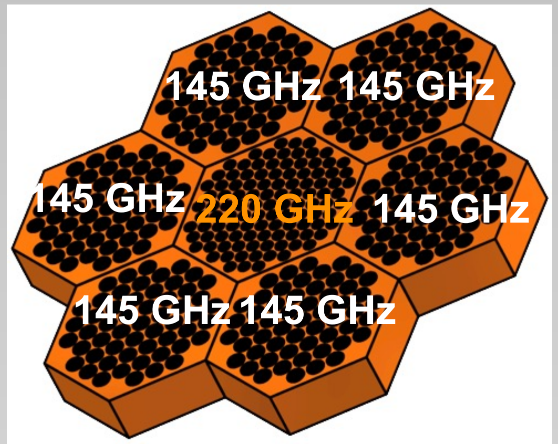
★ **Scan speed:** **120°/sec** (20 rpm)

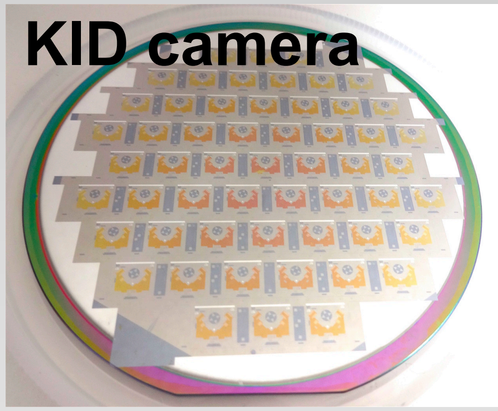
★ **Sky coverage:** f_{sky} ~0.45

★ **Operation plan:** 2020-2022

★ **Goals:**

- Large angular scales ⇒ target the reionisation and the recombination bumps
- **r=0.01**

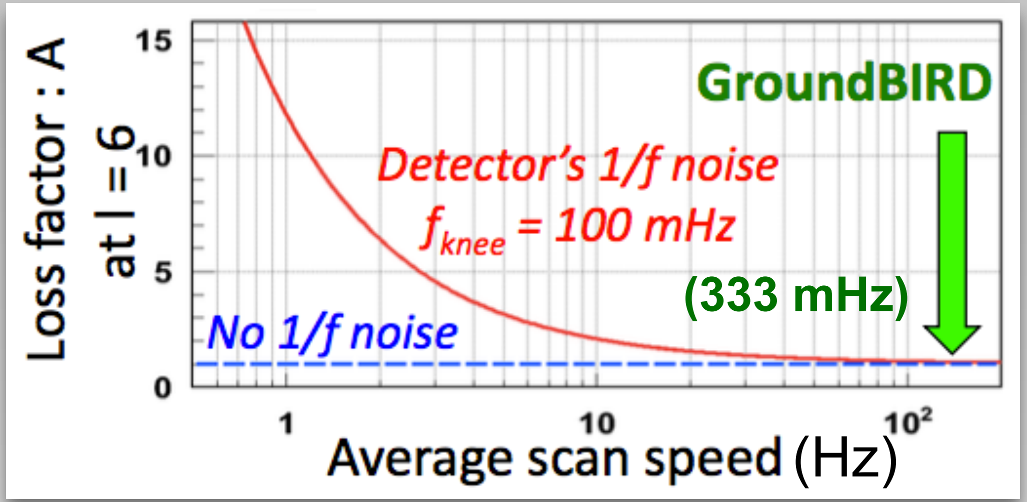


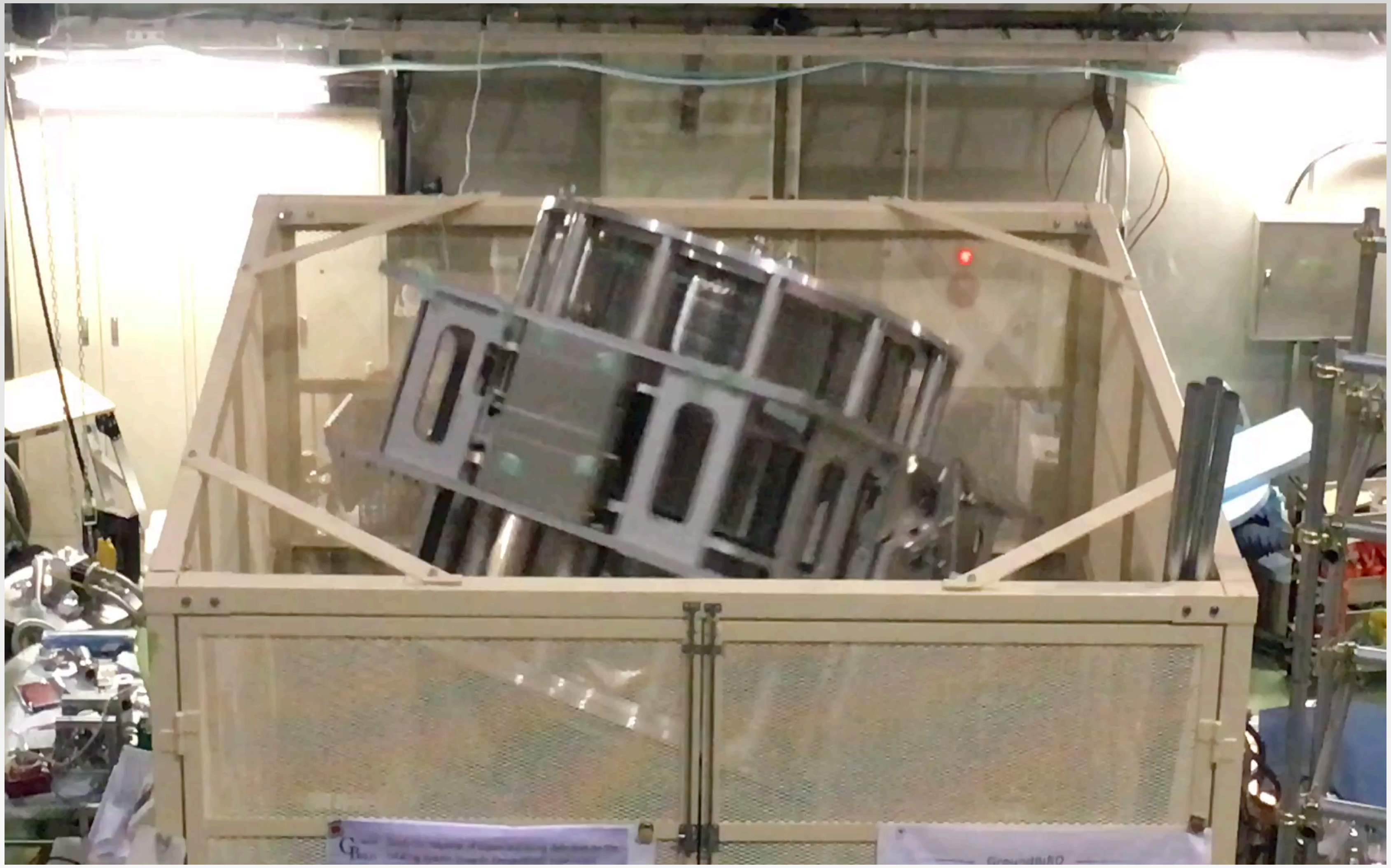


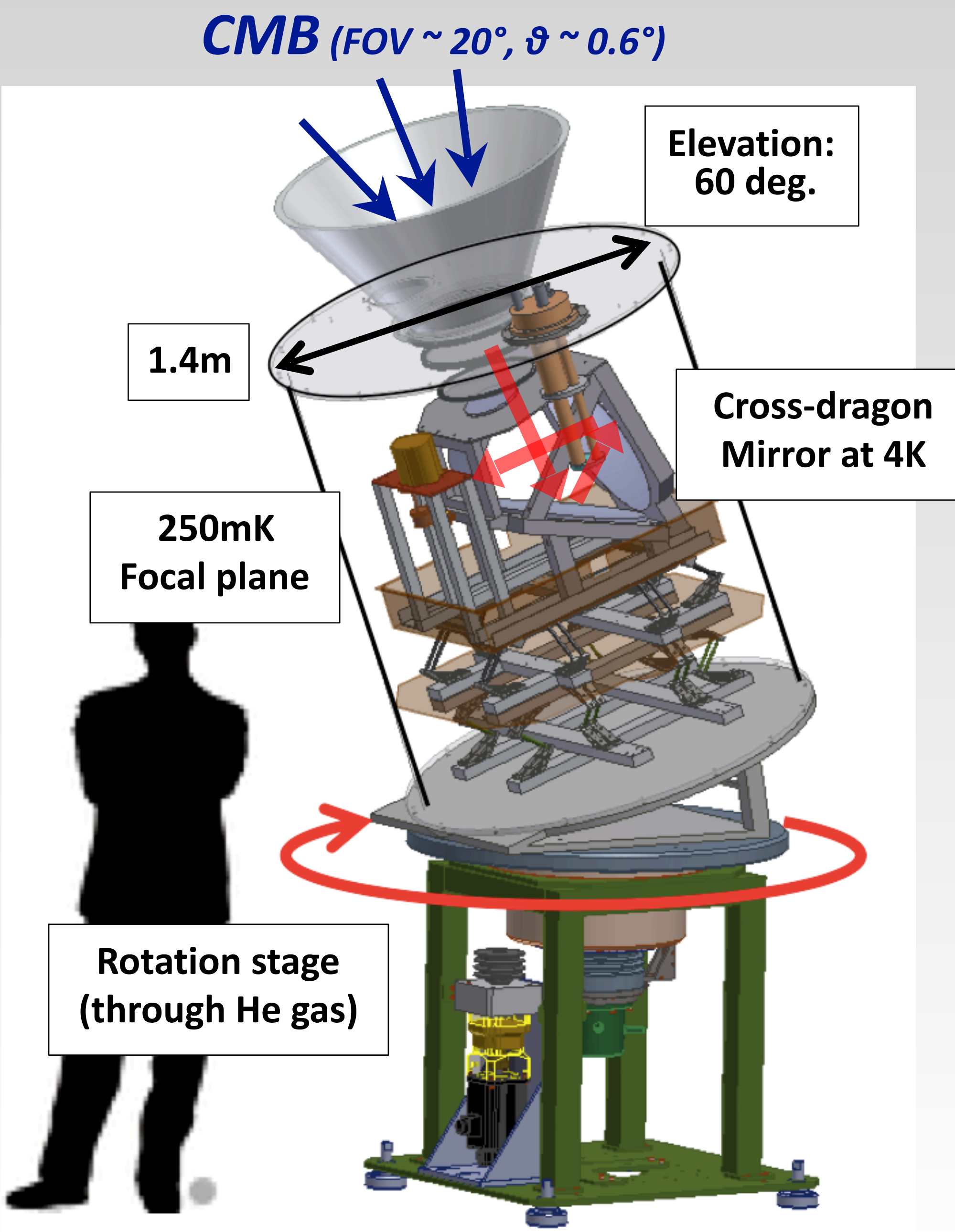
Overview of GroundBIRD

★ Super **high-speed scanning modulation**, 20 rpm (120°/sec), to mitigate 1/f from the atmosphere and from the instrument, $f_{knee} \approx 0.1$ Hz

★ Same as other CMB experiments covering large-scales (QUIJOTE, C-BASS, CLASS), but faster scan speed





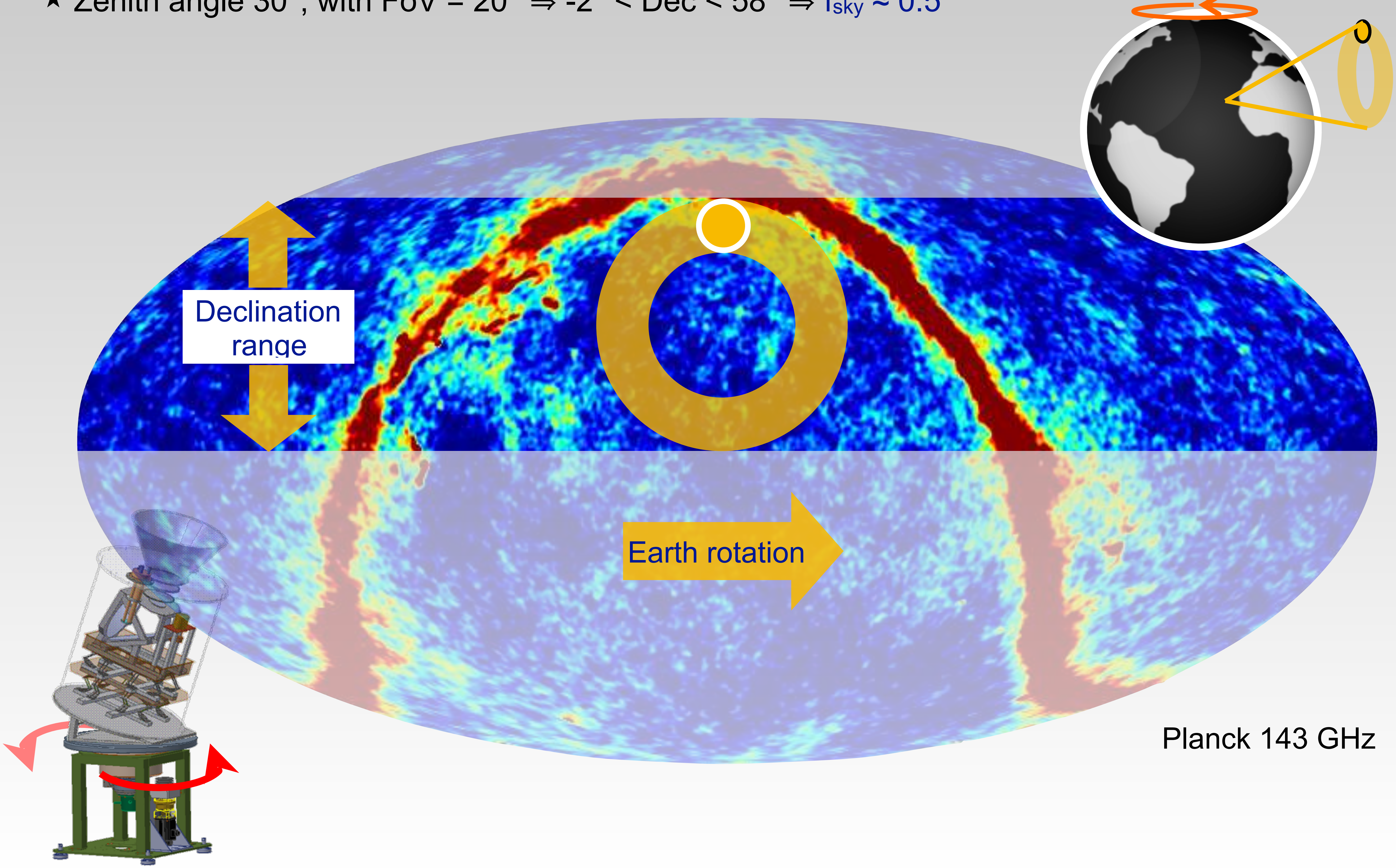


See Oguri et al. 2014 (*J. Low Temp. Phys., 176, 691*) and Tajima et al. 2012 (*Proc. SPIE 8452, 84521M*)

GroundBIRD scanning strategy

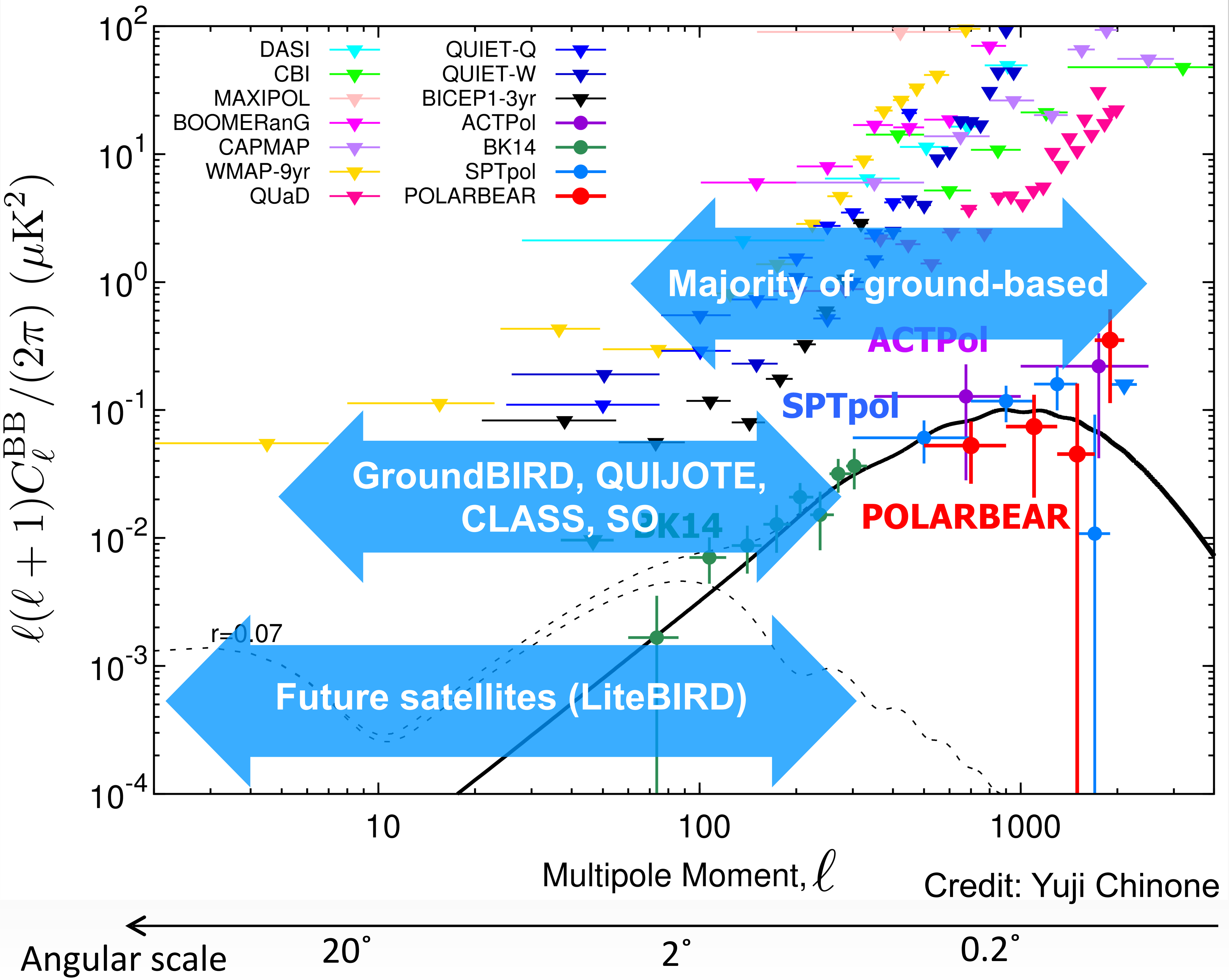
★ AZ spinning (120°/sec), provides Dec. coverage; Earth rotation provides R.A. coverage

★ Zenith angle 30°, with FoV = 20° ⇒ -2° < Dec < 58° ⇒ $f_{sky} \approx 0.5$



GroundBIRD ℓ coverage

★ Goal: $6 < \ell < 300$



GroundBIRD cryogenics

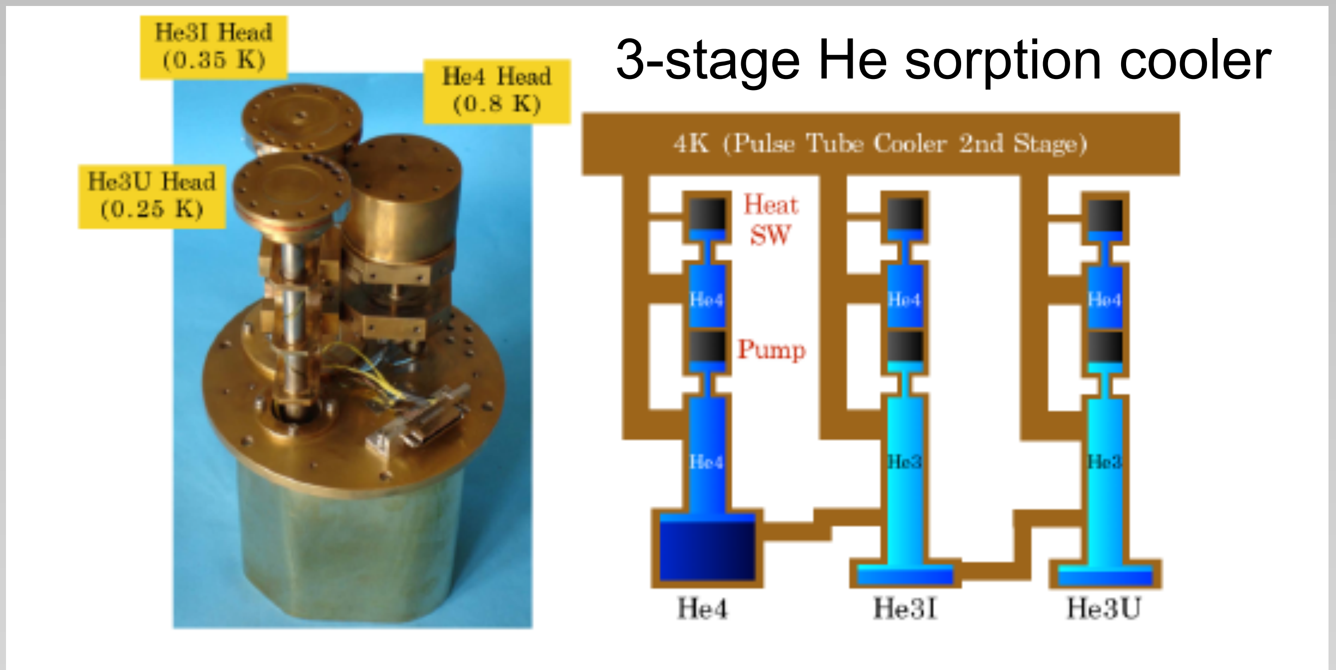
★ Three different shields: 300 K, 50 K and 4 K

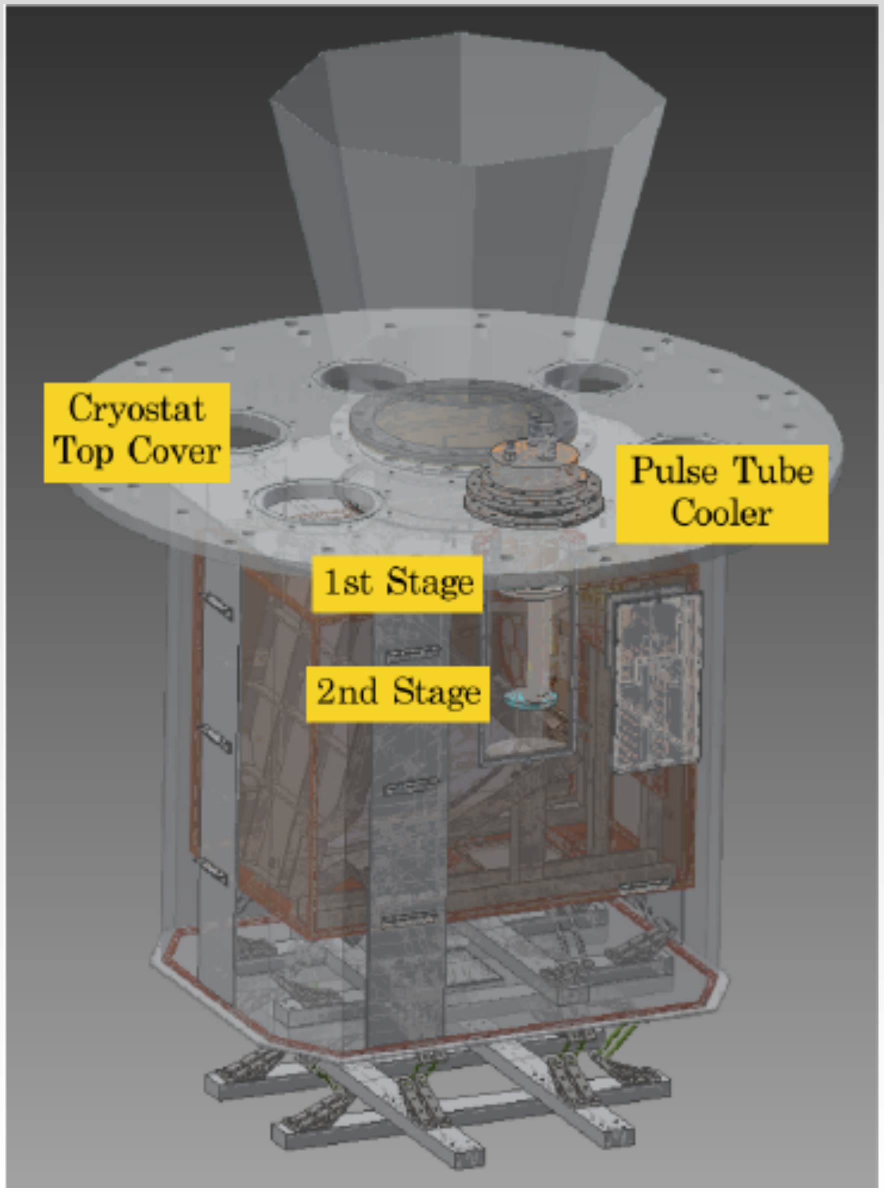
★ First-stage of the PTC at 50 K

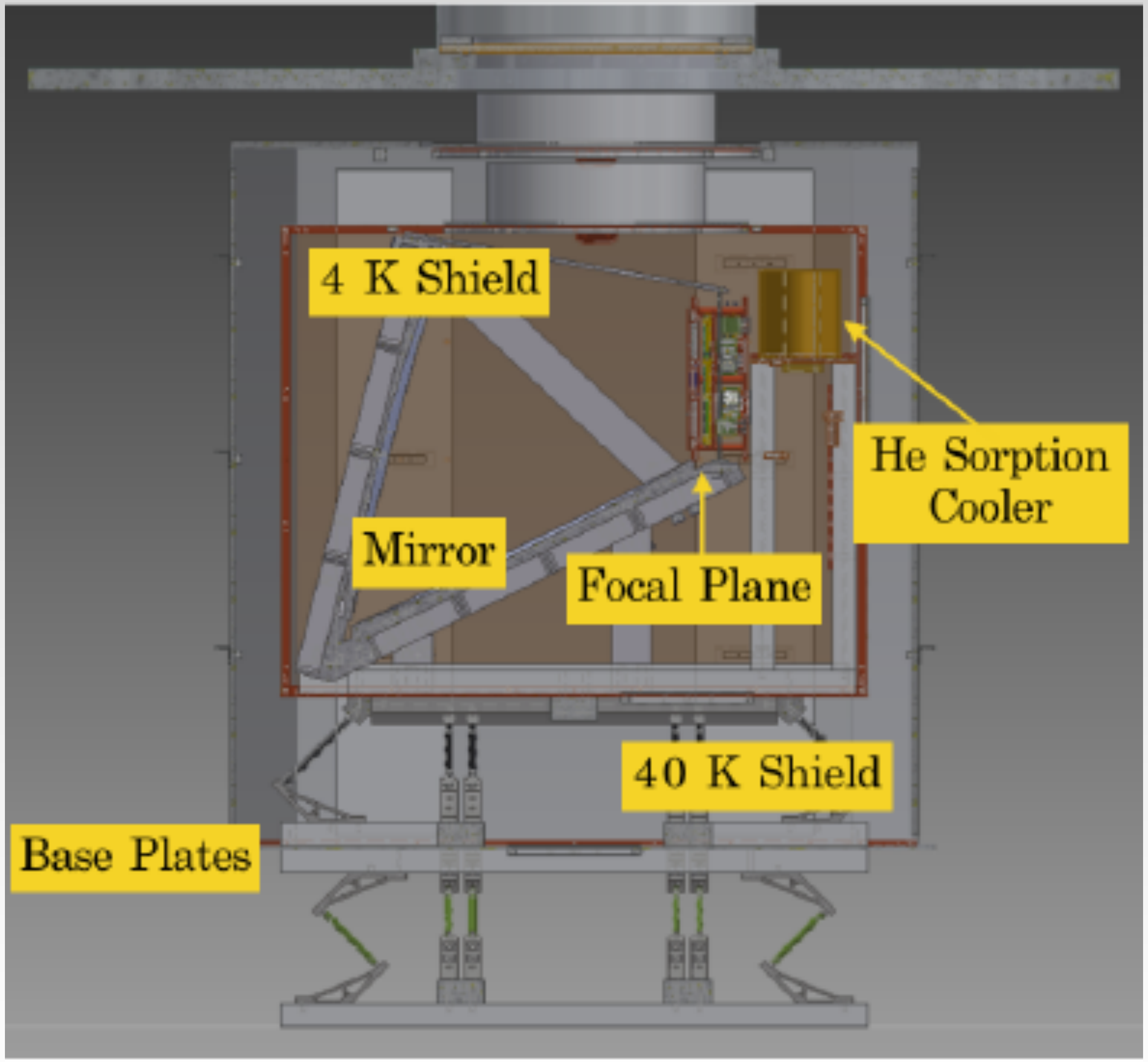
★ Cold optics at **4 K**

★ 3-stage He sorption cooler cools the focal plane down to **250 mK**

★ Rotary joint (Takeda Engineering Co. Ltd.)

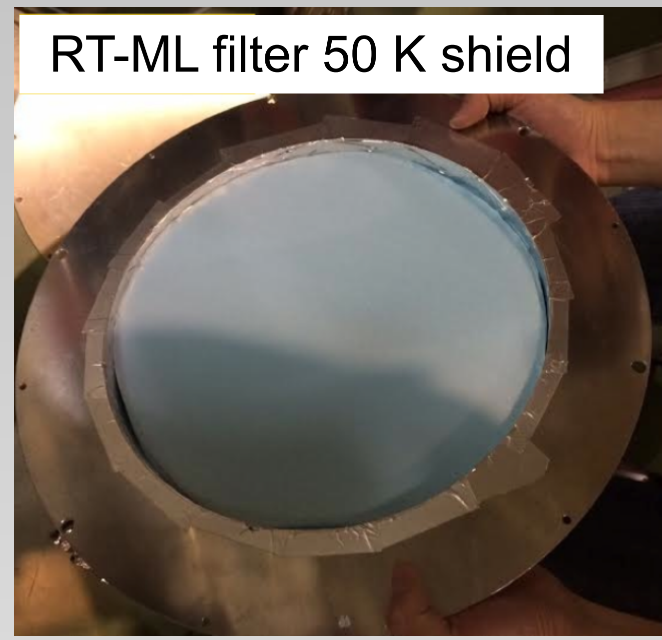


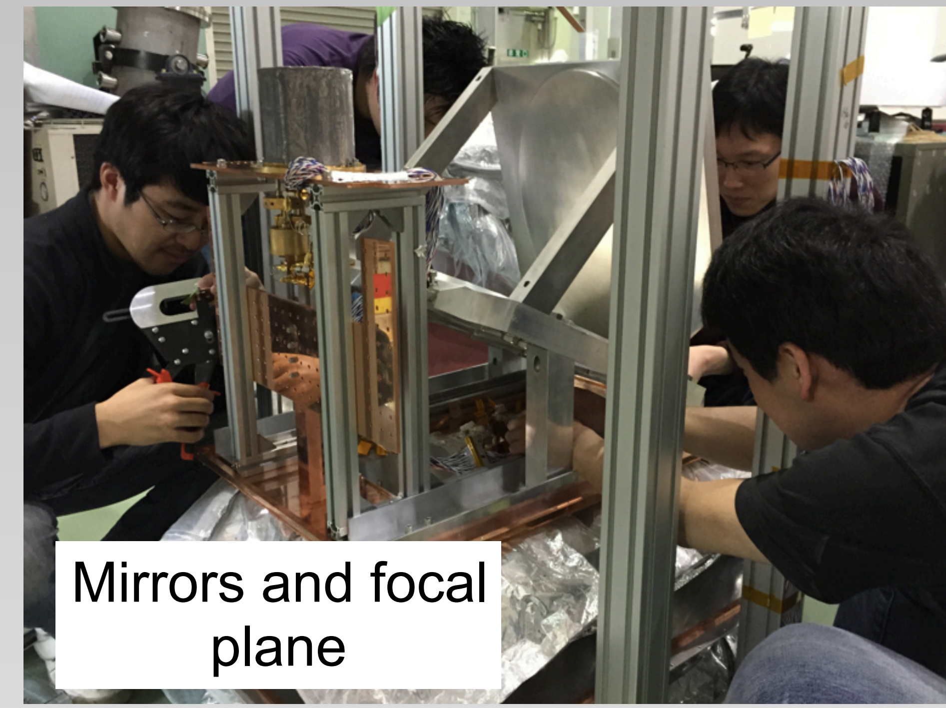




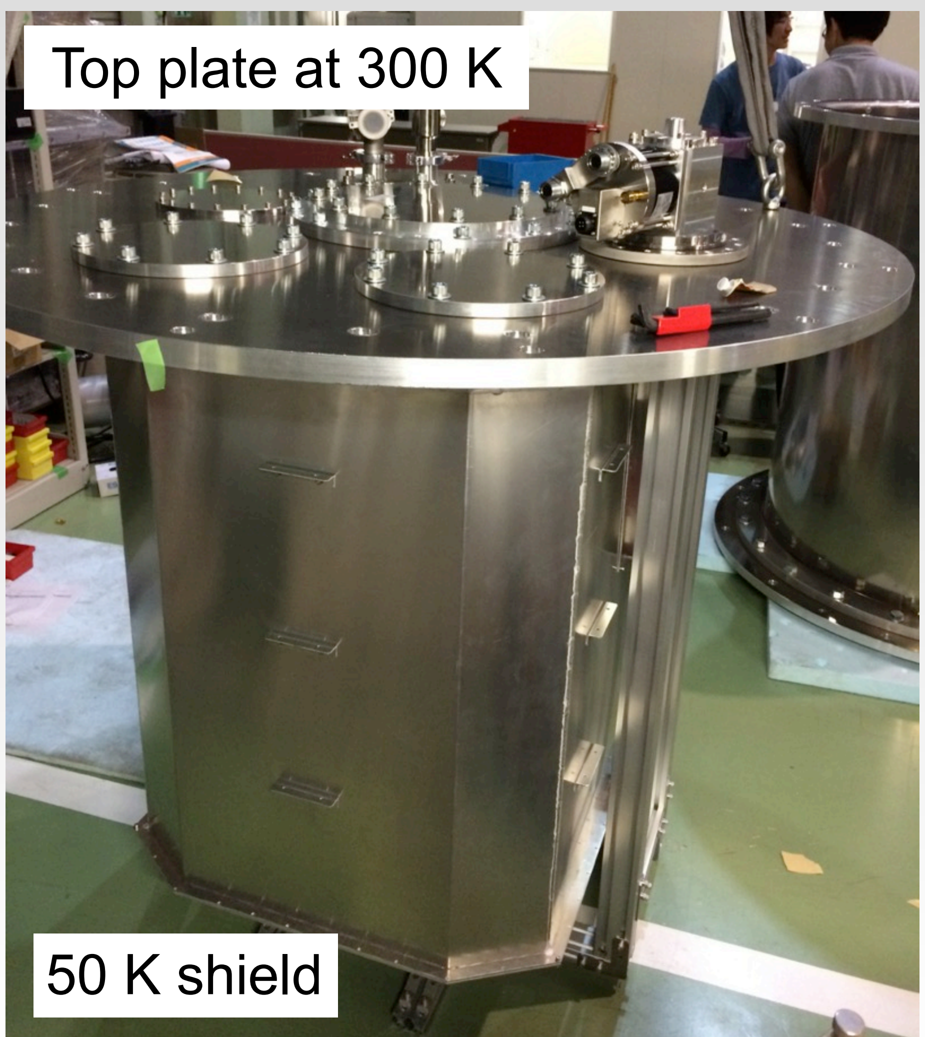
Credit images: Jihoon Choi (PhD thesis)

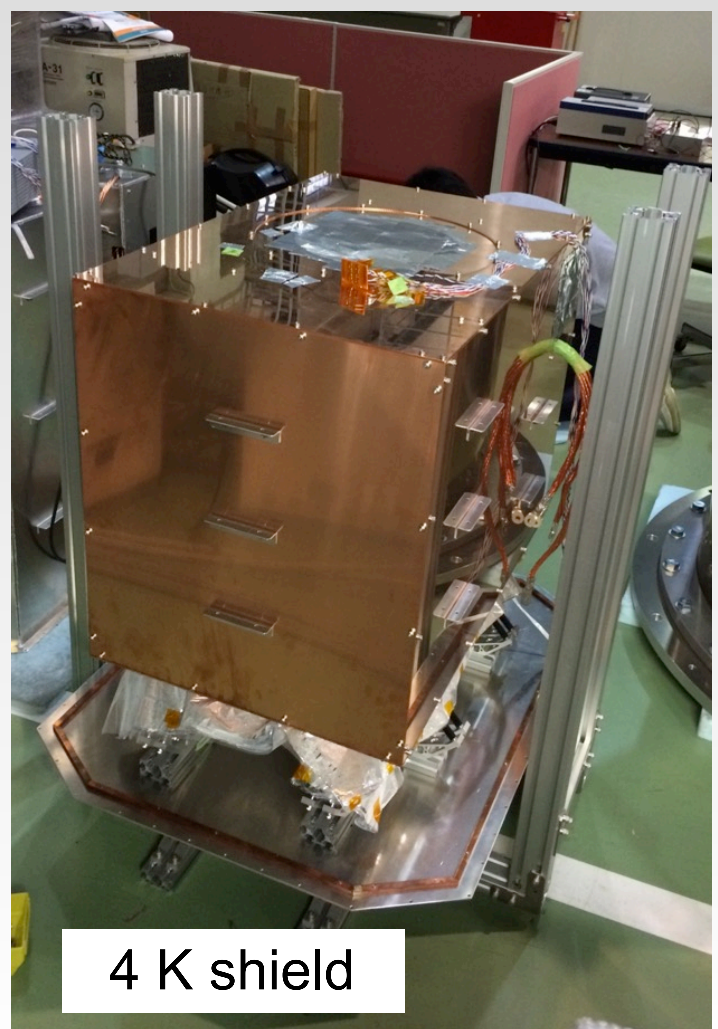
GroundBIRD cryogenics

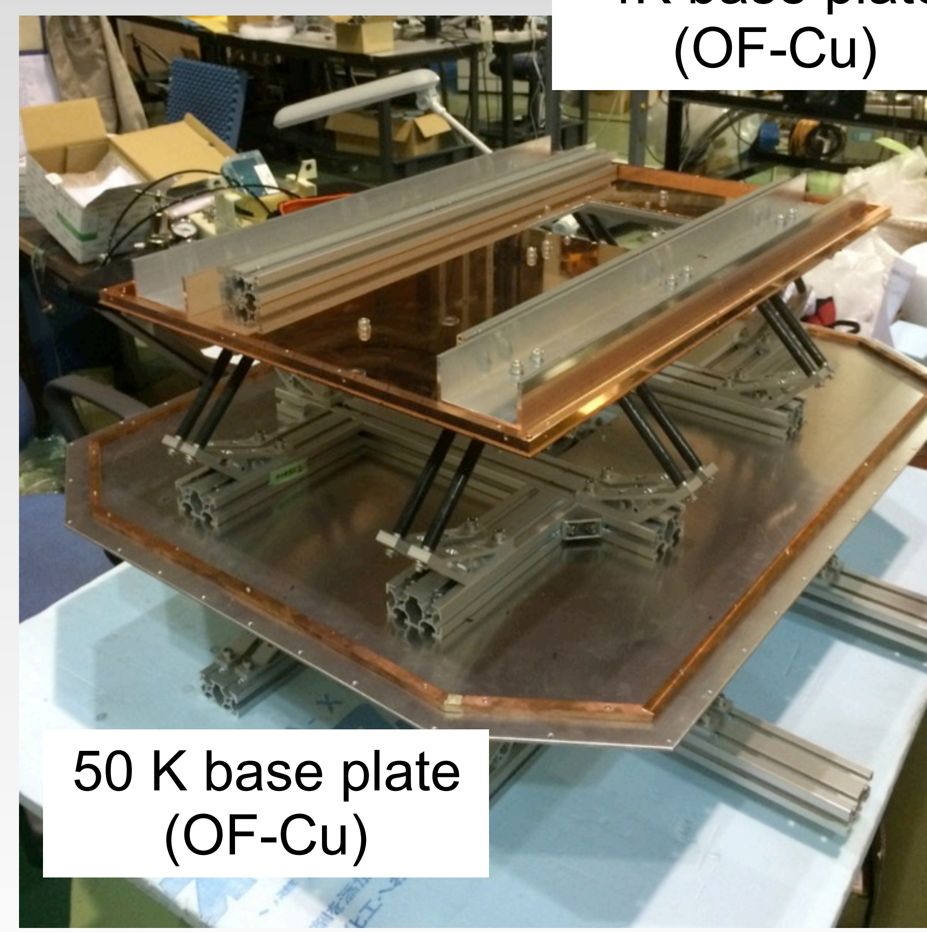




See Choi et al. (2013), *Review of Scientific Instruments 84(11), 114502*





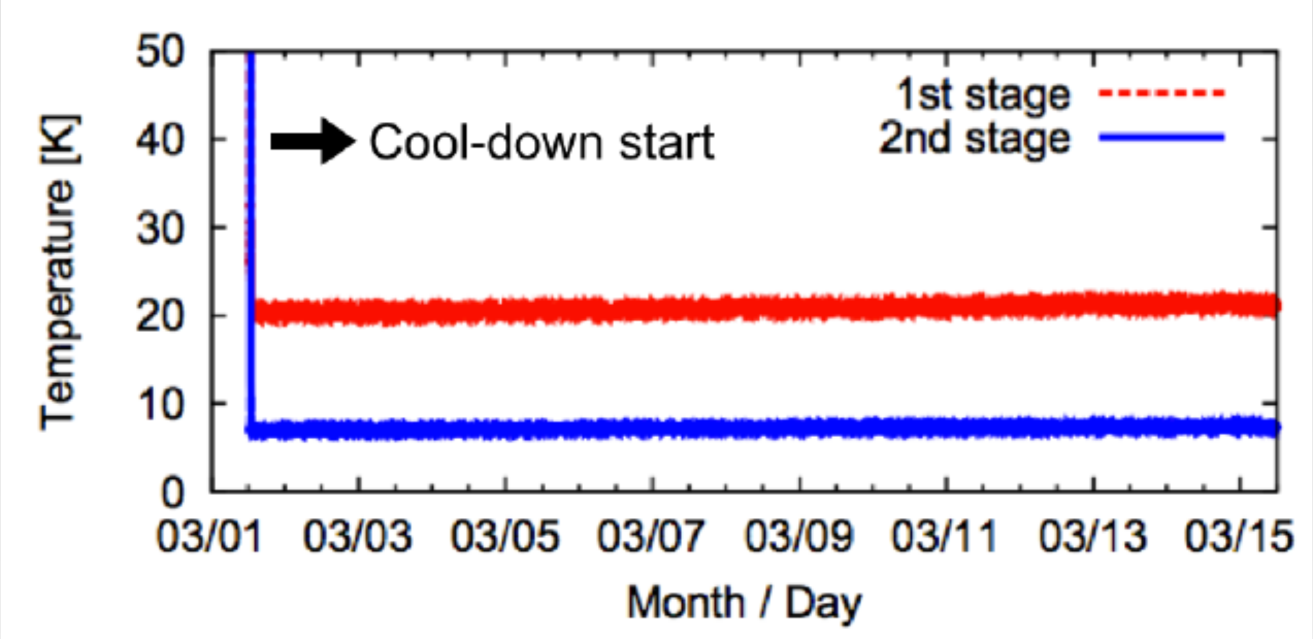


GroundBIRD cryogenics

GM cryocooler: 23 K in the first stage
and 7 K in the second stage

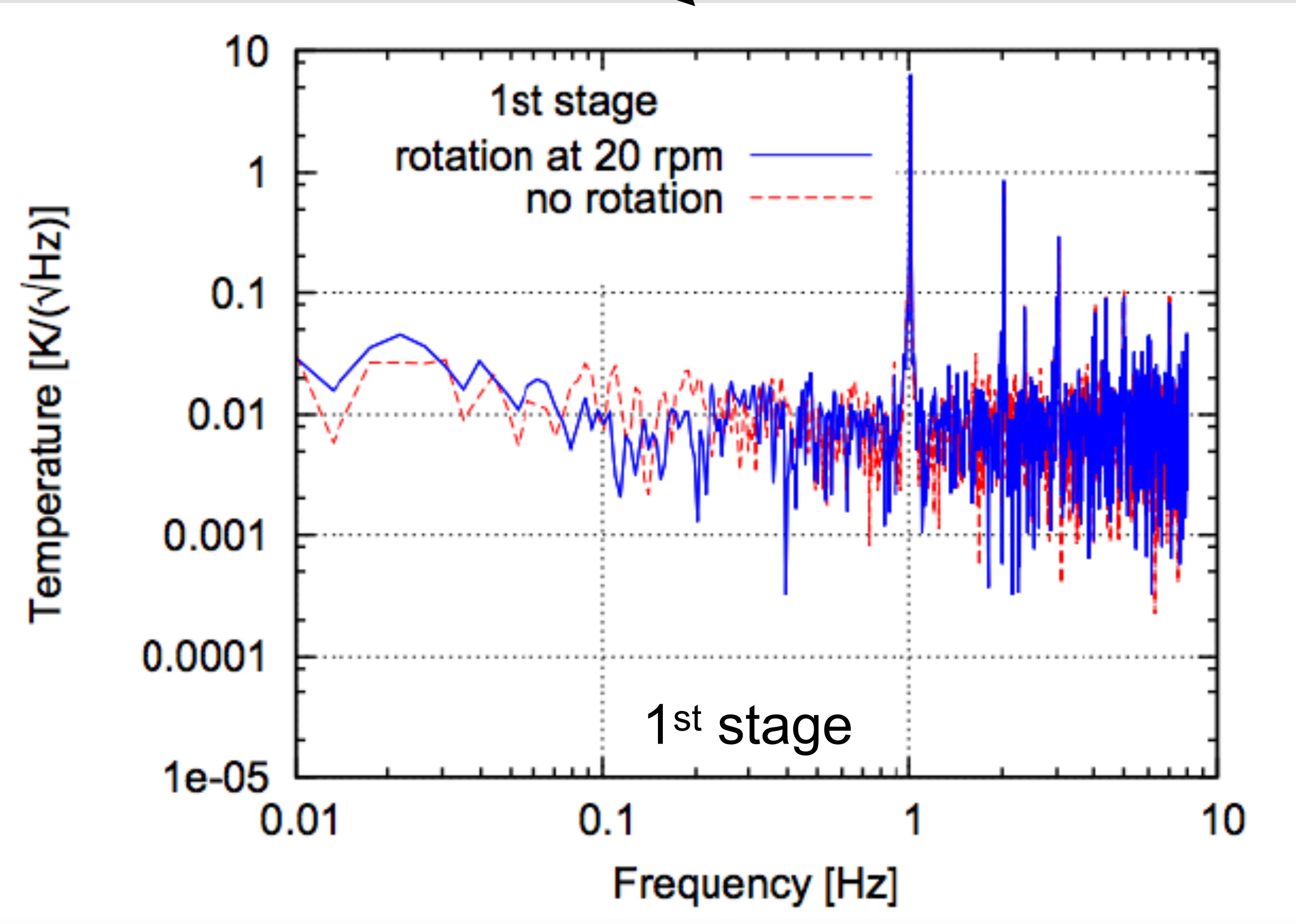
★ Extremely high temperature stability

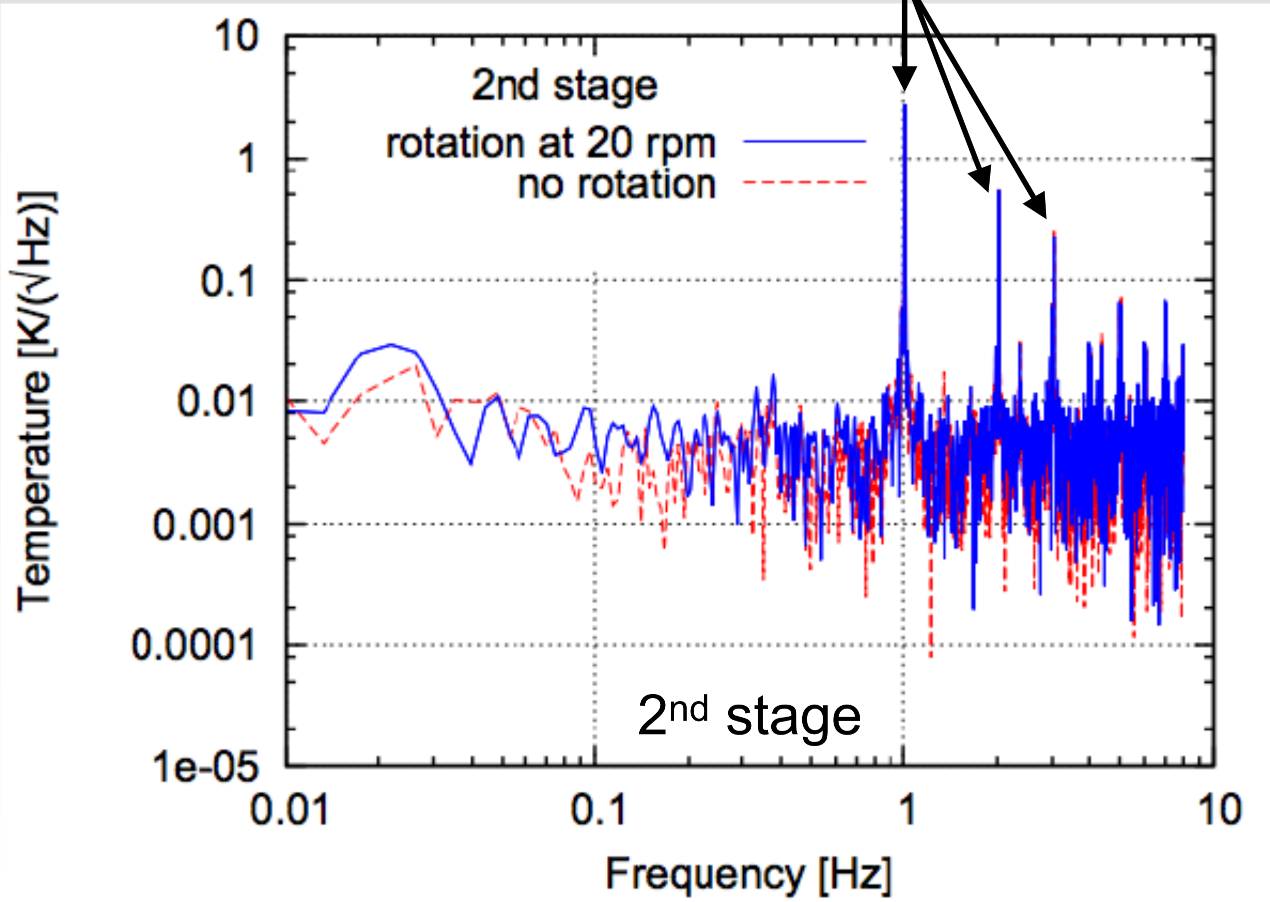
Temperature in the 1st and 2nd stages during long-term operation at 20 rpm



Fourier transform of the temperature under cool-down condition, at 20 rpm

PTC cycle and sub-harmonics



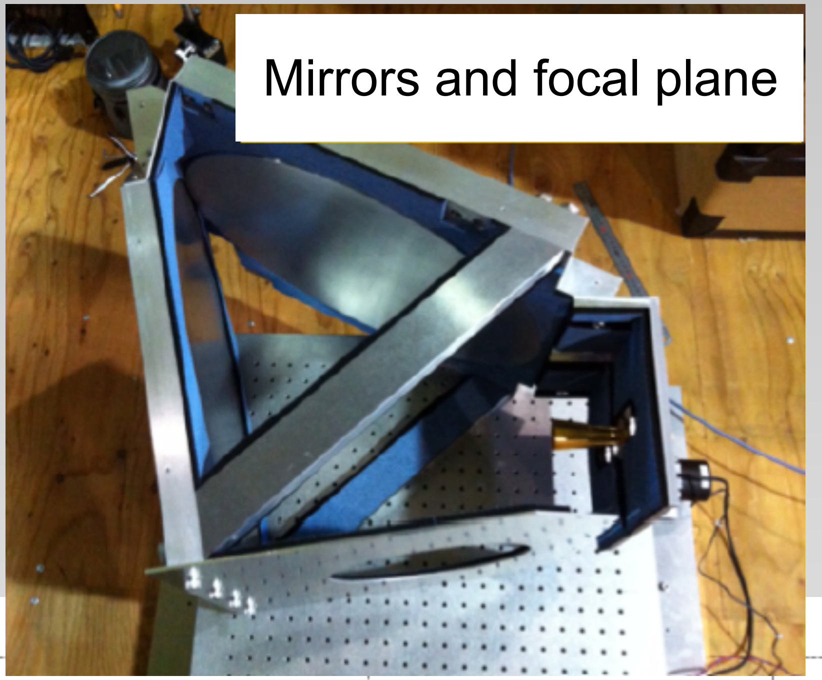


Credit images: Jihoon Choi (PhD thesis)

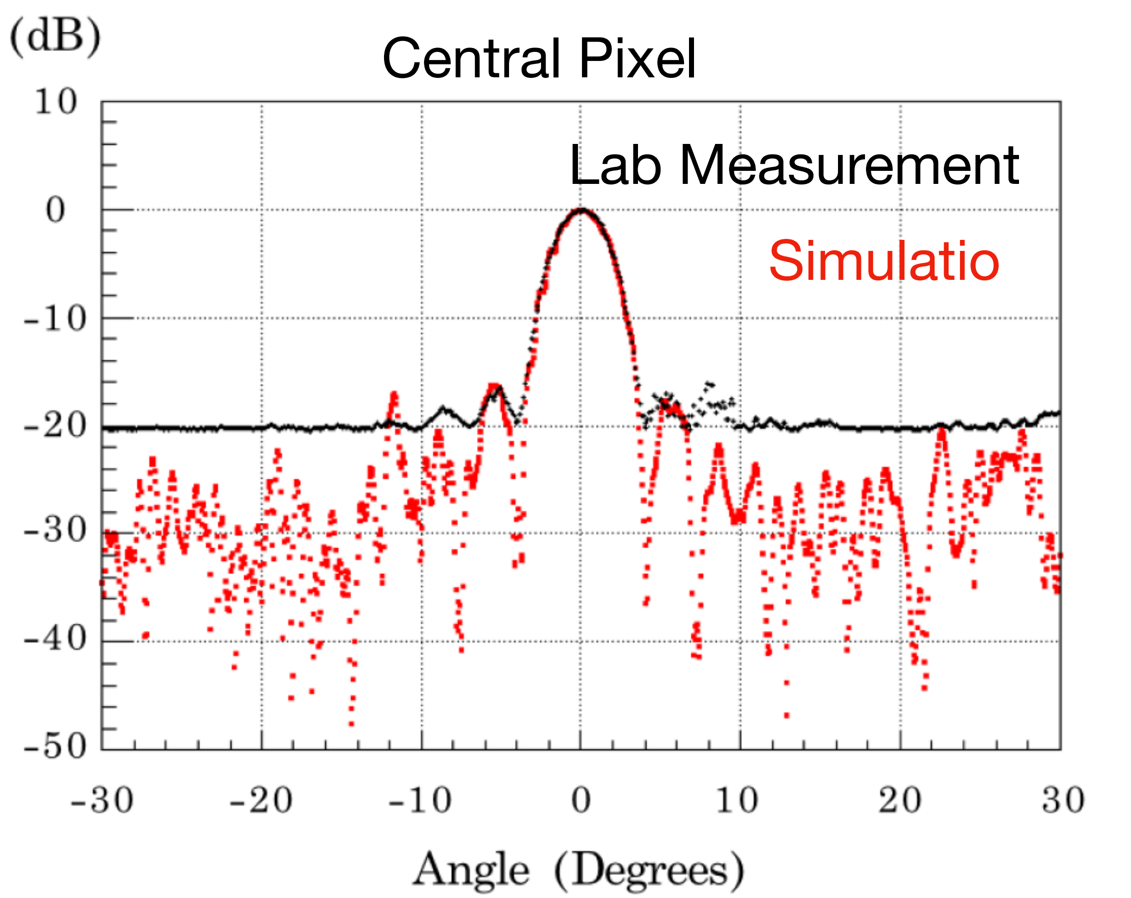
GroundBIRD optics

★ Mizuguchi-Dragone dual-reflector mirror
- Low cross-polarisation
- Large FoV

★ Cold optics at 4 K



Measurement vs simulation (90 GHz)



Cross-polarisation

-31 dB @ 150 GHz

-24 dB @ 220 GHz

FWHM

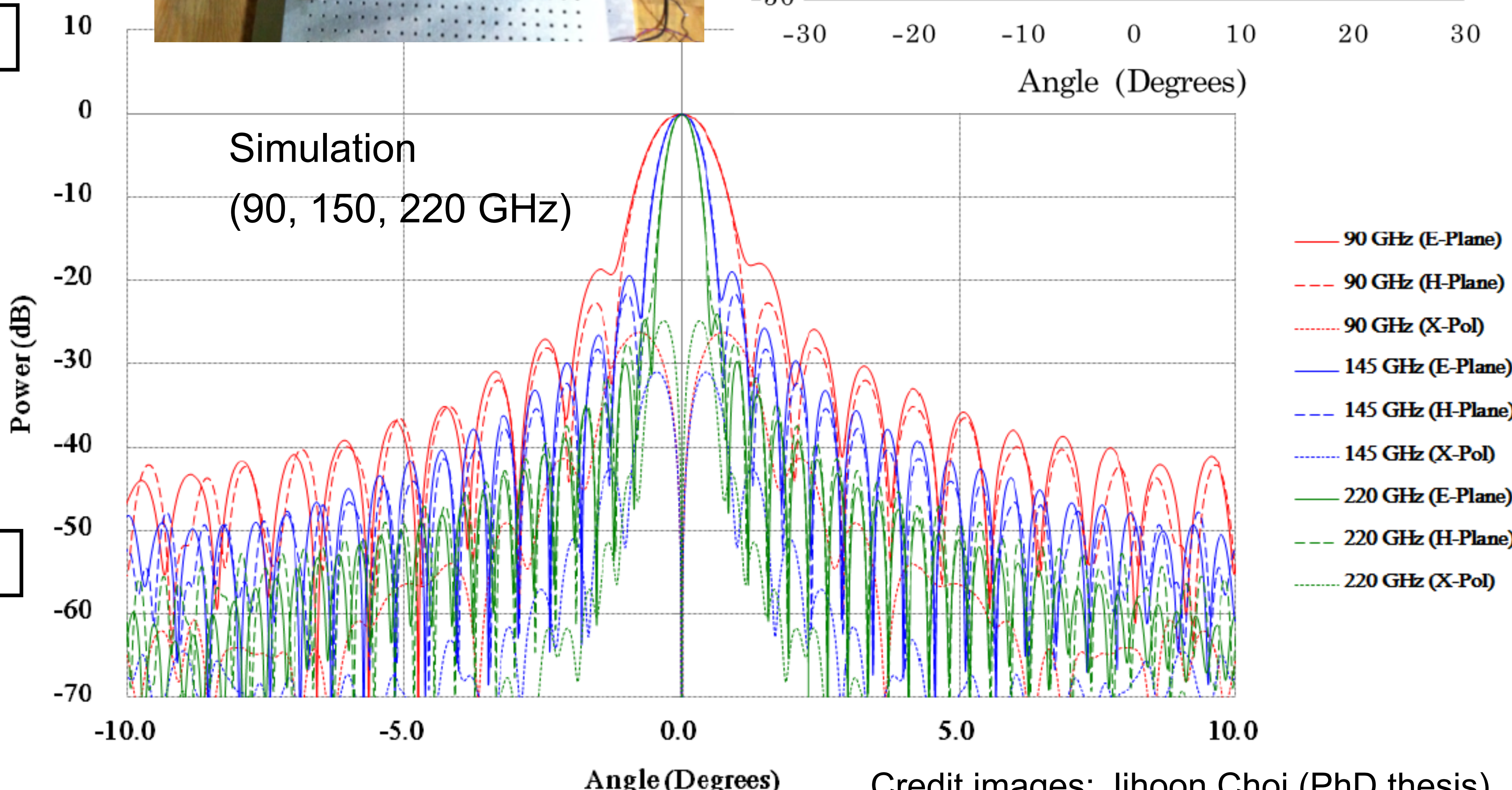
0.60° @ 150 GHz

0.42° @ 220 GHz

First sidelobe

-19 dB @ 150 GHz

-24 dB @ 220 GHz



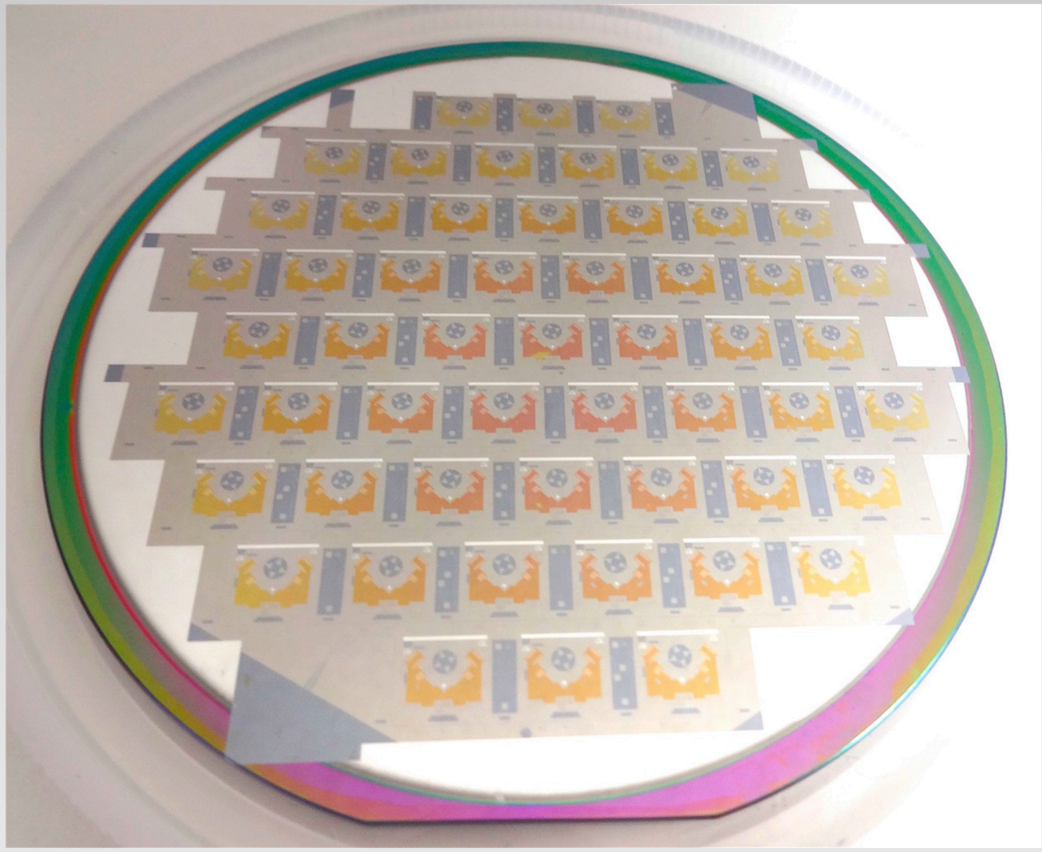
Credit images: Jihoon Choi (PhD thesis)

GroundBIRD focal plane design

★ **MKID** sensors, coupled with a hemispherical silicon lens and with a dual-polarisation antenna (OMT)

★ MKIDs meet GroundBIRD requirements:

- Good scalability
- Easy multiplexing in the frequency domain.
  - Each detector has a different resonant frequency
  - All detectors are then read using a single feed line
- Wide dynamic range
- Small time constant (need kHz sampling)
  - Time constant ~ 10 μs
  - < 0.5 ms, 10 samples/beam, (120°/0.6°=200 Hz)



★ 1 central wafer at 220 and 6 external wafers at 150 GHz

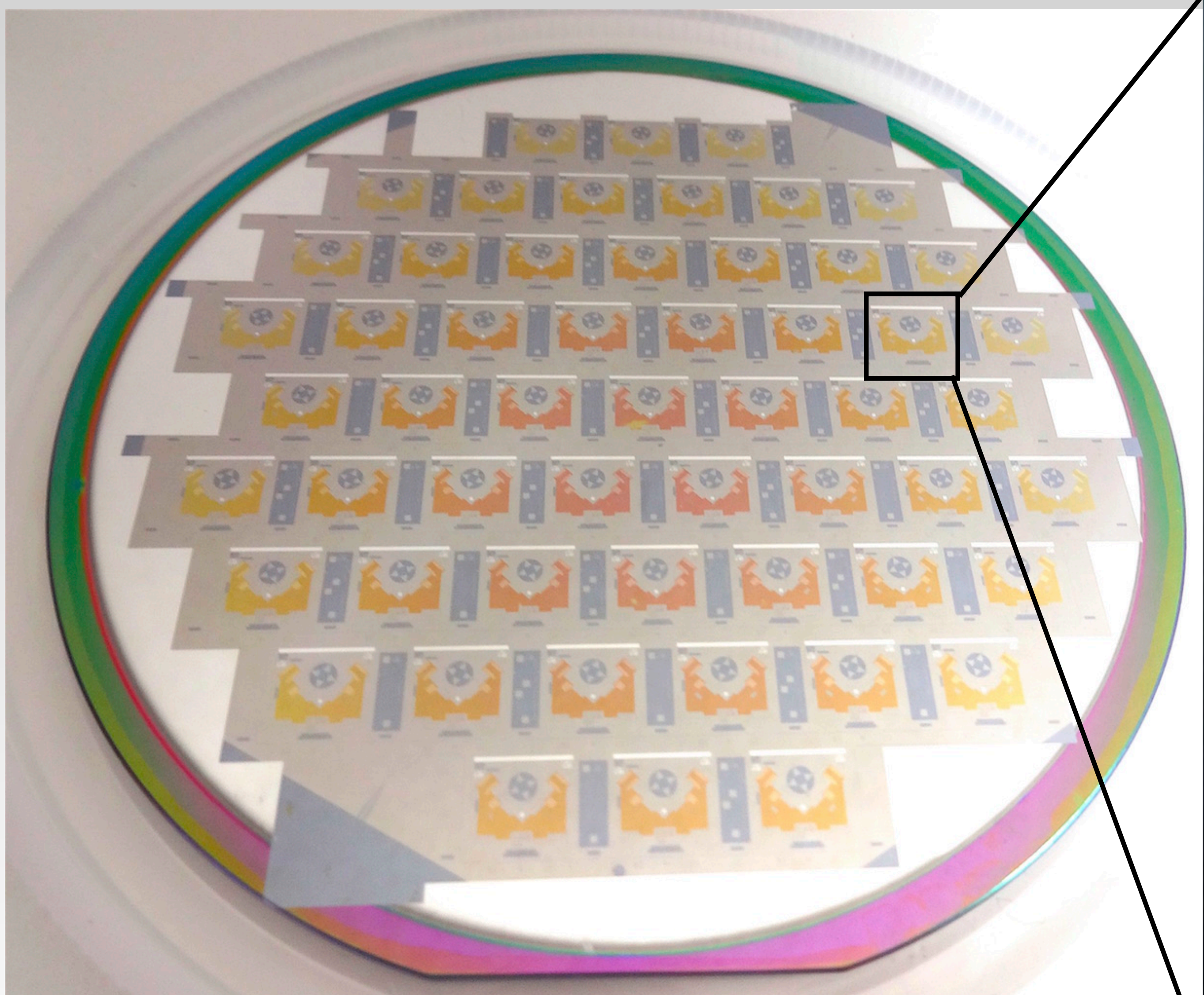
★ Focal planed designed and fabricated in Japan (current commissioning uses both RIKEN and SRON MKIDs)

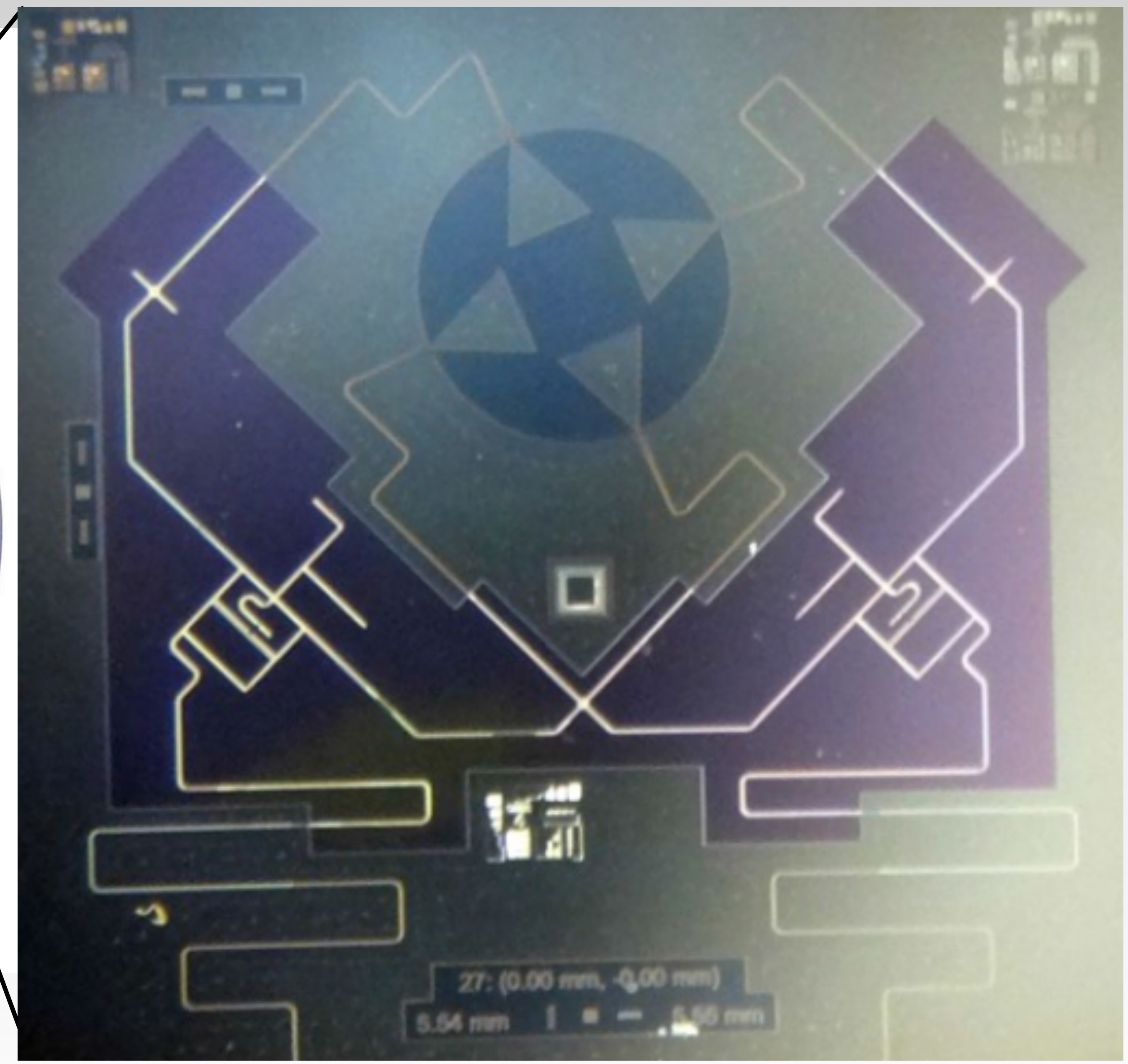
ν (GHz)	Δν (GHz)	NET/pixel ($\mu K \cdot s^{1/2}$)	**NET_{array} Q,U ($\mu K \cdot s^{1/2}$)**
145	40	310	**17**
225	50	530	**50**

GroundBIRD detectors

Close look at a single pixel
(dual pol. antenna with 2 MKIDs)

Fabricated 145 GHz wafer





Prototyped MKID array

GroundBIRD continuous calibration

★ A wire grid located on top of the enclosures induces a polarisation of the ambient-temperature photons that are reflected on the wires, with amplitude 1 K

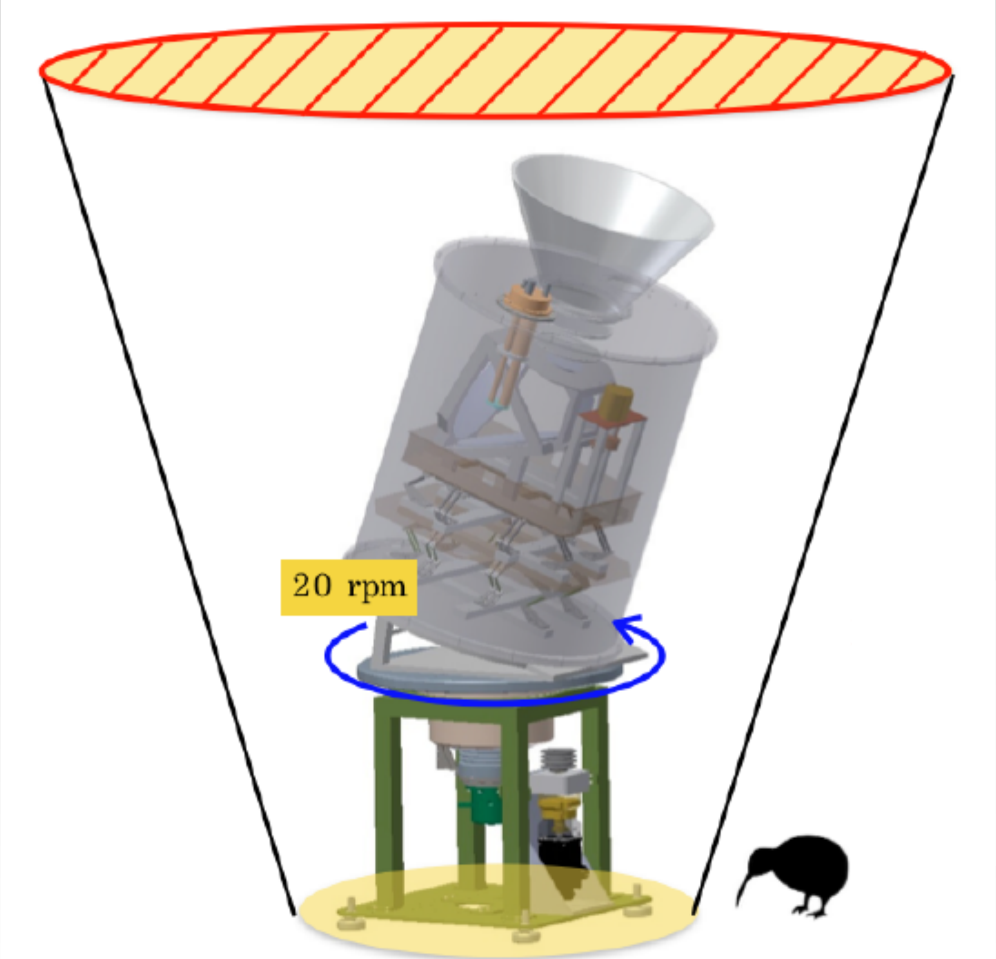
★ Rotation of the telescope creates a sinusoidal signal

★ This system allows calibrating relative gains to **0.3% precision**, and **mitigates atmospheric 1/f**

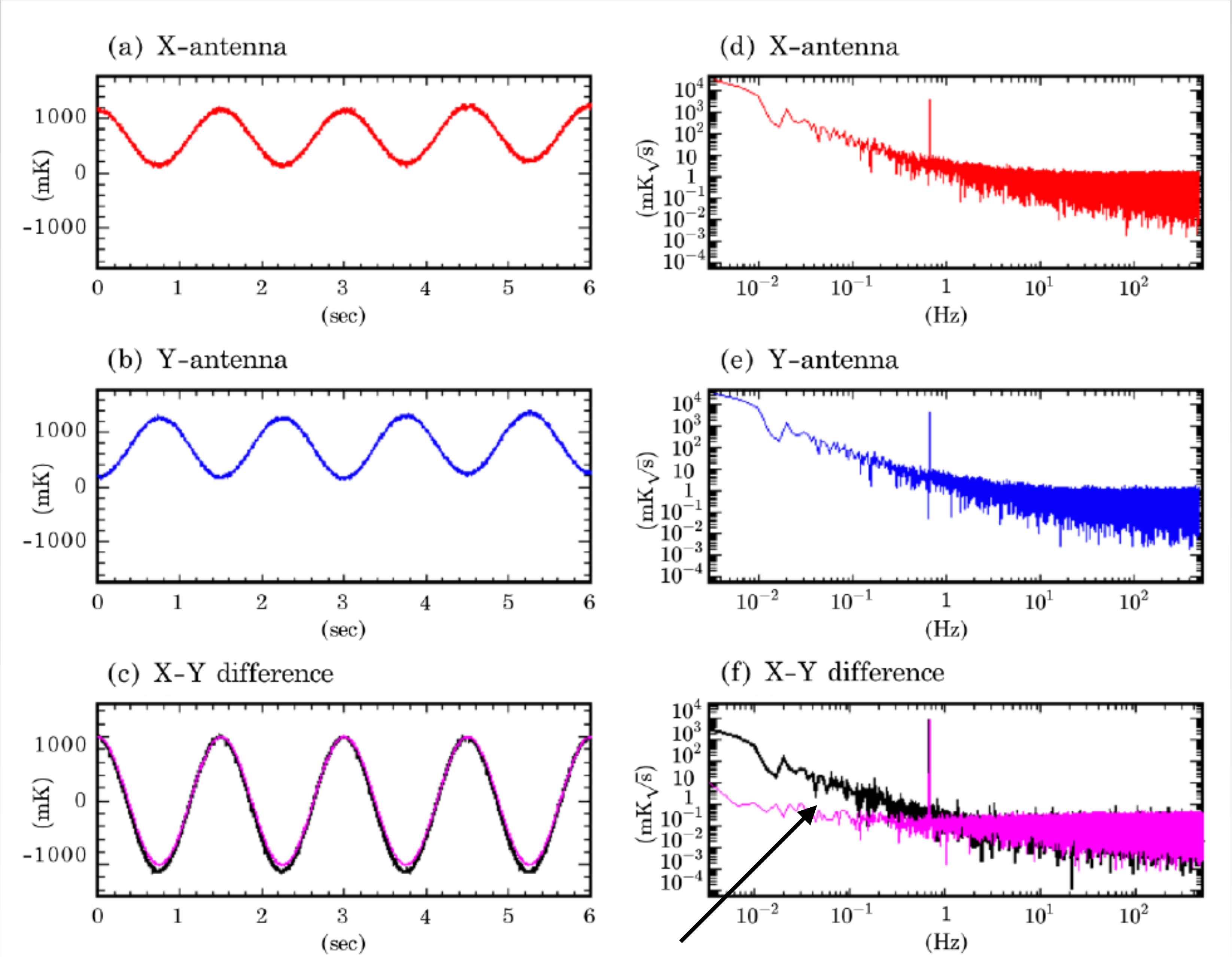
★ Concept was proved by QUIET

See Tajima et al. 2012 (*Journal of Low Temperature Physics, 167, 936)*

Wire grid on top of the enclosure



Tajima et al. 2012 (*Proc. of SPIE, 8452, 84521)*

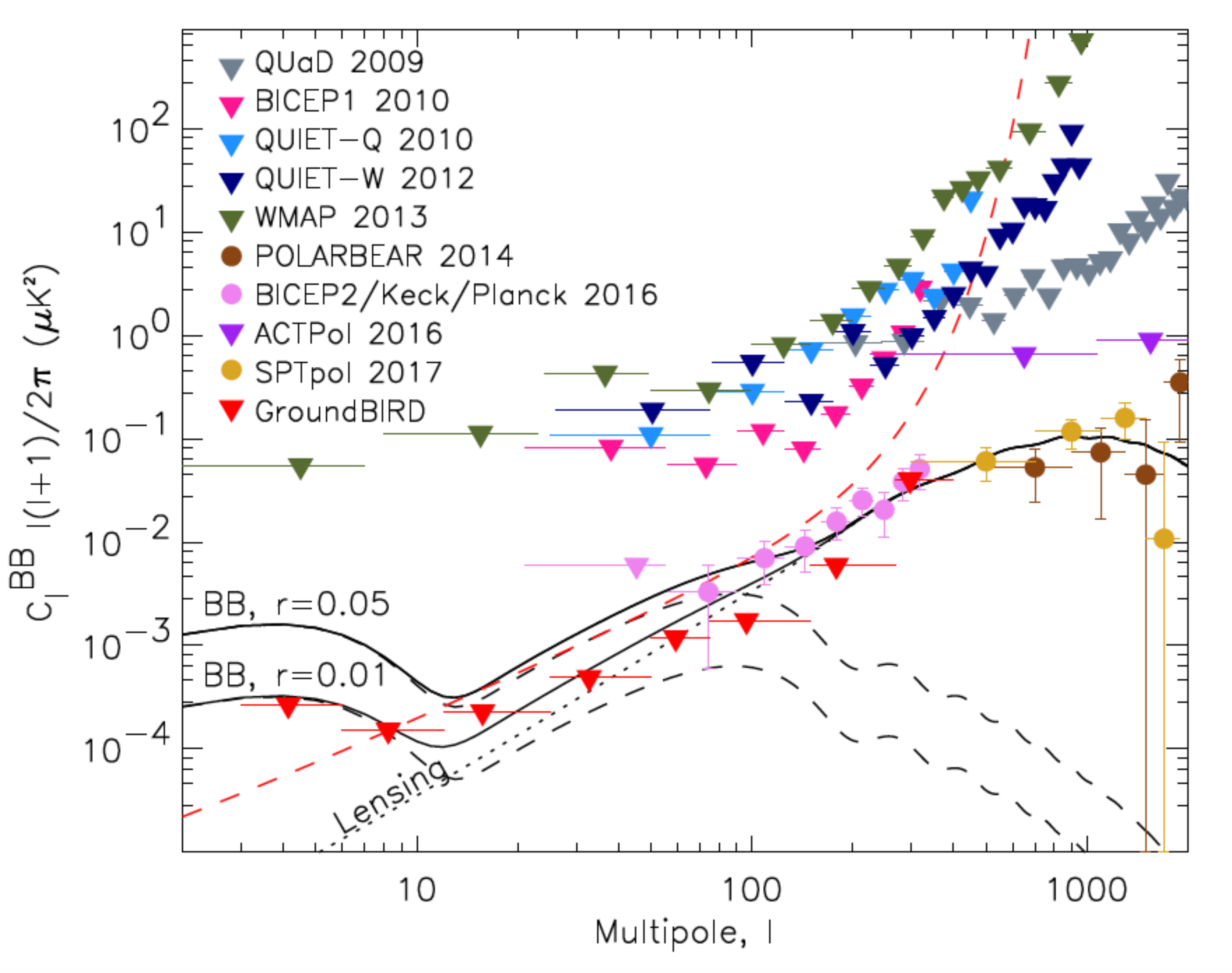


Atmospheric 1/f suppression!

GroundBIRD sensitivity forecasts

★ Forecasts for the measurement of the B-mode power spectrum:

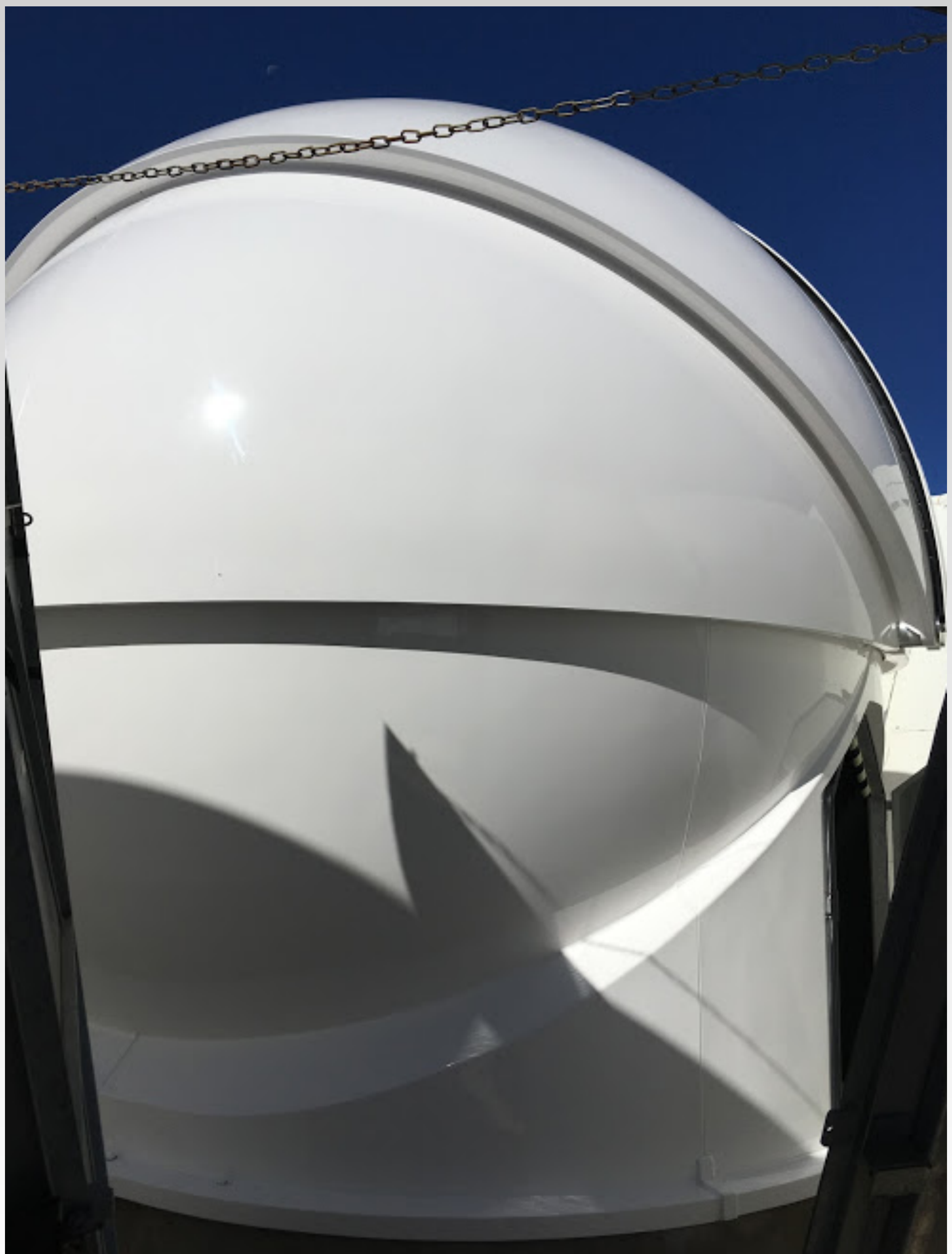
- Target sensitivity, **$\sigma_{Q,U}$ = 17 μK·s$^{1/2}$**
- t_{obs} = 3 yr, with 0.7 efficiency
- f_{sky} = 0.44
- Target map sensitivity (Q,U): **17 μK·arcmin**



GroundBIRD installation at OT

★ Dome installed on October 2018

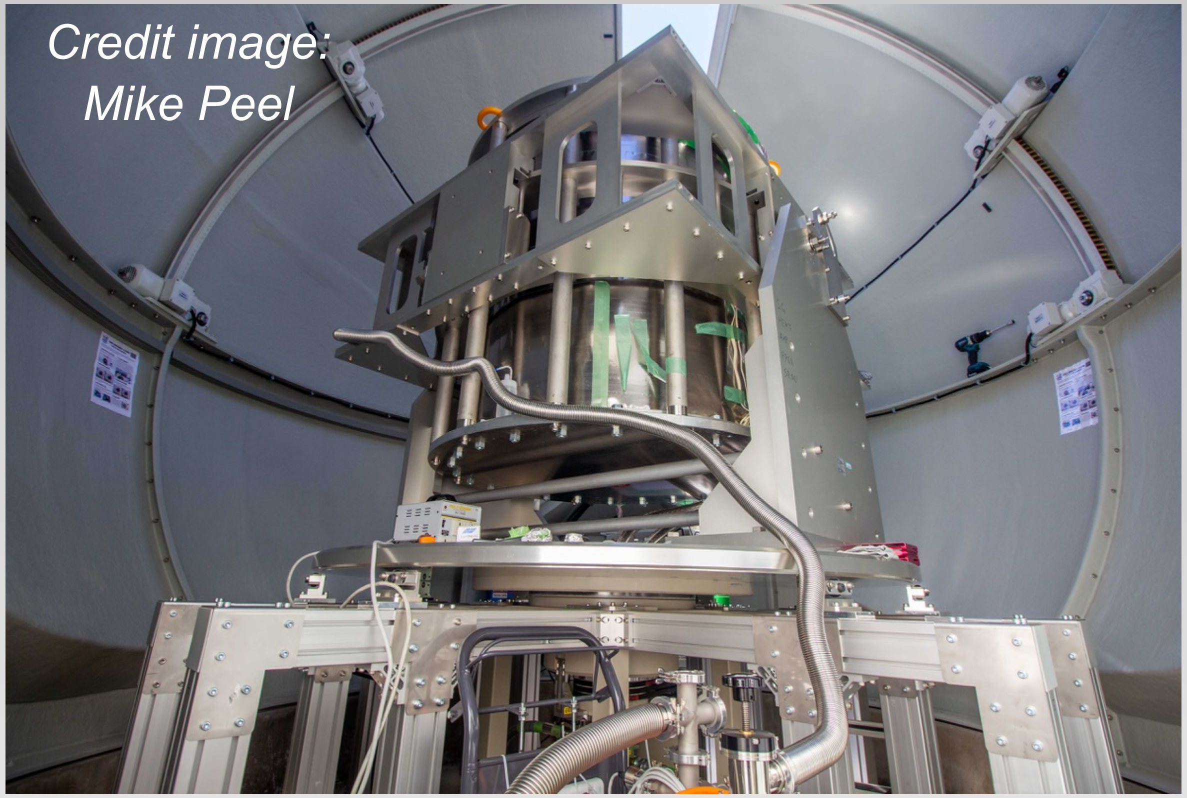
- 4.5m full-sky dome
- Baader Planetarium

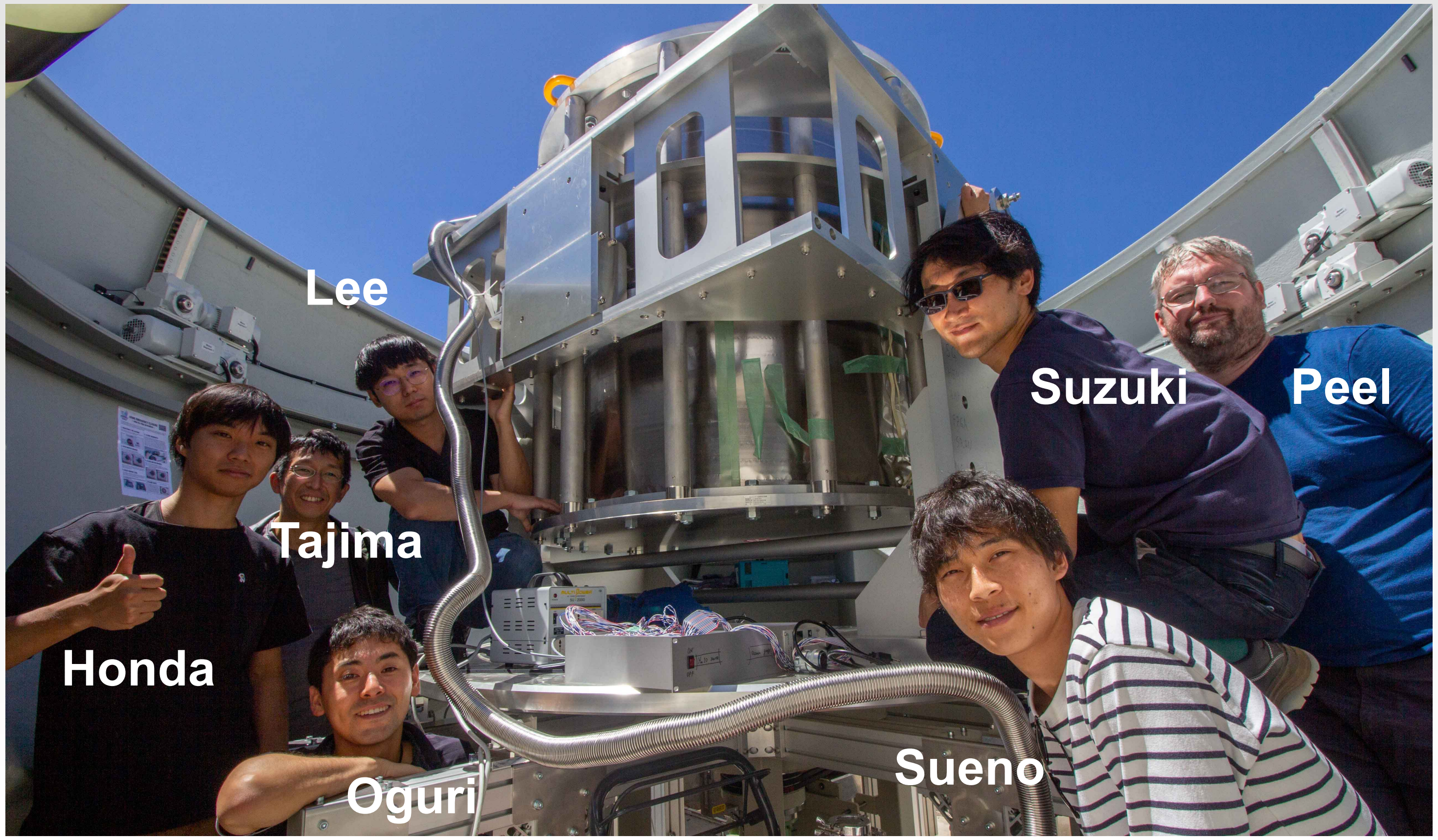


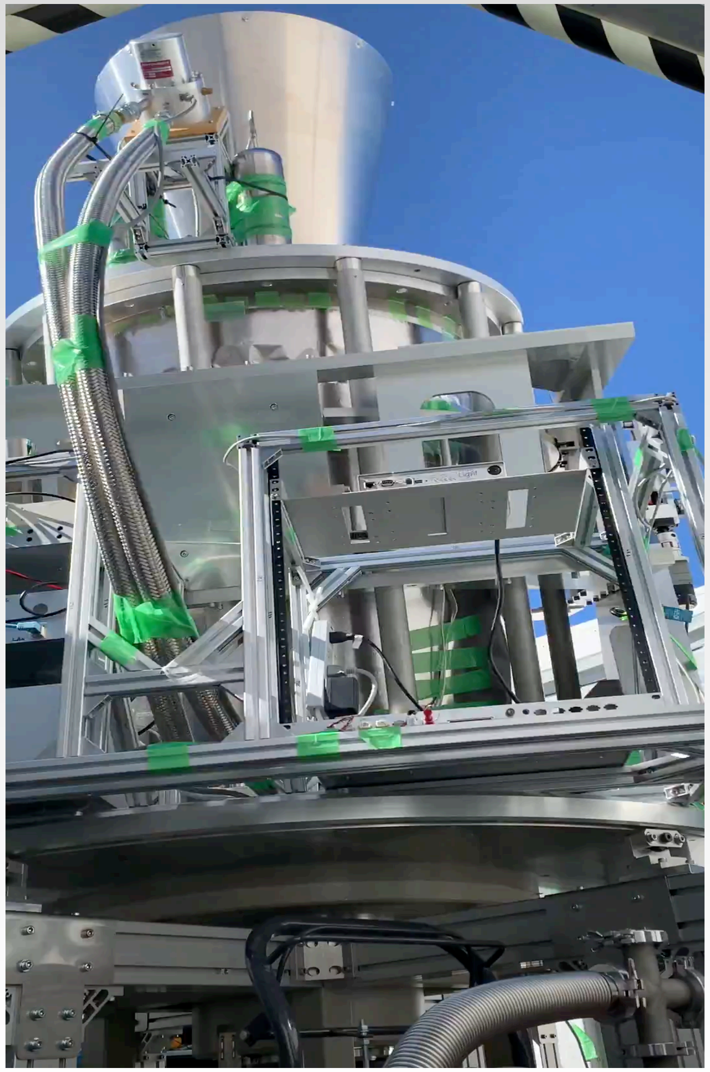
Credit image/video: Shunsuke Honda

GroundBIRD installation at OT

★ Telescope installed on September 2019







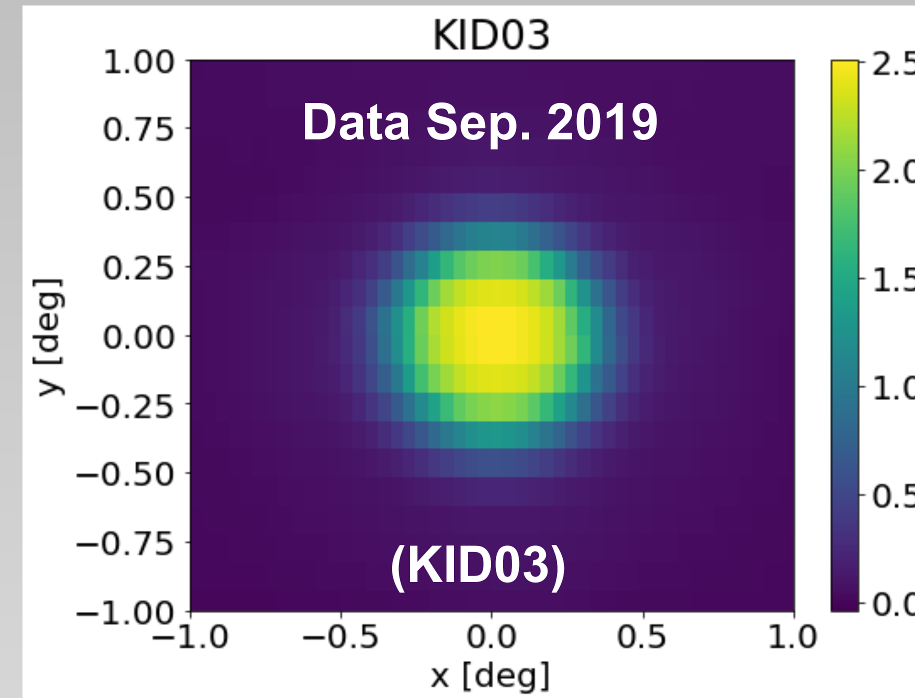
GroundBIRD first light

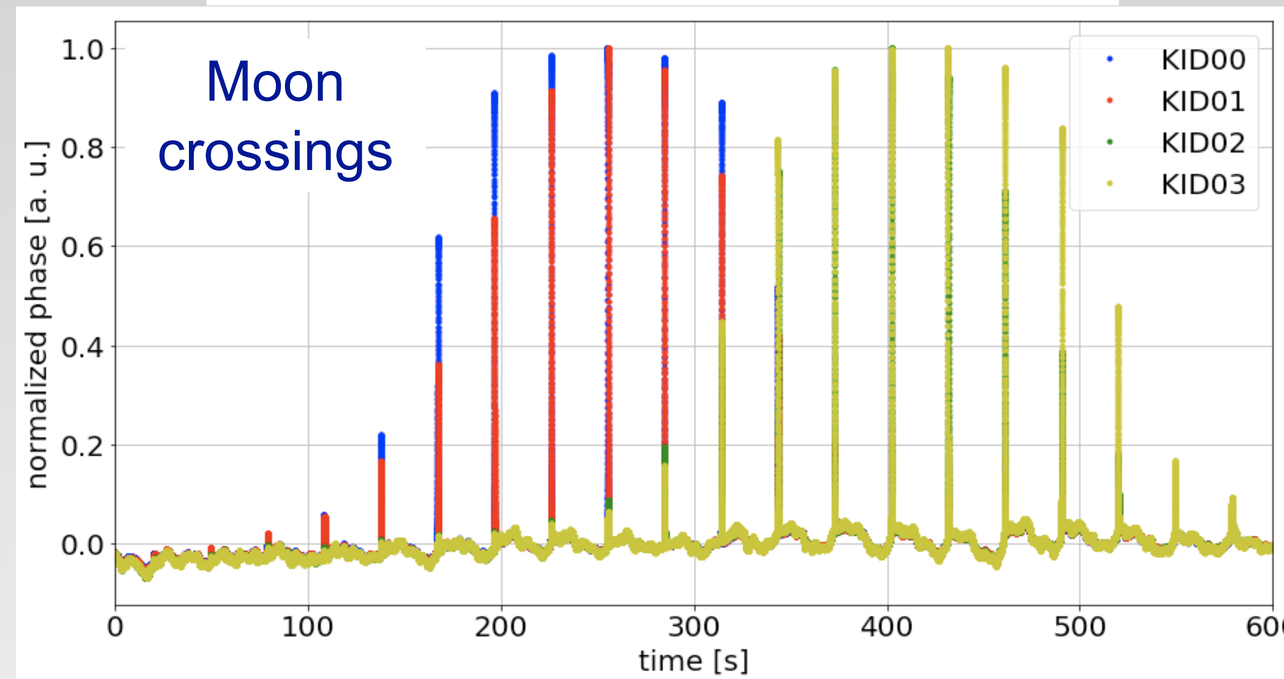
★ First light on the Moon, 21 Sep 2019

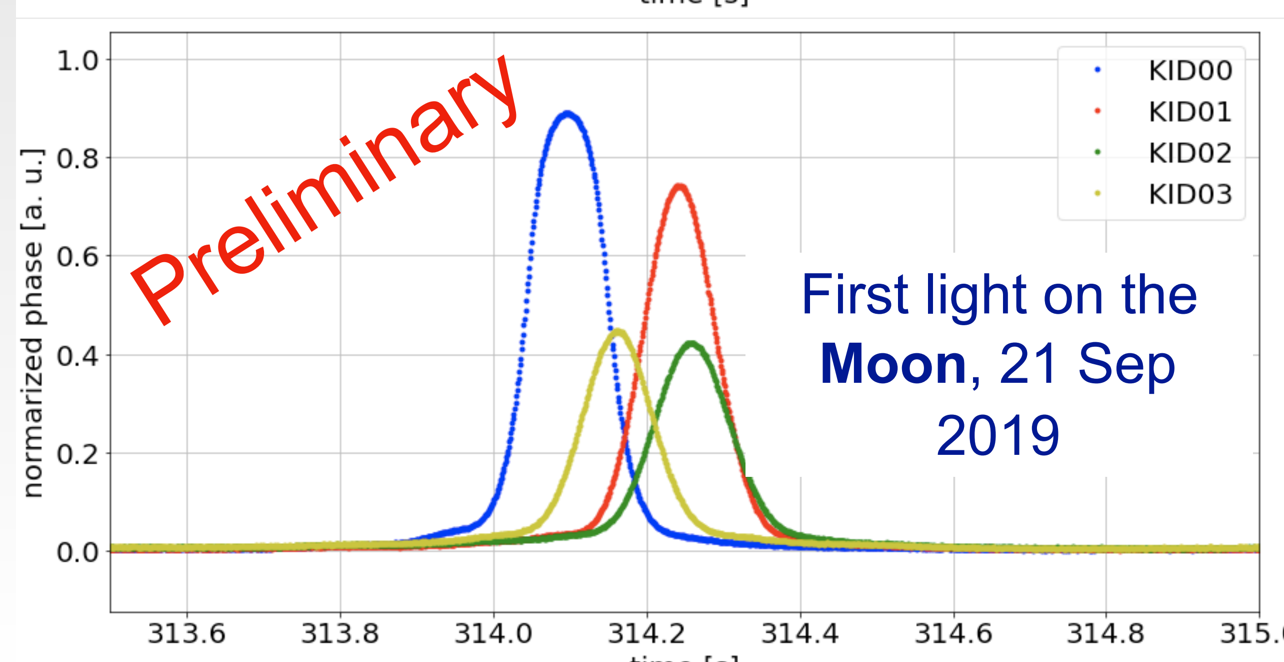
★ Acknowledgment: lens-coupled MKIDs from SRON

★ Preliminary analyses show FWHM ≈ 0.3° (consistent with simulations)

Preliminary analyses by Hiroki Kutsuma (Tohoku University)







GroundBIRD first light

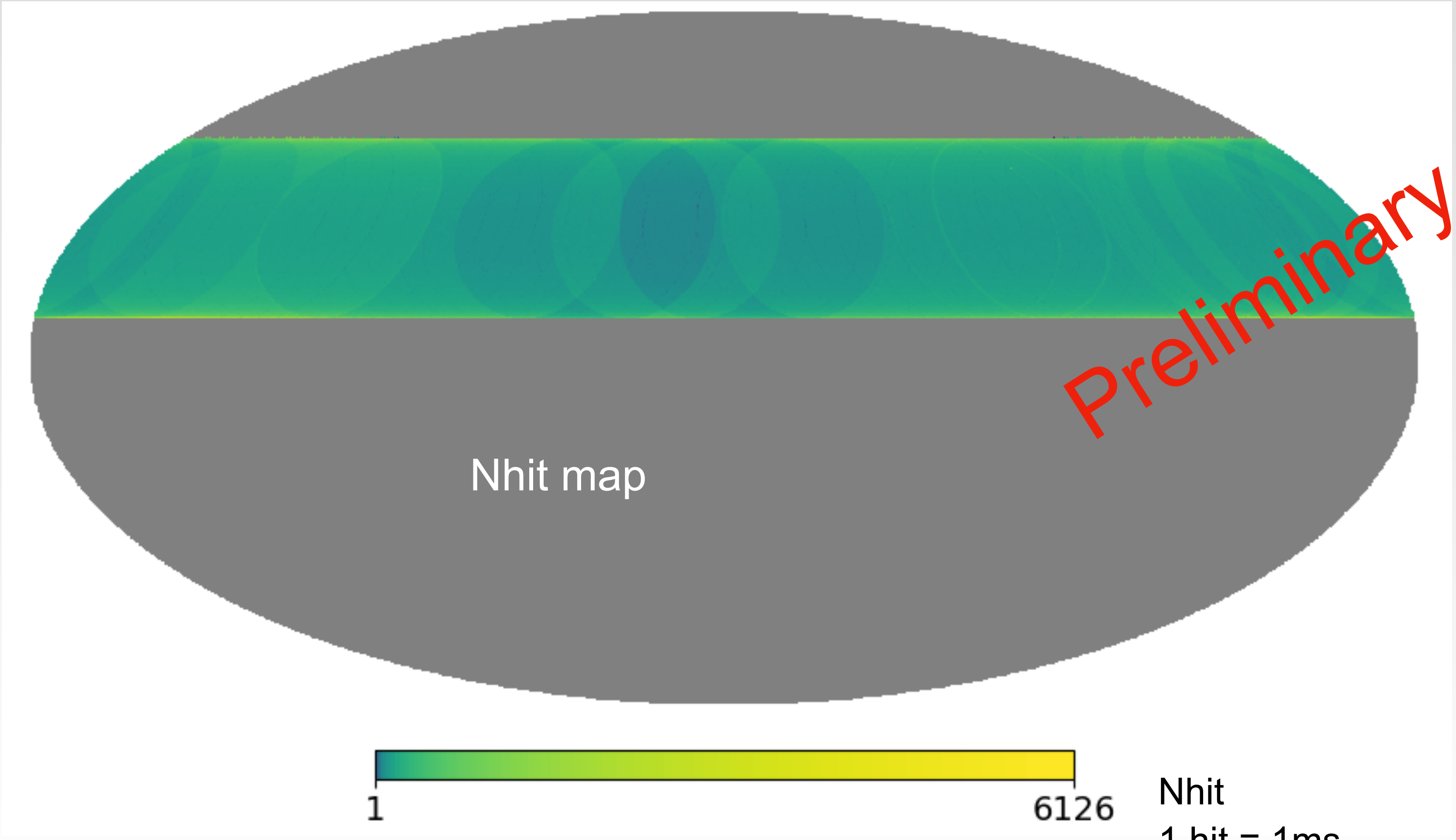
★ First test: 48h continuous rotation at 20 rpm

★ Preliminary analyses, data being analysed

★ SRON MKIDs

★ RIKEN and SRON MKIDs now installed.

★ Observations resumed last night week (150 GHz and 220 GHz - RIKEN and SRON MKIDs)



Preliminary analyses by Mike Peel (IAC)

Summary

★ GroundBIRD is a new CMB polarimeter at 150 and 220 GHz

- Teide observatory (2400 m). Northern hemisphere → important complementarity with the South.
- Nice test-bench to explore the properties of the TO atmosphere in the mm- range
- Complementary with QUIJOTE (11,13,17,19,30,40 GHz) and LSPE-STRIP (40,90 GHz)

★ GroundBIRD key features

- Northern hemisphere
- Ultra-high scanning speed (20 rpm) to mitigate 1/f from the atmosphere and the instrument
- MKIDs-based focal plane (very small time constant, easy fabrication and multiplexing)
- One of the few experiments targeting large-scales from the ground

★ First light on September 2019

★ GroundBIRD surveys and science

- fsky = 0.44 during 3 years, down to 17 μK·arcmin sensitivity
- r = 0.01 (both reionisation and recombination bumps)

★ Future plans/extensions:

- Enlarging the focal plane size (number of detectors)
- Expanding the frequency coverage (90 GHz)