GroundBIRD



Osamu Tajima (Kyoto University)
on behalf of GB collaboration

The GB Collaboration

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Kyoto Shunsuke Honda, Takuji Ikemitsu, Junta Komine, Osamu Tajima (co-PI)

KEK Masashi Hazumi, Hikaru Ishituka, Taketo Nagasaki, Junya Suzuki, Tomohisa Uchida, Mitsuhiro Yoshida, (O. Tajima as visiting staff)

NAOJ Makoto Nagai

ISAS/JAXA Yutaro Sekimoto

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

Tokyo Kenji Kiuchi, Makoto Minowa, Nozomu Tomita

Saitama Ryo Koyano, Masato Naruse, Toru Taino

Korea Kyungmin Lee, Eunil Won

IBS Jihoon Choi

TU Delft Kenichi Karatstu

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

Japan, Spain, Korea, and Netherlands

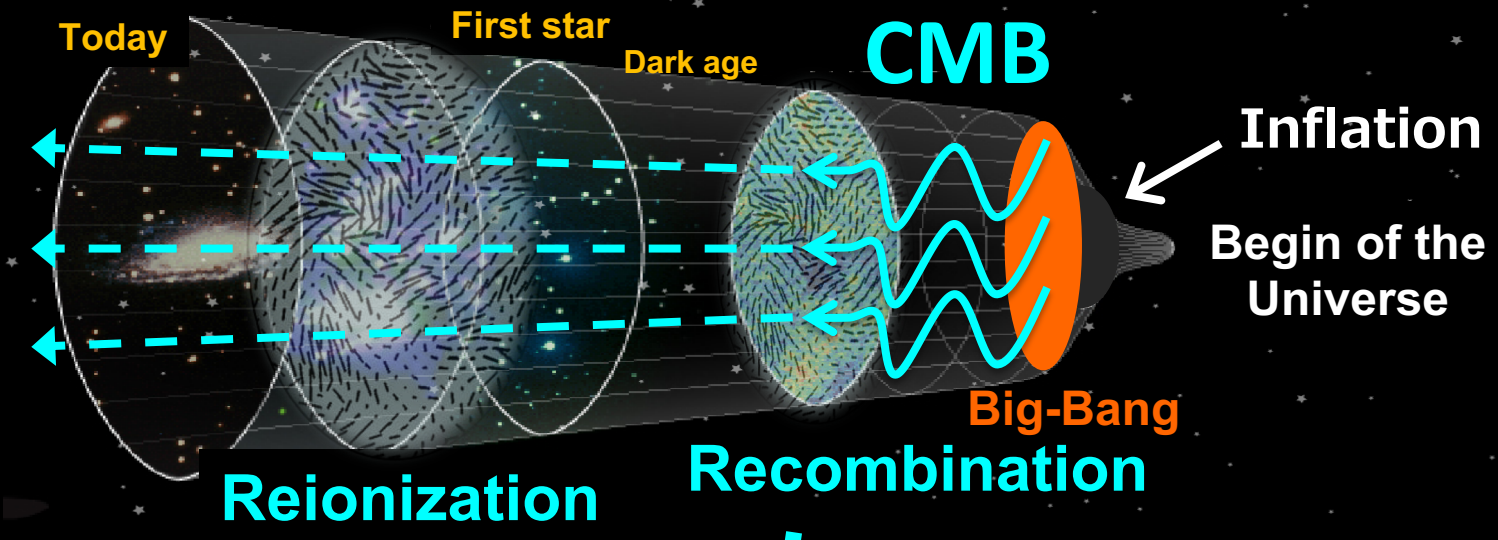
Science Targets of GB

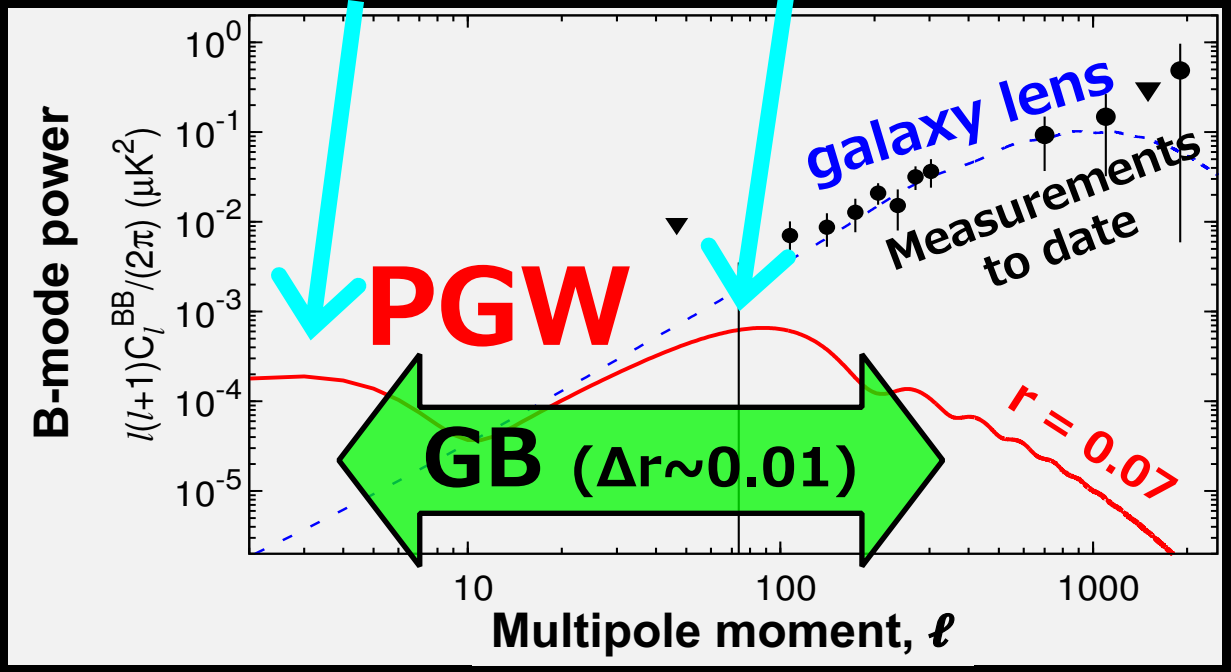
Primordial Gravitational Waves (PGW)

Optical depth (τ) for Σm_ν

E & B-modes at large angular scale

“Look” B-modes patterns

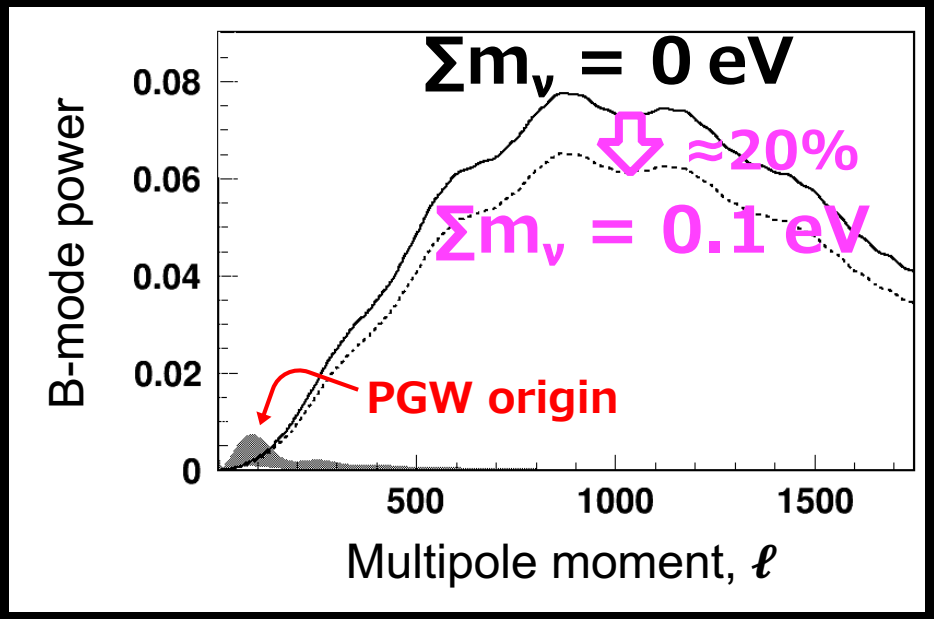


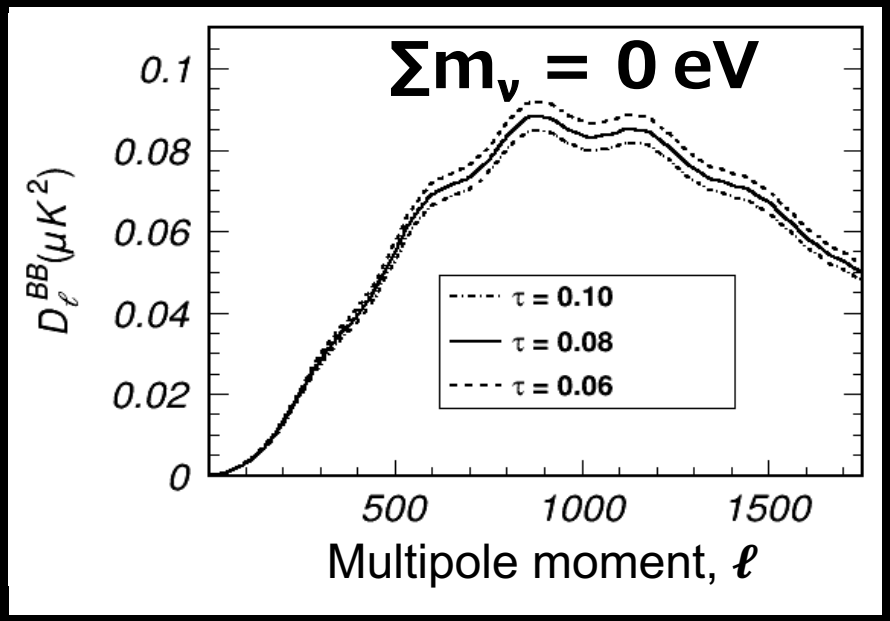


Courtesy of Y. Chinone

Σm_ν makes thinner lens

Correlation with τ should be unfolded





Planck 2018: τ = 0.054 ± 0.007

τ ⇔ Reionization in E-modes

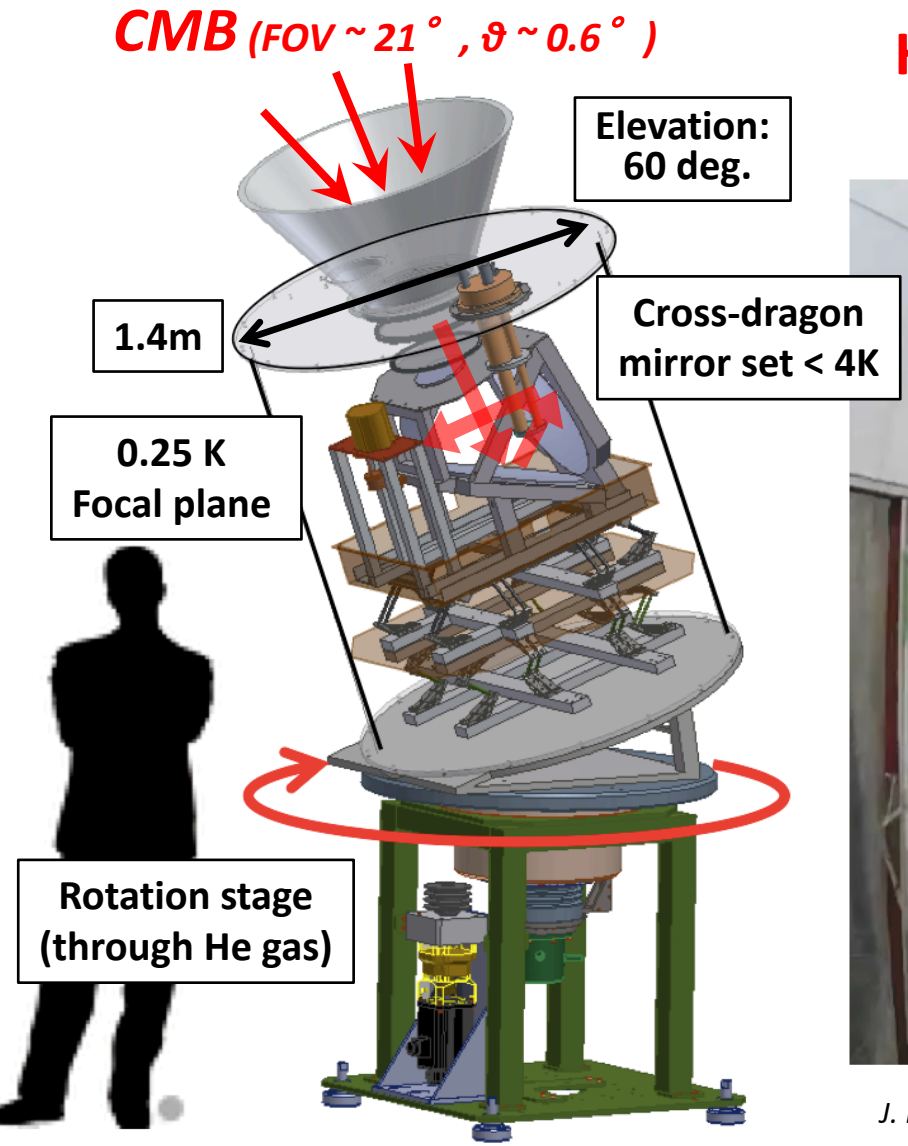
(target $\Delta\tau$~0.01 from single exp.)

Experimental concepts to reach low-ell

- **Wide scan with fast modulation**
  - → **High-speed Rotation-scan (HsRs)**
- **Fast time response for HsRs**
  - → **MKID ($\tau \lesssim 100$ μs)**
- **Be sensitive even though no-large focal plane**
  - → **Cryogenic optics (< 4K)**
  - → **Low-loss IR block (RT-MLI)**
- **Be robust for foregrounds**
  - → **DUST-band (220 GHz) + CMB (150 GHz)**
  - → **(future) alliance with QUIJOTE**

Slim size is preferred

Overview of GB



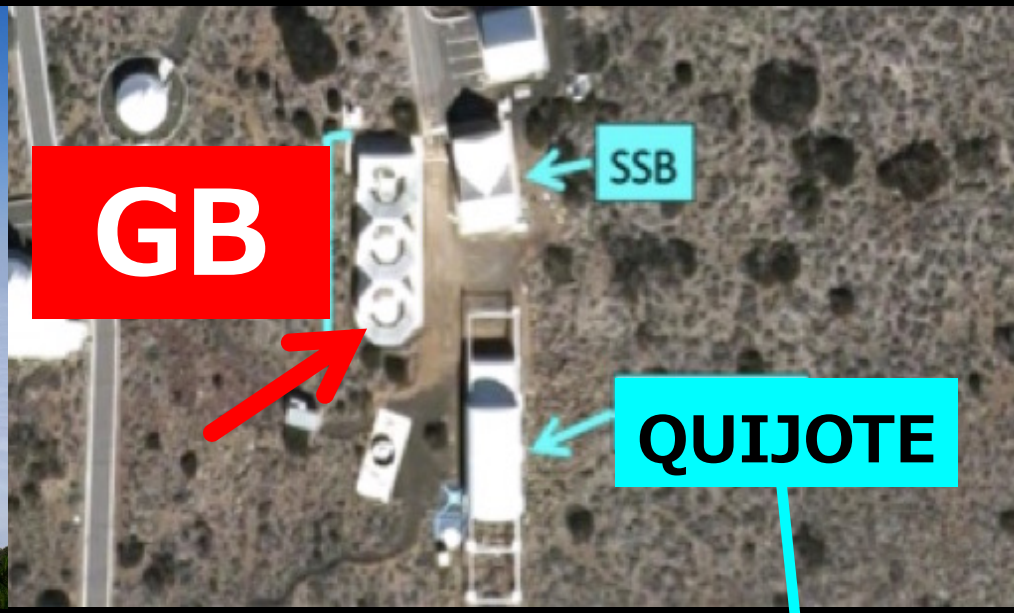
HsRs (120°/s in Az) mitigates effects of atmospheric fluctuation



J. Low Temp. Phys. 176, 691 (2014), and Proc. SPIE 8452, 84521M (2012).

To be deployed near QUIJOTE

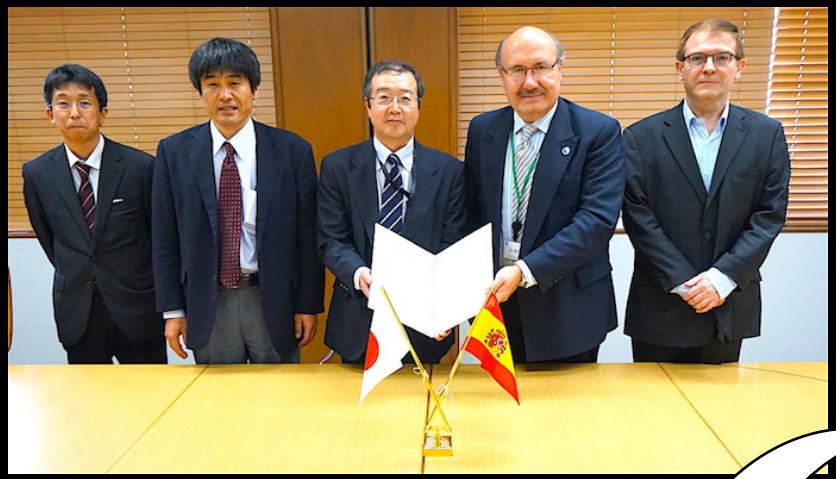




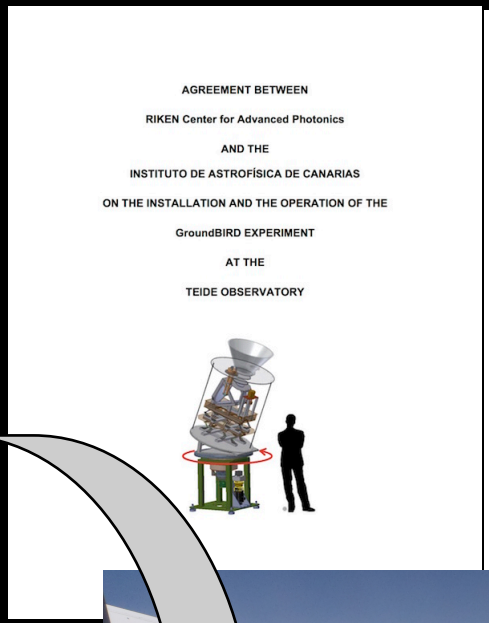


Observation site is in prep.

MOU Riken btw IAC (May, 2015)



Agreements (Aug. 2016)



AGREEMENT BETWEEN

RIKEN Center for Advanced Photonics

AND THE

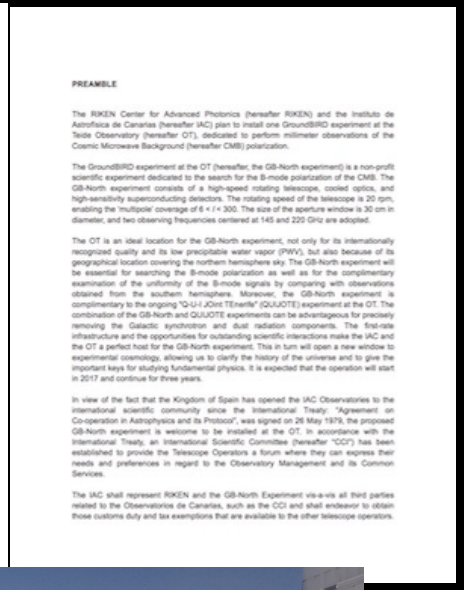
INSTITUTO DE ASTROFÍSICA DE CANARIAS

ON THE INSTALLATION AND THE OPERATION OF THE

GroundBIRD EXPERIMENT

AT THE

TEIDE OBSERVATORY



PREAMBLE

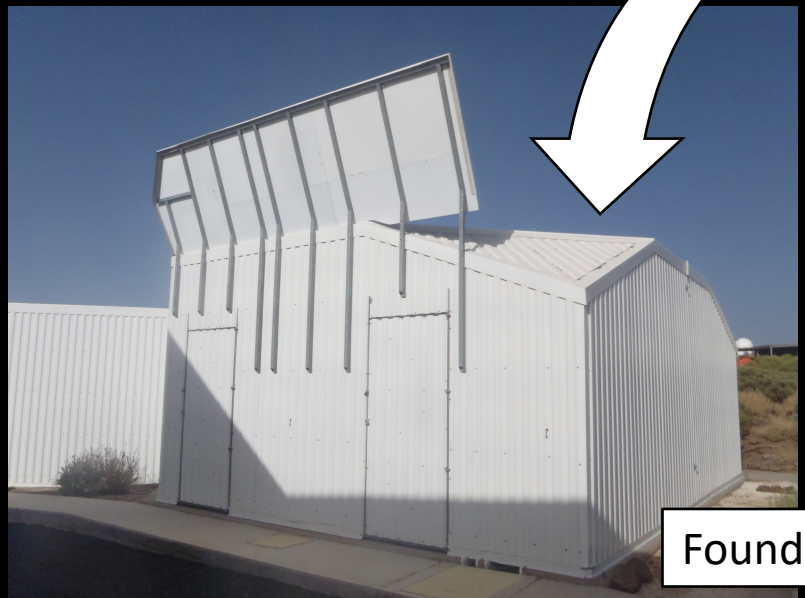
The RIKEN Center for Advanced Photonics (hereafter RIKEN) and the Instituto de Astrofísica de Canarias (hereafter IAC) plan to install one GroundBIRD experiment at the Teide Observatory (hereafter OT), dedicated to perform millimeter observations of the Cosmic Microwave Background (hereafter CMB) polarization.

The GroundBIRD experiment at the OT (hereafter, the GB-North experiment) is a non-profit scientific experiment dedicated to the search for the B-mode polarization of the CMB. The GB-North experiment consists of a high-speed rotating telescope, cooled optics, and high-sensitivity superconducting detectors. The rotating speed of the telescope is 20 rpm, enabling the 'multipole' coverage of 6 < l < 300. The size of the aperture window is 30 cm in diameter, and two observing frequencies centered at 145 and 220 GHz are adopted.

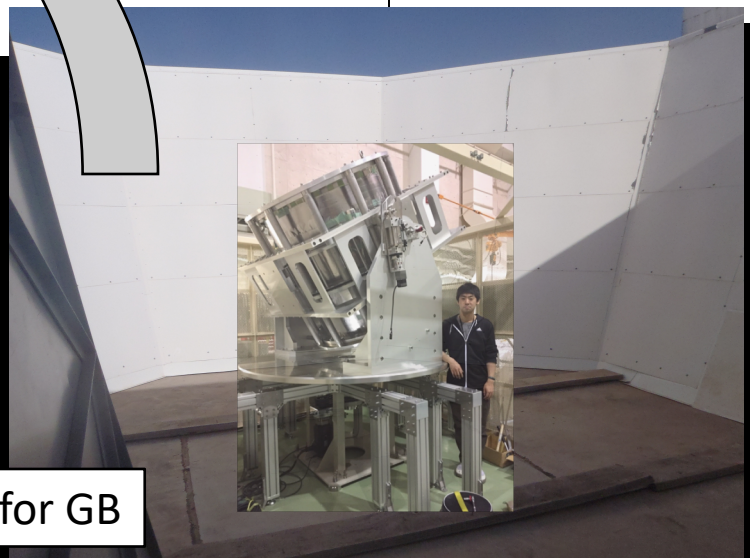
The OT is an ideal location for the GB-North experiment, not only for its internationally recognized quality and its low precipitable water vapor (PWV), but also because of its geographical location covering the northern hemisphere sky. The GB-North experiment will be essential for searching the B-mode polarization as well as for the complimentary examination of the uniformity of the B-mode signals by comparing with observations obtained from the southern hemisphere. Moreover, the GB-North experiment is complimentary to the ongoing "QU-I-JOint TEnerife" (QUIJOTE) experiment at the OT. The combination of the GB-North and QUIJOTE experiments can be advantageous for precisely removing the Galactic synchrotron and dust radiation components. The first-rate infrastructure and the opportunities for outstanding scientific interactions make the IAC and the OT a perfect host for the GB-North experiment. This in turn will open a new window to experimental cosmology, allowing us to clarify the history of the universe and to give the important keys for studying fundamental physics. It is expected that the operation will start in 2017 and continue for three years.

In view of the fact that the Kingdom of Spain has opened the IAC Observatories to the international scientific community since the International Treaty: "Agreement on Co-operation in Astrophysics and its Protocol", was signed on 26 May 1979, the proposed GB-North experiment is welcome to be installed at the OT. In accordance with the International Treaty, an International Scientific Committee (hereafter "CCI") has been established to provide the Telescope Operators a forum where they can express their needs and preferences in regard to the Observatory Management and its Common Services.

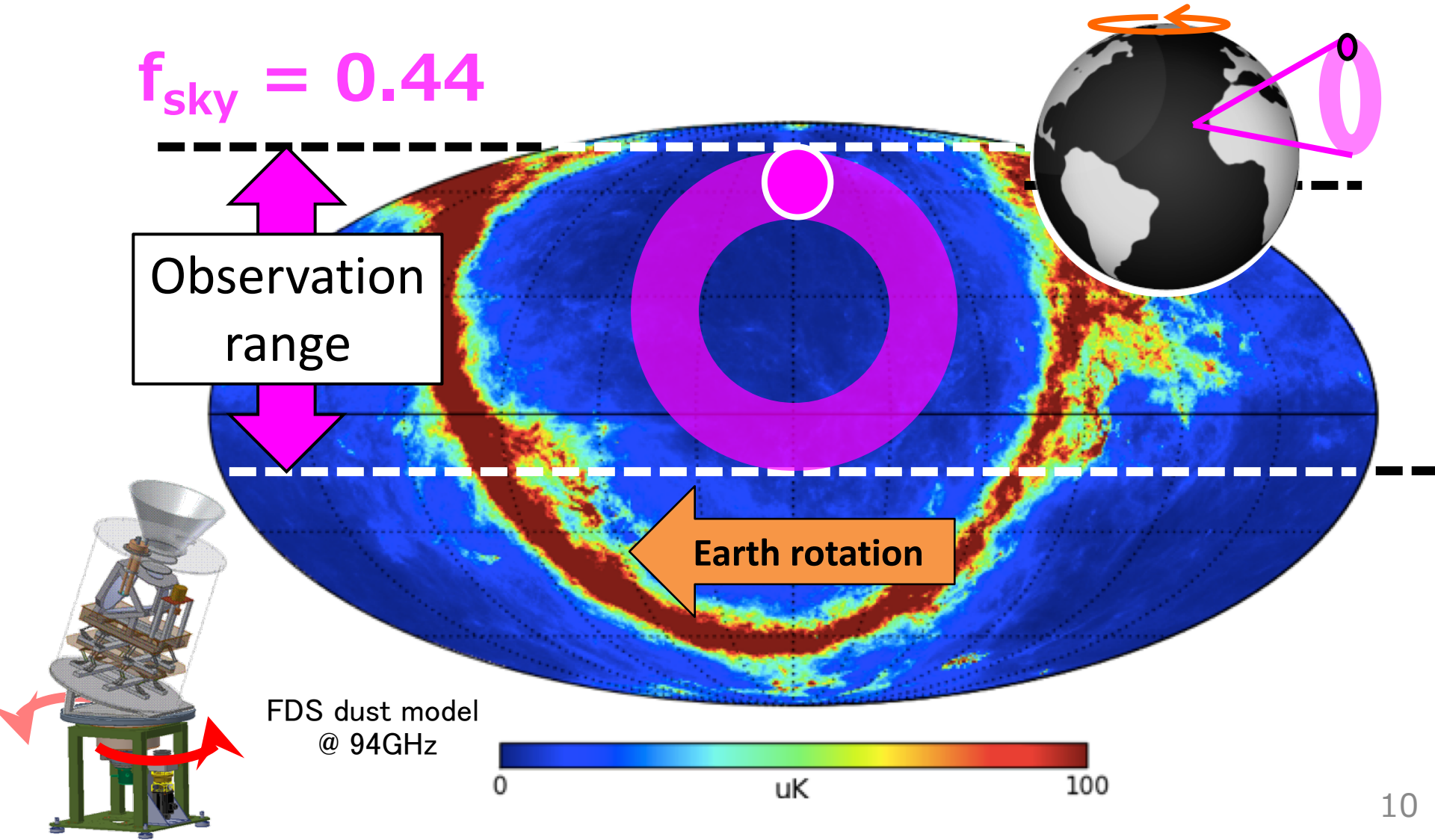
The IAC shall represent RIKEN and the GB-North Experiment vis-a-vis all third parties related to the Observatorios de Canarias, such as the CCI and shall endeavor to obtain those customs duty and tax exemptions that are available to the other telescope operators.



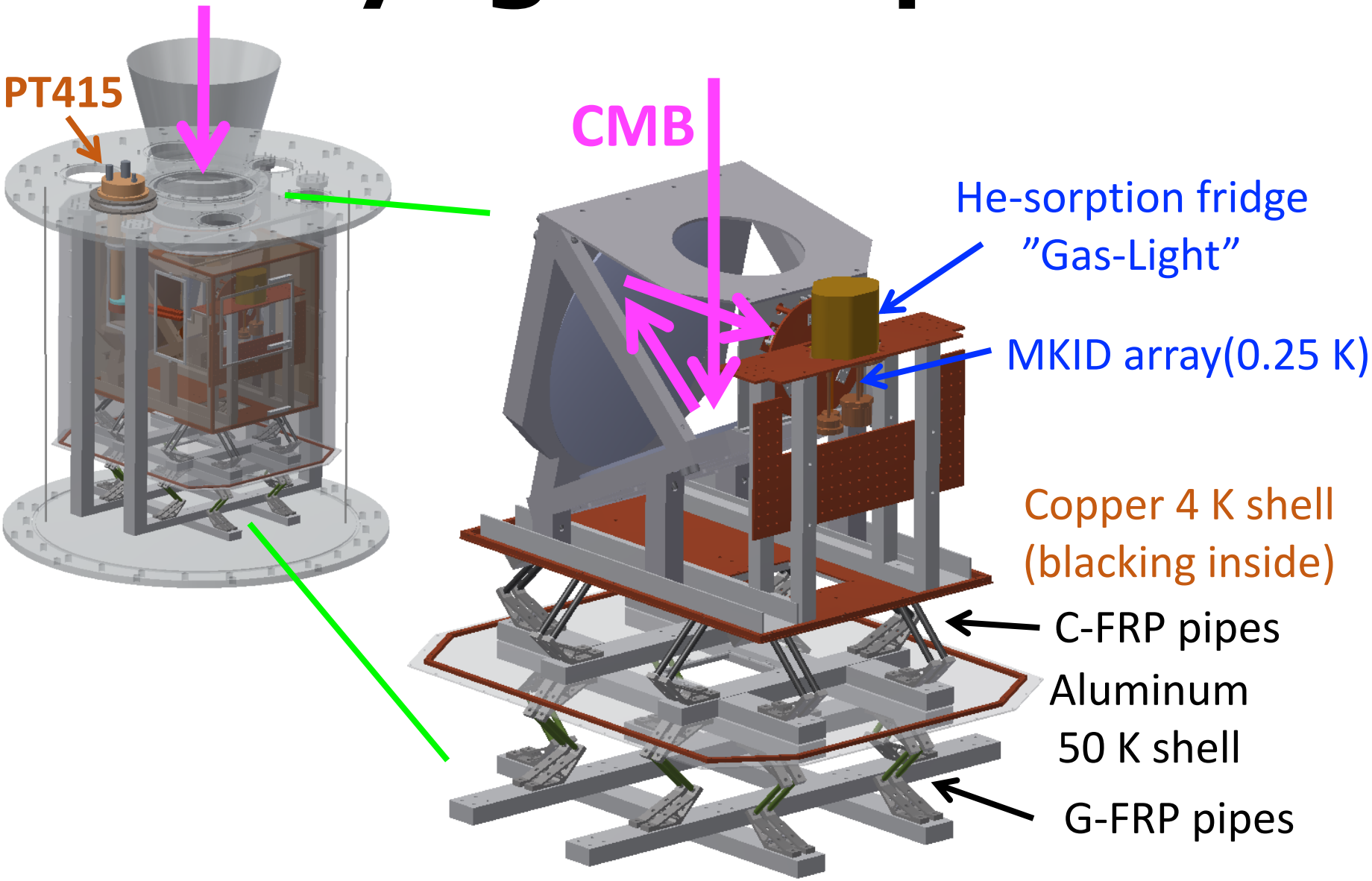
Foundation for GB

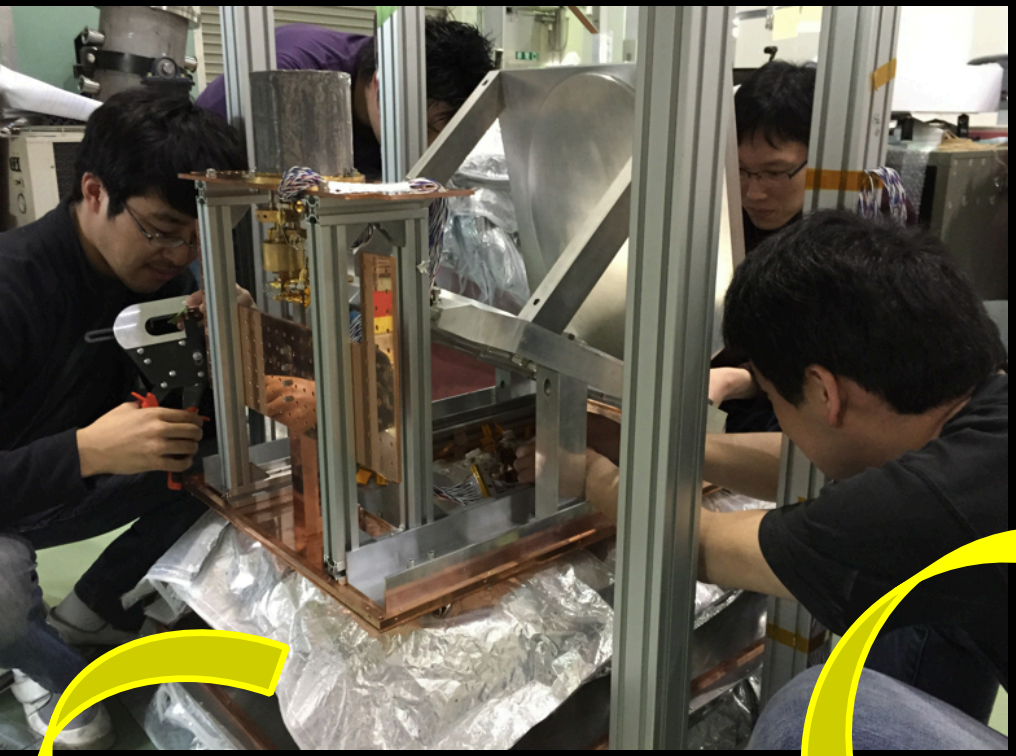


High-speed Rotation-scan provides large-sky coverage



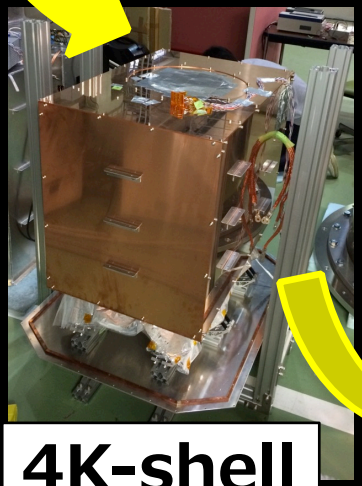
Cryogenic optics





Receiver window is here



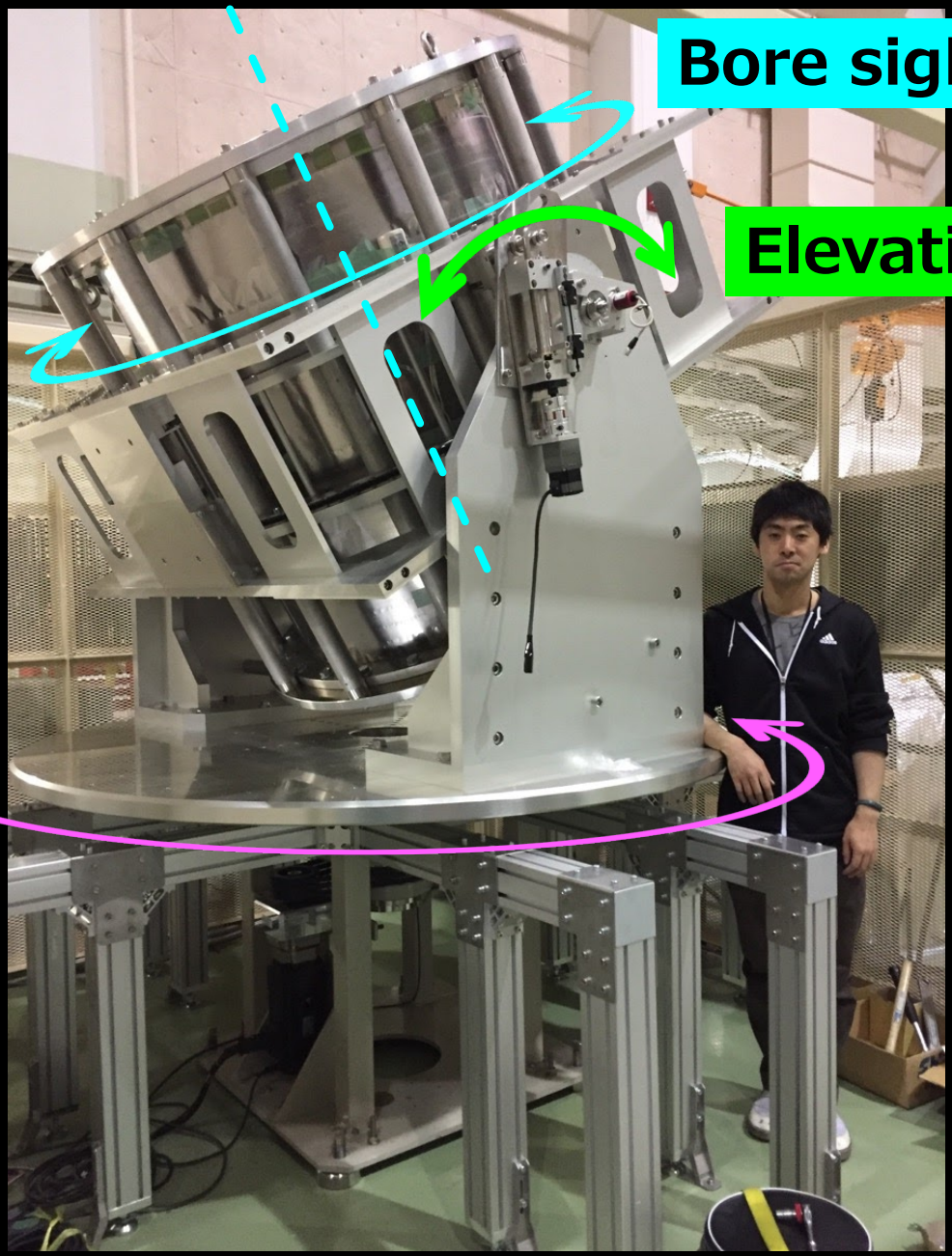


4K-shell

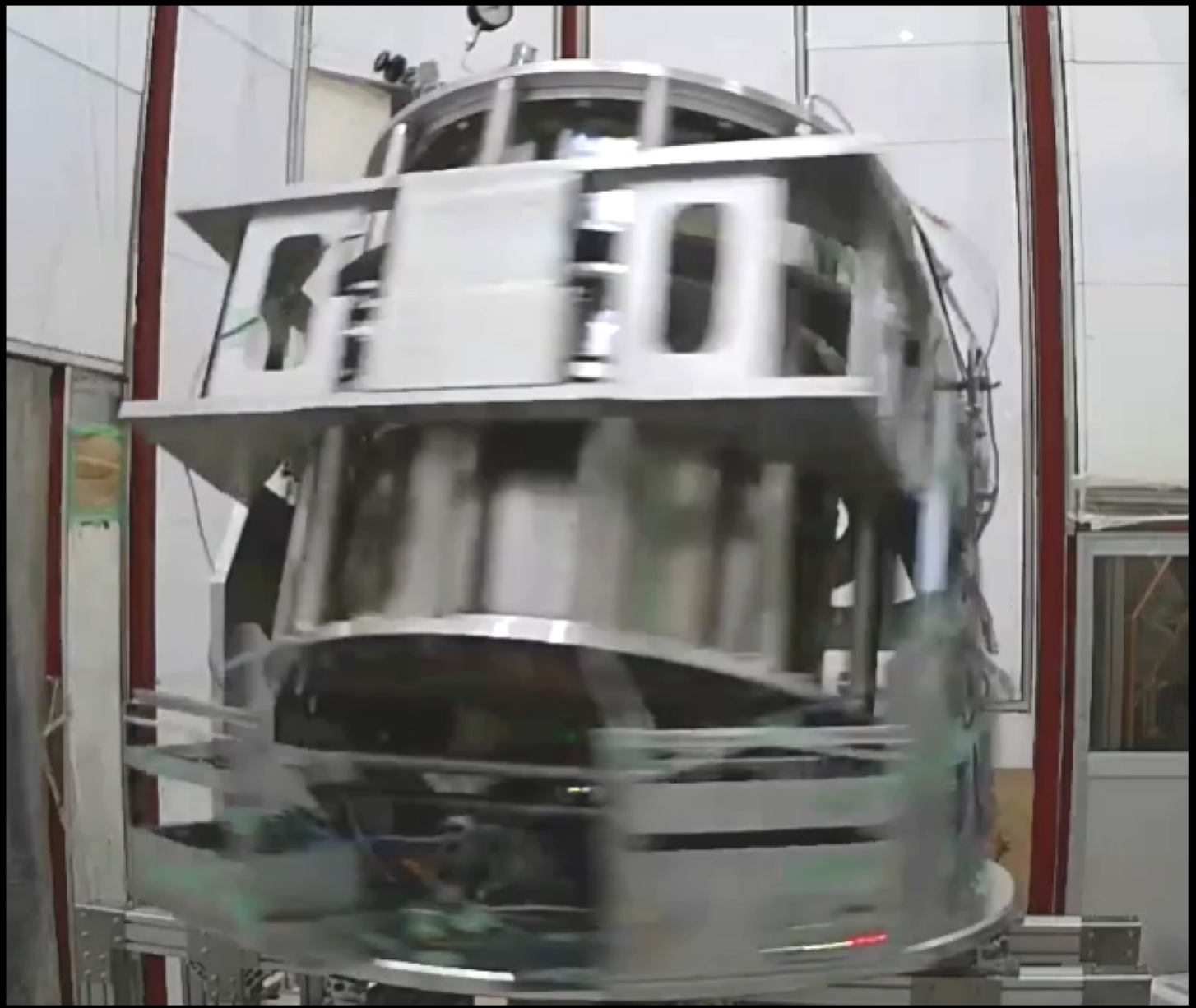


50K-shell

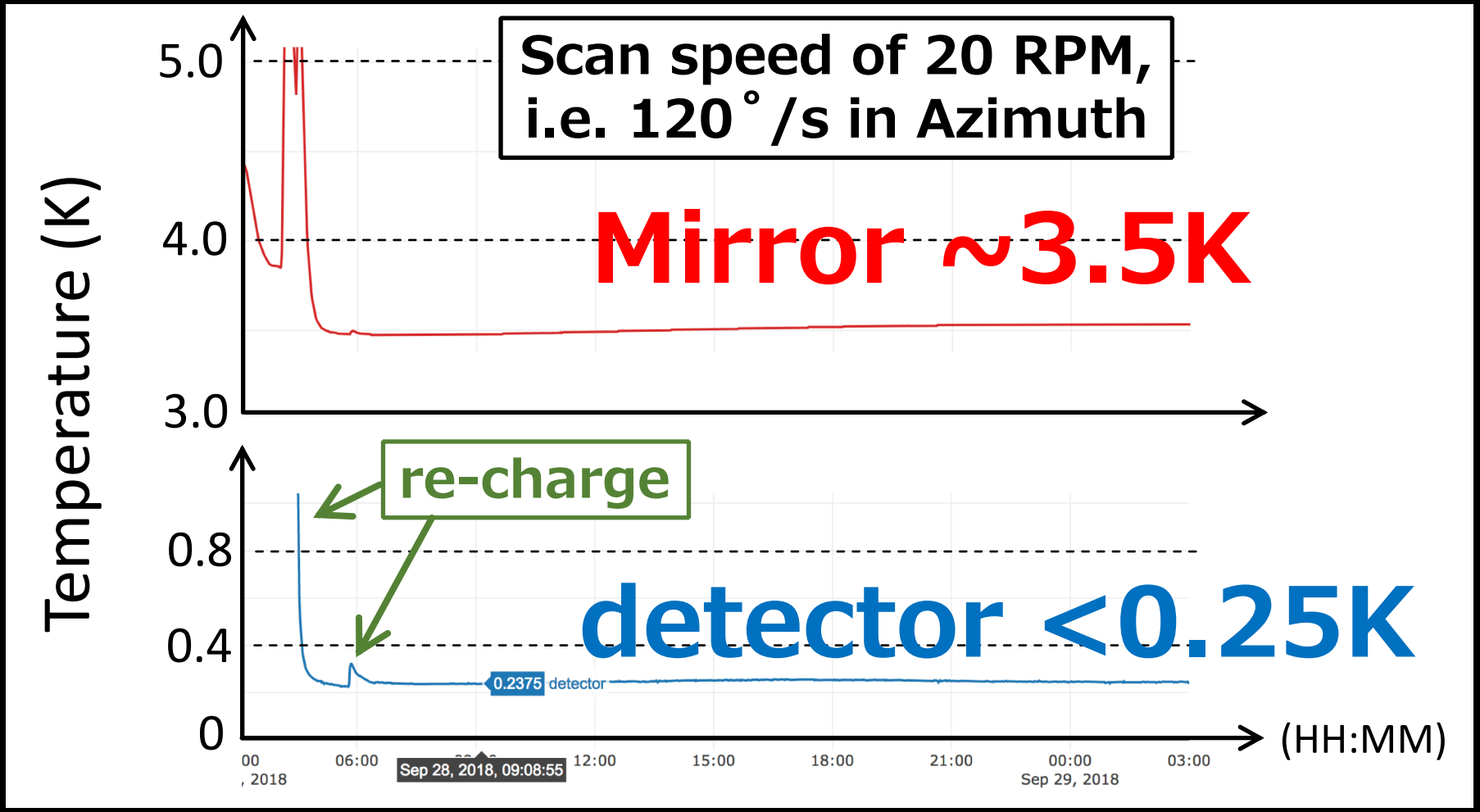
Vac. chamber


Bore sight
Elevation
Azimuth

High-speed Rotation-scan of 120˚/s

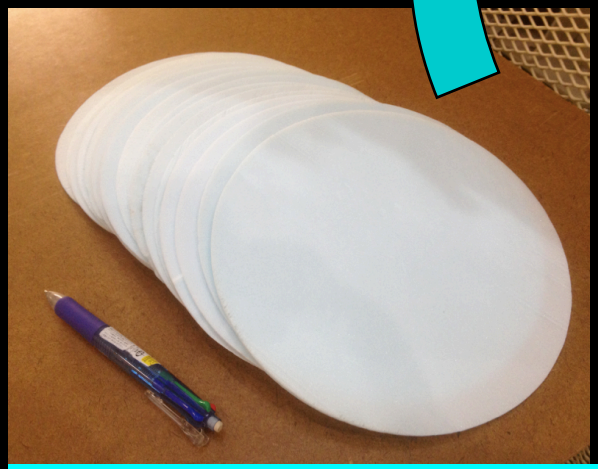


24H *T* trends with HsRs under Eccosorb in T_{room}



“Cool” technologies for GB

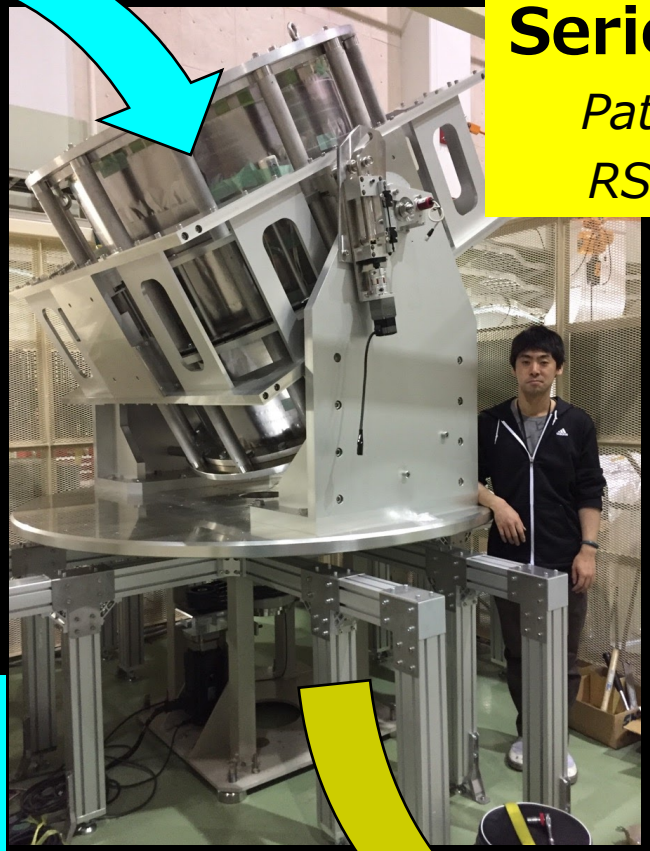




RT-MLI for IR-blocking

Patent: JP6029079

RSI, 84, 114502 (2013).



Series of rotary joints

Patent: US 9,316,418-B2

RSI, 84, 055116 (2013).

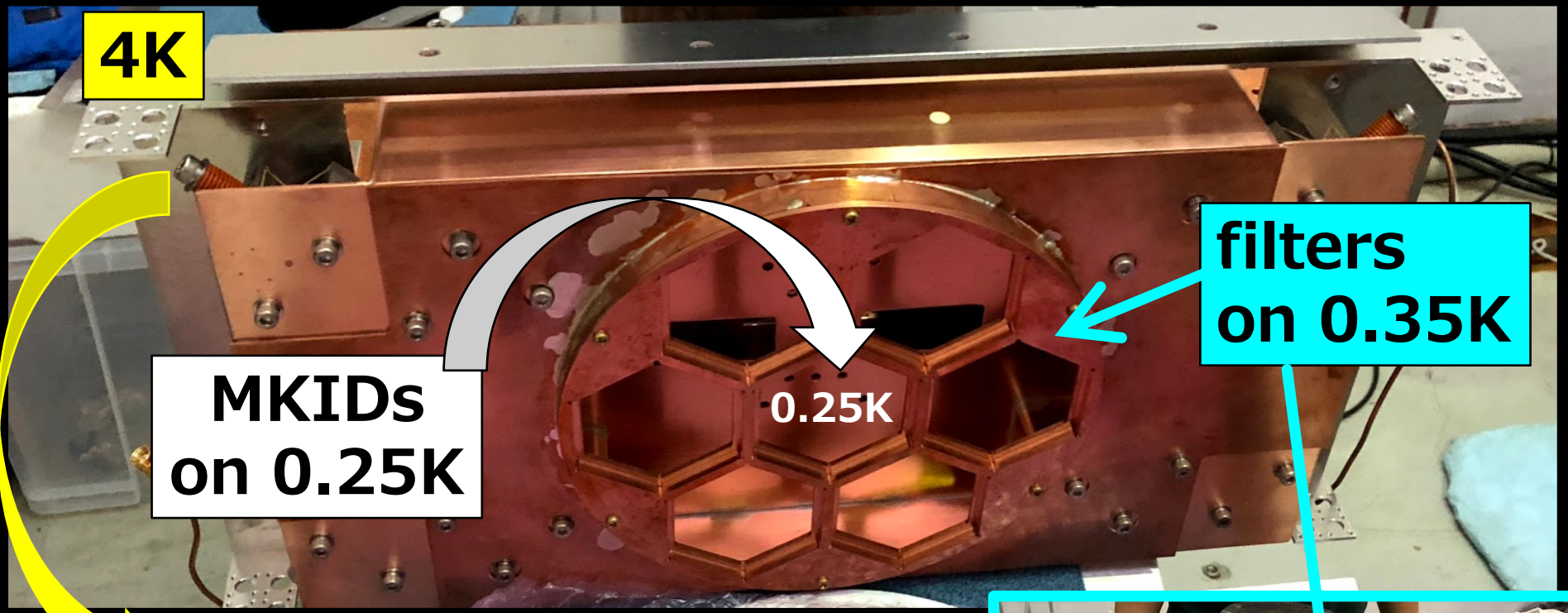
He-gas lines for PTC

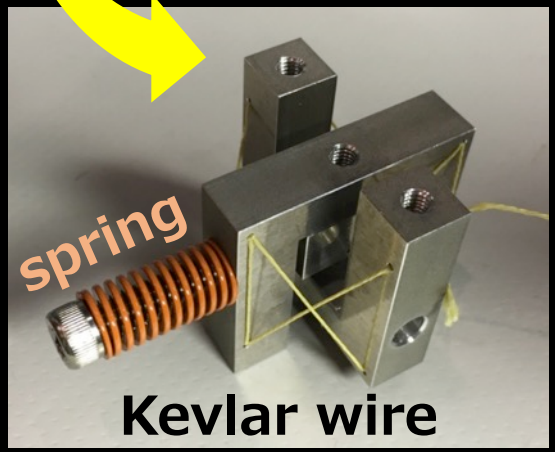




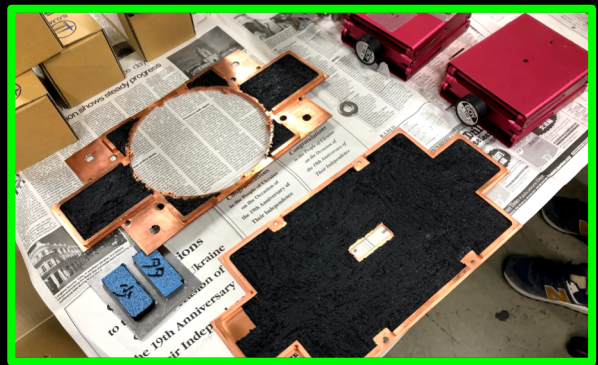
Electric lines

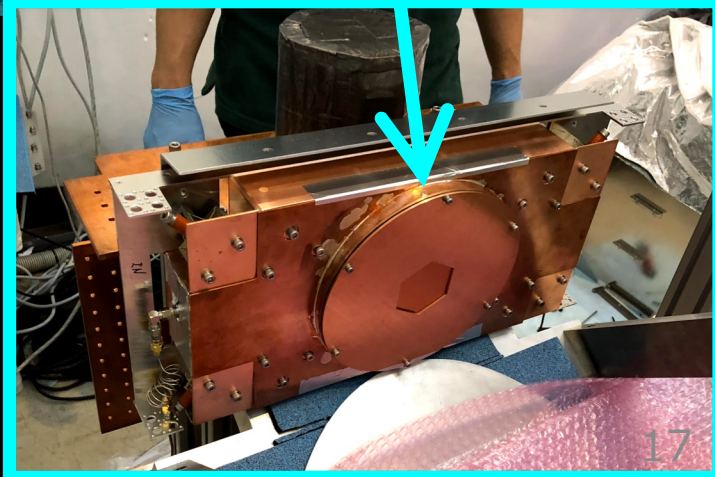
Focal plane set in 0.35K box



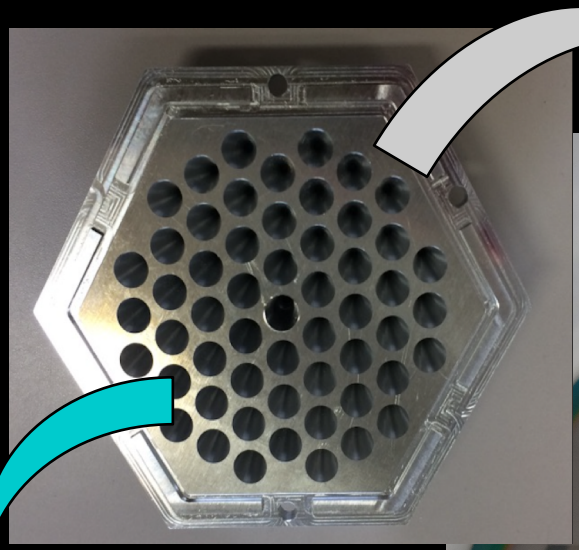


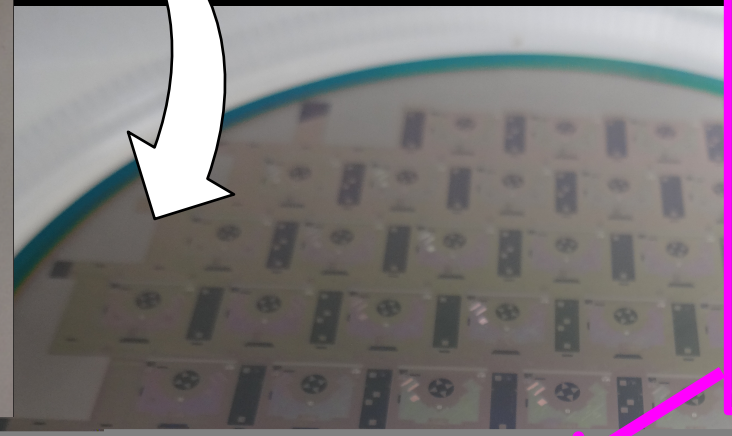
Blacking inside

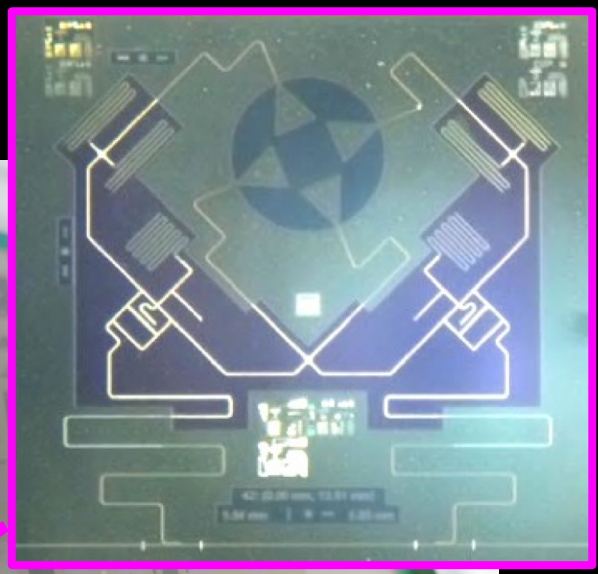


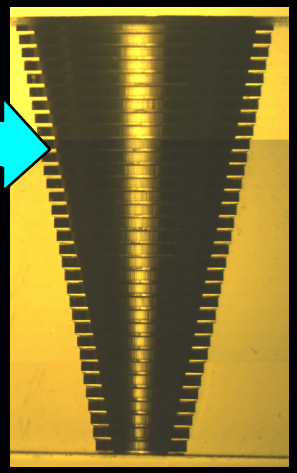


Horn coupled MKID array





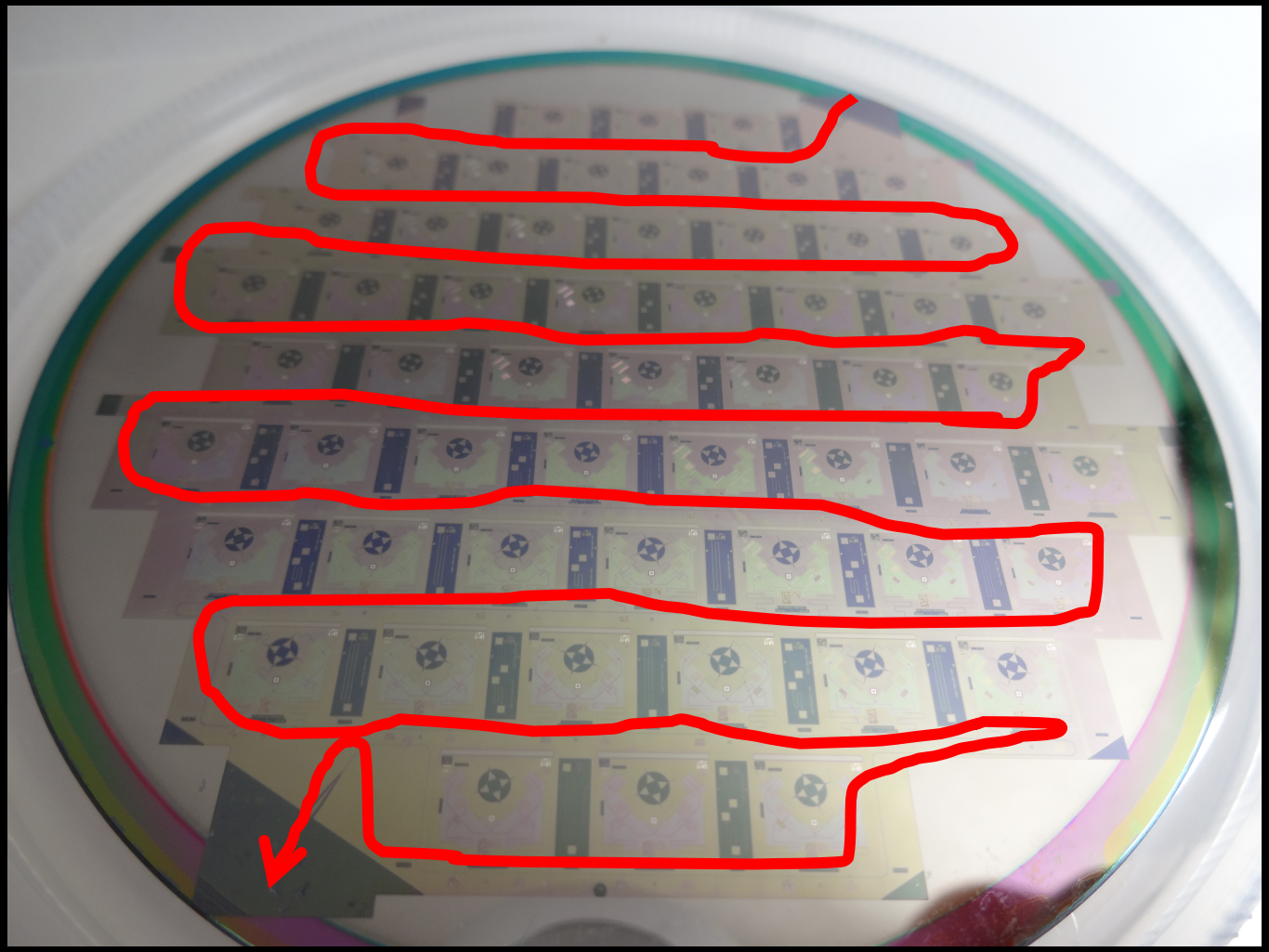




Horn array module by machining

110 MKIDs on 3” wafer

Single line for readout



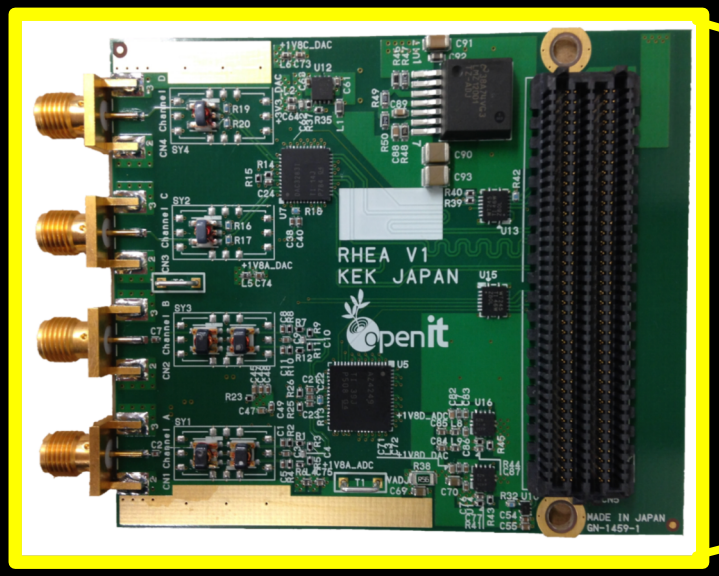
S. Honda, H. Ishitsuka, S. Oguri

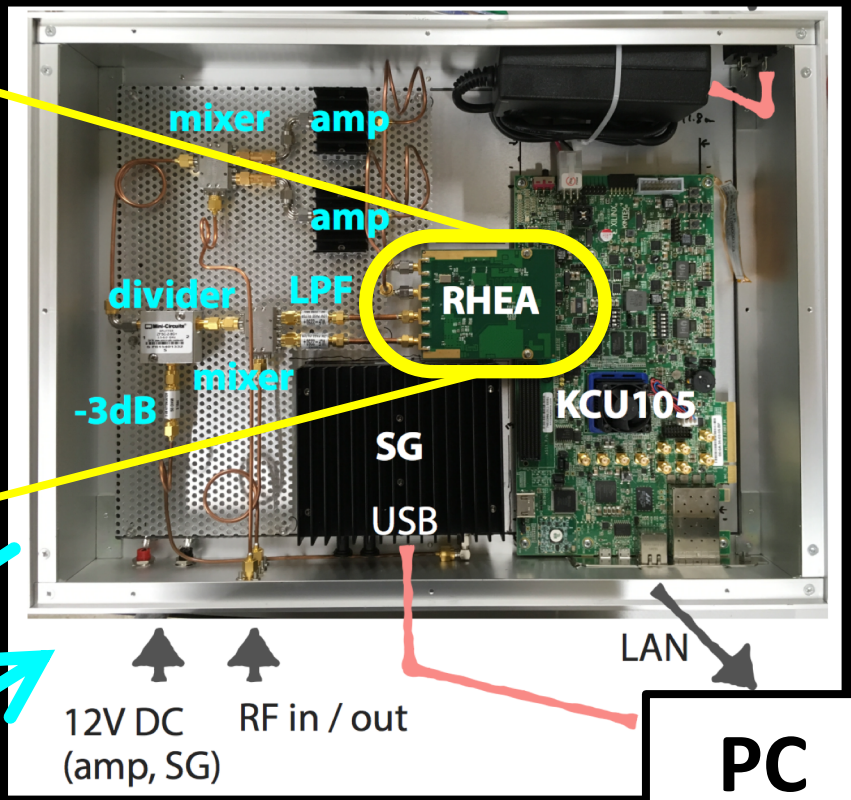
MKID readout electronics

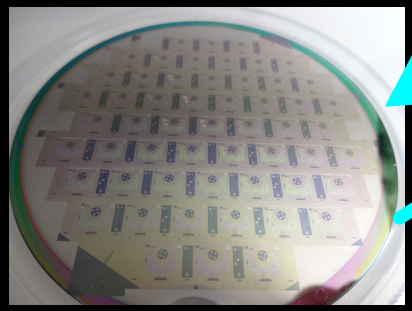
DA/AD board "RHEA" :

- 120-MUX in 250 MHz band width
- 1 kSpS high-speed sampling w/o deadtime

H. Ishitsuka et al, J. Low Temp. Phys., 184, Issue 1 (2016)







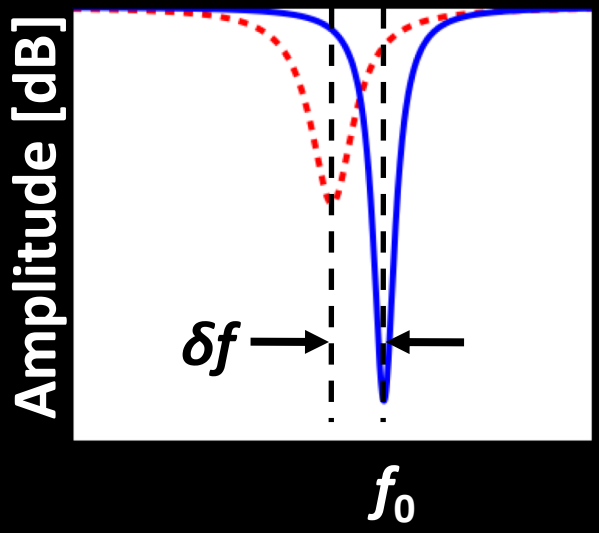
MKIDs in cryostat

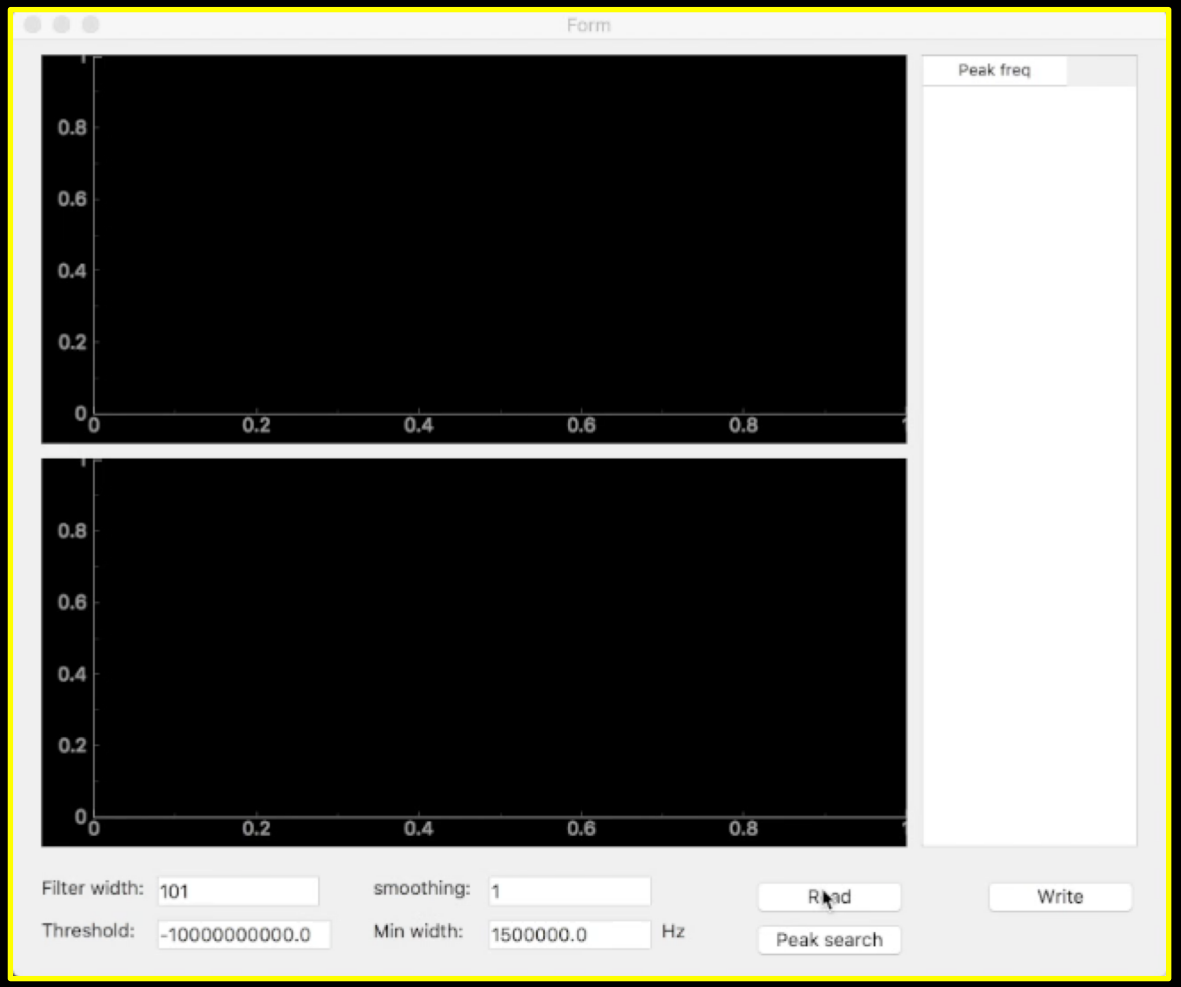
PC

By J. Suzuki

Auto resonant-peak finder

Peak finding for each resonance is necessary prior to meas.

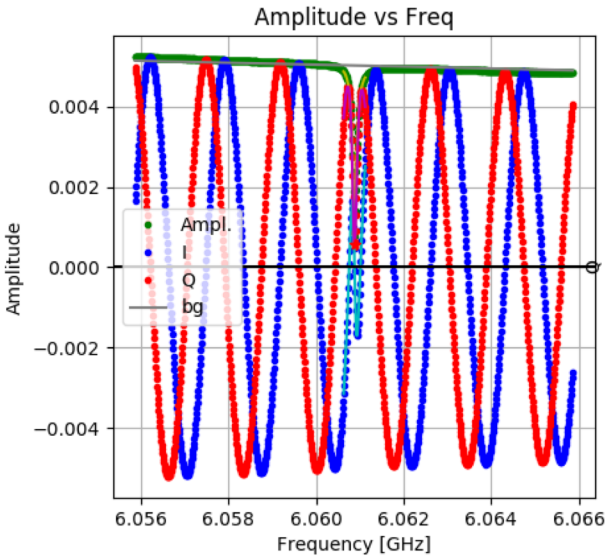


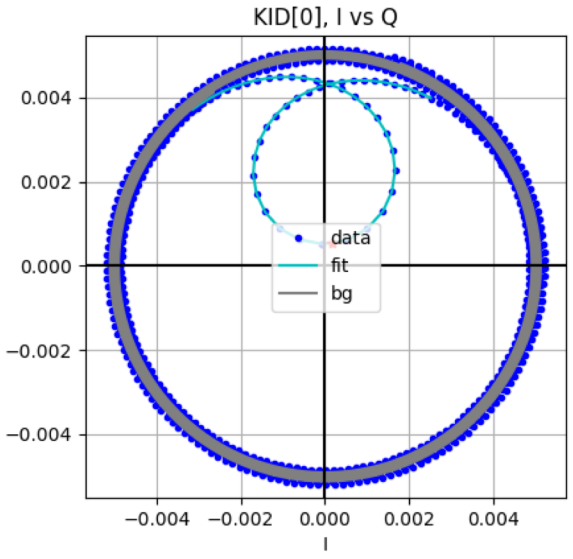


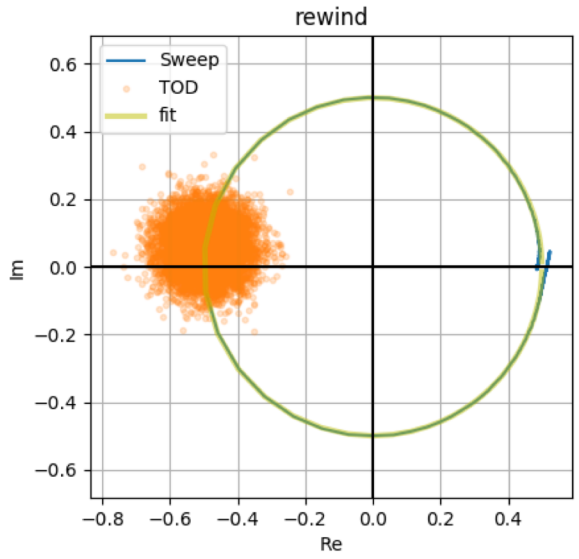
Demonstration of “peak finding” function

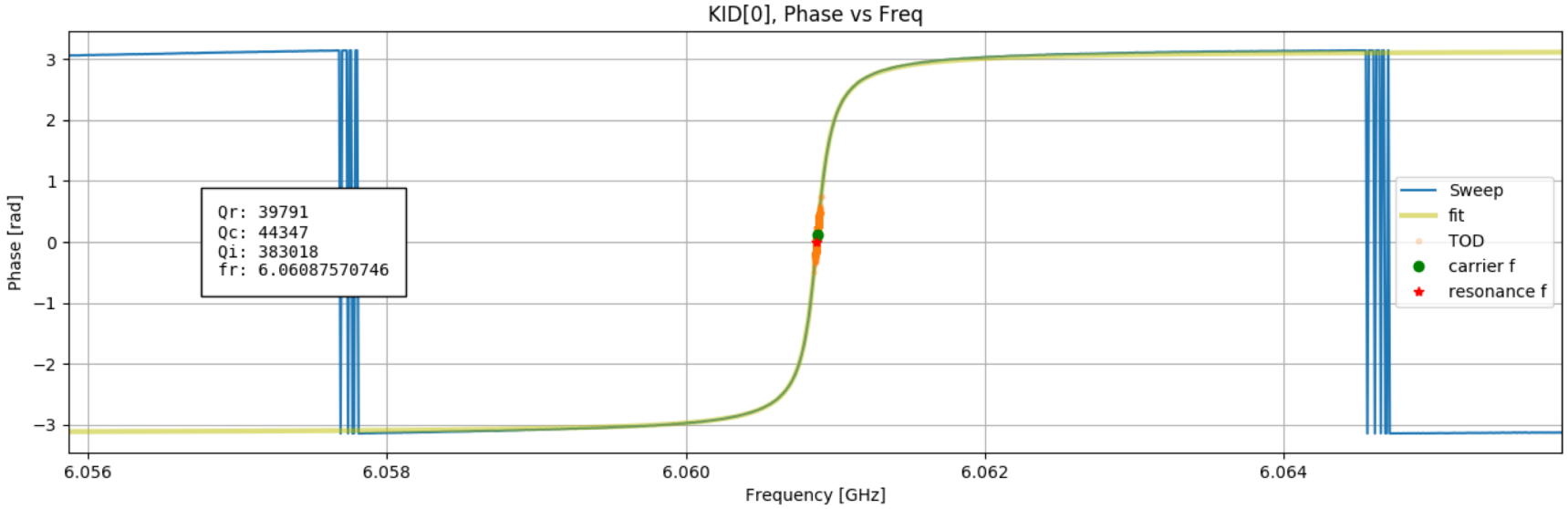
By N. Tomita

Auto characterization

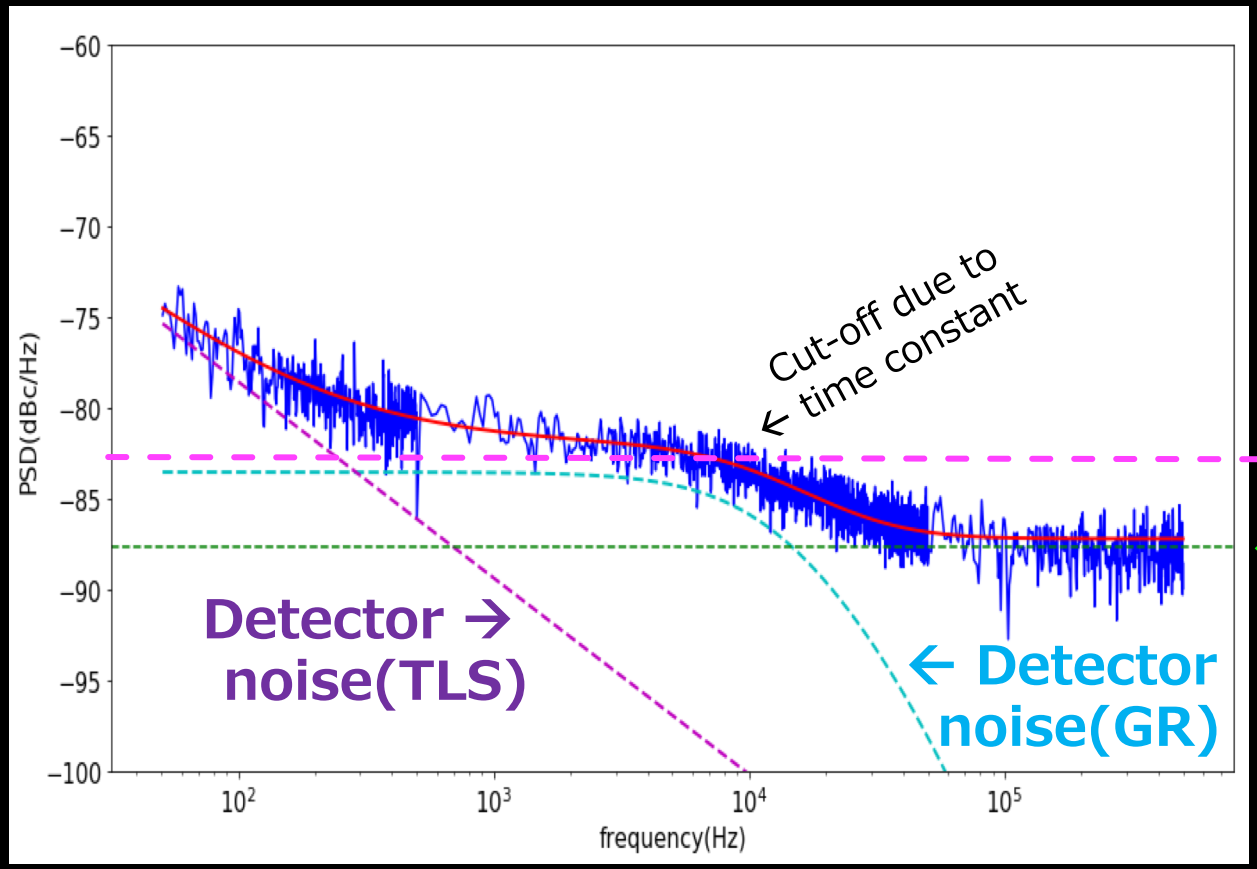








Readout noise is low enough



equivalent for
NEP requirement,
~ 3×10^{-16} W/√Hz

← Readout
noise level

Detector time constant ≈100μs is properly measured

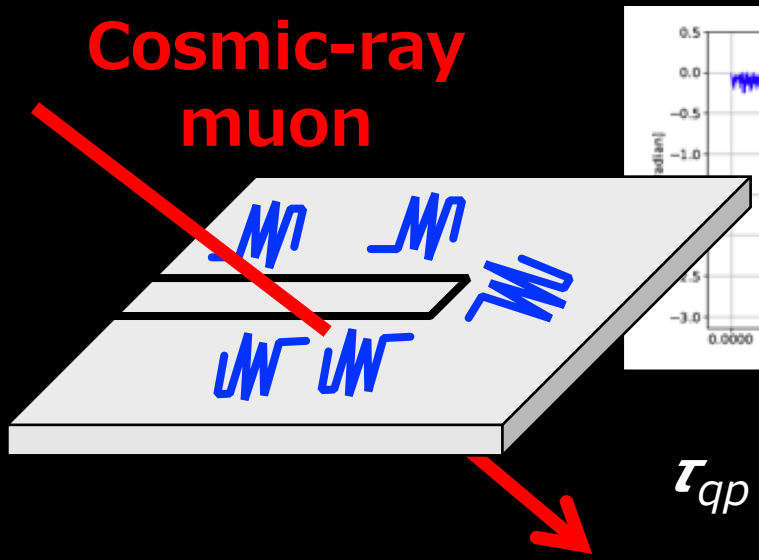
World's first demonstration in case of MUX for MKID

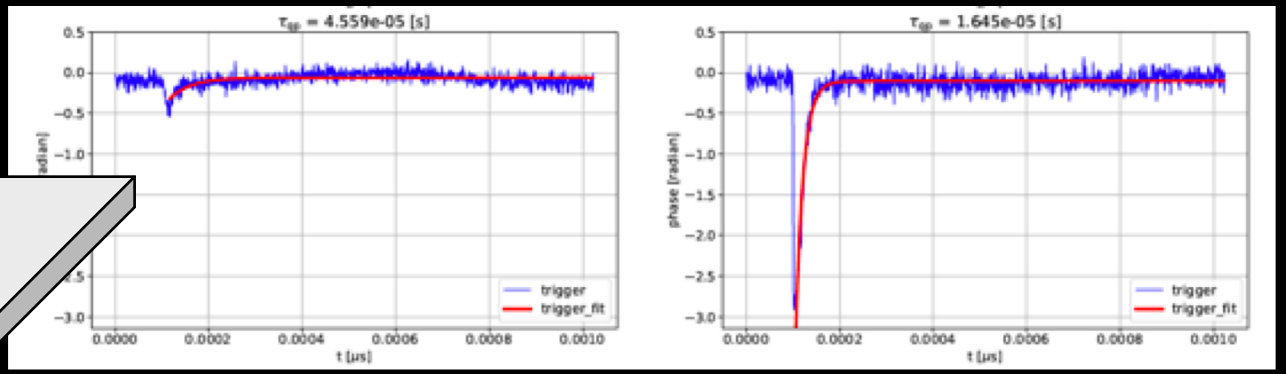
Maybe

By S. Oguri

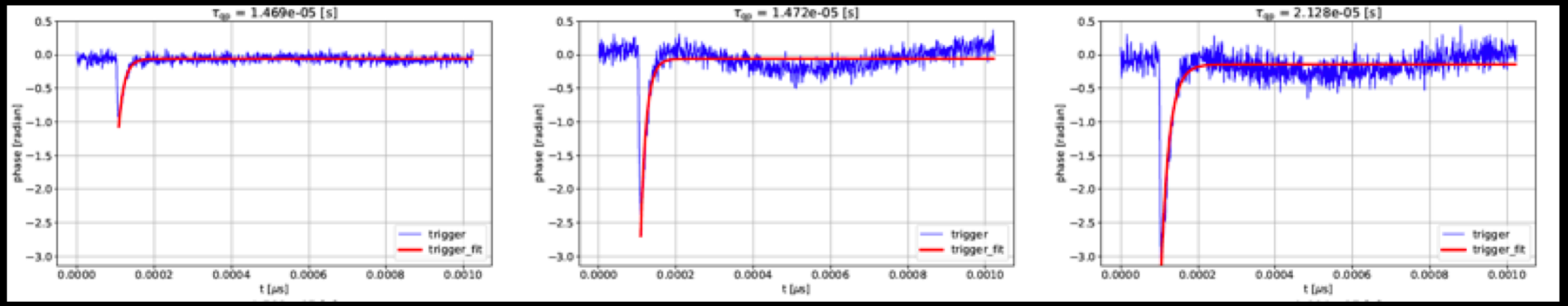
Trigger function

useful for MKID characterization





τ_{qp} , *identification of muon path etc.*

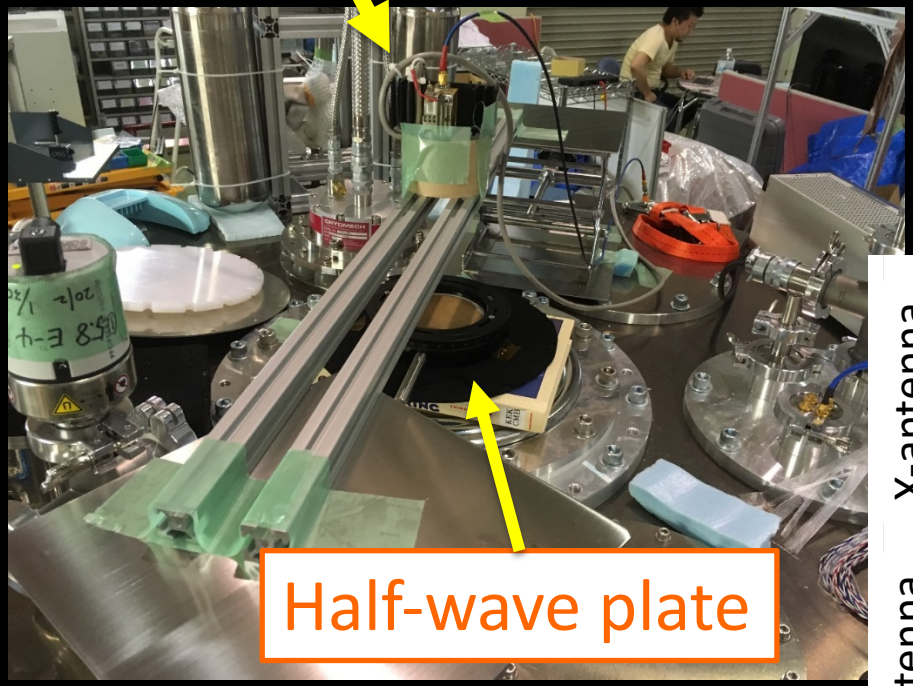


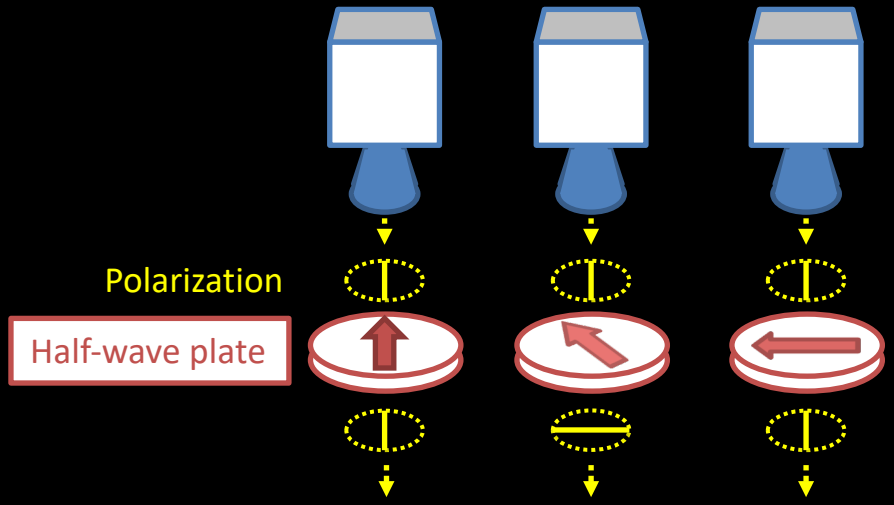
By T. Nagasaki, S. Oguri, J. Suzuki

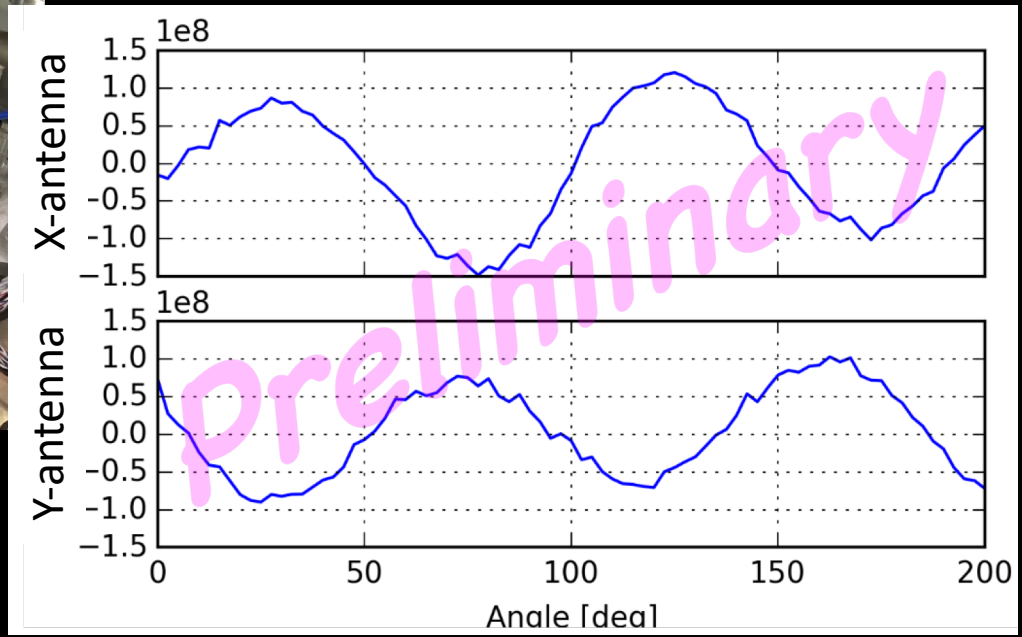
Lab test for pol. response

Frequency multiplier

Signal at 150GHz



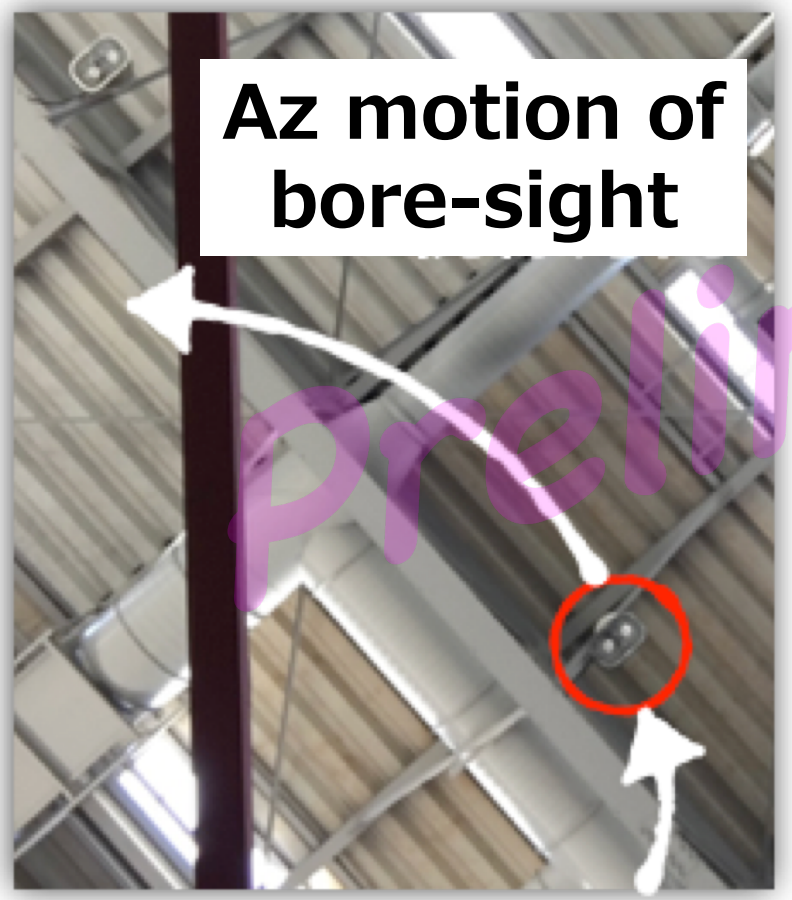


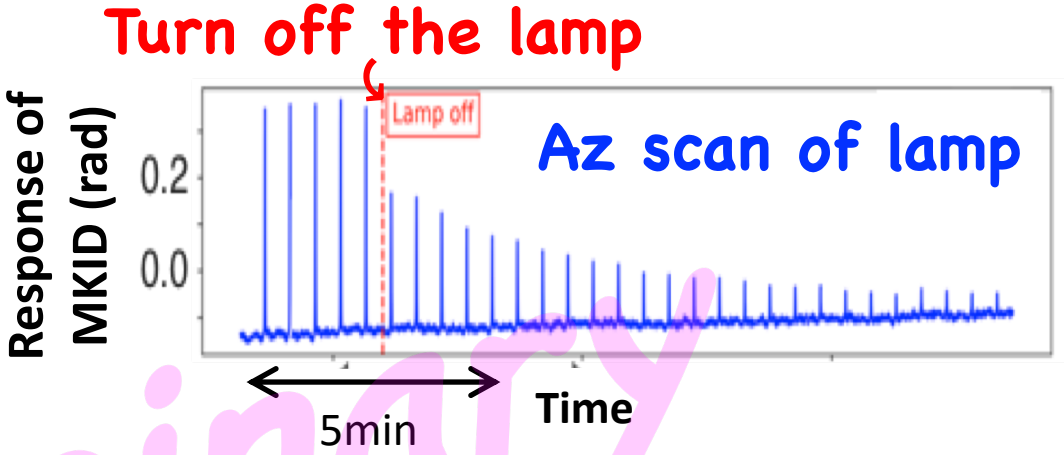


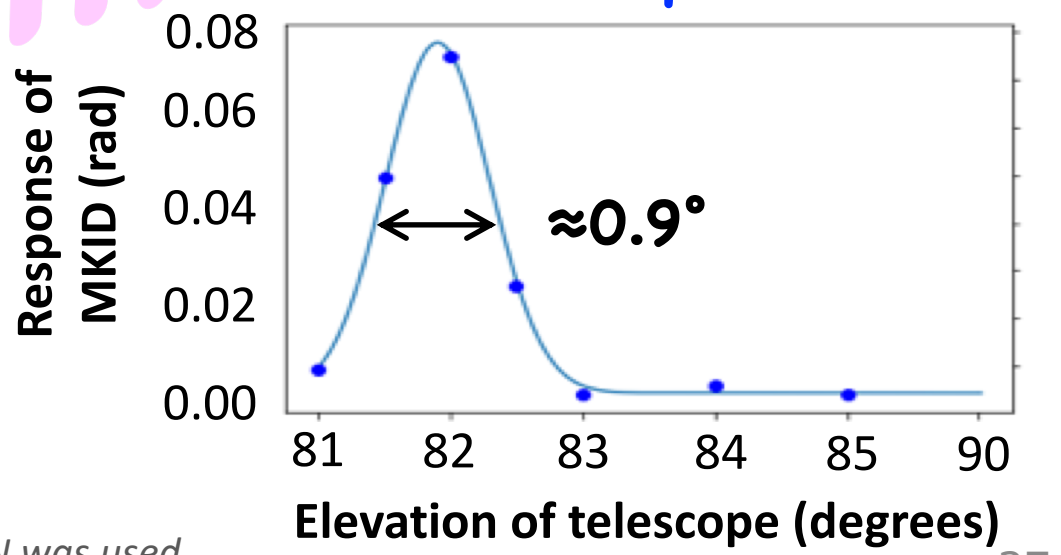
$\cos^2\theta$ responses
w/ opposite phase !!

Scan "lamp" in high-bay

Benefit of MKID:
No saturation under T_{room}



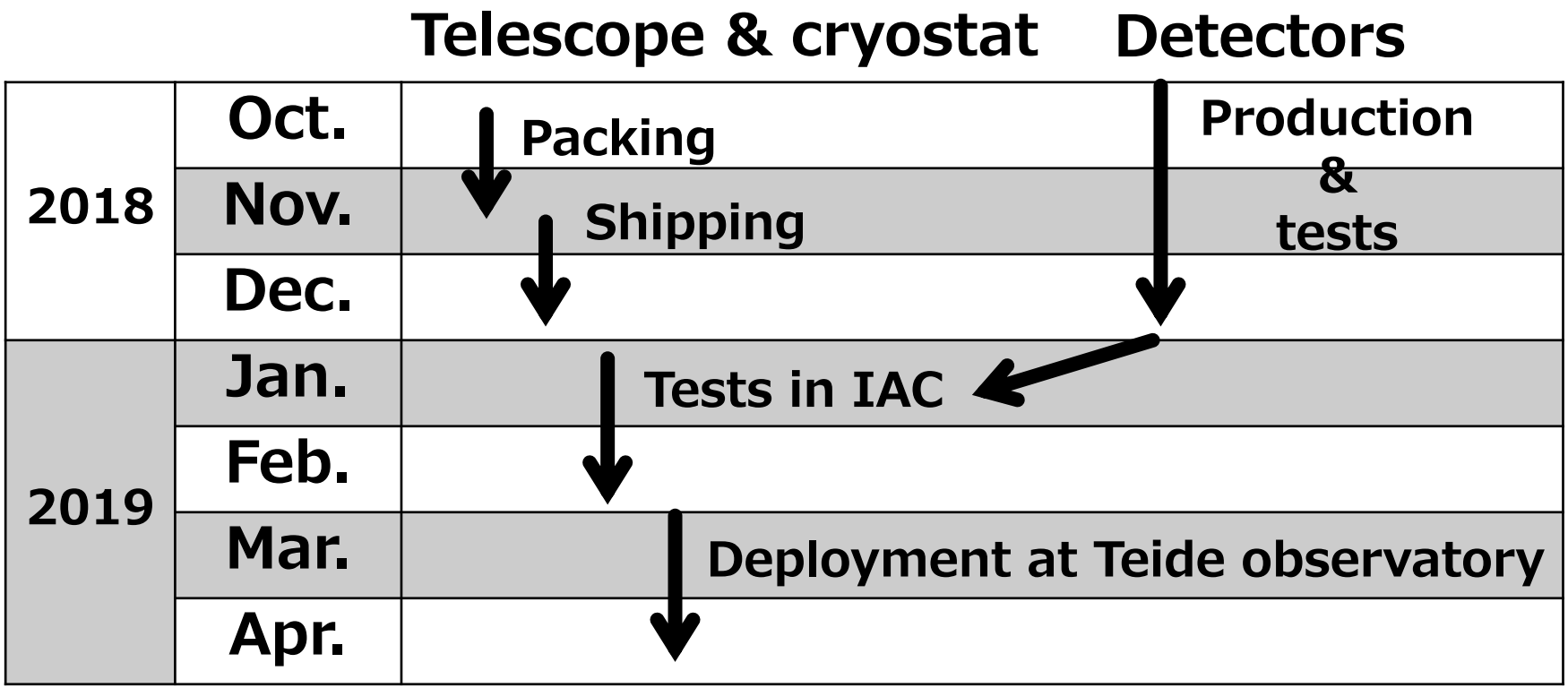




Preliminary

Acknowledgement: MKID borrowed from SRON was used.

Schedule in the near term



First light !

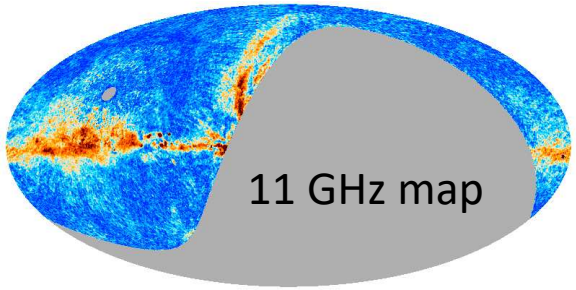
proof-of-concept

First year milestone is POC

Option under discussed

Foregrounds vs QUIJOTE×GB

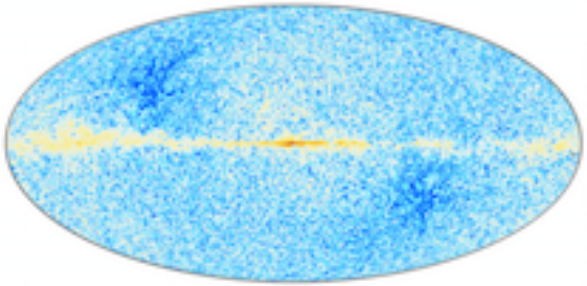
QUIJOTE



10-20, 30, 40 GHz

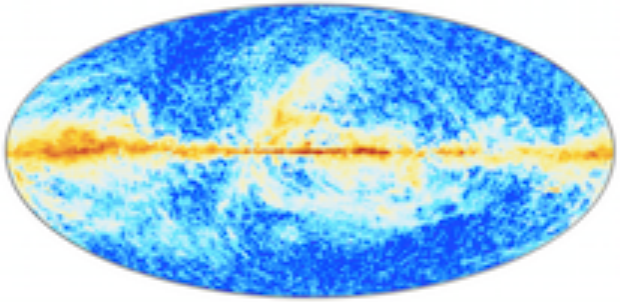
(Courtesy of the QUIJOTE collaboration)

QUIJOTE × GB



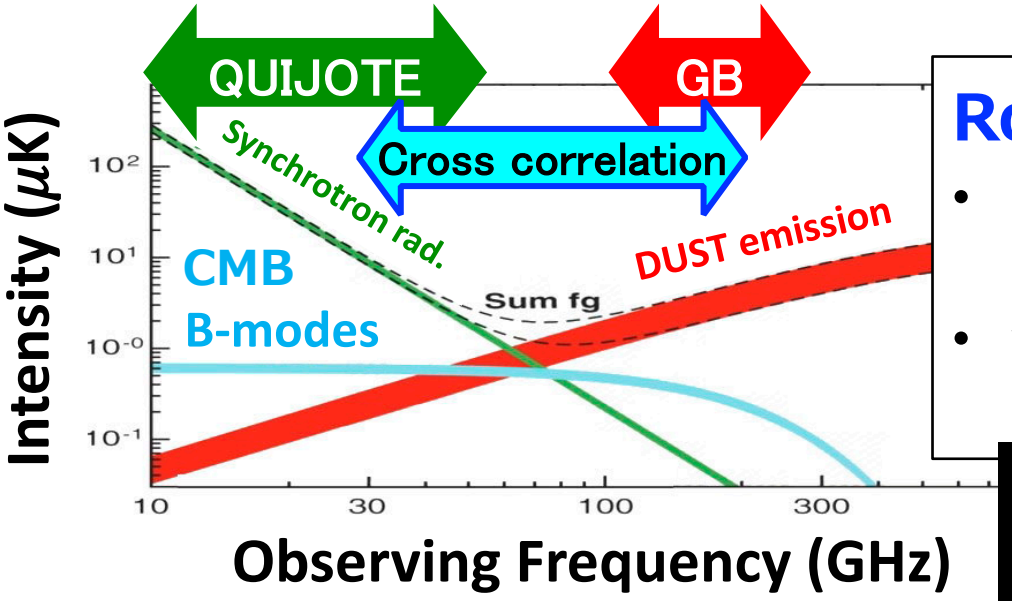
Cross-correlated bands

GB



145, 220 GHz

(Fig. Planck 143 GHz)



Robust strategy to F.G.

- The world's largest number of frequency bands
- "Effective" new freq. bands by cross-correlation

Simulation study underway (led by K. Lee, Korea U.)

Summary of GB

- **Low-ell CMB for PGW & τ**
- **Unique concepts & techs.**

  High-speed Rotation-scan, MKID, ⋯
- **Will come Tenerife, soon**