

B02 CMB

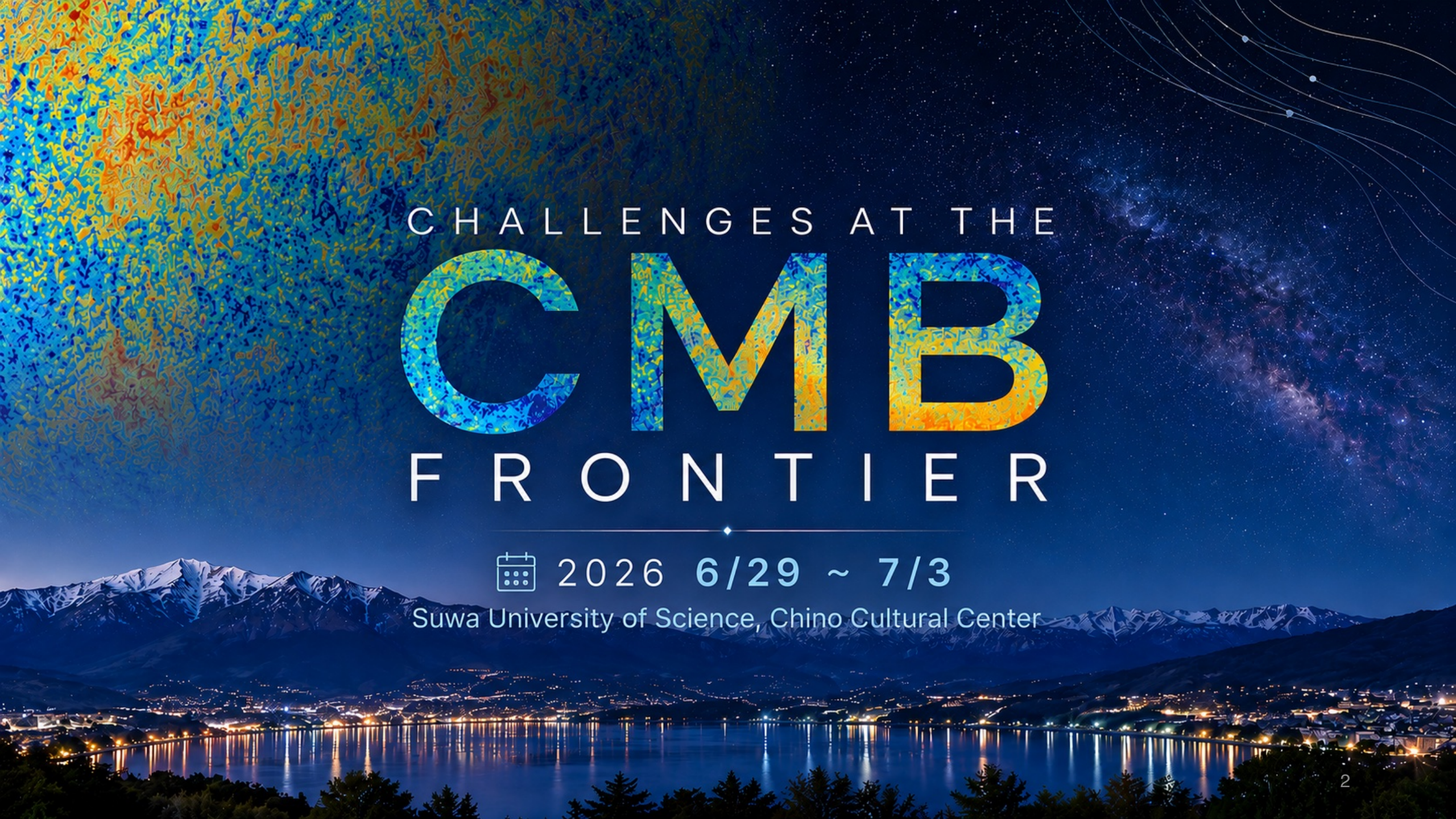
Probing the Physics of Cosmogenesis through Precision **CMB** Observations

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Suwa University of Science

8th July 2026





CHALLENGES AT THE CMB FRONTIER



2026 6/29 ~ 7/3

Suwa University of Science, Chino Cultural Center

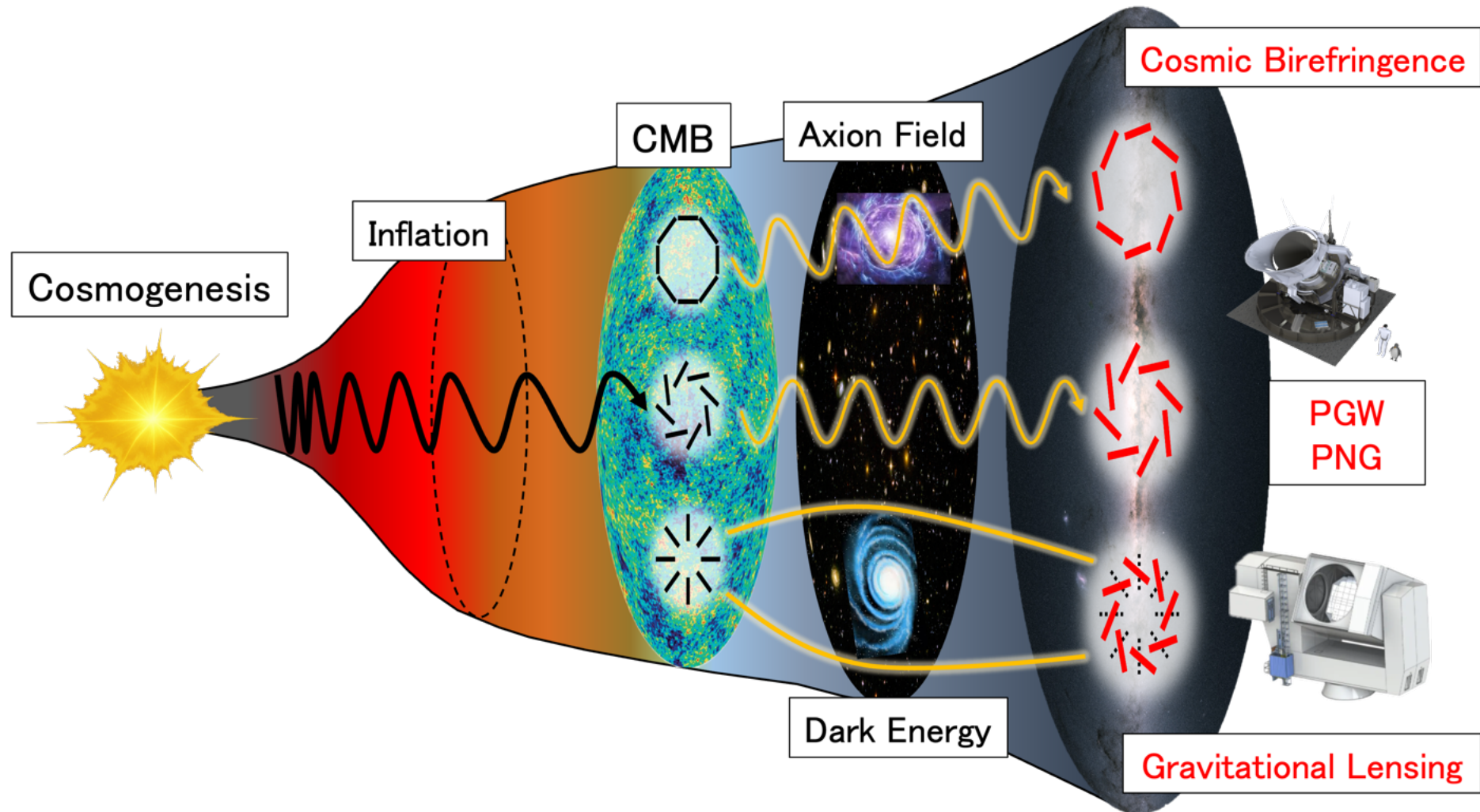


- International CMB workshop at Suwa, Nagano (ALT: ~800m)
- Sponsored by B02 group and CMB inflate, Horizon Europe
- > 80 participants, many young researchers!
- 10 invited speaker from various field
- Discussed about CMB experiments and synergy with astronomy.



Happy to host the next conference if you want to escape summer hot 🌴

B02 Overview

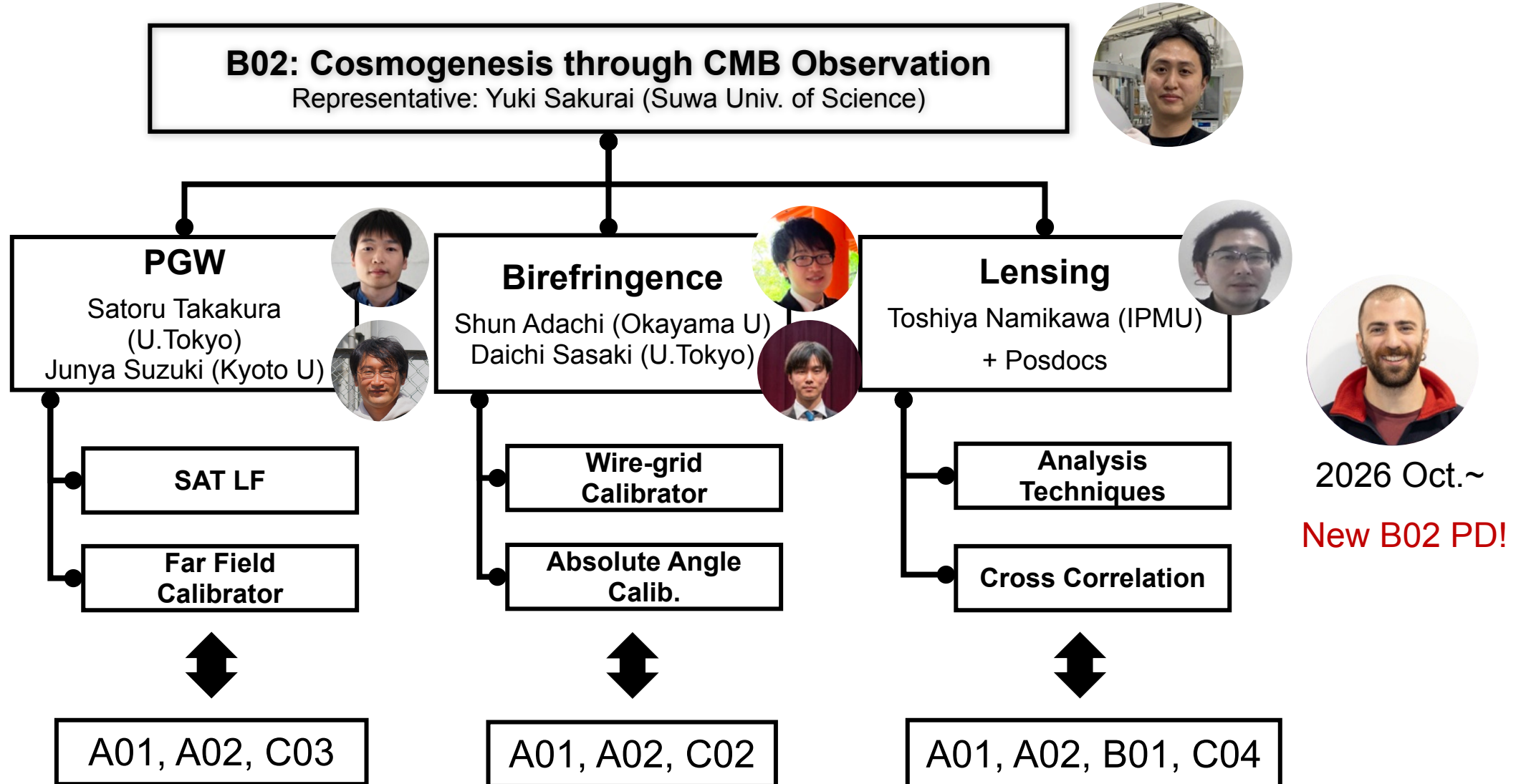


B02 Overview

- Contributing to the **four key science goals** of **CMB** cosmology through the **Simons Observatory**.
- Maximizing the scientific return of CMB experiments through calibration and data analysis.

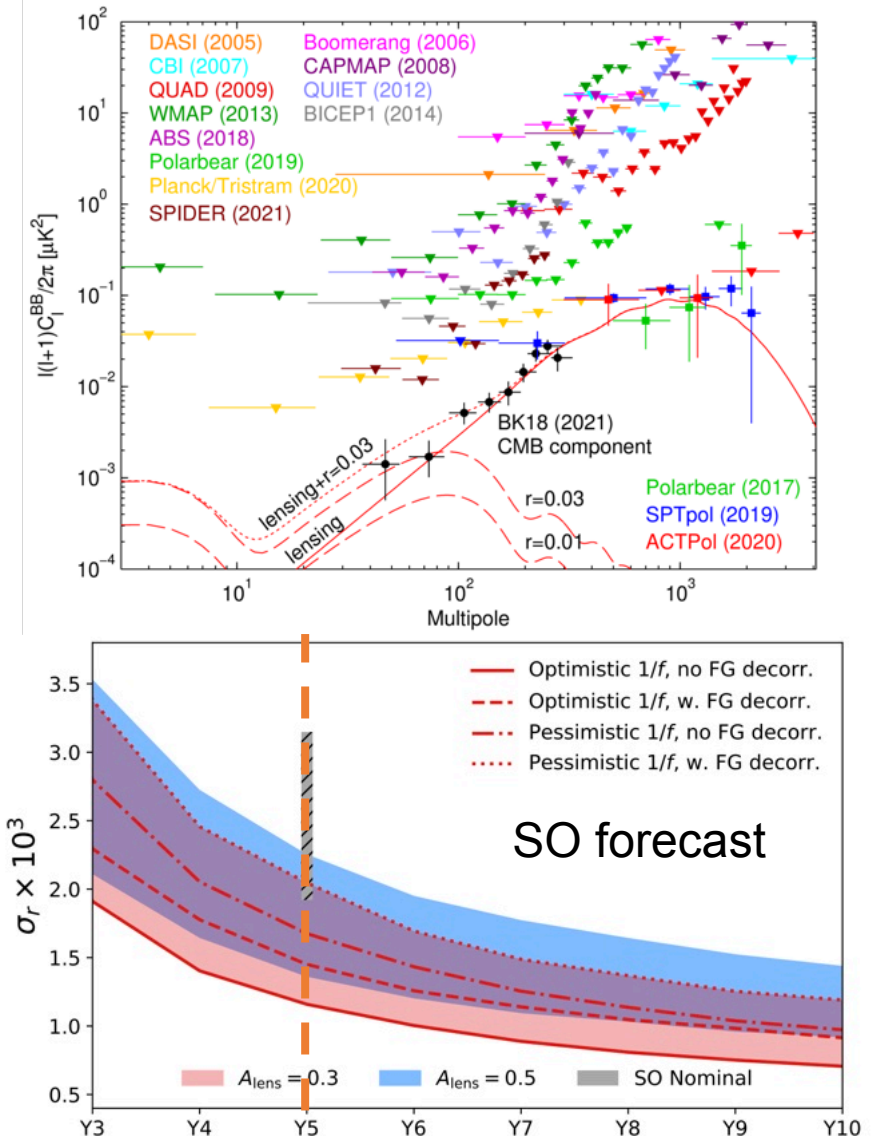
	Latest results	Traget (σ)	Basis
PGW (r)	$r < 0.032$	0.002	Leading models predict $r \sim 0.004$
PNG (f_{NL})	$f_{\text{NL}} = -0.91 \pm 5.1$	2.0	Single-field vs. multi-field inflation
Birefringence (β)	$\beta = 0.34 \pm 0.09^\circ$	0.04°	Testing birefringence ($\beta \neq 0$)
Lensing (A_L)	$A_L = 1.039 \pm 0.052$	0.007	To constrain the time evolution of dark energy with high precision

Our Team



Primordial Gravitational Wave

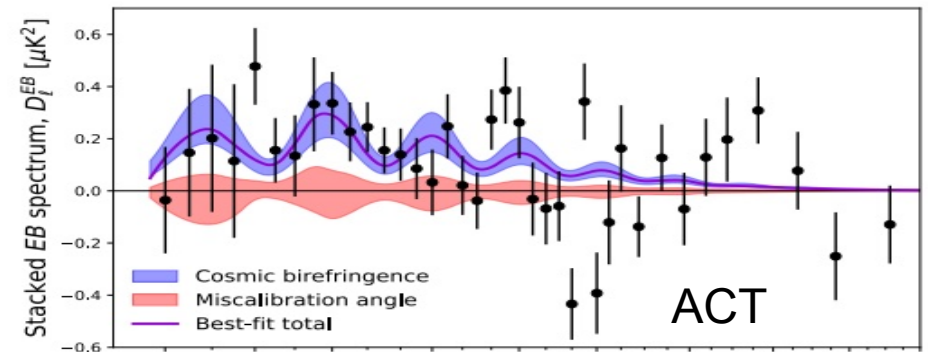
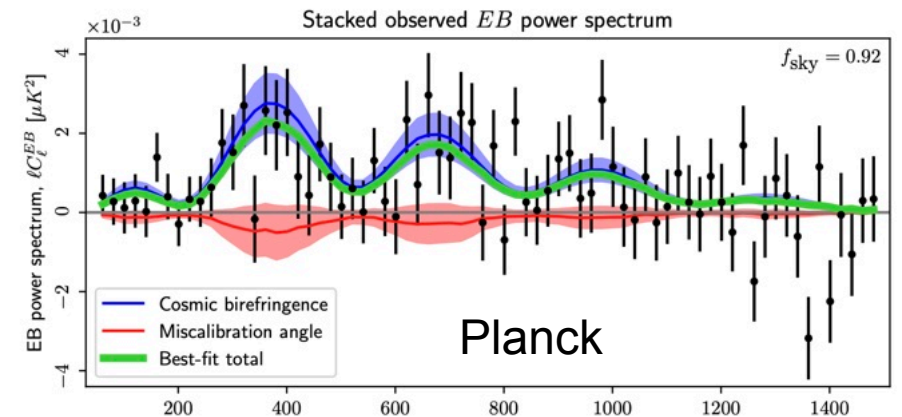
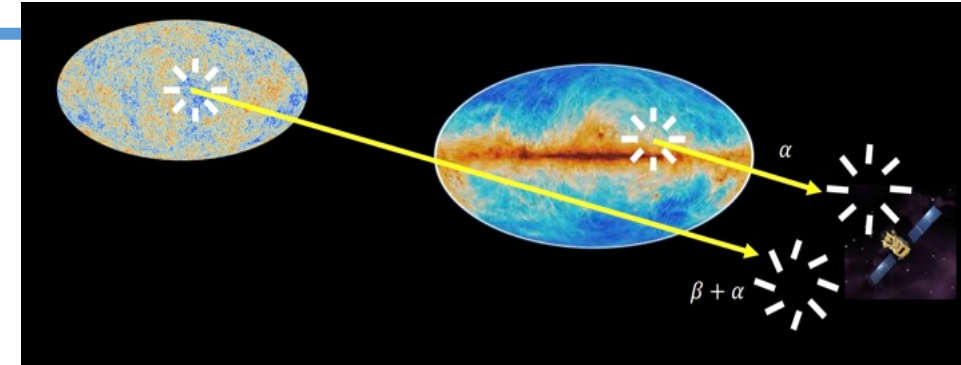
- BICEP/Keck + Planck + WMAP (2021):
 $r < 0.036$ (95% CL)
- Simons Observatory forecast
 - 3 years: $\sigma_r < 0.003$
 - 5 years: $\sigma_r < 0.002$ (Our Target)
 - 10 years: $\sigma_r < 0.001$
- Instrumental systematics are only partially accounted for in forecasts.
 → **Systematics & delensing** are key!



Cosmic Birefringence

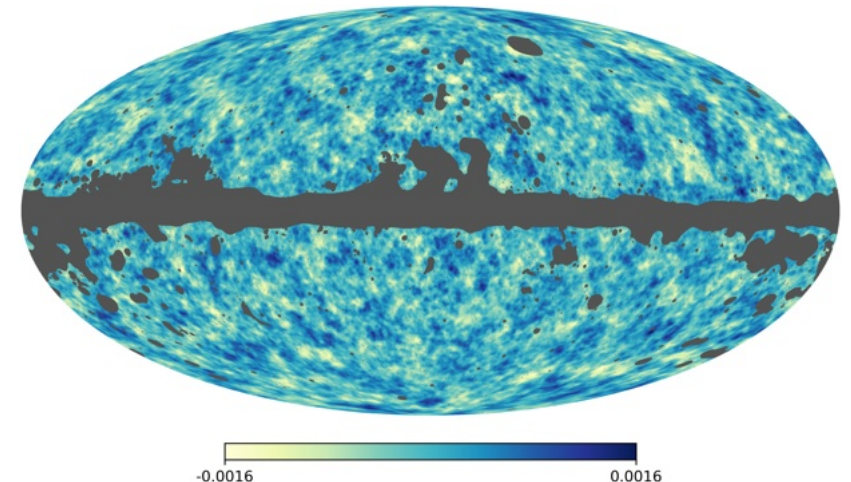
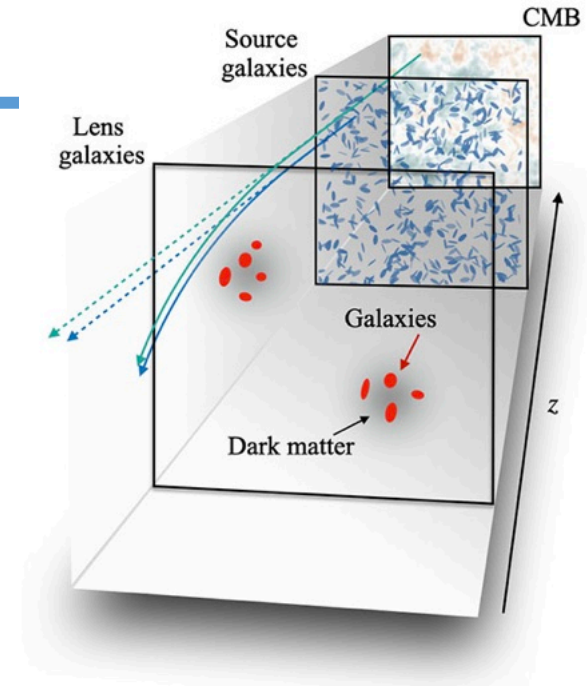
Phys. Rev. D **106**, 063503
Phys. Rev. D **113**, L101302

- Rotation of the CMB polarization during propagation. $\rightarrow C_\ell^{TB} \neq 0, C_\ell^{EB} \neq 0$
- Planck: angle calibration by foreground
 - $\beta = 0.34^\circ \pm 0.09^\circ \rightarrow 3.6\sigma$
- ACT: angle from optics model
 - $\beta = 0.215^\circ \pm 0.074^\circ \rightarrow 2.9\sigma$
- Towards a conclusive measurement
 - $\rightarrow$ Absolute angle calibration
 - $\rightarrow$ wiregrid calibrator



Gravitational Lensing

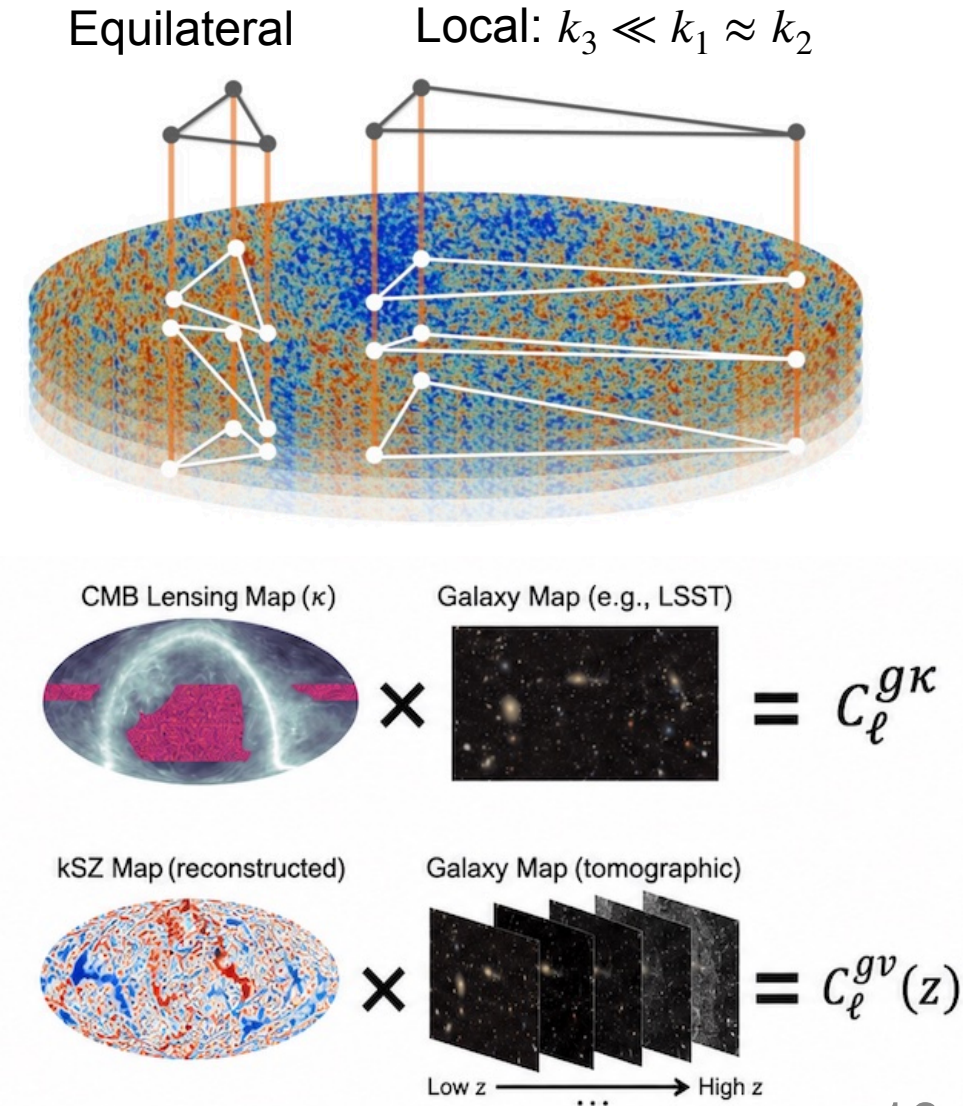
- CMB photons are gravitationally lensed by LSS.
- Reconstructed lensing map using the trispectrum of the quadratic estimator.
- Provides access to the **matter distribution**
→ Dark Energy Structure growth Neutrino
- Crucial for **delensing** primordial B modes.
- Planck $A_L = 1.039 \pm 0.052$ (Λ CDM consistent)
- B02 Target: $\sigma(A_L) < 0.007$



Planck lensing covariance (κ) map

Primordial Non-Gaussianity

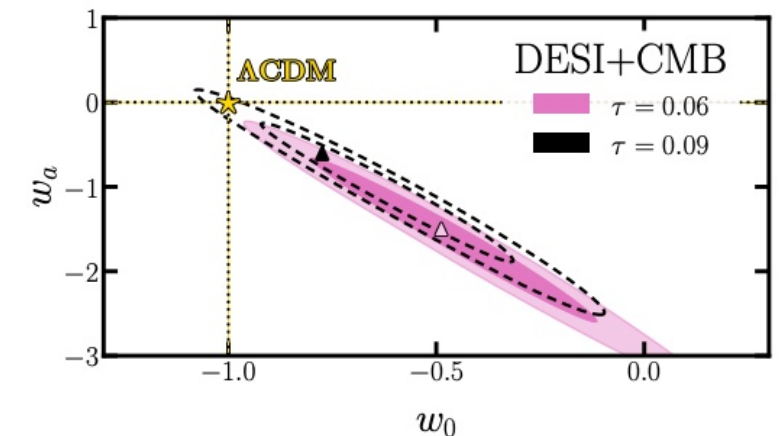
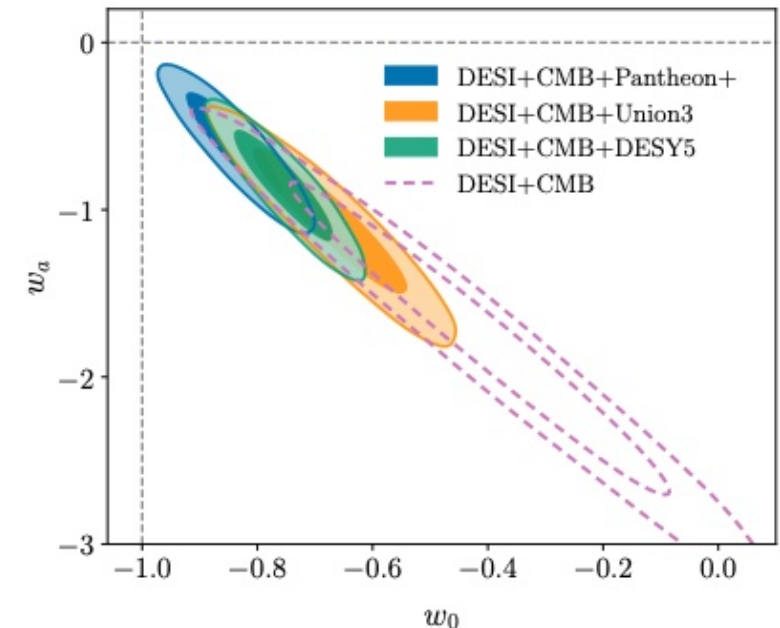
- Local PNG ($f_{\text{NL}}^{\text{local}}$) is a powerful probe of inflation model.
- Planck $f_{\text{NL}}^{\text{local}} = -0.9 \pm 5.1$ (68% C.L)
- Bispectrum is close to cosmic variance limit
- Local-type PNG induces a scale-dependent galaxy bias $\rightarrow C_{\ell}^{g\kappa}$: CMB lensing $\times$ galaxy map
- B02 Target: $\sigma(f_{\text{NL}}^{\text{local}}) < 2$
 - Improve CMB lensing reconstruction
 - Cross correlation with galaxy map (LSST)
 - Synergy with future kSZ tomography



Dark energy

Sailer et al. 2025
Namikawa 2025
Craig et al 2024

- CMB-DESI Ω_m tension $\sim 3\sigma$
- **Possible explanations**
 - Time-varying dark energy
 - Extremely small (or negative) neutrino mass
 - Enhanced CMB lensing ($A_L > 1$)
 - Optical depth $\tau \sim 0.09$ by cosmic birefringence
- **Tests with CMB**
 - Precise measurements on A_L and birefringence
 - SO lensing×PFS galaxy cross-correlations:
 - Redshift evolution of $C_\ell^{gK}(z)$
 - Sensitive probe of time-varying dark energy

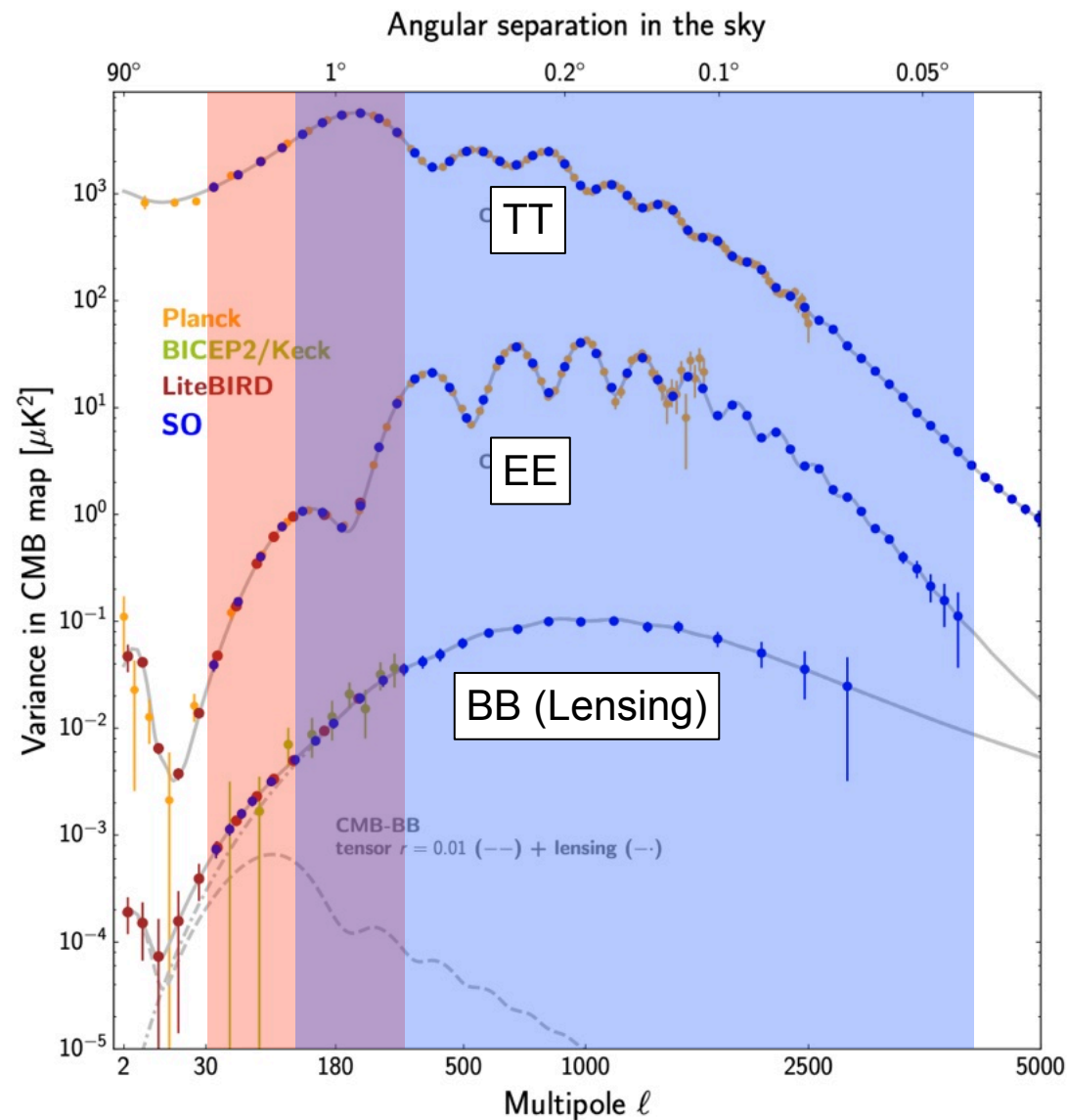
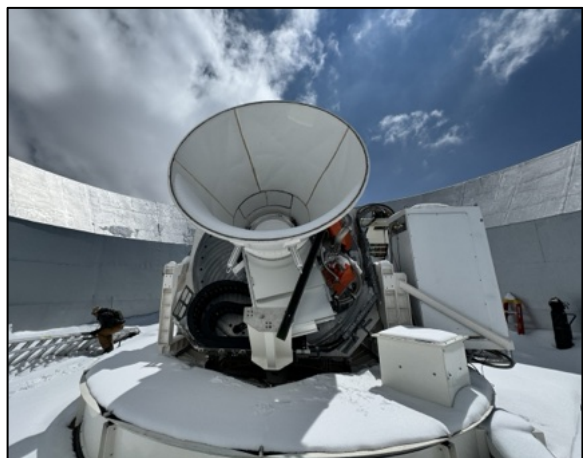
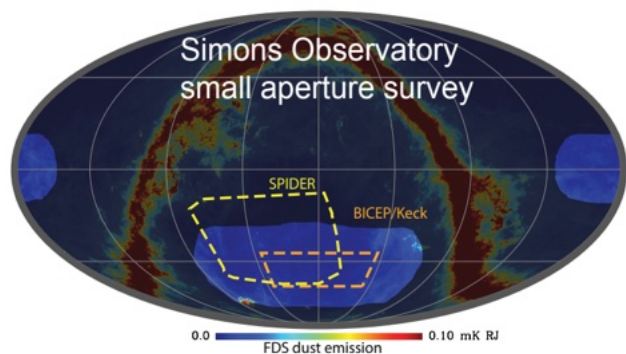


Simons Observatory

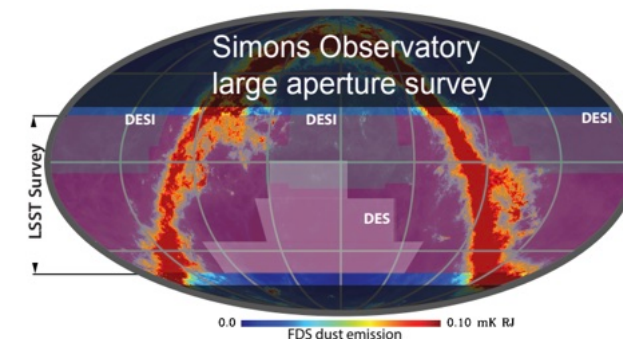


Simons Observatory

SAT



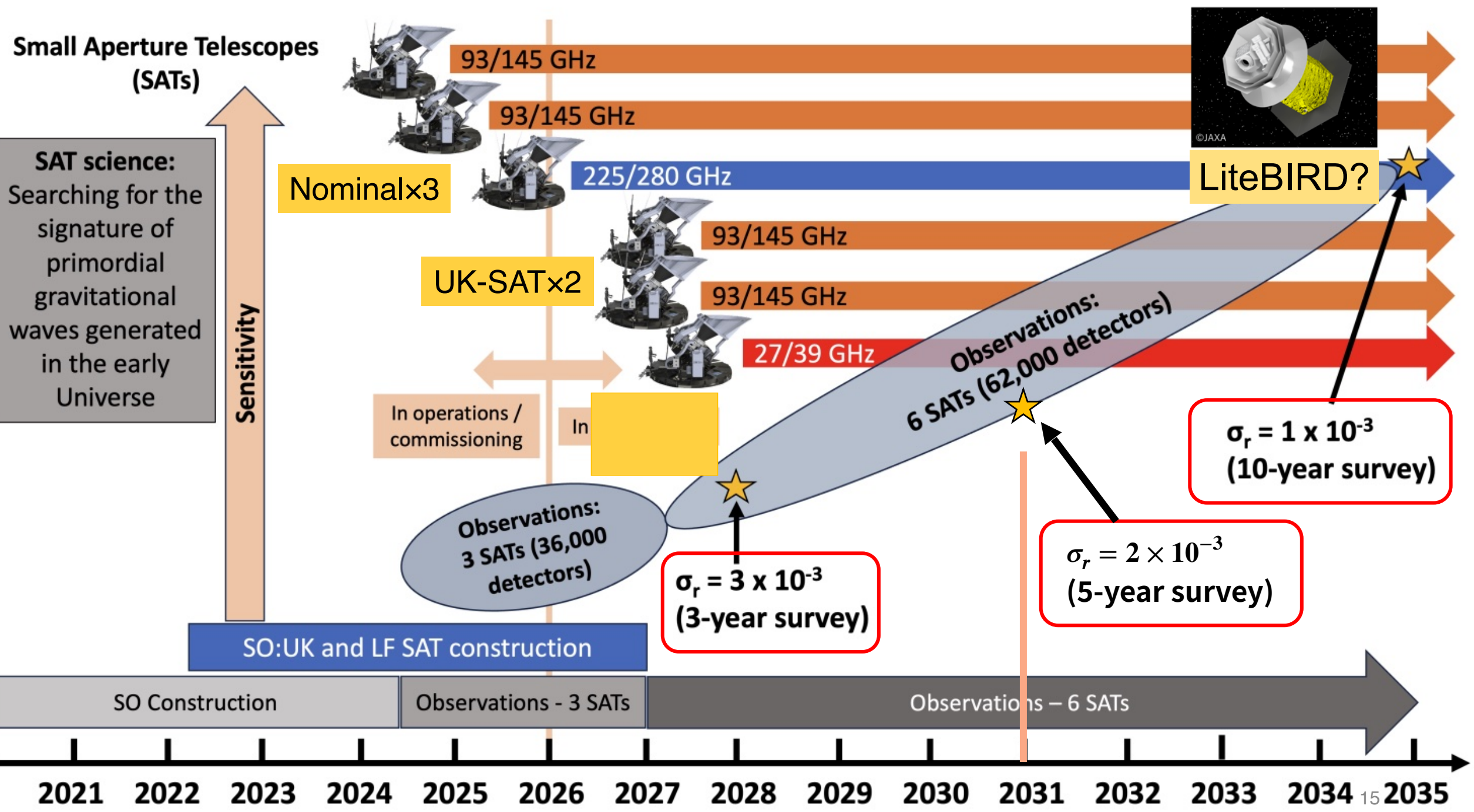
LAT



Why Simons Observatory

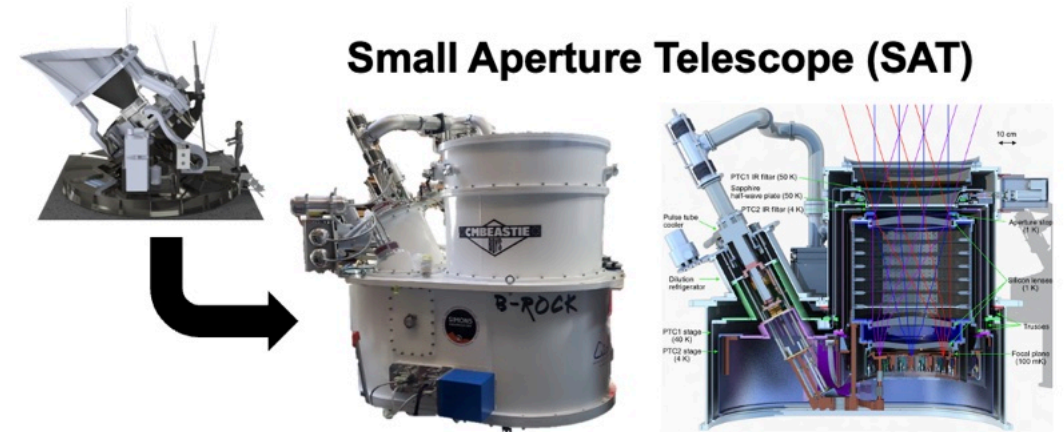
- The largest ground-based CMB experiment currently in “operation”.
- As CMB-S4 will not proceed...
 - SO, together with BICEP Array, SPT 3G, and LiteBIRD, will define the next generation of CMB observations.
- SO will play leading role in CMB observations over the next decade.

	SO SAT/LAT	Ground (ACT/SPT/BICEP)	Satellite (Planck/WMAP)
Number of detector	60,000/60,000	5,000~16,000	74/20
Frequency band [GHz]	30 ~ 280 (6 band)	27 ~ 220 (5 band)	30 ~ 857 (9 band)
Polarization Modulation	HWP/No	No	HEMT switch
Sensitivity [μ K-arcmin]	2.0/6.0	7.8/9.3/2.8	4.0/340
Angle resolution [arcmin]	35/2.2	2.2/1.6/25	10/13.2

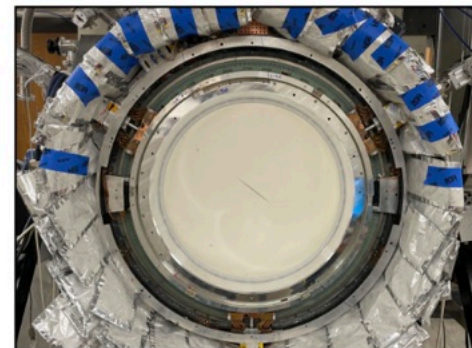


SO-Japan Contributions

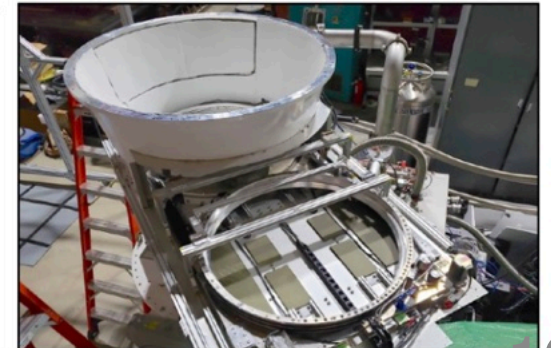
- Developed and built major SAT subsystems over past ~10 years
 - Optics tube, polarization modulators, **wire-grid calibrators**, etc
- SAT development expertise is being carried forward to **JSAT**.
- **CMB lensing analysis** is led by Toshiya (Co-I)



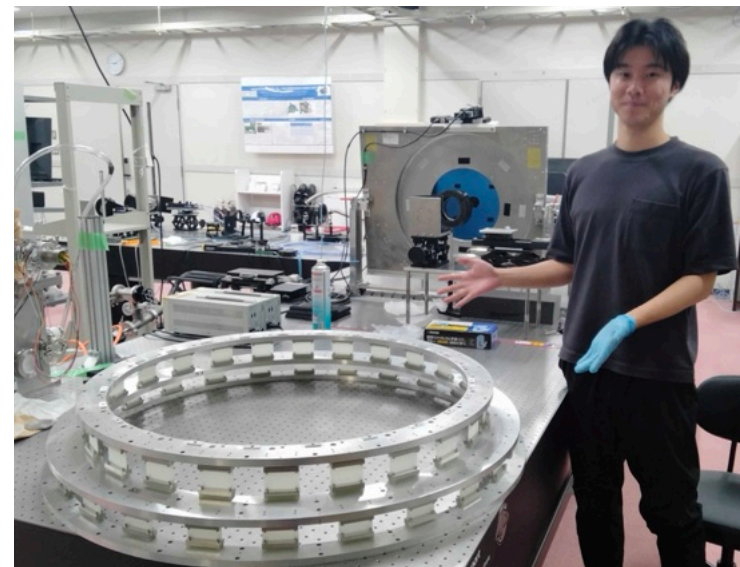
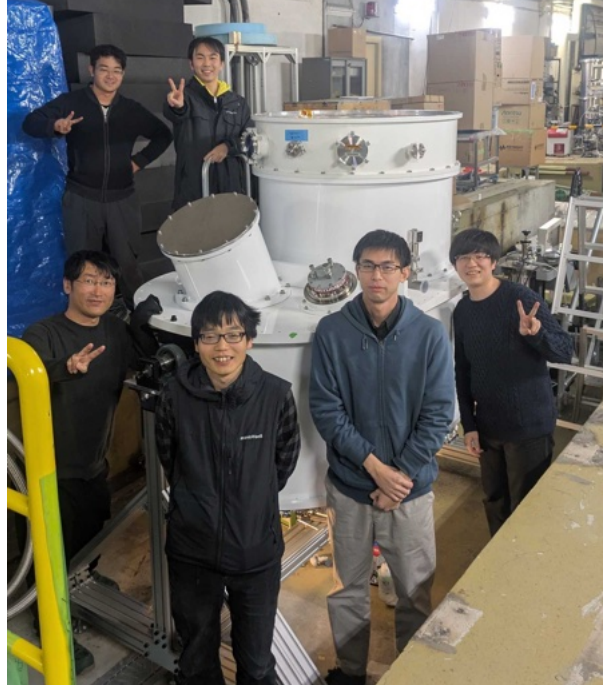
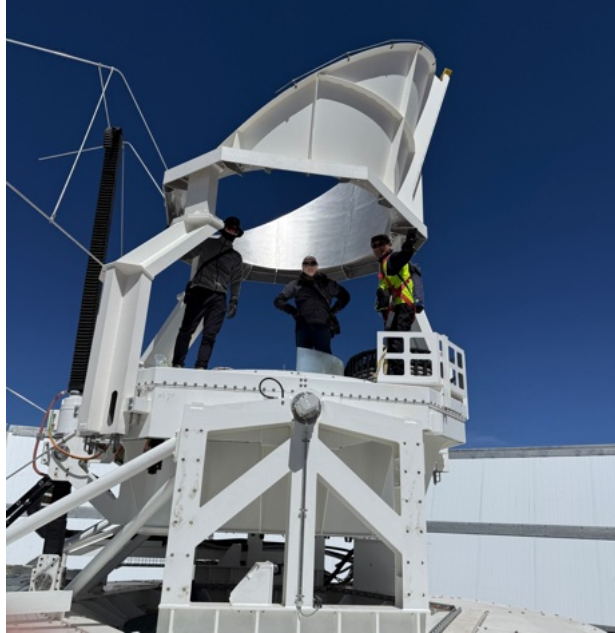
Polarization Modulator



Wire-grid calibrator



SAT-LF (JSAT)



Next talks

- Absolute angle calibration by **wire-grid calibrator**
 - Co-I: Shunsuke Adachi (Okayama U.)
- Developing fast and accurate methods for **CMB lensing**
 - Co-I : Toshiya Namikawa (Kavli IPMU)



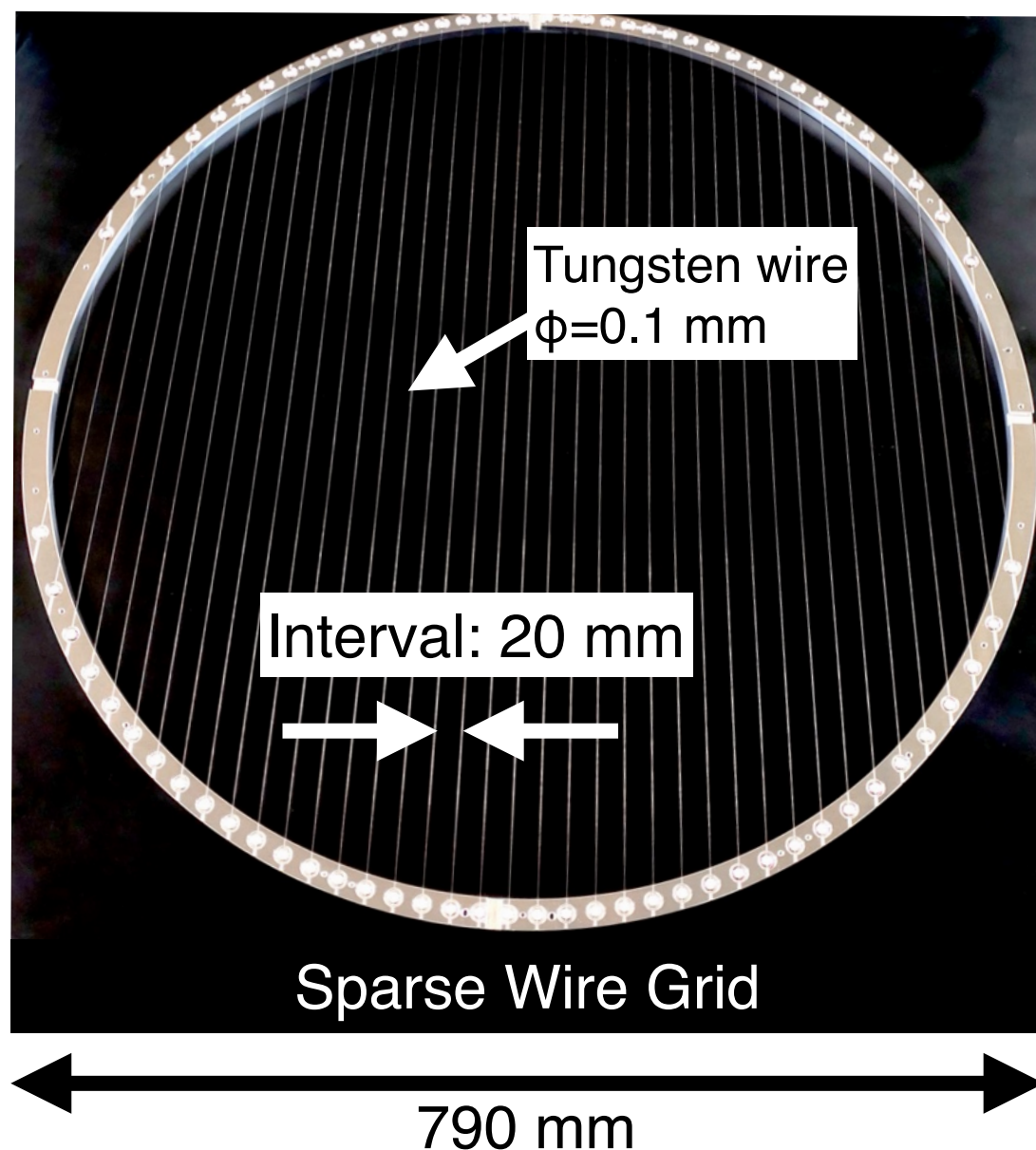
Sparse Wire-grid Calibration for Simons Observatory

Shunsuke Adachi

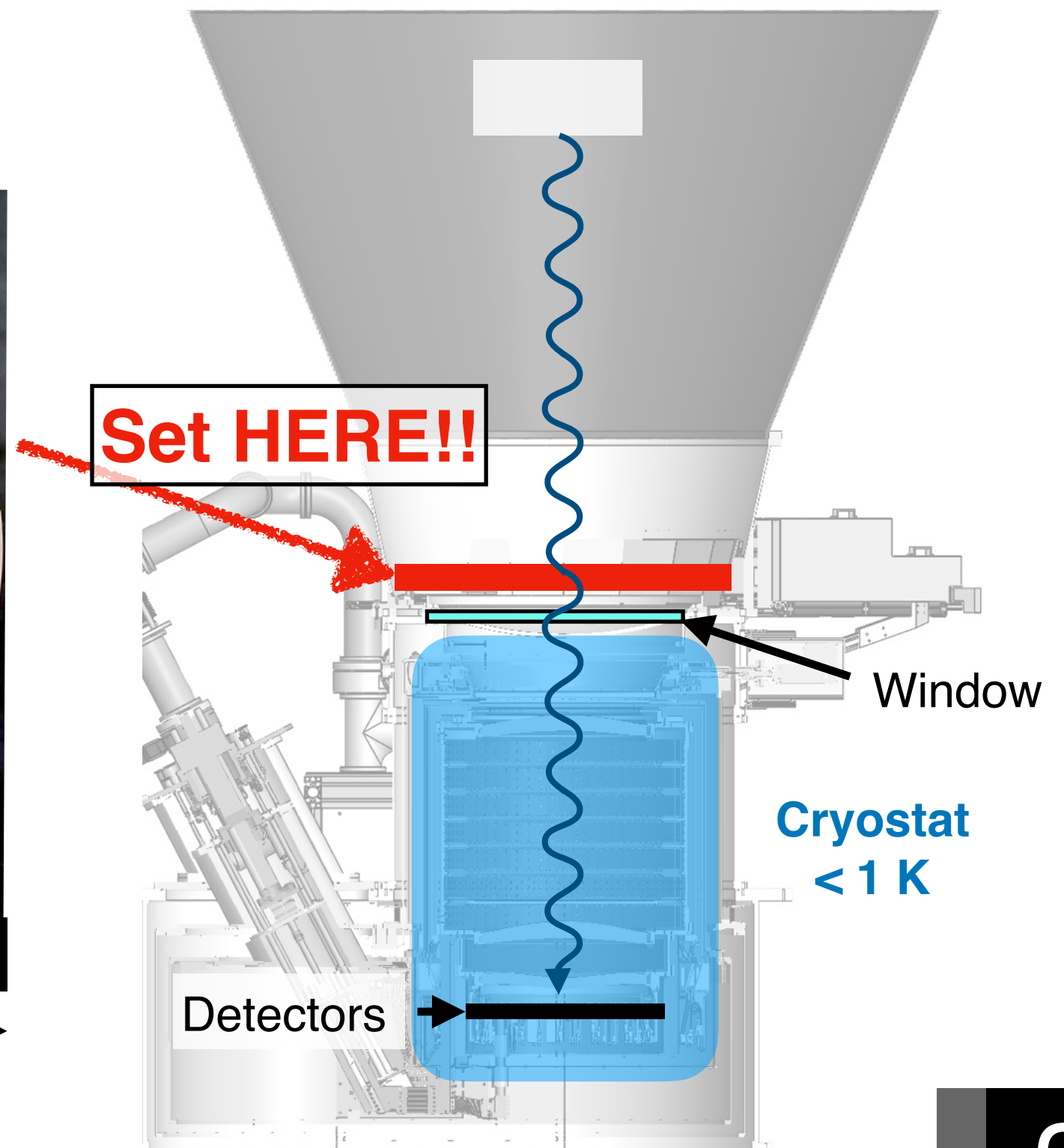
2026.07.08

What is sparse wire-grid?

- Multiple wires with sparse intervals
 $\gg$ wavelength (~ 1 mm)
- It works as an injector of linear polarization for calibration



Cross-section of SO telescope



What is sparse wire-grid?



Baffle

Cross-section of SO telescope

300 K

Thermal Radiation

A wire of wire-grid

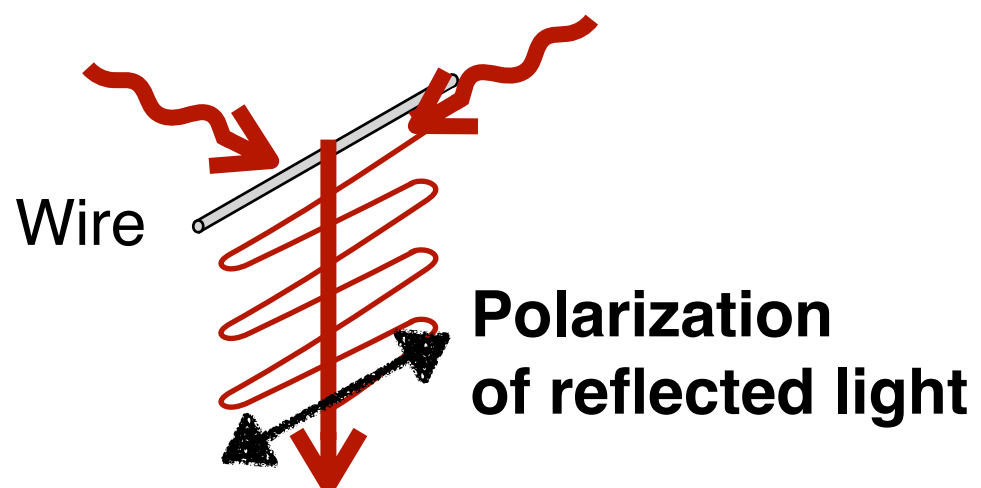
≈ 1 K

Detector

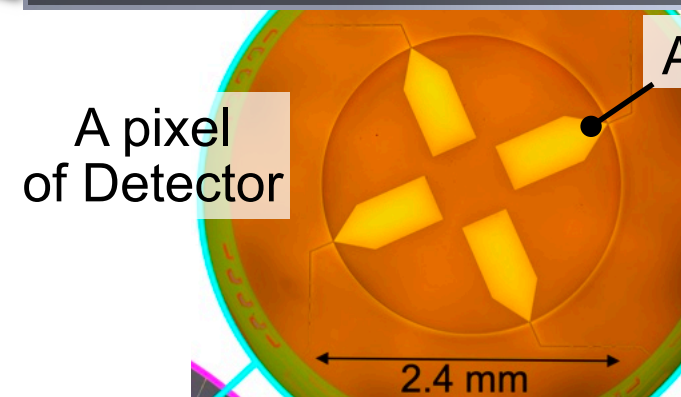
Sensitive directions

2.4 mm

Wire reflects the warm (=strong) radiation to emit linear polarization signal in parallel to the wire direction.



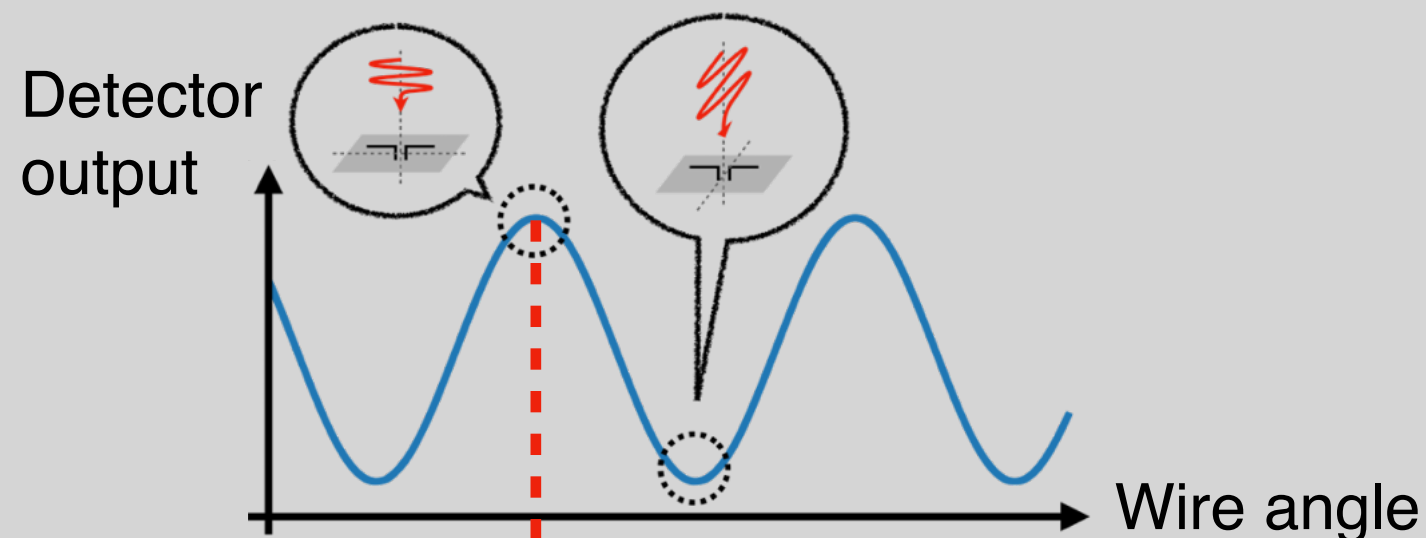
Wiregrid calibration for CMB



Detector output is maximized when they are parallel.

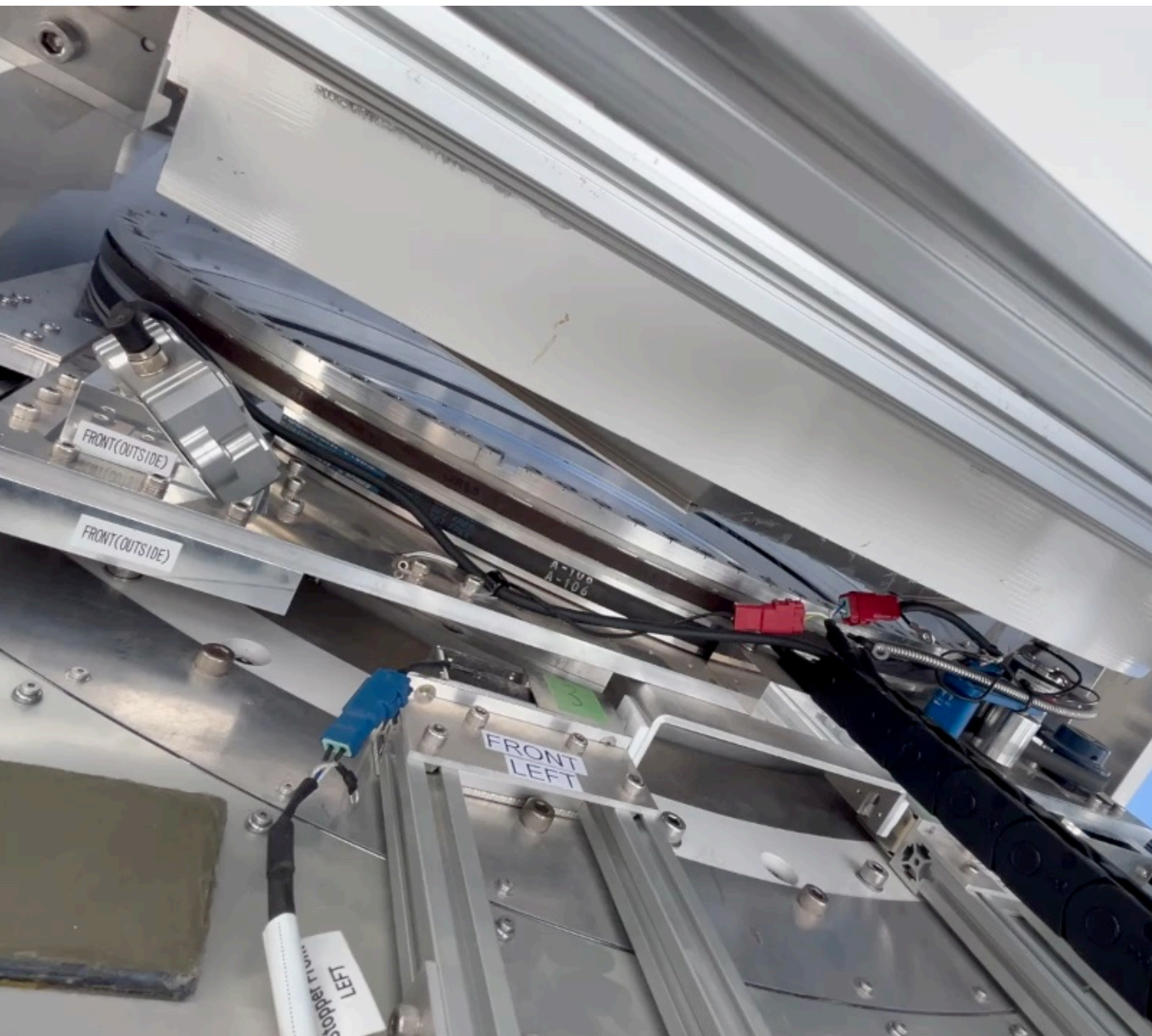
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polarization sensitive direction

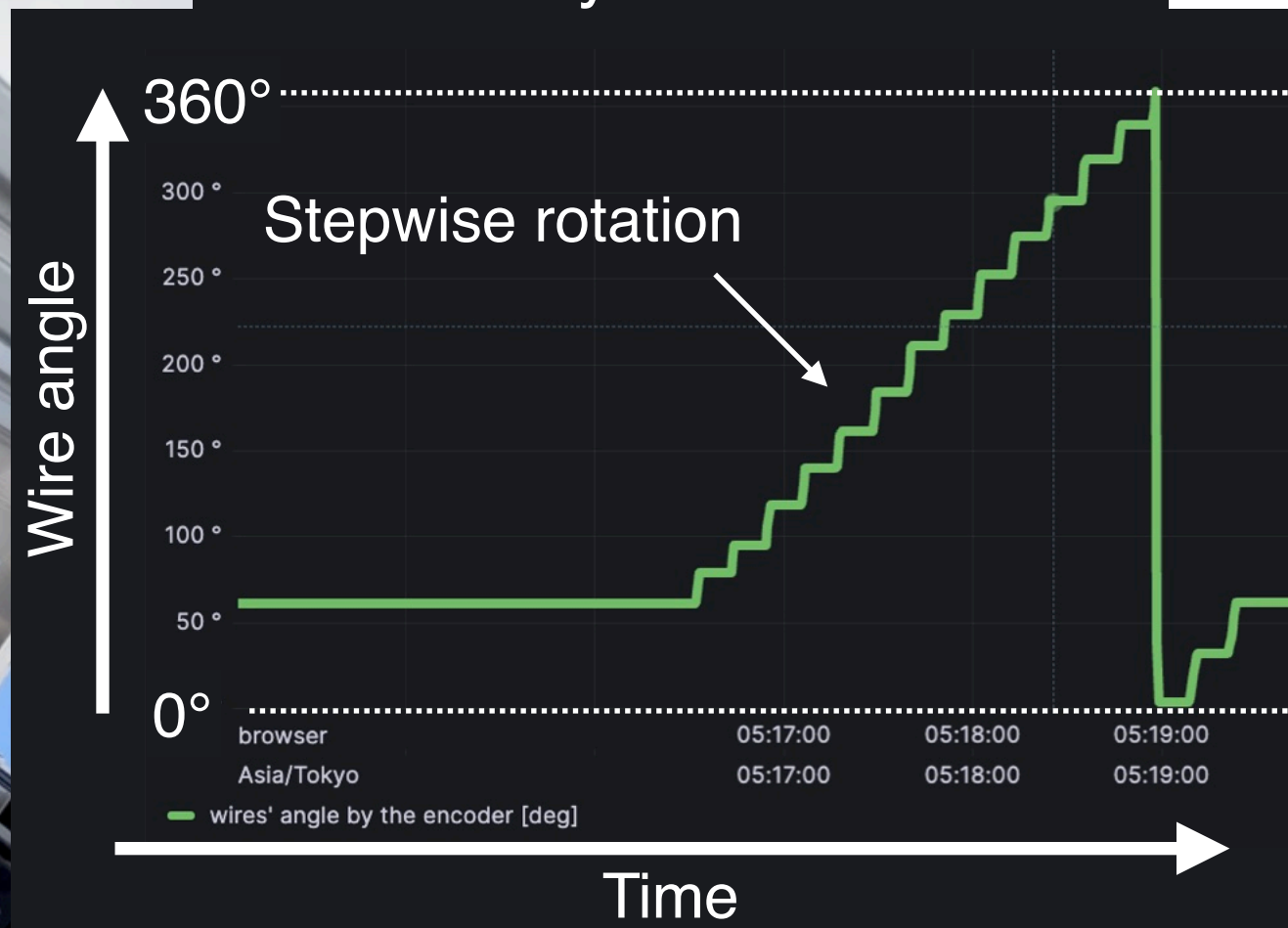


Stepwise rotation of the wire-grid

We rotate the wire-grid in 22.5° steps.

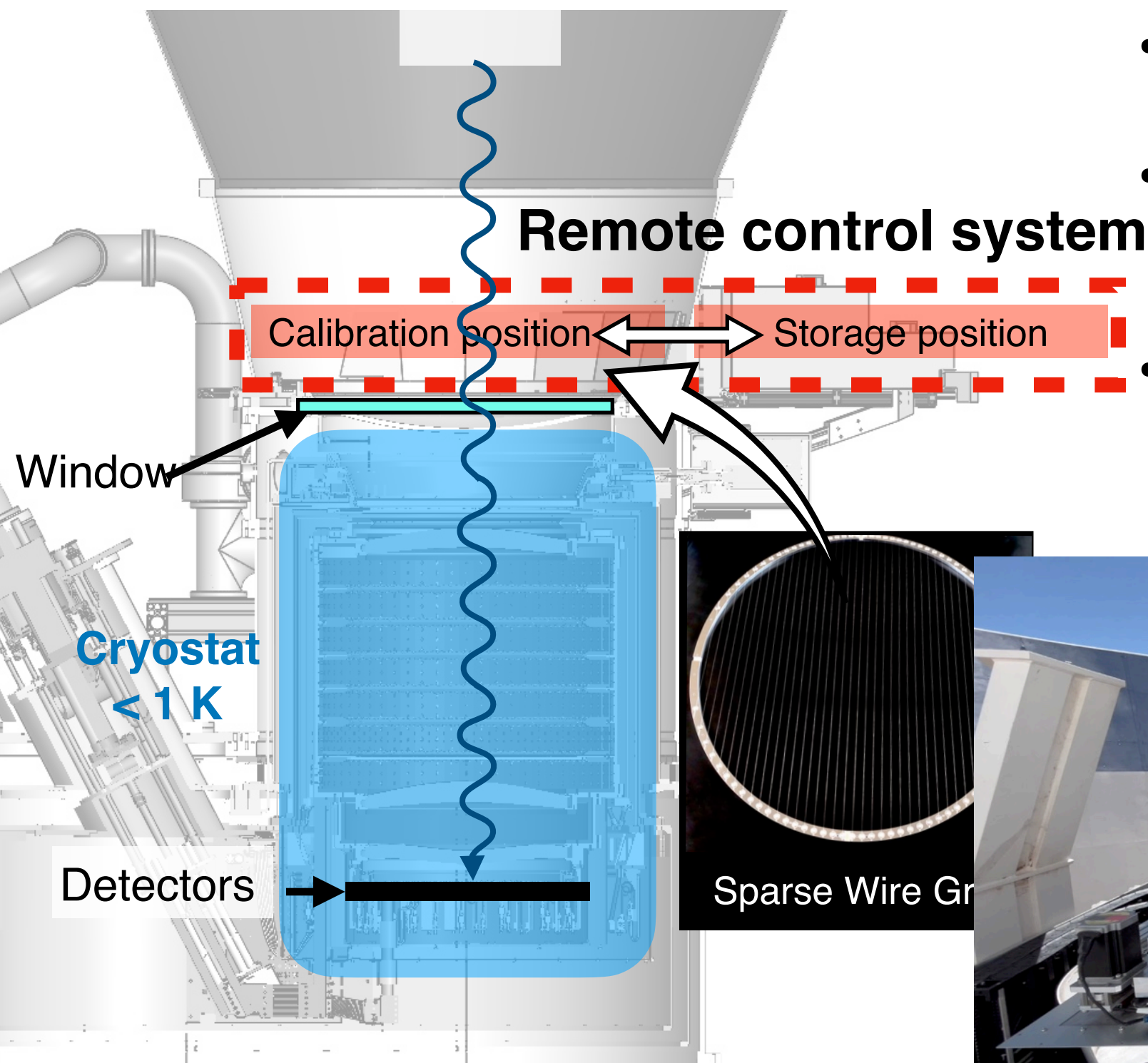


Monitoring display
for the rotary encoder in Chile

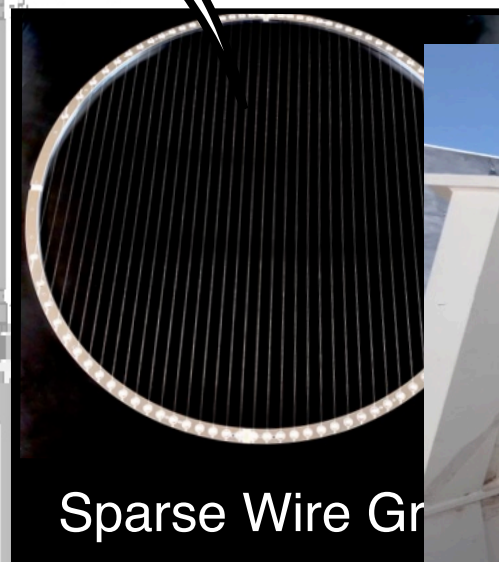


Faster than usual operation

Remote control system for regular calibration

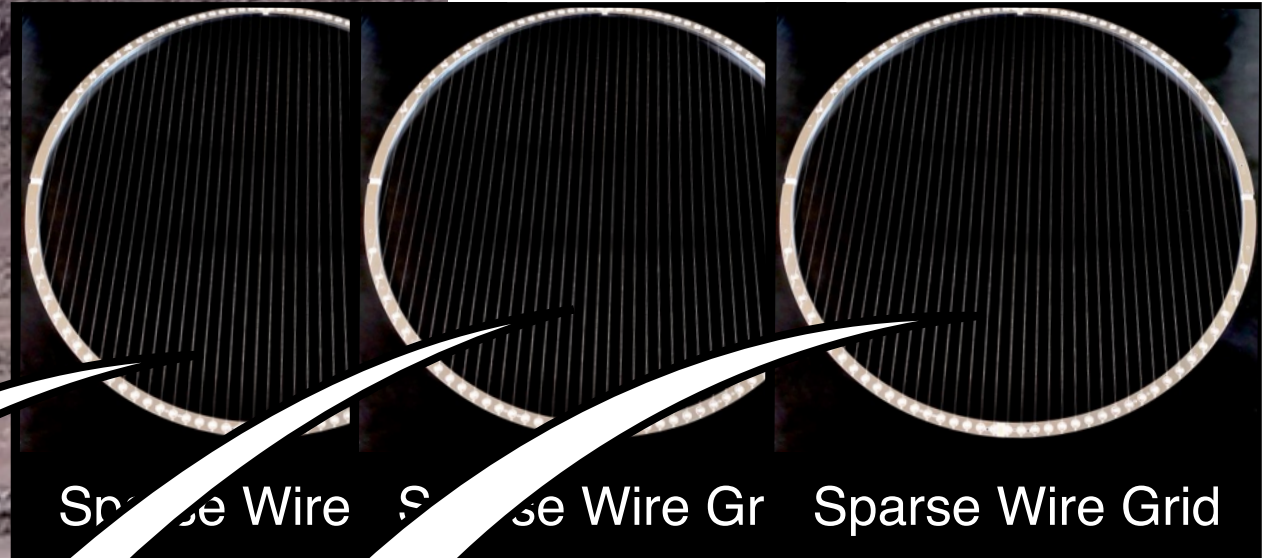
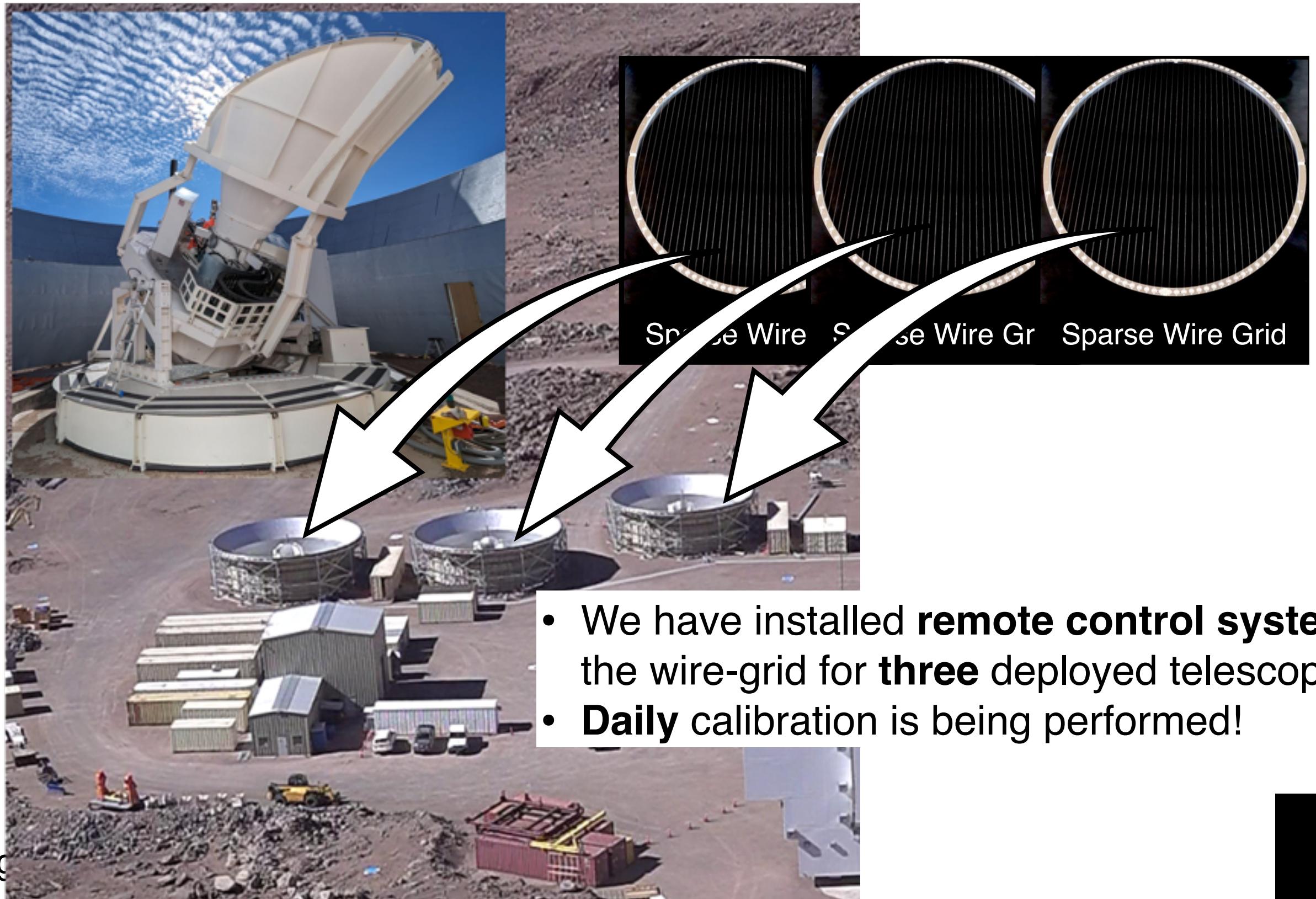


- Wire-grid interferes to observe CMB. (Unwanted light)
- It should be removed from the light path during the CMB observation.
- We have developed the remote control system to insert/eject the wire-grid.



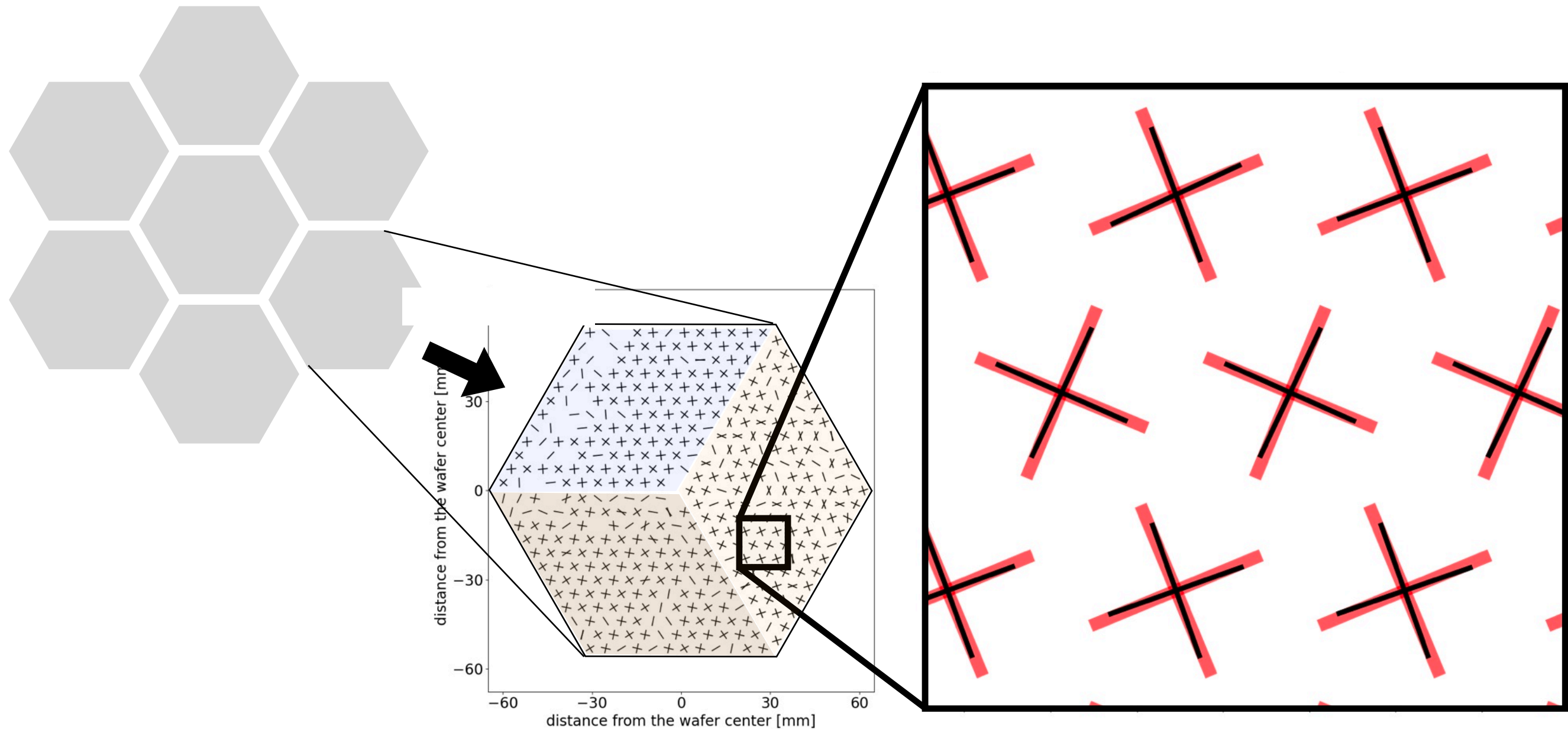
Wiregrid calibration for CMB

We have installed & perform calibration daily!



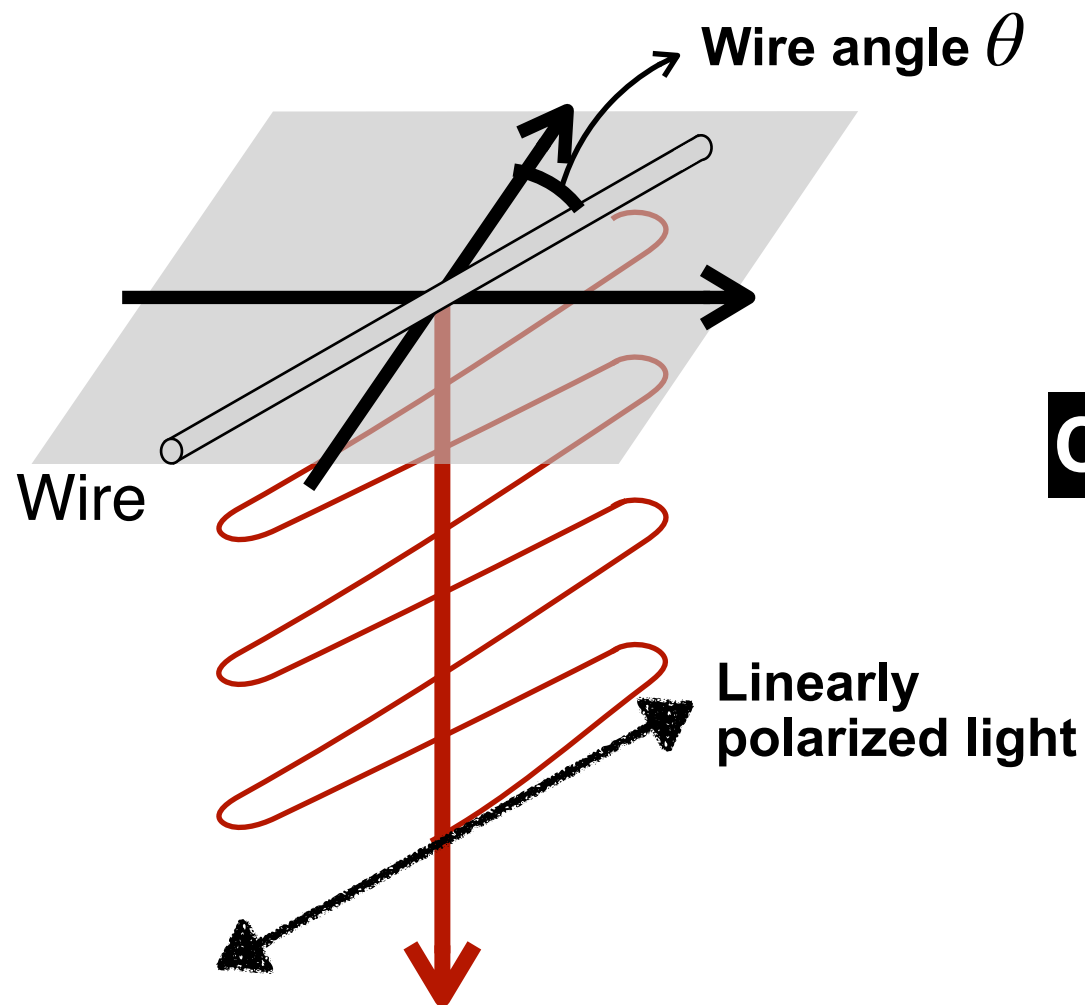
- We have installed **remote control system** of the wire-grid for **three** deployed telescopes.
- **Daily** calibration is being performed!

Initial results of the calibration



Calibration roughly works well!

What is important to obtain accurate calibration?



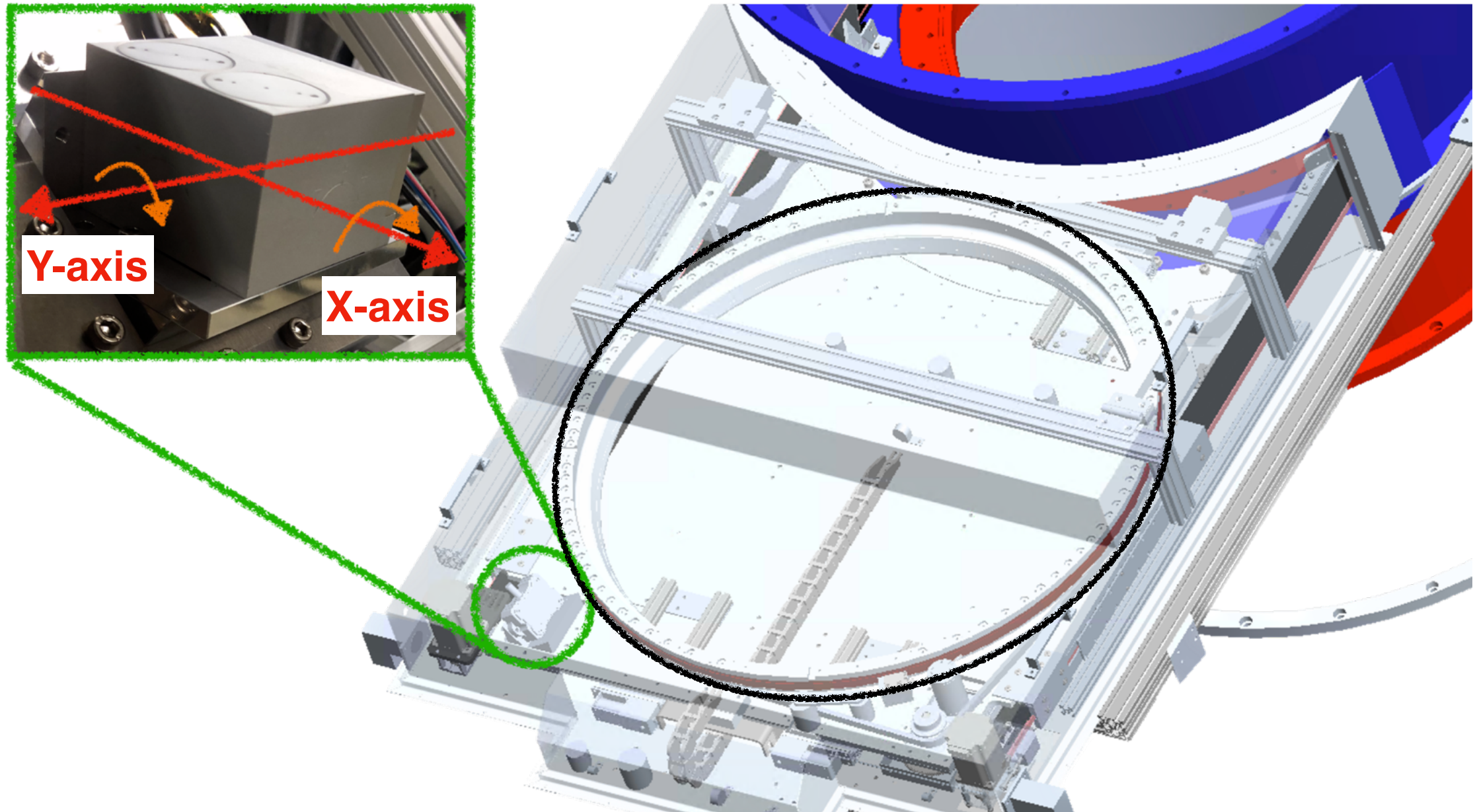
The wire angle θ is essential because it determines the angle of the **linearly polarized light**.

Calibration accuracy $\approx$ wire angle accuracy

- The wire angle is **relatively** measured by **the encoder** equipped on the rotation system. ($\Delta\theta \sim 0.03^\circ$)
- **Absolute** angle should be measured in **the sky coordinates**.

Gravity sensor

To estimate the wire angle in the sky coordinates, we install a two-axis gravity sensor on the base plate for the wire grid.



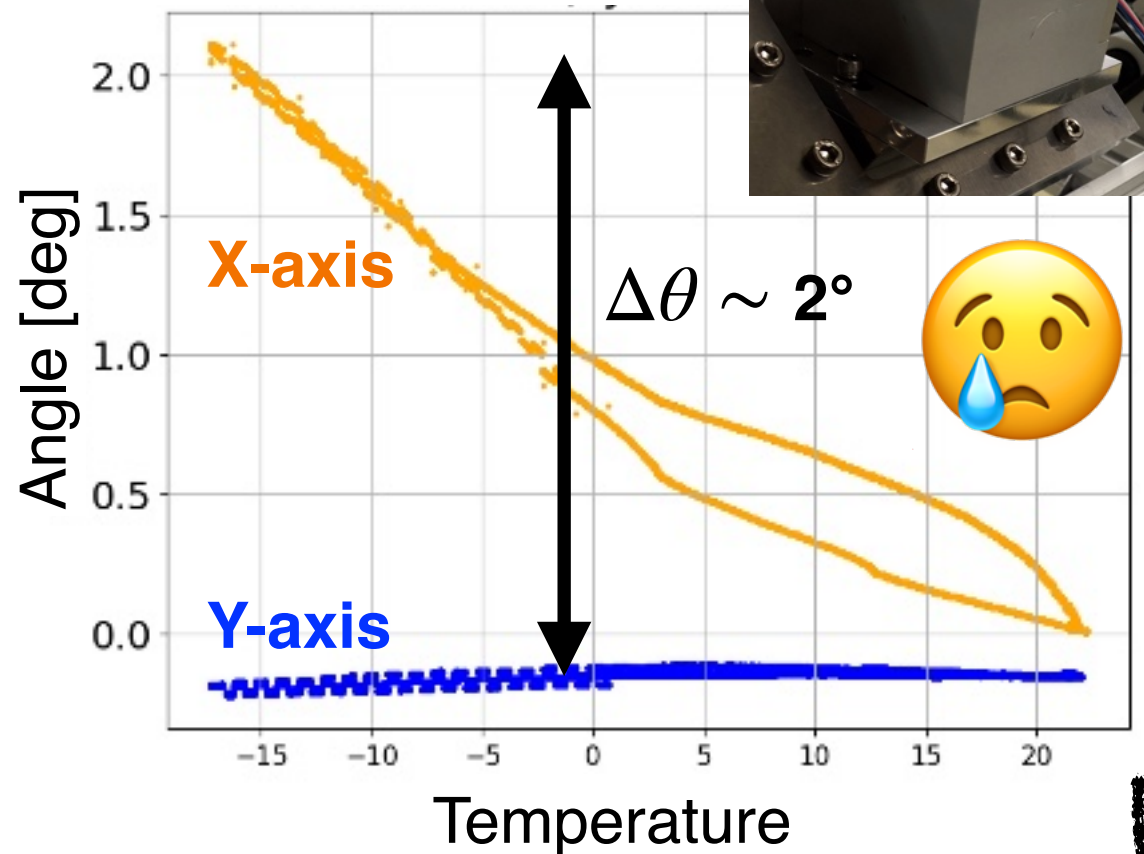
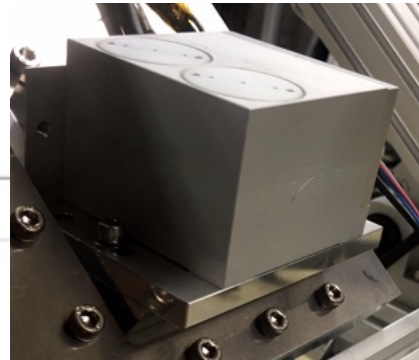
Requirement on the sensor:

$$\Delta\theta < 0.04^\circ$$

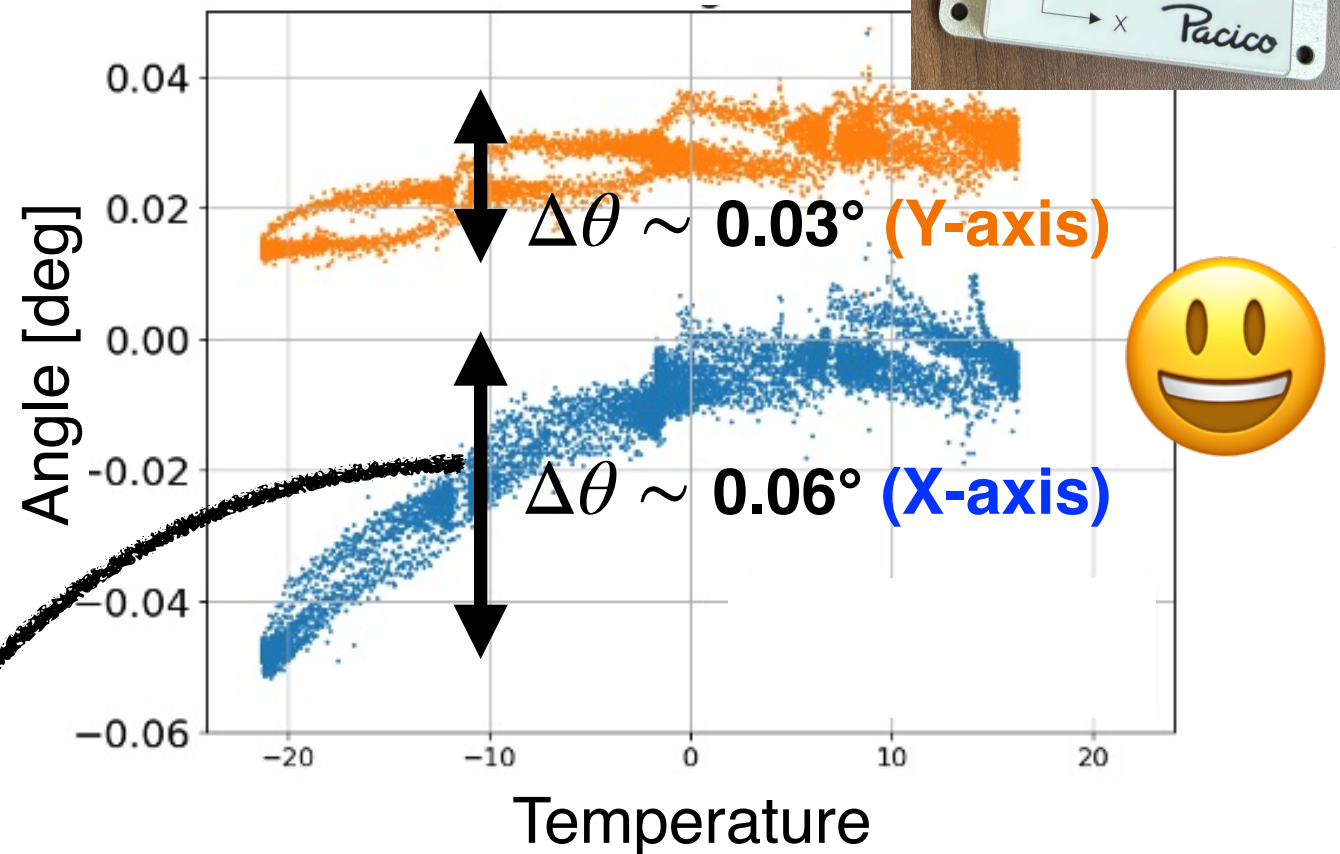
Tilt sensor improvement

- Current sensor has bad temperature dependence.
 - In Chile, it will changed from -20°C to $+20^{\circ}\text{C}$.
- This is the current bottleneck to meet the requirement ($\Delta\theta < 0.5^{\circ}$).

Current sensor



New sensor (Not installed yet)



- Probably it can be suppressed by **correcting** the temperature dependence.

Current works

- **Installation** of the new sensors in Chile
- **Evaluation** of the temperature dependence more for the correction.

Development of the cross-check method

We are considering developing an independent method to cross-check wire angles without the gravity sensor.

Not regularly
(One-time, or seasonal)

Method: Horizontal **laser** (injected from the side) + **photogrammetry**

