LiteBIRD instrument update

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for the LiteBIRD collaboration

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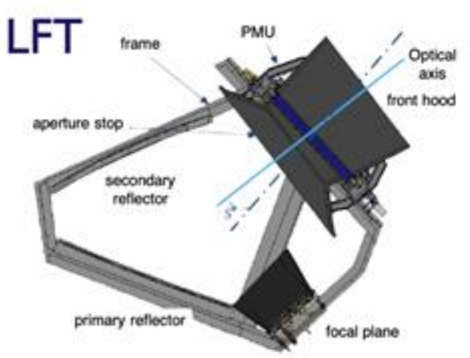
LiteBIRD

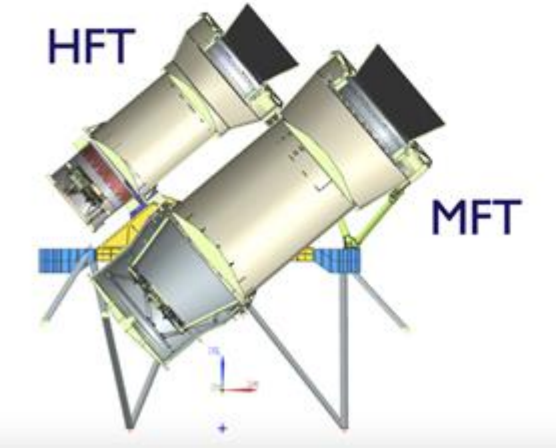
- **LiteBIRD**
  - **Lite** Satellite for the study of **B**-mode polarization and **I**nflation from cosmic background **R**adiation **D**etection

- Space mission for CMB polarization at large angular scales

- Targeting $\delta r < 0.001$

Baseline design (up to 2024)

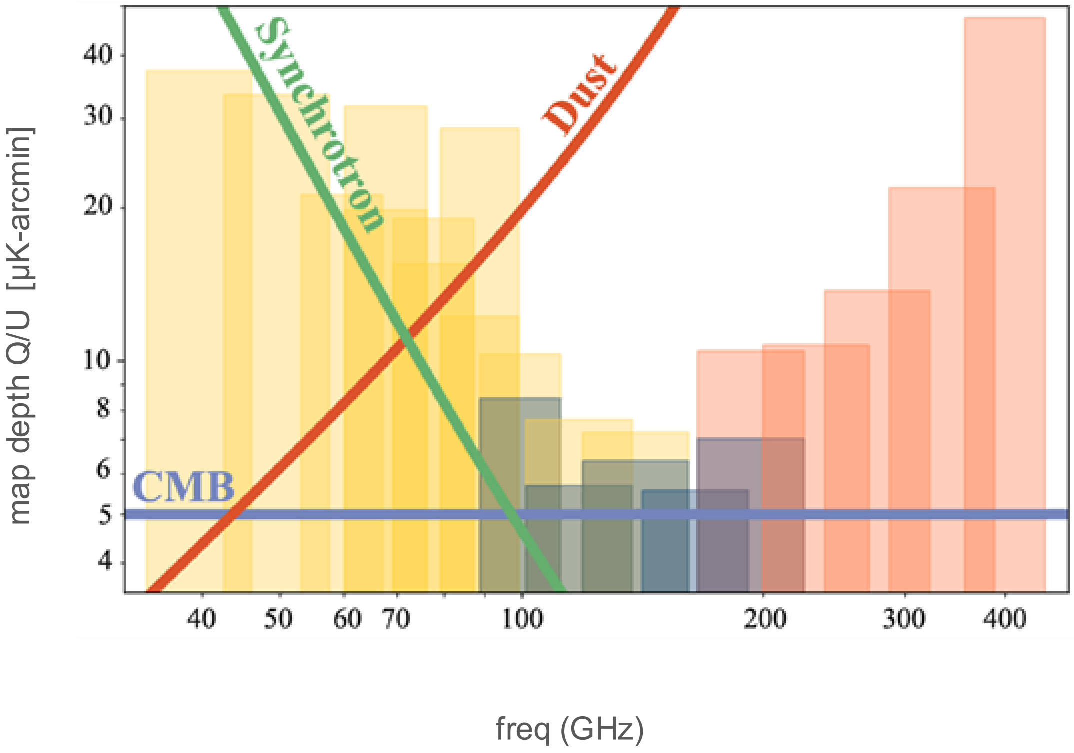




- 3 telescopes: LFT, MFT, HFT
- 40 - 402 GHz range (frequency centers)
  - TES detectors at 100mK
- 3 cryogenic rotating Half Wave Plates for polarization modulation
- LFT (JAXA)
  - 40 - 140 GHz
  - reflective optics
  - sapphire-based cryogenically rotating HWP
- M/HFT (EU with CNES leadership)
  - 100-195 GHz / 195-402 GHz
  - refractive optics
  - metamaterial-based cryogenically rotating HWPs

Baseline sensitivity and bands distribution

- **Projected polarization sensitivities (map depths) for a 3-year full-sky survey**
- Best: 4.6 μK·arcmin @ 119 GHz
- Combined sensitivity to CMB polarization: **2.2 μK·arcmin**
- Angular resolution ~0.5 degrees
- Aiming to the largest angular scales for measurement of **recombination and reionization B-modes peaks**



Polarization Modulation Unit

Polarization is modulated by a cryogenic rotating Half-Wave Plate (HWP) in combination with polarization sensitive detectors

When the HWP rotates, the polarized fraction rotates at 4xHWP rotation frequency: ~1 Hz → ~4 Hz

The **polarized fraction is modulated**/demodulated at $4\mathrm{x}f_{\mathrm{HWP}}$

This allows extraction of the polarization fraction

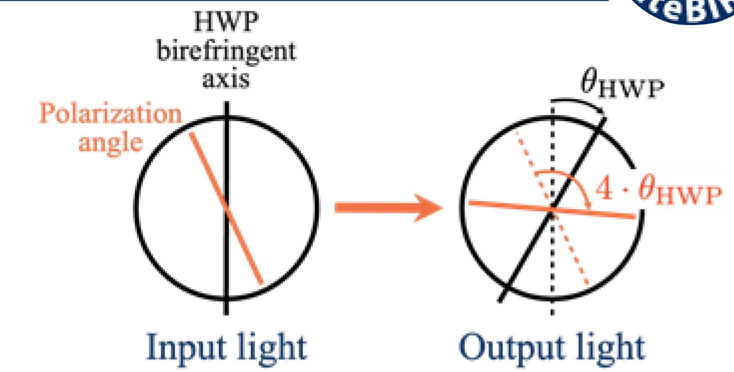
It **reduces the impact of 1/*f* noise** (modulation/demodulation)

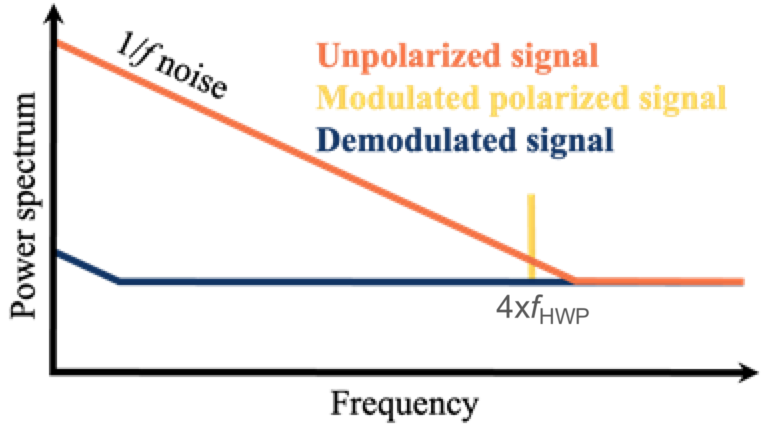
It reduces systematic effects

- **No need of combination of different detectors to solve polarization** (as it was for Planck)
- No problem with differential properties of pairs of detectors, such as gain/beam/bandpass/... mismatches
- Most of HWP induced systematic effects appear at $2\mathrm{x}f_{\mathrm{HWP}}$

The combination of HWP rotation and satellite scanning moves the polarization signal to sidebands of $4\mathrm{x}f_{\mathrm{HWP}}$

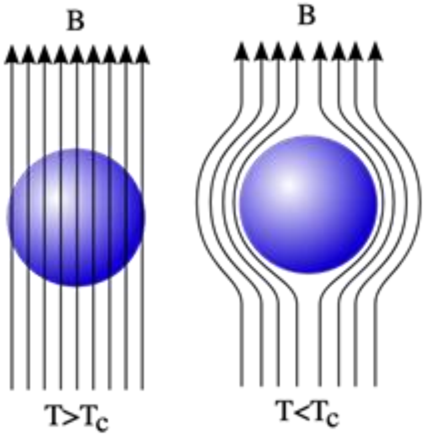
- Systematic effects at $4\mathrm{x}f_{\mathrm{HWP}}$ can be notch filtered





Polarization Modulation Unit - cryogenic rotator

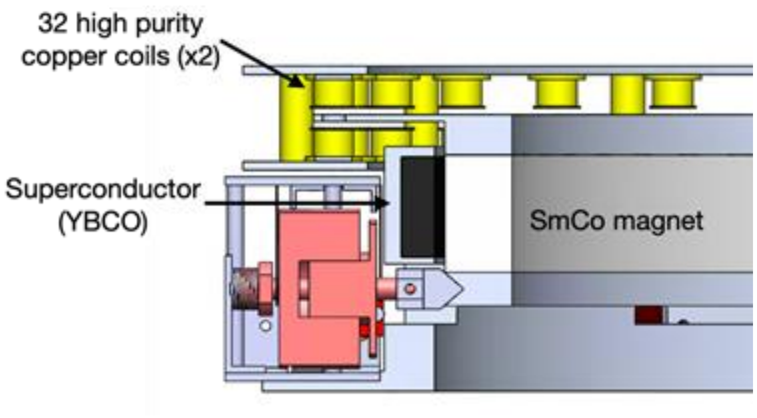
Meissner effect on superconductor



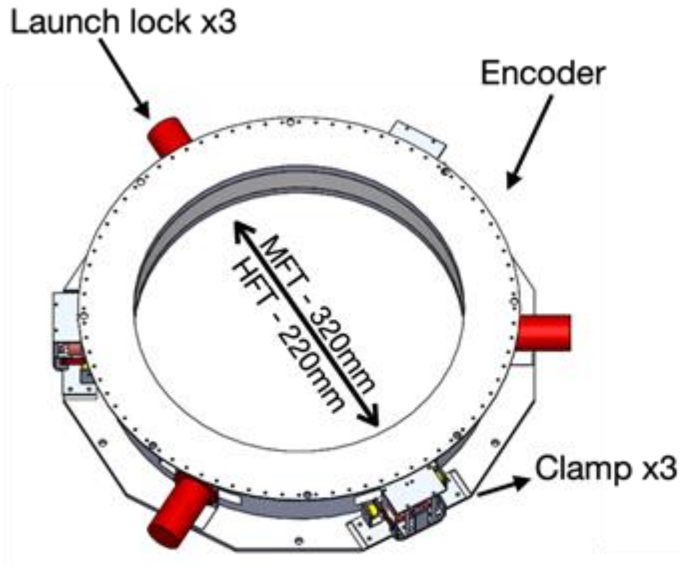
Tc = 93K

YBCO - Yttrium Barium Copper Oxide superconductor

Polarization Modulation Unit - cryogenic rotator



- continuously rotating for mission lifetime (3 yrs)
- Stator (YBCO) temperature: 5K
- Rotor (permanent magnet) temperature <20K
- rotation speed: 50-100 rpm
- heat load on 5K stage ~4mW
- encoder accuracy < 1 arcmin



Fabio Columbro, Silvia Masi, P. de Bernardis,
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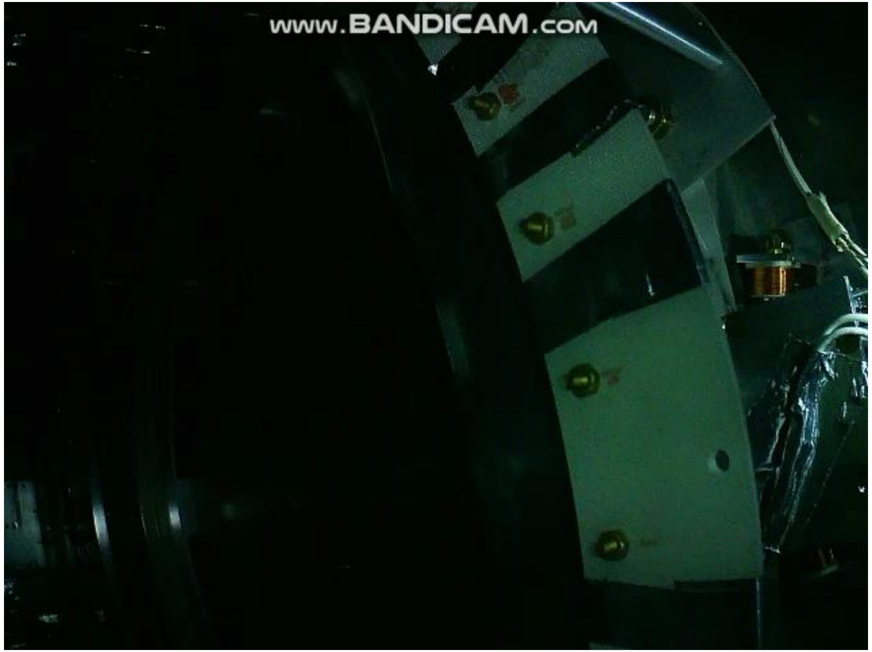
Polarization Modulation Unit - cryogenic rotator



Fabio Columbro, Silvia Masi, P. de Bernardis,
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LiteBIRD is facing a

REFORMATION PLAN

2024-2025

LiteBIRD project status - reformation plan

- **2024-08**: **KEK decided to step down from** his leading role in the procurement of the **TES detectors**
- **2024-09-26**: ISAS/JAXA KDP#1 (**Key Decision Point 1**). Decision:
  - The LiteBIRD collaboration will conduct investigating **reformation plans** for about one year.
  - Then, ISAS/JAXA will judge the continuation of the project. (**~Late 2025**)
- **2024-10** LiteBIRD PI has changed to Tomotake Matsumura (Kavli IPMU, Tokyo University).

→ We are investigating **alternative procurement plans** to replace KEK's technological contributions.

→ The international team is actively conducting **reformation investigations** to further optimize and establish a more robust mission.

LiteBIRD reformation plan - main points

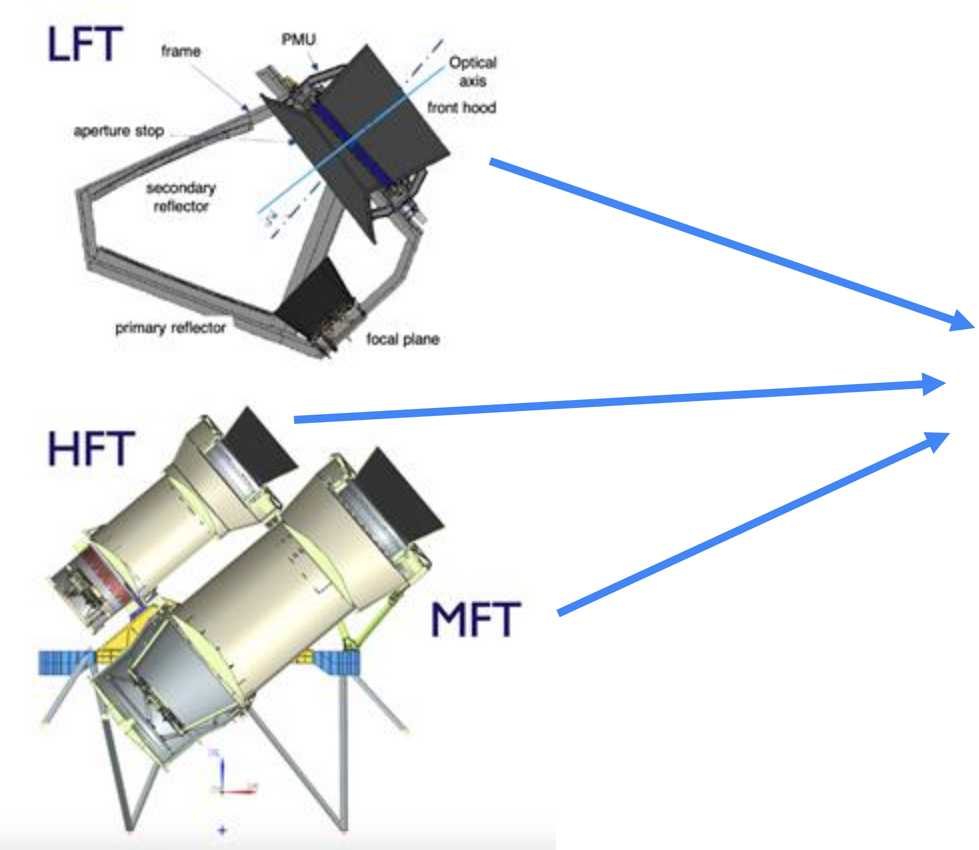
- **Rebuilding the detector procurement plan** and coordinating with new partners is the primary purpose
- Revisit the overall mission aspects, to enhance the robustness, and improve the manageability of the mission, while **keeping the overall science goal**.
    - Revisit the science objectives, so that appropriate error budget and margins can be distributed to the mission instruments and the spacecraft system.
    - **Simplify** the mission configuration.
    - Simplify the **cryo-chain**
- We also emphasize:
    - **rich sciences other than the CMB B-mode** that LiteBIRD can deliver;
    - the **synergy** with the ground-based CMB data.

Science objectives

- **See presentation by Tomotake Matsumura (panel 10)**

  - **The principal science goal remains unchanged, i.e., to verify the inflationary Universe.**
  - The sensitivity to the tensor-to-scalar ratio *r* will be maintained at a level where representative inflationary models, e.g. Starobinsky, can be tested.
  - Will revisit the error budget (statistical, foreground residuals, systematic effects, margin) keeping the science goal
  - **LiteBIRD will survey the millimeter wavelength all-sky**. Maps will allow to address important scientific topics other than the verification of the inflationary universe

LiteBIRD reformation plan - instrument revision

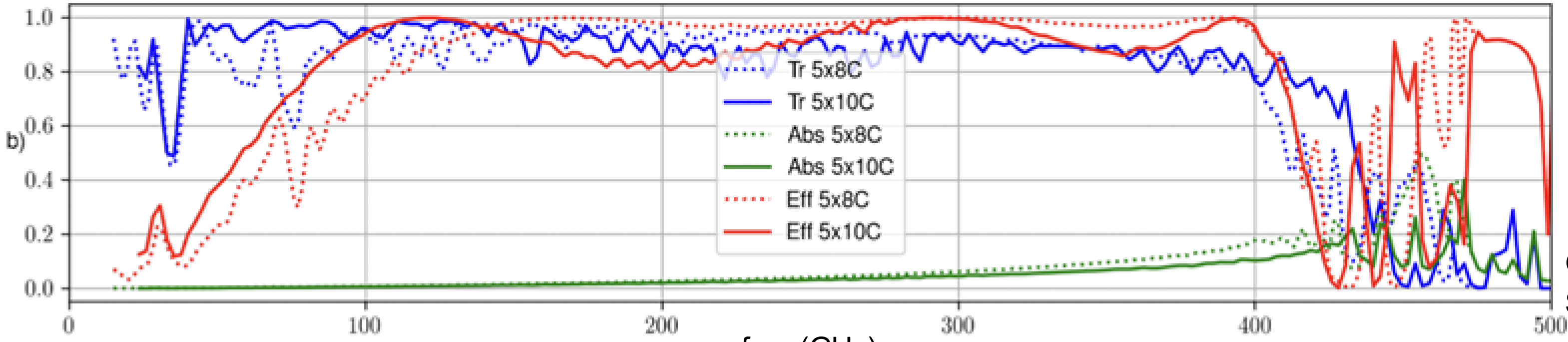


LiteBIRD single telescope, single instrument

Instrument revision - new large bandwidth HWP

- A new large bandwidth HWP can achieve 10:1 frequency range: 40 - 400 GHz
  - it was 2.7:1 before
  - now based on 5 plates in Pancharatnam configuration
  - each plate made of 10 metamaterial mesh layers
    - Design in Sapienza University (Giampaolo Pisano)
    - Production in Cardiff University - same technology as metal mesh filters
    - There is still design margin, to improve low frequency side

New version of Pancharatnam 5x10C

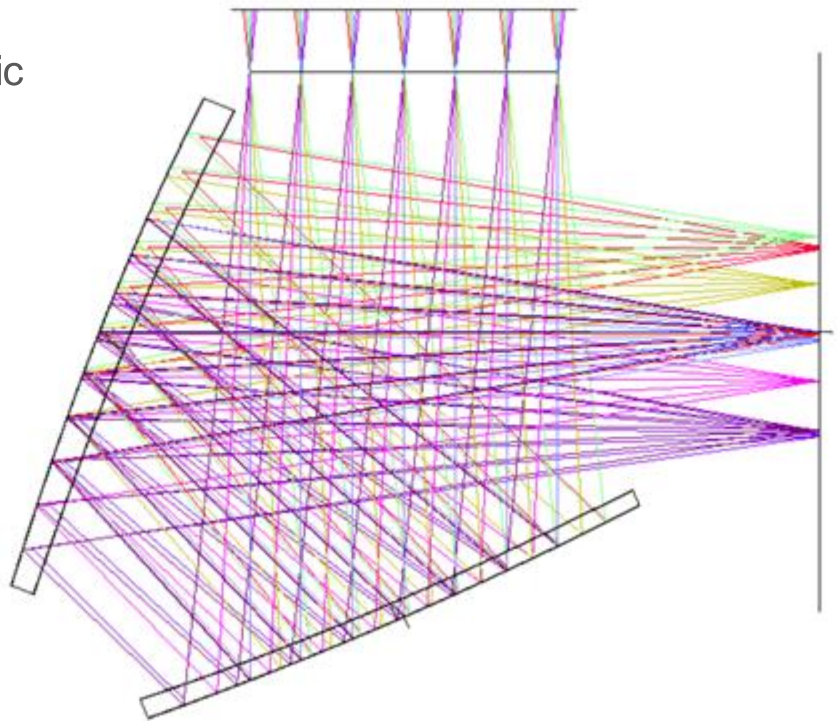


Giampaolo Pisano
Sapienza univ.

Design simplification (in trade-off study) – option 1

Different instrumental configurations are currently under investigation for reaching the same scientific goals

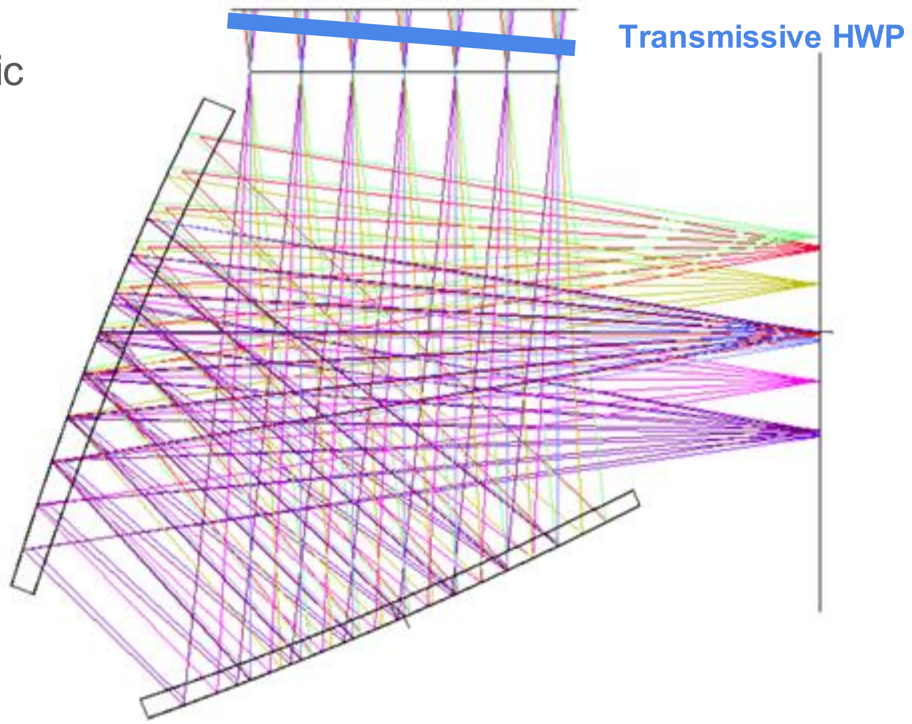
- single reflective telescope
- without HWP
- 40 - 570 GHz (extended)
- *fast* spin rate (1 spin in 3 mins)



Design simplification (in trade-off study) – option 2

Different instrumental configurations are currently under investigation for reaching the same scientific goals

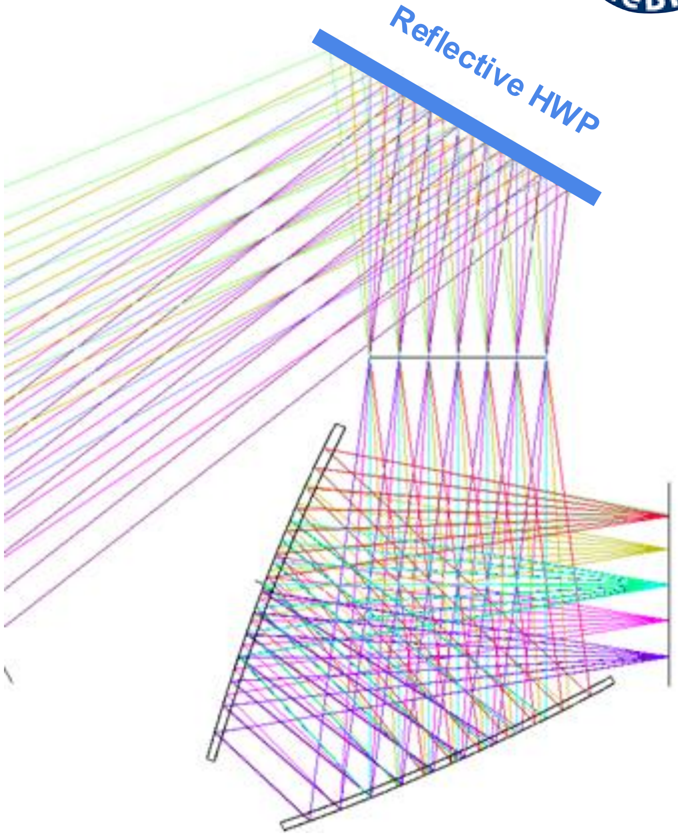
- single reflective telescope
- 40 - 400 GHz (baseline)
- transmissive large-band HWP
- nominal spin rate (1 spin in 20 mins)



Design simplification (in trade-off study) – option 3

Different instrumental configurations are currently under investigation for reaching the same scientific goals

- single reflective telescope
- 40 - 400 GHz (baseline)
- **reflective** ultra large-band HWP
    - 13:1 frequency coverage
    - higher modulation efficiency
    - can accommodate only a smaller focal plane
    - similar mapping speed
- nominal spin rate (1 spin in 20 mins)



Recent status and next steps

- CNES "Key Point" - April 2025
  - a baseline with transmissive HWP has been proposed (no HWP as a backup)
- A **plan to develop TES detectors in Europe** with support by ESA D/TEC has been put in place (with contribution from Italy, UK, NL + FR, ES, CH, FI, ..)
- JAXA Key Decision Point #2 - September 2025
  - JAXA **to approve mission continuation**
- JAXA Mission Definition Review - Spring 2026
  - The collaboration must show that the mission is mature to **enter in JAXA Phase A** (equivalent to ESA Phase B)

Complementarity

Space based CMB observations

- Full-sky observation and sensitivity to the very low-ℓ
- Wide frequency range

Ground based

- adopt cutting-edge challenging technologies to achieve the best possible performance
- sensitivity to very high-ℓ

technological exchange is mandatory between them, to achieve their synergy

MoU between LiteBIRD and CMB-S4 collaborations

GOAL:

- Quantify the synergy between the LiteBIRD and CMB-S4 projects based on forecasts using LiteBIRD and CMB-S4 simulations
    - impact of LiteBIRD high-frequency and low-frequency maps on CMB-S4 *r* forecasts
    - impact of CMB-S4 de-lensing information on LiteBIRD *r* forecasts

Summary

- LiteBIRD is JAXA's mission for **precision measurement of the CMB B-mode**
- High-precision millimeter wave all-sky polarization maps allows **rich science other than CMB** B-mode
- It is the only space-based CMB observatory planned in 2030s.
- It is **currently under reformation**, until autumn 2025.
    - To rebuild the **detector procurement plan** and to coordinate with new partners.
    - To make the mission robust, feasible, and manageable, while **keeping the science targets**.
    - Not to lose the opportunity to conduct the CMB B-mode observation in space in 2030s

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