SAPIENZA
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Simulation and analysis of HWP and TES non-idealities for CMB space missions

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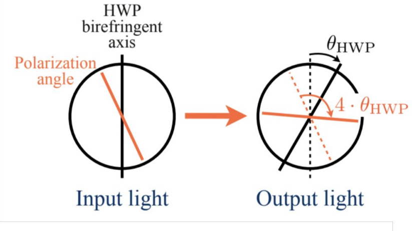
Outline of this talk

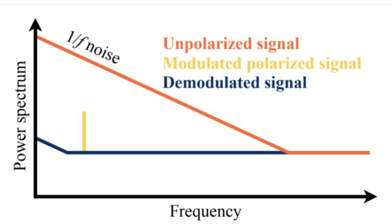
- Introduction
- Analytical model of the systematics
- Simulations applied to LiteBIRD
- Discussion and conclusions

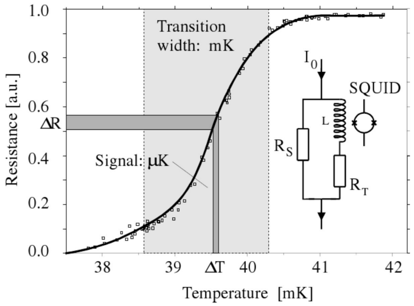
HWP and TES in a nutshell:

- A RHWP moves CMB polarization signal above 1/f noise, reducing systematic effects
- Fast HWP rotation allows quick single-detector measurement of I, Q, U → minimizes need for corrections due to detector mismatches

- A TES is a cryogenic super sensitive thermistor
- It measures current at a fixed voltage; current changes reflect optical power through the resistance shift in a superconducting film.







Höhne+1998

Parasitic signals from HWP systematics

- Parasitic signals at harmonics of HWP rotation frequency (f_{HWP}) can be caused by HWP imperfections.

- HWPSS correction or calibration methods studied in previous experiments (e.g., NIKA, ABS, POLARBEAR).

- HWPSS are usually modeled as: $\boxed{A(\chi) = \sum_{n=1}^{\infty} (A_n + a_n^{opt} I) \cos(n\chi + \phi_n)}$

- Focus on signal at $2f_{HWP}$:
  - Arises from differential transmission and emission along the HWP's ordinary and extraordinary axes.
  - Can bias signal reconstruction when coupled to detector non-linearity

TES bolometers non-linearity

Tommaso's talk for more details!

- Each TES detector has some response function *S* such that $I = S(P)$

we measure this

we want to know this

- Commonly *S* is just assumed as a *linear* gain, which is fine in a small-signal approximation (CMB is small enough)

- If the signal is not-so-small (Galaxy/planets crossing, CMB dipole, HWPSS) → *S* enters a non-linear regime

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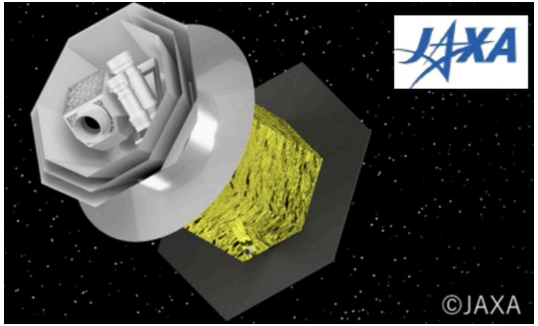
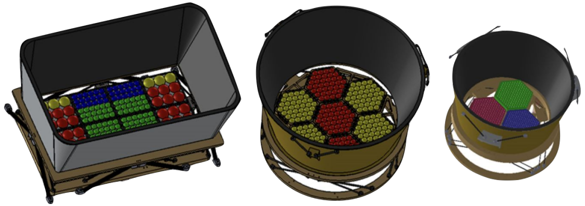
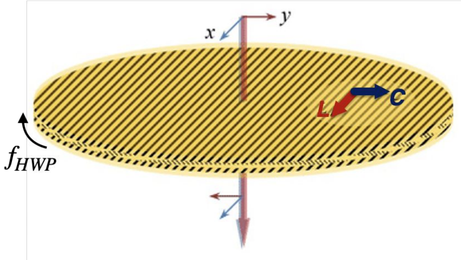
What happens when the HWPSS induces TES non-linearity?
Which level of non-linearity can we tolerate?

Application: the LiteBIRD experiment







Objectives of this work:

- ➔ Evaluate the impact of HWP non-idealities in terms of HWPSS for LiteBIRD baseline configuration
- ➔ Optimize MHFT HWPs design to minimize differential emission/transmission
- ➔ Determine desired residual non-linearity knowledge to ensure accurate estimation of *r* (LiteBIRD collaboration+23)

Application: the LiteBIRD experiment

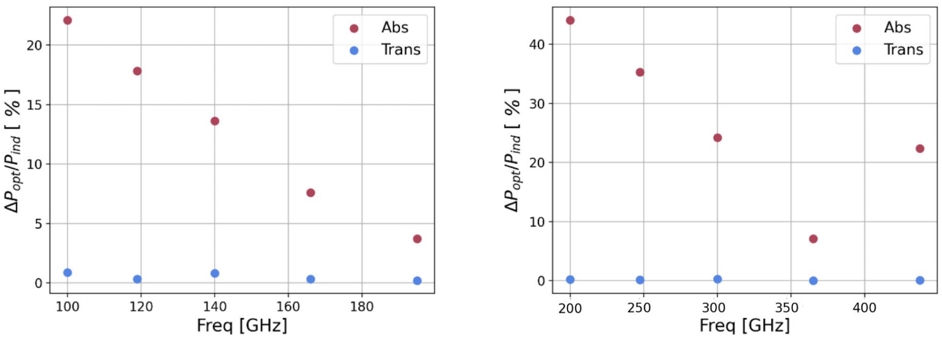
Pipeline described in Micheli+2024

- We build our timeline including HWPSS from differential emission at $2f_{HWP}$

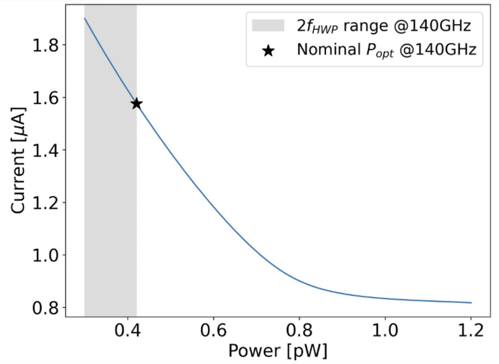
- We model TES non-linearity as a second order gain correction:

$$\boxed{d_{NL}(t) = [1 + g_1 d(t)]d(t)}$$

- TES non-linearity up-modulates the $2f_{HWP}$ signal resulting in a I → $4f_{HWP}$ leakage



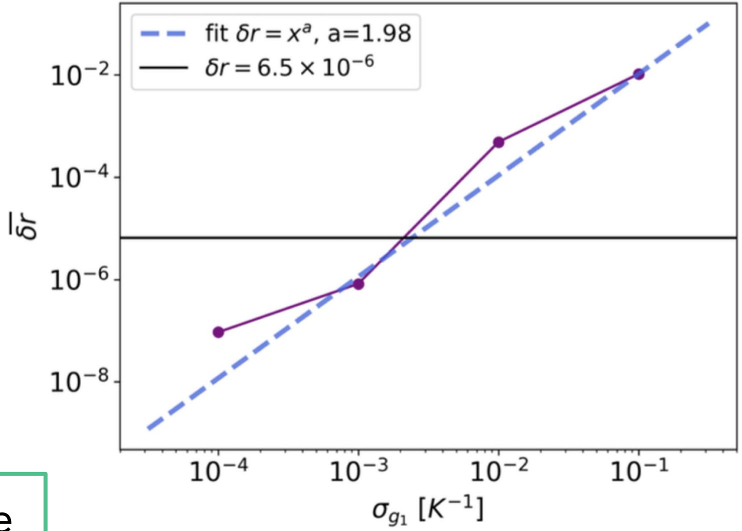
Relative optical power variation in MHFT channels with 20K HWP (baseline config)



Non-linearity knowledge requirement for MHFT

- We chose to fix the HWPSS amplitude (as in the baseline configuration) to find the acceptable non-linearity residual
- We apply a non-linear gain for a pair of orthogonal detectors in each MHFT channel with:

$$d^i_{NL}(t) = d^i(t)[1 + \mathcal{N}(0,\, \sigma_{g_1})]$$



We show that it is crucial to properly account for the coupling between HWP differential emission and TES non-linearity in order not to bias the estimation of *r*

Conclusions

- Modelization and injection of HWPSS and non-linearity in the time streams → done
- Propagation up to the estimation of the bias on r to derive non-linearity knowledge requirement → done for baseline configuration
- Modelling of TES non-linearity for LiteBIRD → done in de Haan+24
- Optimization of HWP design to minimize the impact of HWPSS from differential optical properties → ongoing

Thank you!

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