Gain Calibration for LiteBIRD detectors

23/05/2023

Workshop LiteBIRD-Italia 2023 @ INFN-LNF

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- In order to have an accurate detection of ***r*** we must be able to correctly convert the signal measured by the detectors from μA to K_{CMB}
  - ➔ Strict requirements on Gain calibration

Requirements by Ghigna et al.

Band (GHz)	$\Delta_{g,\gamma}$	$\delta_{g,\gamma}$
40	2.5×10^{-3}	2.0×10^{-2}
50	7.5×10^{-3}	6.0×10^{-2}
60	7.5×10^{-3}	6.0×10^{-2}
68	7.5×10^{-3}	10.8×10^{-2}
78	1.0×10^{-2}	14.4×10^{-2}
89	5.0×10^{-3}	7.2×10^{-2}
100	1.0×10^{-3}	2.3×10^{-2}
119	1.0×10^{-3}	2.5×10^{-2}
140	2.5×10^{-3}	5.7×10^{-2}
166	7.5×10^{-4}	1.6×10^{-2}
195	2.5×10^{-4}	0.6×10^{-2}
235	5.0×10^{-4}	0.8×10^{-2}
280	1.0×10^{-3}	1.6×10^{-2}
337	1.0×10^{-4}	0.16×10^{-2}
402	1.0×10^{-4}	0.18×10^{-2}

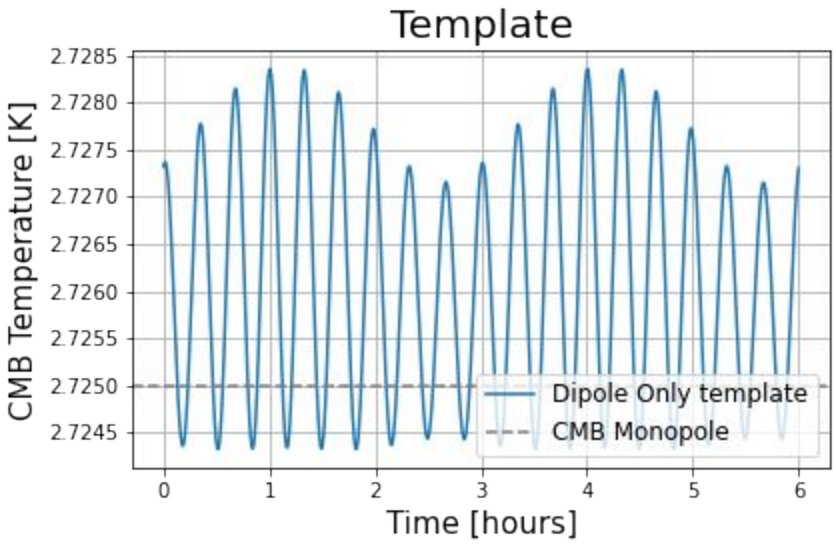
Table 2: A summary of the requirements in terms of the overall frequency bands ($\Delta_{g,\gamma}$), and per detector ($\delta_{g,\gamma}$) assuming the number of detectors in Table 1.

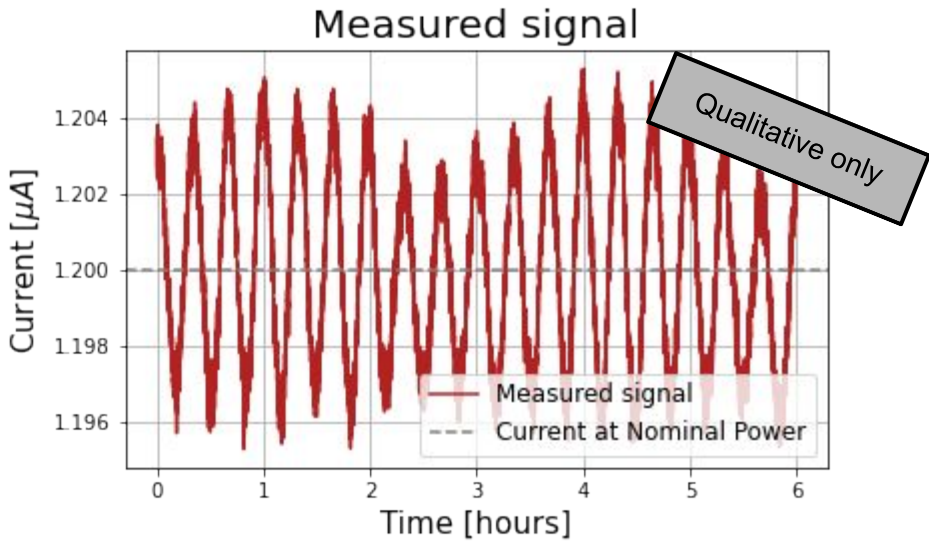
Revisited by F. Carralot

12:05 PM **gain requirements with component separation**

Speaker: Florie Carralot

- We calibrate the gain of the detectors by comparing the measured timelines with a template of the expected signal.





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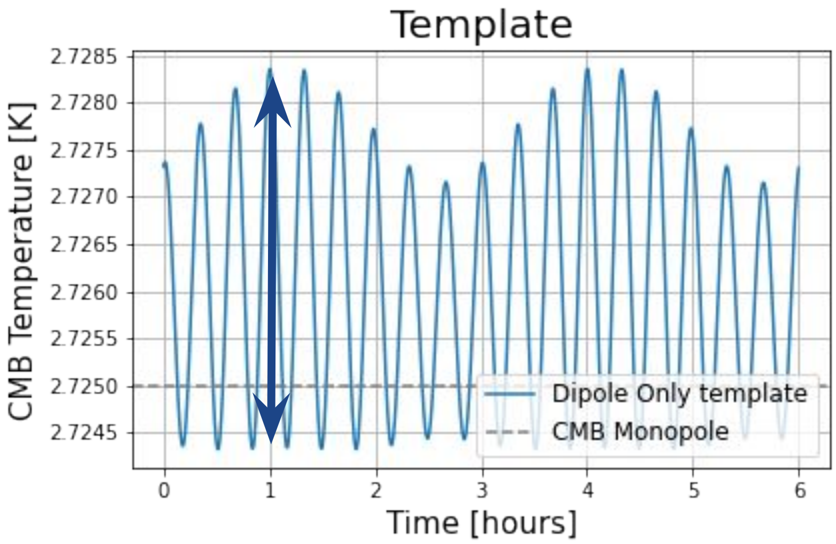
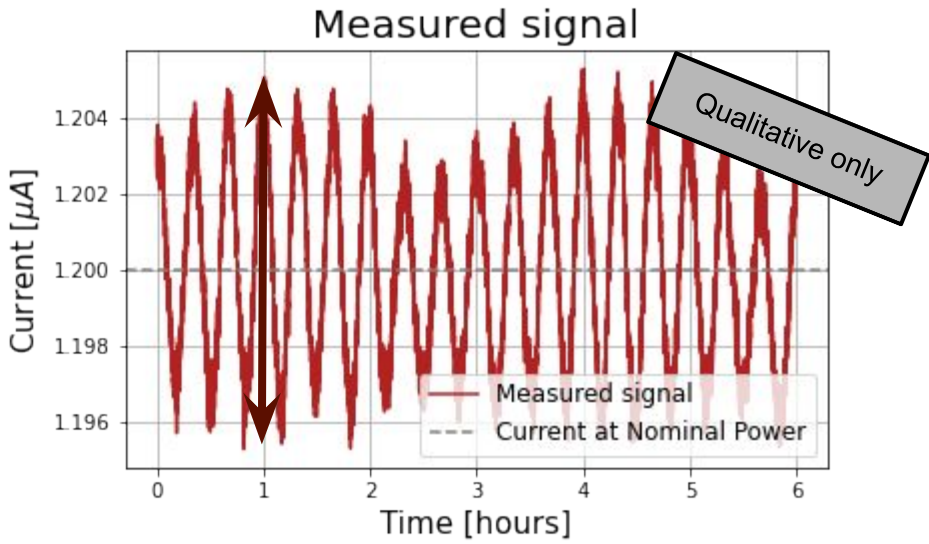




Oversimplification

$$g = \frac{\Delta I}{\Delta T}$$

By comparing the amplitude of the oscillations of the measured signal with the expected dipole signal we can obtain the gain of the detector

- More precisely we can model:
  - Data: $d(t) = g\,(\,m(t) + n(t)\,)$
  - Template: $m_0(t)$
  - Noise: $n(t)$

- The integral formula used to estimate the gain is:

$$\tilde{g} = \frac{\int d(t)\, m_0(t)\, dt}{\int m_0(t)^2\, dt} \approx g\left(1 + \frac{\int n(t)\, m_0(t)\, dt}{\int m_0(t)^2\, dt}\right)$$

- Which means our error on gain calibration is:

$$\delta g = \underbrace{\frac{\int n(t)\, m(t)\, dt}{\int m(t)^2\, dt}}_{\text{Time Domain}} = \underbrace{\frac{\sum_f M(f) N(f)^*}{\sum_f |M(f)|^2}}_{\text{Fourier Domain}}$$

- Things to Notice:

  ★ 1

  If our calibration signal goes to 0 the calibration error diverges.

$$\delta g = \underbrace{\frac{\int n(t)\, m(t)\, dt}{\int m(t)^2\, dt}}_{\text{Time Domain}} = \underbrace{\frac{\sum_f M(f) N(f)^*}{\sum_f |M(f)|^2}}_{\text{Fourier Domain}}$$

  It is therefore better to filter out the frequencies where we have low S/N

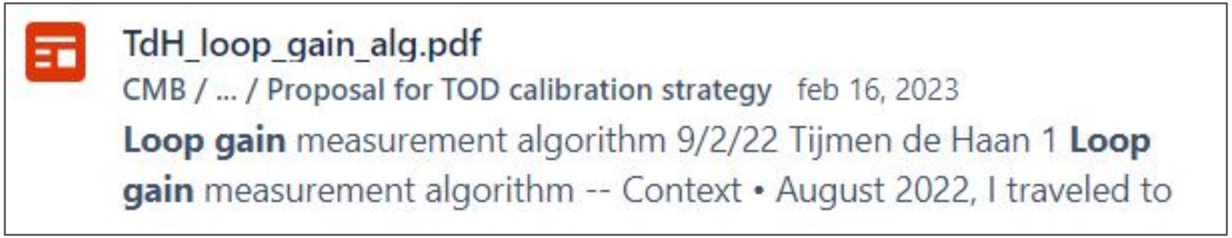
  ➔ It is possible to find analytically the **optimal filter**:

$$\mathbf{F}^{\mathrm{opt}}{}_i = \frac{1}{\mathbf{N}_i} \frac{1}{\sqrt{\sum_i \mathbf{M}_i / \mathbf{N}_i}}$$

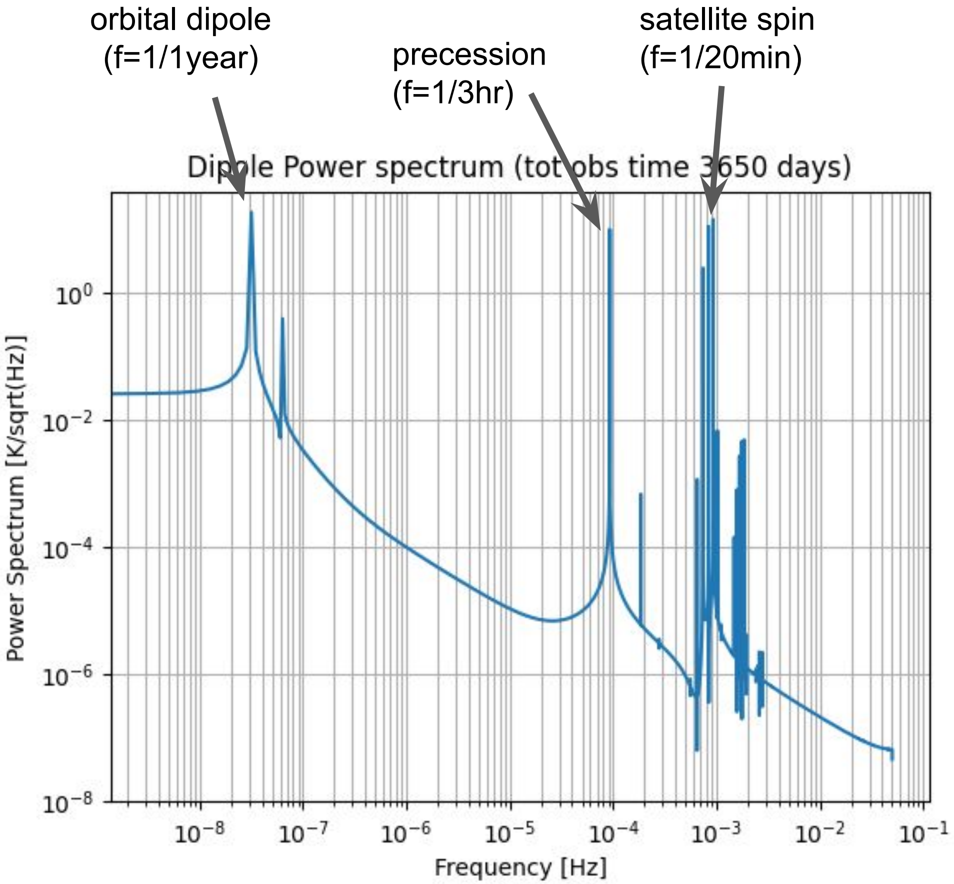
- Things to Notice:

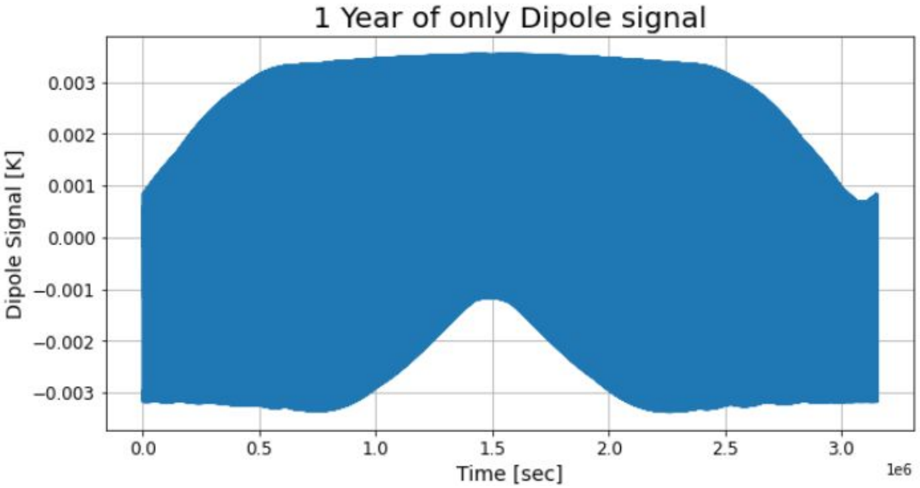
    - ★ 2
      We are assuming a constant gain during the integration time
      This is not true if we calibrate on longer timescales
      - ➔ Loop gain monitor proposed by Tijmen De Haan will be used to **record fluctuations of the gain**
      - ➔ We inject a sinusoidal bias into the TES and we use that signal to calibrate the gain

More information on:



Our main source of calibration: the Dipole signal





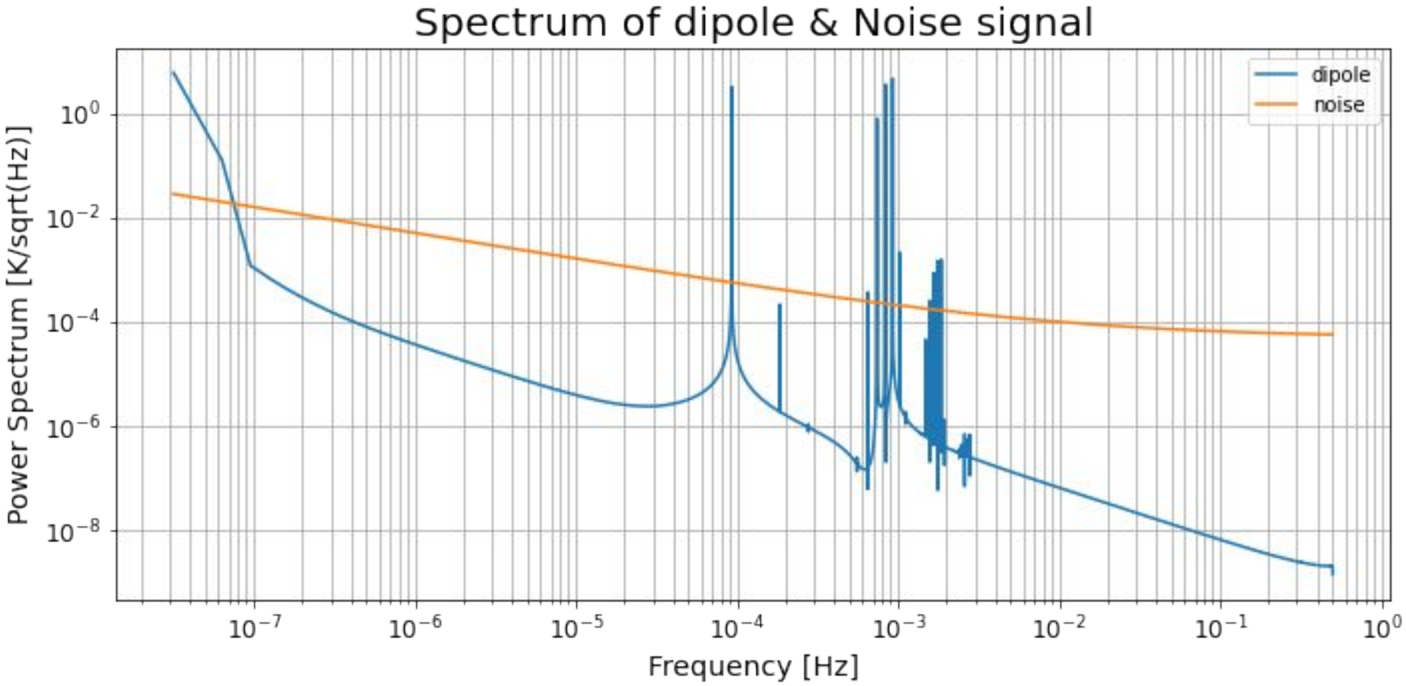
NOTE:
There are several parts of the spectrum where the dipole signal is very faint

Objective:

- I use TOAST / LB_SIM to simulate a detector’s TOD
- I generate multiple realizations of 1/f noise and find the f_K that matches the requirements by Tommaso

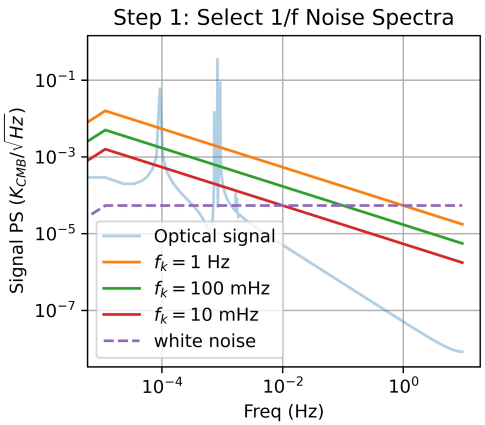
1/f Noise:

- NET 50 uK/sqrt(Hz)
- f_k= 10 mHz

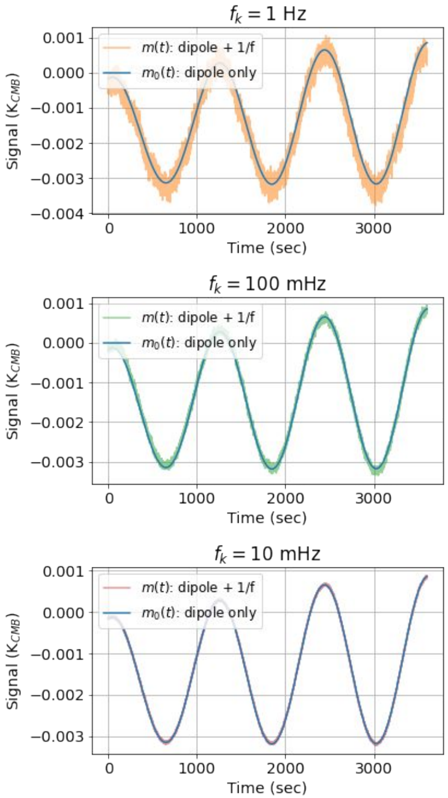


1/f Noise - Monte Carlo Simulations

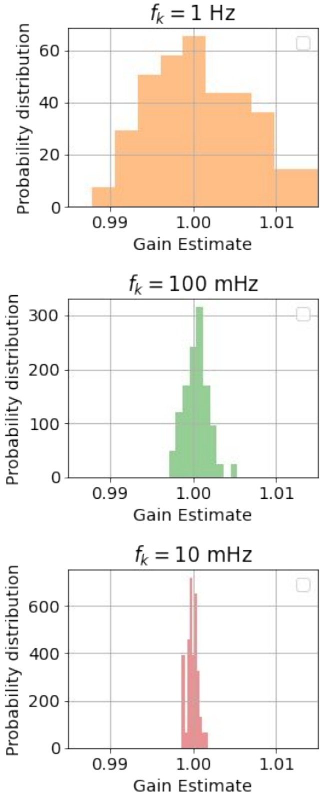
- Noise with different values of f_K



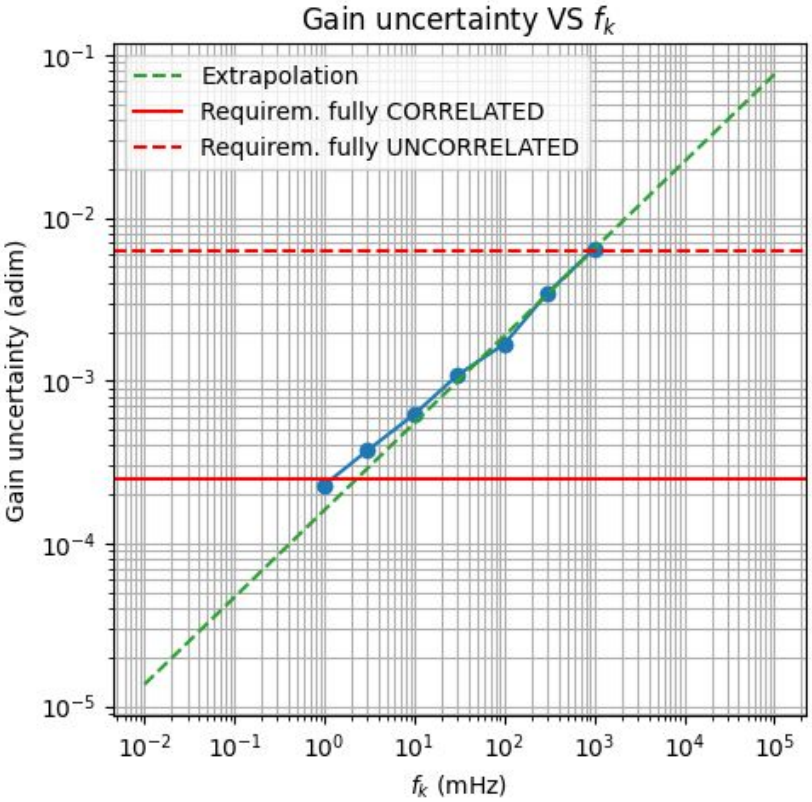
- Simulate TOD



- Calculate Uncertainty on our gain estimate



How to extract a requirement for calibration every 24 hrs



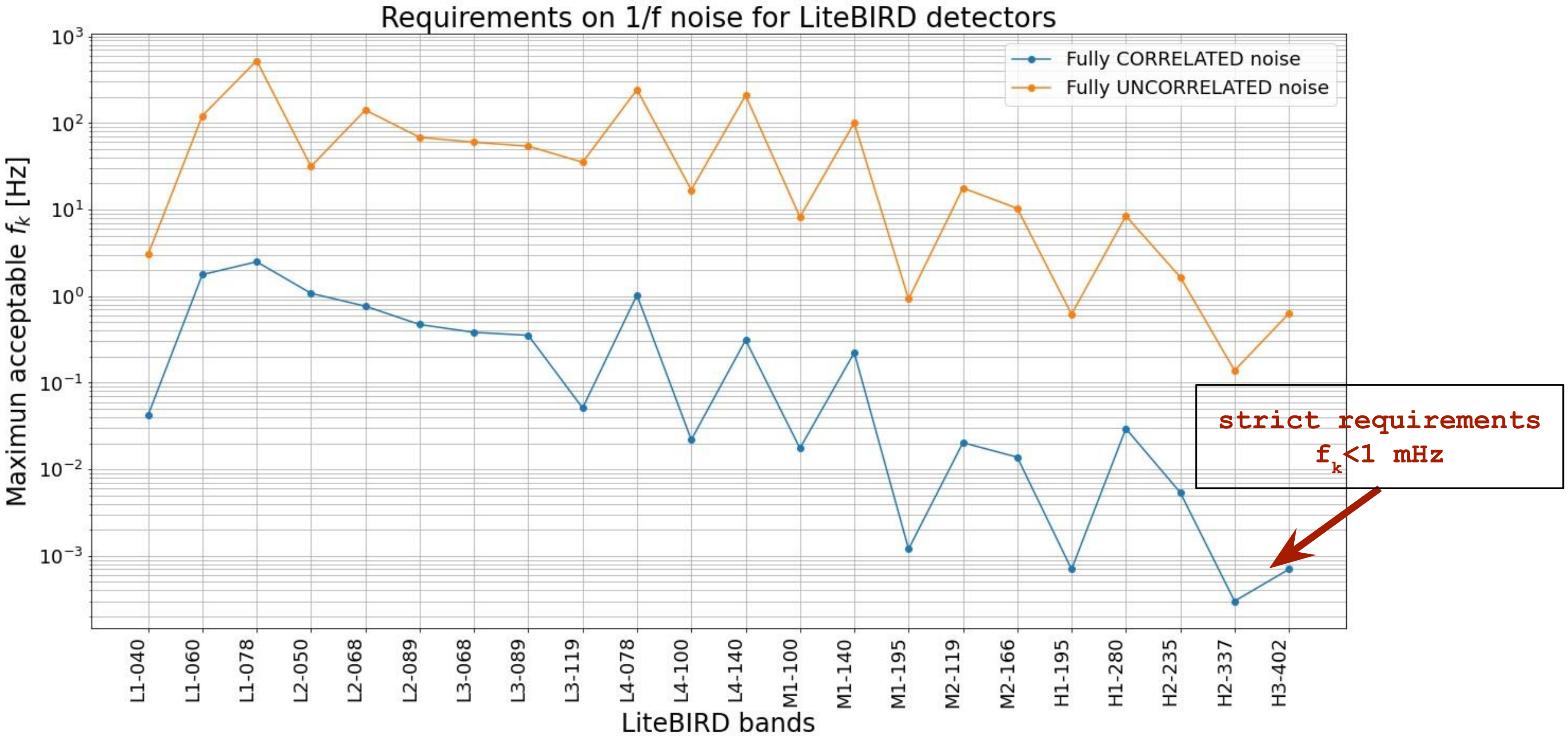
Maximum gain uncertainty if the noise is UNCORRELATED between detectors

(c=0)

Maximum gain uncertainty if the noise is FULLY CORRELATED between detectors

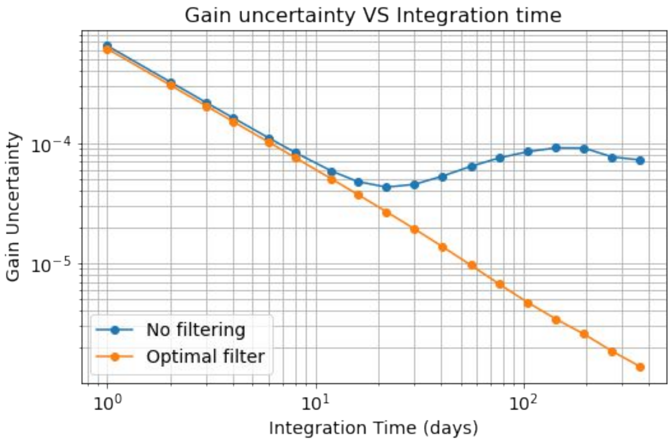
(c=1)

Requirements calibrating in 24 hours



Extrapolating requirements for a calibration every 6 months

We therefore have the following proportionalities:



Using the optimal filter:
(T: integration time)

$\delta g \propto 1/\sqrt{T}$

$$\delta g = \frac{\int n(t)\, m(t)\, dt}{\int m(t)^2\, dt} = \frac{\sum_f M(f) N(f)^*}{\sum_f |M(f)|^2}$$

Time Domain

Fourier Domain

For every frequency:
(ASD_N: Amplitude Spectral Density uK/sqrt(t))

$\delta g \propto ASD_N$

Too keep the same gain uncertainty calibrating in 6 months:

- $APS_{1D/6M;}$: acceptable Amplitude Spectral Density if we calibrate in 1 day / 6 months
- We are **assuming α=1** in the 1/f

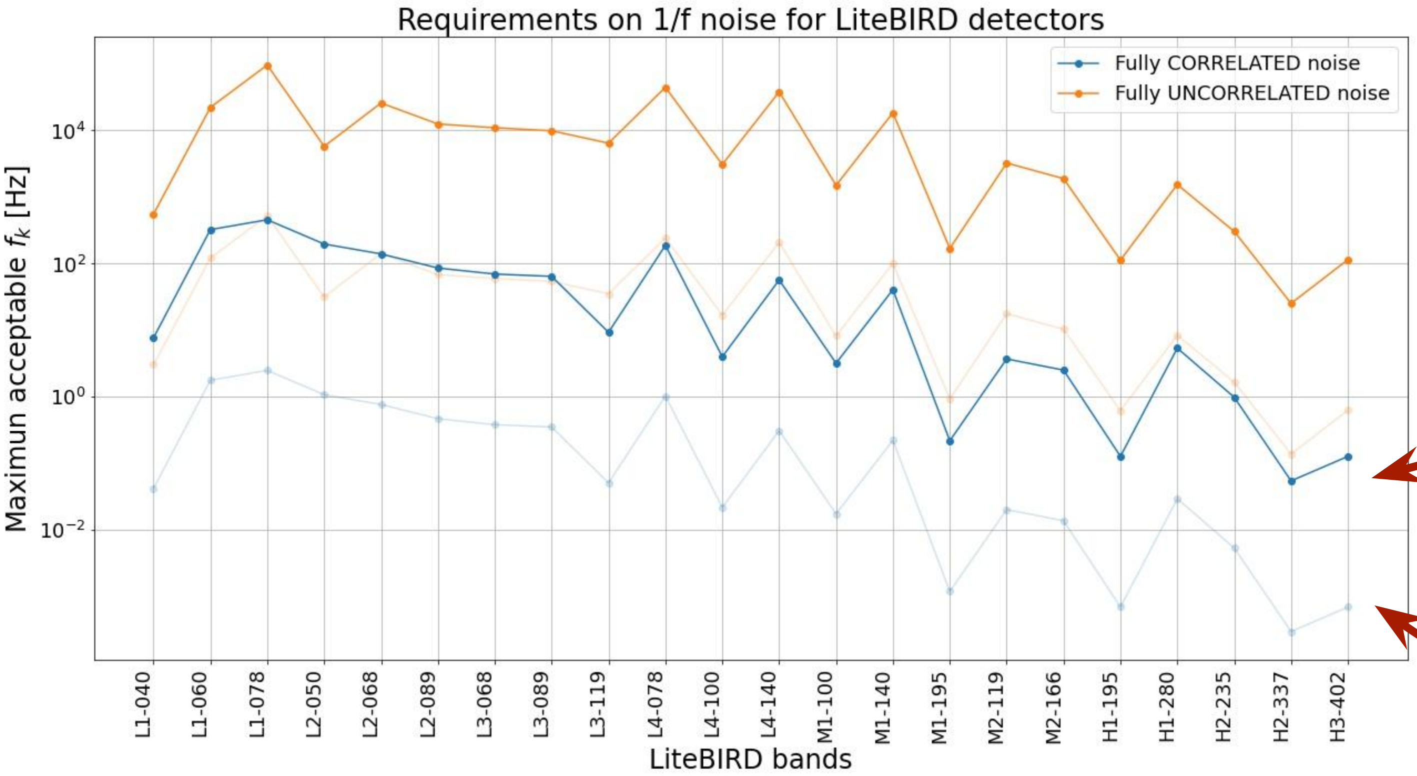
$$APS_{1D} \frac{1}{\sqrt{1\,day}} = APS_{6M} \frac{1}{\sqrt{6\,months}}$$

$$A\left(\frac{f_k^{1D}}{f}\right)^{\frac{1}{2}} \frac{1}{\sqrt{1\,day}} = A\left(\frac{f_k^{6M}}{f}\right)^{\frac{1}{2}} \frac{1}{\sqrt{6\,months}}$$

$$f_k^{1D}\,365/2 = f_k^{6M}$$

We can rescale the requirements on f_K by the number of days we use to calibrate the gain

Requirements calibrating in 6 months



6 month requirements
f_k<50 mHz
(EASIER TO ACHIEVE)

24 hrs requirements
f_k<1 mHz