HWP differential optical load and non-linearity

23/05/2023 Workshop LiteBIRD-Italia 2023 @ INFN-LNF

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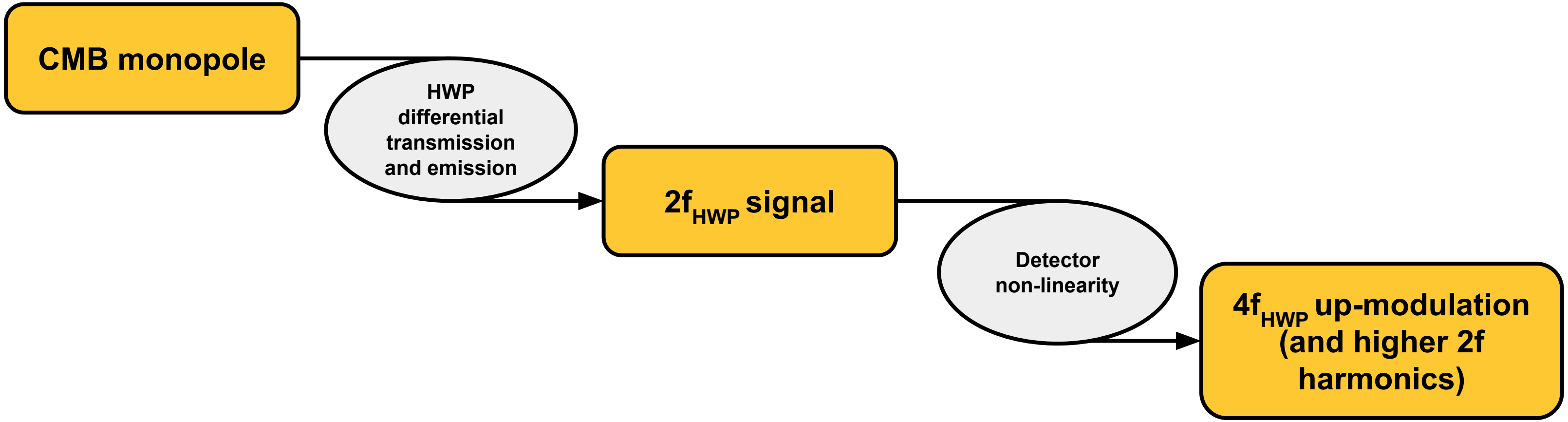
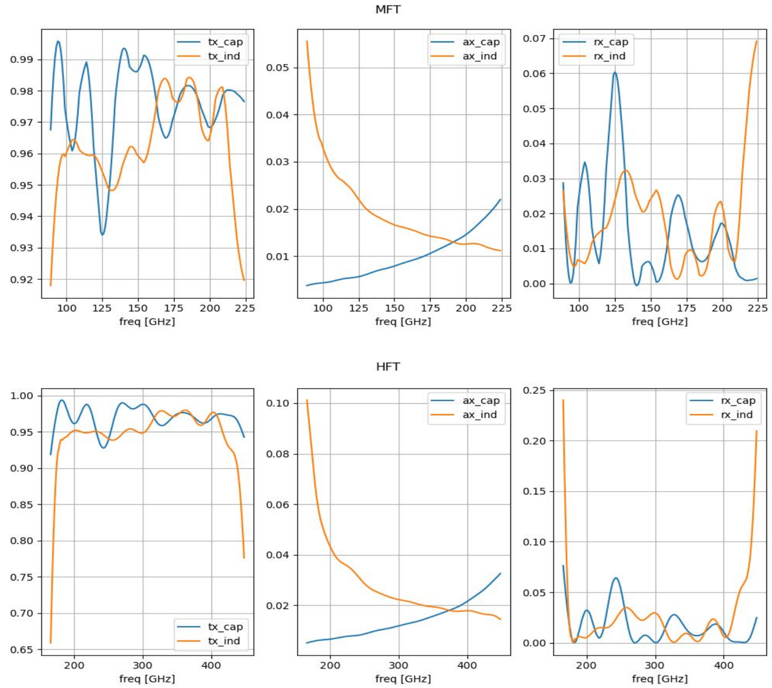
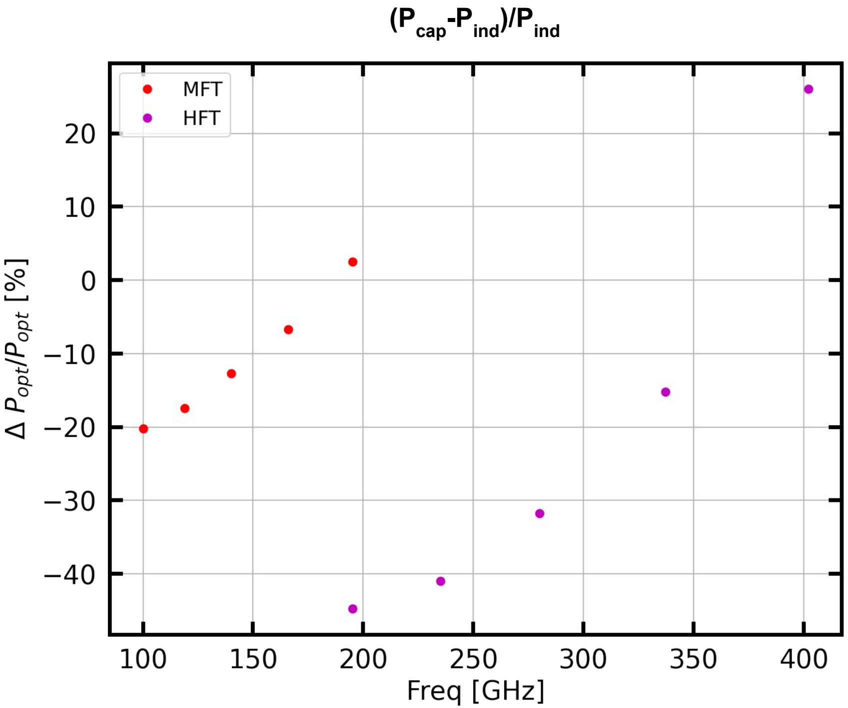


- We calculate how much Popt variation is expected in each band due to HWP differential emissivity and transmission
- We simulate how the TES non-linearity up-modulates the $2f_{HWP}$ signal resulting in a $I \rightarrow 4f_{HWP}$ leakage
- We implement a simplified model to measure and remove the non-linearity

- Nominal power values → worse value in each band for a conservative estimation (inductive axis, except for 195 GHz and 402 GHz bands)
- Band-averaged estimation
- MHFT optical power variation wrt nominal values, due to HWP **differential transmittance and emissivity**

from Giampaolo Pisano data





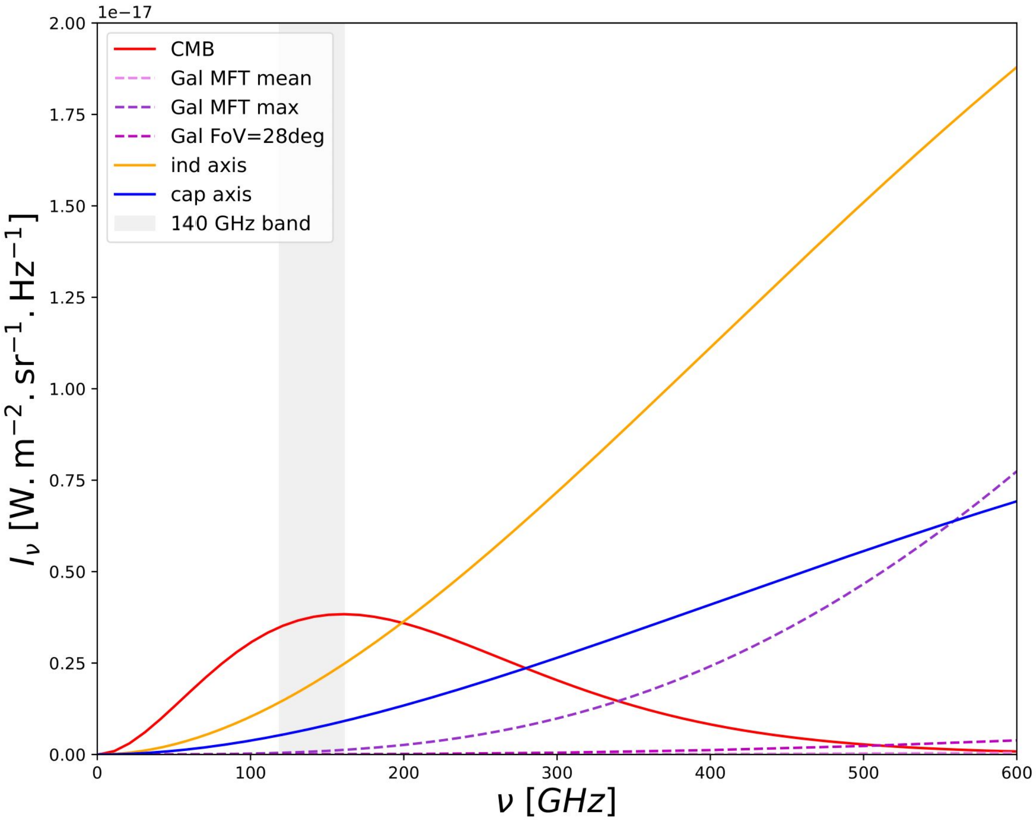
Example: HWP differential emission @140 GHz compared with galactic emission

$$I_\nu^{ind} = BB(\nu, 20K) \cdot \epsilon_{140}^{ind}$$

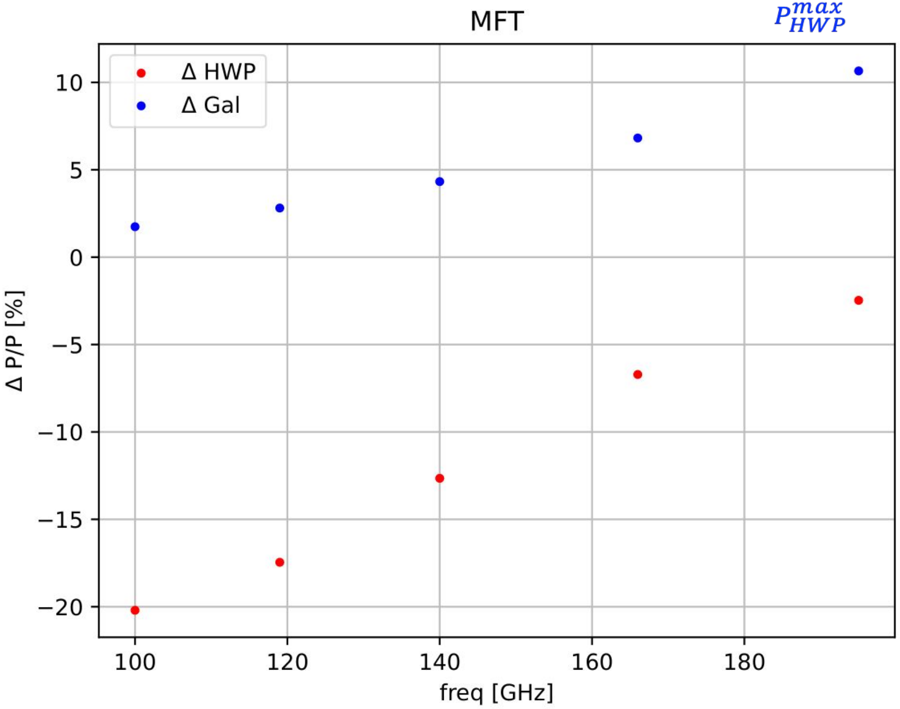
$$I_\nu^{cap} = BB(\nu, 20K) \cdot \epsilon_{140}^{cap}$$

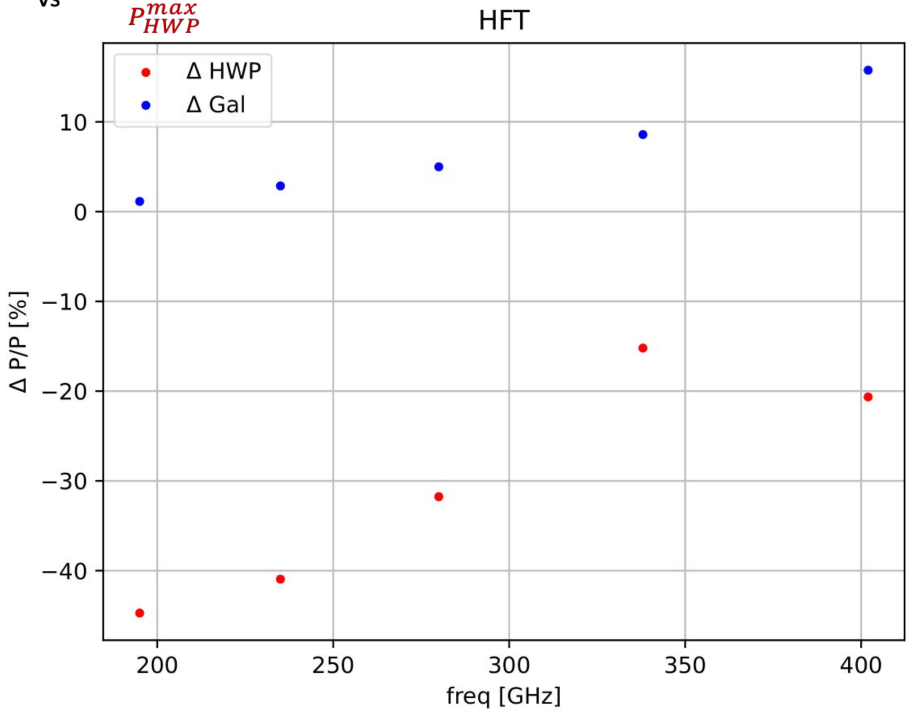
$$\epsilon_{140}^{cap} = 0.007$$

$$\epsilon_{140}^{ind} = 0.019$$



$$\frac{\left(P_{gal}^{max}+P_{HWP}^{max}\right)-P_{HWP}^{max}}{P_{HWP}^{max}} \quad \text{vs} \quad \frac{P_{HWP}^{min}-P_{HWP}^{max}}{P_{HWP}^{max}}$$





- Differential emissivity causes a loss of power wrt the nominal power in each band
- In most bands $\%\Delta P_{HWP} > \%\Delta P_{GAL}$
- **Signal from the sky is modulated by a $2f_{HWP}$ signal with amplitude ΔP_{HWP}**

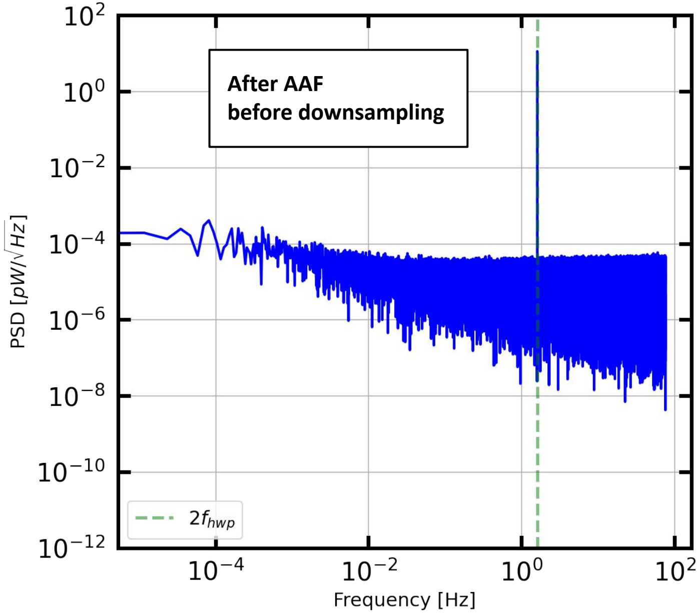
Input signal simulation

nside = 1024 ; smoothing fwhm=0.5 deg, 24 h obs

CMBpol @140 GHz + $2f_{HWP}$ + 1/f noise; no fg

Anti-aliasing filter has been applied:

sample_rate = 152 Hz
duration = 3600*24 s
q = 8 (downsampling factor to be applied later)



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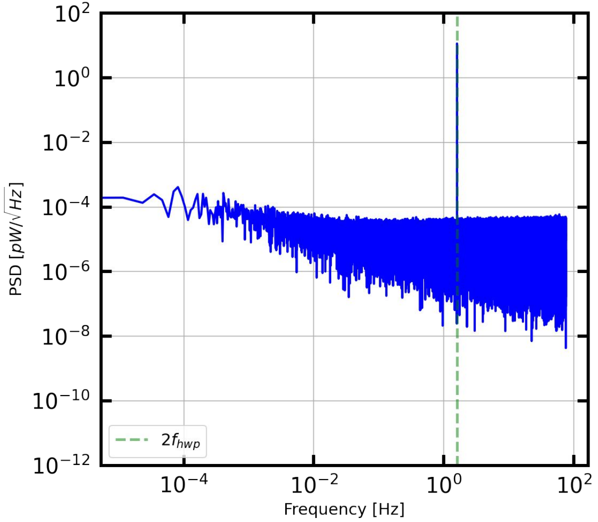
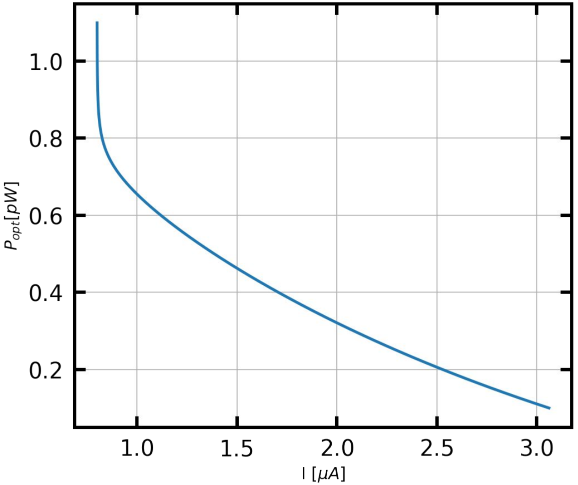


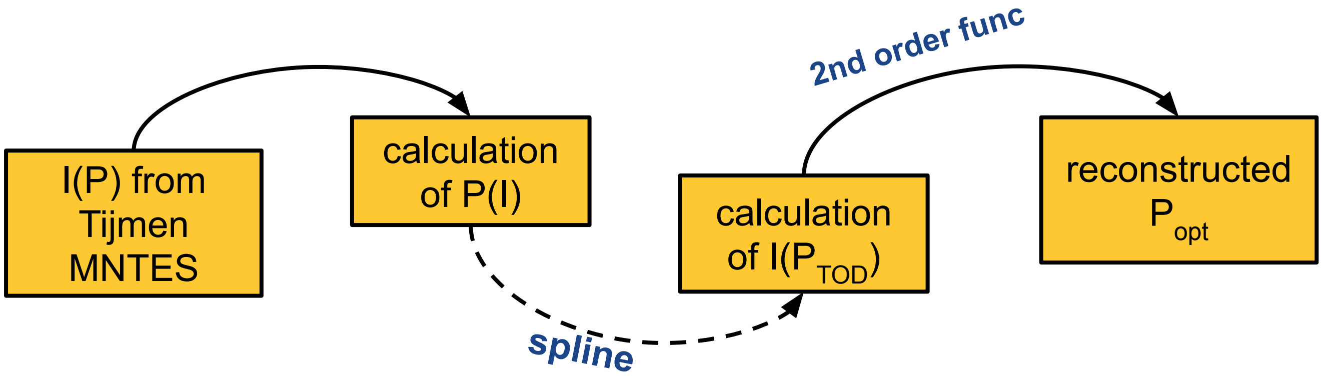
Modeling I(P) from Tijmen code (MNTES)

```
'Voltage bias': 8e-07,
'T_c': 0.18,
'transition_width': 0.002,
'R_normal': 1.0,
'T_bath': 0.1,
'z_series': (0.1+0j),
'n_index': 3.6,
'tau_intrinsic': 0.033,
'V_bias': 8e-07}
```

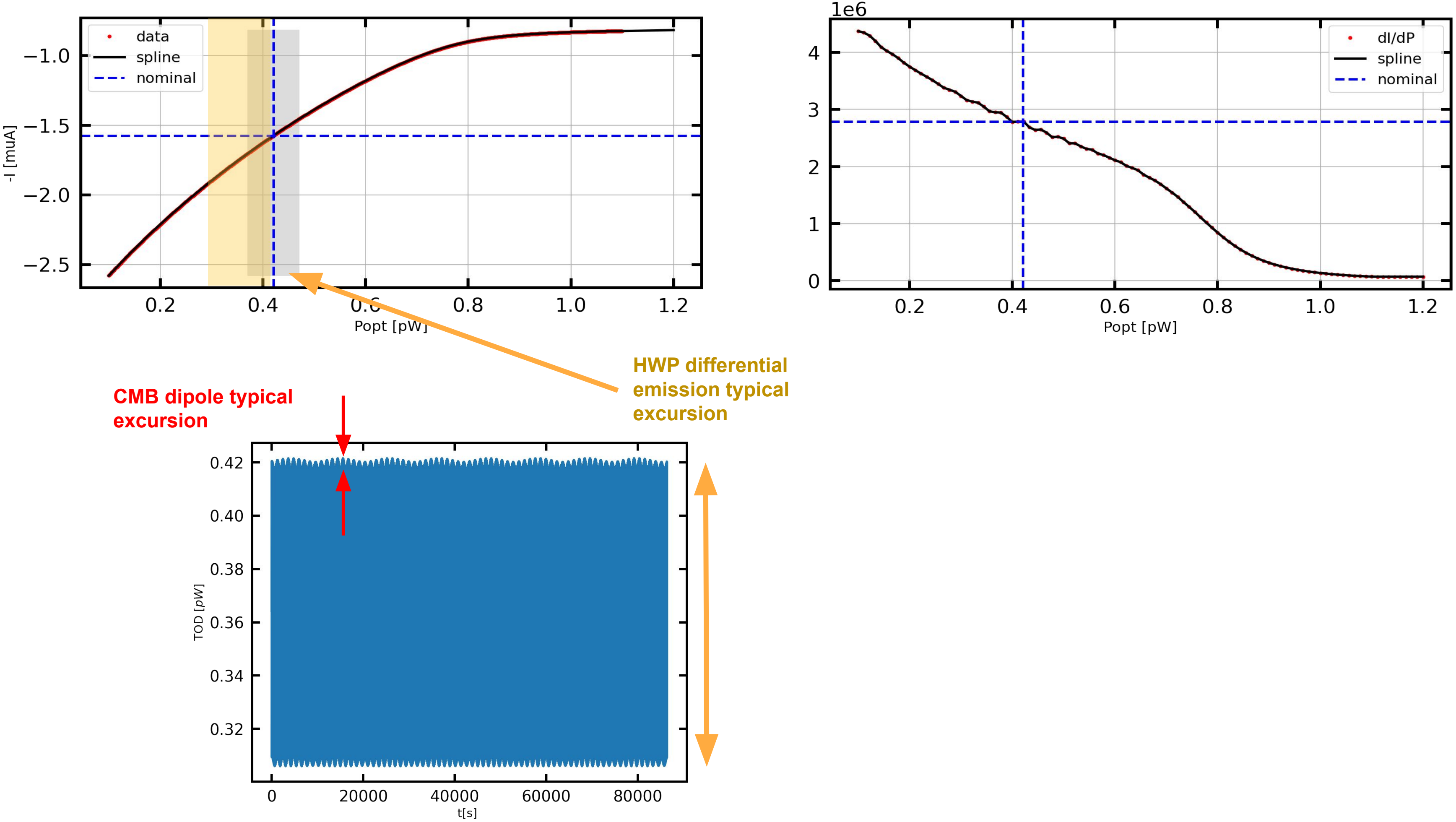


Scheme of the implementation

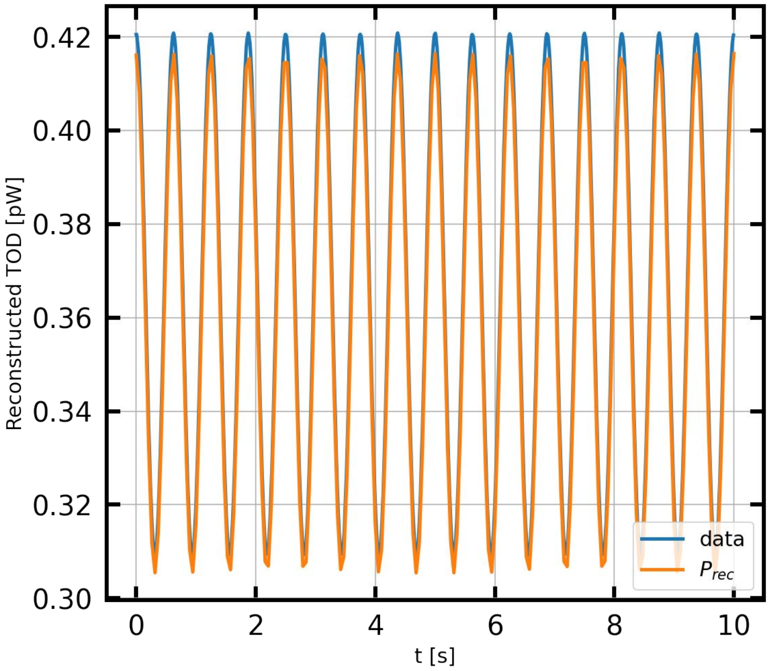
Simulations: TOAST/litebird_sim



(1) - Modeling I(P) from Tijmen code (MNTES)

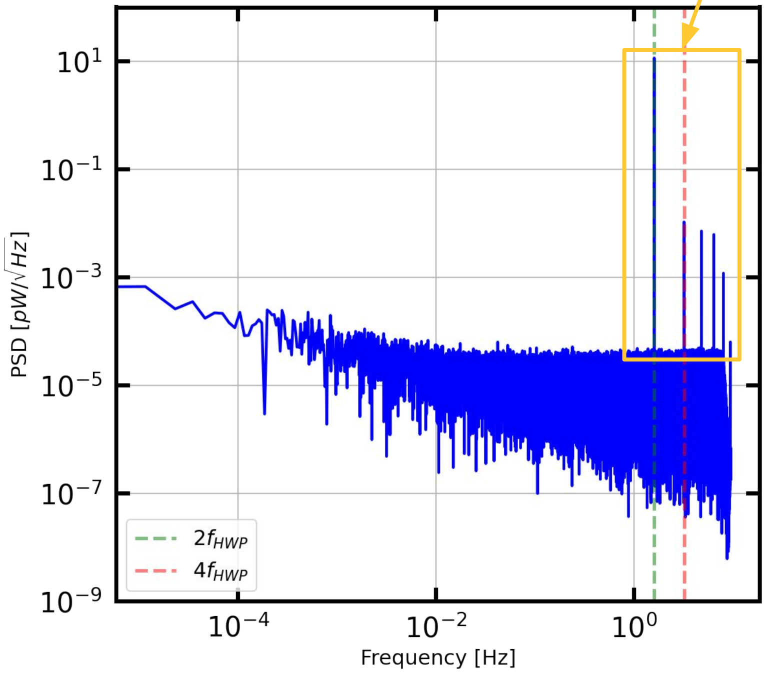


(2) - I(P) is calculated in the P range using (1) spline



TES non linearity
causes 2f → 4f leakage

2f harmonics

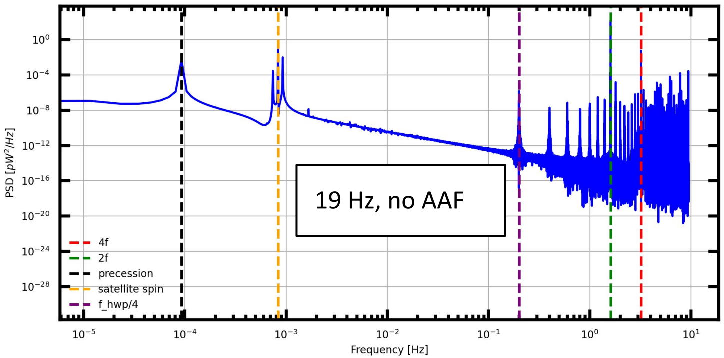


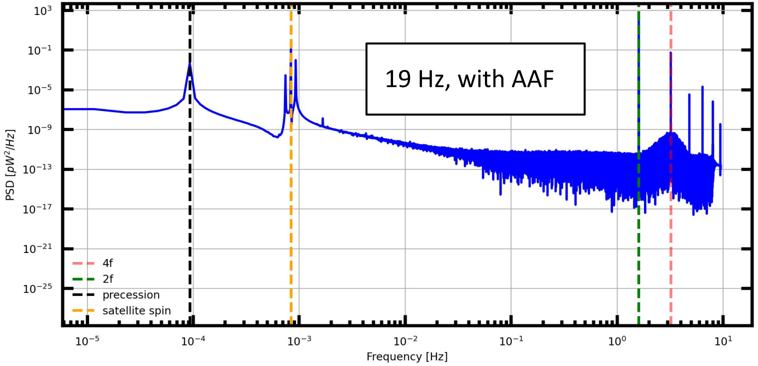
IMPORTANT NOTE FOR SIMULATIONS

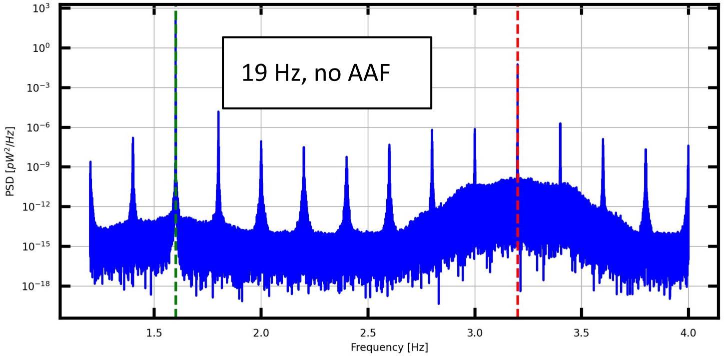
If we simulate at 19 Hz we see a lot of aliased signal!

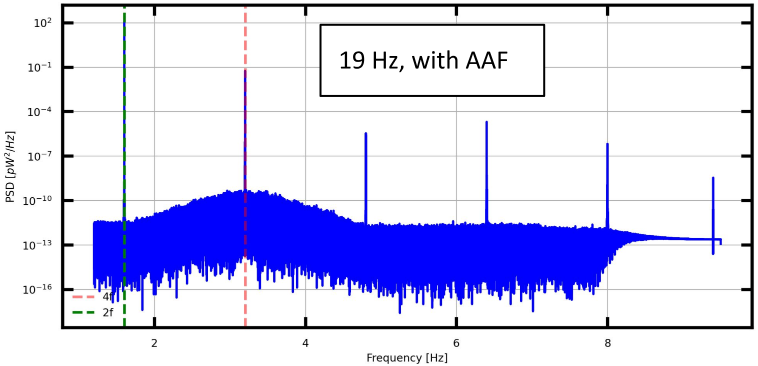
Correct procedure (as in the on-board computer):

- simulation at 152 Hz (20MHz/2^17)
- anti-aliasing filter
- downsampling by a factor 8

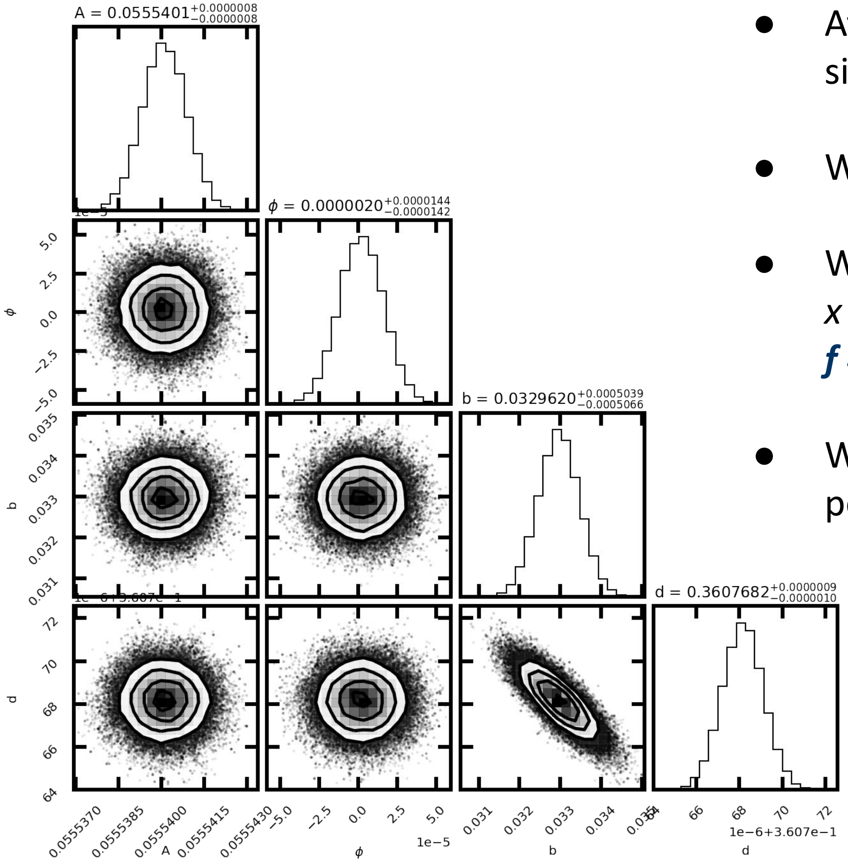








Fitting NL parameters



- At this step we <u>did not include the dipole</u> in the simulation to simplify the analysis
- We simulate a 24 h observation
- We parametrize the HWP signal + NL through <u>4 parameters</u> as:
  $x = A\cos(2\omega t+\phi)$
  $\boldsymbol{f = x + bx^2 + d}$ *(quadratic approximation of the NL)*
- We run a MCMC to find the best fit of the reconstructed power

$\sigma_A = 8\cdot10^{-7}$ pW
$\sigma_\phi = 0.05$ arcmin ← very low uncertainty !
$\sigma_b = 5\cdot10^{-4}$ pW^{-1}
$\sigma_d = 9\cdot10^{-7}$ pW

Correction of the NL:
(3) - P is reconstructed using a quadratic model function

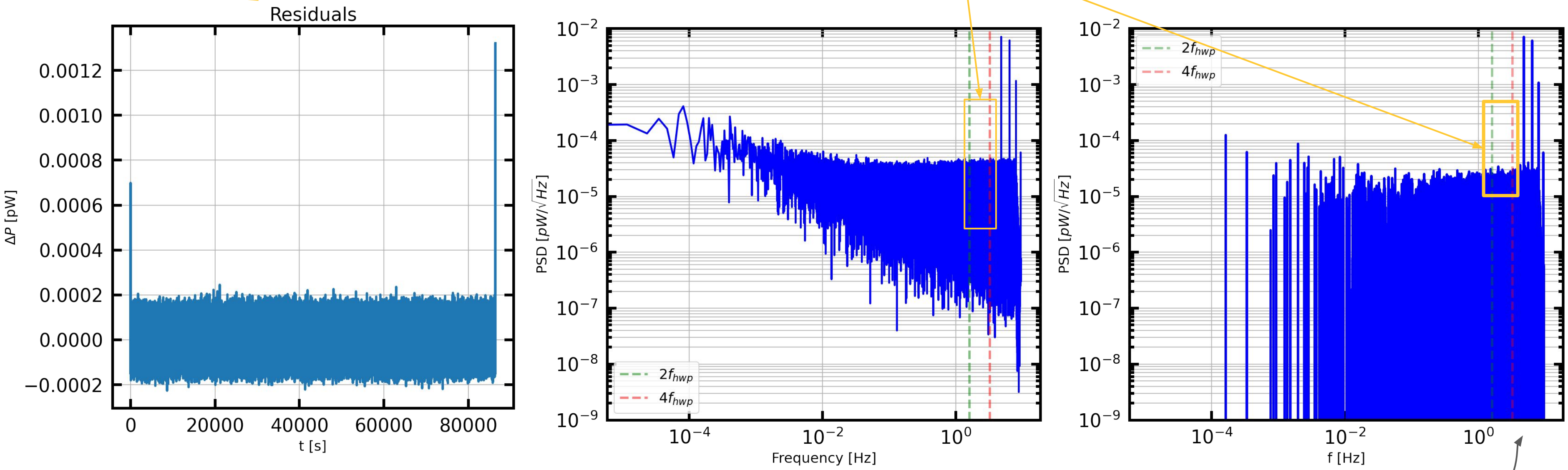
$$x_{rec} = \frac{-1+\sqrt{1-4\tilde{b}(\tilde{d}-P_{rec})}}{2\tilde{b}}$$

$$\tilde{x} = \tilde{A}cos(2\omega t + \tilde{\phi})$$

$$\tilde{x} - x_{rec}$$

2f and 4f harmonics have been removed

1/f noise spectrum has been subracted

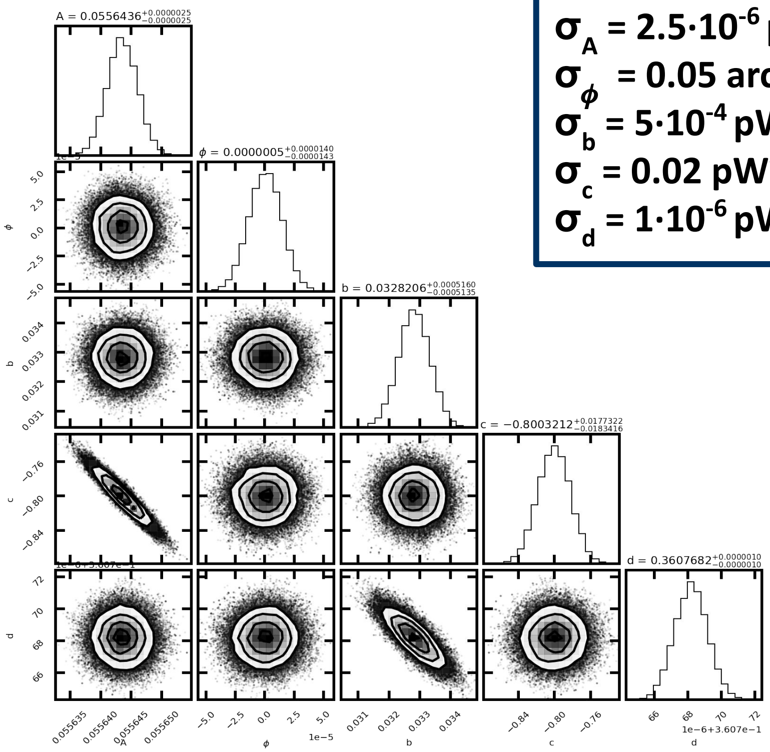


in principle a 3rd order model function should remove the 6f harmonic peak, and so on

In fact, if we apply the same procedure with a **third order model function** we eventually obtain:

$x = A\cos(2\omega t+\phi)$

$f = x + bx^2 + cx^3 + d$



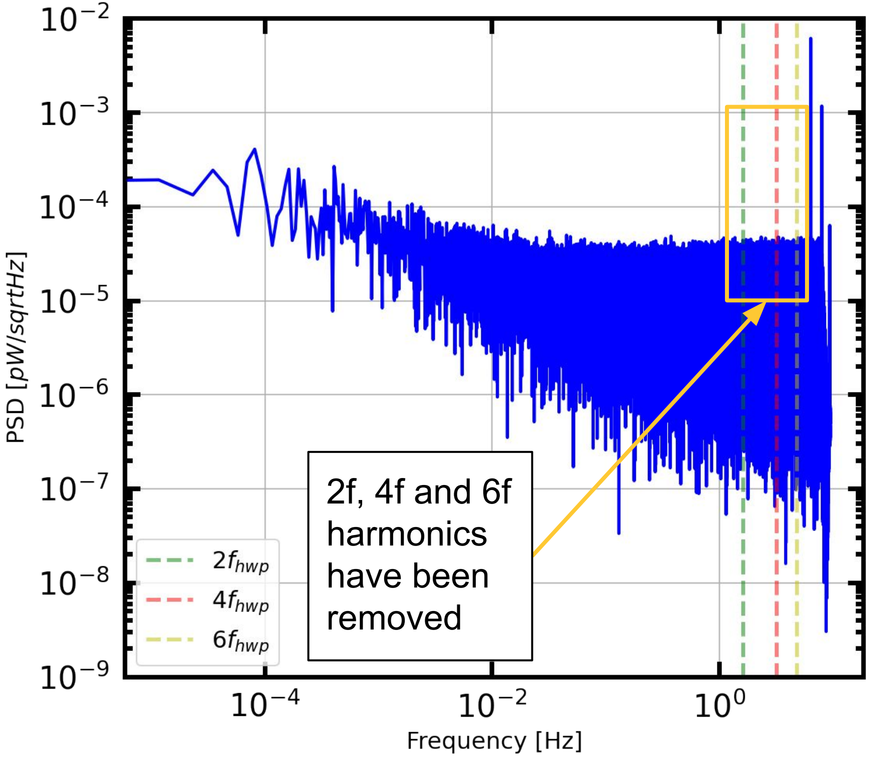
$\sigma_A = 2.5\cdot10^{-6}$ pW

$\sigma_\phi = 0.05$ arcmin

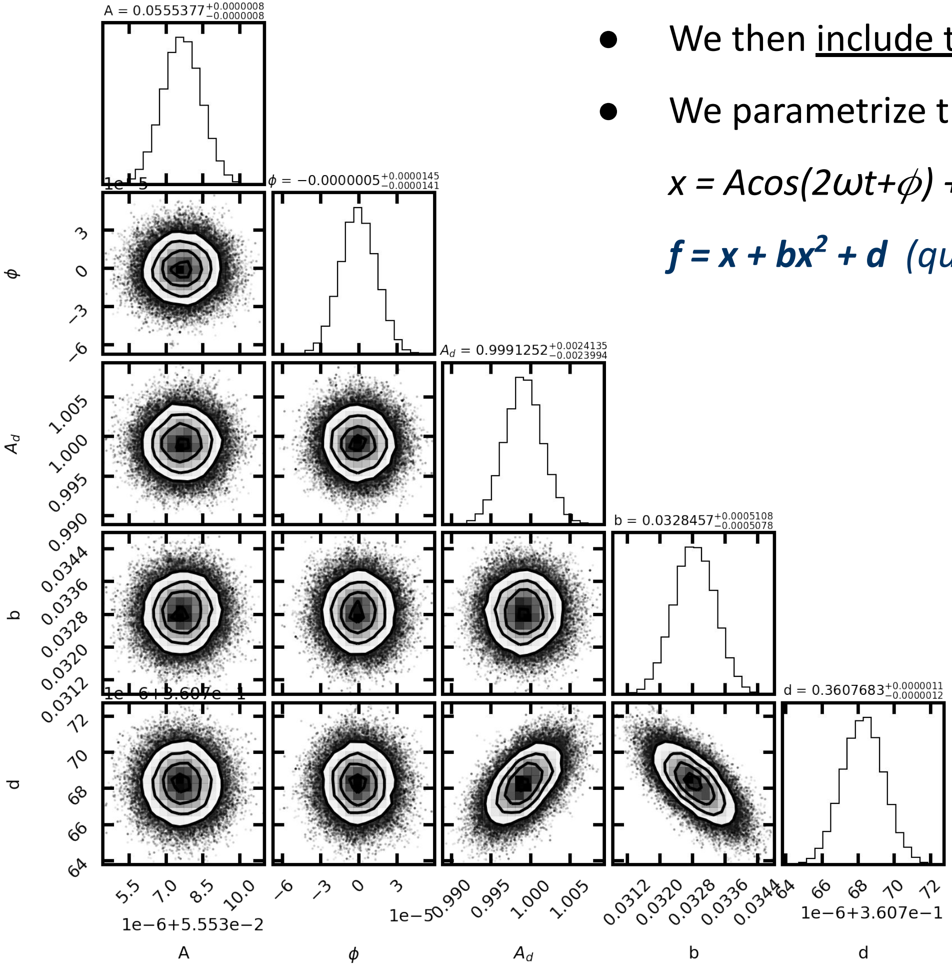
$\sigma_b = 5\cdot10^{-4}$ pW^{-1}

$\sigma_c = 0.02$ pW^{-2}

$\sigma_d = 1\cdot10^{-6}$ pW



Fitting NL parameters with the dipole



- We then <u>include the dipole</u> in the simulation
- We parametrize the HWP signal + dipole + NL through <u>5 parameters</u> as:

$x = A\cos(2\omega t+\phi) + A_d\, dip(t)$

$\boldsymbol{f = x + bx^2 + d}$ *(quadratic approximation of the NL)*

$\sigma_A = 8 \cdot 10^{-7}$ pW
$\sigma_\phi = 0.05$ arcmin
$\sigma_{Ad} = 2 \cdot 10^{-3}$
$\sigma_b = 5 \cdot 10^{-4}$ pW^{-1}
$\sigma_d = 9 \cdot 10^{-7}$ pW

Summary

- We estimate the power variation due to HWP differential emissivity and transmission (up to 44%)
- We include the $2f_{HWP}$ signal in the simulated input signal
- We apply the Tijmen model for TES non-linearity (MNTES) to this total signal
- We fit a quadratic approximation of the MNTES on the $2f_{HWP}$ signal
  - to be assessed if the procedure is affected by other $4f_{HWP}$ effects
  - σ_{ϕ} = 0.05 arcmin
- We correct the $I \rightarrow 4f_{HWP}$ leakage due to detector non-linearity
  - $4f_{HWP}$ residual < white noise level
- <u>On going</u>: maps in presence of detector non-linearity