Lessons learned from Planck

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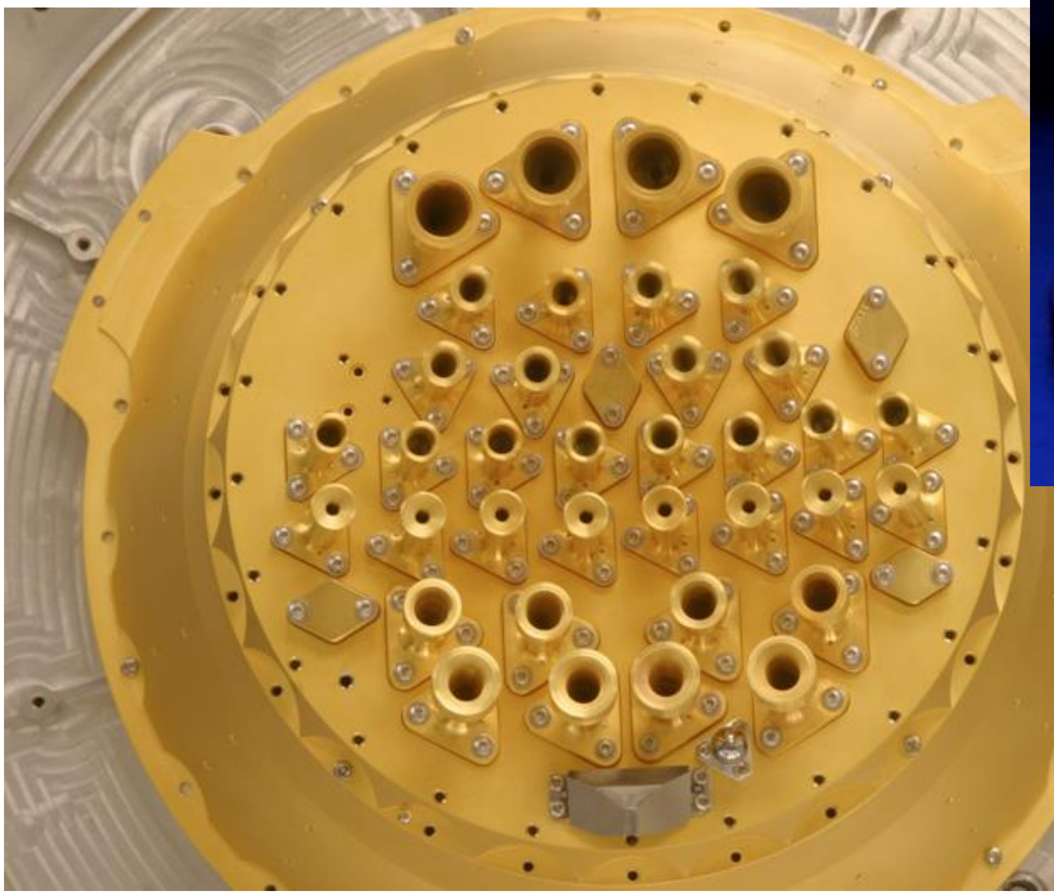
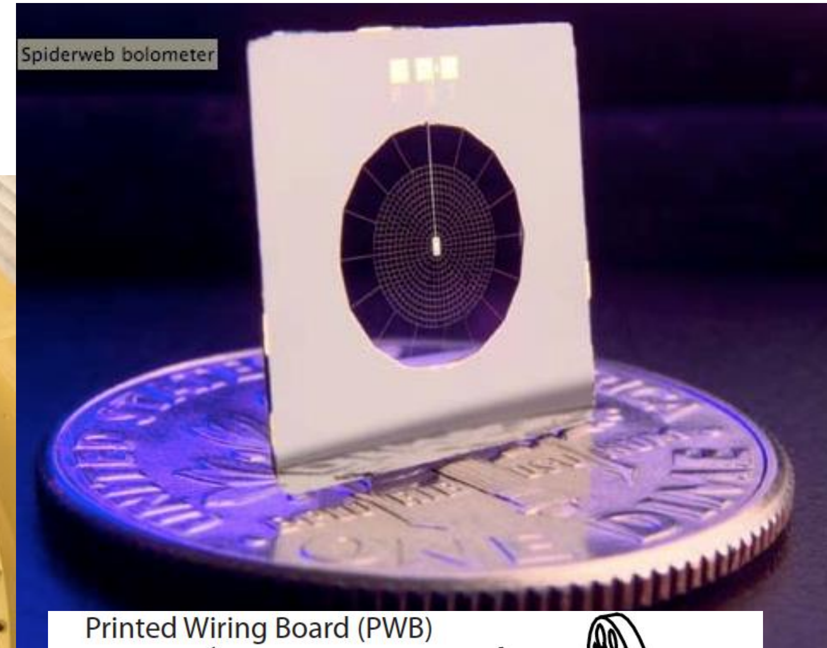
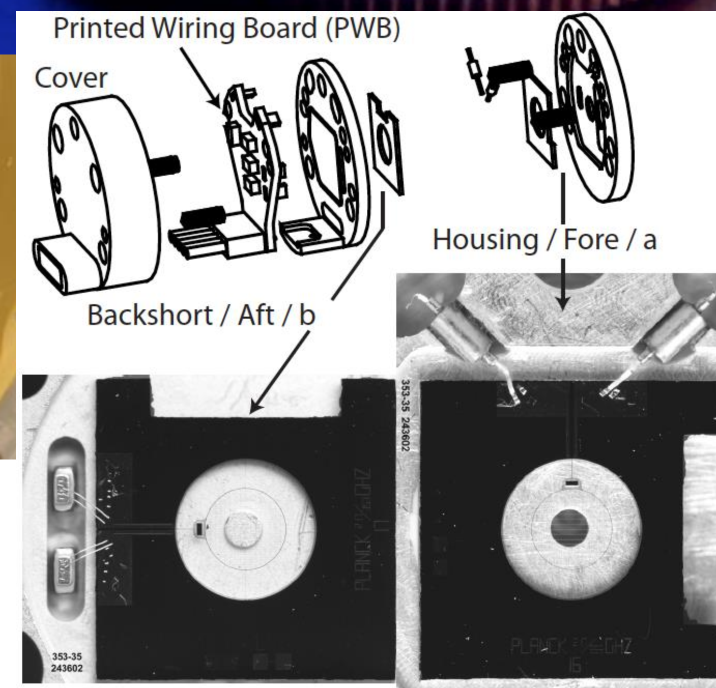
For the Planck Collaboration

HFI focal plane







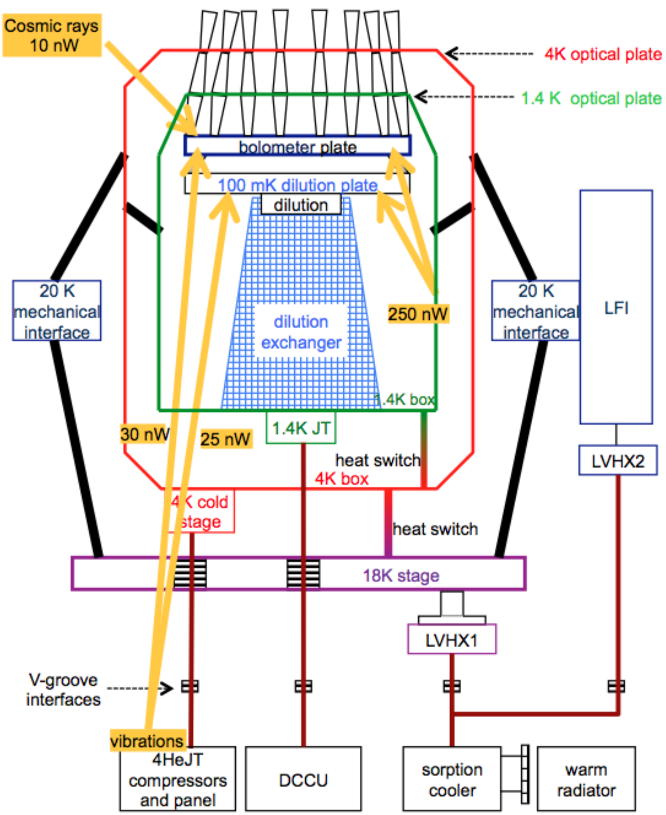
Thermal stability

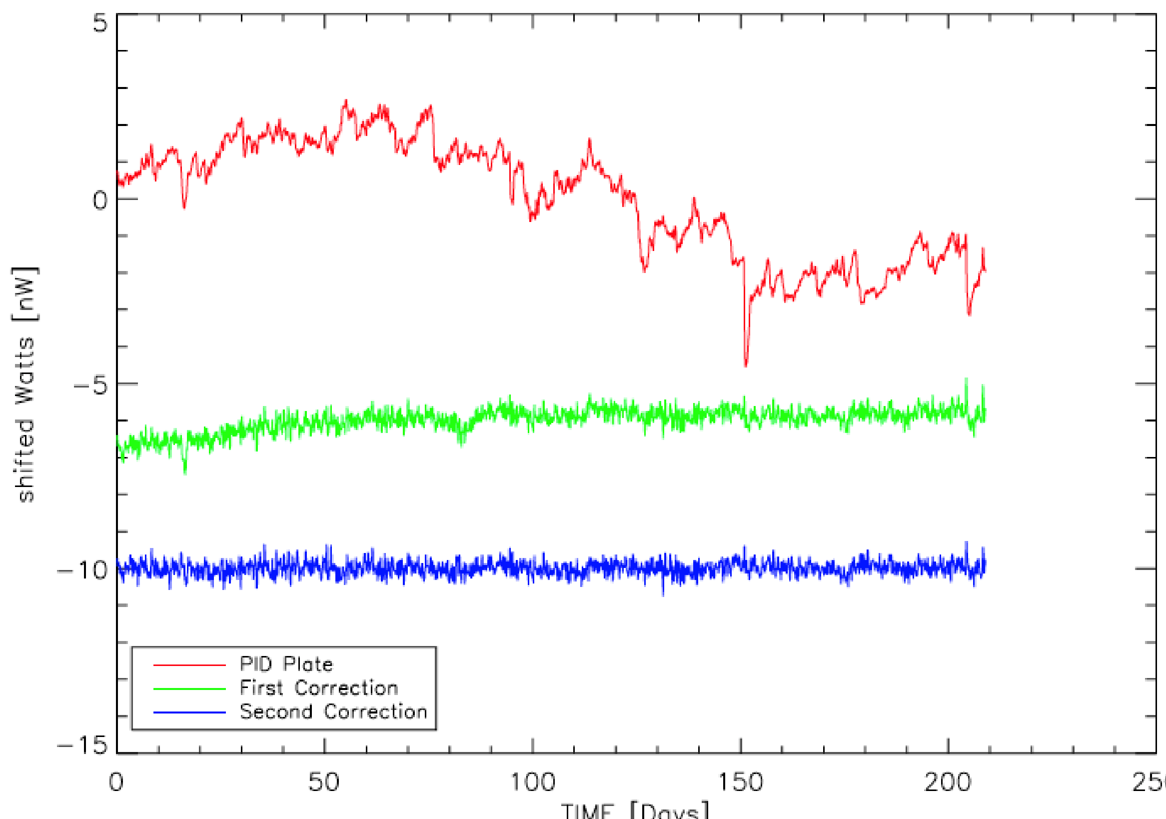
Temperature fluctuations induced by cosmic ray hit fluctuations!!

Corrected by PID at time scales larger than the hour

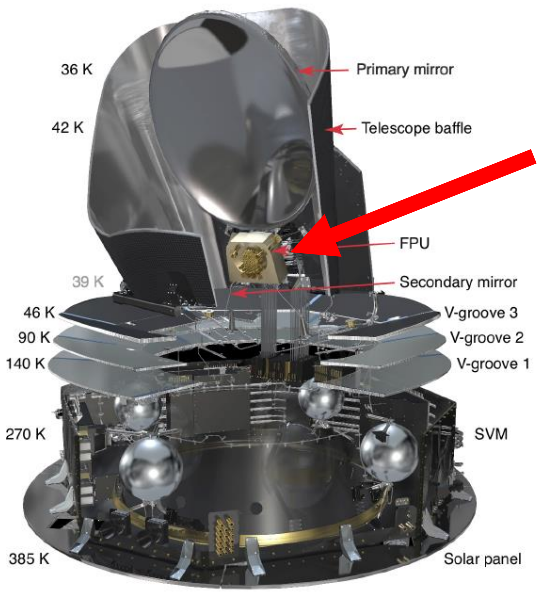
Great thermal stability of detectors

Second correction from the dilution plate PID



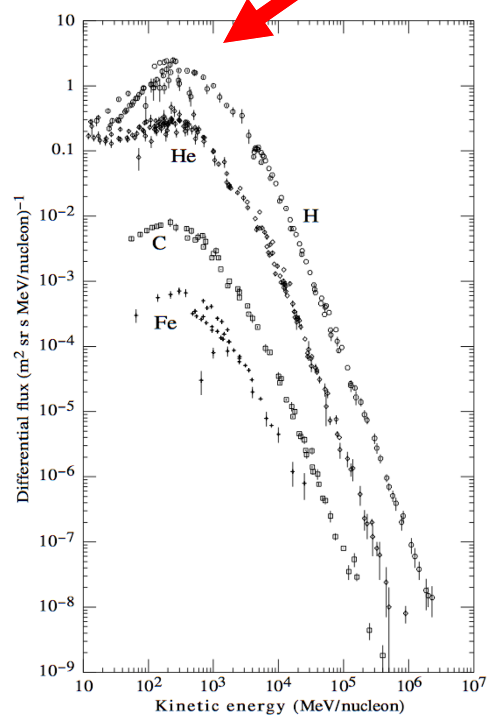


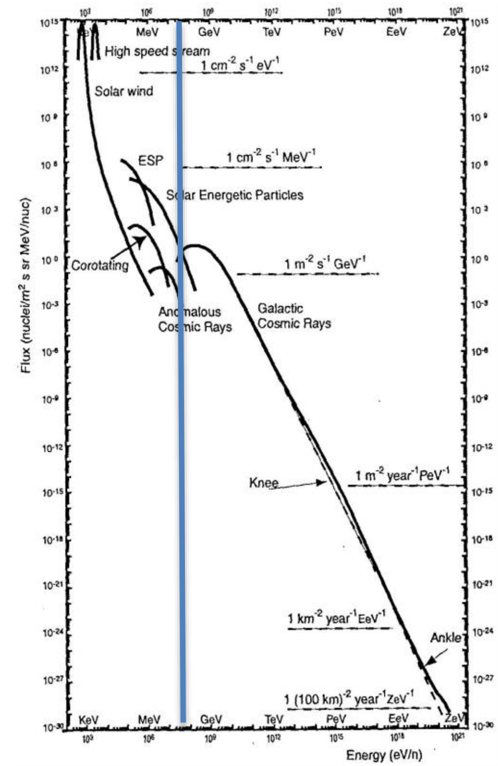
Cosmic rays



Mainly galactic protons and Helium nuclei

CR of ~ 1 GeV dominate



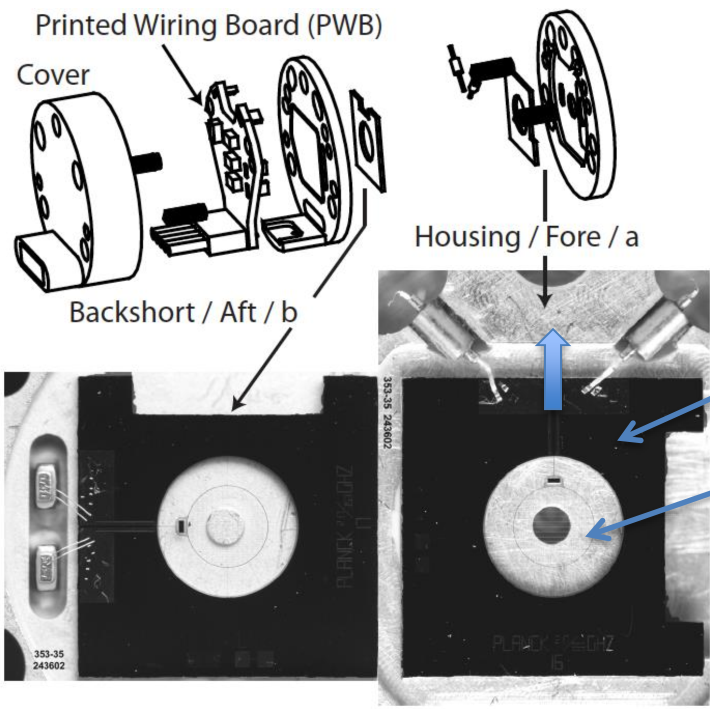


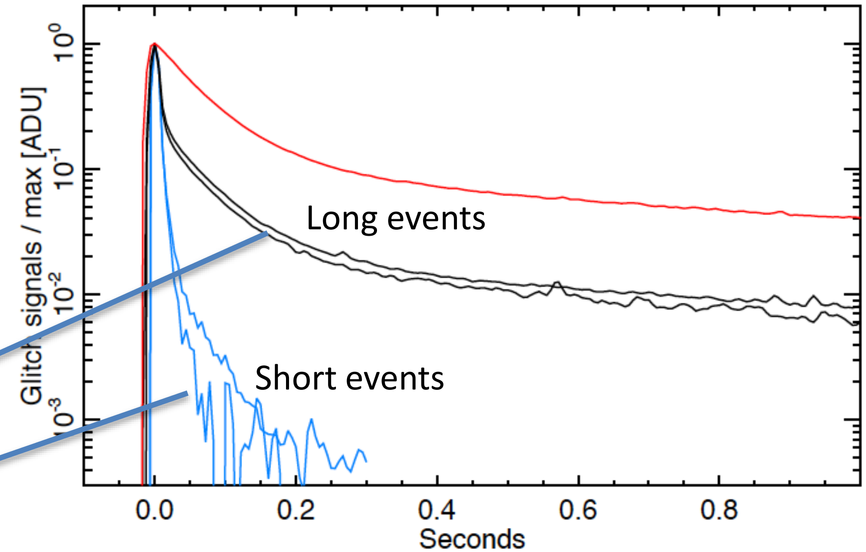
Cut off due to material around the detectors at ~ 50 MeV

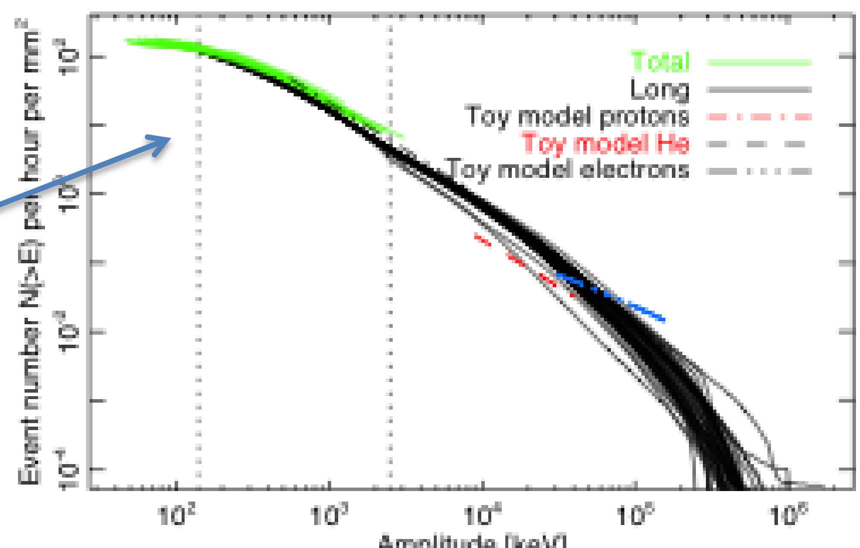
No contribution from solar particles which can not reach the detectors, except during flares

Amplitude of the spectrum at L2 is modulated by solar activity

CR interaction with detectors







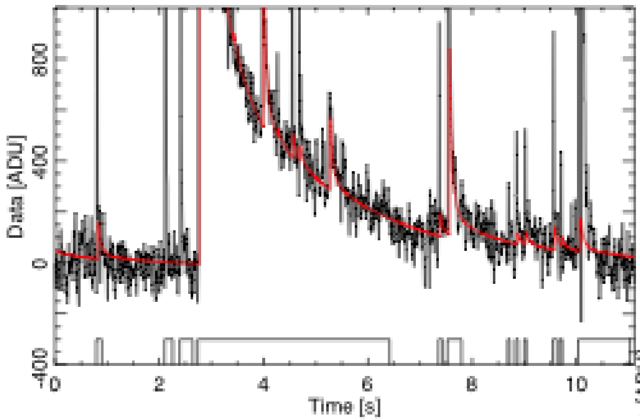
- Only 3 families of glitches

- Almost all depositing energy on the wafer are glitches detected !
Partly because of ballistic phonon

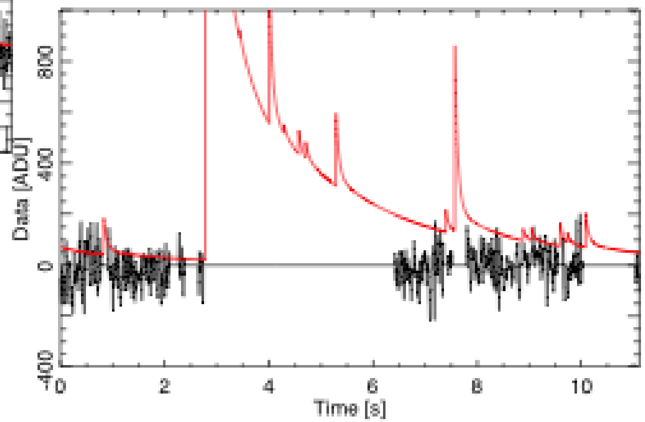
- Long events mostly correlated between PSB a/b

Cosmic ray removal

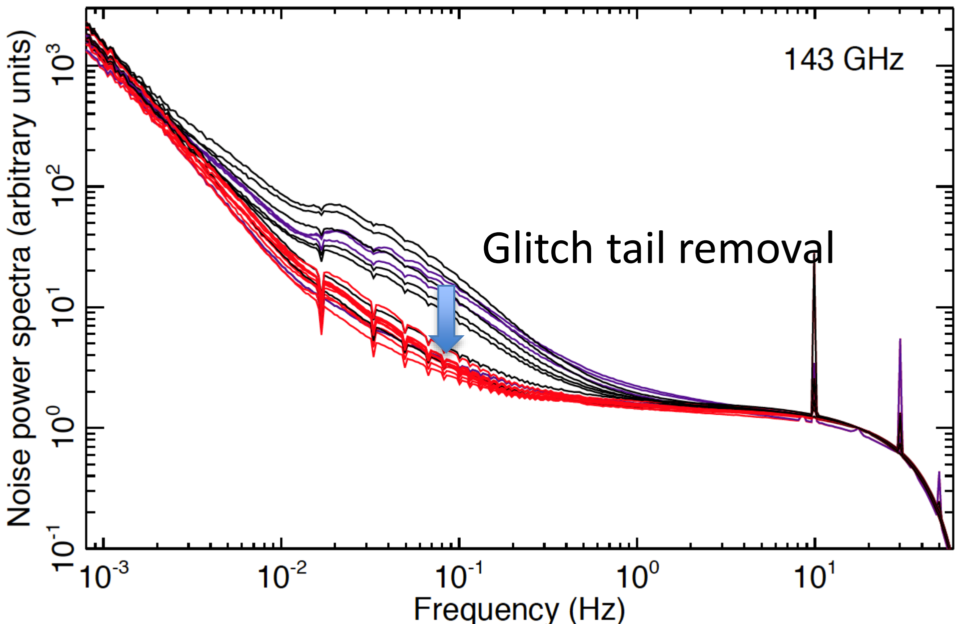
Joint fit of templates for each detected event.



- Removal of long glitch tails
- Flagging 10 to 25 % of data depending on the detector



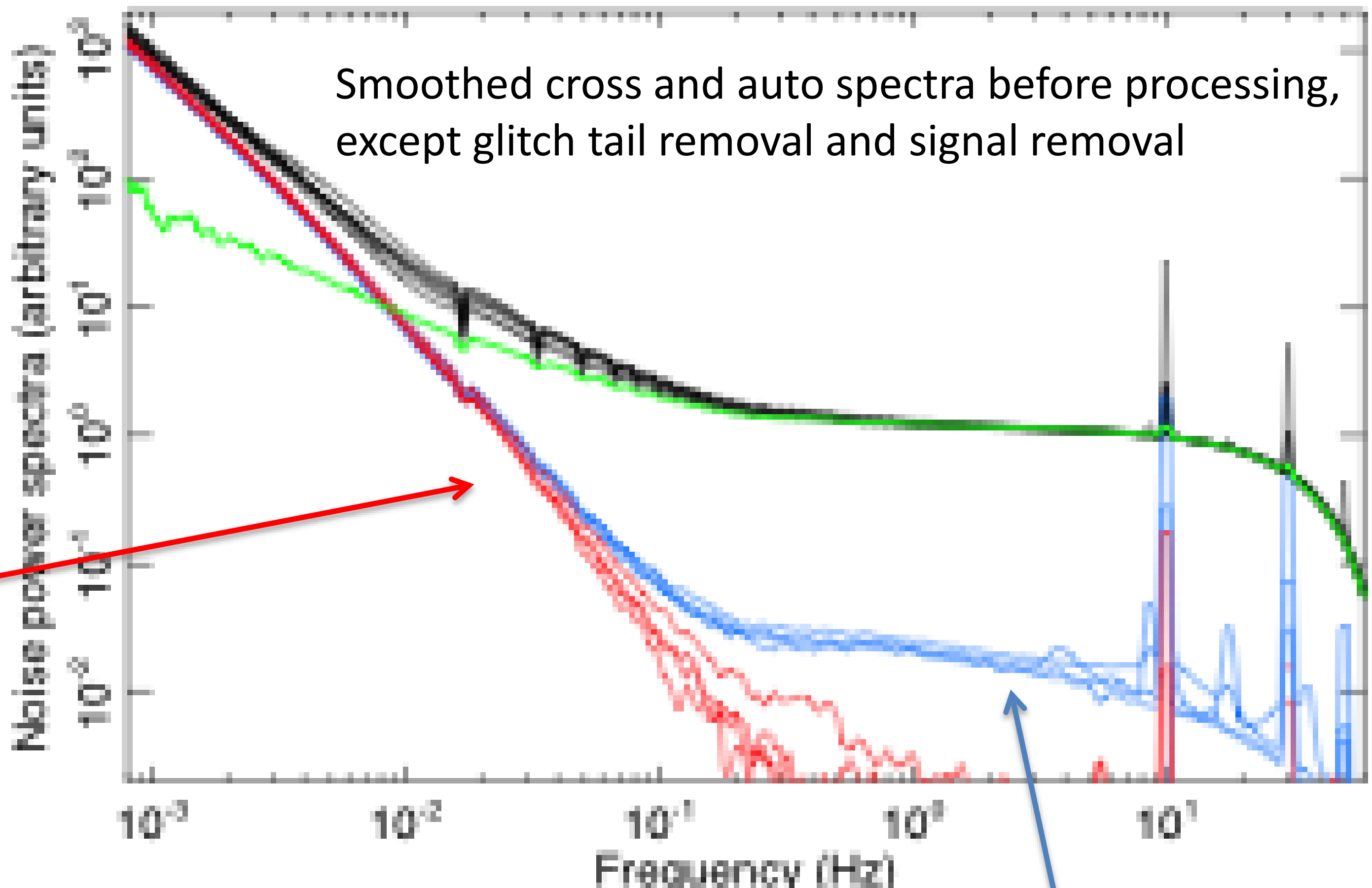
Analysis made difficult because of the high confusion of events



Residual at the level of noise for the worst channels at low frequencies < 0.2 Hz

At the end, the glitch contribution to the noise on the maps is significant only for ell < 10, still smaller than detector noise

Noise spectra on TOIs

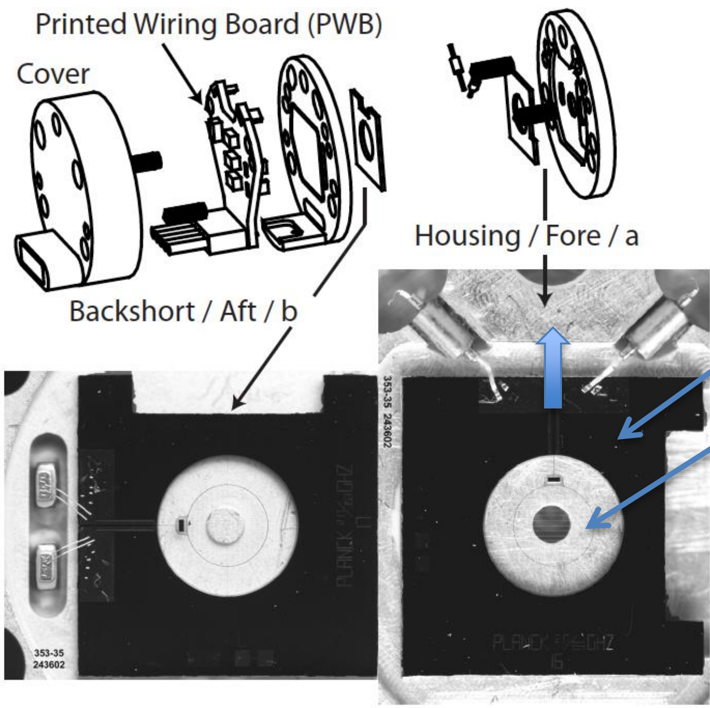


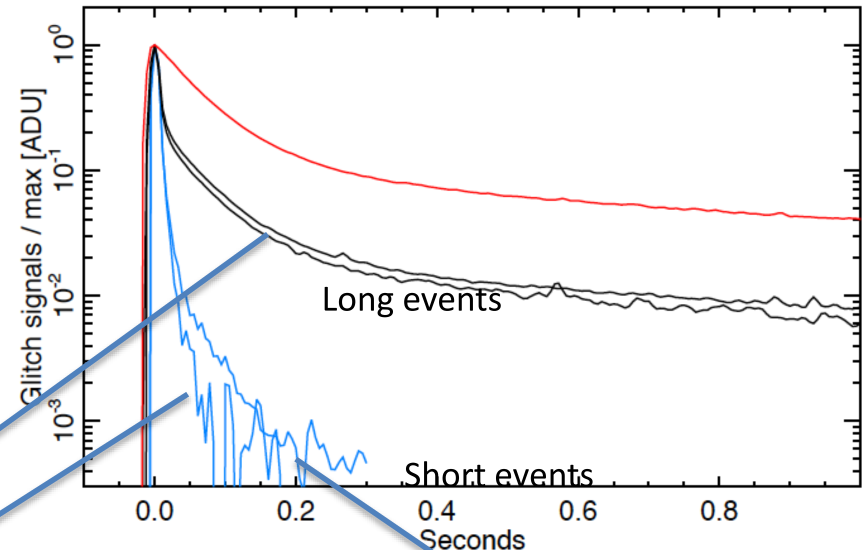
Correlated noise between detectors. Related to thermal fluctuation of the plate due to CR hits

Glitches below the detection threshold common between PSB-a and PSB-b
Provide a limit on the level of remaining glitches in data ~ 5% contribution

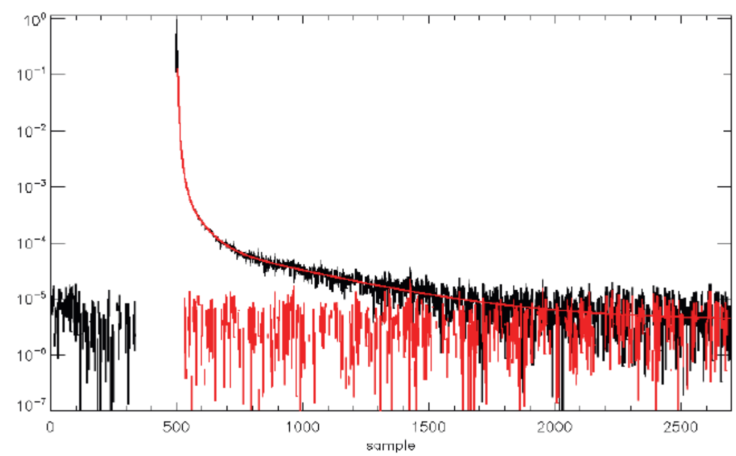
Evidence for long time constants

Only 3 families !





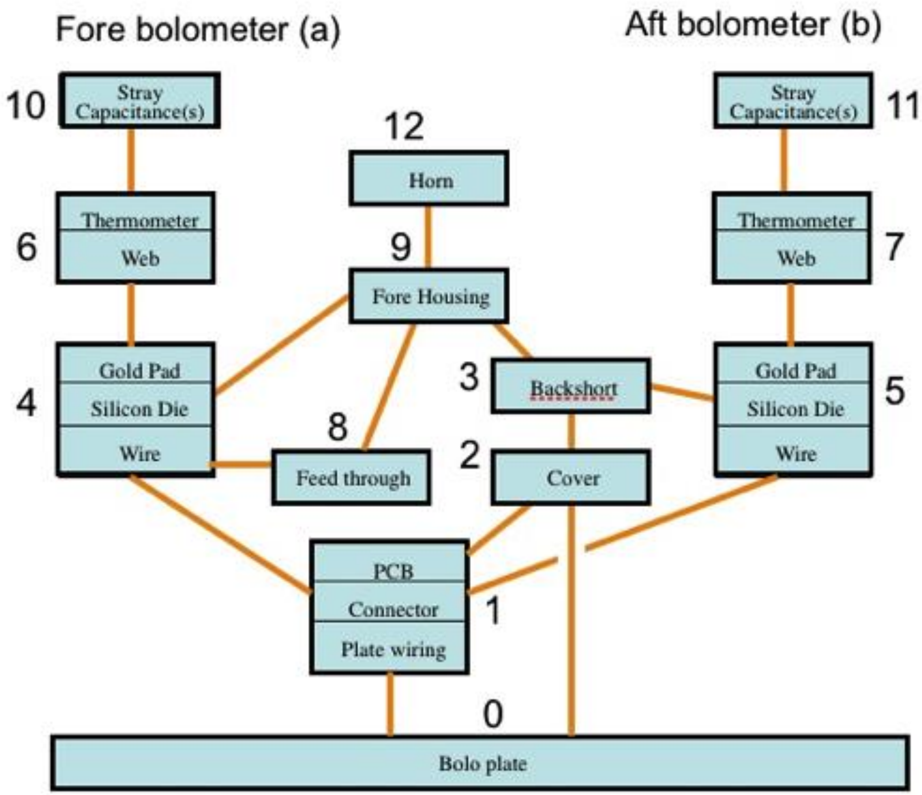
Long time constants seen by stacking all events related to CR hitting on the wafer



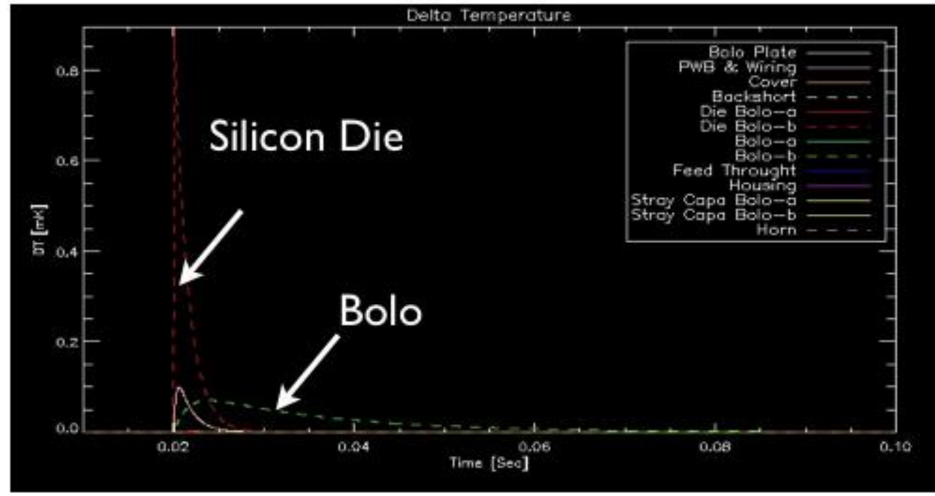
Thermal modeling is important. Long time constants might come from the links between the wafer and the detector housing and are seen on both categories of glitches

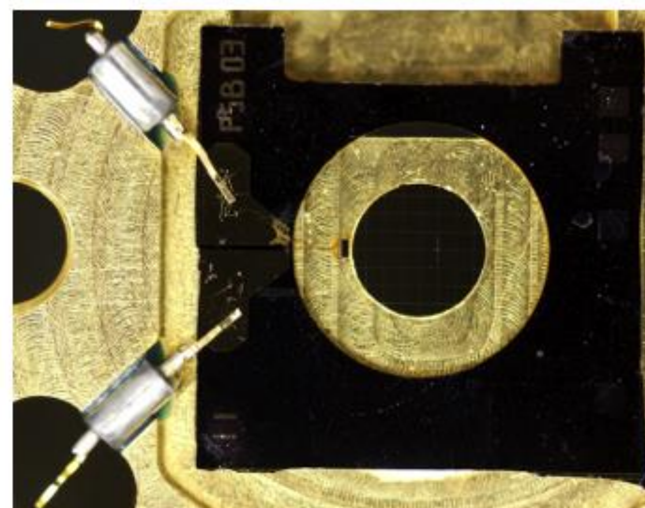
Bolo Thermal Model

PSB "simplified" thermal model



Simulation of a 23MeV Proton in the silicon die



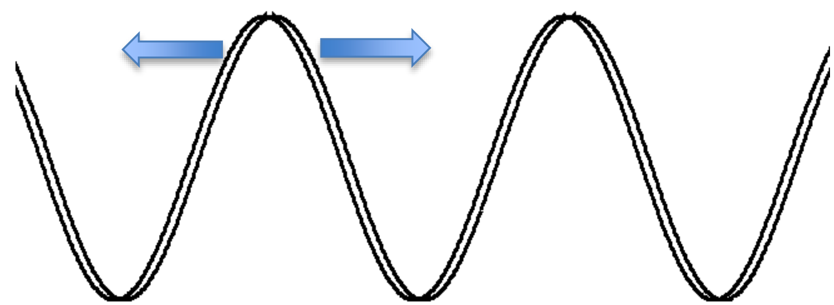


Basic Equation

$$C_j \frac{dT_j}{dt} = \sum_{i=0}^{12} G_{ij} (T_i - T_j)$$

Impact of long time constants on data

• Long time constants are observed in data ~ 2 s for the longest
seen in the tail of short glitches
seen on planet maps
induces a shift of the dipole



• Induce percent effect in the calibration if not properly corrected as it affects the highest and lowest multipoles in a different way

• Time constants are variable from detector to detector

• Having different survey with nearly opposite scan directions helped to constrain and correct the longest time constants

• Solved at the map-making stage by template fitting (largest multipole shifts)

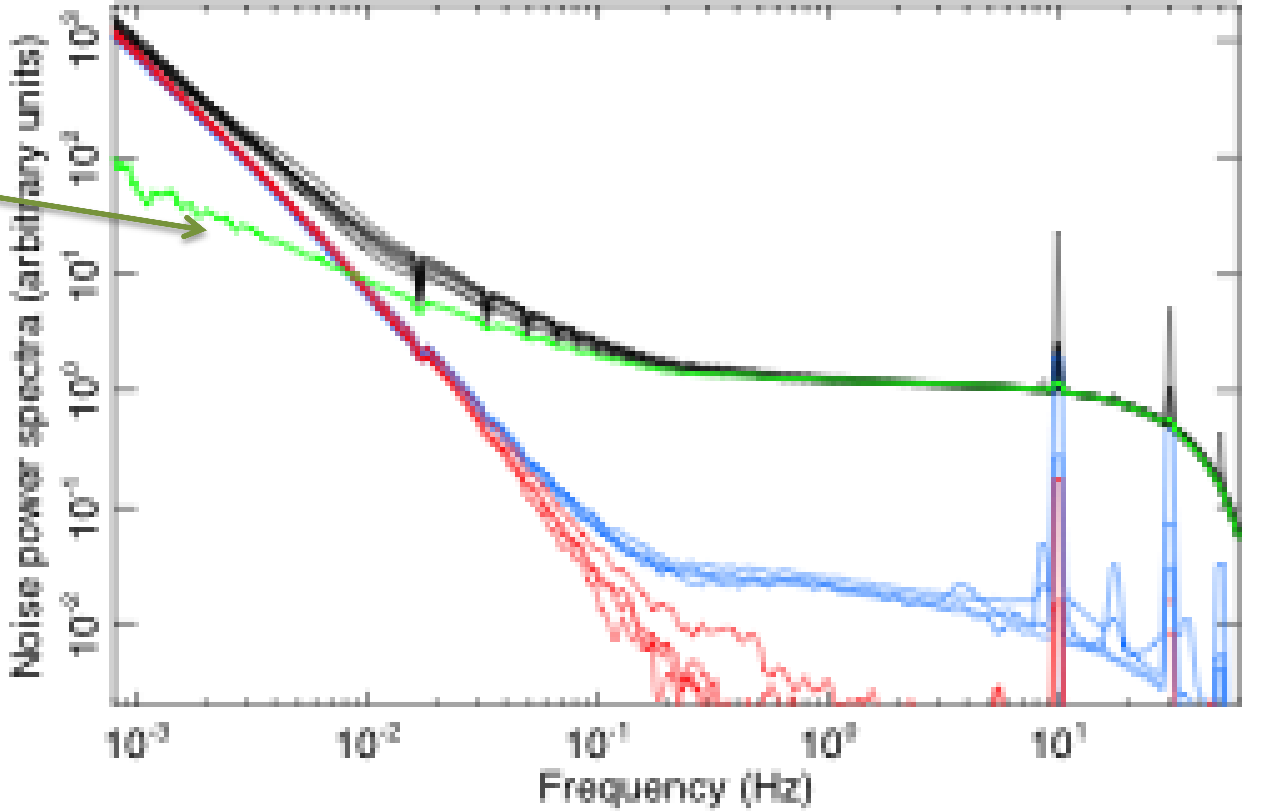
Uncorrelated noise

Uncorrelated component seen in all detector time-streams at higher level than observed from the ground

f_{knee}~ 0.15 Hz

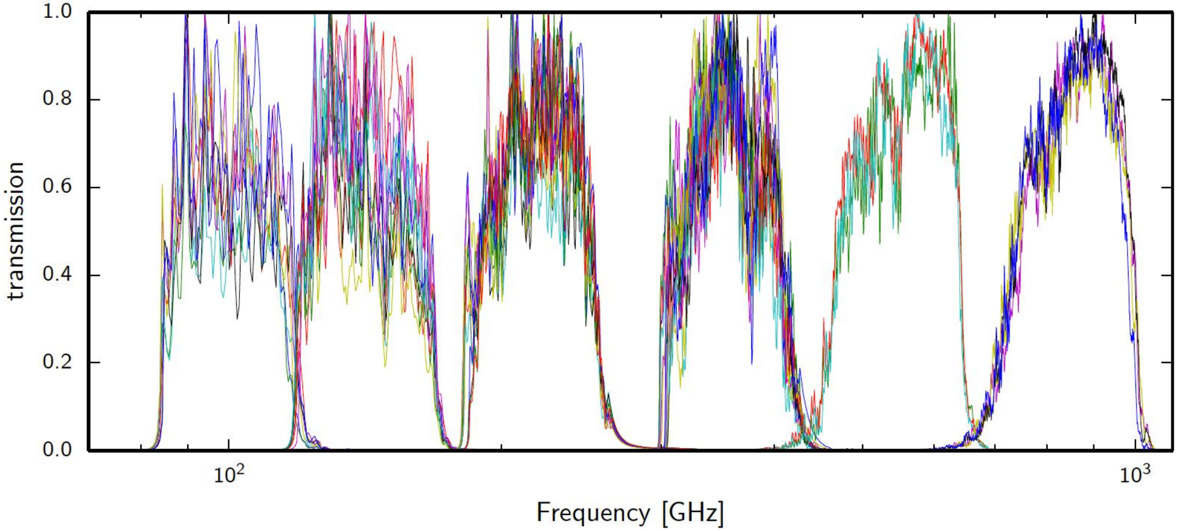
No clear explanation, can’t be due to CRs since not modulated as glitch rate

Gives the fundamental limit after systematics removal

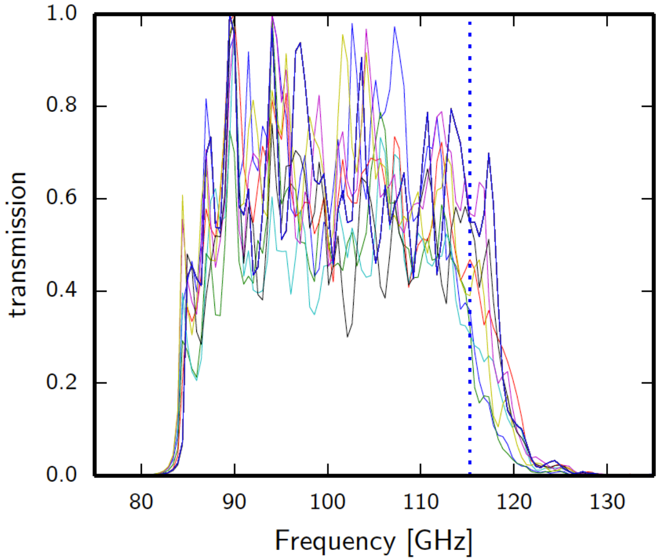


Band-pass mismatch

Differences in the band shapes from detector to detector induced intensity to polarization of galactic components when calibrating on CMB



A few percent effects for the amplitude of the dust from detector to detector

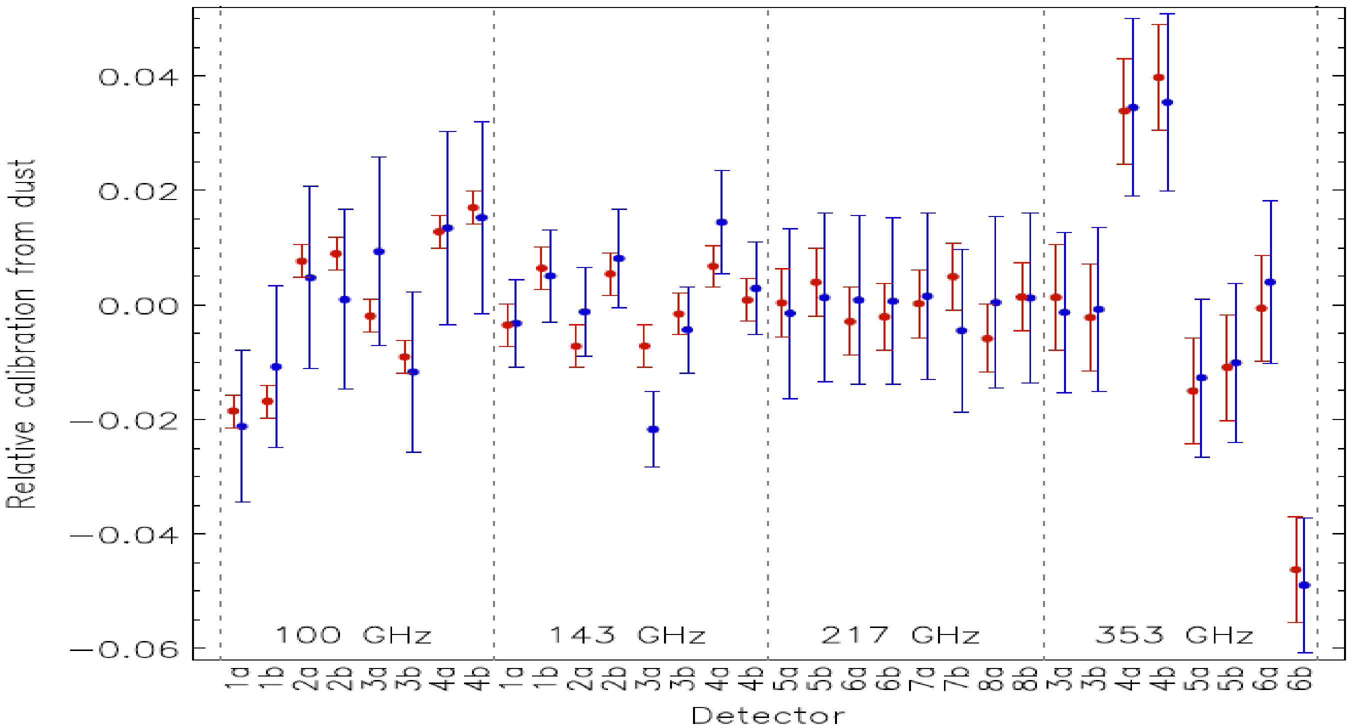


CO transition line 1-> 0 falls at the edge of the 100 Hz filters so the CO components has very different amplitude from detector to detector

Band-pass mismatch correction

-Band passes were measured from the ground. The precision is not accurate enough to remove the dust intensity to polarization leakage with the predicted coefficients

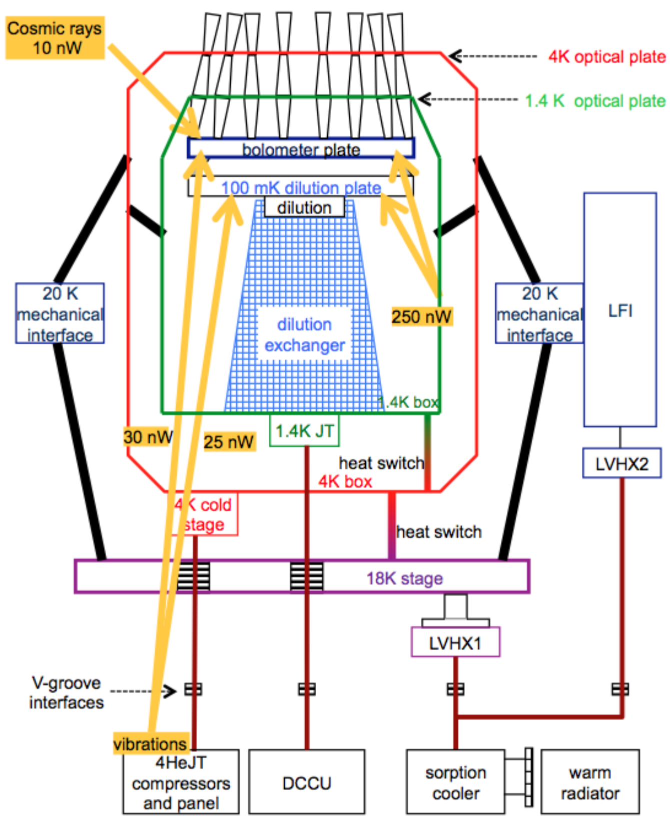
- Estimated at the map-making level. Naturally minimizes the survey difference contamination

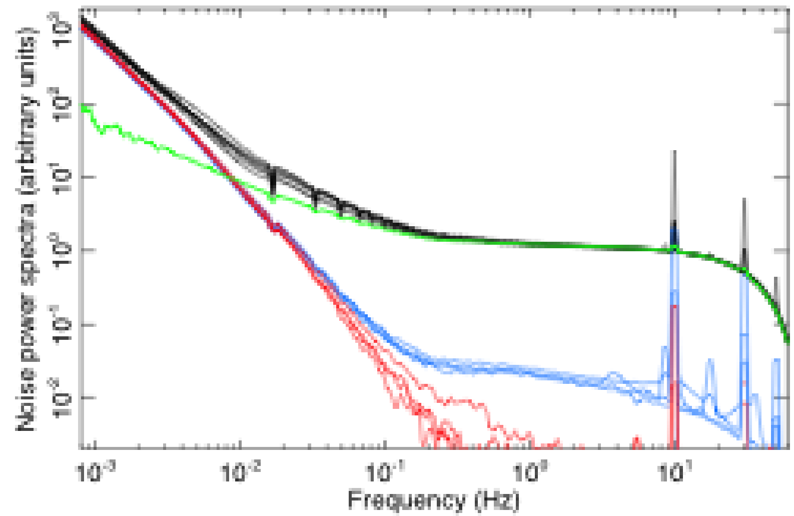


Effect mostly removed at the end

Lines induced by the 4K compressors

4He – JT cooler induced sharp lines in the data, due to electromagnetic and microphonic interference to the detector wires

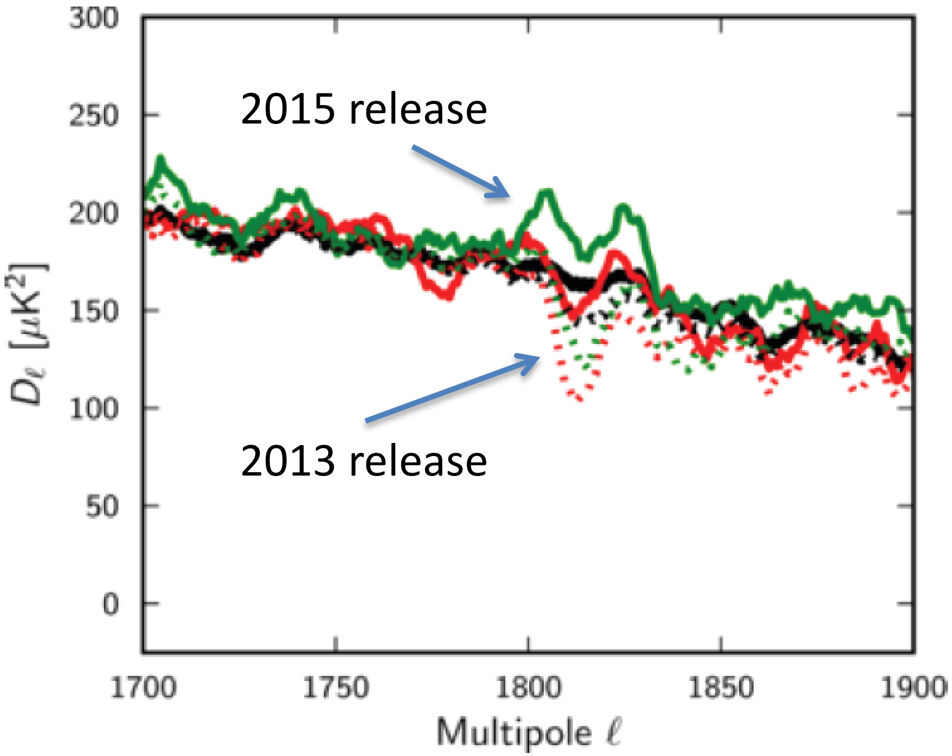




Data acquisition locked on the 4K cooler compressor: fixed line frequencies, multiple of 20 Hz (before demodulation)

Amplitudes vary across the mission

4 K line processing



Removed by notch filters, ring by ring

Resonant rings, for which harmonics of the signal are close to the 4K line frequencies are removed

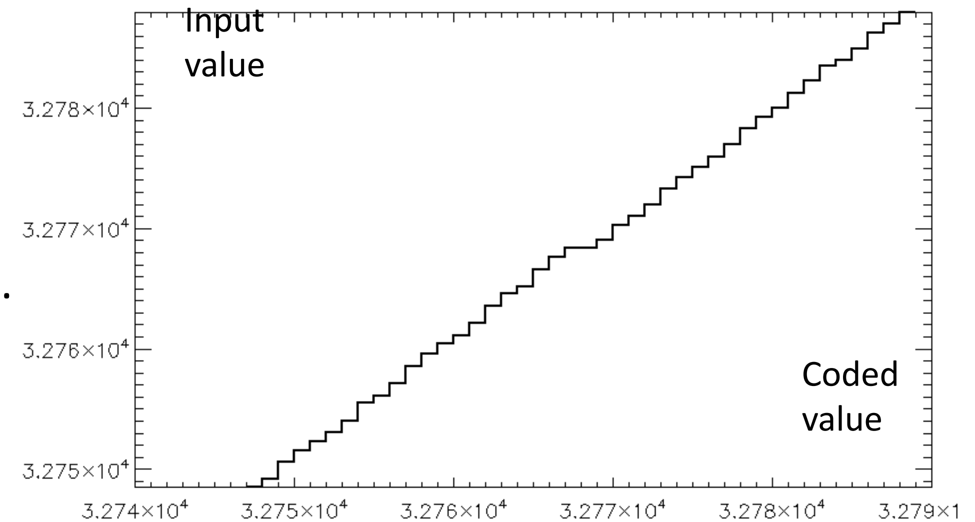
Better rejection for 2015 results correcting an artifact affecting cosmology in 2013 data.

Biggest problem is that 4K lines affect the ADC non-linearities!

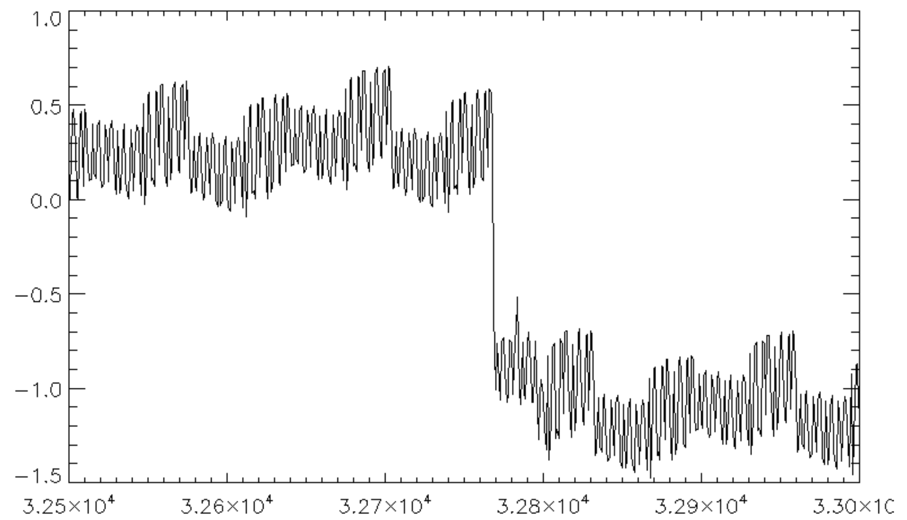
ADC non-linearities

Analog to Digital convertor have some non-linearities

This problem was not considered before flight.



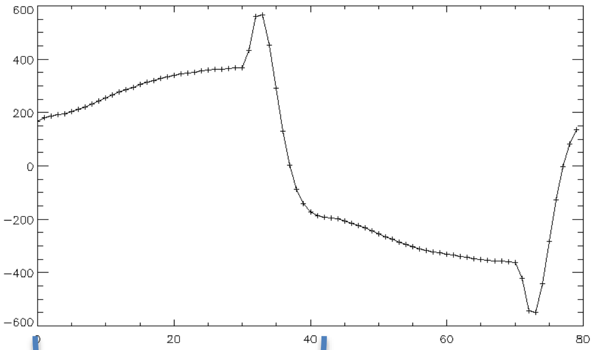
Non-linearity ADC(x) - x:



Planck data are for the very large majority sampling -300 to +300 ADUs around the central value, where the non-linearity is larger!

Data model

Fast sample data (40*180 Hz):



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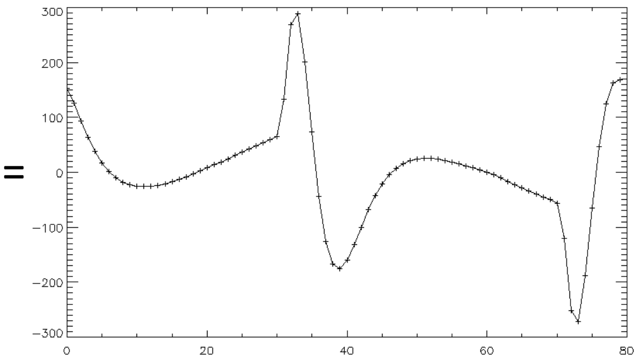

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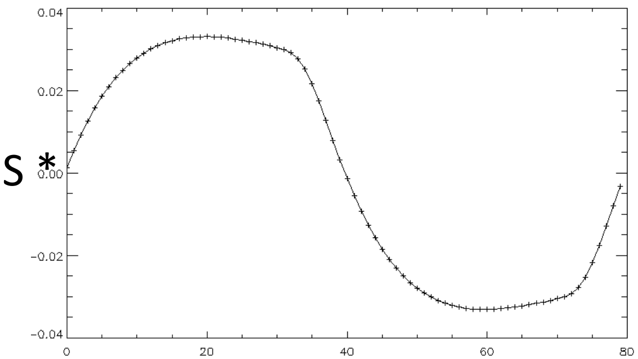


One sample

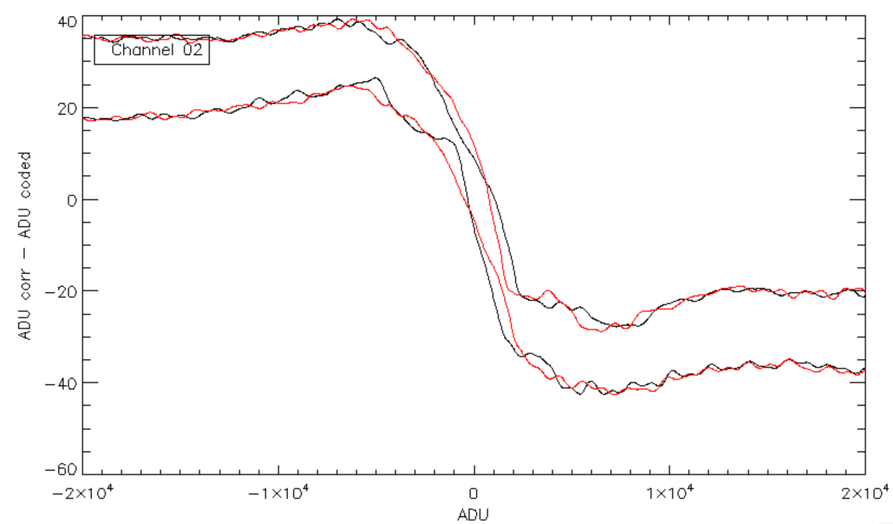
(+ d4K(t))

Digitization: $$d_{\text{int}}(t) = ADC[d(t)]$$

Data sample: $$m_i = \sum_{t_i}^{t_i+40} ADC(d(t))$$

Non-linearity:

$$\langle m \rangle = F(S)$$



F is a non-linear function

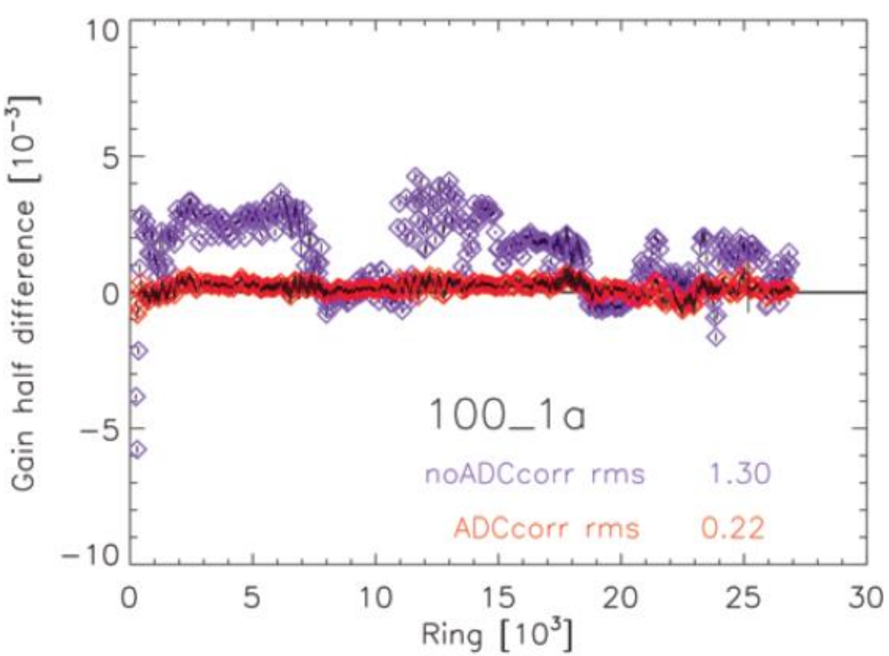
Correction is straightforward with the knowledge of F.

F depends on elect. response and ADC shape

ADC correction

1[st] order correction with time dependant gain is not accurate enough.

The non-linearity function is estimated for each ring using a maximum likelihood approach.
- The ADC shape is estimated using warm data taken at the end of the mission
- The electronic response is measured every 100 seconds for each detector



Data Jackknives are very efficient to test the quality of the ADC correction

Correction allows to reduce the systematics level by 1 to 2 orders of magnitude!!

2[nd] correction performed at the map-making stage.

Estimated contributions to the polarization spectra

- High ell dominated by detector noise

- Low ells have systematics at the level of noise. The ADC non-linearity is dominant effect even after correction

Conclusions

- Main systematics in Planck HFI data affecting the low multipoles:
  - ADC non-linearities/ 4K lines
  - CR glitches
  - Band-pass mismatches
  - Long time constants
  - Far side-lobes
- Some of the systematics could have been avoided or reduced with dedicated measurement on the ground. In particular ADC and glitches
- Dedicated methods removed efficiently most of the effects, many effects are removed at the map-making stage.
- Most of the residuals are below the HFI Planck noise after correction, the dominant effects: residual ADC non-linearities at the level of noise for $l < 10$