Characterisation of Cosmic Rays Impact on detectors: from Planck to next generation CMB space mission

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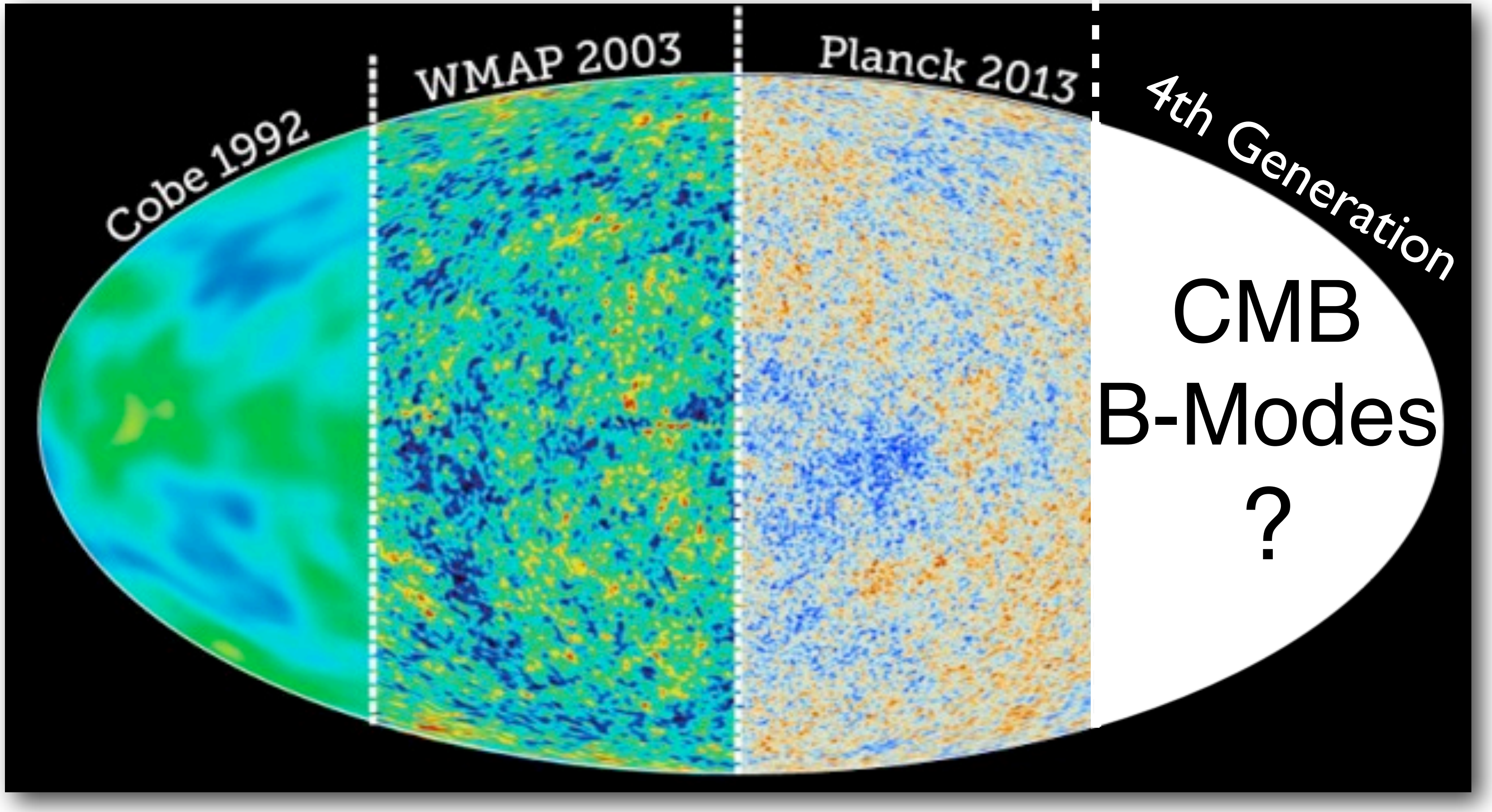
on behalh of the Planck Collaboration



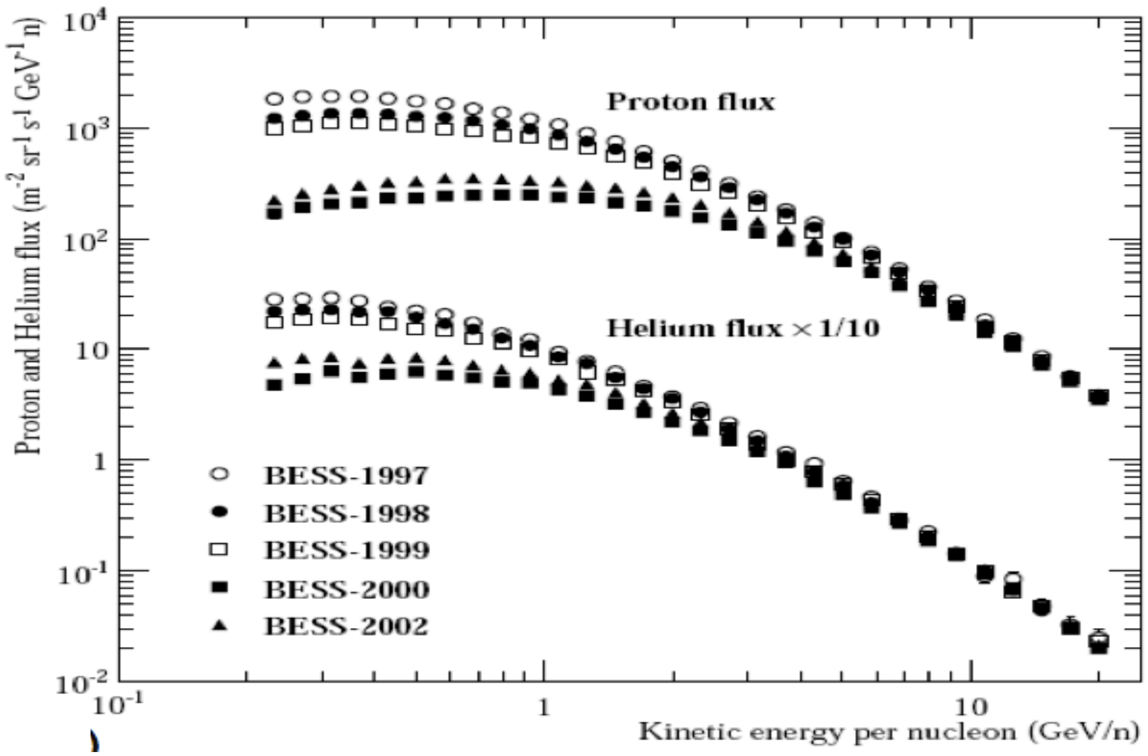
Outline

- Cosmic Rays at second Lagrangian point.
- Impact of cosmic rays on HFI Data.
- CR impact: Needs for a 4th-generation CMB space instrument.
- Impact of particles on array of detectors: LEKID example
- Conclusion

Galactic Cosmic Rays & Solar Activity

[Mewaldt, R. A., Davis, A. J., Lave, K. A., et al. 2010, ApJ, 723, L1]
[Leske, R. A., Cummings, A. C., Mewaldt, R. A., & Stone, E. C. 2011, Space Sci. Rev., 126]

Proton and Helium fluxes at the top of the atmosphere from 1997 through 2002.



3-4 10^3 particles $m^{-2}sr^{-1}s^{-1}MeV^{-1}$ peaks at 300MeV

Galactic Cosmic Rays:

Protons : ~ 89 %

He Ions: ~ 10 %,

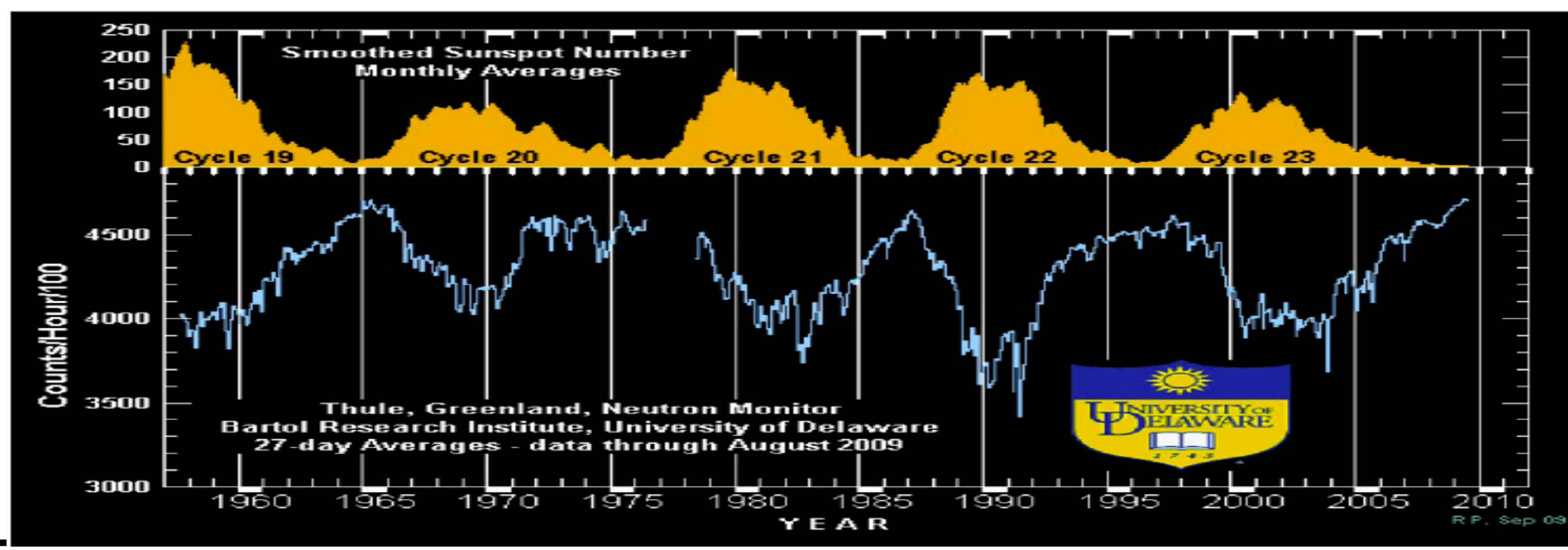
Heavier elements: ~ 1 %

Electrons : < 1 %

Solar Activity

The GCRs are modulated by the solar wind, which decelerates and partially shields the inner solar system from lower energy galactic CRs.

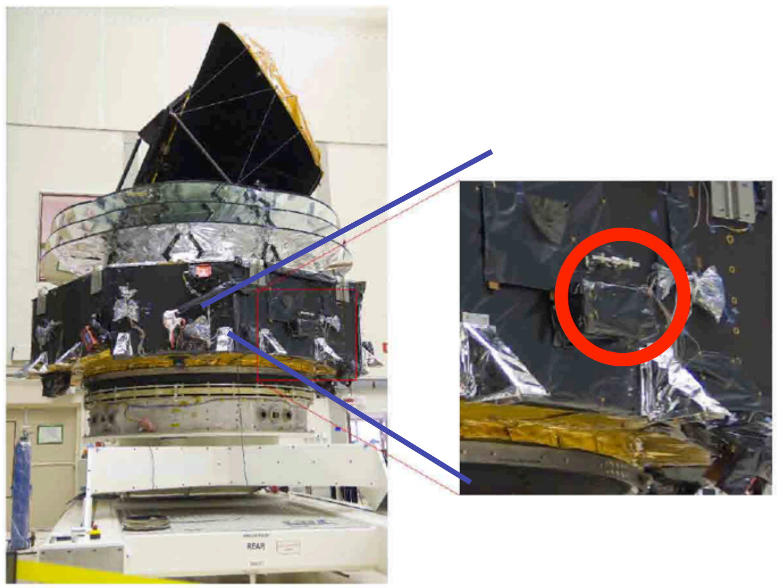
Thule Greenland Neutron Monitor (Delaware University)

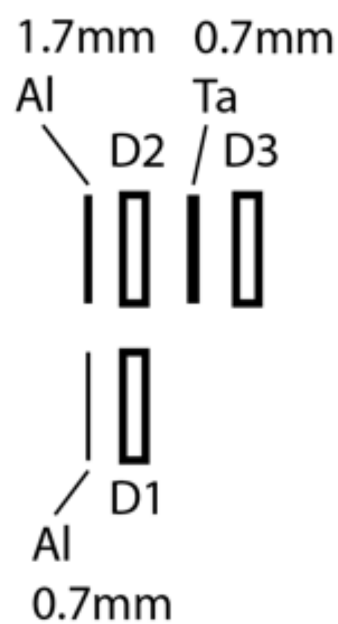


The Standard Radiation Environment Monitor

(Mohammadzadeh et al. 2003)

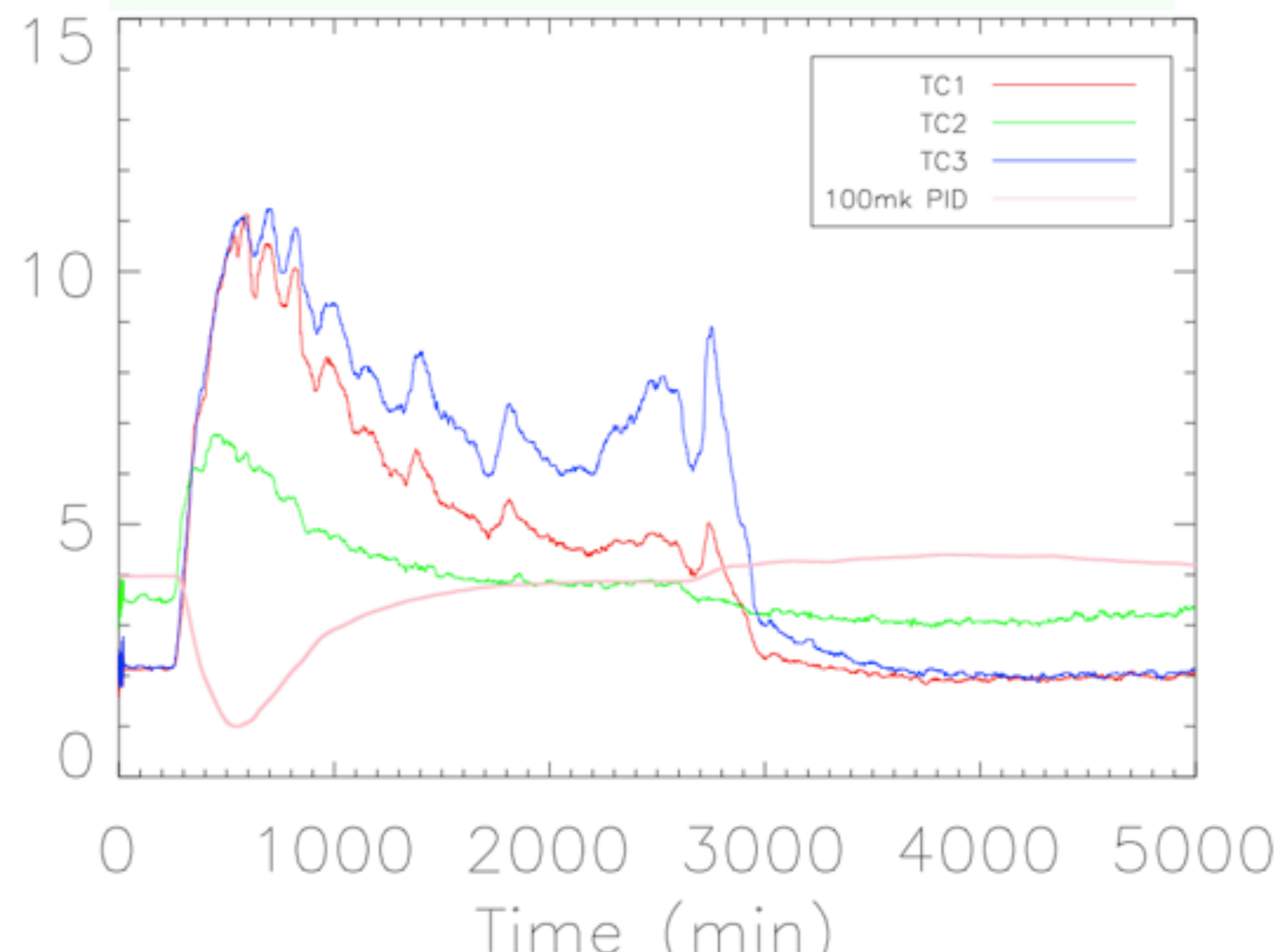
SREM consists of three detectors (D1,D2,D3) in two detectors heads configurations





- TC1 (D1) measures protons in a range of energy between 20 MeV and Inf.
- TC2 (D2) measures protons in a range of energy between 39 MeV and Inf.
- TC3 (D3) measures electrons in a range of energy between 0.5 MeV and Inf and protons.

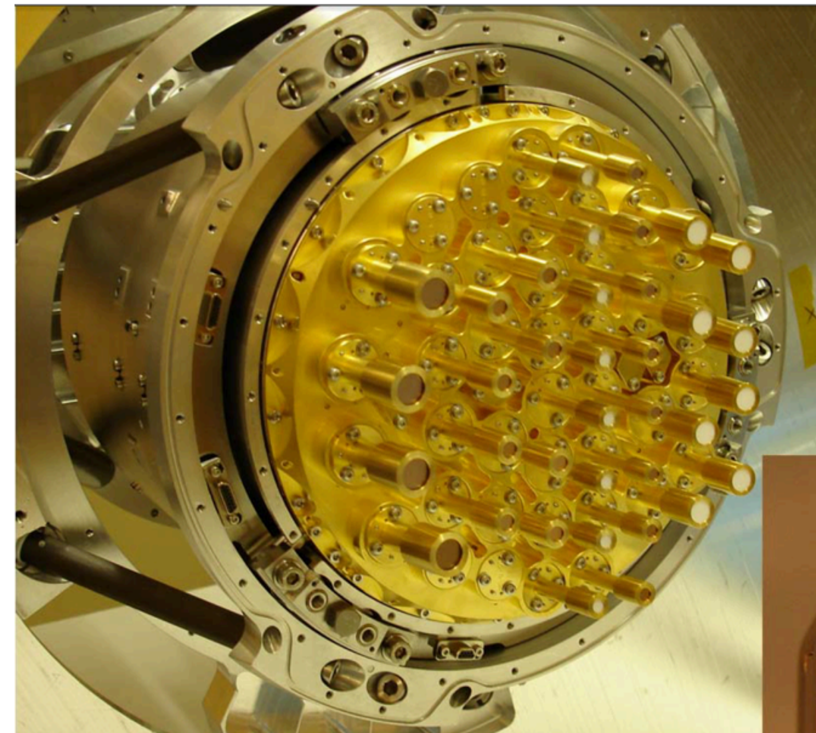
TC1-TC2-TC3 signals during the solar flares and the 100mk stage PID (in arbitrary units)

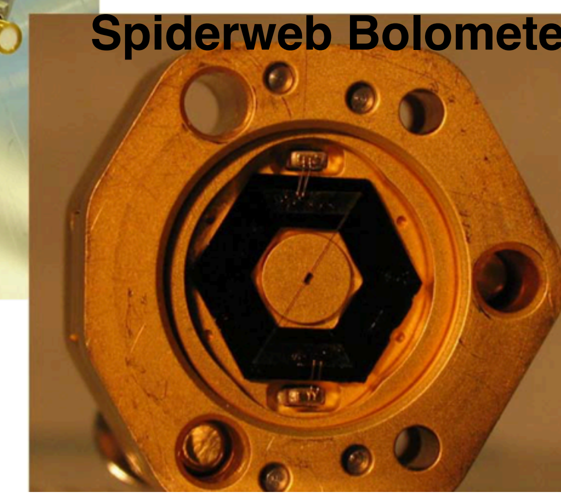


Low energy protons (below 40 Mev) and high energy electrons are not able to penetrate the satellite up to the 100 mK stage.

Cosmic Rays Interaction with HFI

Particles interact with HFI (and LFI) bolometers in two different ways:





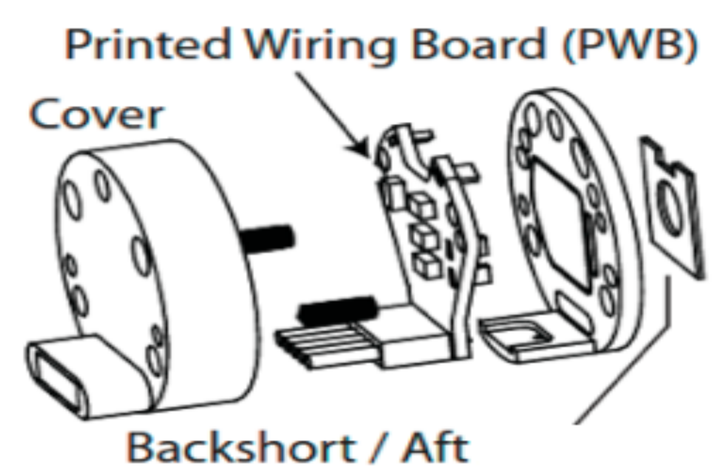
Direct Interaction

• Glitches on TOI: particles hit directly an element of the bolometer module leading to a flux of about 1 glitch/s on each of 54 HFI bolometers.

Indirect Interaction

• Elephant Glitches : simultaneous glitches detected in many bolometers increasing the plate temperature up to several microK.

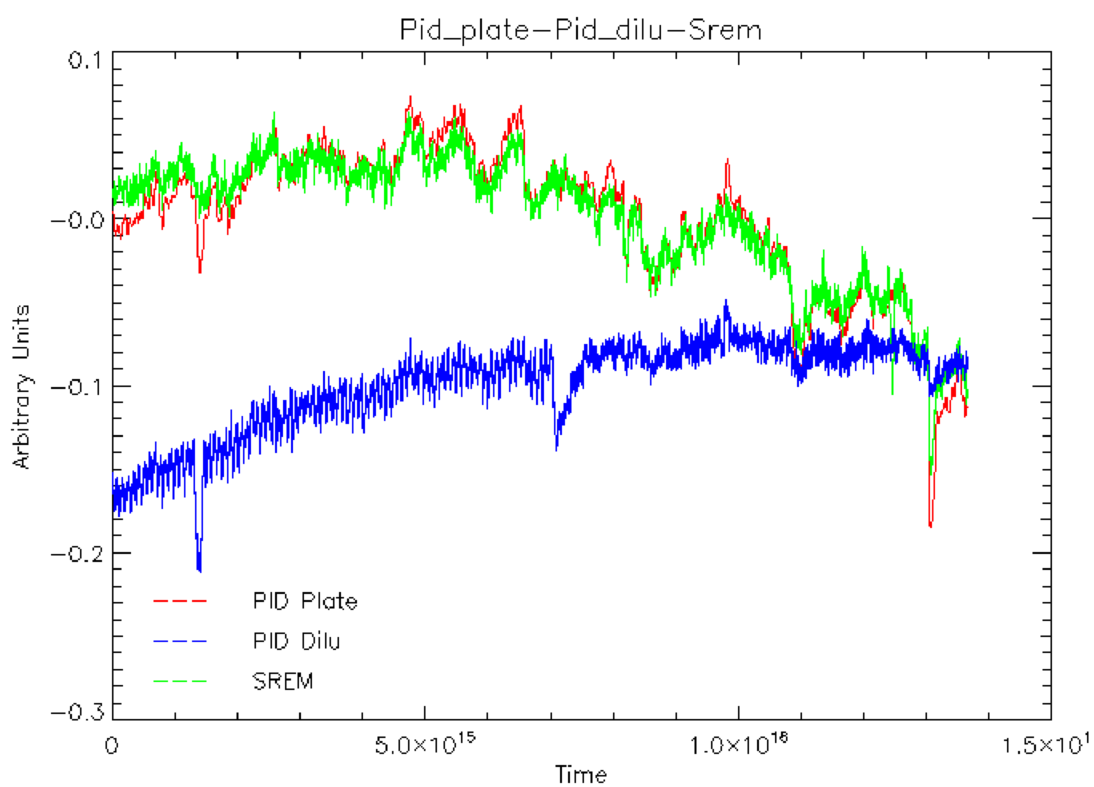
• Thermal effect: ~10nW load on 100mk stage due to the cosmic rays of total ~ 300nW

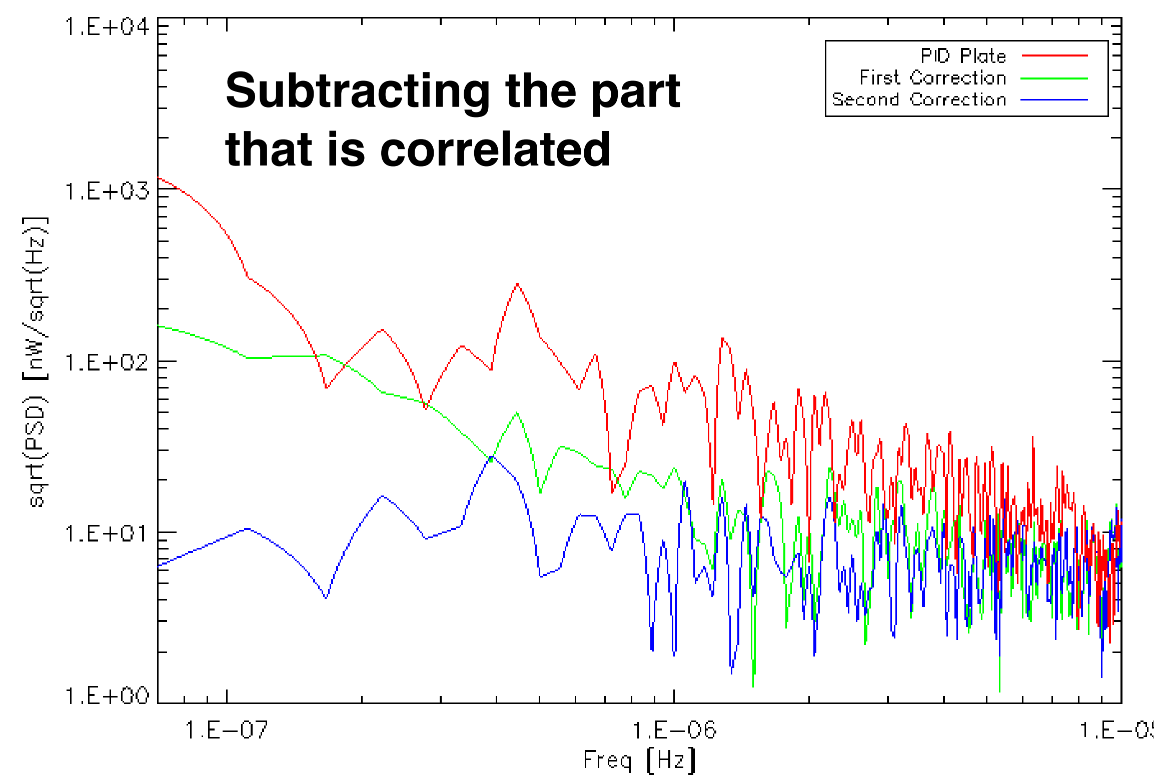


Indirect Effects (Planck coll. - A&A 536, A2 - 2011)

- **Solar modulation effect**: **~10nW load on 100mk stage due to the cosmic rays of total ~ 300nW**

We observed a very good correlation between the signal of the Standard Radiation Environment Monitor (SREM) and the signal of the active regulation of the temperature of the bolometer plate.

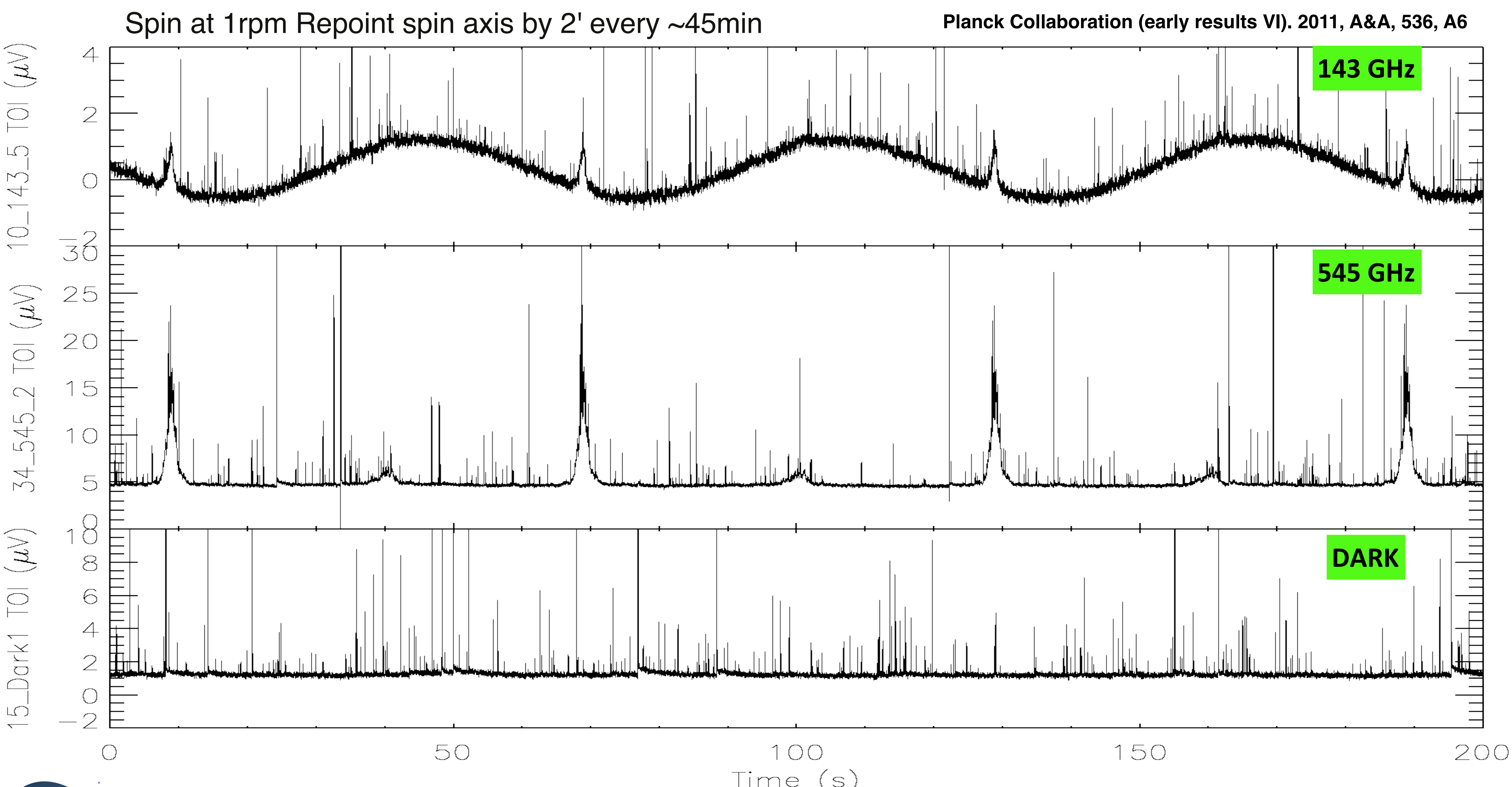




After corrections we find a flat noise spectrum in agreement with requirement.

Direct effect of Cosmic Rays on HFI

Direct effect: flag between 12-20% of data



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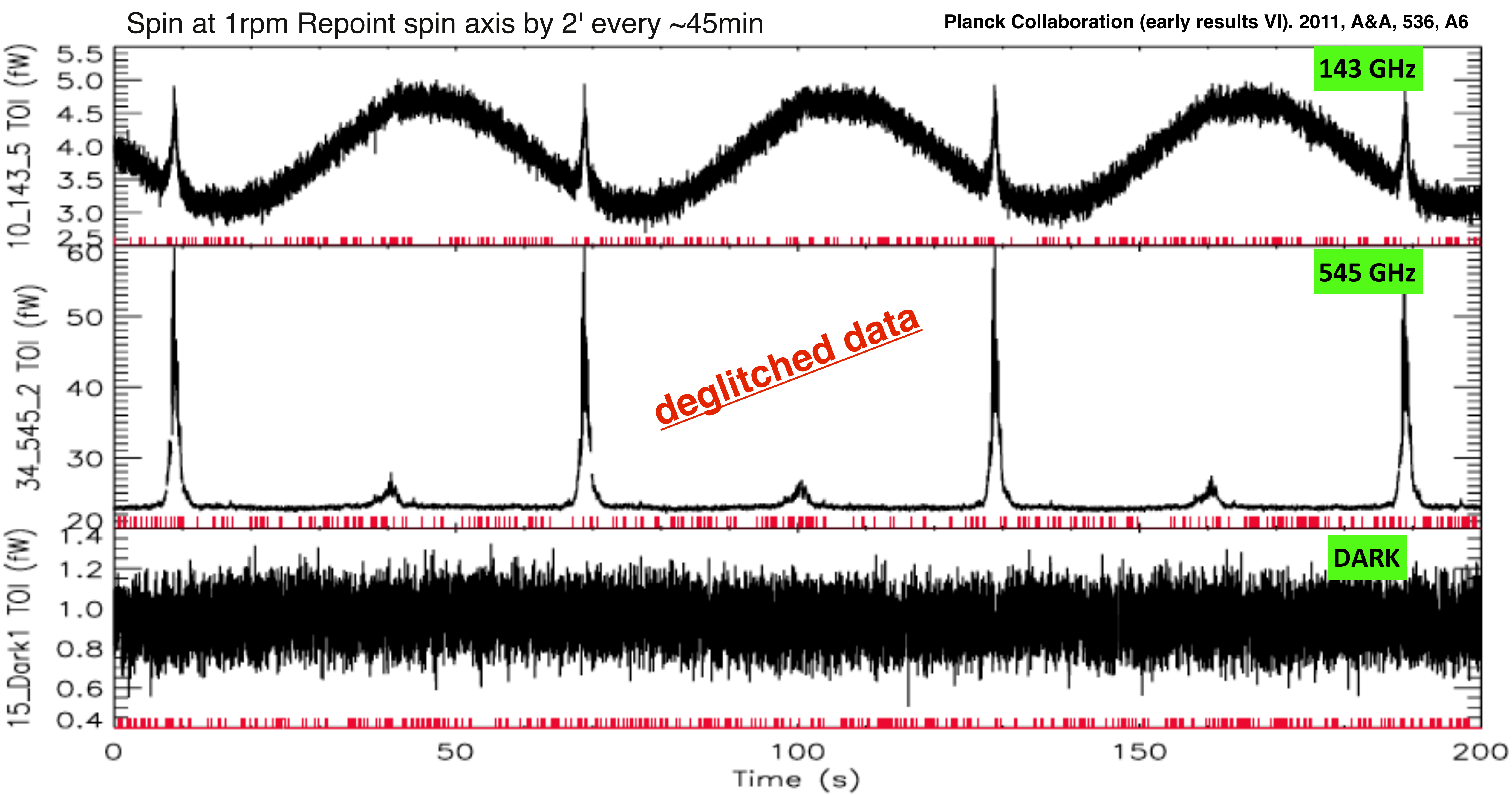


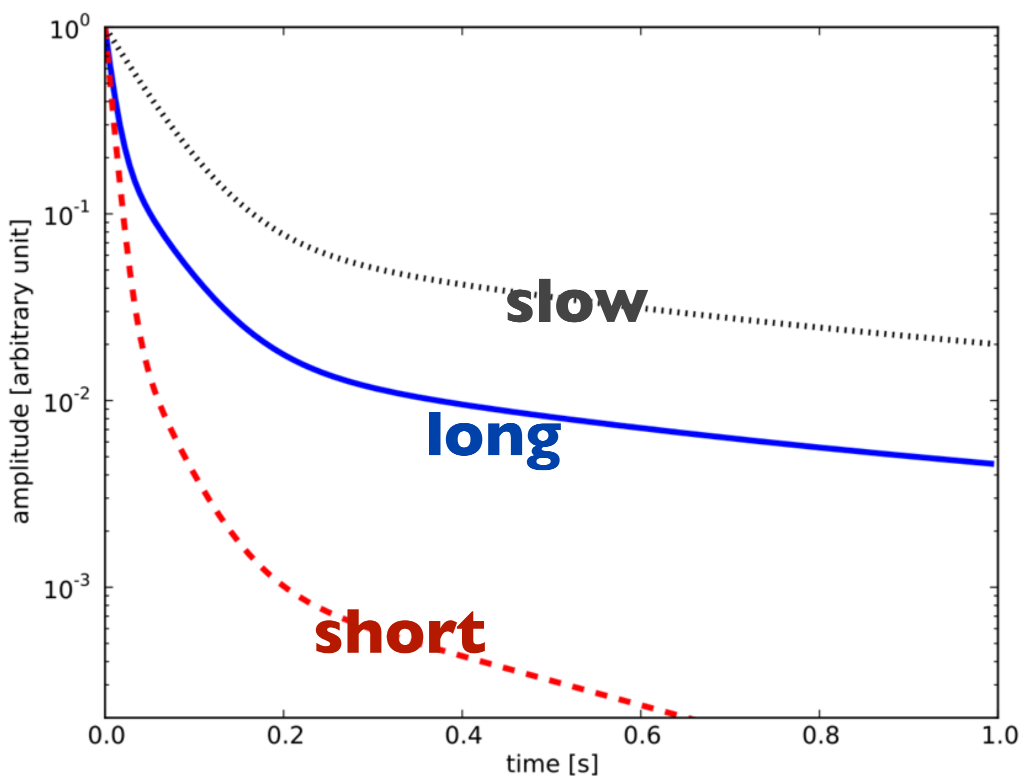
HFI In-Flight Glitches - Shape, Spectrum

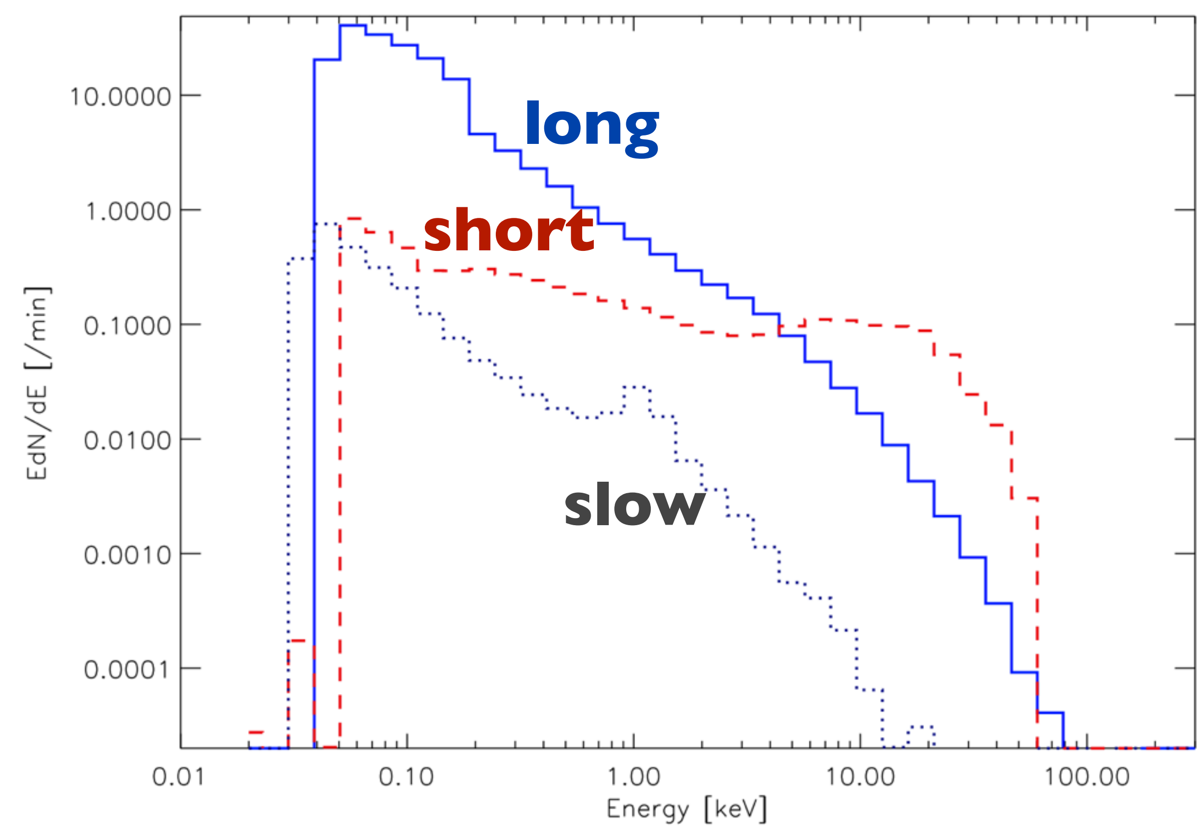
Short Glitches : [interaction with Grid+Thermometer]
Rate : 4 glitch/mm^2/min
Shape: Fast decay but low amplitude tail showing intermediate to long time constants of ~ 40 ms, 100 ms, 2s.
Distribution : double structure, power law fit in the range of small energies, bump in the range of high energies.

Long Glitches : [interaction with silicon substrate]
Rate : 1/cm2/sec
Shape : Time constants: ~ 10ms + 10% 60ms + 1% 2s decays (Seen in coincidence in PSB-a and PSB-b 50%-60%).
Distribution : power law index (ind= 1.3)

Slow/Snail Glitches : [only in PSBa]
Shape : Time constants: ~ 10ms + 10% 60ms + 1% 2s decays.
Distribution : Same as the long glitches.

Planck Collaboration 2014 A&A 571, A10





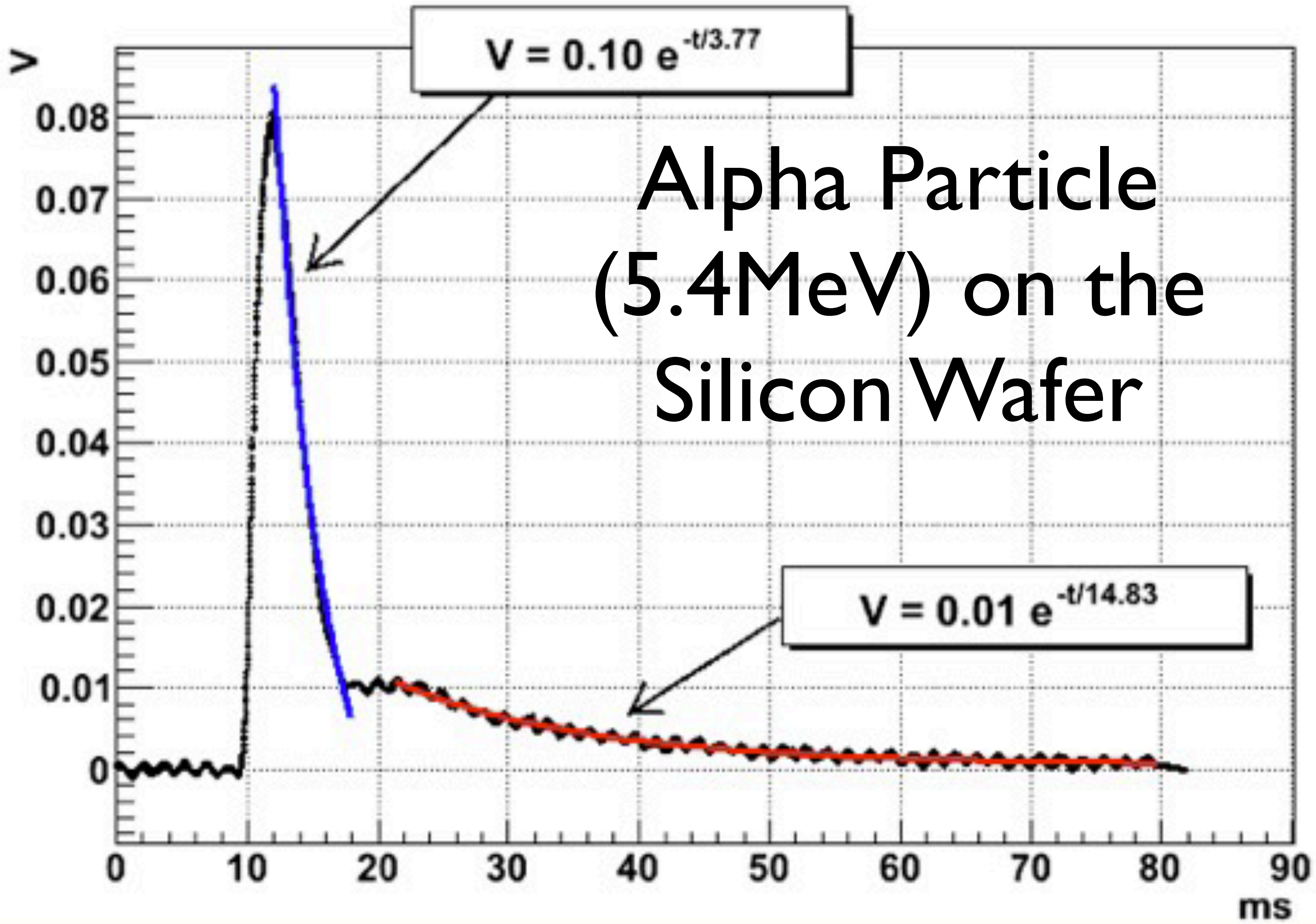
Detected glitches are fit to the template starting from few samples after the maximum and is increased to eight samples after the maximum.

Interpretation: Long Glitch Origin

Catalano et al.
2014 A&A 569, A88

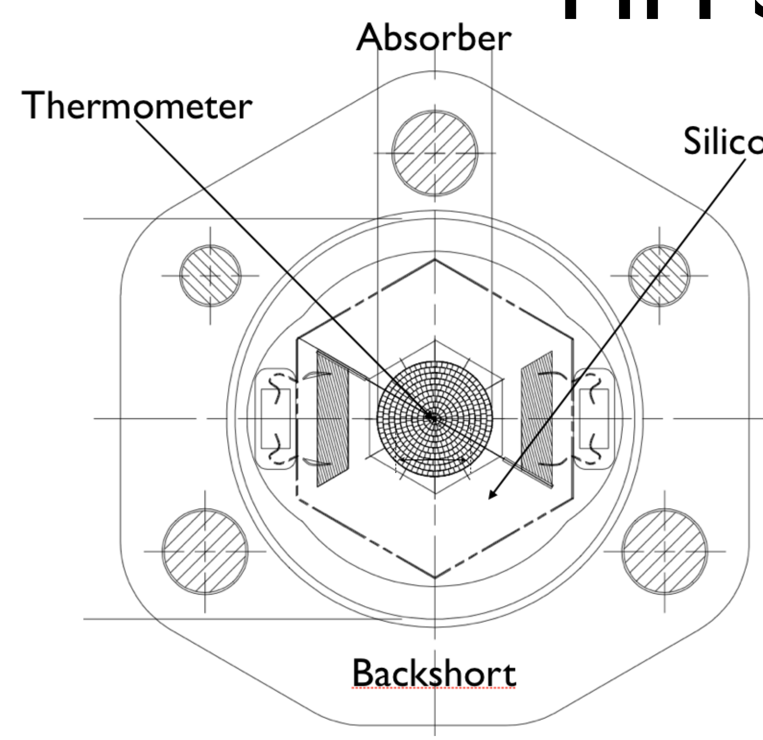
The faster time constant can be explained by ballistic phonons heat conduction. The longer time constant of tens of milliseconds represents the heat diffusion between the silicon die and the NTD thermometers.

Ground-based tests have been performed on spare HFI bolometers



[Catalano, A., Ade, P., Atik, Y., et al. 2014a, A&A, 569, A88]

HFI SWB



Transfered Energy on the thermometer (suppression factor): % of the energy detected by the NTD from a particle deposited in the silicon wafer: 1.5 per-mil.

Conclusions on HFI Bolometers

• Any common thermal mode affecting all thermometers and bolometers that is not fully corrected by the bolometer plate control heaters is removed using the dark bolometer signals. After corrections we find a flat noise spectrum in agreement with requirement.

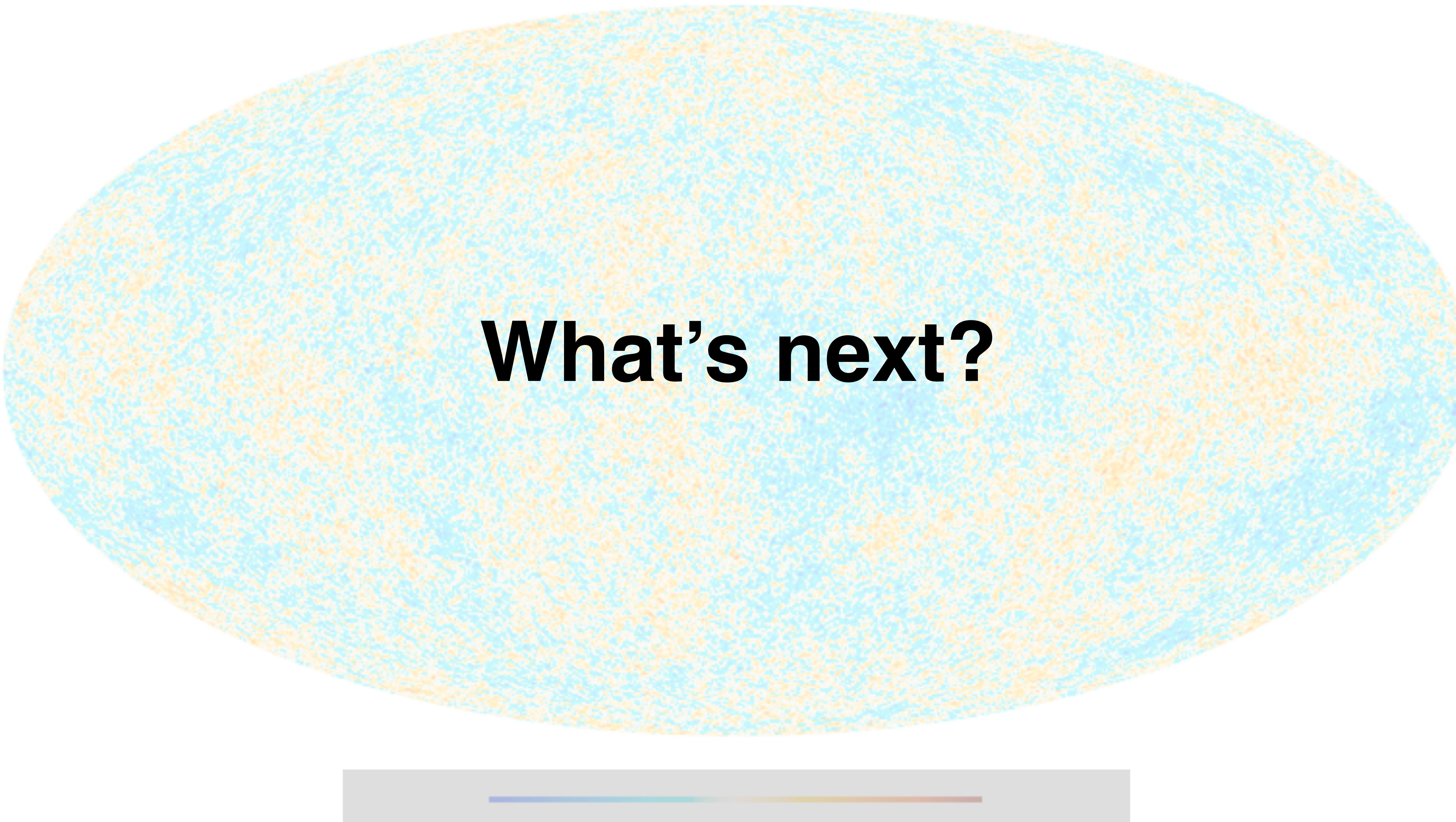
• Glitch shapes are not simple single pole exponential decays and fall into a three families.

• The glitch shape for each family has been characterized empirically in flight data and removed from the detector time streams. The spectrum of the count rate/unit energy as a function is computed for each family and a correspondence to where on the detector the particle hit is made.

• Most of the detected glitches are from particles incident on the Silicon die frame supporting the micro-machined bolometric detectors.

• The influence of CRs for future generation arrays for space must be taken into account from the very first phases of the design in parallel with all the other characteristics like NEP and time response. In particular, beam testing should be planned to study irradiation on whole array of detectors (pixels, substrate and housing).

What’s next?



Needs for Future CMB Space Mission

- CMB photon noise limited detectors.
- Hundreds/thousands pixel array.
- Linearity and fast time constants.
- Control of systematics effects.

Detectors of an array share the same substrate, while HFI bolometers are fully independent.

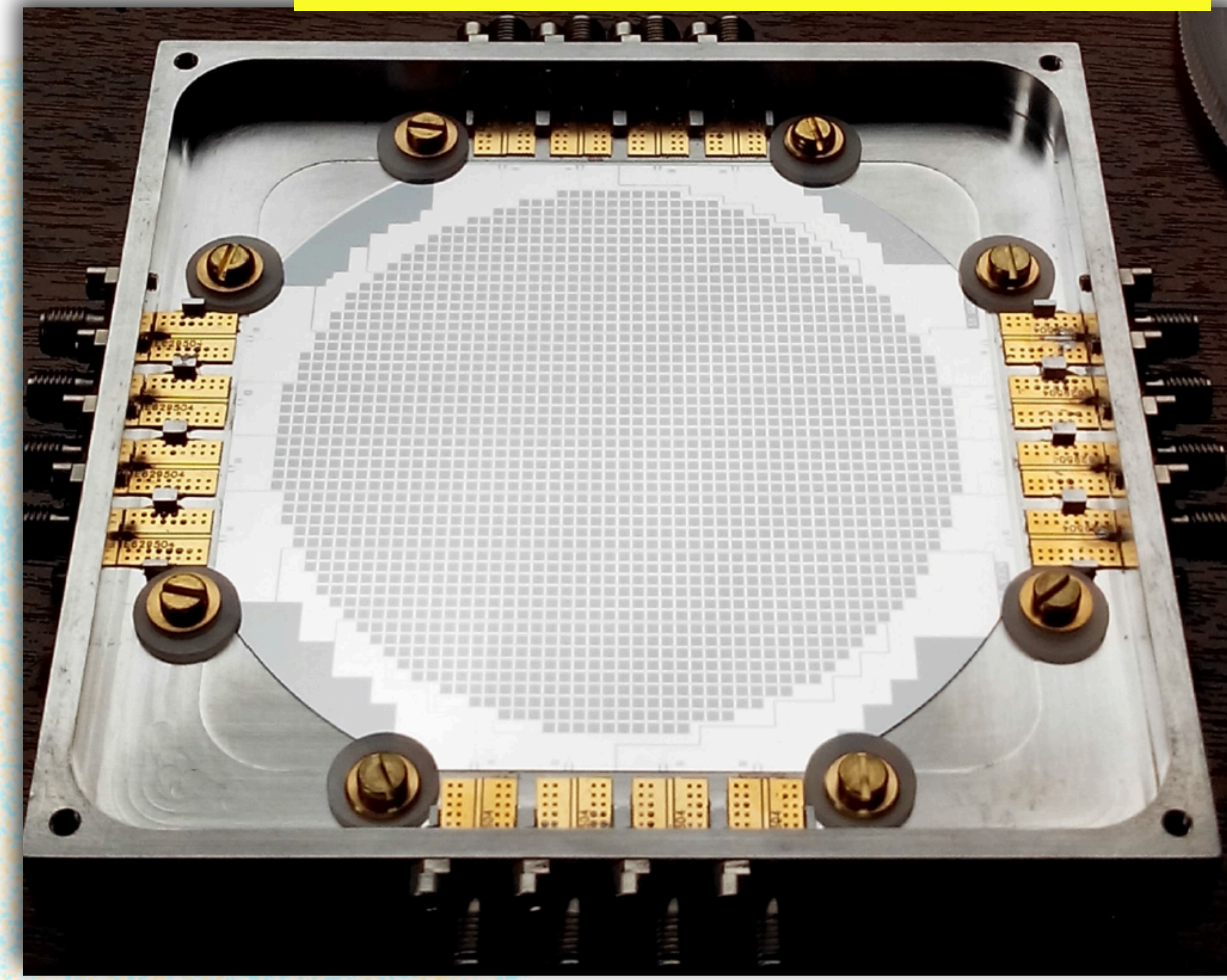
To fully caracterise the impact of CR in an array of Detectors:

- Thermal Stability

- Time Constants

- Suppression Factor

- Surface affected (coincidences) NEW!!!



NIKA2 thousands pixels array installed @ 30m Telescope IRAM

LEKID Arrays: Thermal Stability

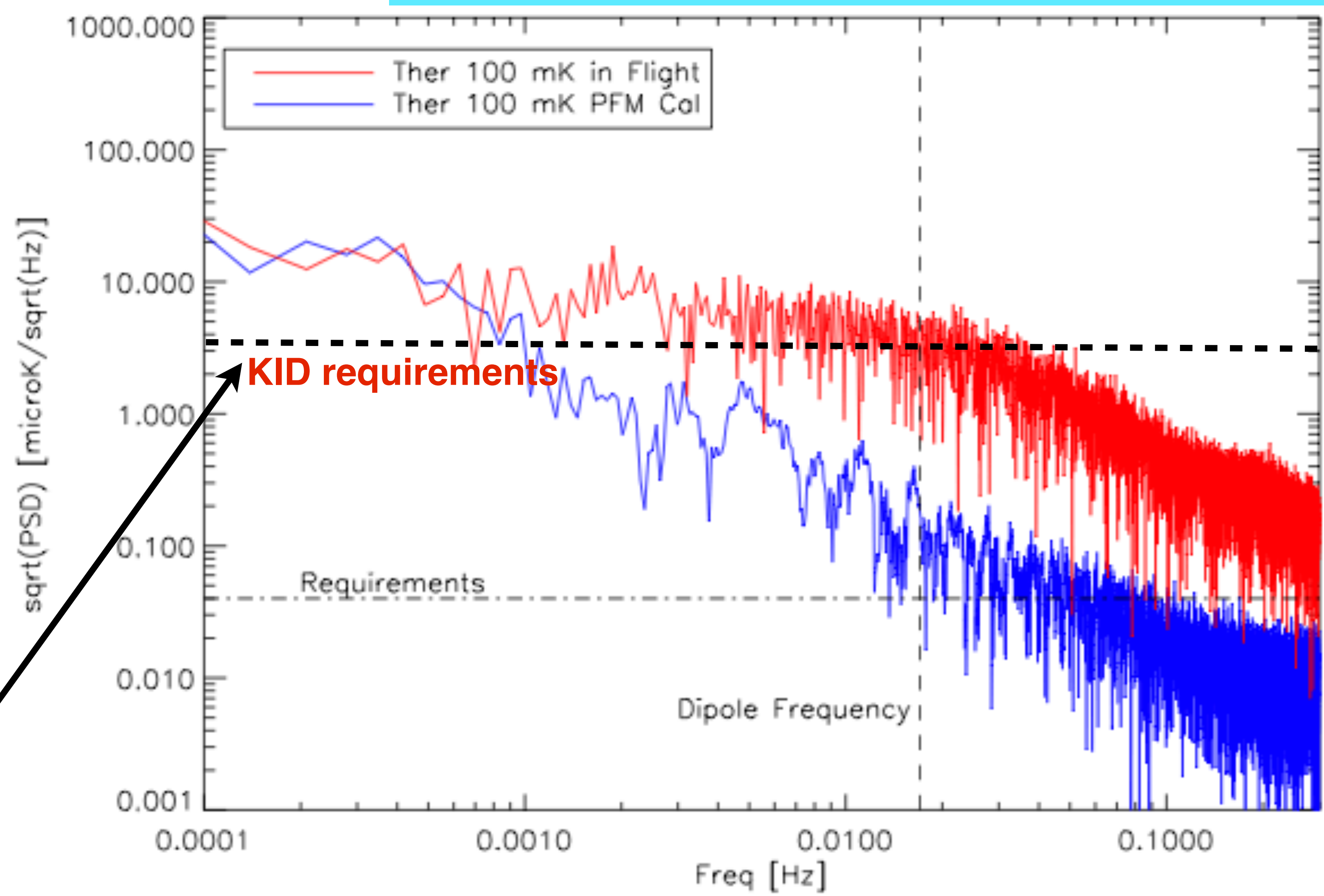
LEKID are much less sensitive than bolometers to Temperature fluctuations

CMB Photon noise estimated between 0.5-1 Hz/sqrt(Hz)

Lab Meas: for a change of plate temperature of 1mk we measured a change of resonance frequency of about 100 Hz

This corresponds: 5-10uK/sqrt(Hz)

Comparison of the signal of the thermometer of the bolometer plate stage between ground calibration and flight in frequency domain. The requirements are calculated for one bolometer.



LEKID Arrays: Impact of Ionising Particles

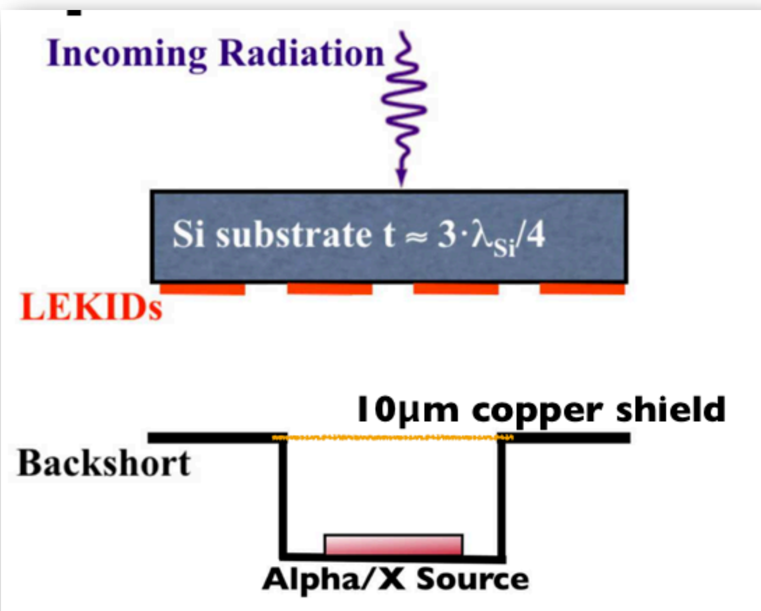
(Catalano et al. arXiv:1511.02652)

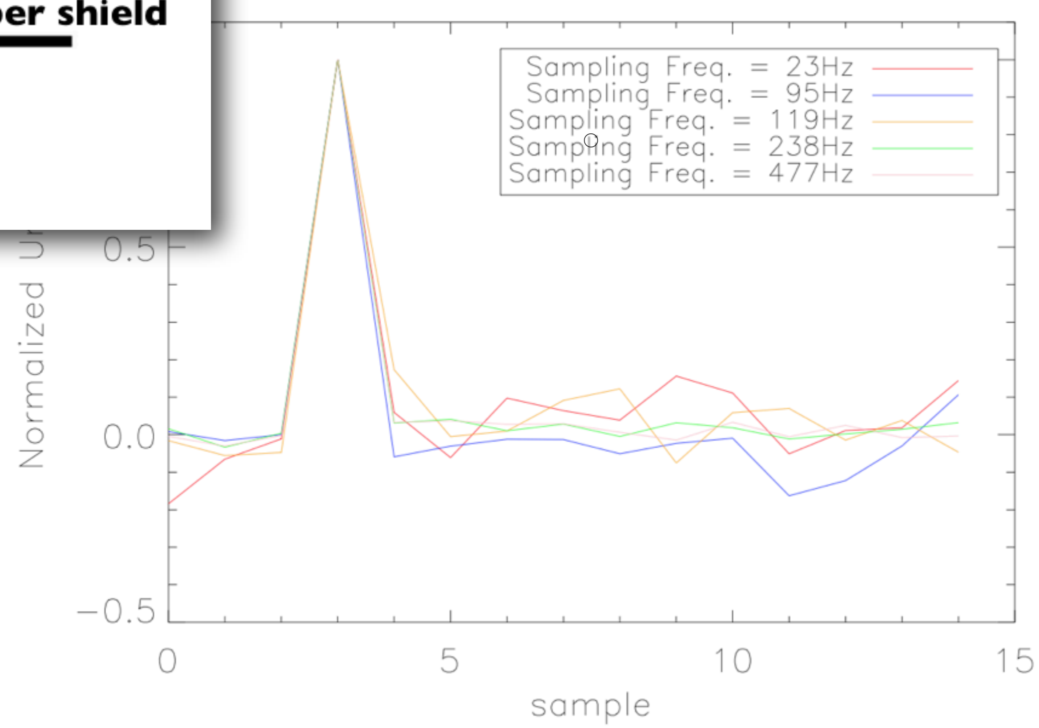
Setup

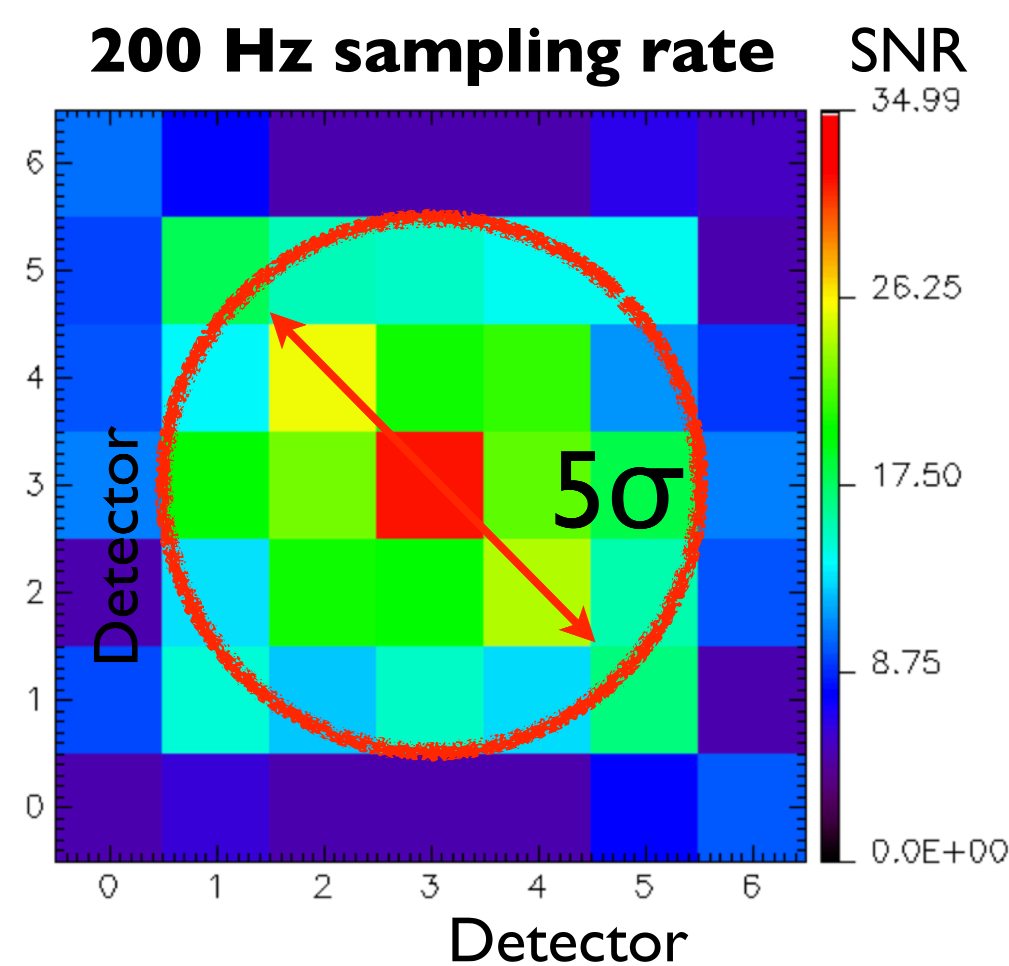
- 150 GHz LEKID array = NIKA-Like Al
  Roesch, M. et al. 2012, ArXiv 1212.4585
- Representative energy of a Proton@L2 (241Americium with copper shield 10μm)
- Sampling rate between 20-500 Hz

Main Results

- **Time Constants:** all the glitches appear as **one** sample in the time ordered data.
- **Transfered Energy on the pixel (suppression factor)**: **0.5 per-mil**
- **Coincidences:** the surface of the silicon wafer impacted by a 630 keV alpha particle never exceeds a square of **6x6 detectors** (about 1.4 cm^2).

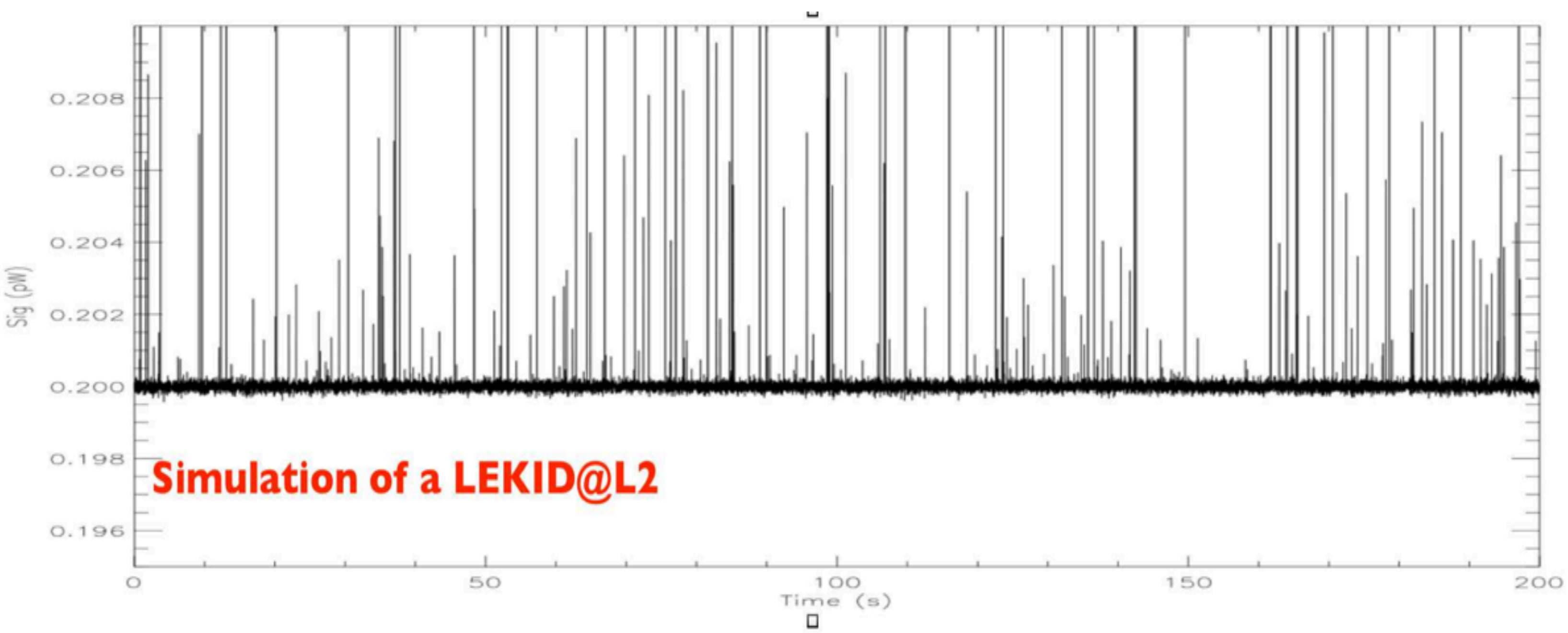


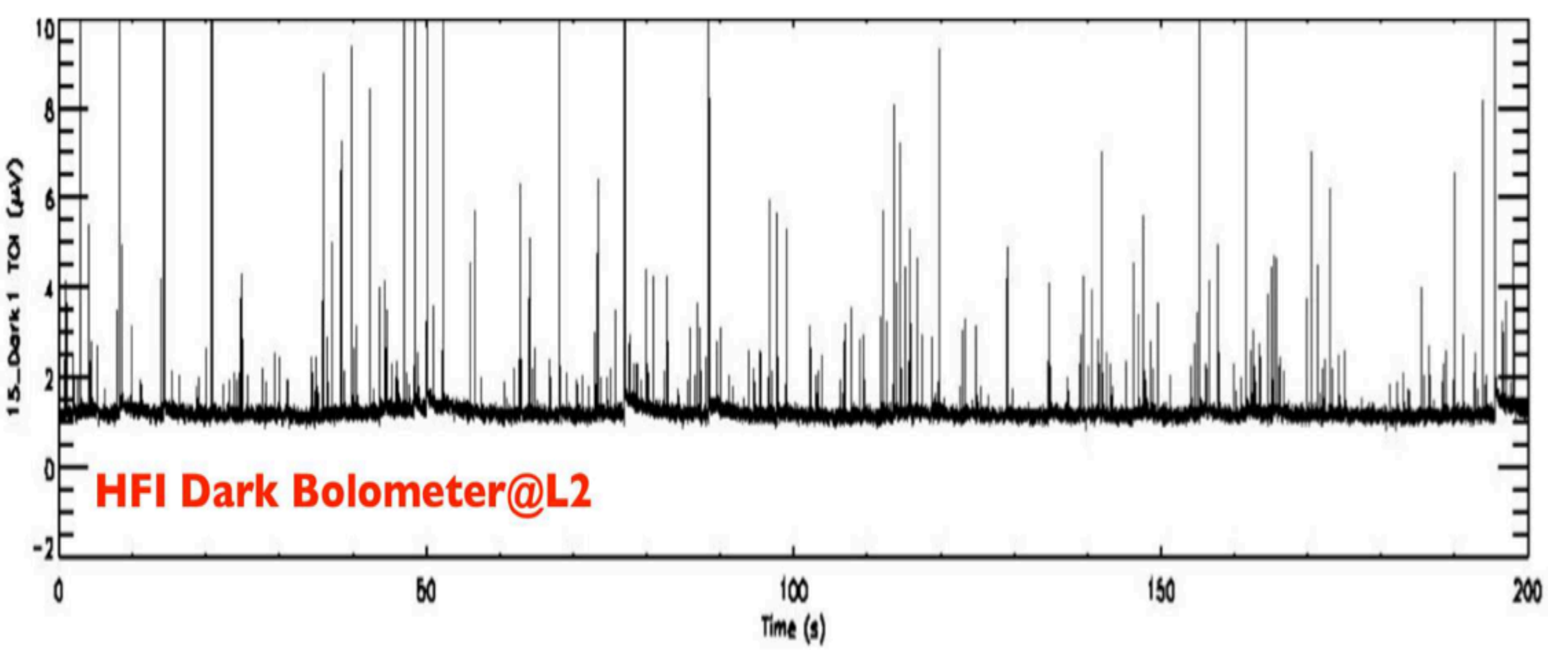




LEKID Arrays: TOI Simulation

We added CRs events to a realisation of noise with a standard deviation σ given from the expected photon noise level with average of 0.2 pW.



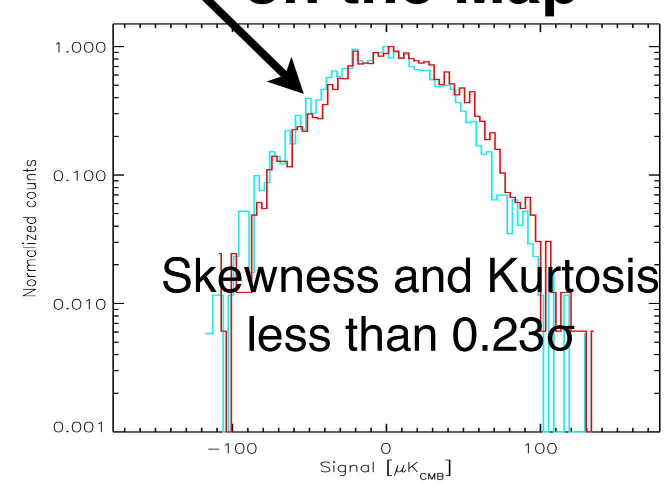


After de-glitching using a Planck-like method :

Main Results

- **Glitch rate:**
1.8 Hz vs 1 Hz (HFI)
- **Flagged Data:**
1% vs 12-20 % (HFI)
- **Increase of Noise:**
giving a level of non-gaussianinity of the same order of HFI.

on the Map



Skewness and Kurtosis less than 0.23σ

Conclusion on LEKID arrays

We have shown that LEKID arrays originally designed for ground-based measurements behave adequately in space-like conditions. Spacekids collaboration have worked hard in order to further decrease the impact of CR on LEKID arrays based on Al film (Ti-layer, ...)

- Less severe requirement in terms of thermal stability of the focal plane unit.

- The maximum energy transferred to a pixel from a particle absorbed on the Silicon wafer is about 0.5 per-mil (3 times less then in HFI bolometers).

- All the glitches appear as one sample in the time ordered data up to a sampling rate of 500 Hz.

- Thanks to a model, we have shown that the impact of CRs on LEKID arrays will be less severe than the one observed for HFI bolometers.