Some “End-User” Notes

Ken Ganga

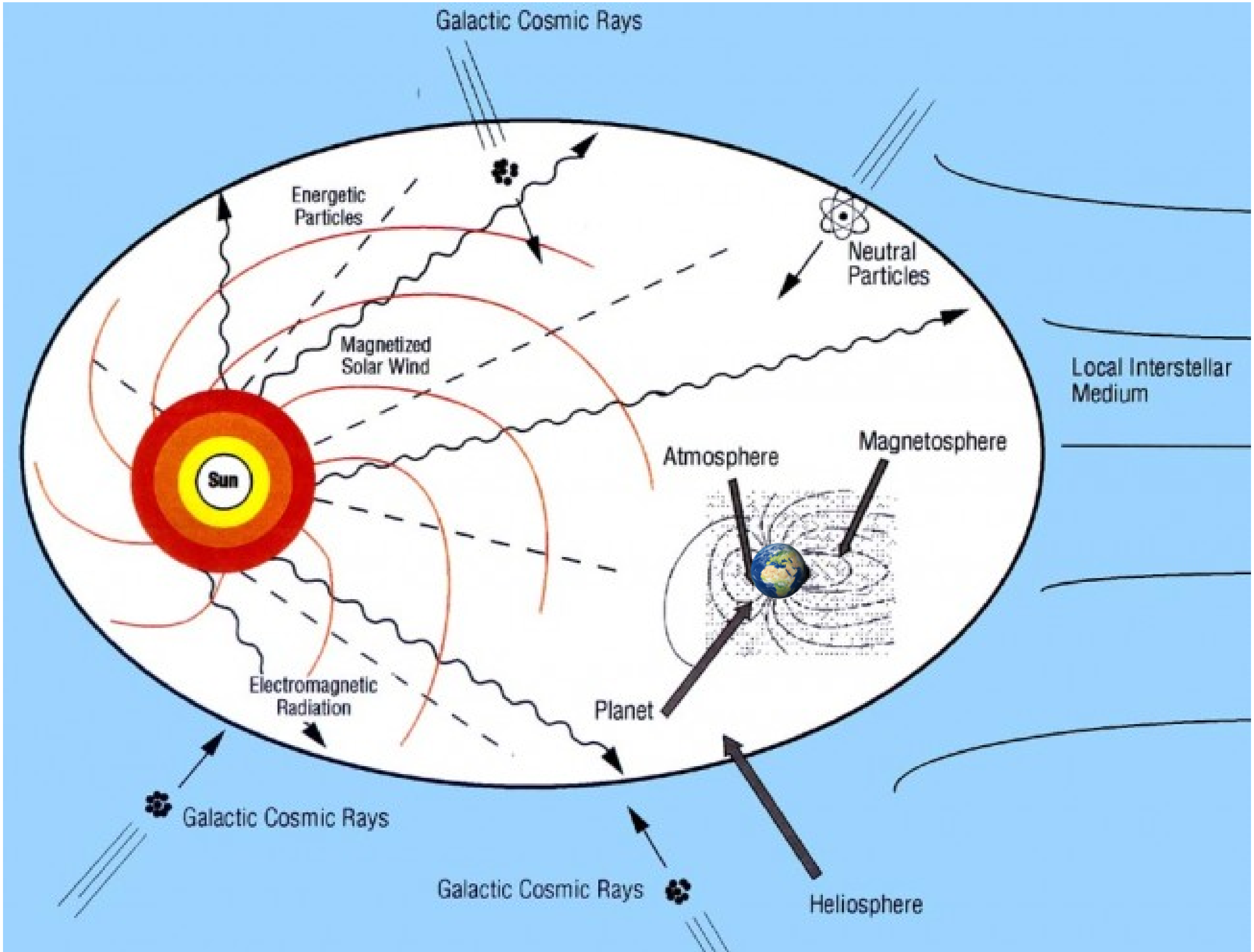
APC/Paris-Diderot
ganga@in2p3.fr

Outline

- I'm NOT a “detector person”
- I'm not even a “fan” of detectors!
- I'm just an “end-user” of detectors

- I'll try to describe some detector experiences with a number of astrophysics (mostly CMB & some subMM/FIR) astrophysics experiments
  - QUAD (Ground-Based)
  - The “Far Infrared Survey” (Balloon)
  - ISO/*CAM (Satellite)*
  - Planck/*HFI (Satellite)*
  - *Spider (Balloon)*
  - Euclid/*NISP (Satellite)*

Solar & Galactic Particles



There are two sources of particles that hit our detectors – those from the Sun, and those from the interstellar medium – Galactic cosmic rays

http://guardianlv.com/2013/09/baffling-extra-galactic-cosmic-rays-origins-soon-to-be-revealed/

Spider-Web Bolometers

Early subMM/microwave bolometers had solid absorbers.

“Spider-web” bolometers have lower cosmic ray cross-sections, but similar photon cross-sections as their “filled” cousins. They also have a lower heat capacity.

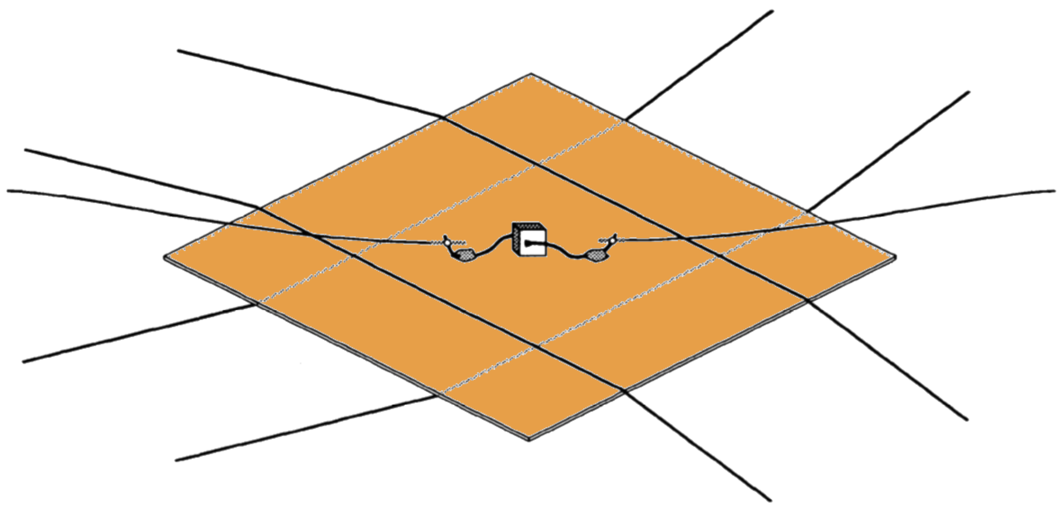
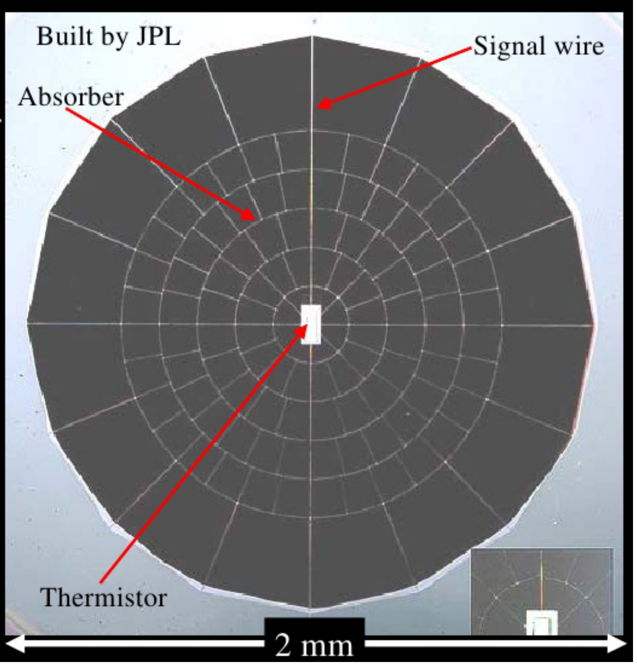


Figure 2. Schematic of a standard composite bolometer. The absorber is a solid dielectric substrate with an evaporated metal film layer. The impedance of the metal film is matched to free space to maximize the quantum efficiency for absorption of incoming radiation. The absorber is supported from a metal ring at the bath temperature, T_0 with low thermal conductivity nylon wires. The thermistor is a cube of semiconductor material with a doping level tailored to give a strong dependence of resistance on temperature at the operating temperature of the bolometer. Low thermal conductivity superconducting readout leads are attached to opposite faces of the thermistor.

Spider-Web Bolometers

- The absorber is micro machined as a web of metallized Si_3N_4 wires, 2 µm thick, with 0.1 mm pitch.
- This is a good absorber for mm-wave photons and features a very low cross section for cosmic rays. Also, the heat capacity is reduced by a large factor with respect to the solid absorber.
- NEP ~ 2 10^{-17} W/$Hz^{0.5}$ is achieved @0.3K
- 150µK_{CMB} in 1 s
- Mauskopf *et al.* Appl.Opt. **36**, 765-771, (1997)



Mauskopf: http://link.springer.com/chapter/10.1007%2F978-94-011-4714-9_28

De Bernardis: http://www.slideshare.net/nipslab/oltre-lorizzonte-cosmologico-3474779

QUAD (~2008)

- We actually removed whole scans (~minutes) when a “glitch” was detected (< ~1 second), rather than deal the hassle of masks, etc.

ArXiv:0805.1944v3

- Removed <<1% of its data from glitches.

- Newer focal planes use TESs or KIDs, but NTD spiderweb bolometers have been a mainstay in the CMB

http://icestories.exploratorium.edu/dispatches/big-ideas/the-south-poles/

Balloons

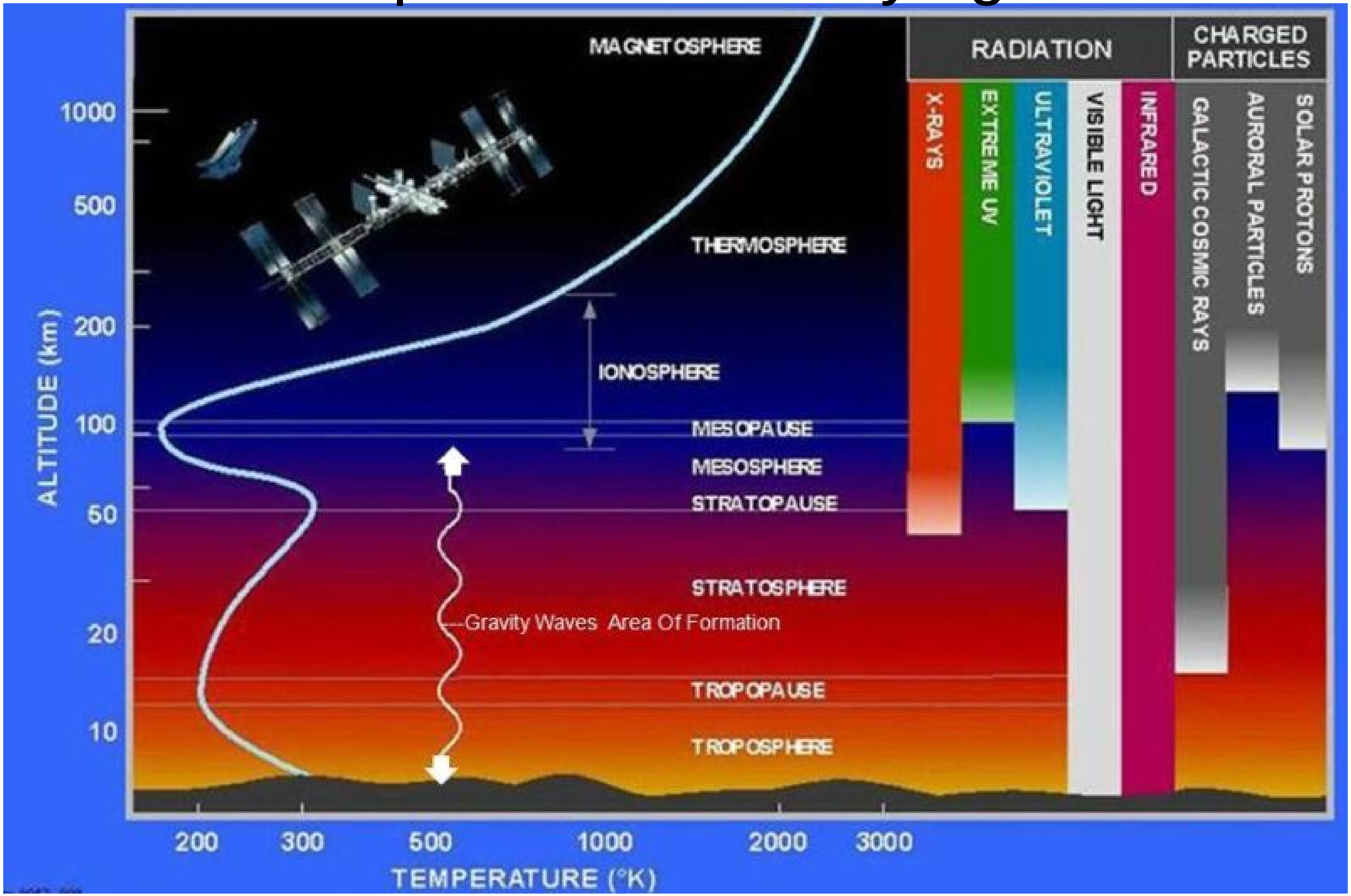
Balloons take data at ~38 km – well above most of the atmos-phere (which protects us from cosmic rays)

https://en.wikipedia.org/wiki/Andrew_E._Lange

The Atmosphere Protects Us

We want to go above the atmosphere to avoid its effects on the photons we're trying to detect.

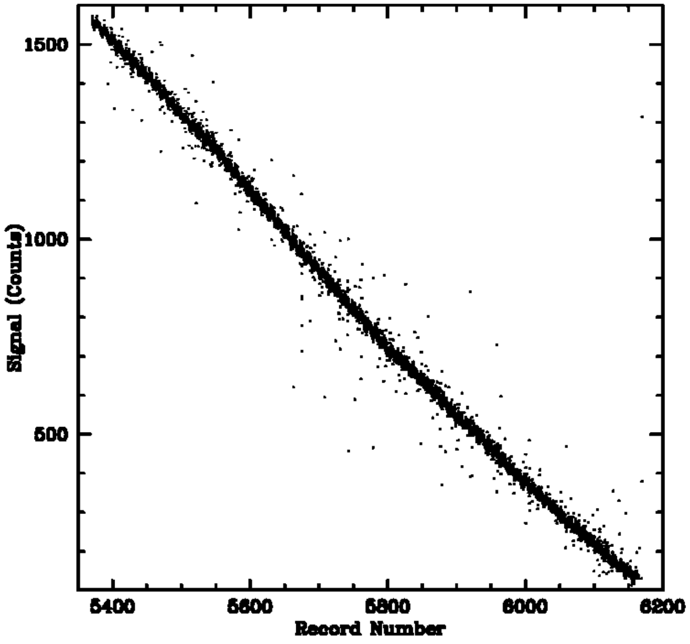
Unfortun-ately, observing above the atmos-phere also makes us more sensitive to particles

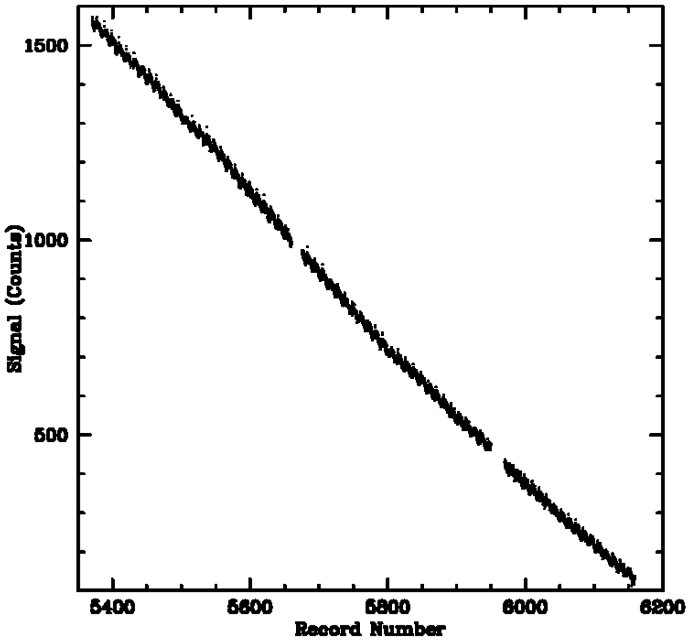


http://www.theozonehole.com/atmosphere.htm

Far Infra-Red Survey (Balloon; ~1990)

- 1 detector (per frequency)
- ~8 hours of data
- Sampled at ~4-5 Hz
- We actually flagged particle hits *completely by hand*!
- It took a couple of weeks of a single graduate student's time
  - With thousands of detectors sampled more quickly for years, this is not really viable any more...





BOOMERANG (~2000)

- It is not just a question of “masking” data
- This was one of the best measurements of our “transfer function”, which was necessary for the data analysis.
- We “deconvolved” it from the data by Fourier transforming timelines, this function, dividing, and inverse-Fourier transforming

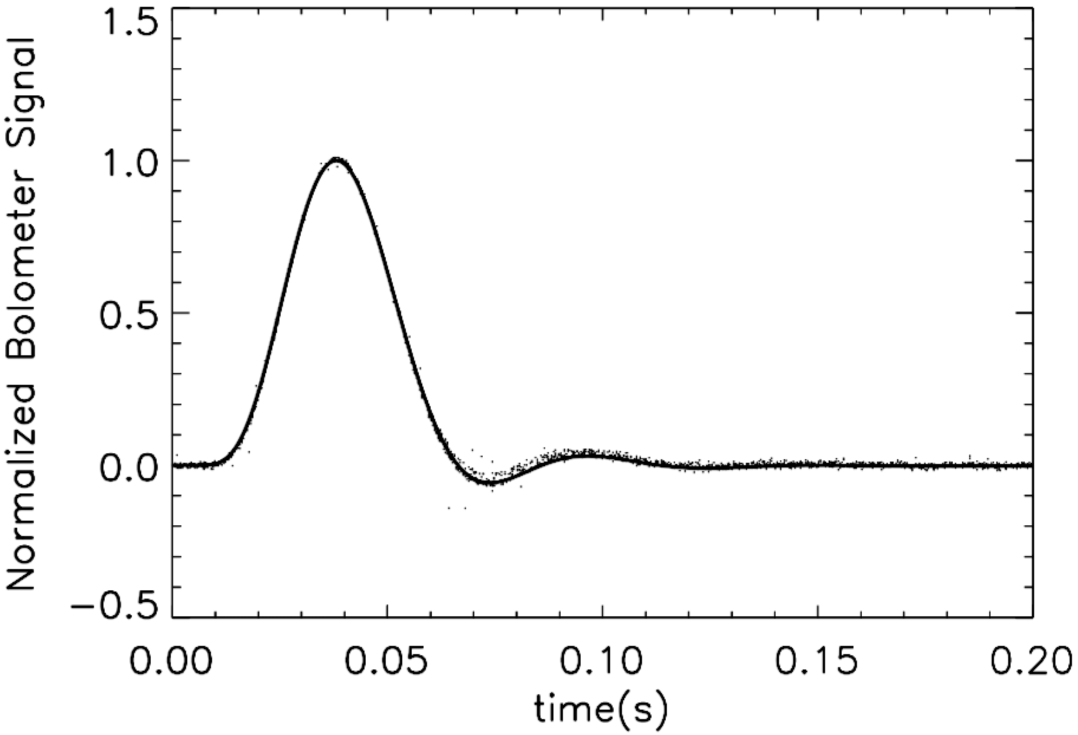


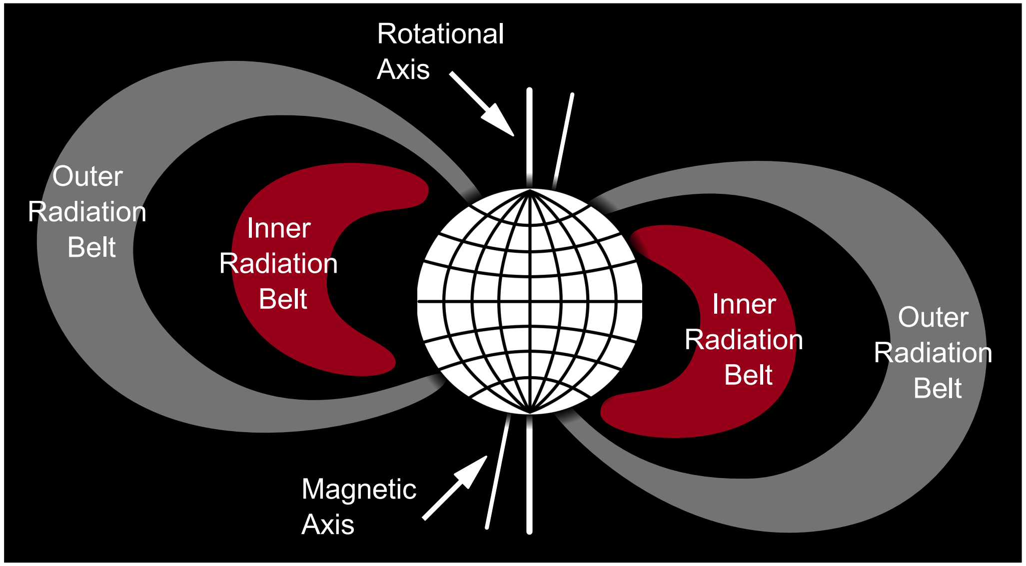
Figure 6.9:
The best fit impulse response function to cosmic ray hits for one of the 150 GHz bolometers.

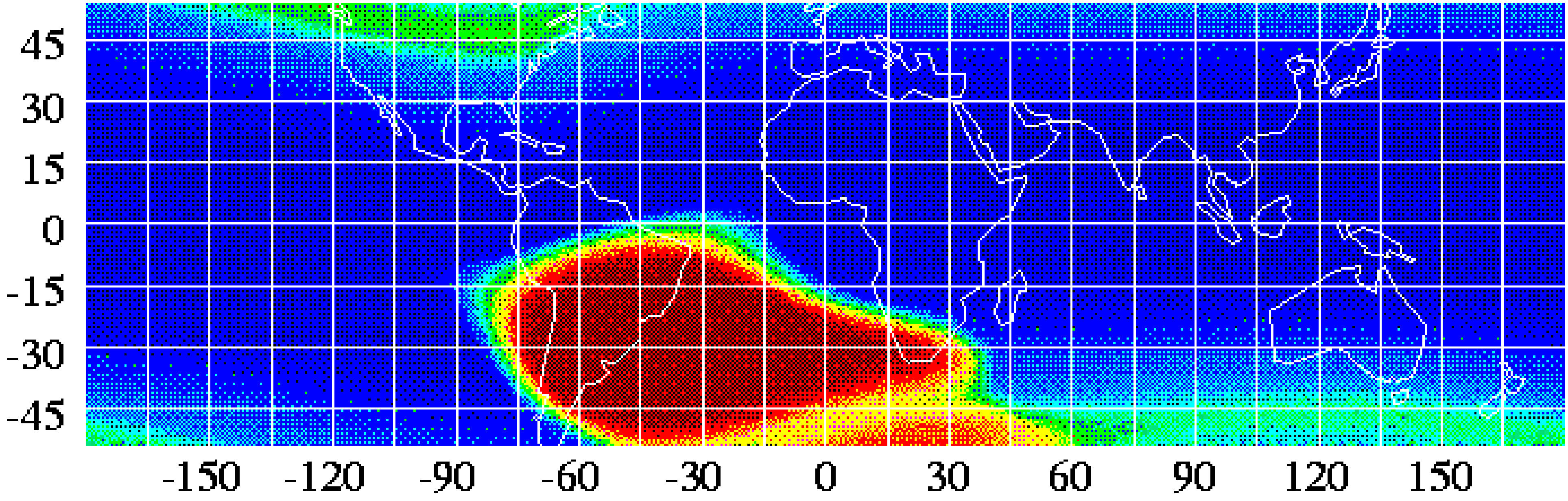
- A couple of detectors
- ~2 weeks of data
- Sampled at ~60 Hz

The South Atlantic Anomaly

- The radiation belts, regions of trapped particles, get close enough to Earth in some areas to cause satellites problems with particle hits

https://upload.wikimedia.org/wikipedia/commons/0/02/Van_Allen_radiation_belt.svg

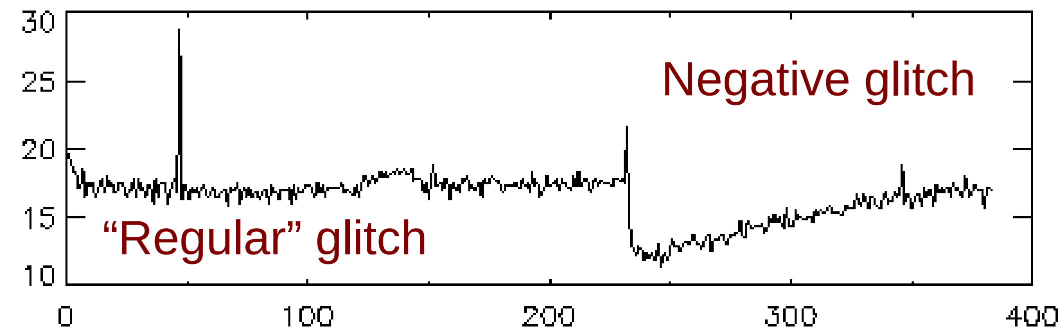




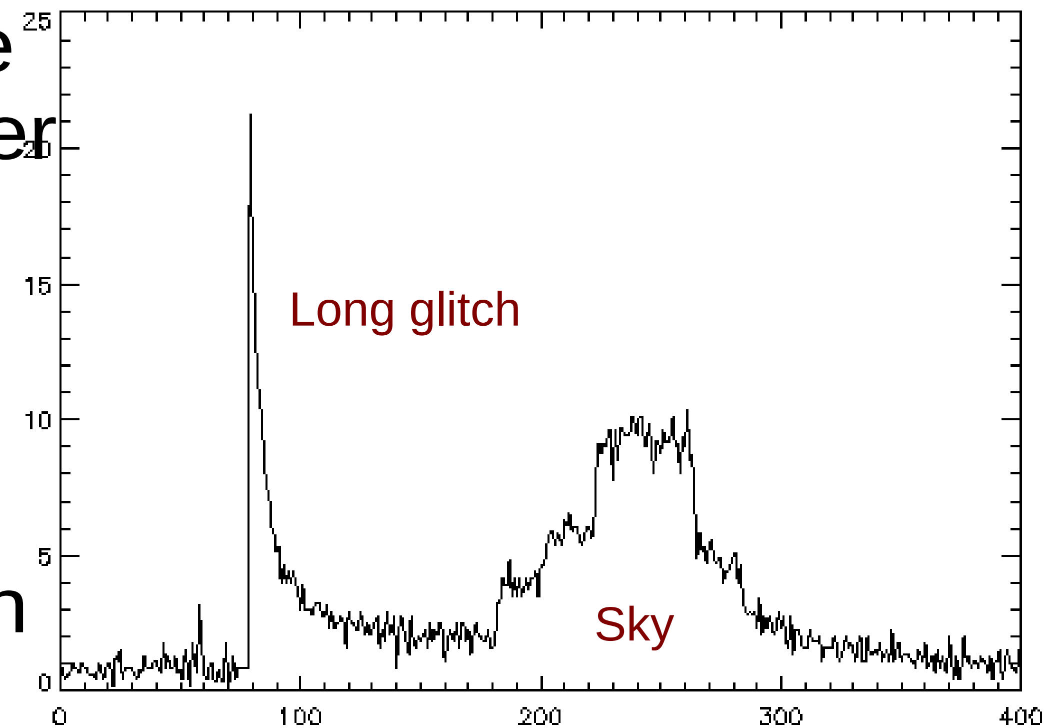
https://upload.wikimedia.org/wikipedia/commons/b/bc/ROSAT_SAA.gif

ISO/CAM (InSb & Si)

- ISO/CAM had faders, dippers, and others I've probably forgotten
- Planck/HFI: grass, trees, elephants, rhinos...



- Here you can see that the time constants were longer than an observation. We had to do "total history" removal



- Solar Flares would occasionally shut us down for whole days (~ 1/mo.)

http://aas.aanda.org/articles/aas/abs/1999/01/ds1478/ds1478.html

Elevated Planck/HFI Glitch Rate

- Planck was at the second Lagrange point, so radiation belts were not a problem.
- However, sensitivity and design led to a *much* higher rate of cosmic rays
  - ~15% of data is flagged
- In addition, 99.9% of the data is “touched” by cosmic rays and must be “corrected” using stacked templates
- We need to look at the whole system

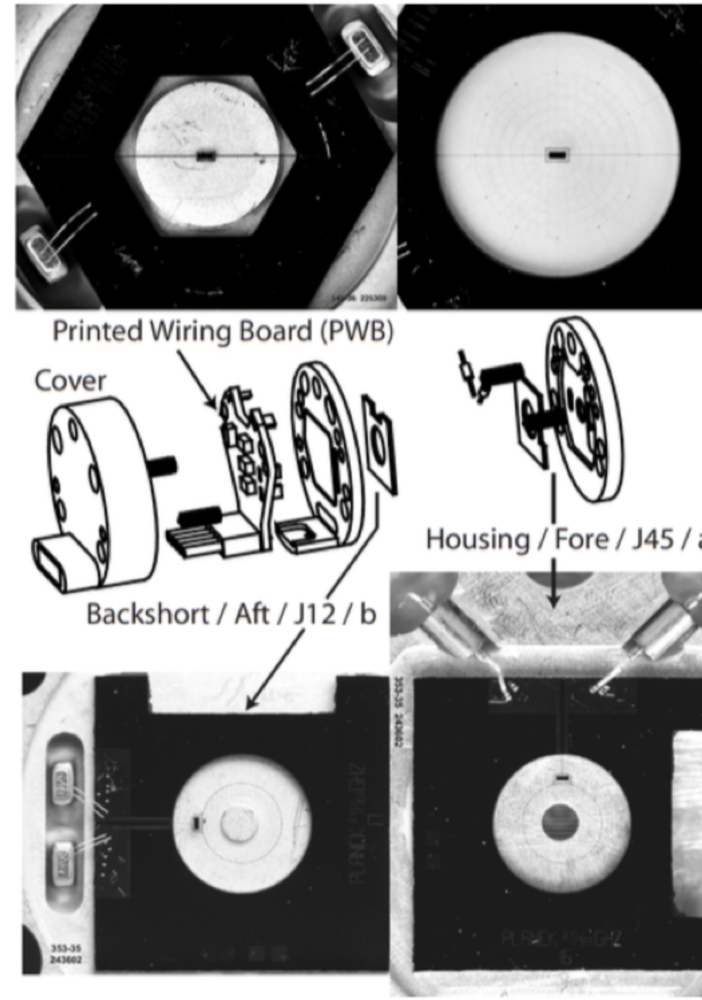
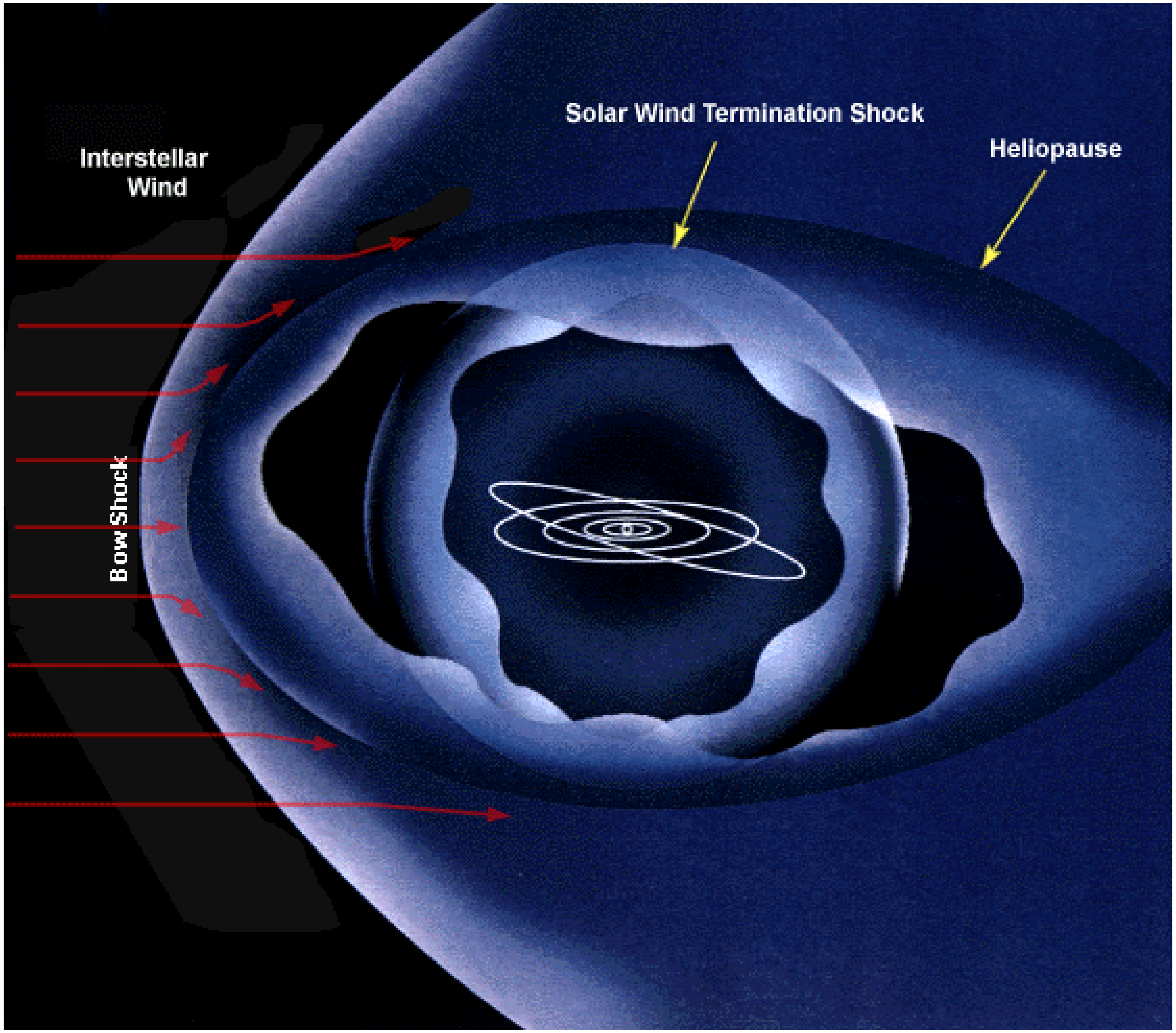


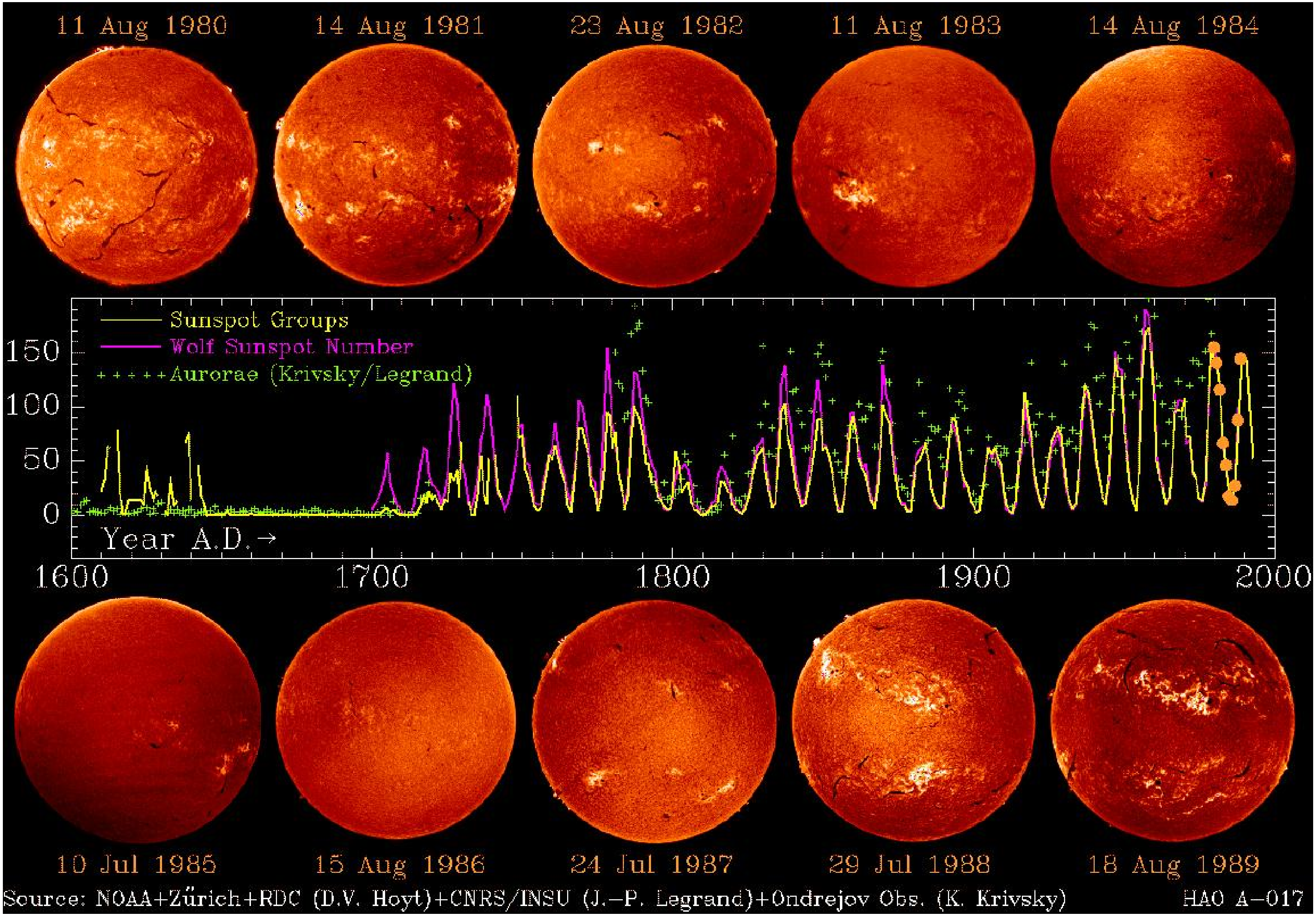
Fig. 1. Top left and right: Completed multimode 545GHz and single mode 143GHz SWB bolometer modules. Middle: An exploded view of the assembly of a PSB. Alignment pins, shown in solid black, fix the aft and fore bolometer assemblies to an angular precision of < 0.1°. The SWB assembly is similar to the PSB aft bolometer assembly and does not include a feedhorn aperture integrated with the module package. Bottom: A PSB pair epoxied in the module parts prior to mating. To the right, the feedhorn aperture can be seen through the fore bolometer in the housing. To the left, the 1/4 wave backshort can be seen through the aft bolometer absorber mesh.

The Galactic Cosmic Rays

- When Solar activity increases, the Solar wind expands and “pushes” high-energy, Galactic cosmic rays out.
- But the number of lower energy Solar particles can increase dramatically during solar flares and coronal mass ejections
- Modulated by 11 year solar cycle



Solar Activity



http://ircamera.as.arizona.edu/NatSci102/NatSci102/images/suncycle.jpg

Planck Glitch Rate Evolution

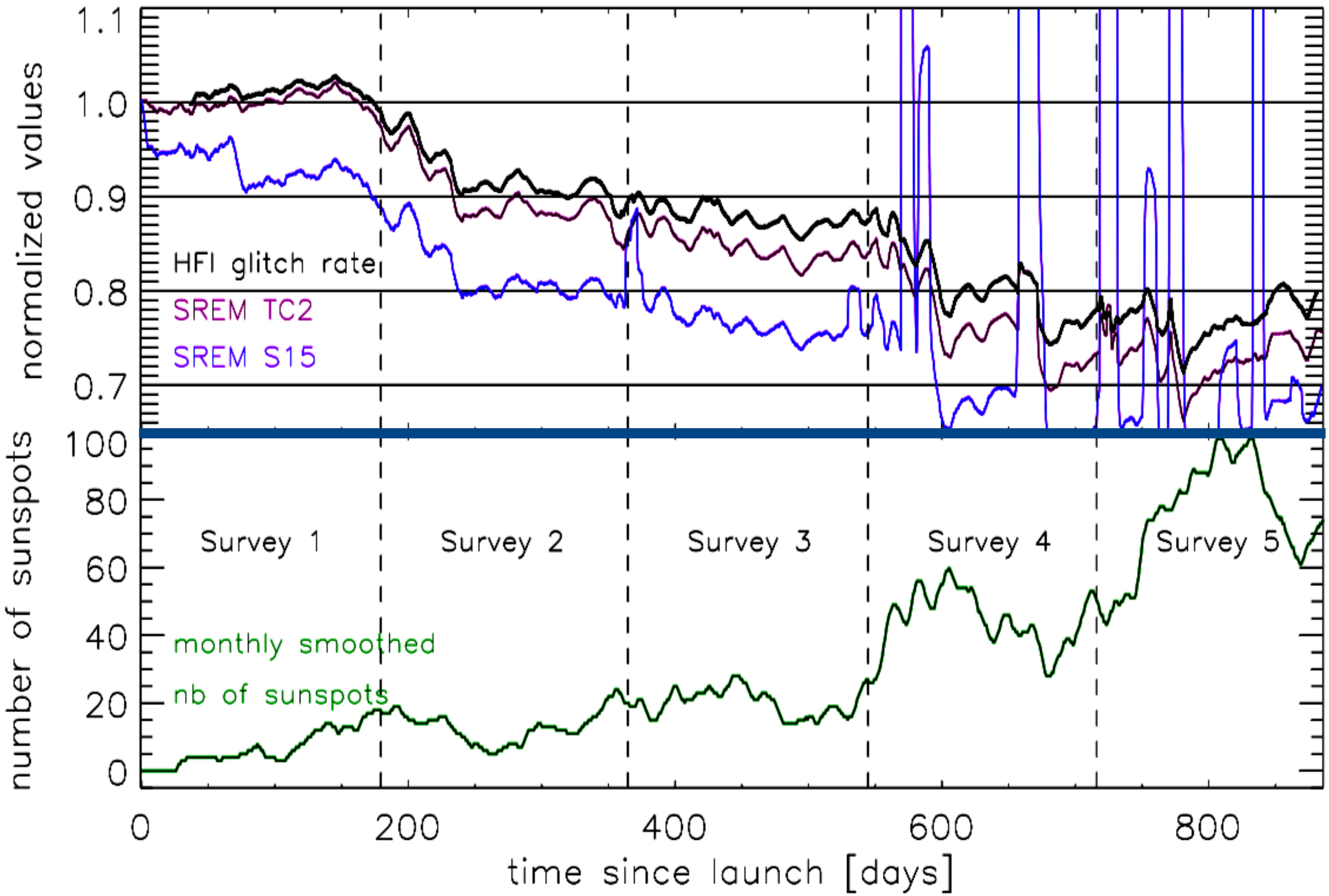


Fig. 10. Top : Normalized glitch rate (black line), cosmic rays flux measured by the SREM for deposited $E > 3$ MeV in purple, and $E > 0.085$ MeV in pink, as a function of time. Bottom : monthly smoothed number of sun spots. arXiv:1303.5071v2

Euclid/NISP (HgCdTe)

- Simulations indicate that NISP will have to reject ~3% of the pixels due to particle hits
- The team, however, is only now starting to understand the “persistence” in NISP
  - Will it make things worse?

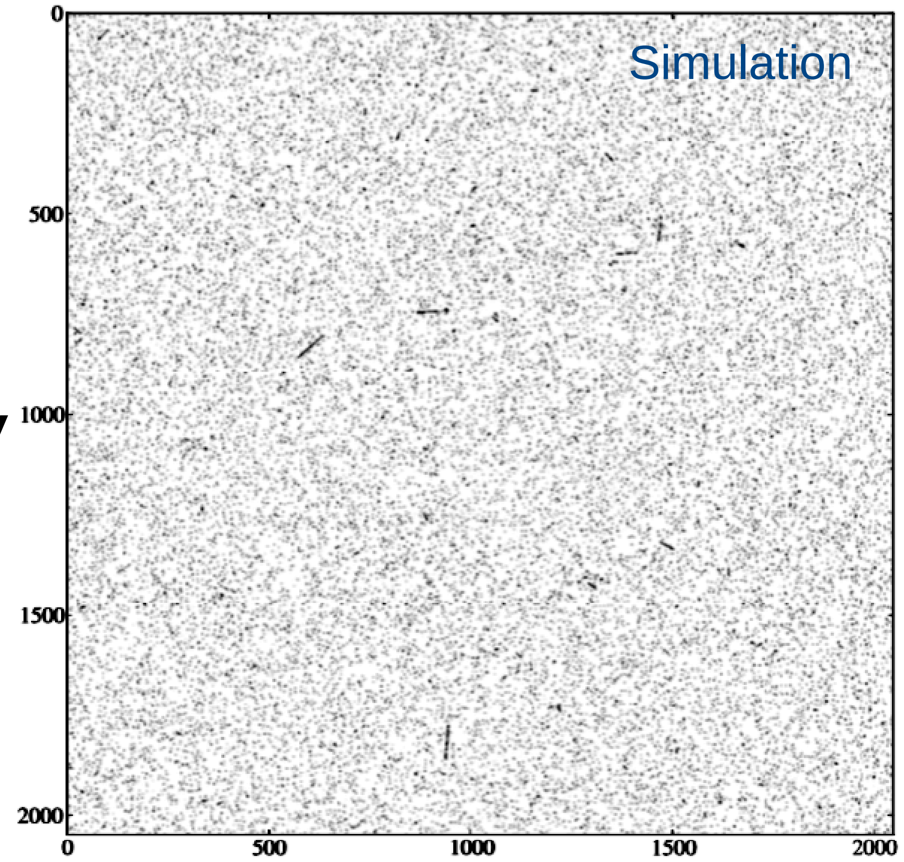
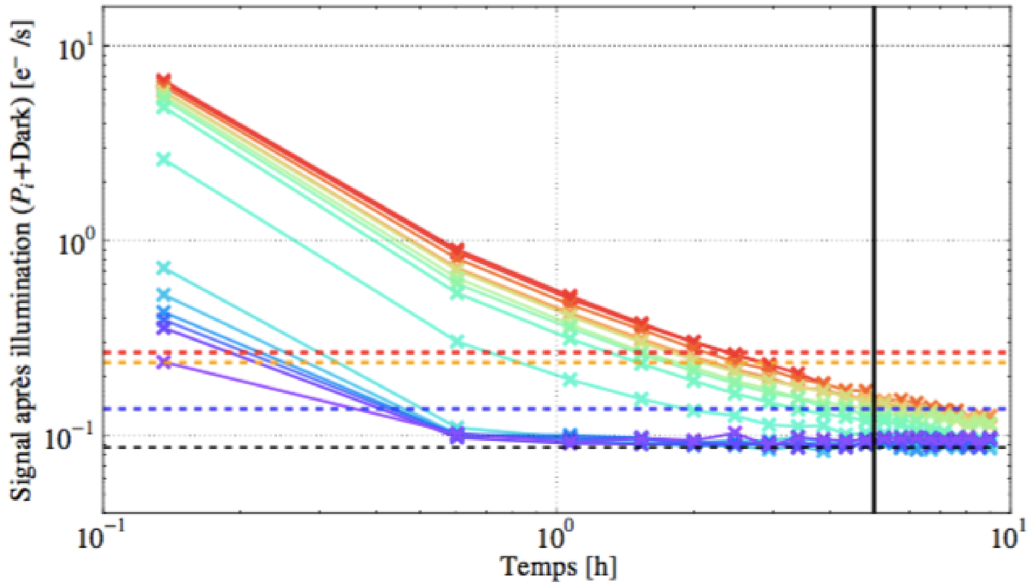


FIGURE 6.4 : *Image simulée d'un détecteur H2RG en fin d'acquisition de type spectrométrie (560 secondes).*

Thèse Benoit Serra

Nombre d'impacts dans la rampe	Pixels	$\%_{détecteur}$
0	4068972	97%
1	123374	2,94%
2	1937	0,05%
3	21	5×10^{-4}%

TABLE 6.2 : *Table répertoriant le nombre de pixels impactés par x particules pendant une exposition de 560 secondes.*



Need to “learn” to Deal with NISP

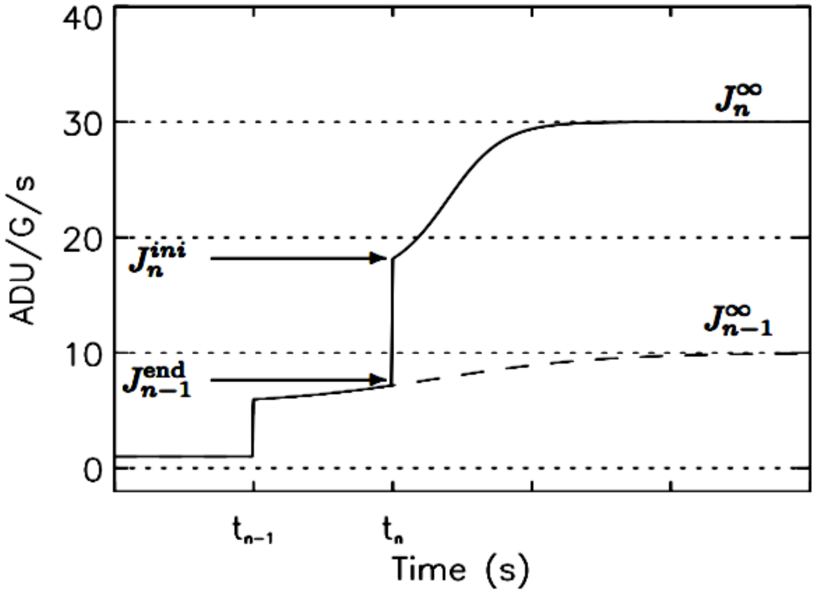


Fig. 5. Response to two successive upward steps of flux (at time $t_{n-1} = 100$ s and $t_n = 200$ s respectively), corresponding to three blocks of constant input fluxes (number $n-2$, $n-1$ and n respectively). We have taken $\beta = 0.55$, $\lambda = 600$. ADU/G, $J_{n-2}^{\text{end}} = J_{n-2}^{\infty} = 1$. ADU/G/s, $J_{n-1}^{\infty} = 10$. ADU/G/s and $J_n^{\infty} = 30$. ADU/G/s. This figure is adapted from Fouks & Schubert (1995)

Coulais & Abergel (1999)

Finally, we obtain from Eq. (4) and Eq. (5):

$$J_n(t) = \beta J_n^{\infty} + ...$$

$$\frac{(1-\beta)(J_{n-1}^{\text{end}} - \beta J_{n-1}^{\infty})J_n^{\infty}}{(J_{n-1}^{\text{end}} - \beta J_{n-1}^{\infty}) + ((1-\beta)J_n^{\infty} - (J_{n-1}^{\text{end}} - \beta J_{n-1}^{\infty}))\mathrm{e}^{-(t-t_n)J_n^{\infty}/\lambda}}. \quad (6)$$

$J_n(t)$ depends on J_n^{∞}, J_{n-1}^{∞} and J_{n-1}^{end} (Fig. 5).

If we take: $J_{n-1}^{\infty} = J_{n-1}^{\text{end}} = 0$, we have $\forall t > 0, J_n(t) = \beta J_n^{\infty}$, and $\forall n' > n, J_{n'}(t) = \beta J_{n'}^{\infty}$.

(One of the)
ISO/Cam Glitch Models

(An early)
Euclid/NISP Glitch Model

7.5. Modèle d'ajustement du signal de persistance 183

$$S_{persis} = \int_0^t F_{persis} \times dt = \int_0^t \sum_{i=1}^{N} c_i \times e^{-t/\tau_i} \times dt$$
$$= \sum_{i=1}^{N} c_i \times \tau_i \times (1 - e^{-t/\tau_i}) \quad (7.2)$$

Thèse Benoit Serra (2016)

Conclusions?

- We will always be affected by Solar particles and cosmic rays to some level.
- Testing detectors in a particle beam can help eliminate unpleasant surprises in orbit.
  - Even if we think you understand the detectors already, we don't always understand the environment well enough
- In France in particular, the *Euclid*/NISP effort might benefit from the *Planck*/HFI experience in fitting data templates and/or the *ISO*/Cam experience in fitting models.
  - The IN2P3 and CEA have a lot of experience with both Planck and ISO, and are all working on Euclid...