Detector Technology
Lessons from Planck / HFI

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JPL / Caltech
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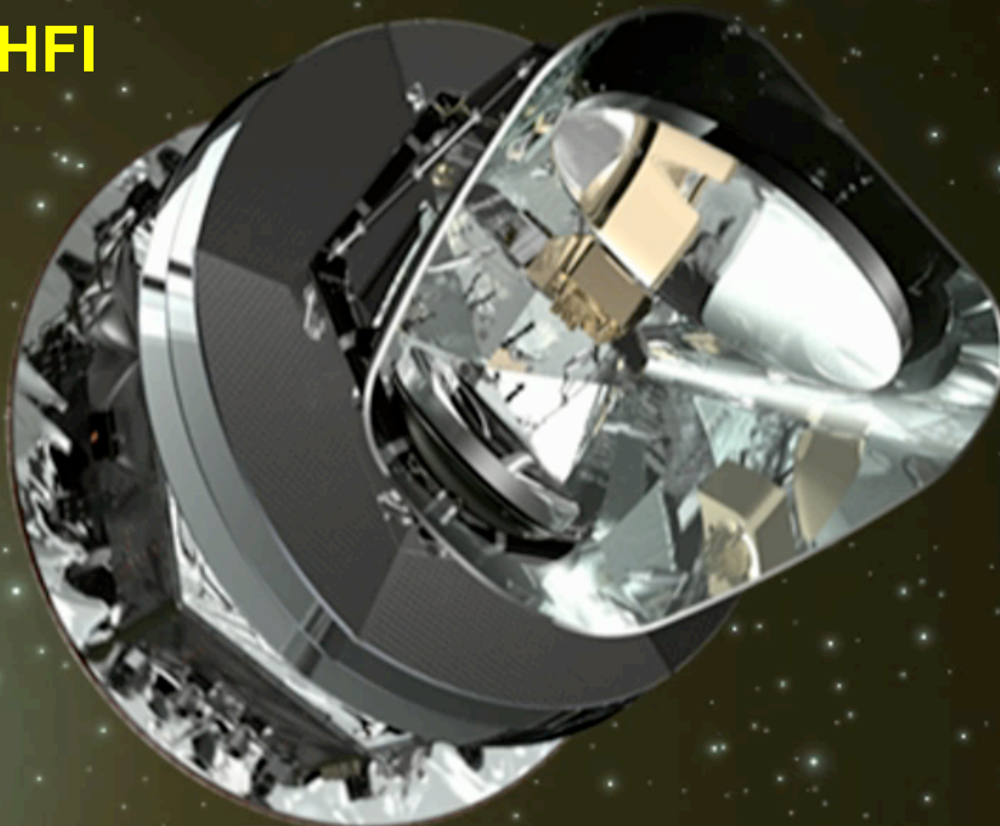


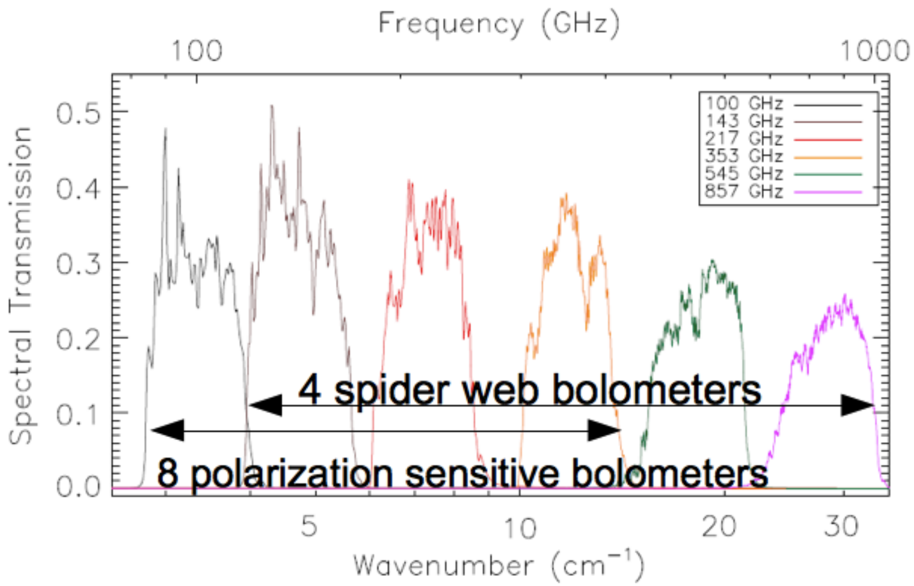
many members of the Planck/HFI core team, especially:
W. Holmes, A. Catalano, G. Patanchon, P. Ade, Y. Atick, A.Benoît, E. Bréelle,
P. Camus, M. Charra, N. Coron, F-X Desert, Y. Giraud-Heraud, J-M. Lamarre,
J. Macias-Perez, D. Giard, M. Martinez, F. Pajot, J-L Puget, C. Renault, C. Rosset,
D. Santos, L. Spencer, R. Sudiwala, A Sauvé, L Montier, J-M Delouis, L. Vibert,

HFI

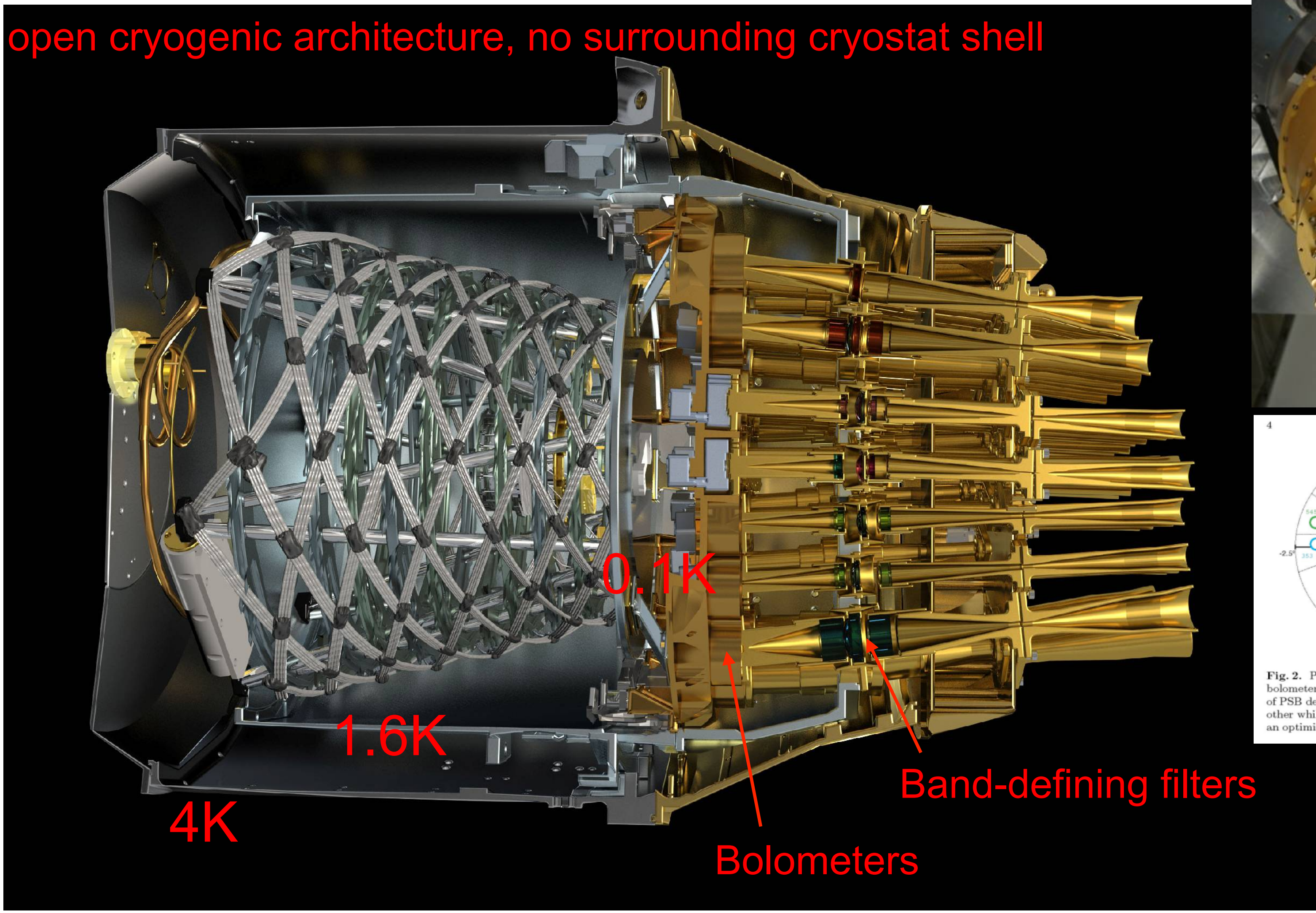
- High Frequency Instrument (HFI) on Planck used SiN micromesh bolometers (spiderweb and polarization sensitive) with NTD Germanium thermistors
- 100mK maintained from July 3, 2009 to January 14, 2012 (5 full sky surveys)
- Detector NEP ~ 1-2x10^{-17} (above 0.6 Hz); NET as low as 40 μK_{CMB} rt s in a single device
- Cosmic ray hit rate higher than expected (1-2 per second per bolometer)
  - Flagged transients (removes 10-20% of data)
  - Long tails of glitches create excess noise from 0.01 – 0.2 Hz
  - Occasional (~1/day) shower events create simultaneous response in many detectors
  - Thermal drift of 100mK plate with variable particle flux
  - Effects of undetected glitches?
- Main lesson: direct hits on the bolometer absorber or thermistor are not the only response to cosmic rays!

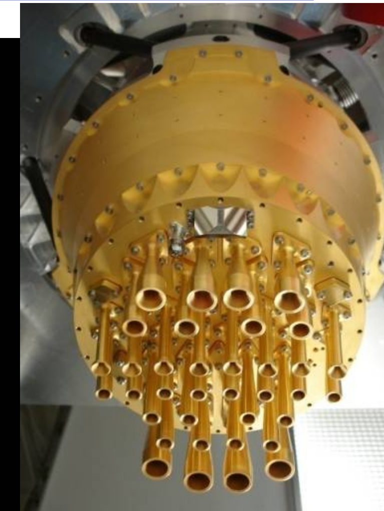
HFI Quick Overview

Center Frequency (GHz)	100	143	217	353	545	857
N Detectors	8	11	12	12	3	4
Resolution (arcmin)	9.5	7.1	4.7	4.5	4.7	4.4
Noise in maps μK_{CMB} deg	1.6	0.9	1.4	5.0	70	1180
Array NET (μK s)	22.6	14.5	20.6	77.3	4.9 (RJ)	2.1 (RJ)



HFI





4 C. Rosset et al.: Beam mismatch i

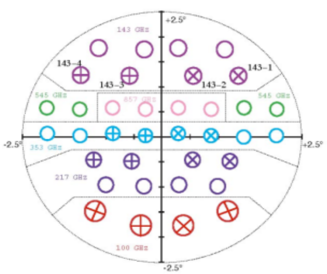
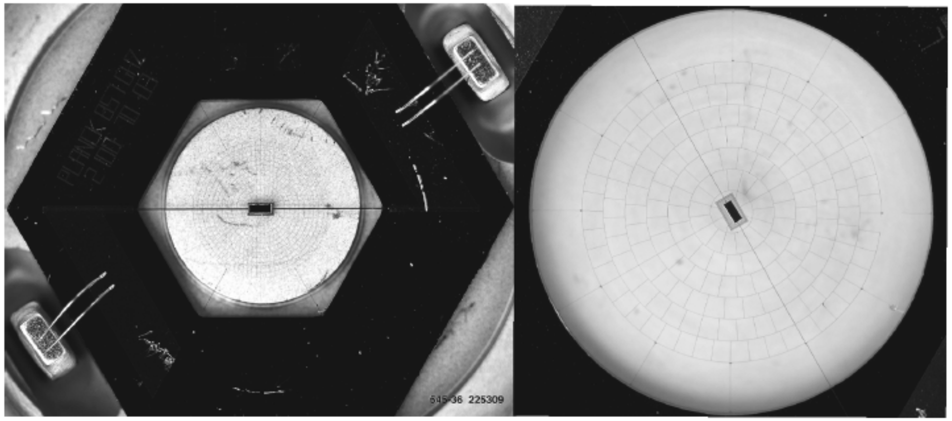
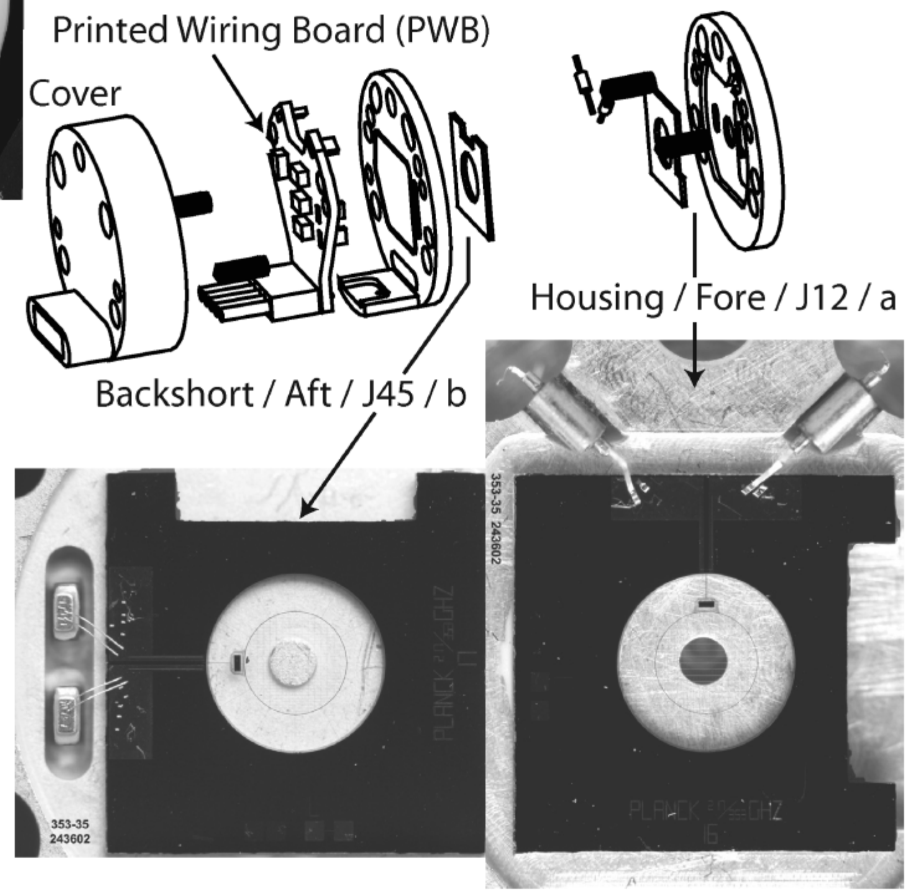


Fig. 2. Planck focal plane with polarization sensitive bolometers as seen from the sky. Complementary pairs of PSB detectors are arranged in two horns following each other while scanning the sky so that four detectors are in an optimized configuration for polarization measurement.

Polarization-sensitive and spider-web bolometers from JPL

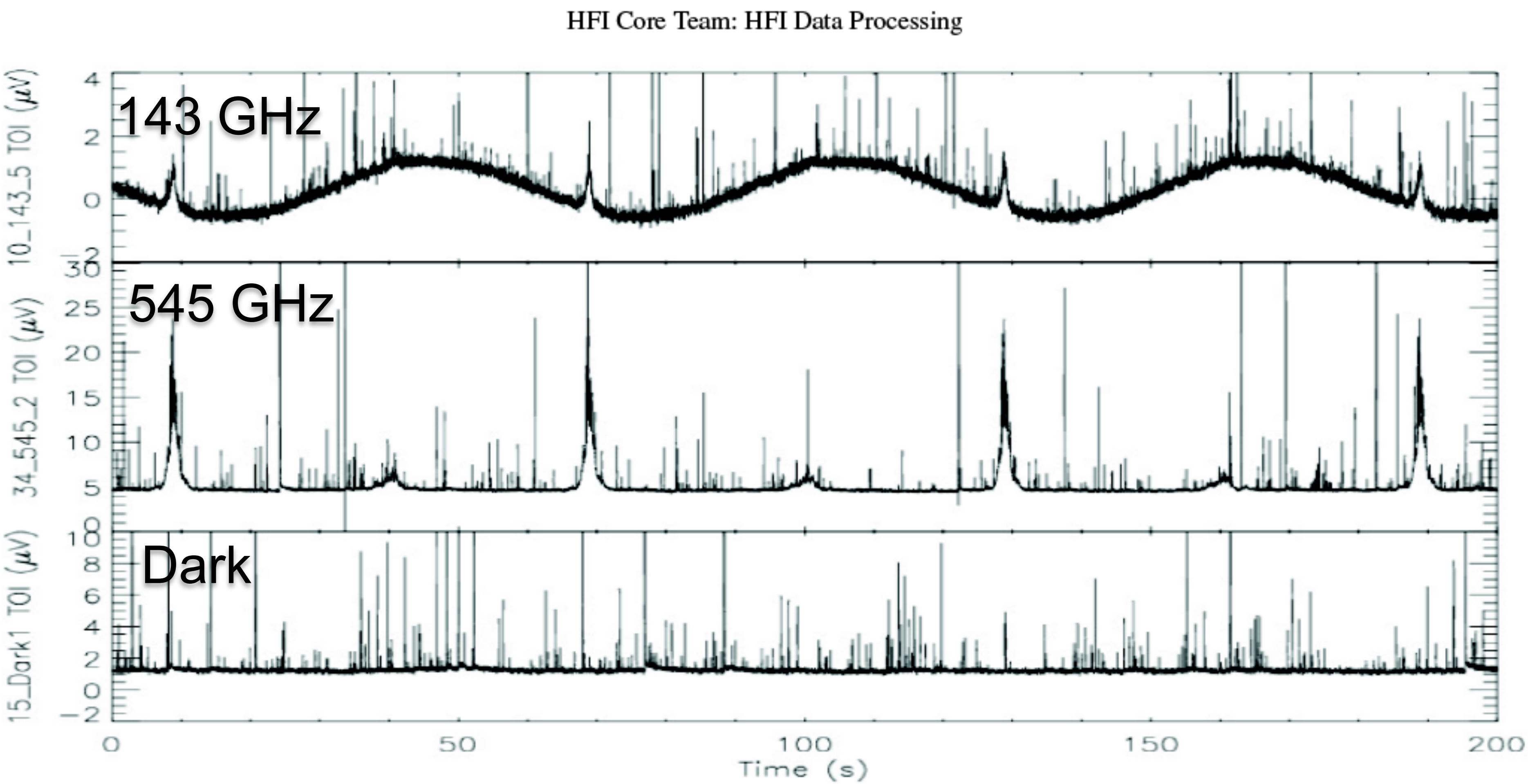


Holmes et al (2008)



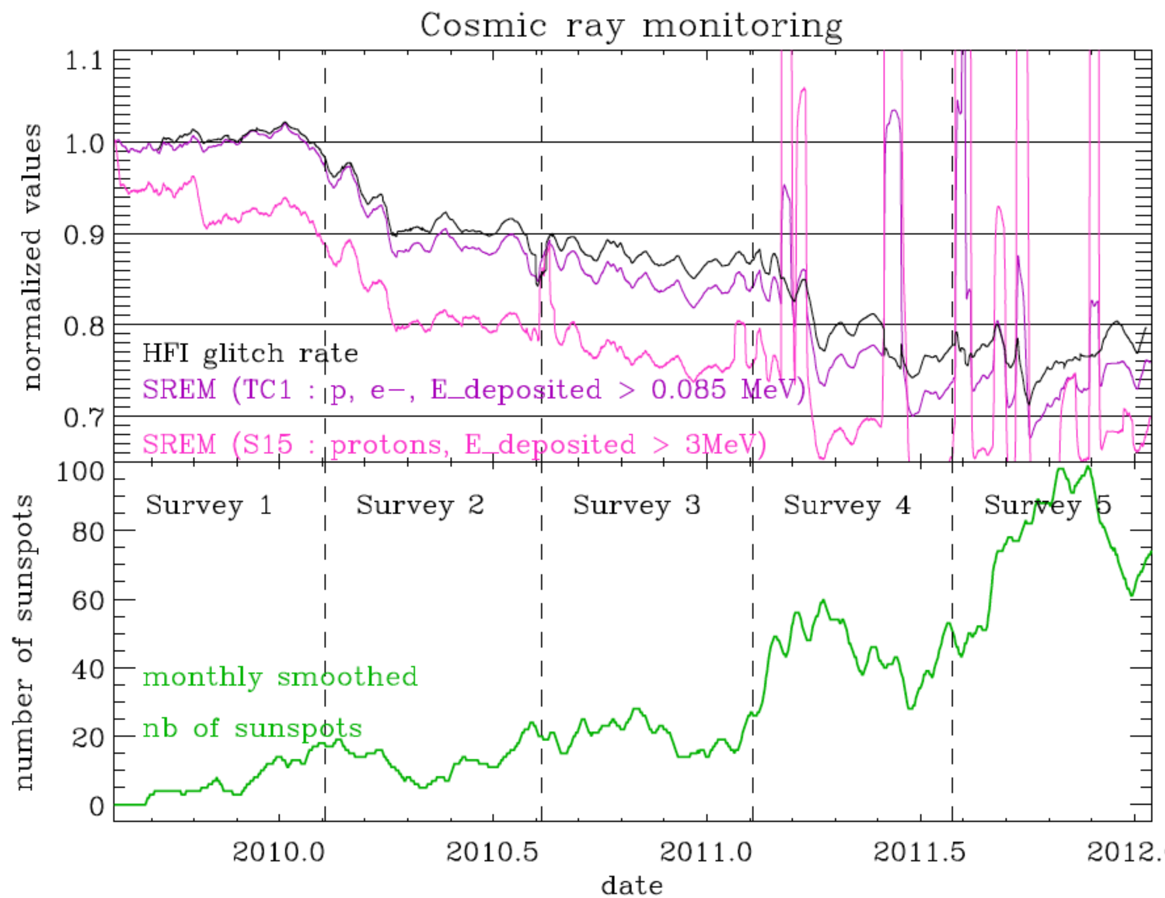
Main heat sink for Si frame
and bolometer is via wire bonds

3 minutes of raw in-flight data



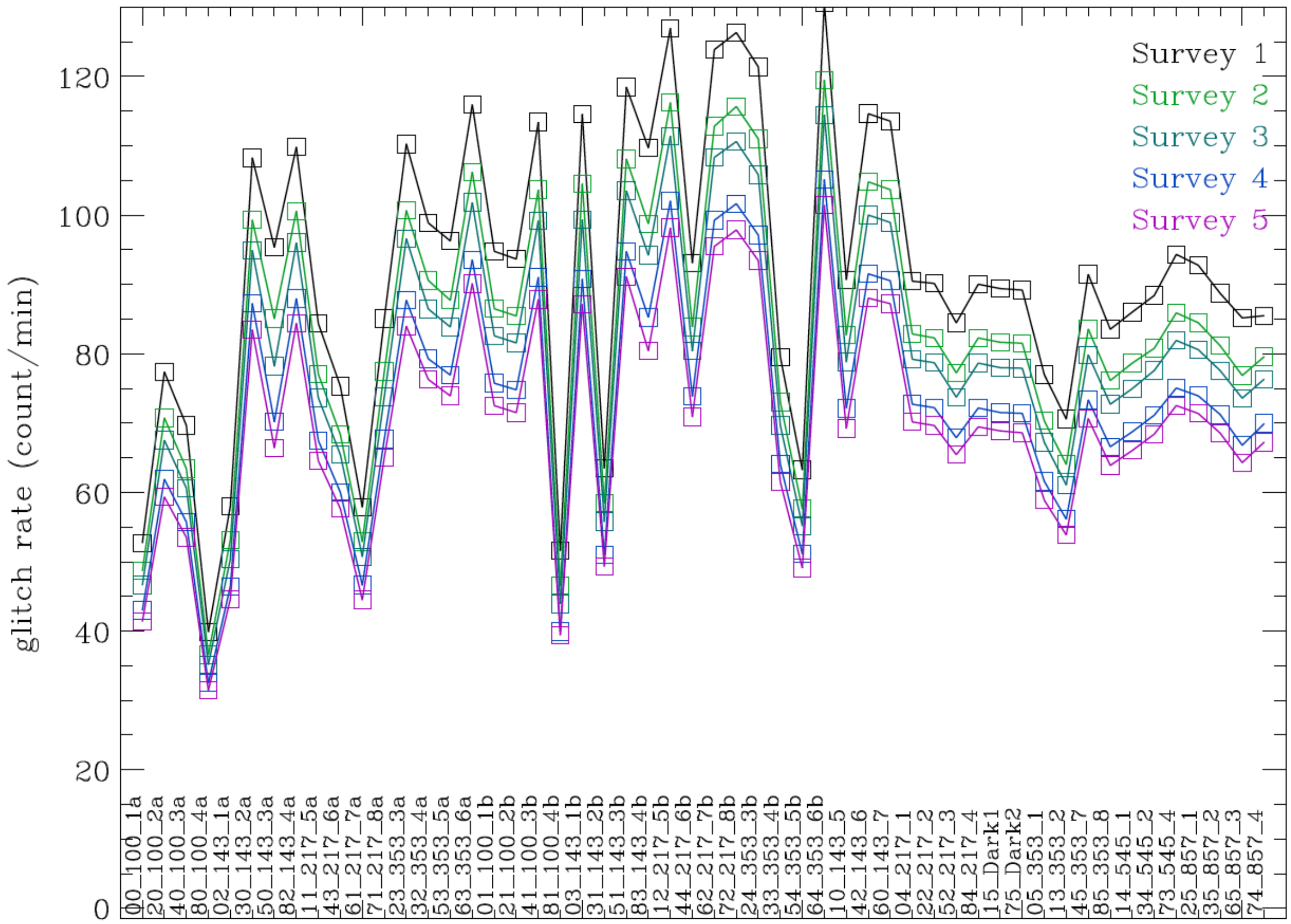
Glitches in the data

- Bolometer glitch rate correlates with on-board particle detectors (SREM) & with SREM data on Herschel and Rosetta
- Planck launched during extreme solar minimum: more low energy galactic particles than expected BUT not enough to explain observed rate

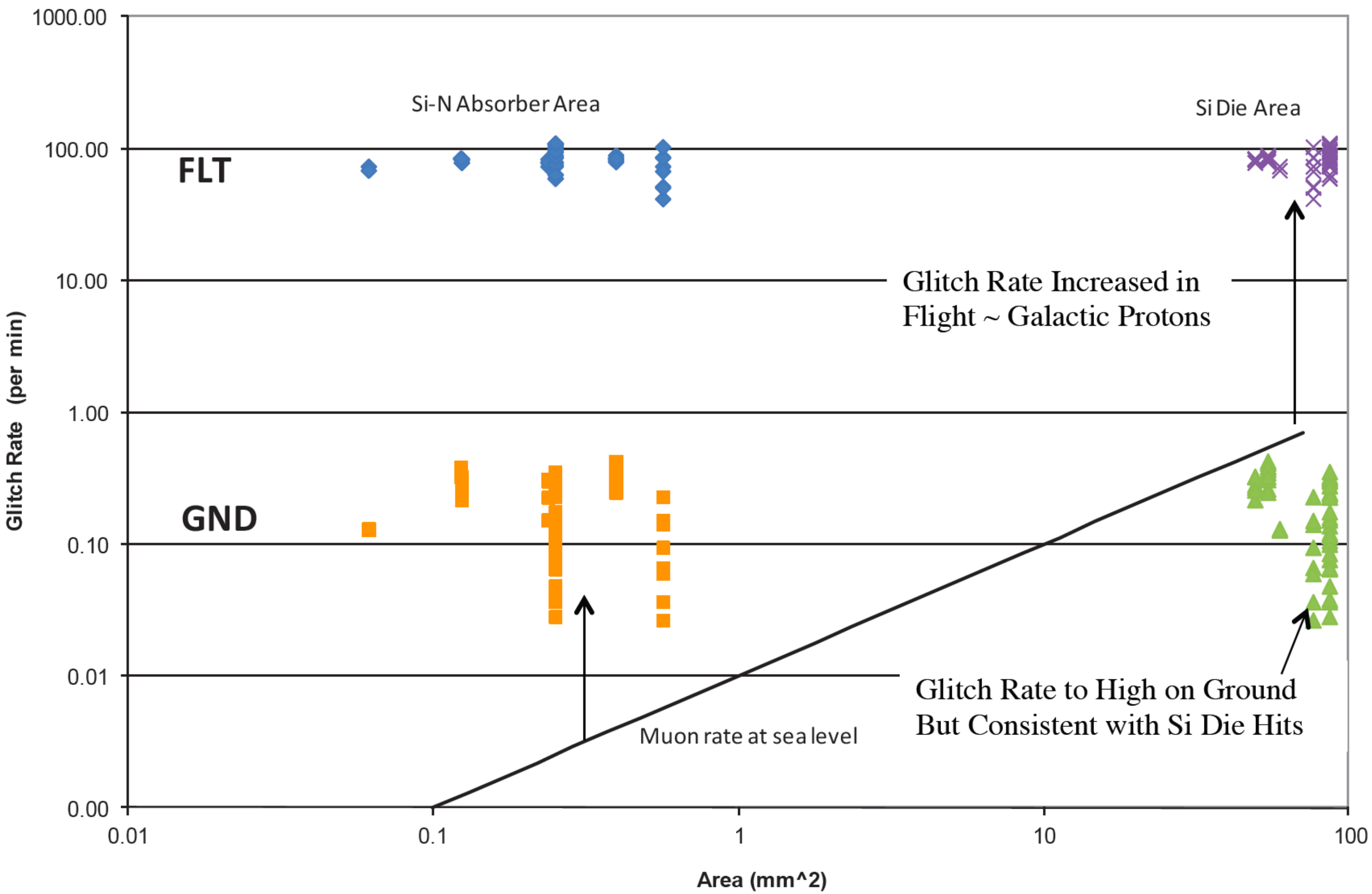


- Solar flares aren't a problem: spacecraft blocks <100MeV solar particles
- Galactics come from all directions; metal surrounding detectors blocks <20 MeV

Glitch rate in each detector: 1-2 per second!

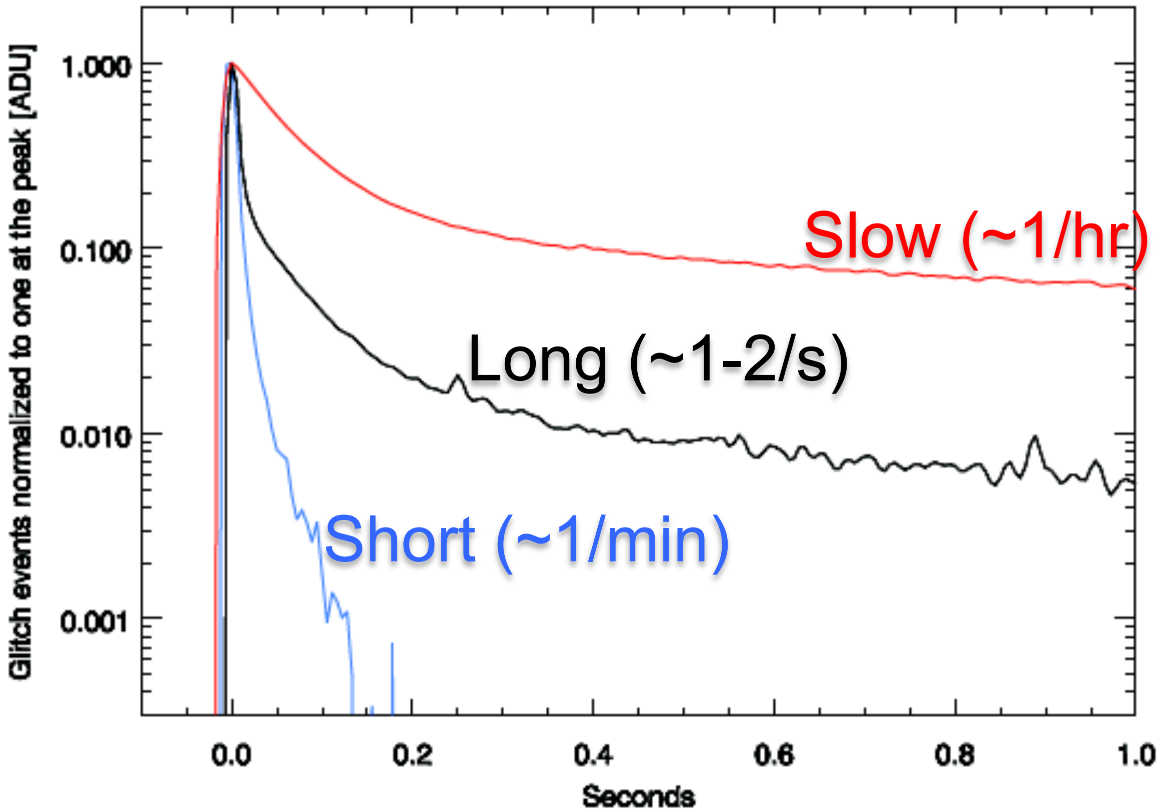


Expected rates: ground vs. flight



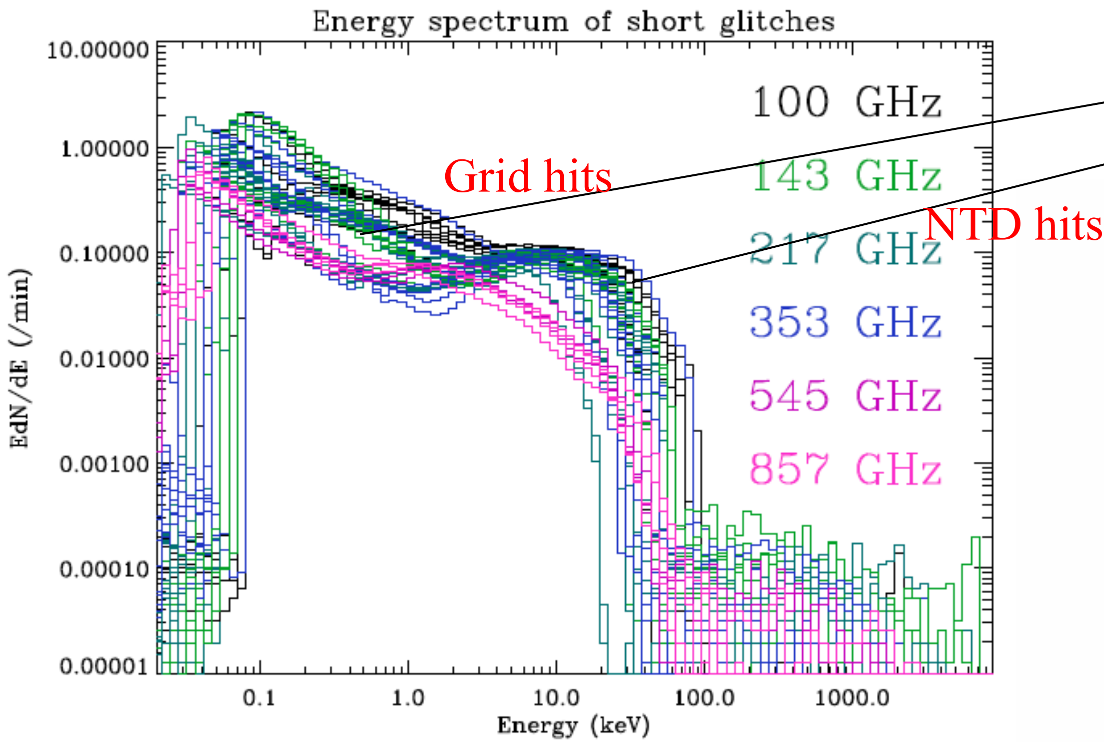
Direct effects of Cosmic rays: transients

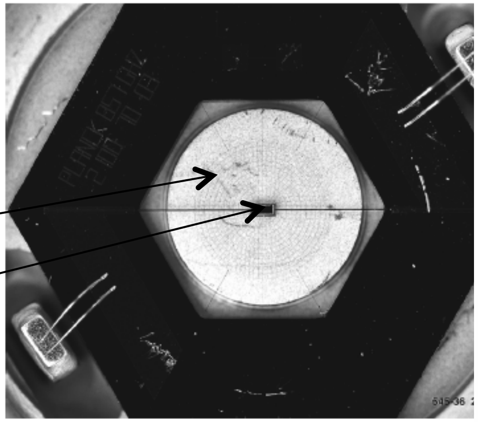
- Easy to detect due to scan redundancy
- Three general families: Short, Long, Slow
- Long and Slow glitches have tails with ~2 second time constants
- Rate is dominated by long glitches
- Slow glitches only seen in "a" arm of PSB



Short glitch energy spectrum

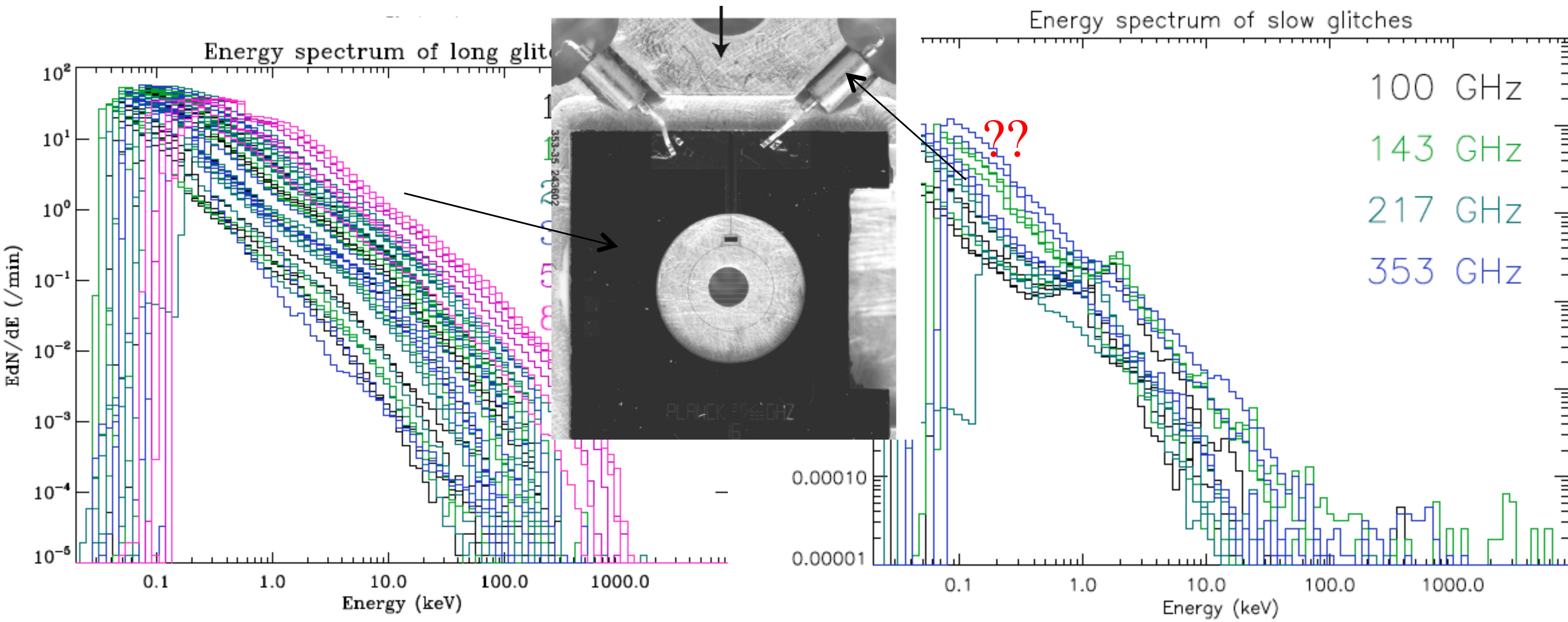
- Caveat: “energy” not well-calibrated yet for particles
- Bump at high energy: ~same in all detectors
- 1 GeV proton should deposit 1-3Kev in grid and 40 KeV in NTD





Long and Slow glitch energy spectrum

- Slow glitches only in “a” PSBs: maybe impacts in feed-through?
- Long glitches: likely to be hits in the Si die (other theory is secondaries)
- Energy spectrum and rate consistent with simple model of Si absorber



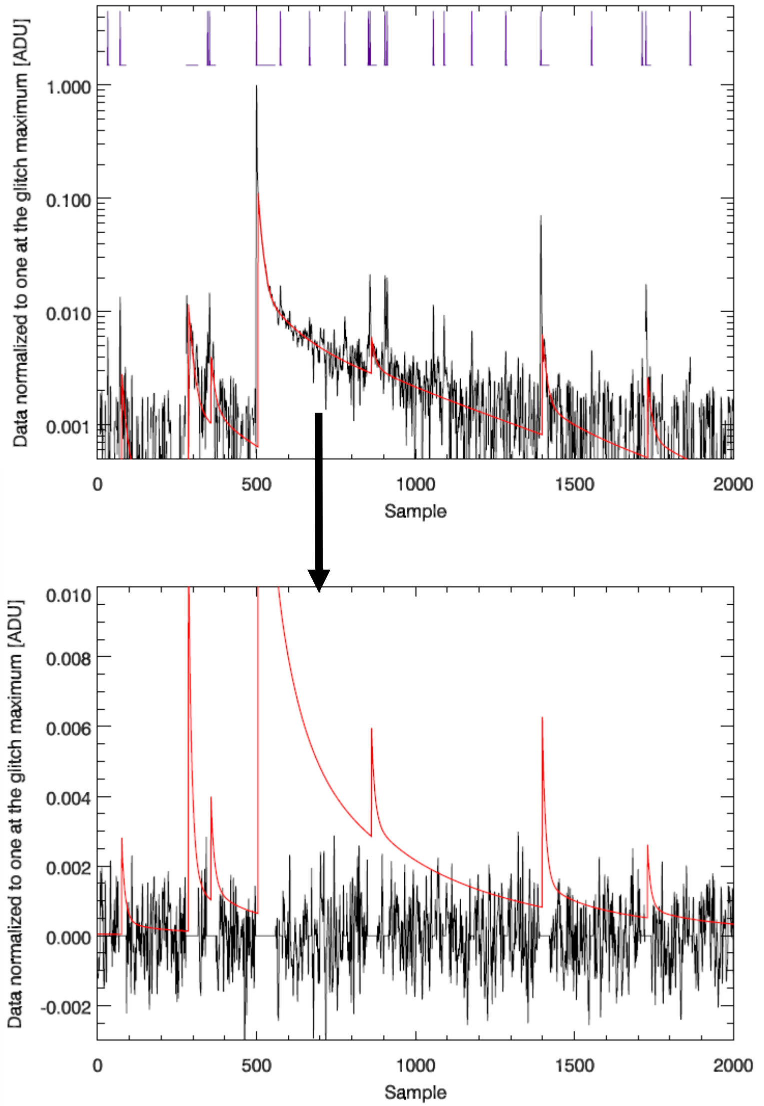
Glitch coincidence

- PSBs are mounted 100 microns apart, see coincidence:
  - Nearly 100% of long glitches: energy deposit is nearly the same
  - In 50% of low energy short glitches
- Secondary showers are seen in the data, but not a significant fraction of total events (more later..)
- Coincidence and rate are well-explained by silicon die model for long glitches

Ongoing flight spare tests

- Ground test campaign underway to study these events further:
  - Understand the glitches in the data better:
    - Model un-detected low energy tail of glitches
    - Long / short misidentification at low S/N
    - Undetected shower events
    - Understand a/b asymmetry
  - Implication for future missions
- Thermal tests: heaters and thermometers mounted on flight spares
  - Is long glitch tail consistent with Si die?
- particle tests:
  - TANDEM linear accelerator: 23MeV protons: give similar results to in-flight (long glitches dominating rate)
  - Delta-electron tests with alpha sources: no secondary e- seen.

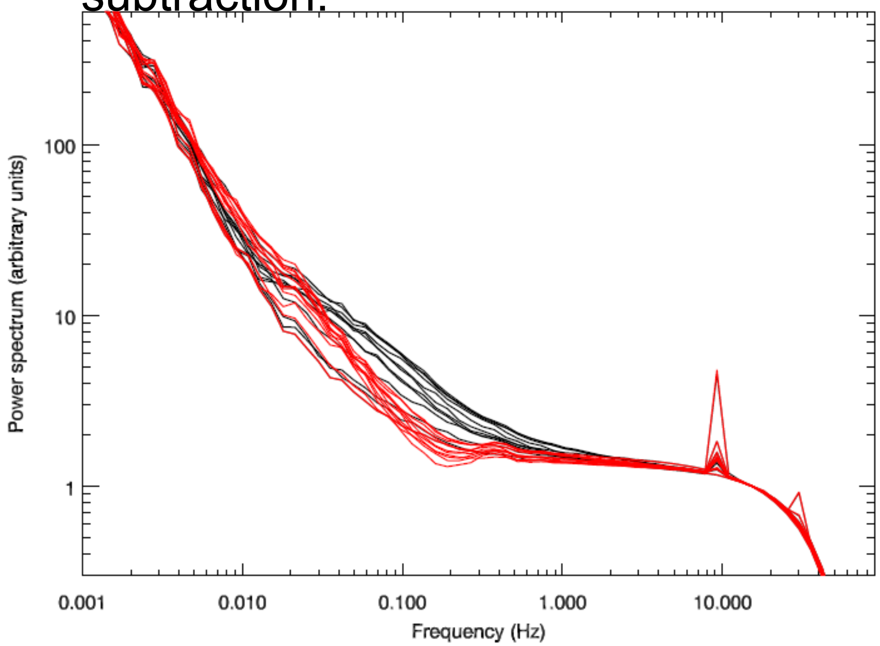
Glitch Handling in data



After detection,

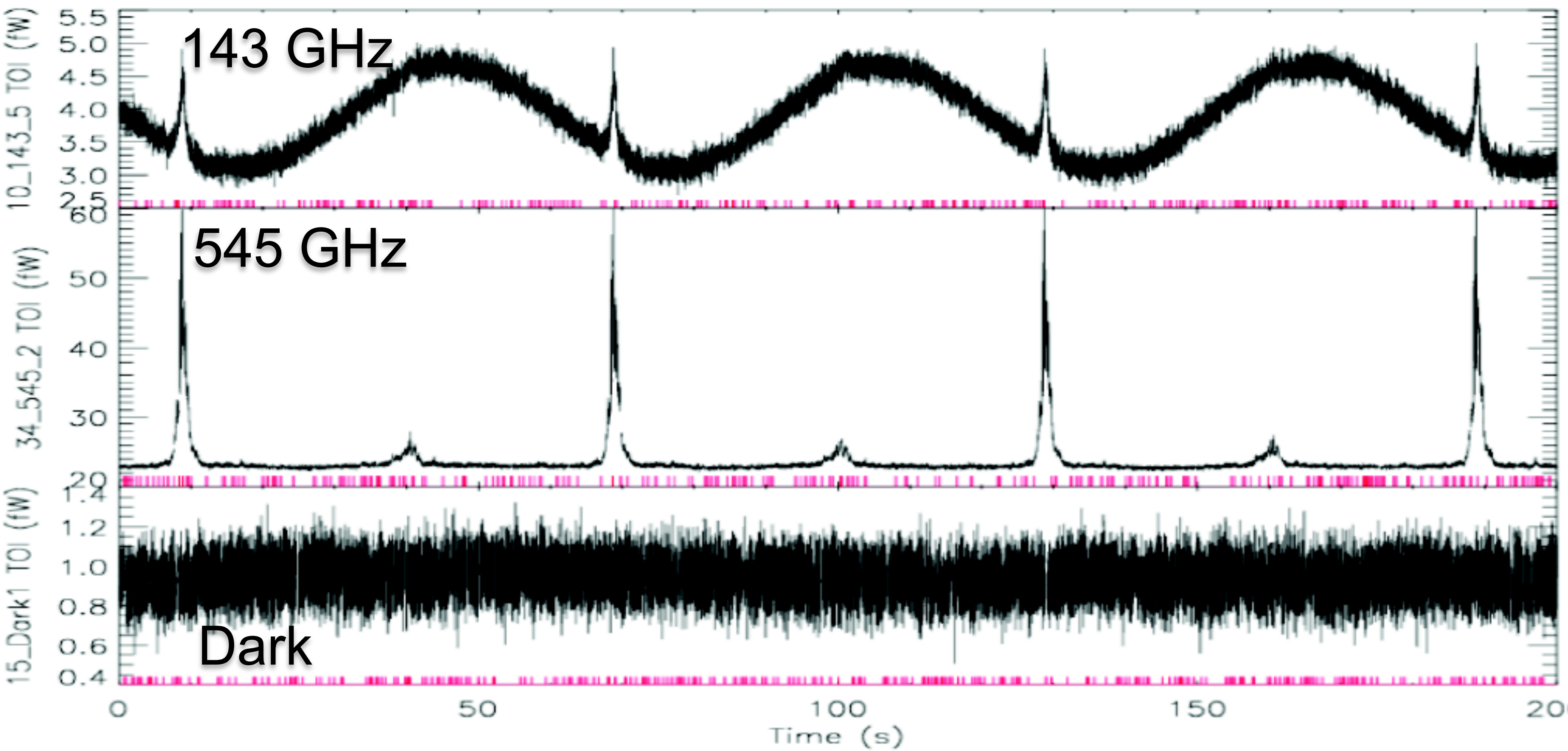
- Flag all shorts, and fast part of long
- Fit amplitude and subtract long tails
- >90% of data touched by this procedure

Noise spectra with and without subtraction:

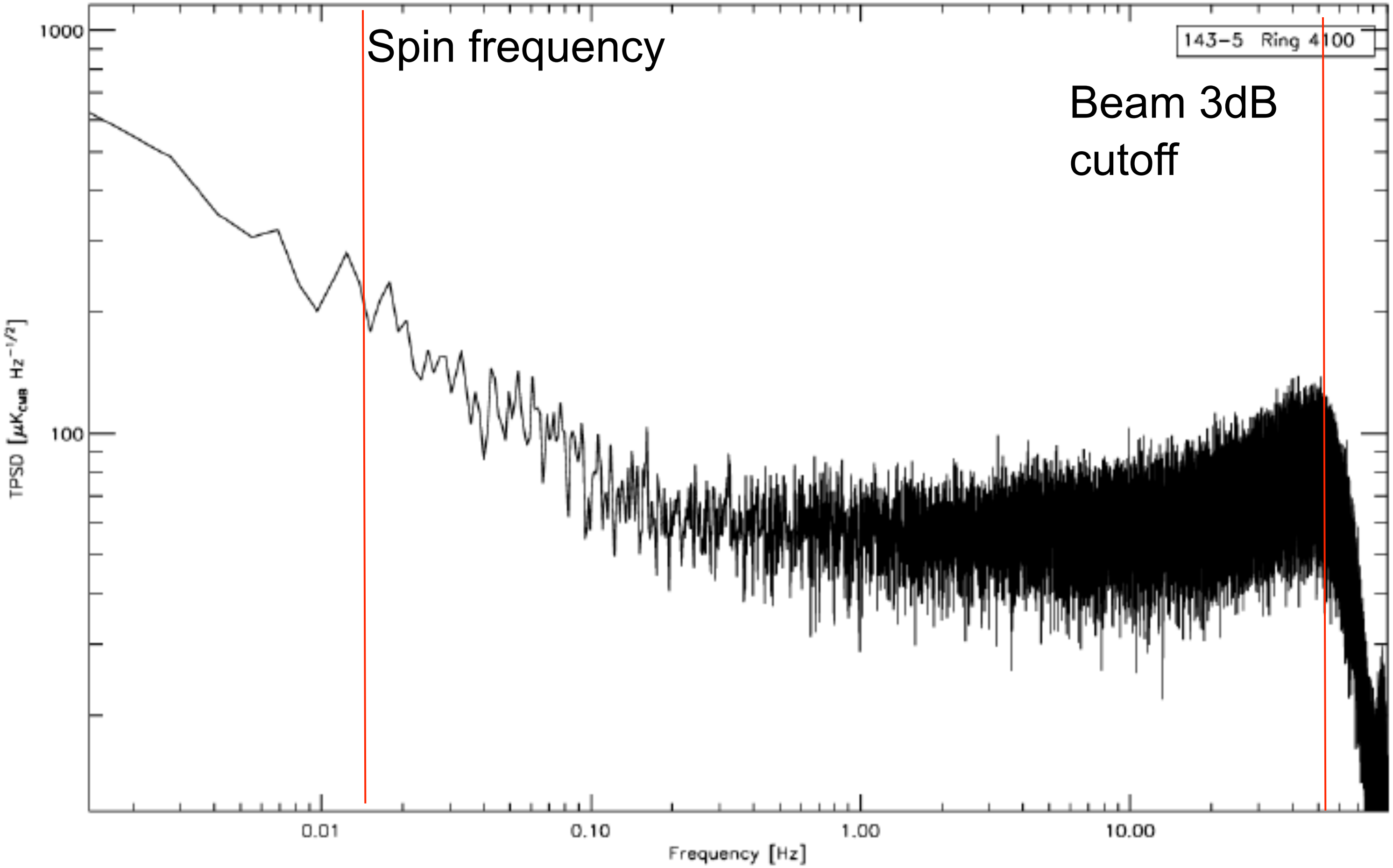


Timelines after cleaning

HFI Core Team: HFI Data Processing

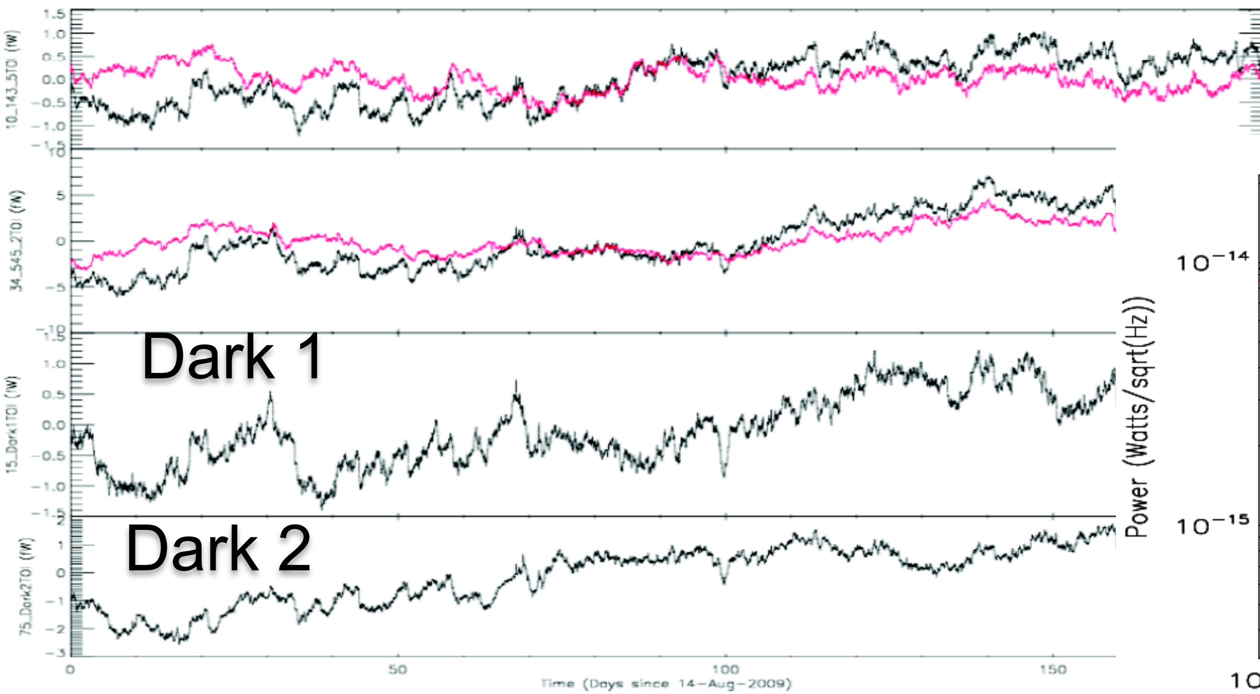


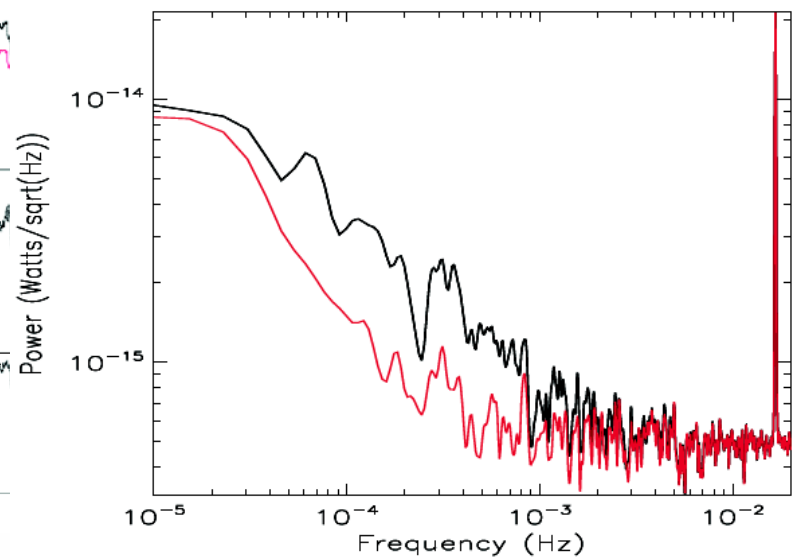
Noise spectrum after cleaning



Thermal effects of cosmic rays

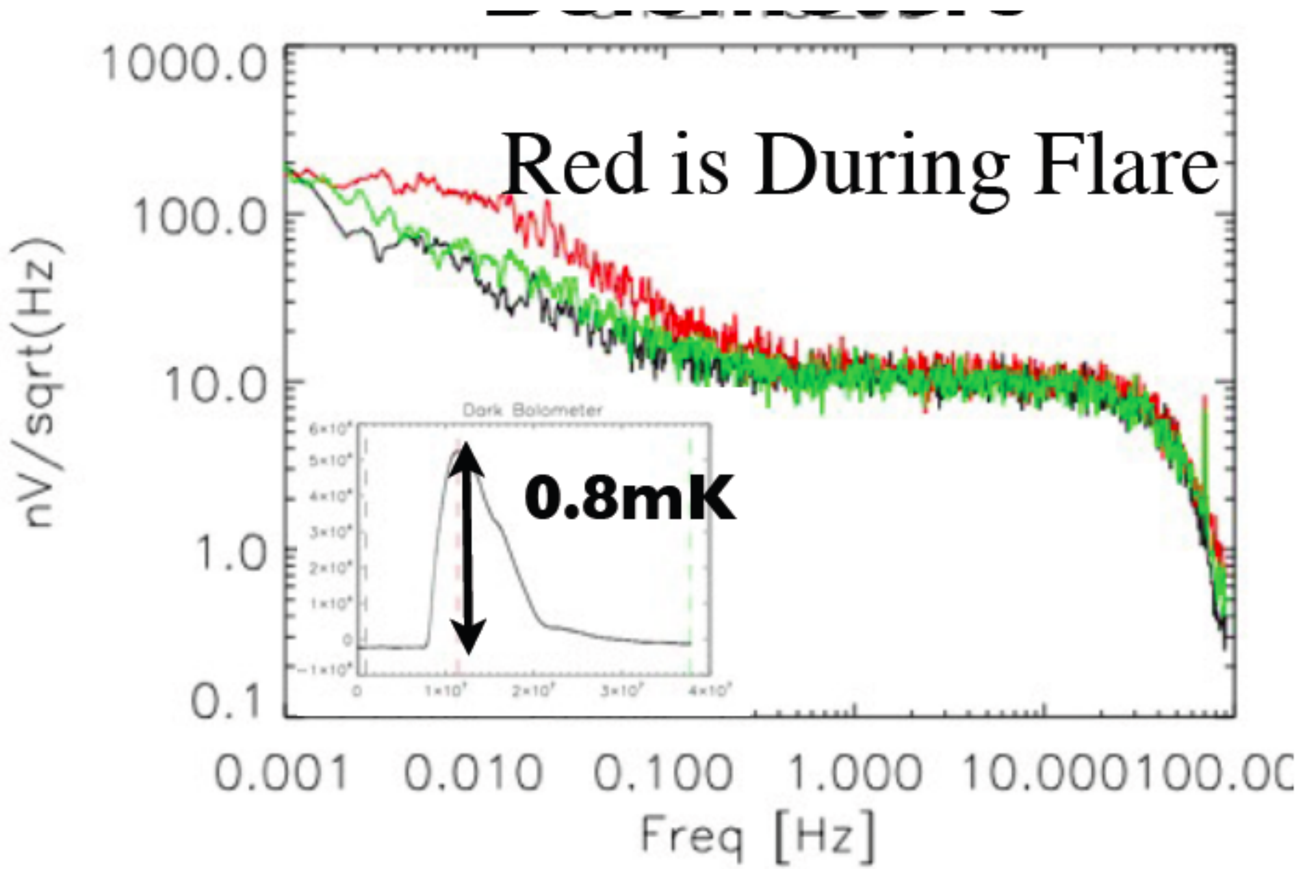
- ~10 nW of 115 nW heat lift on 100mK stage due to cosmic rays
- Common mode drift – removed by decorrelation with dark bolometers
- Lots of uncorrelated drift still remaining
- Note: mapmaking is ~ high pass filter at 1/45 minutes





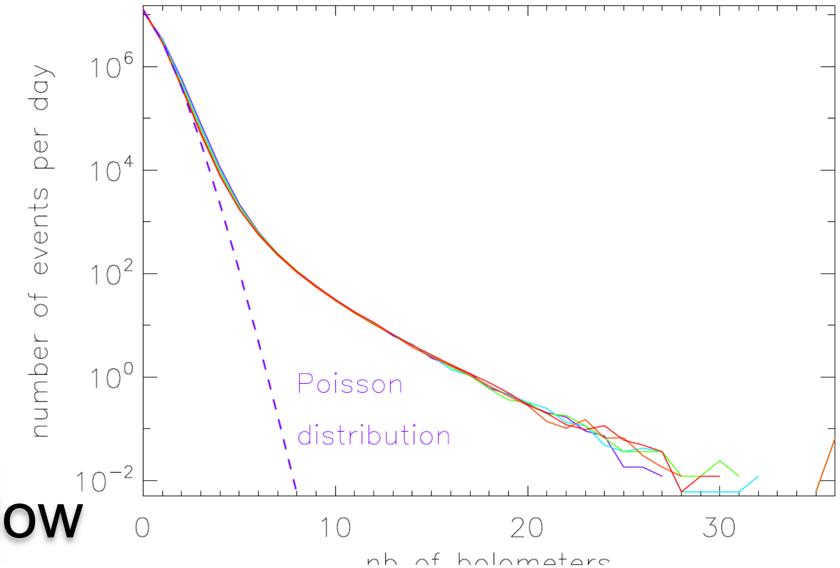
Solar flares

Only ~ 3 solar flares showed any effects on HFI: glitch rate, noise goes up for ~1-2 hours, dark bolometer heats by almost 1 mK

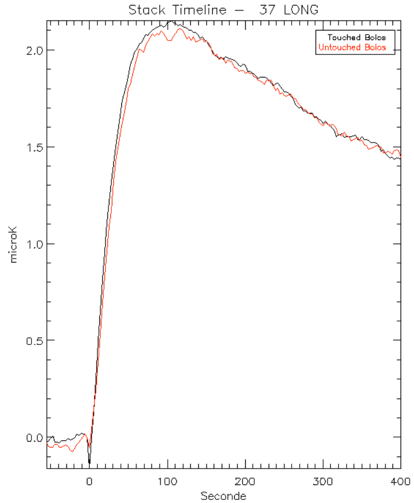


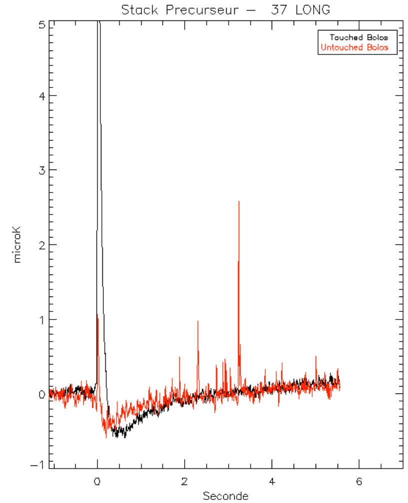
Multiple bolometer coincident hits

- >1 TeV events can create showers inside 100mK box
- Events show heating in all bolometers
- Rate of 1/day > 1 microK heating

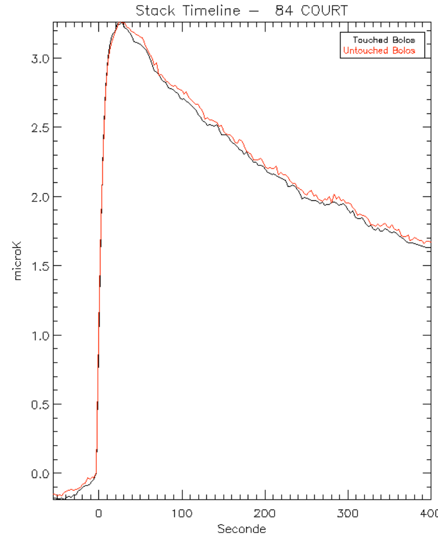


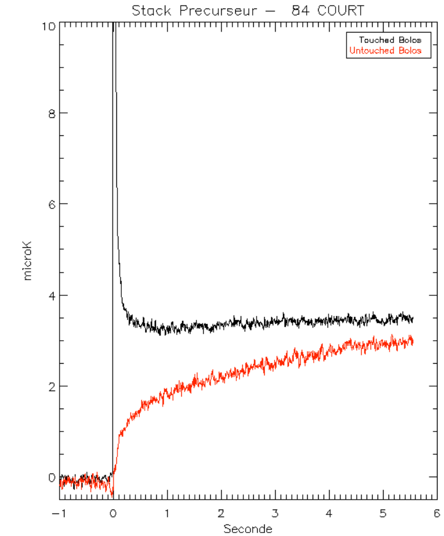
fast



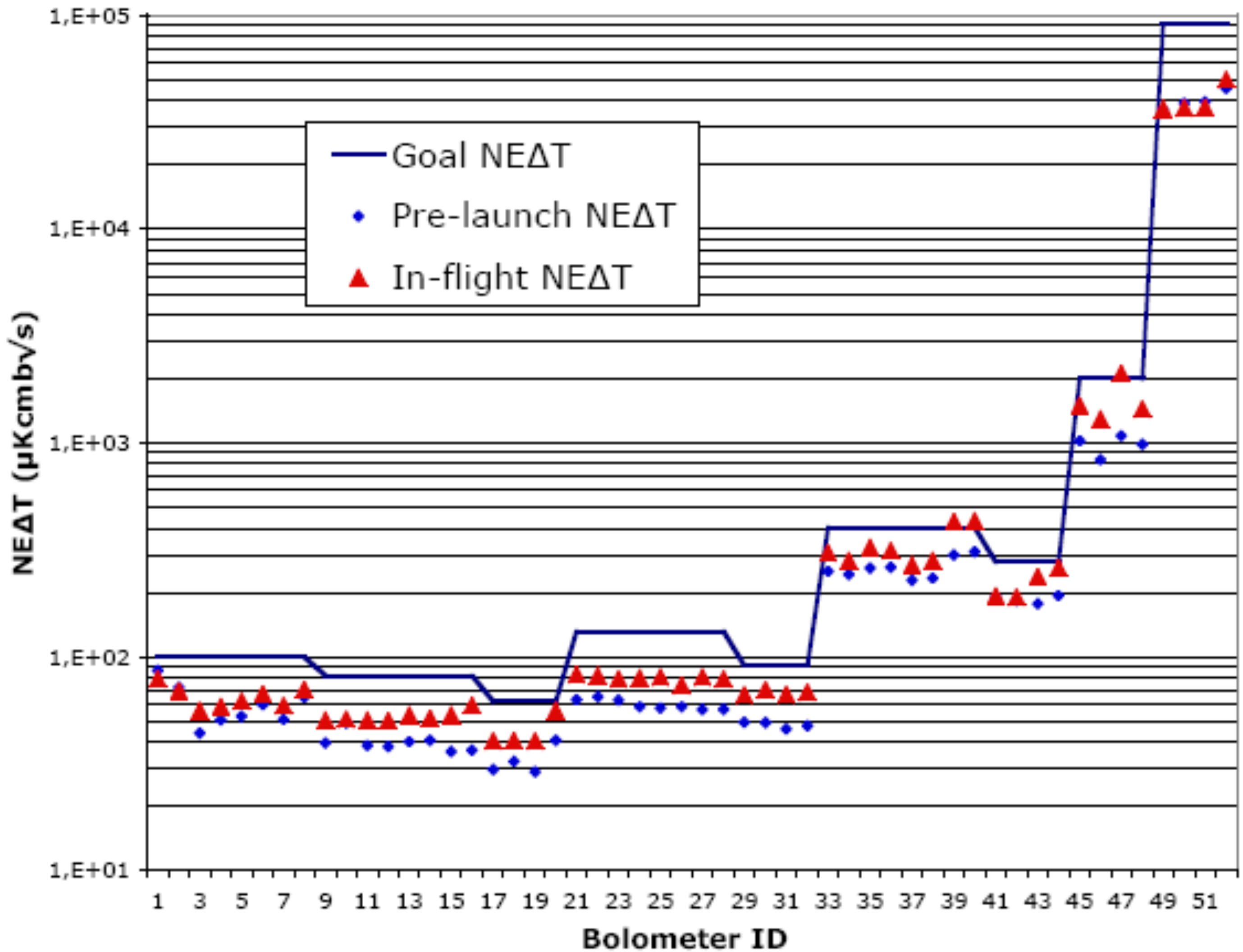


slow





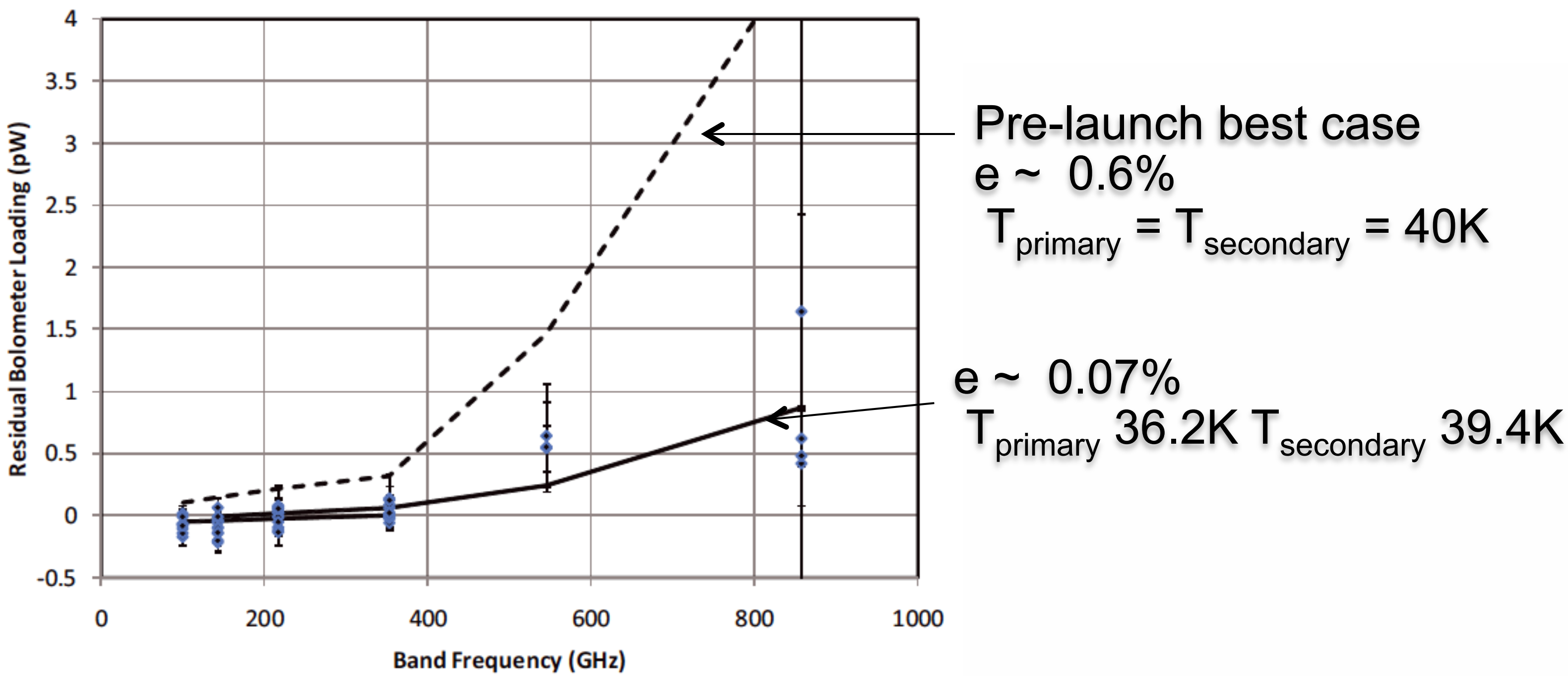
HFI detector Noise Performance



Noise > 0.6 Hz

Other notable Planck successes

- Open cryostat design was successful: all detectors work without additional shielding of closed cryostat
- Telescope emissivity was below 1% (see below)



Conclusions

- Direct hits from solar particles are hardly a concern for detectors surrounded by metal. A few (of order 3) solar flares created ~ hour long periods of increased noise and ~1 microK temperature rise
- Main worry is >30 MeV galactic particles.
- Operation of sub-K instrument during solar maximum is more benign than at solar minimum
- Future space missions with detector NEP<10^{-17} operating at T<100mK are technically possible, BUT
  - Take into account the particle environment (now known much better) and effects on the entire system
  - Do beamline tests pre-launch
- A series of papers from Planck/HFI team is in production describing in-flight cosmic ray response and ground tests. Will be part of 2013 Cosmology data release.

- References for more information:
  - Holmes et al (2008) Applied Optics 47 5996.
  - Lamarre et al (2010) A&A 520 A9.
  - Planck Collaboration (2011) “Planck early results II: The thermal performance of Planck” A&A 536 A2
  - Planck HFI Core Team (2011) “Planck early Results IV: First assessment of HFI In-flight performance” A&A 536 A4.
  - Planck HFI Core Team (2011) “Planck early results VI: HFI data processing” A&A 536 A6.

Bonus Slides!

Stability of 4K and 1.4K stages

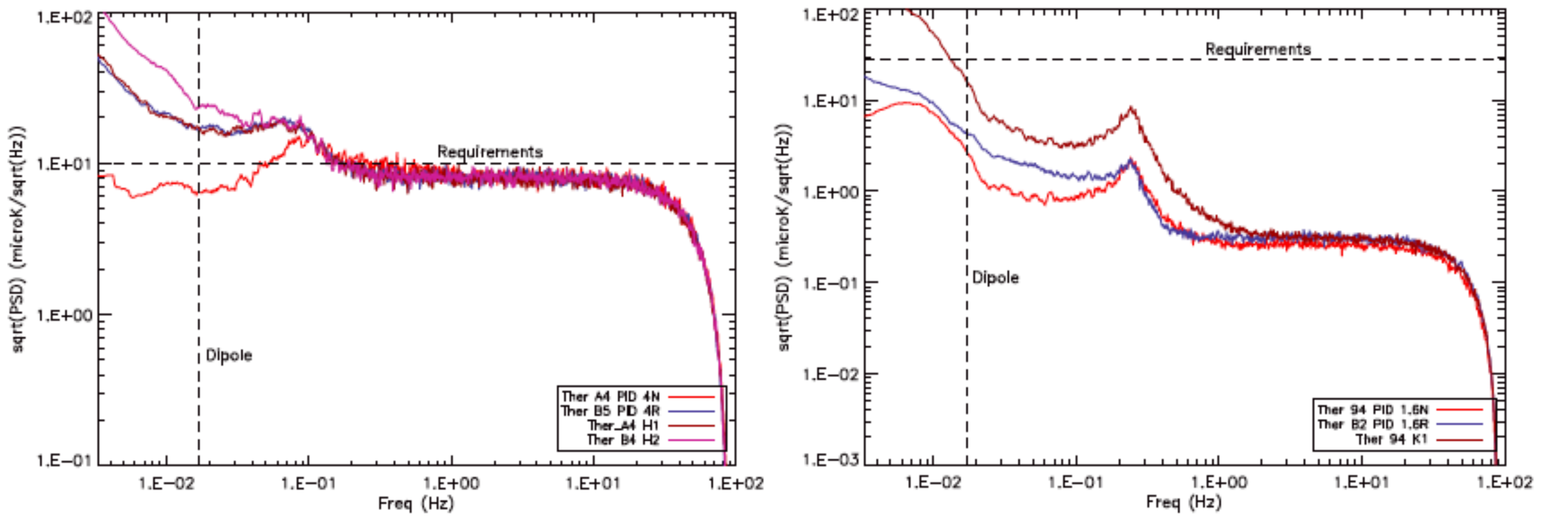


Fig. 27. *Left* – power spectrum of thermal fluctuations measured at the feedhorns that couple to the telescope. *Right* – power spectrum of thermal fluctuations measured at the 1.4 K filter plate.

Stability of 0.1K stage

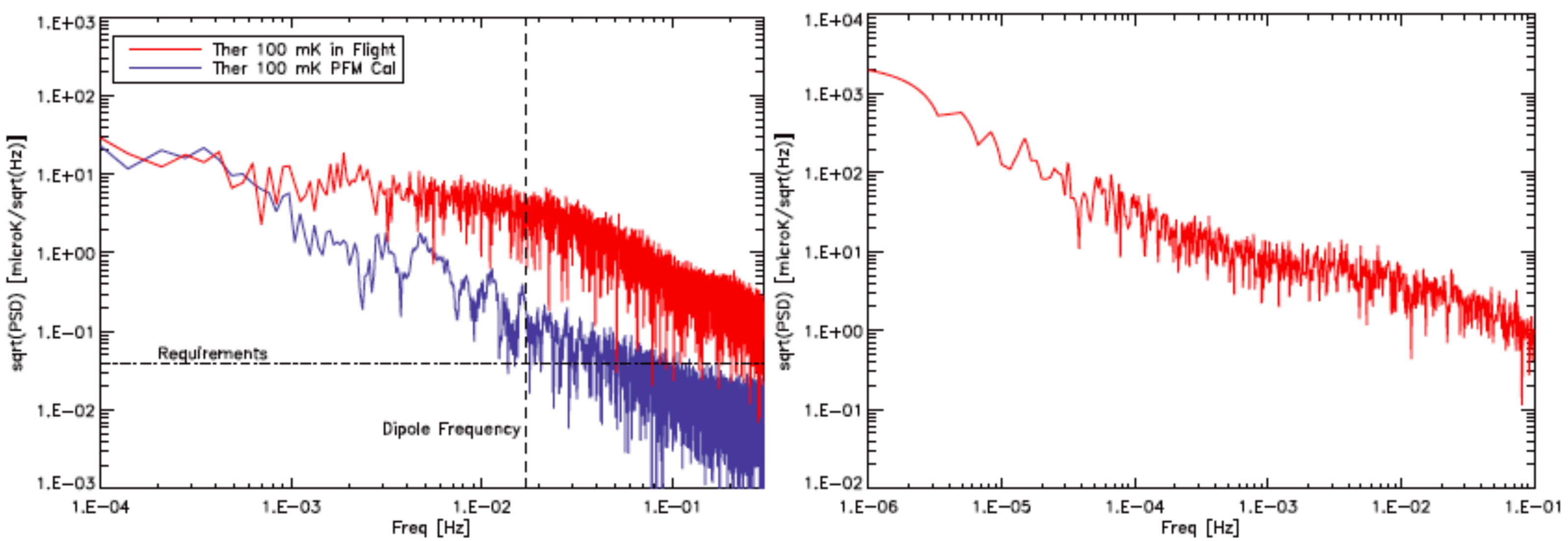
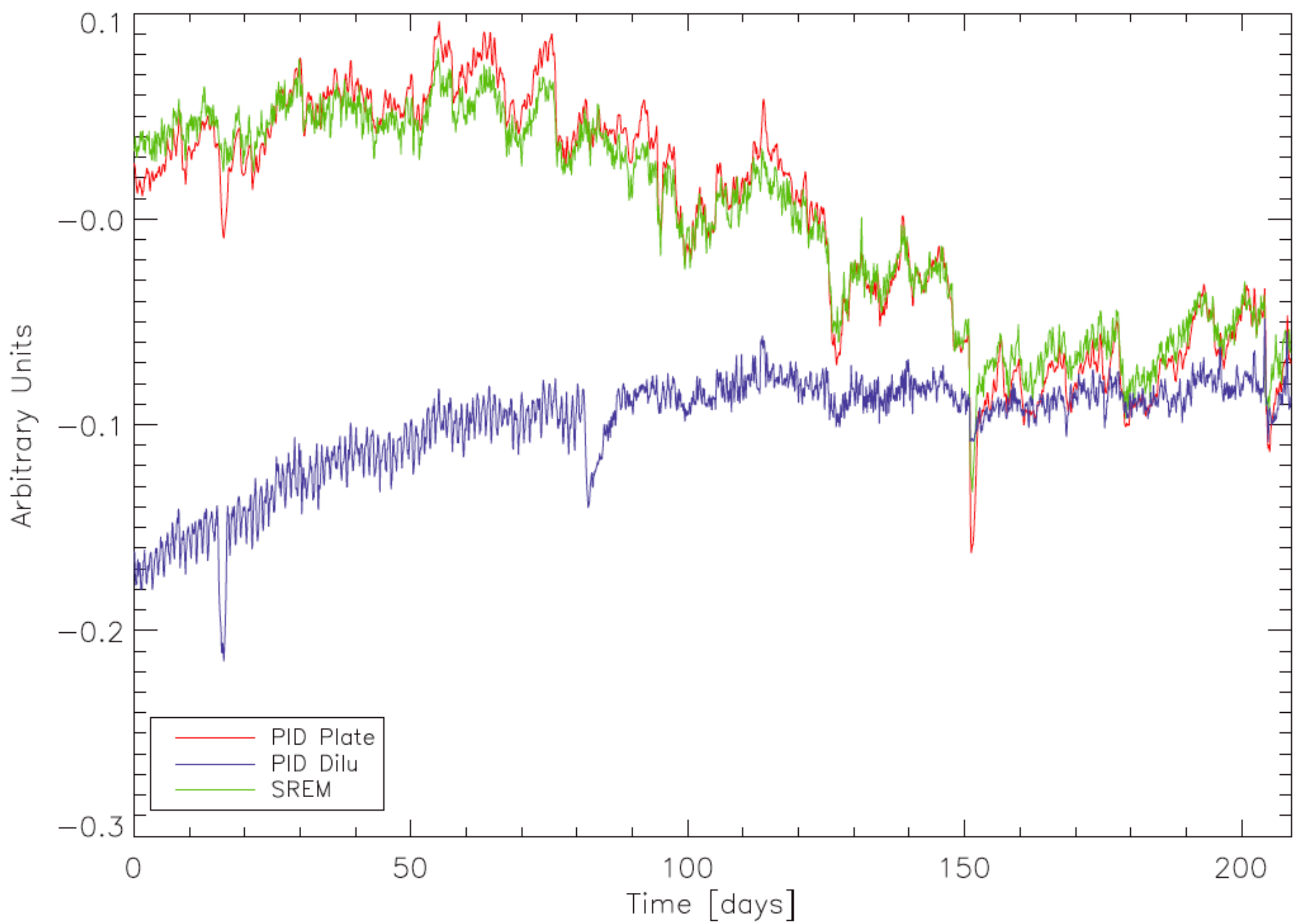


Fig. 28. *Left* – frequency spectrum of the temperature of the bolometer plate, measured in flight (red) and on the ground (blue). *Right* – spectrum of the flight measurements over a wider frequency range. The shoulder on the low frequency side is due to the temperature fluctuations described in Fig. 30. The bump in the 10^{-2} to 10^{-3} Hz range seen, also seen in *the left panel* but only in the flight curve, is probably associated with the effect of cosmic rays in the bolometer structures.

SREM vs plate and dillution PID power



In-flight performance of Planck

Table 3. *Planck* performance parameters determined from flight data.

channel	$N_{\mathrm{detectors}}$ [a]	ν_{center} [b] [GHz]	mean beam[c] FWHM	ellipticity	White-noise[d] sensitivity [μK_{RJ} s$^{1/2}$]	[μK_{CMB} s$^{1/2}$]	calibration[e] uncertainty [%]	faintest source[f] in ERCSC $\|b\| > 30°$ [mJy]
30 GHz	4	28.5	32.65	1.38	143.4	146.8	1	480
44 GHz	6	44.1	27.92	1.26	164.7	173.1	1	585
70 GHz	12	70.3	13.01	1.27	134.7	152.6	1	481
100 GHz	8	100	9.37	1.18	17.3	22.6	2	344
143 GHz	11	143	7.04	1.03	8.6	14.5	2	206
217 GHz	12	217	4.68	1.14	6.8	20.6	2	183
353 GHz	12	353	4.43	1.09	5.5	77.3	2	198
545 GHz	3	545	3.80	1.25	4.9	...	7	381
857 GHz	3	857	3.67	1.03	2.1	...	7	655