Overview of LFI maps generation and their characteristics

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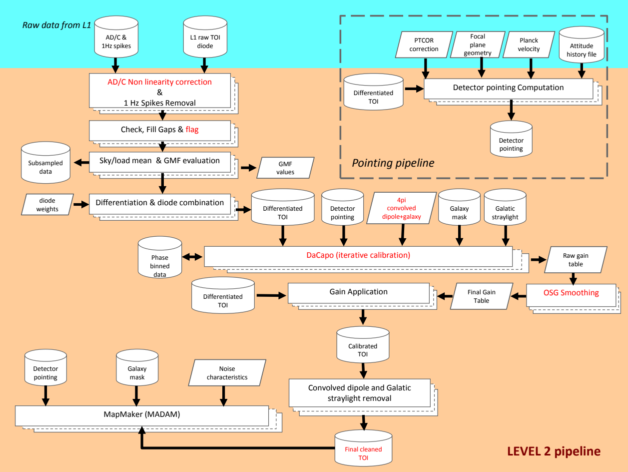
Operations

- *Planck* was launched on 14 May 2009 and the 2018 data release is the official final one and includes
  - temperature and polarisation maps
  - temperature and polarisation power spectra
  - ancillary data product based (e.g. foreground maps)
- It is based on the full set of 48 months of LFI observations
- Data are of incredible quality!

Data Processing Overview

- DPC approaches data reduction with specific tasks aiming to estimate and correct instrumental systematic effects
- There are three main logical levels:
  - Level 1: H/K and Science telemetry from the satellite are transformed into raw timelines and stored into dedicated databases with the associated time information
  - Level 2: instrument information is gathered and ingested into the Instrument Model, removal of systematic effects, flag data of suspected quality, photometric calibration and creation of maps and ancillary products
  - Level 3: more science here with component separation, power spectra estimation and extraction of cosmological parameters
- Each step is internally validated (with dedicated sims) and most of the DPC work is spent cross-checking internally and between the two instruments

LFI pipeline



Flagged data

- We revised the flagging procedure to produce a more conservative and homogeneous criteria for data selection → a slightly higher flagging rate

	30 GHz	44 GHz	70 GHz
Missing [%]	0.15425	0.15425	0.15433
Anomalies [%]	0.82402	0.50997	0.84842
Manoeuvres [%]	8.03104	8.03104	8.03104
Usable [%]	90.99060	91.30474	90.96621

Photometric Calibration - History

- This is the most important and critical aspect of data reduction pipeline:

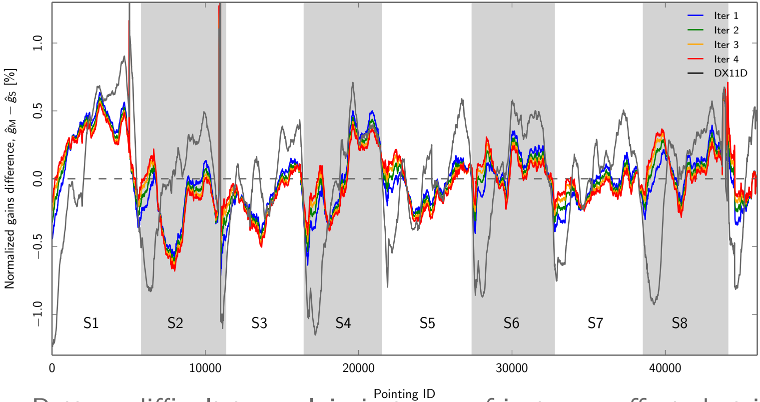
$$V(t) = G(t) \times [B \star (D_{\rm Solar} + D_{\rm orbital} + T_{\rm sky}) + T_0]$$

- **2013**: only 15 months of data $\rightarrow$ no accurate determination of $D_{\rm orbital}$ $\rightarrow$ use only $D_{\rm Solar}$ from *WMAP* 9-yr: 0.3% calibration accuracy
- **2015**: 48 months of data $\rightarrow$ internal self-contained estimation of $D_{\rm Solar}$ using $D_{\rm orbital}$: 0.2% calibration accuracy. High-precision cosmology with temperature data but improvements are crucial for polarisation

Phot. Calib. - Limiting factors

- Problems revealed by internal null-test when considering Survey 2 and Survey 4
- Due to *Planck* scanning strategy, Survey 2 & 4 present a minimum of the dipole modulation $\rightarrow$ possible large impact of systematics
- Several dedicated E2E sims $\rightarrow$ inclusion of polar. component of sky signal
- Each LFI horn feed two radiometers (M and S) with polarisation angles at 90°

Photometric Calibration - I

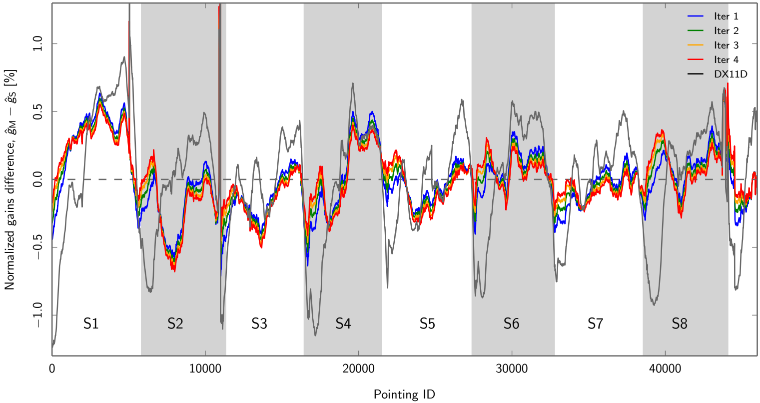


- Pattern difficult to explain in terms of instrum. effects but it is consistent with polarized foregrounds effect
- Since M and S are perpendicular, any polarized signal is obseved with opposite sign (confirmed by sims)

Photometric Calibration - II

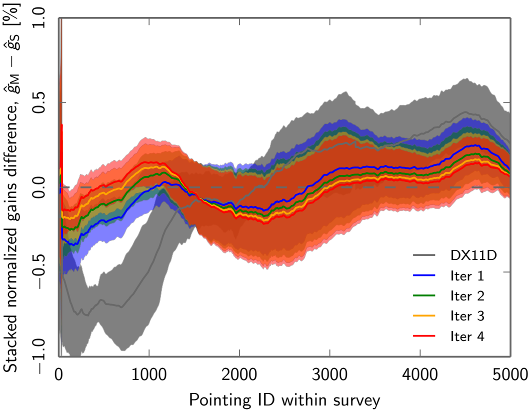
- Solution is to include $T_{\rm sky}$ (both temperature and polar) in the calibrator
- Iterative approach including: **gain calibration**, **map-making** and **component separation**
  0. $T_{\rm sky}$ is the full best-fit from 2015 data release including: CMB, synch, free-free, thermal and spinning dust and CO for temperature maps and polarized components for CMB, synch and thermal dust
  1. Estimate G including this $T_{\rm sky}$ in the calibrator
  2. Compute frequency maps from these new gains
  3. Determine new astrophysical model from these new maps
  4. Iterate step (1) to (3)
- The process converges: as a Gibbs sampler iterating through all involved conditional PDF converging to the joint maximum likelihood

Photometric Calibration - III



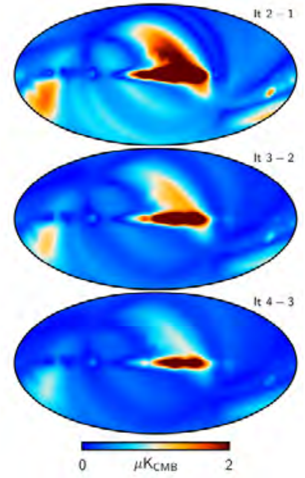
- Process is computationally expensive: 1 iter. takes 1 week
- We stop the process after 4 full complete iterations
- Oscillating pattern greatly removed: possible residual?

Photometric Calibration - III



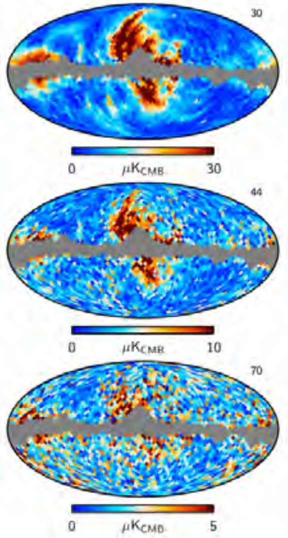
- Took same quantity but with surveys stacked together → suppress random signal

Photometric Calibration - IV



- Magnitude decreases by a factor of 1.5-2 (high gal. lat)
- Morphology similar and dominated by few Ecliptic meridians scans
- Gain uncert. dominated by few strong modes → suppression with iteration
- Not formal convergence → low-level residual still present

Photometric Calibration @ 70 GHz

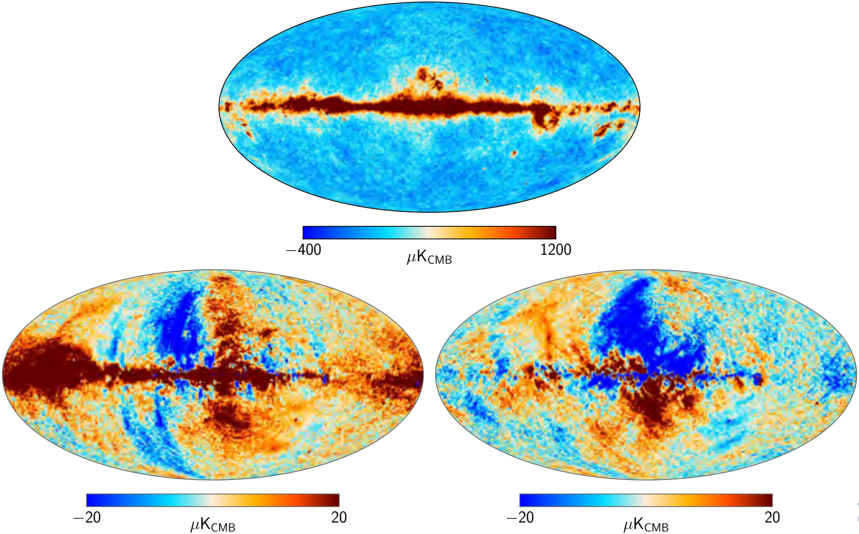


- At 70 GHz the approach is the one adopted in 2015
- Galactic pol. signal is noise dominated and iterative approach fails to converge
- We provide a gain correction template based on 30GHz difference (properly scaled in a ML approach)
- Results with 70GHz have this template removed

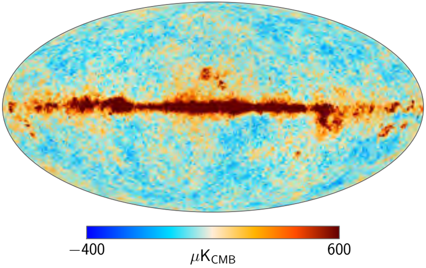
Map-making

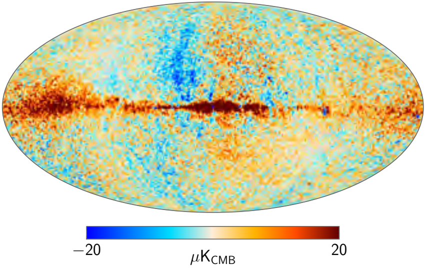
- Calibrated TOI for each radiometer are input of `madam` map-making code, together with pointing data
- The algorithm is a maximum-likelihood destriping and estimates in this fashion the amplitude of the $1/f$-noise baseline, subtract from the timelines and then simply bins the resulting TOI into a map
- Maps produced at different levels:
  - Frequency maps, HR (Half-Ring) maps and Survey maps
  - Low resolution maps used for the computation of the noise covariance matrix

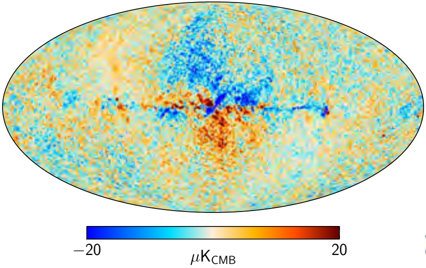
Planck-LFI 30 GHz



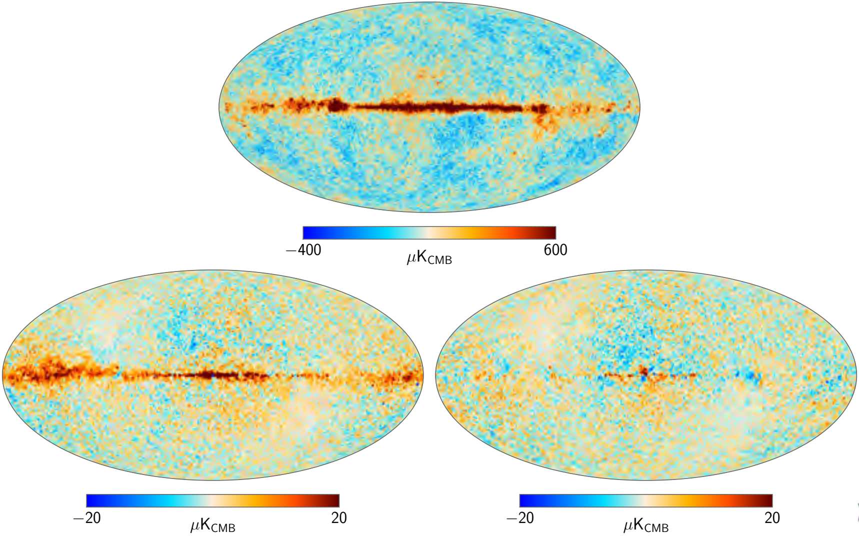
Planck-LFI 44 GHz







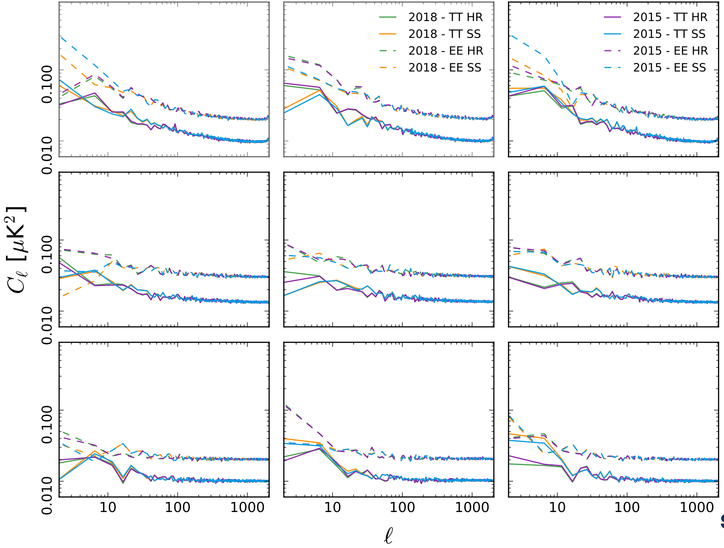
Planck-LFI 70 GHz



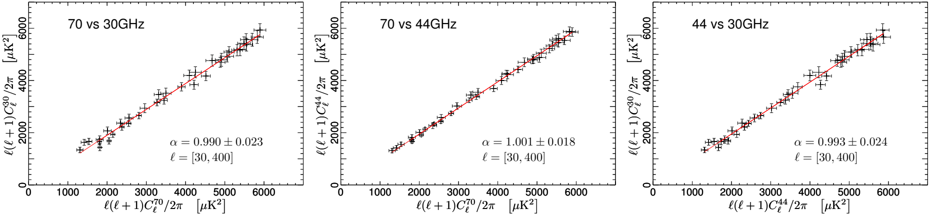
LFI Internal Validation - Null tests

- Quality of LFI maps is assessed and verified by a set of null-tests in an almost automatic way
- Several data combination (radiometer, horn-pairs, frequency) on different time-scales (1 hour, survey, full-mission): difference at horn level at even/odd surveys clearly reveals side lobe effect
- Null-test power spectra are used to check total level of systm. effects to be compared w.r.t. white noise level and systematic effects analysis

LFI Internal Validation - Null tests

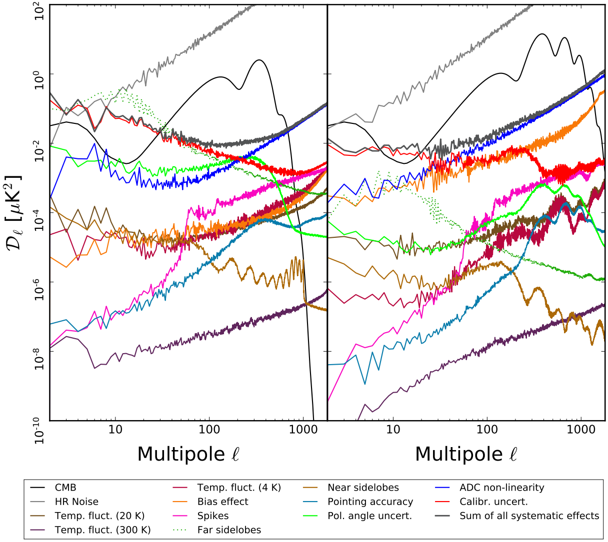


LFI Internal Validation - Spectra



- Compute power spectra in multipole range around the first acoustic peak removing the unresolved point source contributions. Spectra are consistent within errors. 30 and 44/70 have different approaches to gain applied
- Hausman test assess consistency at 70 GHz showing no statistically significant problem
- Spectra from horn-pairs and from all 12 radiometers: χ^2 analysis shows compatibility with null-hypothesis

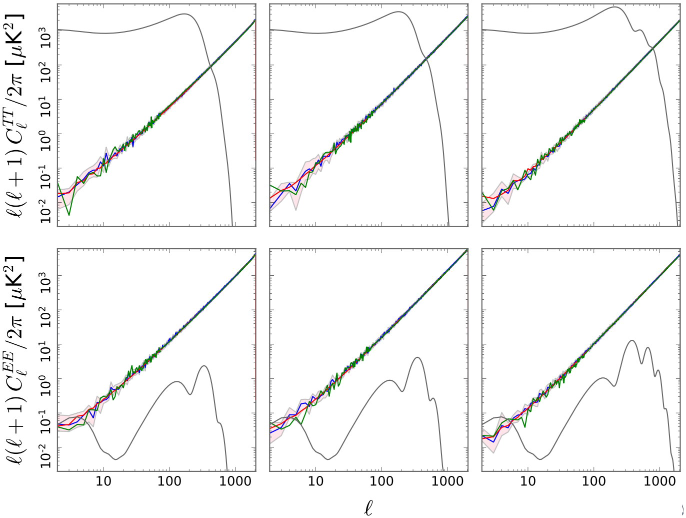
Systematic effects - 2015



Systematic effects - 2018

- Assessment of overall systematic is unchanged
- No more specific effect simulations $\rightarrow$ concentrate effort on those effects impacting on calibration uncertainty (treated separately)
    - ADC - improved wrt to the 2015
    - Gain smoothing procedure
    - Far-sidelobes and Dipole uncertainty
- Overall effects together

Systematic effects - 2018



Systematic effects - 2018

- Good agreement between 2015 and 2018 systematic simulations
- Null spectra from odd-even-year are very close to systematic error expectations
- A few multipoles ($\ell = 2, 3$ @30GHz and $\ell = 2$ @44 and 70GHz) out of the $1 - \sigma$ range in TT: extra noise $\lesssim 0.04 \mu\mathrm{K}^2$ @70GHz
- EE null spectra are in line with sims with only $0.1 \mu\mathrm{K}^2$ excess at 70 GHz for $\ell = 10$

Systematic effects - Conlcusions

- At $\ell \gtrsim 100$: extra noise induced by systematics is well traced by simulations and accounted for in noise estimation
- At large scales: clear overall improvement with the new calibraton scheme
- A few multipoles require attention since extra noise is not traced by sims
- Sytematic sims could be used to create a template useful for a ML approach in more scientific oriented analysis