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THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION

Beyond PLANCK

Deliverable 8.1: Systematic effects assessment

Authors Marco Bersanelli
Cristian Franceschet
Eirik Gjerløw
Håvard Tveit Ihle

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HELSINGIN YLIOPISTO
HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI

planetek hellas

Revision History

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1.0	Marco Bersanelli	November 25th, 2020	Initial Version

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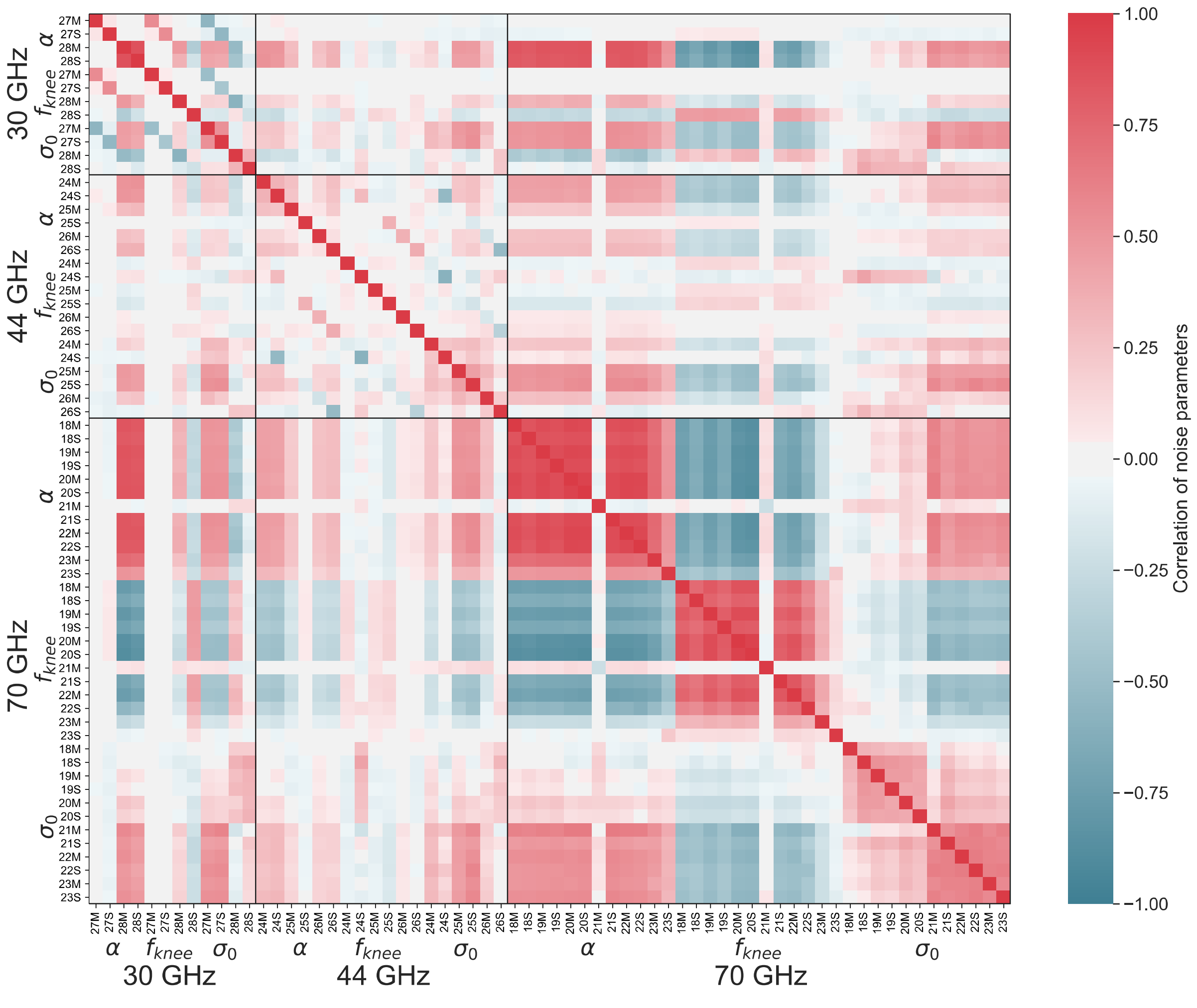

Figure 1: Correlation between the noise parameters of all the LFI radiometers throughout the entire mission. These parameters describe the white noise (sigma_0) and the correlated 1/f noise (f_knee and alpha).

1 Noise properties

The Planck-LFI radiometers demonstrated a stable behavior during the entire Planck survey with noise properties well described, to first order, by a simple three-parameters model (one parameter for the white noise and two parameters for the correlated 1/f noise). In previous analyses, the LFI radiometers noise was assumed to be stationary, i.e., its statistical properties were treated as stable throughout the mission. The BeyondPlanck approach allowed us to go a step forward by estimating the noise parameters for each pointing period (PID), i.e. every 40—60 min. This means increasing the total number of LFI noise parameters from 66 to about 3 million. This huge increase of information allowed us to capture subtle effects of evolution in the radiometers' response to local thermal environment, as well as subtle interactions between channels. These are important when analyzing the LFI data for CMB polarization. We have used this information to characterize potential residual systematic effects in the data, and associate these with independent housekeeping data or known satellite events. Figure 1 shows a comprehensive correlation between the noise properties of all LFI radiometers. These reveal a number of interesting patterns that are uncovered for the first time and which allowed us to understand the instrumental systematic effects in greater detail (see Ihle et al. 2020 for a full discussion).

Figure 2 is a synthetic visualizaiton of the noise properties of all the radiometers throughout the mission. It shows that indeed the noise properties of the LFI instrument vary significantly in time in all three frequency channels (30, 44 and 70GHz). Furthermore, by comparing the time evolution between different radiometers, we observe many common features, both between frequencies and, in particular, among radiometers within the same frequency. Many of these are associated with specific and known changes in the thermal environment of the satellite that were traced using thermometer housekeeping data.

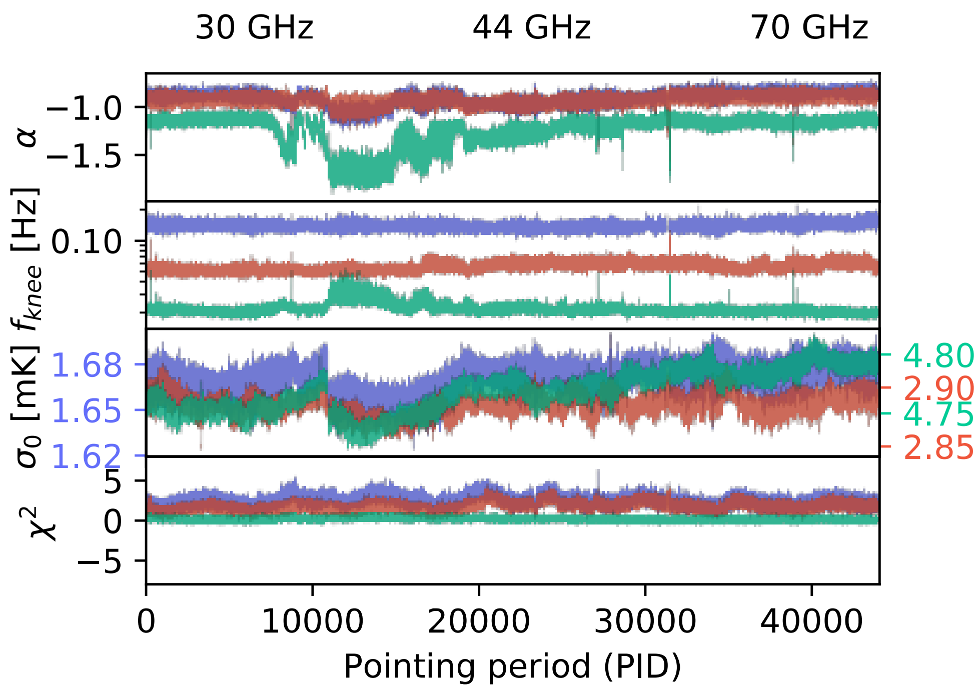

Figure 2. Posterior mean noise parameters averaged over all radiometers in each Planck-LFI band, for the full mission.

2 Thermal effects and excess noise

The LFI was operated at 20K with pseudo-correlation receivers comparing the sky signal to a set of stable blackbody reference loads cooled to 4K. The superb stability of the L2 orbit and the careful thermal design of the Planck satellite ensured a highly stable environment for the LFI. However, some instabilities were present and were tracked by the temperature sensors installed in various parts of the instrument and spacecraft. The main thermal changes affecting the LFI were related to the Planck sorption cooler system (SCS), which provided the 20K stage to the LFI front-end and the 18K pre-cooling stage to HFI. The SCS included a nominal and a redundant unit. In August 2010 the nominal cooler was switched over to the redundant cooler. This “switchover” event implied a redistribution of the temperatures in the LFI focal plane, followed by an instability period. Furthermore, before and after the switchover a series of power input adjustments were commanded to reduce thermal fluctuations in the 20K stage while optimizing the sorption cooler lifetime, which generated a set of step-like increases in the LFI focal plane temperature.

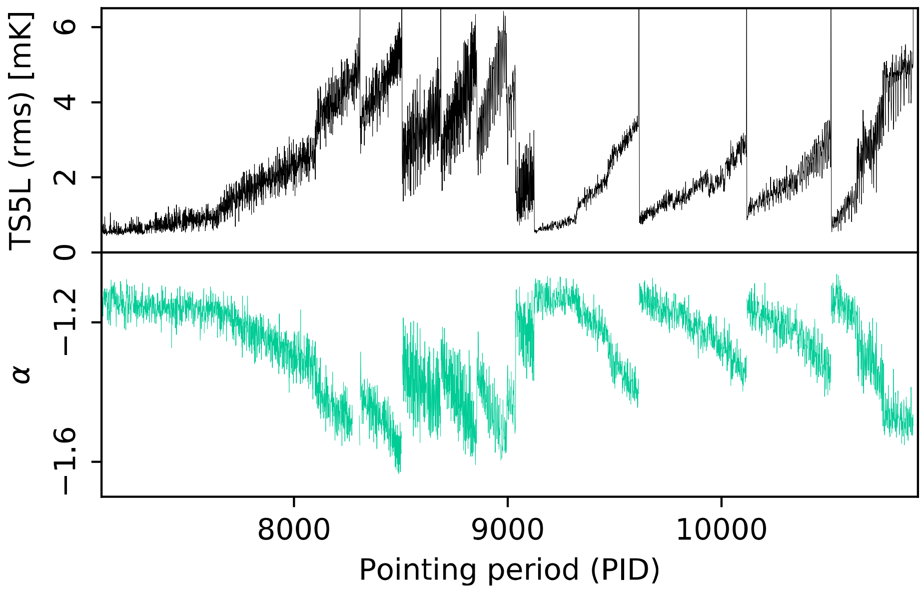

Figure 3: Average correlated noise properties of the 70 GHz radiometers (bottom panel) compared with the rms of a 20K temperature sensor TS5L (top panel) for the period just before the sorption cooler switchover.

The new BeyondPlanck analysis allowed us to study in detail the effects of all these temperature changes in the statistical properties of the radiometer noise (Ihle et al. 2020). Perhaps the most striking example is the correlation observed between the 20K sensors fluctuations and the 70GHz correlated noise parameters (knee frequency and slope). This is illustrated in Fig. 3, where the rms of the physical temperature (black line) is remarkably traced by the average 1/f slope of the 70GHz radiometer noise (green). More details are given in BP06.

The BeyondPlanck approach allowed us to identify specific effects in some radiometers during limited periods of the survey. As a consequence, some data were excluded from the analysis thus improving the quality of the LFI maps. The most significant case is the 44 GHz 26S radiometer (Fig. 4), which compares the noise spectrum averaged over 10 PIDs in two distinct times during the survey. We see an excess in power at intermediate frequencies that is not possible to fit with the canonical 3-parameters noise model. Considering that the Planck spin period is 60 s, temporal frequencies of 0.1–1 Hz correspond to angular scales of 6–60 on the sky. This unmodelled noise therefore represents a significant contaminant with respect to large-scale CMB polarization reconstruction. We therefore exclude all data from 26S after after PID 20 800 (Suur-Uski et al. 2020), implying some loss of sensitivity at 44Ghz (about 17%) but achieving a more complete noise description.

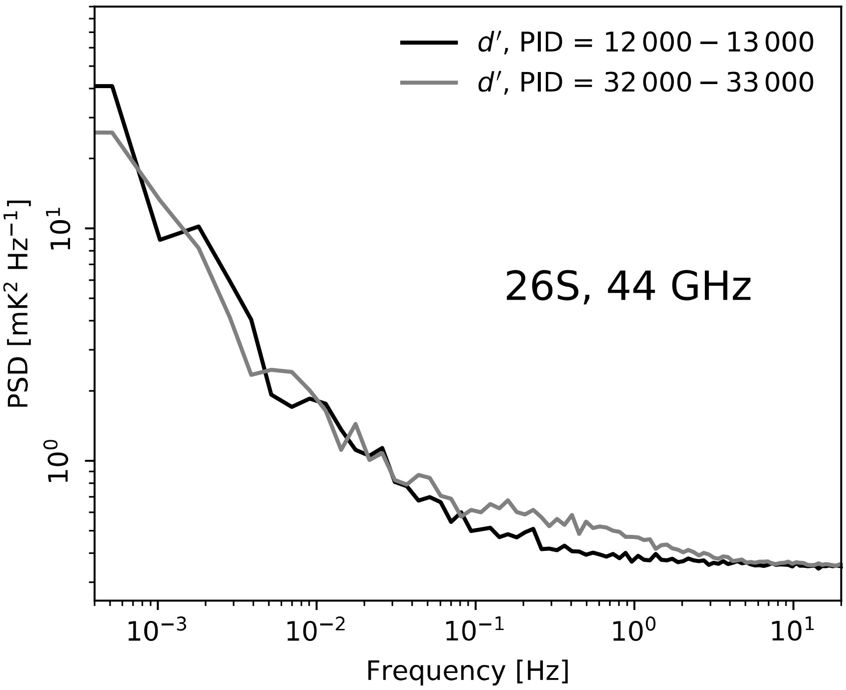

Figure 4. Noise spectrum of signal-subtracted data from radiometer 26S, averaged over 10 PIDs (at intervals of 100 PIDs) in the ranges 12 000–13 000 (black) and 32 000–33 000 (grey). We see that there is significantly more power in the frequency range 0.1–10 Hz in the later period which cannot be ascribed to the canonical 3-parameter noise model.

3 Gain calibration

The Bayesian calibration algorithm of BeyondPlanck decompose the full time-dependent gain into a sum of an absolute calibration term, common to all detectors, a time-independent term that can vary between detectors, and a time-dependent component that is allowed to vary between PIDs. Each term is then sampled conditionally on all other parameters in the global signal model. We find new gain solutions for the LFI radiometers with deviations compared with previous analyses within expected error bounds. As shown in Fig. 5, there are still some evident striped in the data that correlate with the scanning strategy, thus identifying gain errors. We have thus identified an outstanding issue to be pinned down in future BeyondPlanck realizations.

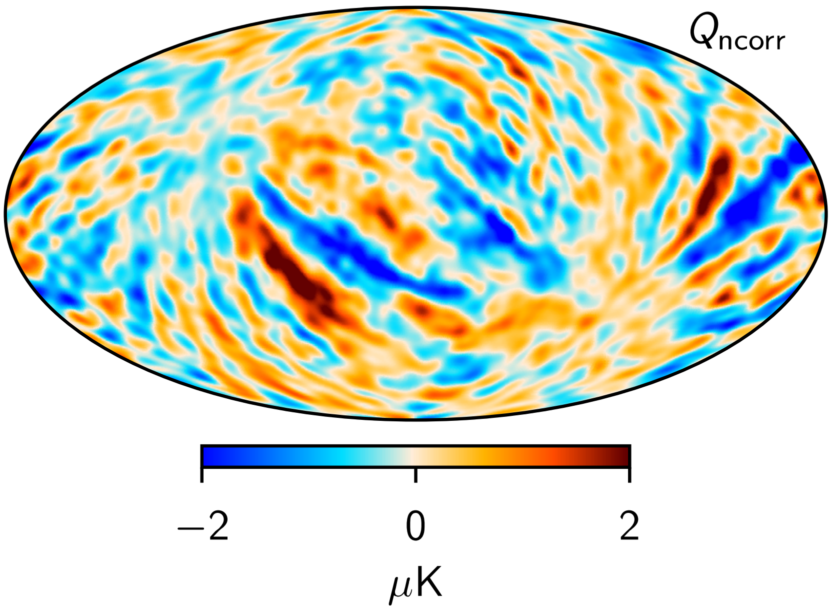

Fig. 5. Map of the correlated noise of the Q Stokes parameter for the 44 GHz frequency channel, smoothed to an effective angular resolution of 5 degrees.

4 Outstanding problems

The BeyondPlanck analysis carried out in this program identified a great deal of insight on the instrument behavior and set the stage for further improvements. In general we find excess noise at 30 and 44GHz that needs more investigation. In particular, the degradation of the 44GHz channel 26S has no simultaneous counterpart in any other LFI radiometer, suggesting a singular event within the 26S itself or in the bias circuits serving its RF components. This example shows BeyondPlanck has allowed to set the stage for more detailed analysis of instrumental systematic effects that were not possible before. As part of BeyondPlanck activity in this WP we have resumed and accurately reconstructed all the relevant housekeeping data (including all electrical bias inputs to the LFU low noise amplifiers and phase switches) from archive files. Searching for further correlations of systematic effects and residual stripes in correlated noise maps with housekeeping data will be the subject of further BeyondPlanck activity.

5 References

BeyondPlanck I. Global Bayesian analysis of the Planck Low Frequency Instrument data, BeyondPlanck Collaboration, 2020, A&A, submitted, [2011.05609]

BeyondPlanck VI. Noise characterization and modelling, Ihle, H. T. et al. 2020, A&A, submittted [2011.06650]

BeyondPlanck VII. Bayesian estimation of gain and absolute calibration for CMB experiments, Gjerløw, E. et al. 2020, A&A, submitted [2011.08082]