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The scientific impact of signal quantization on Planck/LFI observations

M. Maris[1], D. Maino[1,2], C. Burigana[3], A. Mennella[4], M. Bersanelli[2,4], and F. Pasian[1]

[1] INAF, Osservatorio Astronomico di Trieste, Trieste, Italy
[2] Dipartimento di Fisica, Università di Milano, Milano, Italy
[3] CNR, Istituto di Astrofisica Spaziale, Sezione di Bologna, Bologna, Italy
[4] CNR, Istituto di Astrofisica Spaziale, Sezione di Milano, Milano, Italy

Abstract. The real data processing of the signal observed by the Planck Low Frequency Instrument (LFI) introduces systematic effects in the time ordered data (TOD), maps and, finally, in the reconstruction of the sky angular power spectrum C_ℓ^{sky}. With analytical and numerical methods we studied the signal quantization of LFI TOD in order to evaluate the possibility to model and remove its effect on the C_ℓ^{sky} recovery. We find that it introduces a power excess, C_ℓ^{ex}, only weakly dependent on the multipole ℓ at middle and large ℓ. It can be quite accurately subtracted, leaving an uncertainty, ΔC_ℓ^{ex}, of only $1-2\%$ of the RMS uncertainty, ΔC_ℓ^{noise}, on C_ℓ^{sky} reconstruction due to the noise power, C_ℓ^{noise}.

Key words. methods: data analysis – methods: statisticals – astronomical data bases: miscellaneous – space vehicles: instruments

1. Statement of the problem

The Planck satellite, scheduled for launch in 2007, will produce full sky maps with high accuracy and resolution over a wide range of frequencies jointly covered by the Low Frequency Instrument (LFI), operating at 4 frequencies between 30 and 100 GHz (Mandolesi et al. 1998), and the High Frequency Instrument (HFI), operating at 5 frequencies between 100 and 854 GHz (Puget et al. 1998).

The output of each pseudo-correlation radiometer of the LFI array is a measure of the difference between the signal from the sky and from an internal reference load held at a constant temperature, as detected by the two arms of the radiometer chain. The data are taken while the Planck satellite spins at 1 r.p.m. about its spin axis kept along the same direction for 1 hour and then repointed with an angular shift of 2.5 arcmin according to the selected scanning strategy. Each sky location will be then observed at least $N_{\rm s} \gtrsim 60$ times during each mission sky coverage. A complex sequence of on-board data processing steps is applied to each independent mea-

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Send offprint requests to: M. Maris
Correspondence to: INAF, Osservatorio Astronomico di Trieste, Via Tiepolo 11, I-34131 Trieste, Italy

sure of the radiometer output, usually expressed as a differential antenna temperature $\Delta T_{\rm obj}$. One of the potentially most harmful step is the *software quantization* of the data needed to adapt the Shannon's entropy of the signal to the input of the loss-less compression stage. The software quantization is parametrized by the ratio, σ/q, between the RMS of the noise of a single measure, σ, and the digitization step of the software quantization, q. The limited bandwidth available to download LFI data to Earth and the need for loss-less compression (Maris et al. 2000a) imposes to adopt $\sigma/q \simeq 2$; for most of the 'objects' observed by LFI we have $q \gtrsim \Delta T_{\rm obj}$. In most cases $\sigma \gtrsim \Delta T_{\rm obj}$, and repeated measures of the same object will be scattered over more quantization levels. The average of the $N_{\rm s}$ measures will estimate $\Delta T_{\rm obj}$ with an accuracy better than q. Analytical methods used to evaluate the signal digitization effect in standard applications (Kollár 1994) deal with completely different assumptions: $\sigma/q \gg 1$ and no averaging. The LFI data will be reprocessed by using a *destriping* algorithm in order to strongly reduce (Maino et al. 1999) the $1/f$ noise effect (Seiffert et al. 2002). While standard analytical methods are good enough for the mission design, the overall effect of these processes on the data can be described only with realistic simulations that are necessary for an accurate data reduction (Maris et al. 2003).

2. Results

We have numerically compared the two different final TOD, as well as the corresponding reconstructed maps and C_ℓ, generated by our mission simulator (Burigana et al. 1998) applying or not the software quantization to the same realization of radiometer simulated outputs (Maris et al. 2000b). At TOD level, the effect of the quantization can be approximated as a source of white noise, nearly normally distributed, with RMS $\simeq q/\sqrt{12 N_{\rm s}}$, while deviations from normality are relevant for $N_{\rm s} \lesssim 20$. At map level, the data quantization alters the noise distribution and the expectation of some higher order moments. We find a constant ratio, $\simeq 1/(\sqrt{12}\sigma/q)$, between the RMS of the quantization noise and of the instrumental noise over the map ($\simeq 0.14$ for $\sigma/q \simeq 2$). The bias on the expectation for higher order moments may be treated with methods similar to Sheppard's correction; however for $\sigma/q \sim 2$ this bias is comparable to their sampling variances. Finally, we find that the quantization introduces a power excess, C_ℓ^{ex}, that, although related to the instrument and mission parameters, is weakly dependent on the multipole ℓ at middle and large ℓ and can be quite accurately subtracted. For $\sigma/q \simeq 2$, the residual uncertainty, ΔC_ℓ^{ex}, implied by this subtraction is of only $\simeq$1–2% of the RMS uncertainty, ΔC_ℓ^{noise}, on C_ℓ^{sky} reconstruction due to the noise power, C_ℓ^{noise}. Only for $\ell \lesssim 30$ the quantization removal is less accurate; in fact, the $1/f$ noise features, although efficiently destripped, increase C_ℓ^{noise}, ΔC_ℓ^{noise}, C_ℓ^{ex} and then ΔC_ℓ^{ex}; anyway, at low multipoles $C_\ell^{\rm sky} \gg \Delta C_\ell^{\rm noise} > \Delta C_\ell^{ex}$. In conclusion, the application of such a large quantization step will not harm the Planck/LFI scientific return.

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