

Automated Programming and Simulations of Signal Compression from the Cosmic Microwave Background for the Planck Low Frequency Instrument

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Abstract. The concept of Automatic Programming and Managing of simulations is applied to the compression of the data stream expected from the Low Frequency Instrument (LFI) aboard Planck Surveyor, the next millennium European Space Agency (ESA) satellite for imaging the Cosmic Microwave Background (CMB). A first analysis of the efficiency of several compression algorithms for different combinations of cosmological and astrophysical signals and for instrumental noise is presented.

1. Introduction

The Planck satellite (formerly COBRAS/SAMBA, Bersanelli et al. 1996), which is planned to be launched in 2007, will produce full sky CMB maps with high accuracy and resolution over a wide range of frequencies. Table 1. summarizes the basic properties of LFI aboard Planck (the reported sensitivities per resolution element, in terms of thermodynamic temperature, represents the goals of LFI for a one-year mission).

The limited bandwidth reserved to the downlink of scientific data calls for huge lossless compression, the theoretical upper limit being a bit less than eight. Careful simulations are demanded to quantify the capability of true compressors for “realistic” synthetic data including CMB signal, foregrounds and instru-

Table 1. Summary of LFI characteristics (Mandolesi et al. 1998a).

Characteristic				
Center frequency [GHz]	30	44	70	100
Number of detectors	4	6	12	34
Angular resolutions, FWHM [μ]	33	23	14	10
Bandwidth [$\Delta\nu/\nu$]	0.2	0.2	0.2	0.2
$10^6\Delta T/T$	1.6	2.4	3.6	4.3
ΔT_{rms} [μ K]	4	7	10	12
Both polarizations	yes	yes	yes	yes

mental noise. An Automated Program Generator was applied to perform this exploratory process by changing the signal components, the dynamic range of detectors and the compression algorithms, which enables to save time, reduce errors and simplify the simulations management.

2. Planck Operations Data Rate and Compression

During the data acquisition phase, the Planck satellite will rotate at a rate of one circle per minute around a given spin axis that changes its direction every hour (of 2.5 on the ecliptic plane in the case of simple scanning strategy), thus observing the same circle on the sky for 60 consecutive times (Mandolesi et al. 1998a,b). The LFI instrument will produce continuous data streams of temperature differences between the microwave sky and a set of onboard reference sources; both differential measurements and reference source temperatures must be recorded.

The data rate will depend on the sampling time, the present LFI Proposal is ~ 7 msec for each detector (Mandolesi et al. 1998a), thus calling for a typical data rate of ~ 260 kB/sec, while the allocated bandwidth for the data is on average only 20 kB/sec. The data flow have to be downloaded on ground without information losses, and by minimizing scientific elaboration on board. The solution of this problem asks for an efficient and lossless compression of LFI data before they are sent to Earth.

As shown by Gaztñaga et al. (1998), theoretical upper limits for the lossless compression factor of noise data are located between 7.75 and 7.82. On the other hand, such a level of efficiency can be reached under certain optimization hypotheses, it is crucial to study the efficiency of real compression algorithms applied to “real” LFI data (as obtained by simulations) in the form of time series. This may lead, as a second step, to the definition of some level of simple “a priori” data coding or preprocessing to be performed, aimed at increasing the compression factor by allowing the simulated data to better satisfy the optimization hypotheses. The whole work is aimed at the optimization of the transmission bandwidth dedicated to the downlink of LFI data from the Planck spacecraft to the FIRST/Planck Ground Segment.

3. Experimental Strategy

For the successful development of the project, the following steps have been identified:

- select different compression algorithms
- run simulations producing data which contain different types of signal sources, instrumental characteristics and detection electronics:
 1. noise spectrum: *i*) white noise; *ii*) white noise coupled to $1/f$ noise with different knee frequencies
 2. signal sources subsequently added to the noise: *i*) + CMB fluctuations; *ii*) + dipole; *iii*) + Galaxy; *iv*) + extragalactic point sources
 3. different time lengths
 4. reference load temperature (20 K for present text)
 5. different frequency channels with the corresponding beam sizes (we have considered the 30 GHz and 100 GHz channels with 30' and 10' FWHM beam sizes respectively)
 6. different signal offset and scaling
- apply compression algorithms to simulated data
- analysis of results and discussion on possible data coding or preprocessing.

The combination of the above items yields a large number of combinations to be systematically explored. Automatic simulation generation and management through one simplified Automated Program Generator (APG; Maris 1998; Maris & Staniszkis 1999) implementing a Virtual Scanner (VuScanner) under IDL were considered both for analysis and realization. This version of the Virtual Scanner is similar to the **MatLab** version used for neutrino studies (Maris 1999) with some modifications to take into account the reduced flexibility of the IDL language if compared to **MatLab**.

4. Results and Conclusions

The simulated cosmological and astrophysical components are generated according to the methods described in Burigana et al. (1998) and the data stream and noise generation as in Burigana et al. (1997) and Seiffert et al. (1997).

Signal detection is simulated through the formula (M. Bersanelli, J. Herrera, & M. Seiffert 1998, private communication) $V = AFO + VOT \cdot \Delta T$, where V is the detection chain output in Volts ($-10V \leq V \leq 10V$), AFO is the detection chain offset ($-5V \leq AFO \leq +5V$), VOT is the antenna temperature / voltage conversion factor ($-0.5V/K \leq VOT \leq +1.5 V/K$), ΔT is the difference between antenna temperatures due to the sky signal and a reference load. Sixteen bits quantization is applied to the signal before compression and before writing into a binary file.

The output of the compression chain is a set of compression evaluation tables for the components of the incremental cosmological signal, one for each set of conditions. The compression efficiency η_c is evaluated as the ratio $\eta_c = L_u/L_c$, where L_u is the uncompressed signal length in bytes and L_c is the compressed signal size.

We have analyzed the efficiency of four kinds of compression algorithms (**compress**, **compact**, **gzip** and **gzip**) for a limited sample of the full set of

simulations. For these tests, the full range found was 1.9 – 6.5. Our preliminary conclusions are summarized as follows:

1. the compression efficiency η_c is influenced by: VOT , AFO , and by the signal length L_u
2. compressing more circles at a time (i.e. increasing L_u) slightly improves η_c
3. the compression efficiency depends on the frequency and on the components included in the sky signal
4. in particular, removing the cosmological dipole through a reversible fit improves the η_c
5. the best compressor tested is **gzip**, but **szip** is comparable to it and is NASA space qualified
6. the **gzip** compression efficiency for the “central” detector values ($VOT = 1$ V/K, $AFO = 0.0$ V) for 1 min data stream at 30 GHz (100 GHz) is $\eta_c^{\text{gzip}} \sim 4.9 - 5.1$ ($\eta_c^{\text{gzip}} \sim 4.4 - 4.5$).

In conclusion these realistic compression factors, albeit encouraging as a first result, are about a factor two worse than the theoretical upper limit. Further investigations are required to reach the target compression factor without any on-board data averaging at all. In addition, the choice of a given compressor can not be based only on its efficiency, but also on the on-board available CPU and on the official ESA space qualification: tests with this hardware platform and other compressors will be made. In the near future, long-duration flight balloon experiments will provide a solid base to test and improve compression algorithms.

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