Abstract. We study the astrophysical foreground emissions in the context of the effort for constraining the Cosmic Microwave Background (CMB) anisotropy non-Gaussianity (NG). We parametrize the NG signal by an equivalent $f_{\text{NL}}$ evaluated through the Komatsu-Spergel-Wandelt (KSW) estimator and induced by the known Galactic emissions. We analysed foregrounds template and CMB at 70 GHz adopting Planck specifications and finding a possible induced bias inconsistent with zero at $8\sigma$ for a mask of 70% of free sky coverage.

1. Introduction

Emissions from our Galaxy are the limiting factor in most of CMB measurements, in particular for studies related to the search for primordial NG.

In this article we investigate the effect of contamination of Galactic foregrounds on the phenomenological parameter $f_{\text{NL}}$. This parameter is a measure of deviation from a Gaussian distribution of the primordial curvature perturbations [1], basically measuring the 3-point function in harmonic space, the bispectrum, of the primordial curvature perturbations distribution. In this work we will focus on a particular form of the bispectrum, the so-called “local shape bispectrum$^1$” that is motivated by inflationary models. The parameter $f_{\text{NL}}^{\text{local}}$ is then the value estimated using the local shape bispectrum.

We will consider the following Galactic foregrounds [2]: free-free emission, arising from electron-ion scattering; synchrotron emission, arising from the acceleration of cosmic ray electrons in the Galactic magnetic field; and dust emission, arising from thermal emission of large grains of dust in our Galaxy.

We set up our investigation on Galactic foregrounds adopting the specifications of the Planck satellite experiment that is currently taking data on the micro-wave sky [3]. In particular we will focus on the 70 GHz Planck channel where the Galactic foreground contamination is minimum [2].

The WMAP team gives an estimation of the effect of Galactic foreground in $f_{\text{NL}}$ studies [5]. They compared the $f_{\text{NL}}$ estimated from the optimal combination of V- and W-band foreground-reduced maps with the $f_{\text{NL}}$ estimated from the same clean map but marginalized over the synchrotron, free-free, and dust foreground templates. Considering the local shape bispectrum they found $f_{\text{NL}}^{\text{local}} = 41 \pm 21$ for the clean map and $f_{\text{NL}}^{\text{local}} = 31 \pm 21$ for the marginalized map concluding that Galactic foreground emission gives rise to a contamination effect of $\Delta f_{\text{NL}}^{\text{local}} \sim 10$.

$^1$ This form is called the local form, as this bispectrum can arise from the curvature local perturbation in the form of $\Phi = \Phi_L + f_{\text{NL}}\Phi_L^2$, where both sides are evaluated at the same location in space ($\Phi_L$ is a linear Gaussian fluctuation) [1].
With Planck we can improve the understanding of the foreground contamination on $f_{\text{NL}}$ for two main reasons: Planck has a higher resolution and sensitivity with respect to WMAP and, will observe in 9 frequency bands tuned to improve the reliability of the foreground templates with respect to the CMB studies.

The Planck satellite is expected to have an accuracy of $\Delta f_{\text{NL}}^{\text{local}} \sim 5$ (see [4]) giving us the possibility of constrain the Galactic foreground contamination.

We will focus on the combined effect of the Galactic foreground emission, in section 2 will be described the simulation set-up. In section 3 we will describe the estimator that will be use for NG studies. In section 4 we will describe the sky masks used for this work, how they were realised and we will show the $f_{\text{NL}}$ due to the galactic foreground template. In the conclusion we analyse the results and discuss future investigations.

2. Sky simulations

The foregrounds template used in this work will be consistent with that used in [6]. We construct all sky maps template including the effect of three main diffuse Galactic emission mechanisms: the synchrotron emission using the data by [11], treated by [12] with space varying spectral index obtained from the WMAP analysis [2]; the dust total intensity is based on the analysis of IRAS and DIRBE data by [13], implementing model 8 of frequency scaling including spatial variations of dust frequency scaling; the free-free emission, traced by H$\alpha$ emission, has also been included.

We simulate sky maps with foreground emissions and CMB at 70 GHz channel using Planck specifications, with a Gaussian beam of 13 arcmin and homogeneous noise taken from Planck bluebook. We adopt a $\Lambda$CDM model with WMAP 7yr cosmological parameters [15]. We choose HEALPix\textsuperscript{2} parameter $N_{\text{side}} = 1024$ and $l_{\text{max}} = 2000$. Then we applied the KSW algorithm described in the next section.

3. KSW estimator for $f_{\text{NL}}$

KSW estimator was originally proposed in [7]. It is a bispectrum based estimator [8] but have the advantage of being much faster than a brute force computation of all possible configuration of the bispectrum. The idea is to use a well suited set of filtered maps for constructing the cubic statistics optimal for the primordial NG. We will focus on the local bispectrum shape related to the parameter $f_{\text{NL}}^{\text{local}}$. Then KSW is built from a cubic statistic obtained by combining the following filtered maps

\begin{align*}
A(\hat{n}, r) &= \sum_{lm} b_l \alpha_l(r)(C^{-1}a)_{lm}Y_{lm}(\hat{n}), \\
B(\hat{n}, r) &= \sum_{lm} b_l \beta_l(r)(C^{-1}a)_{lm}Y_{lm}(\hat{n}),
\end{align*}

where $b_l$ is the experimental beam, $C^{-1}$ is the inverse of the total power spectrum including the CMB signal, $C_l^{CMB}$, and noise, $N_l$, ($C_l \equiv C_l^{CMB}b_l^2 + N_l$) [9]; and

\begin{align*}
\alpha_l(r) &= \frac{2}{\pi} \int k^2 dk g_{Tl}(k)j_l(kr), \\
\beta_l(r) &= \frac{2}{\pi} \int k^2 dk P_\Phi(k)g_{Tl}(k)j_l(kr),
\end{align*}

where $g_{Tl}$ is the temperature radiation transfer function\textsuperscript{3} and $P_\Phi$ is the primordial curvature perturbation power spectrum.

\textsuperscript{2} Hierarchical Equal Area isoLatitude Pixelization, http://healpix.jpl.nasa.gov
\textsuperscript{3} Obtained from a modified version of CAMB code, http://camb.info
The cubic statistic for the local shape bispectrum is written as

\[ S_{\text{local}} = \int r^2 dr \int d^2 \hat{n} \left[ A(\hat{n}, r)B^2(\hat{n}, r) - 2B(\hat{n}, r) \langle A(\hat{n}, r)B(\hat{n}, r) \rangle_{\text{MC}} \right. \]

\[ \left. - A(\hat{n}, r) \langle B^2(\hat{n}, r) \rangle_{\text{MC}} \right], \tag{5} \]

In the formula above MC denotes Monte-Carlo averages over CMB simulations including all experimental features. Those MC averages appear in terms that are linear in the \( a_{lm} \)'s so that they are zero on average (The “real” cubic statistic is entirely contained by \( AB^2 \) term). The linear term is necessarily to make the estimator optimal in presence of statistical anisotropic terms in the data, in particular sky cut and anisotropic noise [1]. Using the definitions above it is possible to evaluate the value \( f_{\text{NL}}^{\text{local}} \) with the formula

\[ f_{\text{NL}}^{\text{local}} = S_{\text{local}} / F_{\text{local}}, \tag{6} \]

where \( F_{\text{local}} \) is the Fisher matrix for the local shape bispectrum.

In this article we shall adopt the so-called pseudo-optimal estimator, where the covariance matrix is supposed to be diagonal. The disadvantages is that the variance is higher with respect to the optimal estimator, but in this way, the KSW estimator is much faster, making the analysis that will be shown in the next section feasible.

4. Foreground \( f_{\text{NL}} \)

In this section we show the analysis done with the KSW on the 70 GHz Planck channel. We choose to analyse two different free sky fraction to highlight latitude dependent effects from foregrounds. Then we analyze the results with the KSW estimator.

Figure 1. This galactic template map is obtained by the sum of the main Galactic foreground template: free-free, synchrotron and dust with 13 arcmin angular resolution. The units are adimensional with logarithmic scale color to highlight the shape of foreground template at high latitude.

The sky emission is in figure 1. We construct two masks with 40% and 70% of available sky using the method described in [2]. Those mask are shown in figures 2 and 3.

Figure 2. 40% sky mask.  
Figure 3. 70% sky mask.

For each mask we perform a “control” run using 128 Gaussian CMB maps and no template added, then a second run using the same Gaussian realizations but including foreground template. We then estimate the mean value of local \( f_{\text{NL}} \).
Table 1. Estimation of foreground induced $f_{NL}^{\text{local}}$. 

| Template added | Mask | $\langle f_{NL}^{\text{local}} \rangle_{128 \text{ maps}}$ | $\sigma_{f_{NL}}$ |
|----------------|------|---------------------------------|-----------------|
| No             | 40%  | 1.6                             | 17.5 (68% CL)   |
| No             | 70%  | 2.0                             | 14.6 (68% CL)   |
| Yes            | 40%  | 1.3                             | 17.5 (68% CL)   |
| Yes            | 70%  | $-25.1$                         | 34.9 (68% CL)   |

Results are indicated in table 1, showing some interesting features. The first one is that with the 40% sky coverage we are effectively masking the foreground template $f_{NL}^{\text{local}}$ induced signal (our control $f_{NL}$ is basically the same as $f_{NL}$ measured in presence of foregrounds). The second one, as expected, is that decreasing the masked sky the effect of the foregrounds enter in the $f_{NL}$ estimation. In this particular case the $\langle f_{NL}^{\text{local}} \rangle$ is $\sim -25$. When a less conservative sky cuts is used the foreground contamination became evident. Not only $f_{NL}^{\text{local}}$ present a negative bias, but also the variance is doubled with respect to the reference run. A negative bias is exactly the kind of contribution that you expect from a foreground since it skews positively the temperature contribution. Better investigation is needed the understand the variance increase: it may be due to the fact that the foreground template heavily breaks statistical rotational invariance, an effect that is known to make the bispectrum-based estimators suboptimal in absence of an appropriate linear term correction [1].

5. Conclusion

In this preliminary analysis we show how the galactic foregrounds emission can potentially contaminate measurement of $f_{NL}^{\text{local}}$ for Planck 70 GHz channel, finding in particular that decreasing the mask dimension the effect of contamination can be huge, bringing $\langle f_{NL}^{\text{local}} \rangle$ from a value compatible with zero to a value $\sim -25$ which according to our results is inconsistent with zero at order 8$\sigma$. The factor two increase of the variance in the case of 70% free sky mask is another important effect which require more investigation to be understood.

Some of the results in this paper have been derived using the HEALPix [14] and CAMB packages [16].

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