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Searching for non-Gaussianity in the Planck data

Marcelo J. Rebouças[1] **and Armando Bernui**[2]

[1]Centro Brasileiro de Pesquisas Físicas,
Rua Dr. Xavier Sigaud 150, 22290-180 Rio de Janeiro – RJ, Brazil
email: `reboucas@cbpf.br`

[2]Observatório Nacional
Rua General José Cristino 77, 20921-400 Rio de Janeiro – RJ, Brazil
email: `bernui@on.br`

Abstract. The statistical properties of the temperature anisotropies and polarization of the of cosmic microwave background (CMB) radiation offer a powerful probe of the physics of the early universe. In recent works a statistical procedure based upon the calculation of the kurtosis and skewness of the data in patches of CMB sky-sphere has been proposed and used to investigate the large-angle deviation from Gaussianity in WMAP maps. Here we briefly address the question as to how this analysis of Gaussianity is modified if the foreground-cleaned Planck maps are considered. We show that although the foreground-cleaned Planck maps present significant deviation from Gaussianity of different degrees when a less severe mask is used, they become consistent with Gaussianity, as detected by our indicators, when masked with the union mask U73.

Keywords. Non-Gaussianity, Cosmic Microwave Background Radiation, CMB Planck maps

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1. Introduction

The statistical properties of the temperature fluctuations and polarization of cosmic microwave background (CMB) radiation offer a powerful probe of the physics of the early universe (Komatsu 2010). In this way, a detection of a significant level of primordial non-Gaussianity (NG) of local type ($f_{\rm NL}^{\rm local} \gg 1$) would rule out, for example, the entire class of single scalar field models (see, e.g., Creminelli & Zaldarriaga 2004 and Komatsu 2010).

It is conceivable, however, that no single statistical estimator can be sensitive and suitable to capture all forms of non-Gaussianity that may be present in the observed CMB data. Thus, it is important to test CMB data for non-Gaussianity by using different statistical indicators.

In a recent paper (Bernui & Rebouças 2009) statistical procedure based upon the calculation of the skewness and kurtosis by taking the values of the CMB temperatures fluctuations assigned to the pixels inside patches of CMB sky-sphere has been proposed and used to study deviation from Gaussianity in foreground-reduced WMAP maps (Bernui & Rebouças 2010) as well as in simulated maps (Bernui & Rebouças 2012). A pertinent question is how the analysis of Gaussianity made by using WMAP data is modified if the foreground-cleaned maps released by the Planck are considered. We have addressed this question and here we report partially the results of our analyses performed with the skewness estimator. For a comprehensive statistical analysis we refer the readers to our recent paper (Bernui & Rebouças 2014).

2. Statistical procedure and main results

Perhaps the simplest test for Gaussianity of a CMB map can be made by computing the skewness, S, and kurtosis, K from the whole set of CMB temperature fluctuations values of a given CMB map. However, one can go a step further and, instead of calculate two numbers, one can compute n values of the skewness as well as n values of the kurtosis, and obtain with directional information on NG, by dividing the CMB sphere $\mathbb{S}^2$ into a number n of uniformly distributed spherical patches of equal area that cover $\mathbb{S}^2$, and by calculating the skewness and the kurtosis

$$S_j = \frac{1}{N_{\rm p}\,\sigma_j^3} \sum_{i=1}^{N_{\rm p}} \left(T_i - \overline{T_j} \right)^3 , \tag{2.1}$$

$$K_j = \frac{1}{N_{\rm p}\,\sigma_j^4} \sum_{i=1}^{N_{\rm p}} \left(T_i - \overline{T_j} \right)^4 - 3 , \tag{2.2}$$

for each patch $j = 1, \dots, n$. Here $N_{\rm p}$ is the number of pixels in the $j^{\,\rm th}$ patch, T_i is the temperature at the $i^{\,\rm th}$ pixel, $\overline{T_j}$ is the CMB mean temperature in the $j^{\,\rm th}$ patch, and σ is the standard deviation. In this work, we have chosen these patches to be spherical caps (calottes) with aperture $\gamma = 90^\circ$.

The two set of n values (each) $\{S_j\}$ and $\{K_j\}$ along with the spherical coordinates of the center of the patches, θ_j, ϕ_j can then be employed to define two discrete functions on $\mathbb{S}^2$, namely $S(\theta_i, \phi_i)$ and $K(\theta_i, \phi_i)$ in such way that $S(\theta_j, \phi_j) = S_j$ and $K(\theta_j, \phi_j) = K_j$ for every $j = 1, \dots, n$. These functions give local measurements of NG as functions of angular coordinates. The Mollweide projections of $S(\theta_j, \phi_j)$ and $K(\theta_j, \phi_j)$ are skewness and kurtosis maps, whose power spectra S_ℓ and K_ℓ can be used to study large-angle deviation from Gaussianity by determinig the goodness of fit of these power spectra obtained from the Planck maps as compared to the mean power spectra calculated from 1 000 simulated Gaussian maps ($\overline{S}_\ell^G$ and $\overline{K}_\ell^G$) through a χ^2 analysis. In this way, for S_ℓ obtained from a given Planck map one has

$$\chi^2_{S_\ell} = \frac{1}{N-1} \sum_{\ell=1}^{N} \frac{\left(S_\ell - \overline{S}_\ell^G \right)^2}{(\,\sigma_\ell^G\,)^2} , \tag{2.3}$$

where $\overline{S}_\ell^G$ are the mean multipole values for each ℓ mode, $(\sigma_\ell^G)^2$ is the variance computed from 1 000 Gaussian maps, and N is the highest multipole taken in the analysis of NG.

Clearly a similar expression and reasoning can be used for K_ℓ. In what follows, however, for the sake of brevity we will only briefly report the results of our analysis related to the skewness. For a comprehensive statistical analysis see our recent paper (Bernui & Rebouças 2014).

Fig. 1 shows the power spectra S_ℓ calculated from SMICA and NILC maps masked with INPMASK (left panel). The right panel of this figure shows the power spectra S_ℓ computed from SMICA, NILC and SEVEM maps with the U73 mask. This figure also contains the points of the averaged power spectra $\overline{S}_\ell^G$ calculated from 1 000 Gaussian simulated CMB maps and the 1σ error bars. To the extent that some of power spectra values S_ℓ fall off the 1σ error bars centered at $\overline{S}_\ell^G$ value, the left panel of this figure indicates departure from Gaussianity in both SMICA and NILC maps when masked with INPMASK. However, the right panel indicates that departure disappear when the more severe U73 mask is used.

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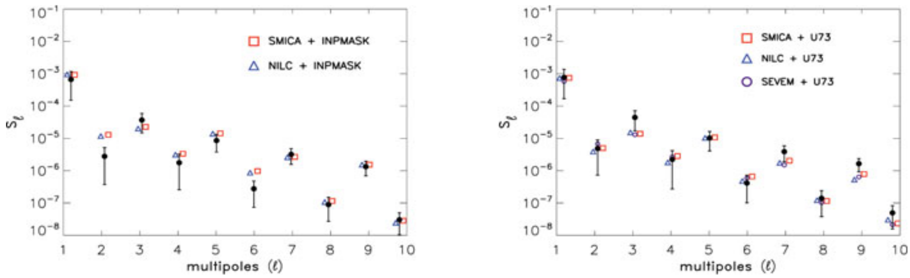

Figure 1. Low ℓ power spectra S_ℓ calculated from SMICA and NILC Planck maps equipped with INPMASK (left panel) and with U73 mask. We note that since there is no available INPMASK for the SEVEM map we have not included this map in the analysis with the INPMASK. Tiny horizontal shifts were used to avoid overlaps of symbols.

The above comparison of the power spectra by using Fig. 1 is useful as a qualitative indication of NG of Planck maps with different masks. However, to have a quantitative overall assessment of large-angle deviation from Gaussianity we have used the power spectra S_ℓ (calculated from the Planck maps) to carry out the above-mentioned χ^2 analysis to determine the goodness of fit of S_ℓ computed from the Planck maps as compared to the mean power spectra $\overline{S}_\ell^G$. Table 1 makes clear that although with different χ^2–probabilities the SMICA, NILC and SEVEM masked with INPMASK exhibit small level of NG, but when the union mask U73 is used these maps are consistent with Gaussianity as detected by our indicator S, in agreement with the results found by the Planck team (Ade *et al.* 2013).

Map & Mask	$\chi^2_{S_\ell}$– probability
SMICA–INPMASK	1.00×10^{-4}
NILC–INPMASK	1.80×10^{-3}
SMICA–U73	8.43×10^{-1}
NILC–U73	8.25×10^{-1}
SEVEM–U73	7.29×10^{-1}

Table 1. Results of the χ^2– probability test to determine the goodness of fit for S_ℓ multipole values, calculated from the SMICA, NILC and SEVEM with INPMASK and U73 masks, as compared to the mean power spectra $\overline{S}_\ell^G$ obtained from 1 000 simulated Gaussian maps.

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