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Amplitude-Phase Analysis of Cosmic Microwave Background Maps

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Abstract. We propose a novel method for the extraction of unresolved point sources from CMB maps. This method is based on the analysis of the phase distribution of the Fourier components for the observed signal and unlike most other methods of denoising does not require any significant assumptions about the expected CMB signal. The aim of our investigation is to show how, using our algorithm, the contribution from point sources can be separated from the resulting signal on all scales.

1. Introduction

Observations of the Cosmic Microwave Background (CMB) is fundamental for our understanding the primordial inhomogeneity of the Universe. After the successful COBE experiment, attention has been focused on the investigation of small scale perturbations, that can provide unique information about the most important cosmological parameters. One of the major problems in the modern CMB cosmology is to separate noise of various origins (such as dust emission, synchrotron radiation and unresolved point sources (see e.g. Banday et al. 1996)) from the original cosmological signal. Many authors have already applied various methods such as Wiener filtering (Tegmark and Efstathiou 1996, Bouchet and Gispert 1999), maximum entropy technique (Hobson et al. 1999), radical compression (Bond et al. 1998), power filtering (Gorski et al. 1997, Naselsky et. al. 1999) and wavelet techniques (e.g. Sanz et al. 1999) to extract noise from the CMB data. The aim of our paper is to overcome the problem of detecting and extracting the background of unresolved point sources from the original map. The measured signal in the real observational data is always smoothed with some filtering angle θ_f because of the final antenna beam resolution. Therefore, unresolved point sources could make a significant

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contribution to the resulting signal on all scales. This type of noise should be removed from the original map before any subsequent analysis is made. In our paper we consider the approach, which is based on the distribution of phases of the CMB and point sources.

2. Point sources in one and two-dimensional scans.

In 1D the deviation of the temperature from its mean value $\Delta T = T - \langle T \rangle$ in a scan is described by the simple Fourier series:

$$\Delta T(\theta) = \sum_k a_k cos(k\theta) + b_k sin(k\theta) \tag{1}$$

where k is an integer number and θ can be expressed in terms of of the real angle on the sky (θ_{sky}) as follows: $\theta = \frac{\theta_{tot}}{2\pi}\theta_{sky}$. Here θ_{tot} means the total length of the scan.

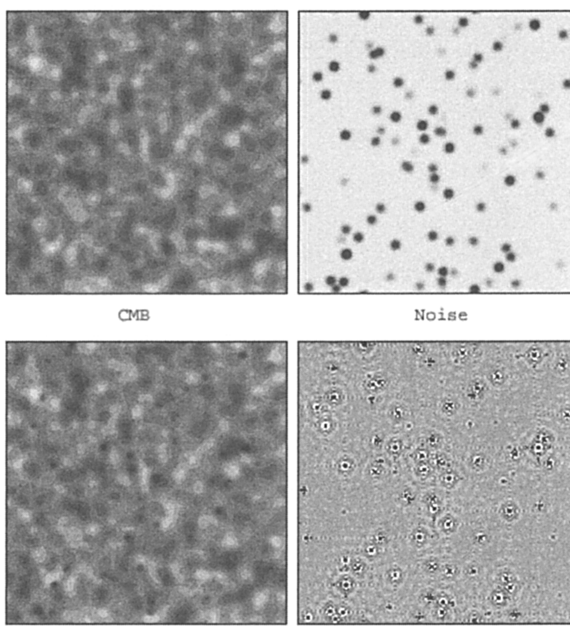

Figure 1. Simulated sky maps of $10^o \times 10^o$.

The detected temperature fluctuations ΔT can as usual be naturally divided into two parts: cosmological signal and noise:

$$\Delta T(\theta) = \Delta T^s(\theta) + \Delta T^n(\theta) \tag{2}$$

where s and n denote signal and noise respectively. Therefore, the Fourier transform components a_k, b_k can be also expressed as a sum of Fourier decomposition of these two terms:

$$a_k = a_k^s + a_k^n, b_k = b_k^s + b_k^n. \tag{3}$$

For further investigation we have to introduce the phase: φ_k of the k-th harmonic:

$$\varphi_k = arctg\left[\frac{b_k}{a_k}\right] = arctg\left[\frac{b_k^s + b_k^n}{a_k^s + a_k^n}\right] \tag{4}$$

Follow Naselsky et al,(2000) for the amplitude -phase analysis of the CMB + PS images we will use the iteration technic. The total number of iterations that is needed to significantly reduce the initial dispersion gives us approximately the number of point sources N_{ps} and each iteration gives the location θ_i and the amplitude γ_i of the i-th source.

Finally, since we have the position θ_i and amplitude γ_i, the contribution to the field from all point sources may be removed in the same manner, as was done by Naselsky et al,(2000) . Let us we briefly describe our results in two dimensions. In our simulations of the signal+noise we use the standard

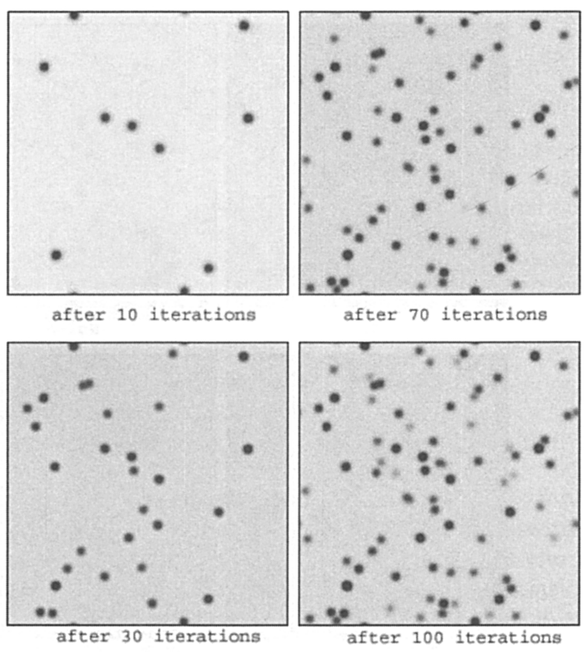

Figure 2. Noise maps (i.e. removed sources) after different numbers of iterations. The size and shading of each source is proportional to its amplitude.

CDM model and background of 100 point sources randomly distributed over the $10^o \times 10^o$ map. Without loss of generality we use the simple symmetric Gaussian antenna profile. All these calculations, of course, could be done for any arbitrary antenna beam. In figure 1 , we show the map of the CMB together with the maps of noise, CMB+noise and the filtered map of CMB+noise. The last one shows us more or less clearly the positions and powers of point sources. The significant anisotropy that appears in the last map occurs for the following reason. We use

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only the set of harmonics k_1, k_2, that obey the relation $k_1^2 + k_2^2 > k_d^2$. Therefore, the number of horizontal and vertical waves is larger than the number of waves in any other direction. (This problem does not occur if we use spherical harmonics Y_l^m with $l > l_d$). In fig. 2 we plot the maps of point sources for different numbers of iterations. As one can see from fig.2 , after 100 iterations we separate all 100 point sources from the cosmological signal .

3. Conclusions

In this paper we present a powerful method for extraction of unresolved point sources from future high resolution CMB maps (such as MAP, Planck, VSA, CBI, DASY, AMI and RATAN 600). Our method is based on the distribution of phases. The most important advantage of our technique is that we do not make any strong assumptions about the expected CMB signal for the point sources images reconstruction.

Acknowledgments

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