2006

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Recommended Citation

Hernández-Monteaguado, C., Génova-Santos, R., & Atrio-Barandela, F. (2006). Is there Any Evidence for Integrated Sachs-Wolfe Signal in WMAP First Year Data?. Retrieved from http://repository.upenn.edu/physics_papers/201

Suggested Citation:
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Disciplines

Physical Sciences and Mathematics | Physics

Comments

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Is there Any Evidence for Integrated Sachs-Wolfe Signal in WMAP First Year Data?

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Abstract. We introduce a pixel-to-pixel comparison method to detect the temperature anisotropies on the Cosmic Microwave Background induced by the time variation of gravitational potentials along the line of sight. We demonstrate it to be more sensitive than the cross-correlation method used in previous studies. We compare the recent WMAP data with templates constructed from galaxy catalogues. A positive cross-correlation between both data sets will be a signature of an accelerated expansion of the Universe. Contrary to other authors, we fail to detect any signal, except those coming from foreground residuals. Either the effect of an accelerated expansion is not present on the WMAP data or the galaxy catalogues at present do not trace the evolution of the large scale gravitational field.

Keywords: cosmic microwave background, cosmological constant, Cosmology, Relativity.
PACS: 98.80.Es, 98.70.Vc, 98.65.Dx

INTRODUCTION

Observations of high redshift supernovae [1] and of the Cosmic Microwave Background (CMB) temperature anisotropies by the WMAP satellite [2] indicate the Universe is expanding with positive acceleration. In this period, the growth of matter density perturbations slows down and variations of the gravitational potential along the line of sight induce a late time temperature anisotropy on CMB photons. We write the perturbed metric element as: $ds^2 = a^2[-(1+2\Psi)d\eta^2 + (1-2\Phi)\gamma_{ij}dx^i dx^j]$ where Ψ, Φ are the Bardeen potentials that give the gravitational time dilation and the perturbation to the 3-space curvature. The temperature pattern of a photon gas of wavenumber $k\hat{k}$ in the direction of observation $\hat{n}$ is ($\mu = \hat{k}\hat{n}$):

$$\begin{aligned}
\Theta(\eta_o,k,\mu) &= e^{ik\mu(\eta_{dec}-\eta_o)}\left[\Theta^{SW}+\Theta^{Dopl}+\Theta^{ISW}\right] \qquad (1)\\
\Theta^{SW} &= \left[\frac{1}{4}D_{intrinsic,\gamma}+\Psi\right](\eta_{dec},k)\\
\Theta^{Dopl} &= -i\mu k V_\gamma(\eta_{dec},k)\\
\Theta^{ISW} &= \int_{\eta_{dec}}^{\eta_o} d\eta\, e^{ik\mu(\eta-\eta_o)}(\dot{\Psi}+\dot{\Phi})(\eta,k).
\end{aligned}$$

The Integrated Sachs-Wolfe (ISW) effect [3, 4] can be detected by cross-correlating the distribution of matter density perturbations with the pattern of temperature anisotropies

CP841, *A Century of Relativity Physics: XXVIIIth Spanish Relativity Meeting,*
edited by L. Mornas and J. Diaz Alonso

TABLE 1. Results of the pixel-to-pixel comparison method.

BAND	**Q**		**V**		**W**	
FWHM	1°	2°	1°	2°	1°	2°
2MASS	-	-1.8± 0.3	-	-1.15 ± 0.3	-	-0.9 ± 0.3
NVSS-I	1.0±0.14	0.9±0.2	0.5±0.14	0.4±0.2	0.1±0.14	0.13±0.2
NVSS-II	0.9±0.15	-	0.4 ± 0.15	0.4± 0.2	0.18 ± 0.15	-
NVSS-III	0.8±0.17	-	0.4 ± 0.17	-	0.2 ± 0.17	-

on the sky. Several groups have carried out this analysis using the latest CMB data and galaxy catalogues [5] and found positive correlations at the $\approx$ 2–3 σ confidence level.

THE PIXEL-TO-PIXEL COMPARISON METHOD.

Up to date, positive detections of the ISW contribution to CMB data were based on computing different variants of the 2-point cross-correlation of galaxy templates and CMB data. We shall introduce a different method, the pixel-to-pixel comparison, that has been succesfully apply to trace the contribution of hot gas to the CMB data [6]. In this method, we assume that the CMB temperature anisotropy in a given direction of the sky has several components: intrinsic $\mathbf{T}_{cmb}$ of cosmological origin, noise $\mathbf{N}$, foreground residuals $\mathbf{F}$, and an additional component that can be traced by a template constructed from the matter distribution $\mathbf{M}$; i.e. $\mathbf{T} = \mathbf{T}_{cmb} + \tilde{\alpha}\mathbf{M} + \mathbf{N} + \mathbf{F}$, where $\tilde{\alpha}$ gives the matter contribution (in units of temperature) to the CMB anisotropies. The pixel-to-pixel comparison method is a minimum variance estimator of $\tilde{\alpha}$ with error bar σ_α:

$$\alpha = \frac{\mathbf{T}\mathscr{C}^{-1}\mathbf{M}^T}{\mathbf{M}\mathscr{C}^{-1}\mathbf{M}^T};\ \ \sigma_\alpha = \sqrt{\frac{1}{\mathbf{M}\mathscr{C}^{-1}\mathbf{M}^T}}, \tag{2}$$

Due to the large number of data points, the covariance matrix C of the CMB data can not be inverted for the whole sky. Therefore we divide the sky in patches of the same number of N_{pix} compute α^β for each patch and compute a weighted average α with error bar σ_α

$$\alpha = \frac{\sum_\beta \alpha^\beta/(\sigma_\alpha^\beta)^2}{\sum_\beta 1/(\sigma_\alpha^\beta)^2}, \sigma_\alpha^2 = \frac{1}{\sum_\beta 1/(\sigma_\alpha^\beta)^2}\left[1 + \frac{2\sum_{\beta_1<\beta_2} \mathbf{M}_{\beta_1} \mathscr{C}^{-1}_{\beta_1\beta_1}\ \mathscr{C}^{\beta_1\beta_2}\ \mathscr{C}^{-1}_{\beta_2\beta_2}\mathbf{M}^T_{\beta_2}}{\sum_\beta 1/(\sigma_\alpha^\beta)^2}\right]. \tag{3}$$

$\mathscr{C}^{\beta_1,\beta_2}$ is the covariance matrix between pixels of two different patches β_1, β_2.

We tested the efficiency of our method by generating 500 Monte Carlo realizations of the CMB sky. At each realization we added a map of temperature anisotropies of rms 1.5μK distributed like a galaxy template. We estimate $\tilde{\alpha}$ using the cross-correlation function and the pixel-to-pixel comparison methods. In either method, the mean value of α was 1.5μK, the input value, but the dispersion was 6 times smaller in the pixel-to-pixel comparison method than in the correlation method.

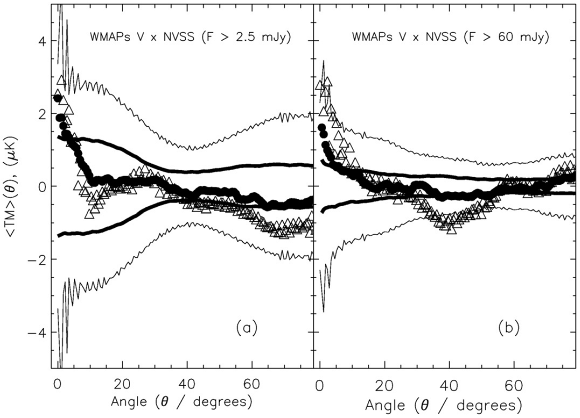

FIGURE 1. *(a)* Cross correlation function of the WMAP V band with the template based on NVSS-I. Templates and data were convolved with a gaussian beam FWHM equal to 1° (filled circles) and 4° (triangles). Error bars are given by the thick and thin solid lines, respectively. *(b)* As in *(a)*, but for the template based on NVSS-II sources of flux greater than 60 mJy.

CMB DATA AND GALAXY CATALOGUE TEMPLATES

We constructed templates from galaxy catalogues assignig to each pixel a value equal to the number of galaxies within that pixel. We assumed that the depth of gravitational potential wells was proportional to the number of collapsed halos at each location. Although this hypothesis is correct in linear theory and on large scales, is not clear how well our galaxy samples trace the real halo population at every redshift. Sources located at redshifts where there is no significant ISW contribution could degrade our templates as potential ISW tracers. We constructed different templates containing galaxies at different redshift intervals to test this effect. To describe the low redshift Universe, we used the 2MASS catalog [7]. To probe the high redshift universe, we used the NVSS survey of extragalactic sources [8]. We constructed 3 templates: containing all sources brighter than 2.5 mJy (NVSS-I), brighter than 60 mJy (NVSS-II) and containing only unresolved sources (NVSS-III). The templates were convolved with beams of width 1 and 2 degrees.

RESULTS AND DISCUSSION

We compared the WMAP data and the different templates using both the cross-correlation and the pixel-to-pixel comparison method. In Table 1 we show our results of comparing WMAP V-band with all the templates. The analysis was carried out in the V-band and only when their was a positive detection the analysis was carried out at different frequencies. The data indicates an anticorrelation of the 2MASS template with the CMB dada. This anticorrelation desappeared after rotating the template a beam size, indicating the signal was associated to point sources and has a Sunyaev-Zeldovich spectrum. It corresponds to the same signal found at 12 arcmin scales [6]. We repeated the analysis using the cross-correlation techniques. With respect to the results for the NVSS catalogues, the correlation was posivite but depends on frequency, as would do foreground residuals associated to an unresolved population of radio galaxies. Also in this case the correlation desapeared after rotating one beam size.

In Fig. 1 we give the cross-correlation function for the NVSS-I and NVSS-II templates. The results are compatible with those of the pixel-to-pixel method: there was no evidence for an ISW signal in the 2MASS based template. For NVSS templates, the pixel-to-pixel comparison and cross correlation detected a positive signal of amplitude $\sim$ 0.5–1 μK. Comparing with observations from other bands, we found the amplitude depended on frequency. We checked that the correlation disappear when the template was rotated 0.5 degrees, suggesting the contribution was coming from a foreground residual. Since the pixel-to-pixel comparison method is more sensitive that the cross-correlation method, we conclude that what other authors could have taken a positive detection was no more than contribution from foreground residuals. To conclude, our results suggest that there is no evidence of ISW signatures in first-year WMAP data, suggesting that galaxy catalogues do not properly trace the time evolution of the large scale gravitational field. Since the galaxy catalogues used here have been also used to claim detection of the ISW effect in CMB data, they are in clear contradiction with previous studies.

ACKNOWLEDGMENTS

CHM was supported by the European Community through the Human Potential Programme under contract HPRN-CT-2002-00124 (CMBNET). FAB acknowledges financial support from the Spanish Ministerio de Educación y Ciencia (projects BFM2000-1322 and AYA2000-2465-E) and from the Junta de Castilla y León (projects SA002/03 and SA010C05).

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