COMPARISON OF COBE DMR AND ROSAT ALL-SKY SURVEY DATA

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Abstract

Statistical comparisons of microwave maps in the GHz range and X-ray maps at around 1 keV are an interesting probe to constrain different astrophysical phenomena. Possible correlations on various angular scales and with different frequency (energy) dependences, although not expected at present day experimental sensitivity, could in principle be due to Galactic emission/absorption, the Sunyaev-Zel’dovich effect, the Integrated Sachs-Wolfe effect in cosmological models with a cosmological constant or low density, or X-ray luminous radio sources such as radio-loud AGNs. I report on work cross-correlating the COBE DMR and ROSAT All-Sky Survey in a selected area of the sky. This area (+40° < b, 70° < l < 250°) is the best presently available data set probing the medium-hard extragalactic X-ray background around 1 keV. No significant correlation on astrophysically relevant scales has been found in this analysis, but it will be possible to infer constraints from the limits.

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1 Introduction

Statistical comparison between experiments probing different astrophysical backgrounds are motivated by physical effects leading to possible correlations. These effects, galactic emission or absorption in X-rays, Sunyaev-Zel’dovich effect (SZ) in hot plasmas such as galaxy clusters or group halos, point sources, and the Integrated Sachs-Wolfe effect (ISW), are astrophysically interesting (see also Table 1) and test sources of possible confusion for the measurement of the cosmic microwave (CMB) and X-ray (XRB) backgrounds.

Comparisons between CMB and XRB observations were first carried out by Boughn & Jahoda [1] comparing the 19 GHz map with HEAO-1 A2 (∼10 keV, 3° resolution), and they found no significant correlation based on Monte Carlo simulations for noise properties. Bennett et al. [2] cross-correlating the 1 yr DMR data to HEAO-1 found no significant correlation for $|b| > 30°$ and the LMC masked. In the latest analysis by Banday et al. [3] an expansion in orthogonal functions on a cut sky and a likelihood analysis for the coupling constant between the 4 year DMR and HEAO-1 data was used. Again no significant correlation was found, when applying a specially designed Galactic cut based on correlations obtained from the Dirbe 140 µm map and masking the LMC.

The present analysis uses another X-ray data set, the ROSAT [4] PSPC [5] All-sky Survey (RASS) which measures the sky in the soft X-rays from 0.1 – 2 keV with an angular resolution of ∼10 arcmin. These data have not previously been used for this kind of analysis and are particularly sensitive to galaxy clusters even in the diffuse XRB component, as has been shown by Soltan et al. [9]. They find an extended X-ray component around clusters. The present work is also motivated towards constraining a possible extended gas halo.

2 The COBE and ROSAT data

A full description of the COBE DMR data and the 4 year results can be found in the contribution by G.F. Smoot [6] and references therein.

For our analysis we used various maps of the COBE DMR data. The final analysis uses the 4 year data, although consistency tests with the 1 year and 2 year data were performed. From the different channels we constructed inverse noise weighted A+B sum maps. The same procedure was used for combining the different frequency channels (31.5, 53 & 90 GHz), which were converted from antenna to Planck temperatures. The standard frequency combination for this analysis is the 53+90 GHz map, having low noise and little galactic contribution [7], but the individual frequency maps and the linearly combined and subtracted galaxy reduced maps were used for comparison.

The RASS R6 energy band, 0.73 – 1.56 keV with maximum response around 1.1 keV, is regarded as the best probe for the diffuse cosmological XRB because the content of foreground, non-cosmic photons, and contamination by charged particles is minimized. In spite of the careful corrections for exposure and elimination of non-cosmic backgrounds [8] the final count rate distribution is not completely free from residual contamination. To test for spectral dependence we compared to the neighbouring partly overlapping band R5 (maximum response around 0.9 keV), which is low in non-cosmic photons and in contamination by charged particles, but contains increased galactic foreground. The maps supplied for this work were binned as $0.7° x 0.7°$, with point sources left in to compare to the complete integrated flux. The mean intensity of the XRB in the R6 is $\sim 80 \times 10^{-6}$ cts s$^{-1}$ arcmin$^{-2}$ with a fluctuation level of $\sim 7 \times 10^{-6}$ cts s$^{-1}$ arcmin$^{-2}$ at the COBE pixelization level 6 ($2°.6 x 2°.6$). Even the high energy R6 band
is, in large regions of the sky, dominated by galactic emission. The chosen area (+40° < b, 70° < l < 250°) is the largest simply connected patch probing dominantly the XRB. Properties of the XRB in this field have been studied in a series of papers ([9], [10], [11]).

3 Correlation Method

Due to the small size (∼8% of the sky) and the peculiar geometry of the patch a local statistical measure, the 2-point cross-correlation function, is preferred. The form of the correlation function used in this analysis is the Pearson product moment correlation coefficient

\[
C(\alpha) = \frac{< X_i T_j >_\alpha - < X_i >_\alpha < T_j >_\alpha}{\sqrt{< X_i^2 >_\alpha - < X_i >^2_\alpha} \sqrt{< T_j^2 >_\alpha - < T_j >^2_\alpha}}
\]

in an unweighted scheme. Inverse noise variance weighting has also been applied and was found to give similar results. The average is taken over all pixel pairs \{ij\} with separation \(\alpha\) in the patch. The subscript \(\alpha\) denotes that all the terms are evaluated separately for each angular bin. To determine the uncertainties, which are assumed to be dominated by the DMR noise on small scales and the cosmic variance of the CMB structure on large scales, different techniques were applied. These are a simple rotation method using random samples, and simulation of DMR maps. The CMB structure is taken to be a random Gaussian field with a power law \(Q_{\text{rms}} - PS = 15.3 \, \mu\text{K}, n = 1.2\) power spectrum [12] convolved with the DMR filter function [13] and the DMR noise to be Gaussian pixel noise distributed according to the coverage.

4 Results

Correlating the raw data yields a marginally significant positive correlation on large angular scales, which appeared to be independent of different procedures that had been applied. Different source exclusion thresholds in the ROSAT maps ranging from 0.3 - 1 cts s\(^{-1}\) were compared. By far the strongest source in the field with 5.3 cts s\(^{-1}\) in the R6 is MKN 421, a BL Lac object at z ∼ 0.031, which had to be removed, because it clearly produces positive correlation on the beam scale. Otherwise the different thresholds affect the results only marginally. Different sampling tests were undertaken also showing stability of the result against small scale features such as point sources and noise. The maps were smoothed on various angular scales including smoothing of the ROSAT maps with the actual DMR beam [13], and Gaussian smoothing of both maps out to 20° with the effect of smoothing the correlation function, but not significantly changing the correlated signal. Correlating to noise maps revealed no correlated noise feature. The energy dependence in X-rays is found to be consistent with a galactic signal increasing from hard to soft energies. The frequency dependence in microwaves is unclear. There is a clear signal in both the 53 and 90 GHz channels and no signal at 31.5 GHz.

To determine the angular scale of the correlated signal, gradients were removed from the field. This was done in fitting dipoles onto the field in both maps and subtracting them. As a result the signal vanished. The multipoles on the sky dominating these gradients turn out to be of low order (Figure 1). The best fit DMR residual dipole, which would introduce substantial correlation of no physical significance had been removed in addition to the standard removed dipole. The gradient in the ROSAT field is produced by a whole map dipole which has the following galactic signatures, the positive pole lying near the galactic center, and increasing relative amplitude from the hard to the soft energies, also in comparison to R7 and R4. The
Figure 1: Cross-correlation function between the COBE DMR 53+90 GHz (A+B)/2 and the ROSAT All-sky survey energy bands R5 (softer band, open circles) and R6 (harder band, full circles) in a ROSAT selected area (+ 40° < b, 70° < l < 250°). The effect of lowering the zero-lag amplitude by subtracting either a best fit quadrupole from the Galactic cut DMR map or a best fit dipole which has Galactic signature from the full ROSAT map can be seen. The 1-σ error bands are taken from DMR simulations correlated to R6.
gradient in the COBE field is dominated by a quadrupole fitted to the COBE cut sky, a combination of the cosmic and the Galactic quadrupole. In the field the cosmic quadrupole seems to dominate, not inconsistent with the COBE frequency dependence of the correlated signal.

5 Discussion

The conclusion of this work is that no significant correlation on scales from $7^\circ$ to $60^\circ$ has been found between the COBE DMR and the ROSAT All-Sky Survey in the area investigated. A possible correlation on larger scales can not be distinguished from chance alignment, because the corresponding multipole terms are different and the frequency and energy dependences are not conclusive for a single physical mechanism. The full description of this work, also including the analysis of larger areas of the sky, as well as results on a ROSAT dipole determination and limits on the correlation coefficient with a discussion of the possible mechanisms, can be found in a paper by our collaboration [14].

Different effects resulting in a possible, although not at present expected, angular correlation between microwave and X-ray experiments are known or have been suggested recently.

| EFFECT / SOURCE       | SIGN | ANGULAR SCALE | FREQU. DEP. microwave | ENERGY DEP. X-ray | AUTHOR |
|-----------------------|------|---------------|-----------------------|-------------------|--------|
| Galaxy geometrical ?  | +    | large         | $\beta_{\text{synch,ff,dust}}$ | thermal 0.3 keV   |        |
| SZ thermal            | −    | (< 10° clust.)| y - dist.             | thermal 10 keV    |        |
| (clusters / super-)   | −    | (< 5° c-corr) | y - dist.             |                   |        |
| SZ thermal            | −    | large         | y - dist.             |                   |        |
| local group halo      |      |               |                       |                   |        |
| X-ray/radio           | +    | small         | flat, $\alpha < 0.5$  | $\gamma \approx 2 - 2.5$ |
| point sources         |      | (10−100 GHz)  |                       | $I = I_0(E/E_0)^{-\gamma}$ | [16]  |
| ISW / RS in $\Lambda$ | +    | large         | Planck                | $\gamma \approx 2 - 2.5$ |
| / open universe       |      | $\ell \approx 10$ |                       | $I = I_0(E/E_0)^{-\gamma}$ | [17], [18] |

Table 1: Overview of different effects introducing possible correlations between microwave and X-ray data

At the present state of observations, and with the available data, no astrophysically interesting correlation could be found. Still interesting limits can be drawn from this analysis, although no direct quantification of the effects. The current X-ray observations have much higher angular resolution and better signal to noise ratio than CMB measurements. But as these data were taken in the soft X-rays ($< 2$ keV) they show predominantly a galactic signal limiting a comparison with the XRB to small patches of the sky. This situation is going to change dramatically in the future. With the European CMB mission COBRAS/SAMBA and the German X-ray satellite ABRIXAS, two all sky data sets will be available that have wide angular and spectral coverage and high angular and spectral resolution. COBRAS/SAMBA [19], [20] will have 9 frequency channels from 31 to 857 GHz with an angular resolution of $\sim 10$ arcmin and a best sensitivity of $10^{-6}$ per resolution element. ABRIXAS [21] will cover the energy range from 0.5 to 10 keV with a sensitivity of 1.6 cts s$^{-1}$ for the XRB, a spectral resolution of 150 eV and an angular resolution of 1 arcmin. With these data sets a detailed statistical
analysis for all the effects discussed above will be feasible, including the direct comparison of radio loud, X-ray luminous point sources and distant galaxy clusters.

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