Limits on the cosmic infrared background from clustering in COBE/DIRBE maps.

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Abstract. We discuss a new method of estimating the cosmic infrared background (CIB) from the spatial properties of infrared maps and give the limits on the CIB from applying it to the COBE/DIRBE maps. The strongest limits are obtained at mid- to far-IR where foregrounds are bright, but smooth. If the CIB comes from matter clustered like galaxies, the smoothness of the maps implies CIB levels less than $\sim$(10-15) nW/m^2/sr over this wavelength range.

1. Introduction

The cosmic infrared background (CIB) contains information about the conditions in the post-recombination Universe and links the microwave background, which probes the last scattering surface, and the optical part of the cosmic spectrum, which probes the conditions in the Universe today at $z \sim 0$. The predicted spectral properties and the amplitude of the CIB depend on the various cosmological assumptions used, such as the cosmological density parameter, the history of star formation, and the power spectrum of the primordial density field among others. A typical prediction over the range of wavelengths probed by the COBE/DIRBE, 1.25 - 240 μm, is $\nu I_\nu \sim 10$ nW/m^2/sr. It is difficult to measure such levels directly because the foreground emissions from stars and interstellar and interplanetary dust are bright.

An alternative to direct photometric measurements of the uniform (DC) component of the CIB is to study its spatial structure. In such a method, the groundwork for which has been laid in Kashlinsky, Mather, Odenwald and Hauser (1996, KMOH), one compares the predicted fluctuations of the CIB with the measured angular correlation function of the maps. Here we discuss the results from applying this method to the all-sky DIRBE maps and show that it imposes interesting limits on the CIB from clustered matter, particularly in the mid- to far-IR (Kashlinsky, Mather and Odenwald 1996; KMO).

2. Theoretical expectations

In general, the intrinsic correlation function of the diffuse background, $C(\theta) \equiv \langle \nu\delta I_\nu(\mathbf{x}) \cdot \nu\delta I_\nu(\mathbf{x}+\theta)\rangle$, where $\delta I \equiv I - \langle I \rangle$ is the map of spatial fluctuations, depends on the 3-dimensional correlation function $\xi(r)$ of the emitters, the history of their emission and cosmological parameters. The correlation function of the diffuse background, $C(\theta)$ produced by a population of emitters (e.g. galaxies) clustered with a 2-dimensional correlation function $\xi(r)$ is given in the small angle limit ($\theta < 1$) by:

$$C(\theta) = \int_0^\infty A_\theta(z)(\frac{d\lambda I_\lambda}{dz})^2[\Psi^2(z)(1+z)^2\sqrt{1+\Omega z}]dz \qquad (1)$$

where it was assumed that the cosmological constant is zero, $\Psi(z)$ accounts for the evolution of the clustering pattern, $A_\theta(z){=}2R_H^{-1}\int_0^\infty \xi(\sqrt{v^2+\frac{x^2(z)}{(1+z)^2}})dv$, $R_H{=}cH_0^{-1}$ and $x(z)$ is the comoving distance. Convolving (1) with the beam leads to the zero-lag signal for the DIRBE sky:

$$C_\vartheta(0) = \int_0^\infty A_\vartheta(z)(\frac{d\lambda I_\lambda}{dz})^2[\Psi^2(1+z)^2\sqrt{1+\Omega z}]dz \qquad (2)$$

$$A_\vartheta(z) = \frac{1}{2\pi R_H}\int_0^\infty P_{3,0}(k)kW(\frac{kx(z)\vartheta}{1+z})dk \qquad (3)$$

For the top-hat beam of DIRBE $W(x) = [2J_1(x)/x]^2$ and $\vartheta{=}0.46°$. In the above equation $P_{3,0}(k)$ is the spectrum of galaxy clustering at the present epoch. If ξ is known the measurement of $C(\theta)$ can give information on the diffuse background (Gunn 1965). Such method was applied in the V (Shectman 1973,1974) and UV bands (Martin and Bowyer 1989). In the rest of the paper we omit the subscript ϑ in (2) with $C(0)$ referring to the DIRBE convolved zero-lag correlation signal.

The functional form of $A_\vartheta(z)$, for the data on the present day power spectrum $P_{3,0}(k)$ taken from galaxy catalogs, is discussed in KMO and it is shown that it reaches a minimum at $z{\gtrsim}1$. The minimal value of $A_\vartheta(z)$ for the scales probed by the DIRBE beam is $\sim 10^{-2}$ and is practically independent of Ω. Thus we can rewrite (2) as an inequality in order to derive upper limit on a measure of the CIB flux from any upper limit on $C(0)$ derived from the DIRBE data: $(\lambda I_\lambda)_{z,rms}{\leq}B\sqrt{C(0)}$ where $B{\equiv}1/\sqrt{\min\{A_\vartheta(z)\}}$=(11-13) over the entire range of parameters and the measure of the CIB flux used in (4) is defined as $[(\lambda I_\lambda)_{z,rms}]^2{\equiv}\int(\frac{d\lambda I_\lambda}{dz})^2[\Psi^2(z)(1+z)^2\sqrt{1+\Omega z}]dz$. The latter is $\simeq\int(\frac{d\lambda I_\lambda}{dz})^2 dz$ since the term in the brackets has little variation with z for two extremes of clustering evolution when it is stable in either proper or comoving coordinates.

Thus for scales probed by DIRBE, the CIB produced by objects clustered like galaxies should have significant fluctuations, $\geq 10\%$ of the total flux, on the angular scale subtended by the DIRBE beam. The upper limit on $C(0)$ would imply an upper limit on the total CIB from clustered matter.

3. Data analysis

We analyzed maps for all 10 DIRBE bands derived from the entire 41 week DIRBE data set available from the NSSDC. A parametrized model developed by the DIRBE team (Reach et al. 1996) was used to remove the time-varying zodiacal component from each weekly map (KMOH). The maps were pixelized using the quadrilateralized spherical cube projection of the sky maps. After the maps were constructed, the sky was divided into 384 patches of 32×32 pixels $\simeq 10^\circ \times 10^\circ$ each.

Each field was cleaned of bright sources by the program developed by the DIRBE team and discussed and used in KMOH, KMO. The flux distribution in each patch was modelled with a smooth 4-th order polynomial component. Pixels with fluxes $> N_{\rm cut}$ standard deviations above the fitted model were removed along with the surrounding 8 pixels. Three values of $N_{\rm cut}$ were used: $N_{\rm cut} = 7, 5, 3.5$. Since any large-scale gradients in the emission are clearly due to the local foregrounds, a 3rd order polynomial was removed from each patch after desourcing. As discussed in Paper I we verified that there is a good correlation between removed bright objects at $N_{\rm cut}$ and the stars from the SAO catalog; at lower $N_{\rm cut}$ the removed peaks would be too dim to enter the catalog.

Three types of foregrounds provide dominant contributions at various bands: in the near-IR bands (1-4) the main foreground contribution to the zero-lag signal comes from the Galactic stars, in the mid-IR (bands 5-7) from the zodiacal light emission, and in bands 8-10 the main contribution is from the cirrus clouds in the Galaxy. The structure of the near-IR maps and the distribution of fluctuations within the various fields have been discussed at length in KMO; the histograms for these bands are shown there in Fig.5. They are highly asymmetric with respect to δI_λ and are consistent with those from simulated stellar catalogs. The distribution at mid- to far-IR bands is more symmetric and comes from a more extended emission. Furthermore, because of the extended character of the mid-to far-IR foreground emission the decrease of the width of the histogram (another measure of $C(0)$) with $N_{\rm cut}$ is significantly less prominent than for near-IR where stars provide the dominant foreground.

Removal of the large-scale gradients does not lead to any noticeable difference in the histograms at the near-IR bands (1-4). On the other hand, at longer wavelengths the bulk of the foreground comes from extended emission and removing large-scale gradients, which are clearly of local origin, changes the structure significantly.

Histograms of the distribution of $C(0)$ on the sky show that in the near-IR where Galactic stars dominate the foreground fluctuations there is a significant decrease in the minimal value of $C(0)$ with $N_{\rm cut}$. The reason for this is that the structure of the foreground is dominated by fluctuations in point sources (stars) affecting the small scale structure of the correlation function. In the near-IR the histograms become increasingly asymmetric with decreasing $N_{\rm cut}$ and the bins with low $C(0)$ patches at higher clipping thresholds now have essentially the same $C(0)$. On the other hand, at mid- to far-IR there is very little change in the distribution of the zero-lag signal with decreasing $N_{\rm cut}$; this is due to the fact that the foreground emission is extended with little small-scale structure. The latter in turn leads to much smaller upper limits on the value of $C(0)$ at mid- to far-IR. At bands 9,10 the instrumental noise is substantially larger and the correlations analysis of the DIRBE maps leads to significantly less interesting limits at these wavelengths ($\lambda = 150, 240\mu$m).

We calculated the minimum of $C(0)$ from this analysis in all 10 bands. The estimated upper limits come from the quietest patch in each band for the entire sky. The histogram distribution of $C(0)$ shows that the minimum is estimated from around 30-80 patches in each of the bands making it a reliable estimate of the true upper limit. Since the distribution of $C(0)$ is highly anisotropic on the sky, the signal must come from the foreground emission and it is thus further unlikely that any of the truly cosmological contributions have been removed in the process. In the near IR these are located around Galactic poles; in the mid-IR they are near Ecliptic poles and in the far-IR they shift back to the Galactic poles. Our data processing does not remove real fluctuations unless they appear to come from point sources, or to have very large scale gradients. The instrument digitization noise, estimated to be below 1.0 nW/m^2/sr in all bands after averaging, is not a problem at the level probed here.

4. Conclusions

We measured the smoothness of the infrared sky using the COBE DIRBE maps, and obtain interesting limits on the production of the diffuse cosmic infrared background (CIB) light by matter clustered like galaxies. The predicted fluctuations of the CIB with the DIRBE beam size of 0.7° are of the order of 10%, and the maps are smooth at the level of $\nu\delta I_\nu \sim$ a few nW/m^2/sr rms from 2.2 to 100 μm. The lowest numbers are achieved at mid- to far-IR where the foreground is bright but smooth; they are $\sqrt{C(0)} \leq (1-1.5)$ nW/m^2/sr at λ=10-100 μm. If the CIB comes from clustered matter evolving according to typical scenarios, then the smoothness of the maps implies CIB levels less than $\sim$(10-15) nW/m^2/sr over this wavelength range.

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Discussion

A. Franceschini: Since the long wavelength detections ($\lambda = 60, 100$ micron) are dominated by late type galaxies which are quite less clustered than optical or near-IR galaxies, the correct limits then are probably somewhat higher than appearing in the figure.

: It is true that radio galaxies are clustered more weakly on scales where density field is non-linear ($< 5h^{-1}$Mpc). However, at the relevant range of redshifts the DIRBE beam of roughly 1 degree subtends scales which are today in linear or quasilinear regime of clustering and where one would expect that all galaxies probe the same density field. Our correlation amplitude estimates use as an input the data on the correlation function of blue (APM) and red (POSS) galaxies. Most contribution to the CIB fluctuations at 1 degree comes from scales $\simeq$

$(10-30)h^{-1}$Mpc where (presumably) radio or IR galaxies would be distributed similarly. But the effect you are referring to may indeed be significant in smaller beam surveys.

T. Matsumoto: I suppose you can estimate the fluctuation of stars using lg$N$/lg$S$ plot, and can obtain lower fluctuation limit for CIB.

: Yes, the fluctuation in stars can be estimated from the lg$N$/lg$S$ plots and we find the estimates to be in agreement with the direct computation. But we did not succeed in obtaining robust model-independent limits on the CIB in this or similar ways.

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