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Cold Galactic dust observed with COBE data

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Abstract. A new study of the Galactic dust in thermal equilibrium as observed by COBE is presented taking into account the presence of an isotropic sub-mm background. The cold component of the dust emission revealed from the DIRBE data at $\lambda \geq 100\,\mu$m appears well correlated with large molecular complexes with low star forming activity. Together with the FIRAS spectra, these cold maps show a significant difference in the dust temperature in the atomic and molecular parts of the ISM (T distributed around 17.5 K and 14.8 K respectively, with a ν^2 emissivity law in both cases). The spectral residues of our analysis do not indicate that any very cold dust is ubiquitous in the Galaxy.

1. Introduction

The FIRAS and DIRBE experiments on board COBE have covered the whole emission spectrum of the Galactic dust in thermal equilibrium (large grains of size $\geq$ 10 nm). The averaged spectrum of the dust emission in the atomic medium derived by Boulanger et al. (1996), which is free of any isotropic contribution, is very well-fitted by one dust component with T = 17.5 K and a ν^2 emissivity law, compatible with the standard models of compact dust grains in thermal equilibrium. At high Galactic latitudes, Reach et al. (1995) have found a very cold component (T= 4-7K) in the FIRAS spectra that is spatially correlated with the atomic component. However, Puget et al. (1996) have detected a positive residual, after removing all Galactic components in the FIRAS spectra, interpreted as the Cosmic Far Infrared Background Radiation (CFIBR), which may have strongly contaminated the study of Reach et al. (1995).

We present a new analysis of the Galactic dust in thermal equilibrium using the COBE data corrected for this isotropic background (we have also removed the zodiacal emission, the CMB and its dipole). The DIRBE data at $\lambda \geq 60\mu$m allow us to build maps of the cold components of the dust emission (sect. 2). Together with the FIRAS spectra, these maps point out the significant difference in the dust temperatures in the atomic and molecular parts of the ISM (sect. 3). In section 4, we study the spectral residues of our analysis in order to check whether very cold dust is detected in the FIRAS data.

2. DIRBE maps of the cold dust (at a resolution of 40')

Let $I_D(\lambda)$ ($\lambda = 60, 100, 140, 240\,\mu$m) be the DIRBE emission and R(λ,60) the $I_\nu(\lambda)/I_\nu(60)$ flux ratio observed in cirrus clouds. The cold component of the dust emission is computed at each wavelength according to the equation: $I_D(\lambda)_{\rm cold} = I_D(\lambda) - R(\lambda, 60) * I_D(60)$ (following the method detailed in Laureijs et al. 1991 and Abergel et al. 1994). Values of $R(\lambda, 60)$ are obtained by computing the slope of the $I_D(\lambda)$ vs $I_D(60)$ correlation diagrams for all pixels at $|b| > 20°$ and $|\beta| > 20°$, outside known molecular complexes and the Magellanic Clouds. They are equal to 4 ± 0.7, 6 ± 1 and 3.2 ± 0.5 at 240, 140 and 100 μm respectively. The cold component maps still contain a zodiacal residue which was removed by a 21°x21° median filtering. All bright features at $|b| > 10°$ on the cold maps are associated with cold known molecular complexes with low star forming activity (see Lagache et al., 1997).

3. Dust temperature in the cirrus and molecular components

In this section, we work at the FIRAS resolution (7°) to use the spectral information of the FIRAS data. We convolve the cold DIRBE emission maps with the FIRAS PSF ($I_F(240)_{\rm cold}$, $I_F(140)_{\rm cold}$ and $I_F(100)_{\rm cold}$). These maps contain the emission of the cold dust component in the FIRAS beam.

In order to select pixels with significant cold emission, we compute the rms of the maps of the cold emission at the FIRAS resolution (σ_λ) using the rms of DIRBE maps and the FIRAS PSF. Cold component spectra are obtained for all pixels with $I_F(\lambda)_{\rm cold} > 3\sigma_\lambda$ and $|b| > 10°$, which represent about 18% of the sky. First we compute $T_{\rm cold}$ and $\tau_{\rm cold}$ using $I_F(100)_{\rm cold}$, $I_F(140)_{\rm cold}$ and $I_F(240)_{\rm cold}$ and assuming a ν^2 emissivity law. Then we derive spectra of the dust outside cold regions ("cirrus component") by substracting the cold modified Planck curves defined by $T_{\rm cold}$ and $\tau_{\rm cold}$ from the FIRAS spectra. Finally, each cirrus spectrum is individually fitted in order to determine T_{cirr} and τ_{cirr}. The temperatures of the two components are significantly different (Fig. 1). The cold component has temperatures distributed around 14.8 K with a dispersion of 1.2 K. The coldest temperatures are ~10 K. Since our temperatures are averaged inside the FIRAS

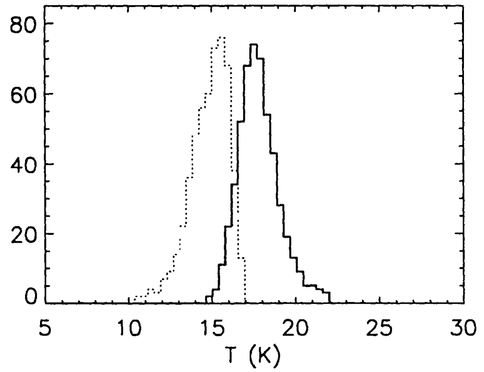

Figure 1. Histograms of the temperatures for the cirrus component (continuous line) and the cold component (dashed line).

beam, the physical value of the dust temperature in molecular regions can be lower than 10 K. This is not surprising since the conditions determined from CO and isotopes excitation observations are compatible with temperatures around 10 K or even lower (Falgarone et al., 1991).

The temperatures of the cirrus component are distributed around 17.9 K with a dispersion of 1.4 K. All pixels with $I_F(\lambda)_{cold} \leq 3\sigma_\lambda$ and $|b| > 10°$ (61% of the sky) only detect a cirrus component, so each FIRAS spectrum is fitted by one single modified Planck curve with a ν^2 emissivity. The mean temperature is equal to 17.5 K with a higher dispersion than for those pixels containing cold emission (2.5 K instead of 1.4 K) which is due to lower brightnesses. In both cases, we confirm that in the atomic medium, the averaged temperature of the interstellar dust which is in thermal equilibrium is rather uniform and of about 17.5K (Désert et al. 1990, Boulanger et al. 1996).

4. Very cold dust (T=4-7 K) in the Galaxy?

The presence of very cold dust, not detectable using the DIRBE data at 140 and 240 μm, should be revealed on the residual FIRAS emission. We compute two residual spectra: one for regions with detected cold emission, by removing the cirrus and cold contributions from the FIRAS spectra; and one for regions with no detected cold emission, by removing only the cirrus contribution from the FIRAS spectra.

For pixels containing a detected cold emission, the mean residue (Fig. 2) shows a lack of emission in the range $280 - 390\,\mu$m and an excess above $400\,\mu$m which persist whatever value is used for the emissivity index. We have checked that this residue can be due to a wide distribution of temperatures within the cold component in the FIRAS beam (typically from a few K to 20 K). This is compatible with the fact that the selected regions used to analyse the cold component contain molecular clouds which are known to have a dimension smaller than the FIRAS beam and, as discussed before, contain dust at temperatures as low as 10 K in the densest regions.

For those pixels which only contain a cirrus component, a positive excess above $400\,\mu$m is clearly visible, and can be fitted by a modified Planck curve with a ν^2 emissivity law, T=5 K and $\tau = 1.6\ 10^{-7}$ (Fig. 2) . Therefore we could conclude that very cold dust at a temperature ~5K is detected at high Galactic latitudes in the atomic medium. However, this detection can also be an artefact due to an incorrect removal of the isotropic background. Analysis of the Galactic emission without removing any isotropic background (Reach et al. 1995) yielded a very cold component (4-7 K) with its optical depth spatially correlated with the warm component (~18 K). Such a detection is not confirmed by all the analysis at high latitudes which are based on differential approachs and therefore which are free of any extragalactic or any isotropic Galactic emission components (see the discussion in Abergel et al., this issue). Therefore, the detection of a very cold component correlated with the warm component can be due to poor correction of the isotropic background, at least at high Galactic latitudes.

The very cold component that we have found in our residue for those pixels containing only a cirrus component (with the FIRAS data corrected for the

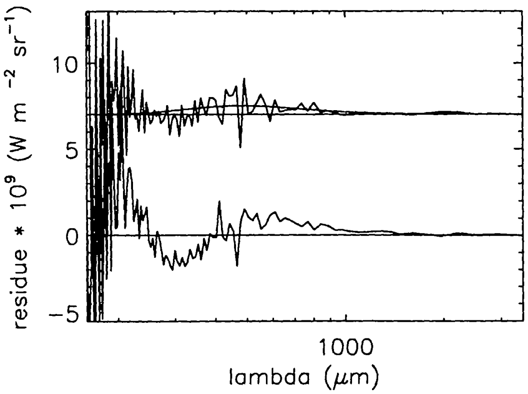

Figure 2. Mean residue for pixels with significant cold emission (lower curve), and for pixels with no significant cold emission (upper curve). The zero levels are given by the horizontal lines.

isotropic background) is also correlated with the warm component, although it is ~ 7 times weaker than the one found in Reach et al. (1995) (averaged for $|b| > 10°$). This could be due to an incorrect removal of the isotropic background. To test this idea, we have added our model of the sub-mm excess to the isotropic background spectrum of Puget et al. (1996). This correction is inside the error bars of the isotropic background spectrum. After analysing the FIRAS data using the method described in section 3, there is no more positive excess in the mean residue for those regions containing no significant cold emission.

In conclusion, we cannot exclude that the sub-mm excess in our residual spectrum could be due to the presence of very cold Galactic dust in the cirrus component of the ISM, with an origin still to be explained. However, a small correction (19% at 500 μm) of the isotropic background spectrum determined by Puget et al. (1996), compatible with the uncertainties of the first determination, definitively removes this component at high Galactic latitudes.

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Part 5. Interstellar Line Emission