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Cold component of the galactic emission and extragalactic sub-mm background observed by COBE

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Abstract. We present an update of different results concerning the galactic and extragalactic emission observed by COBE. The averaged spectrum of the atomic medium is well fitted by one component (T=17.5 K with a ν^2 emissivity law) compatible with the standard models of compact dust grains (Boulanger et al. 1996). This spectrum has been used to derive the residual spectrum free of any galactic contribution, considered as the first detection of the Cosmic Far Infrared Background (Puget et al. 1996). This background can mimic the presence of very cold dust (T $\sim$ 5 K) at high b. After removing it, only the molecular regions appear to contain dust colder than in the atomic medium (Lagache et al. 1996). We do not find evidence for any very cold dust ubiquitous in the galaxy.

1. Introduction

Since the detection of a sub-millimeter excess in the averaged galactic spectrum derived by Wright et al. (1991) from FIRAS data, the presence of very cold dust in the galaxy (at T $\sim$ 5 K) is a matter of debate. Up to now three components have been suggested to explain the exinction and the far-infrared emission of the ISM (Désert et al. 1990). The large grains (of size a $\geq$ 10 nm) are at thermal equilibrium with the radiation field at $\sim$18 K in the atomic medium, and contribute to most of the emission above 100 μm. Very recently, ISOPHOT observations of dense clouds have confirmed that the emission at $\lambda \geq 135\mu$m is mainly due to one type of grains (Larureijs et al. 1996).

The first averaged galactic spectrum using FIRAS data (from 104 μm to 4.5 mm) was derived by Wright et al. (1991). The best fit of this spectrum uses the sum of two components at a temperature equal to 20.4 and 4.77 K assuming a far infrared emissivity varying as ν^2, which suggests the existence of very cold dust at a temperature significantly lower than in the atomic medium. Working inside 146 bins over the whole sky, Reach et al. (1995) have identified a very cold galactic component (4-7 K) correlated with the warm component (16-21 K). The presence of such a very cold dust, which appears from these studies to be ubiquitous in the galaxy, strongly questionned our understanding of the physics of the far-infrared galactic emitters. As explained by Reach et al., only clouds with a central extinction Av higher than a few 10 could sufficiently attenuate the heating rate for classical interstellar grains (graphite or silicate). Such high extinctions correspond to very dense molecular clouds which are not ubiquitous in the galaxy. This very cold component cannot be due to temperature fluctuating small grains whose sub-mm emission is constrained by the IRAS emission at $\lambda \leq 60\mu$m. Therefore new mechanisms have been invoked, as a spectral feature in the warm dust or needle-like or fractal grains, or very large particles.

However, at high galactic latitude the presence of non galactic emission, which have been neglected in the Reach et al. paper (only the zodiacal emission, the CMB and the dipole have been removed), could be not negligeable. A cosmic background radiation due to the initial phase of galaxy formation has long been predicted (Partridge and Peebles 1967), and several studies have shown that a Cosmic Far Infrared Background Radiation (CFIBR) could come from star light reprocessed by dust in host galaxies (Sunyaev et al. 1978 and references therein). Many models (see for instance Franceschini et al. 1994) predict a CFIBR comparable to the galactic sub-mm emission at high b in the atomic medium (for typically $10^{20}\,\mathrm{Hcm}^{-2}$). Therefore the detection of very cold galatic dust can be strongly contaminated by the presence of the CFIBR. In section 2 we present mean galactic spectra at high b derived from differential approaches. In section 3 the principle of the detection of the CFIBR from FIRAS data is discussed. Then in the last section a synthesis of our understanding of the sub-mm emission of the sky is presented.

2. Differential approach: Mean spectrum of the atomic medium

Boulanger et al (1996) have derived a sub-mm spectrum of the dust associated to the atomic medium from FIRAS spectra (after removing the zodiacal foreground, the CMB and dipole emission). They have subtracted two spectra which are averaged for two sets of pixels selected using the integrated HI emission. Practically, the sky north of $-30°$ declination (set by the HI survey) for which the HI emission is smaller than 250 K km/s was used, out of known molecular regions (36% of the sky). For an optically thin emission this threshold corresponds to $\mathrm{N(HI)} = 5 10^{20}\,\mathrm{Hcm}^{-2}$. Above this value, the contribution of dust associated with molecular hydrogen to the far infrared emission should be not negligeable. Then two sets of equal sizes are selected with an HI emission above and below 140 K km/s, and the spectra averaged for these two sets. As the derived spectrum is obtained by subtracting two averaged spectra, it is free of any isotropic contribution. It is well fitted by one dust component with T = 17.5K and a dust emissivity $\tau/\mathrm{N_H} = 1.0\,10^{-25}(\lambda/250\mu\mathrm{m})^{-2}\,\mathrm{cm}^2$ remarkably close to the value of the Draine and Lee model (1984) of a mixture of compact grains of graphite and silicate.

The residuals to this one temperature fit have allowed to put an upper limit on the sub-mm emission from the very cold component almost one order magnitude lower than the value claimed by Reach et al. (1995). By correlating the FIRAS spectra with the DIRBE emission at 100 μm, Dwek et al. (1996) have derived a high galactic spectrum which shows a small excess just below the upper limit set by the Boulanger et al. analysis.

Bouchet et al. (1996) have compared the galactic HI spectrum of Boulanger et al. with the few measurements at high b done with balloon borne experiments (de Bernardis et al. 1990, Fischer et al. 1995). They show that, taking into account the uncertainties on the correction of the IRAS 100 μm emission used by Fischer et al., the emission of cirrus clouds has a spectrum very similar to the galactic HI spectrum. Clearly, there is no detectable very cold dust at high b at the level found by Reach et al. However, we have to keep in mind that the Boulanger et al. spectrum and the Baloon borne results are derived using a differencial approach. They are free of any isotropic-like emission.

3. Estimate of the non-galactic sub-millimeter background

Puget et al. (1996) have used the HI spectrum of Boulanger et al. (1996) as a spectral template to remove the galactic atomic emission from all FIRAS pixels out of known molecular regions at $|b| > 20°$ and $W_{HI} < 250\,K\,km/s$ (36% of the sky), after proper normalisation by the HI emission. The residues still contain a galactic pattern due to dust emission associated with the diffuse ionized gas not traced by the HI emission, and also to the large scale variations in the IR/HI emission ratio and/or from low contrast molecular clouds. The contribution of the ionized medium is difficult to quantify, since it is still unclear how much emission comes from this gas component and also what fraction of it is left after subtraction of the dust emission correlated with HI gas. However, the averaged spectrum of the galactic pattern of the residues (which follows a csc(b) variation) is similar to that of dust correlated with the HI emission (Boulanger et al. 1996). After removing this averaged galactic spectrum, a residual spectrum free of any galactic contribution is deduced (Puget et al. 1996). This spectrum is considered as the first detection of the CFIBR, if there is no unknown instrumental stray light, for the four following reasons:

i. The residues do not present any detectable latitude or longitude dependance. So, to be galactic this excess would have to originate in a large halo ($> 50kpc$). Such halos are not oberved in external galaxies.

ii. The width of the histogram of the residual brightness appears dominated by the measurement noise, which indicate that at the FIRAS resolution (7°) the residuals are essentially isotropic.

iii. The averaged residual spectrum is above systematic FIRAS offsets.

iv. It is compatible with different CFIBR models (for instance the model of Franceschini et al. 1994)

4. Discussion

We have seen that the galactic spectra at high b which are free from the contribution of an isotropic background because derived from differential approaches do not allow the detection of very cold dust in the galaxy. These spectra are fitted by one single dust component with T $\sim$ 17.5 K and a ν^2 emissivity law compatible with the standard models of dust grains at thermal equilibrium and interstellar radiation field (Draine and Lee 1984, Désert et al 1990). The amplitude of the sub-mm isotropic background considered as the first detection of the CFIBR (section 3) is comparable to that of the galactic dust at high b.

Therefore the detection of the very cold components correlated with the warm component in the Reach et al. paper can be due to a not proper removal of this background, at least at high b (see the discussion in Lagache et al., this issue).

However, there is in the galaxy dust which is colder than in the atomic component. By combining DIRBE and FIRAS data, Lagache et al. (1996) have shown that the temperatures of the dense molecular clouds with low star forming activity and out of the galactic plane is distributed around 14.8 K, with minimal values ~10 K. These temperatures are averaged inside the FIRAS beam, so the physical values of the dust temperature are widely ditributed from the temperature in the atomic medium (T ~ 17.5 K) down to temperatures lower than 10 K. The dust properties in molecular clouds should differ from that in the more diffuse gas components. We believe that the difference in temperature cannot be accounted for by the attenuation of the radiation field but that it reflects a change in the emissivity properties of large grains.

The sub-mm excess detected in the averaged galactic spectrum derived by Wright et al. (1991) from FIRAS data cannot be due to a not proper removal of the isotropic background, because of the high values of the far-infrared emission in the galactic plane. However, most of the lines of sight crossing the galactic plane detect the emission of dust in a very wide range of physical conditions and densities. Therefore the sub-mm excess detected in the galaxy plane can be due to dust emission coming from the dense molecular regions of the galaxy plane. The recent observations of the balloon-borne SPM-PRONAOS experiment confirms this hypothesis: cold dust at a temperature in the range 12-14 K has been detected in several molecular cores (Ristorcelli et al, this issue). The cold emission of the galaxy does not appear to come from the diffuse regions, but from the densest clouds.

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