The large-scale anomalous microwave emission revisited by \textit{WMAP}*

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Abstract. We present a new study of the high latitude galactic contributions to the millimeter sky, based on an analysis of the \textit{WMAP} data combined with several templates of dust emission (\textit{DIRBE/COBE} and \textit{FIRAS/COBE}) and gas tracers (HI and H$_\alpha$). To study the IR to millimeter properties of the diffuse sky at high galactic latitude, we concentrate on the emission correlated with the HI gas. We compute the emission spectrum of the dust/free-free/synchrotron components associated with HI gas from low to large column densities. A significant residual \textit{WMAP} emission over the free-free, synchrotron and dust contributions is found from 3.2 to 9.1 mm. We show that this residual \textit{WMAP} emission (normalised to $10^{20}$ atoms/cm$^2$) (1) exhibits a constant spectrum from 3.2 to 9.1 mm and (2) significantly decreases in amplitude when $N_{\text{HI}}$ increases, contrary to the HI-normalised far-infrared emission which stays rather constant. It is thus very likely that the residual \textit{WMAP} emission is not associated with the Large Grain dust component. The decrease in amplitude with increasing opacity resembles in fact to the decrease of the transiently heated dust grain emission observed in dense interstellar clouds. This is supported by an observed decrease of the HI-normalised 60 $\mu$m emission with HI column densities. Although this result should be interpreted with care due to residual zodiacal contaminations at 60 $\mu$m, it suggests that the \textit{WMAP} excess emission is associated with the small transiently heated dust particles. On the possible models of this so-called “anomalous microwave emission” linked to the small dust particles are the spinning dust and the excess millimeter emission of the small grains, due to the cold temperatures they can reach between two successive impacts with photons.

Key words. ISM: general – cosmology: miscellaneous – radio continuum: general

1. Introduction

At millimeter wavelengths, one of the major challenges in high sensitivity Cosmic Microwave Background (CMB) anisotropy study is to determine the fraction of the observed signal due to diffuse galactic foregrounds. Three different components have been firmly identified at high latitudes ($|b|>10^\circ$): thermal dust emission, synchrotron and free-free. Dust emission dominates the far-infrared surveys. Its spatial distribution and frequency dependence are quite well-determined for wavelengths shorter than ~800 $\mu$m. Above ~800 $\mu$m, present data currently do not give any strong constraints. So far, dust emission estimates in the millimeter range are thus an extrapolation of what is known at shorter wavelengths. Synchrotron radiation dominates radio-frequency surveys, but Banday & Wolfendale (1991) and Bennett et al. (1992) showed that the spectral index steepens with frequency and exhibits spatial variations which are poorly known. Free-free emission has a well-determined spectral behavior and templates are now available thanks to the \textit{WHAM} $H_\alpha$ survey of the northern sky (Reynolds et al. 1998; Haffner 1999) and the \textit{SHASSA} $H_\alpha$ survey of the southern sky (Gaustad et al. 2001).

Cross-correlations of CMB data with far-infrared maps have revealed the existence of a microwave emission component (the so-called “anomalous microwave emission”) with spatial distribution traced by these maps. This component has a spectral index suggestive of free-free emission and so has been first interpreted as free-free emission (Kogut et al. 1996). However, Kogut (1999) showed in small parts of the sky that were covered by $H_\alpha$ data that the microwave emission was consistently brighter than the free-free emission traced by $H_\alpha$. Thus, the correlated component cannot be due to free-free emission alone. This is confirmed more recently by Banday et al. (2003) also using \textit{COBE}/DMR data.

Recent works suggest that this anomalous far-infrared correlated component originates from spinning dust grain emission (Draine & Lazarian 1998a; De Oliveira-Costa et al. 1999, 2002), tentatively detected at 5, 8 and 10 GHz by Finkbeiner et al. (2002). An alternative explanation is provided by thermal fluctuations in the magnetization of interstellar grains causing magnetic dipole radiation (Draine & Lazarian 1999). However, very recently, Bennett et al. (2003) using \textit{WMAP} data do not find any evidence for the anomalous microwave emission. Their foreground component model comprises only free-free, synchrotron and thermal dust emission, and the observed

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galactic emission matches the model to <1%. Note that in their global analysis, they are dominated by the brightest parts of the sky i.e. the galactic plane and the high latitude dense interstellar clouds. Thus, results may not apply to the most diffuse regions.

We present in this paper a new study of the galactic contributions to the millimeter sky, based on an analysis of the WMAP data combined with several templates of dust emission (DIRBE/COBE and FIRAS/COBE) and gas tracers (HI and H$_\alpha$). We focus only on the high latitude regions where the results are easier to interpret in term of physical properties of dust and where CMB analysis are performed. The paper is organised as follows. We first present the data we use together with their preparation (Sect. 2). We then derive the spectrum (from 100 $\mu$m to 10 mm) of the HI-correlated component (Sect. 3.1) and show that there exists a residual microwave emission (over free-free, synchrotron and far-infrared dust emission) whose HI-normalised amplitude decreases when the HI column density increases but without any significant spectral variations (Sect. 3.2). We then discuss the results in Sect. 4.

2. Data-sets used and their preparation

2.1. COBE data

The COBE satellite was developed by NASA’s Goddard Space Flight Center to measure the diffuse infrared and microwave radiation from the early universe to the limits set by our astrophysical environment. It was launched November 18, 1989 and carried three instruments:

- a Far Infrared Absolute Spectrophotometer (FIRAS) to compare the spectrum of the cosmic microwave background radiation with a precise blackbody (at each sky position, with an angular resolution of 7°, we have one spectrum from 1 to 97 cm$^{-1}$);
- a Differential Microwave Radiometer (DMR) to map the cosmic radiation (at 31, 53, 90 GHz with a 7° beam);
- a Diffuse Infrared Background Experiment (DIRBE) to search for the cosmic infrared background radiation (10 photometric bands from 1 to 240 $\mu$m with an angular resolution of 40°).

COBE data are presented in a quadrilateralized spherical projection (the so-called COBE Quadrilateralized Spherical Cube, CSC), an approximately equal-area projection in which the celestial sphere is projected onto an inscribed cube. The DIRBE convention is to divide each cube face into 256 $\times$ 256 pixels; thus all sky-maps have 256 $\times$ 256 $\times$ 6 = 393216 pixels. Each pixel is approximatively 0.32° on a side. For FIRAS and DMR, each cube face is 32 $\times$ 32 pixels leading to a total of 6144 pixels (of ~2.6°).

We use the so-called (i) “Sky Maps and Analyzed Science Data Sets” DMR Data (ii) “Galactic Dust Continuum Spectra and Interstellar Dust Parameters” FIRAS data, that give the residual sky spectrum after modelled emission from the CMB, zodiacal emission, and interstellar lines have been subtracted. (iii) DIRBE “Zodi-Subtracted Mission Average (ZSMA) Maps” for which the zodiacal light intensities were subtracted week by week and the residual intensity values were averaged to create Maps. All COBE data are available at http://lambda.gsfc.nasa.gov/product/cobe

2.2. Gas tracers

The HI data we used are those of the Leiden/Dwingeloo survey which covers the entire sky down to $\delta = -30^\circ$ with a grid spacing of 30’ in both l and b. The 36’ half power beam width of the Dwingeloo 25 m telescope provides 21 cm maps at an angular resolution which closely matches that of the DIRBE maps. Details of the observations and correction procedures are given by Hartmann (1994) and by Hartmann & Burton (1997). It should be noted that in this data-set special care was taken for the removal of far sidelobes emission which makes it particularly suitable for high latitude studies. We derive the HI column densities using $1\, \text{K}\,\text{km}\,\text{s}^{-1} = 1.82 \times 10^{18}\,\text{H}\,\text{cm}^{-2}$ (optically thin emission).

Thanks to the WHAM survey of the northern sky (Reynolds et al. 1998; Haffner 1999) and the SHASSA survey of the southern sky (Gaustad et al. 2001), it is now possible to have a whole sky map of the H$_\alpha$ emission (Dickinson et al. 2003; Finkbeiner 2003). Since the HI maps cover the sky down to $\delta = -30^\circ$, the H$_\alpha$ emission we use is our analysis is mostly given by the WHAM survey. WHAM provides a 12 km s$^{-1}$ velocity resolution with one-degree angular resolution down to sensitivity limits of 0.2 $R$ ($1\, R = 10^6/4\pi\,\text{ph}\,\text{cm}^{-2}\,\text{s}^{-1}\,\text{sr}^{-1}$) in a 30 second exposure. The one-degree angular resolution nicely matches the DIRBE resolution. We use the H$_\alpha$ map and the conversion factors to free-free emission (using $T_e = 8000\,\text{K}$) from Finkbeiner (2003) to derive templates of free-free emission. Since we work only on high latitude regions, the H$_\alpha$ emission has not been corrected for extinction (the dust absorption is likely to be very small, less than 5%). The free-free templates are used to derive a well-understood contribution to the millimeter channels.

2.3. Synchrotron templates

Synchrotron emission arises from relativistic cosmic ray electrons spiralling in the galactic magnetic field. This emission dominates surveys at radio frequencies. The only all-sky map at low frequencies that probe the synchrotron emission is the 408 MHz survey of Haslam et al. (1982). For many years, this map has been used to predict the synchrotron emission in the millimeter channels, assuming a frequency dependence with a constant spectral index of about 2.75. However, Bennett et al. (2003) have shown that the synchrotron spectral index exhibit strong spatial variations and is steeper in the WMAP bands than at radio frequencies. We thus use the WMAP synchrotron maps derived by Bennett et al. (2003) using the Maximum Entropy Method as frequency dependent well-determined synchrotron templates.
2.4. WMAP data

The WMAP1 (Wilkinson Microwave Anisotropy Probe) mission, designed to determine the geometry, content, and evolution of the universe, has successfully provided full sky maps at 23, 33, 41, 61 and 94 GHz at respectively 13.2, 39.6, 30.6, 21 and 13.2′ FWHM resolution with unprecedented sensitivity. A detailed description of the delivered data-sets for the first 12 months of operation of WMAP is given in the WMAP: explanatory Supplement (editor M. Limon et al., Greenbelt, MD: NASA/GSFC). The data we use are the first-year “Smoothed I maps” which are the temperature maps at each frequency, smoothed to a common resolution of 1 degree. Data are delivered in the HEALPix2 format with $N_{\text{side}} = 256$.

2.5. Data preparation

All the data have to be put in the same projection and at the same resolution. The resolution is set by the FIRAS experiment since it is the lowest resolution of our data-sets (7′). All data but DMR and FIRAS are thus converted in the DIRBE CSC format and then convolved with the FIRAS beam and degraded to the FIRAS CSC resolution (see Lagache 2003 for more details).

We have removed for each data-set the cosecant law variation (1) to avoid the obvious large scale correlations between all galactic components concentrated in the disc and (2) to be consistent with the WMAP data that measure only differentially on the sky and thus does not measure the largest angular scales.

We restrict our analysis to $|b| > 15°$ and exclude the Small and Large Magellanic clouds, together with the $\rho$-Ophiucus complex. We also remove cold molecular complexes (as the Taurus cloud), and regions where the dust is locally heated by nearby stars (like the HII regions) following Lagache et al. (1998). We stress out that this latter pixel selection, although necessary to keep in the analysis only diffuse parts of the sky, does not change the results and conclusions of the paper.

3. Analysing the data

3.1. Deriving the HI-correlated component spectrum

The HI-correlated dust emission is the dominant component at high galactic latitude at infrared/far-infrared/submillimeter wavelengths (except in the very low HI column density regions where the Cosmic Infrared Background becomes an important contribution, e.g. Lagache et al. 1999). One way to study the infrared to millimeter properties of the diffuse sky at high galactic latitude is therefore to concentrate on the emission correlated with the HI gas. We search here for the spatial/spectral variations of the infrared to millimeter emission with the HI gas column densities.

To compute the emission spectrum of the component associated with HI gas from low to large column densities, we use a differential method that removes, within statistical variance, any residual infrared emission that is not correlated with the HI gas such as an isotropic component. We first select sky pixels according to their HI column density and sort them into sets of pixels bracketed by selected values of $N_{\text{HI}}$. Correlated HI emission spectra are then computed for each set of pixel $k$ using the equation:

$$F_i(k) = \frac{<F_i > - <F_0 >}{<N_{\text{HI}} > - <N_{\text{HI}} >_0}$$

where $<F_i>$ corresponds to the mean emission computed for the set of pixels $i$, and $<N_{\text{HI}}>$, to the mean HI column density for the same set of pixels. Note that all the data-sets used here are cosexacant-law subtracted (see Sect. 2.5).

To keep high signal-to-noise ratio, only 5 sets of pixels are considered here, with increasing $N_{\text{HI}}$. The first set (labeled “0” in Eq. (1)), serves as the “reference” set and corresponds to the lowest column density regions (representing ~5% of the sky). We are thus left with 4 sets of pixels $k$ with increasing $N_{\text{HI}}$ and derive accordingly four mean spectra $F_i(k)$. The sets of pixels are selected on the cosecant-law removed HI emission that can be negative. For reference, the total mean HI column density (i.e. non cosexacant-law subtracted) for the 4 bins are 3.3, 4.1, 5.6 and 9.9×10$^{20}$ cm$^{-2}$. By construction, the spectra are normalised to 10$^{20}$ cm$^{-2}$. Note that $F$ in Eq. (1) represents alternatively the DIRBE, FIRAS, DMR, WMAP, free-free and synchrotorn data.

3.2. Results

The four spectra are presented in Fig. 1 with the DIRBE data points at 100 and 140 $\mu$m, the FIRAS spectra (displayed only between 210 and 1000 $\mu$m), the DMR data points at 90, 53 and 31 GHz and the WMAP data points at 3.2, 4.9, 7.3 and 9.1 mm (all these data points are in black in Fig. 1). A zoom on the millimeter part of the figure is presented in Fig. 2. We fit the DIRBE 100, 140 $\mu$m and FIRAS spectra (200 < $\lambda$ < 500 $\mu$m) with a modified Planck curve with a $v^2$ emissivity law (the result of the fit is displayed in Fig. 1 and 2). We know that this fit is inconsistent with FIRAS data below ~500 GHz where an excess component is detected (Reach et al. 1995; Finkbeiner et al. 1999). However, discussing this component is not the goal of this paper. We only concentrate on the millimeter part on the spectra and how it relates to the far-infrared emission. It is important to note that this far-infrared dust emission has a stable spectrum, not changing with increasing opacity (Lagache et al. 1999). In this framework, the $v^2$ modified black body is well representative and useful for comparison between spectral far-infrared and millimeter shapes3. This far-infrared dust emission extrapolated at millimeter wavelengths will be called the “stable thermal dust component”.

First, we see in Fig. 2 that there is a strong millimeter excess (with both DMR and WMAP data) with respect to the stable thermal dust component (i.e. the $v^2$ modified black body). This excess decreases significantly (by a factor of about 5 at 3.2 mm) when the HI column density increases, although the far-infrared emission remains nearly constant (at the ~6% excess).
level). The far-infrared emission is dominated by the so-called Large Grain dust component. The millimeter excess, which changes rapidly with opacity, is thus not likely associated with this dust component.

We can go further by removing to the WMAP emission the corresponding free-free, synchrotron and stable thermal dust component contribution. The residual WMAP emission is shown in Figs. 1 and 2 (red stars) and detailed in Table 1. First, at each frequency, the residual emission exhibits a strong decrease (by about a factor of 5) with HI column densities (from bin 1 to 4). Second, the residual decreases from 3.2 to 9.1 mm in each HI bin. In Fig. 3 are shown the WMAP residual emissions for the 4 bins at 3.2, 4.9, 7.3 and 9.1 mm, normalised to the 90 GHz DMR residual emission (the 31 and 53 GHz DMR residual emissions have also been computed but are not displayed to avoid confusion. Results, although more noisy, are in very good agreement with WMAP). This figure shows that we do not detect any significant variations in the spectral shape of the residual emission. Thus, the HI-normalised residual emission, although decreasing in amplitude with the HI column density, has a constant spectrum.

4. Discussion
To account for the galactic energy emitted from the mid-infrared to the submillimeter, it is necessary to have a broad dust size distribution from large grains down to large molecules. For example, Désert et al. (1990) (see also Draine & Anderson 1985; Puget et al. 1995; Weiland et al. 1986; Siebenmorgen & Krügel 1992; Dwek et al. 1997 and more recently Li & Draine 2001) have proposed a consistent interpretation of both the infrared emission in diffuse HI clouds and the interstellar extinction curve using a model with three components: PAHs (Policyclic Aromatic Hydrocarbons), Very Small Grains (VSGs) and Large Grains. PAHs and VSGs are small molecules.

| Component         | 3.2 mm | 4.3 mm | 7.9 mm | 9.1 mm |
|-------------------|--------|--------|--------|--------|
| WMAP              | 1      | 2.05 x 10^{-12} | 6.15 x 10^{-13} | 2.92 x 10^{-13} | 2.19 x 10^{-13} |
|                   | 2      | 1.52 x 10^{-12} | 4.65 x 10^{-13} | 2.25 x 10^{-13} | 1.80 x 10^{-13} |
|                   | 3      | 7.59 x 10^{-13} | 2.26 x 10^{-13} | 1.31 x 10^{-13} | 1.27 x 10^{-13} |
|                   | 4      | 7.22 x 10^{-13} | 2.03 x 10^{-13} | 1.34 x 10^{-13} | 1.37 x 10^{-13} |
| Free-free         | 1      | 1.46 x 10^{-13} | 1.02 x 10^{-13} | 7.23 x 10^{-14} | 6.03 x 10^{-14} |
|                   | 2      | 1.14 x 10^{-13} | 7.93 x 10^{-14} | 5.65 x 10^{-14} | 4.71 x 10^{-14} |
|                   | 3      | 8.33 x 10^{-14} | 5.79 x 10^{-14} | 4.12 x 10^{-14} | 3.44 x 10^{-14} |
|                   | 4      | 7.36 x 10^{-14} | 5.12 x 10^{-14} | 3.64 x 10^{-14} | 3.04 x 10^{-14} |
| Synchrotron       | 1      | 5.32 x 10^{-15} | 4.28 x 10^{-14} | 6.56 x 10^{-14} | 7.60 x 10^{-14} |
|                   | 2      | 3.57 x 10^{-14} | 3.95 x 10^{-14} | 5.67 x 10^{-14} | 7.24 x 10^{-14} |
|                   | 3      | 4.27 x 10^{-14} | 3.40 x 10^{-14} | 5.01 x 10^{-14} | 6.76 x 10^{-14} |
|                   | 4      | 3.79 x 10^{-14} | 4.64 x 10^{-14} | 6.19 x 10^{-14} | 8.20 x 10^{-14} |
| Stable thermal dust | 1     | 3.17 x 10^{-13} | 3.95 x 10^{-14} | 5.53 x 10^{-15} | 1.86 x 10^{-15} |
|                   | 2      | 2.81 x 10^{-13} | 3.50 x 10^{-14} | 4.90 x 10^{-15} | 1.64 x 10^{-15} |
|                   | 3      | 2.91 x 10^{-13} | 3.62 x 10^{-14} | 5.08 x 10^{-15} | 1.71 x 10^{-15} |
|                   | 4      | 3.66 x 10^{-13} | 4.55 x 10^{-14} | 6.39 x 10^{-15} | 2.15 x 10^{-15} |
| Residue           | 1      | 1.58 x 10^{-12} | 4.31 x 10^{-13} | 1.48 x 10^{-13} | 8.11 x 10^{-14} |
|                   | 2      | 1.09 x 10^{-12} | 3.12 x 10^{-13} | 1.02 x 10^{-13} | 5.89 x 10^{-14} |
|                   | 3      | 3.41 x 10^{-13} | 9.75 x 10^{-14} | 3.42 x 10^{-14} | 2.29 x 10^{-14} |
|                   | 4      | 2.45 x 10^{-13} | 5.94 x 10^{-14} | 2.95 x 10^{-14} | 2.20 x 10^{-14} |
Fig. 1. Spectrum of the HI-correlated component normalised to $10^{20}$ at/cm$^2$ (with increasing $N$(HI) from a) to d). The black diamonds at 100 and 140 $\mu$m are the DIRBE data, the black curve is the FIRAS spectrum, the black crosses with error bars are the DMR data and the black triangles at 3.2, 4.9, 7.3 and 9.1 mm are the WMAP data. Also displayed are the free-free and synchrotron contributions (blue stars and green triangles respectively). The green continuous line is the result of a fit of the DIRBE 100, 140 $\mu$m and FIRAS spectra ($200 < \lambda < 500$ $\mu$m) with a modified Planck curve with a $\nu^2$ emissivity law (the so-called stable thermal dust component). The residual WMAP emission (which is the WMAP-free-free – synchrotron – stable thermal dust component) is shown as red stars.

Fig. 2. Zoom on the millimeter part of Fig. 1. Symbols and colors are the same as in Fig. 1. Added is the residual WMAP emission after having removed only the free-free and synchrotron contributions (light-blue diamonds).
constant spectrum from 3.2 to 9.1 mm but (2) significantly decreases in amplitude when $N_{\text{HI}}$ increases, contrary to the far-infrared emission (associated with the so-called stable thermal dust component) which stays rather constant (cf. Table 2). It is thus very likely that the residual WMAP emission is not associated with the Large Grain dust component. The decrease in amplitude resembles in fact to the decrease of the PAH/VSGs emission observed in dense interstellar clouds. By extrapolating the PAH/VSGs behaviour from dense interstellar clouds to the diffuse medium, we may expect, when increasing the HI column density, to decrease the PAH and VSGs proportion and thus the HI-normalised mid-infrared emission. If this is true, then the PAH/VSGs HI-correlated emission should decrease with HI column densities. This decrease, if present, is very hard to observe in the mid-infrared due to the strong residual interplanetary dust emission at large scale. On the DIRBE bands, only the 60 $\mu$m may be used. We have computed for the 4 HI bins the 60 $\mu$m HI-correlated emission with two different cuts in ecliptic latitude ($|\beta| > 3^\circ$ and $|\beta| > 15^\circ$). Although the absolute level of the 60 $\mu$m HI-correlated emission varies for the 2 cuts, we observe nearly the same significant decrease of the HI-normalised 60 $\mu$m emission with the HI column density (cf. Table 2). The 60 $\mu$m band may be contaminated by the Large Grain emission (30 to 40%, e.g. Désert et al. 1990). Therefore, we remove to the 60 $\mu$m the thermal Large Grain contamination using the best $v^2$ modified black body fit (Fig. 1). The observed decrease at 60 $\mu$m becomes even larger (Table 2). Although this result should be interpreted with care due to the zodiacal contamination at 60 $\mu$m, it suggests that the WMAP residual emission is associated with the small transiently heated particles.

The previous results suggest the anomalous microwave component is associated with the transiently heated dust particles, but its exact physical mechanism remains to be found. On the possible models of the anomalous emission linked to the transiently heated particles are:

- The “spinning-dust” which is the rotational emission from very small dust grains (Draine & Lazarian, 1998a, 1998b). However, although the spinning dust emission is in good agreement with the WMAP emission at 7.3 and 9.1 mm, it is inconsistent with the 3.2 mm emission.

- The VSGs long-wavelength emission. VSGs are transiently heated when an ultraviolet photon is absorbed. The mean interval between successive ultraviolet photons is longer than the cooling time and thus, between 2 impacts, the temperature of the particles is very low (but is at least the CMB temperature). Such particles could therefore emit significant emission in the millimeter channels.

The models have large uncertainties linked to the unknown properties of the small particles. It is therefore very difficult to predict the exact contribution of the two in the millimeter.

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References

Abergel, A., Boulanger, F., Mizuno, A., & Fukui, Y. 1994, ApJ, 423, L59
Banday A. J., & Wolfendale, A. W. 1991, MNRAS, 248, 705
Banday, A. J., Dickinson, C., Davies, R. D., et al. 2003, MNRAS, submitted
Bernard, J. P., Boulanger, F., & Puget, J.-L., 1993, ApJ, 277, 609
Bennett, C. L., Smoot, G. F., & Hinshaw, G. 1992, 396, L7
Bennett, C. L., Hill, R. S., Hinshaw, G., et al. 2003, ApJ, submitted
Boulanger, F., Abergel, A., Bernard, J.-P., et al. 1996, A&A, 312, 256
Boulanger, F., Falgarone, E., Puget, J.-L., & Helou, G. 1990, ApJ, 364, 136
Désert, F.-X., Boulanger, F., & Puget, J.-L., 1990, A&A, 327, 215
De Oliveira-Costa, A., Tegmark, M., Gutierrez, C., et al. 1999, ApJ, 527, L9
De Oliveira-Costa, A., Tegmark, M., Finkbeiner, D., et al. 2002, ApJ, 567, 363
Dickinson, C., Davies, R. D., & Davis, R. J. 2003, MNRAS, 341, 369
Draine, B. T., & Anderson, N. 1985, ApJ, 292, 494
Draine, B. T., & Lazarian, A. 1998a, ApJ, 494, L19
Draine, B. T., & Lazarian, A. 1998b, ApJ, 508, 157
Draine, B. T., & Lazarian, A. 1999, ApJ, 512, 740
Dwek, E., Arendt, R. G., Fixsen, D. J., et al. 1997, ApJ, 475, 565
Finkbeiner, D., Davis, M., & Schlegel, D. J. 1999, ApJ, 524, 867
Finkbeiner, D., Schlegel, D. J, Frank, C., & Heiles, C. 2002, ApJ, 566, 898
Finkbeiner, D. 2003, ApJS, 146, 407
Gaustad, J. E., Mc Cullough, P. R., Rosing, W. R., & Buren, D. V. 2001, PASP, 113, 1326
Haßner, L. M. 1999, Ph.D. Thesis, University of Wisconsin
Hartmann, D. 1994, Ph.D. Thesis, University of Leiden
Hartmann, D., & Burton, W. B. 1997, Atlas of galactic neutral hydrogen (Cambridge, New-York: Cambridge University Press), ISBN 0521471117
Haslam, C. G. T., Salter, C. J., Stoffel, H., & Wilson, W. 1982, A&AS, 47, 1
Kogut, A., Banday, A. J., Bennett, C. L., et al. 1996, ApJ, 460, 1
Kogut, A. 1999, in Microwave Foregrounds, ed. A. De Oliveira Costa, & M. Tegmark, ASP Conf. Ser., 181, 91
Lagache, G., Abergel, A., Boulanger, F., & Puget, J.-L. 1998, A&A, 333, 709
Lagache, G., Abergel, A., Boulanger, F., et al., 1999, A&A, 344, 322
Lagache, G. 2003, Absolute photometric calibration of Planck/HFI high-frequency channels on the Galaxy: Application to Archeops data, A&A, submitted
Laurejs, R. J., Clark, F. O., & Prusti, T. 1991, ApJ, 372, 185
Li, A., & Draine, B. T. 2001, ApJ, 554, 778
Puget, J. L., Léger, A., & Boulanger, F. 1985, A&A, 142, L19
Reach, W. T., Dwek, E., Fixsen, D. J., et al. 1995, ApJ, 451, 188
Reynolds, R. J., Tufte, S. L., Haßner, L. M., et al. 1998, PASA, 15, 14
Siebenmorgen, R., & Krügel, E. 1992, A&A, 259, 614
Stepnik, B., Abergel, A., Bernard, J.-P., et al. 2003, A&A, 398, 551
Weiland, J. L., Blitz, L., Dwek, E., et al. 1986, ApJ, 306, L101