Properties of dust in the high-latitude translucent cloud L1780

I. Spatially distinct dust populations and increased dust emissivity from ISO observations

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ABSTRACT

We have analyzed the properties of dust in the high galactic latitude translucent cloud Lynds 1780 using ISOPHOT maps at 100 µm and 200 µm and raster scans at 60 µm, 80 µm, 100 µm, 120 µm, 150 µm and 200 µm. In far-infrared (FIR) emission, the cloud has a single core that coincides with the maxima of visual extinction and 200 µm optical depth. At the resolution of 3.0′, the maximum visual extinction is 4.0 mag. At the cloud core, the minimum temperature and the maximum 200 µm optical depth are 14.9 ± 0.4 K and 2.0 ± 0.2 × 10−3, respectively, at the resolution of 1.5′. The cloud mass is estimated to be 18 $M_\odot$. The FIR observations, combined with IRAS observations, suggest the presence of different, spatially distinct dust grain populations in the cloud: the FIR core region is the realm of the “classical” large grains, whereas the very small grains and the PAHs have separate maxima on the Eastern side of the cold core, towards the “tail” of this cometary-shaped cloud. The color ratios indicate an overabundance of PAHs and VSGs in L1780. Our FIR observations combined with the optical extinction data indicate an increase of the emissivity of the big grain dust component in the cold core, suggesting grain coagulation or some other change in the properties of the large grains. Based on our observations, we also address the question, to what extent the 80 µm emission and even the 100 µm and the 120 µm emission contain a contribution from the small-grain component.

Key words. ISM: clouds – infrared: ISM – ISM: individual objects: L1780

1. Introduction

Recent ISM dust models (e.g. Désert et al. 1990) typically have three dust components for which a power law size distribution is assumed: the big “classical” silicate or carbonaceous dust grains with maximum emission at about 100–200 µm; very small grains (VSGs), which mainly emit at $\lambda = 20–60$ µm; and polycyclic aromatic hydrocarbons (PAHs) which have emission features in the wavelength range 3–20 µm and a possible continuum contribution. It has been known since the IRAS observations that both the small and the big interstellar grains contribute to the heating and cooling of the interstellar medium (ISM), and it is believed that also PAHs contribute significantly to the heating process (Bakes & Tielens 1994). In a typical translucent cloud, such as L1780, heating takes place mainly through photoelectrons that are created when energetic photons from the interstellar radiation field (ISRF) hit dust grains. When heated by the solar neighborhood ISRF, large grains are able to remain at an equilibrium temperature, emitting mostly at far-infrared (FIR) wavelengths. On the other hand, when small grains or PAHs absorb an energetic UV photon they are temporarily heated to higher temperatures, which causes their temperature to fluctuate. While small grains, which radiate mostly at shorter wavelengths (below 100 µm), play a significant part in both the heating and cooling of clouds, their relationship to the large grains, their relative abundance, as well as their internal properties, are still incompletely understood.

COBE and ISO satellites extended the infrared observational range to longer wavelengths, enabling the measurement of the large-grain temperatures and emissivities. Observations show that the spectral energy distribution of the interstellar dust varies from the diffuse medium to molecular clouds and also from cloud to cloud. This probably implies changes in the dust composition, and especially variations in the abundances of VSGs and PAHs (Boulanger et al. 1990; Lagache et al. 1998; Verter et al. 2000). Variations in the abundances of grain populations within a single cloud have also been suggested (Bernard et al. 1992, 1993; Rawlings et al. 2005). Moreover, the observed very cold temperatures and changes in the emissivity of the large grains also suggest that the properties of the large grains change in regions of high dust column density in the interiors of molecular clouds (Bernard et al. 1999; Stepnik et al. 2003). In this paper, and in a subsequent paper, where a radiative transfer model of L1780 will be presented (Ridderstad et al., in preparation), we address some of the above questions through observations obtained towards the translucent cloud Lynds 1780.

Lynds 1780 (hereafter L1780; also listed as MBM 33 in Magnani et al. (1985)) is a high galactic latitude ($l = 359.0^\circ$, $b = 36.7^\circ$) cloud with the size of $\sim 40' \times 30'$. The brighter central part of the cloud was listed as a separate source, L1778, in Lynds’ (1962) catalogue. L1780 was classified as a cometary globule associated with Loop I by Töth et al. (1995). It is located...
in the dark cloud complex that includes the clouds L134, L169, and L183 (L134N), and is likely to be physically associated with it (Clark & Johnson 1981). We refer to these clouds, including L1780, as the L134 complex. The distance to the L134 complex was determined to be 110 ± 10 pc by Strömgren photometry (Franco 1989) and 140 ± 20 pc by Vilnius photometry (Cernis & Straizys 1992). The NaI measurements by Lallement et al. (1993) indicate a distance of ~100 pc. In this paper, we adopt the distance of 110 pc.

The L134 complex is the northernmost extension of the Scorpianus-Ophiuchus star-forming region and is located at the border of the Local Bubble (Kuntz et al. 1997; Lallement et al. 2003). In addition to L1780, also other clouds in this complex have displaced, cometary-like cores. In L183, very early phases of star formation are indicated (Ward-Thompson et al. 1994, 2000; Lehtinen et al. 2003). No star formation has been observed in L1780, although young Hα emission line stars with ages a few times 10⁶ years have been observed around L1780 (Martin & Kun 1996). One of these Hα stars has the same radial velocity as L1780 (Martin & Kun 1996), and they may be related to an old SNR expansion shell (Tóth et al. 1995; Martin & Kun 1996).

Observations of HI in L1780 have shown that, on its Southern half, the cloud has excess emission, which is probably caused by the UV-radiation of the bright OB stars in the direction of the galactic plane (Matilla & Sandell 1979). Tóth et al. (1995) discussed in detail the virial equilibrium conditions and the evolutionary history of L1780, and suggested that the cometary structure of the cloud is produced by the shock fronts of supernovae and stellar winds from the Sco-Cen association of OB stars. They also found that the 13CO core, which coincides with the IRAS 100 μm emission core, is in virial equilibrium.

The maximum optical extinction A_ν in the cloud has been estimated to be 4 mag by Matilla (1986). He also found a good correlation between CH column density and optical extinction in L1780. The HI and CO distributions in L1780 (Matilla & Sandell 1979; Tóth et al. 1995) were correlated with different IRAS band distributions, which suggested that there are different grain populations present in L1780, and their distributions are distinct from each other and related to the local physical conditions. Laureijs (1989) studied L1780 in the optical and infrared, and suggested that the optical excess red emission observed in the cloud by Matilla (1979) is analogous to that observed in the Red Rectangle (Schmidt et al. 1980). If this interpretation is correct, L1780 is so far the only translucent cloud in which this Extended Red Emission (ERE) has been observed.

In this paper, we study the 60–200 μm emission of L1780 using ISO observations. We also compare these data with the IRAS observations at 12 μm and 25 μm to investigate the PAH abundance within L1780, as the radiation at 12 μm is generally believed to be due to PAHs, and the 25 μm emission is mainly from VSGs (Desert et al. 1990). While the radiation at 60 μm is due to VSGs, the radiation at ~100–200 μm can be described as a modified blackbody emission from the “classical big” dust grains, which are in equilibrium with the surrounding radiation field. It is not entirely clear, to what extent the 100 μm emission contains a small-grain contribution; we compare our ISO raster scan observations to the current ISM dust model to address this question. However, since the small-grain contribution at 100 μm is small, the 100–200 μm maps and raster scans can be used to effectively trace the domain of the large grains, which are responsible for most of the interstellar extinction at optical wavelengths and make up most of the dust mass. We use the 100 μm and 200 μm ISO observations to derive estimates on the dust temperature, column density and mass. From the 60 μm, 80 μm, 100 μm, 120 μm, 150 μm and 200 μm ISO raster scans, the spectral energy distributions (SEDs) and temperatures at selected positions of the cloud are obtained. 2MASS data are used to derive an optical extinction map. The locations of the maxima and the spatial distributions of the emission at different wavelengths are compared, and the distributions of the three dust components (PAHs, VSGs and the large grains) are estimated. We also compare our results on L1780 with the recent observations suggesting that the FIR emissivity of dust increases where low dust temperatures are observed (Cambrésy et al. 2001; del Burgo et al. 2003; Stepnik et al. 2003; Kramer et al. 2003).

### 2. Observations and data reduction

#### 2.1. FIR observations

The observations were made with the ISOPHOT instrument aboard the Infrared Space Observatory (ISO) (Kessler et al. 1996) satellite, using the C100 and C200 detectors (Lemke et al. 1996) with the observing template PHT22 in raster mode. The data analysis was done with PIA (ISOPHOT Interactive Analysis) V10.0 (Gabriel et al. 1997). At the first processing level, the detector ramps were corrected for non-linearity in the detector response, glitches in ramps were removed using the two-threshold glitch recognition method, and the ramps were fitted with 1st order polynomials. At subsequent levels the signals were deglitched, reset interval correction was applied, signals were linearized for the dependence of the detector response on illumination, and orbital position-dependent dark currents were subtracted.

Table 1 shows the parameters of the individual observations. All the maps were calibrated using the FCS (Fine Calibration Source) measurements bracketing the actual measurements. The sizes of the map pixels of the C100 maps and the C200 maps are 43.5″ and 89″, respectively. A typical statistical uncertainty

| Filter | A_ref | c | TDT | Raster steps | Map size | Camera |
|--------|-------|---|-----|--------------|----------|--------|
| C100   | 100   | 102.6 | 47.1 | 43 100.630  | 18 × 24  | 40 × 36 | C100   |
| C200   | 200   | 202.1 | 56.9 | 43 199.629  | 13 × 13  | 39 × 39 | C200   |
| C60    | 60    | 61.8  | 24.6 | 43 100.206  | 2 × 16   | 47 × 37 | C100   |
| C70    | 80    | 80.7  | 48.4 | 43 100.207  | 2 × 16   | 47 × 37 | C100   |
| C100   | 100   | 102.6 | 47.1 | 43 100.208  | 2 × 16   | 47 × 37 | C100   |
| C120   | 120   | 118.7 | 49.5 | 43 100.209  | 2 × 13   | 39 × 45 | C200   |
| C135   | 150   | 155.1 | 81.2 | 43 100.212  | 2 × 13   | 39 × 45 | C200   |
| C200   | 200   | 202.1 | 56.9 | 43 100.210  | 2 × 13   | 39 × 45 | C200   |
is 0.2 MJy sr\(^{-1}\) for a map pixel of the large 100 \(\mu\)m map and 1.2 MJy sr\(^{-1}\) for a 200 \(\mu\)m map pixel. For the raster scans, the average uncertainties are 0.4, 0.4, 0.3, 1.5, 0.1 and 0.2 MJy sr\(^{-1}\) for a 60 \(\mu\)m, 80 \(\mu\)m, 100 \(\mu\)m, 120 \(\mu\)m, 150 \(\mu\)m and 200 \(\mu\)m map pixel, respectively. The uncertainty in the absolute calibration is \(\sim\)25\% for the C100 and \(\sim\)20\% for the C200 data (Klaas et al. 2000).

For the flat-field correction of the large C100 and C200 maps a statistical method was applied: the pixel values were corre-
lated against the reference pixel at each raster position. Rather than com-
paring the reference pixel only with pixels belonging to the
same raster position, a mean of two pixels located sym-
metrically around the reference pixel was taken. This reduces the
scatter in the pixel-to-pixel relation caused by surface brightness
gradients. For the flat-fielding of the ISO raster scans, a similar
procedure was used. The value of the reference pixel was calcu-
lated as a weighted average using a Gaussian that was placed at
the position of the studied pixel and had a \(\text{FWHM}\) of 2.0'.
For both the large ISO maps and the raster scans the reference pixels
were chosen to be the pixels number 8 and 3 in the C100 and
C200 rasters, respectively. The data from pixel No. 3 of the ISO
60 \(\mu\)m raster scan was of such bad quality that it was replaced by the
average of the values of the surrounding raster pixels.

It is known that the primary intensity calibrators, the fine cal-
ibration source (FCS) measurements used to derive the respons-
ivities of the detectors, suffer from signal transients in the case of the
C100 camera. Lehtinen et al. (2001) showed that even af-
ter these transients were corrected using the PIA signal drift in-
terface, there remained a difference of 20\% between the 100 \(\mu\)m
ISO and DIRBE surface brightmesses. Therefore, the C100 meas-
urements on L1780 were compared with DIRBE.

IRAS data was first scaled to DIRBE scale using the rela-
tion \(I_{\text{DIRBE}}(100 \mu\text{m}) = 0.73 \times I_{\text{IRAS}}(100 \mu\text{m})\) that was derived for a 6' diameter circular region around L1780. A linear fit
ISO vs. scaled IRAS values gave \(I_{\text{RAS,DIRBE}}(100 \mu\text{m}) = 0.61 \times I_{\text{ISO}}(100 \mu\text{m})\).
In the comparison both DIRBE and ISO observations were color corrected assuming a spectrum \(B_\nu(T_{\text{dust}} = 17 \text{K})\). The larger 100 \(\mu\)m map was scaled to the DIRBE sur-
face brightness scale using this relation, and the 100 \(\mu\)m raster scan was included in the calculation. The 60 \(\mu\)m raster scan values were similarly scaled to
DIRBE via IRAS, using the relation \(I_{\text{DIRBE}}(60 \mu\text{m}) = 0.69 \times I_{\text{IRAS}}(60 \mu\text{m})\) and \(I_{\text{RAS,DIRBE}}(60 \mu\text{m}) = 0.86 \times I_{\text{ISO}}(60 \mu\text{m})\).
No color correction was included at 60 \(\mu\)m as the dust spectrum is rather close to a flat spectrum, \(\nu L_\nu = \text{const}\). We also compared the
values calculated from the zodiacial light model of Good (1994),
to the corresponding empty-sky values of the 60 \(\mu\)m raster map
(raster position within the circle marked in Fig. 1f) that were
corrected for a 270 K black body spectrum. This gave the
relation \(I_{\text{model}}(60 \mu\text{m}) = 0.89 \times I_{\text{ISO}}(60 \mu\text{m})\). We took the average
of the two scaling factors, obtaining \(I_{\text{model}}(60 \mu\text{m}) = 0.88 \times I_{\text{ISO}}(60 \mu\text{m})\) as the final scaling relation.

The 80 \(\mu\)m data was scaled by linearly interpolating the scal-
ing coefficients for the 60 \(\mu\)m and 100 \(\mu\)m ISO data, which gave
0.71 as the scaling coefficient for 80 \(\mu\)m.

The IRAS 12 \(\mu\)m and 25 \(\mu\)m Infrared Sky Survey Atlas (ISSA) map data were re-scaled to DIRBE scale using the relations
\(I_{\text{DIRBE}}(12 \mu\text{m}) = 1.06 \times I_{\text{IRAS}}(12 \mu\text{m})\) and \(I_{\text{DIRBE}}(25 \mu\text{m}) = 1.01 \times I_{\text{IRAS}}(25 \mu\text{m})\), as given in the ISSA Explanatory Supplement (Wheelock et al. 1994).

The ISO 200 \(\mu\)m map surface brightness values were also
compared with DIRBE data. There are only 4 DIRBE pixels
within the 200 \(\mu\)m map area. The DIRBE surface brightness values at 100 \(\mu\)m, 140 \(\mu\)m and 240 \(\mu\)m were fitted with a modified
blackbody function with \(A^2\) emissivity law in order to get inter-
polated values at 200 \(\mu\)m. The ISO 200 \(\mu\)m map was convolved with a scan-averaged DIRBE beam and the ISO surface bright-
ness values were color corrected using the temperatures derived from fitting the DIRBE values. A linear fit forced to go through the origin gives \(I_{\text{DIRBE}}(200 \mu\text{m}) = 0.98 \times I_{\text{ISO}}(200 \mu\text{m})\), which is well within the estimated uncertainties of the ISO data. Since
this fit is made based on four points only, which results in con-
siderable uncertainty, and the C200 detector does not suffer from
such problems as described above for the C100 detector, we re-
tain the FCS based calibration for the 200 \(\mu\)m and other C200
ISO data (the 120 \(\mu\)m and 150 \(\mu\)m data).

The sky area used for subtracting the background values in the
100 \(\mu\)m and 200 \(\mu\)m maps is shown in Fig. 1a. The background sky values for background subtraction for all the
six raster scans and the IRAS data used were determined at the
same position outside the cloud (Fig. 1f): this way we obtained
a common zero level for comparison with the raster scans.
To compare the six raster scans with each other, we calcu-
lated average values at 16 evenly-spaced positions along the
C100 scans, and at 13 positions along the (shorter) C200 scans
(see Fig. 1f for these positions; three C100 positions in the west
fall outside the figure). The averaging was done using a Gaussian
weight function with \(\text{FWHM} = 4.5'\). This resolution also cor-
sponds to the resolution of the ISSA maps.

2.2. Extinction data

An extinction map of L1780 was derived using the \(J\), \(H\) and \(K_s\) band magnitudes obtained from the 2MASS archive. The
extinction measurements are based on the near-infrared (NIR) color excesses of stars visible through the cloud. We applied the
optimized multi-band NICER technique of Lombardi & Alves
(2001), which is a generalization of the traditional color excess
method (using data on two bands only), to derive the NIR color excesses.

 Stellar density of the detected stars at all three bands is fairly
constant over the map, with an average of about one star per
square arcminute. As the reference field, representing an area
without significant extinction, we selected a 1° diameter cir-
cular area located close to L1780 and at the same galactic lati-
titude. The coordinates of the centre of this area are RA(J2000) = \(15^\circ 23^\prime 0^\prime 0\), Dec(J2000) = –6°05′00″. The colors of the stars in the
reference field have the mean values and standard deviations of
\((J − H)_0 = 0.49 \pm 0.19\) and \((H − K)_0 = 0.12 \pm 0.23\). As the
effective wavelengths of the 2MASS \(J\), \(H\) and \(K_s\) bands we use
1.25 \(\mu\)m, 1.65 \(\mu\)m and 2.17 \(\mu\)m, respectively (Kleinmann et al.
1994). For the ratios of visual extinction to color excess we used the
values \(A_V/E(J−H) = 8.86\) and \(A_V/E(H−K_s) = 15.98\),
which correspond to an extinction curve with \(R_V = 3.1\) (Mathis
1990).

The extinction value in each map pixel was derived from the
individual extinction values of the stars by applying the sigma-
clipping technique of Lombardi & Alves (2001). In order to ob-
tain a sufficient signal-to-noise ratio in the \(A_V\) map, the indi-
vidual extinction values were averaged using a Gaussian with
\(\text{FWHM} = 3.0'\).

The extinction map has two error sources, the variance of the
intrinsic colors \((J − H)_0\) and \((H − K)_0\), and the variance of the
observed magnitudes of the field stars. The former dominates with
a 1\(\sigma\) error of \(-0.42\) mag per pixel, while the latter gives a
1\(\sigma\) error of \(-0.23\) mag per pixel, resulting in a typical
error of 0.47 mag in \(A_V\).

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Fig. 1. a) The 100 µm ISO surface brightness map of L1780 at 43.5″ resolution. The contour values range from 4.0 to 18.0 MJy sr$^{-1}$ in steps of 2.0 MJy sr$^{-1}$. The area used for the background sky value determination and subtraction is marked with a rectangle. b) The 200 µm ISO surface brightness map of L1780 at the resolution of 1.5″, with contours from 13 MJy sr$^{-1}$ to 61 MJy sr$^{-1}$ in steps of 6 MJy sr$^{-1}$. c) The visual extinction map of L1780 at 3.0″ resolution, with contours from 0.8 mag to 4.0 mag in steps of 0.8 mag, i.e. one step corresponds to about 2σ. The tickmarks point towards decreasing $A_V$. d) The 200 µm optical depth map of L1780 at 1.5″ resolution, with contours from $2.0 \times 10^{-4}$ to $16.0 \times 10^{-4}$ in steps of $2.0 \times 10^{-4}$. e) The temperature map of L1780 at the resolution of 1.5″, with contours from 15.2 K to 16.8 K in steps of 0.5 K. The tickmarks point towards decreasing $T$. f) The 100 µm ISO map showing the positions of the IRAS 12 µm (dotted line), IRAS 25 µm (thick solid line), IRAS 60 µm (thin solid line), ISO 100 µm (dash-dot line) and ISOCAM 6.7 µm (large triangle) maxima (Miville-Deschênes 2002), and the positions of the detector center of an ISO raster scan (marked with crosses). The circles show the positions used in calculating the averaged values of the raster scans (see the text). The black circle indicates the sky position used for background subtraction for the raster scans. On the SE side of the L1780, the IRAS 12 µm contours show a point source, IRAS 15383-0709, which is probably not associated with the cloud.
The map of visual extinction is shown in Fig. 1c. At the resolution of 3.0′ the value of maximum extinction is 4.0 mag.

When the extinction data is compared with the 100 µm and 200 µm surface brightness, temperature and optical depth maps, the latter are convolved to this resolution.

3. Results

3.1. General structure of the FIR emission from L1780

The 100 µm and 200 µm surface brightness maps are shown in Figs. 1a and b. In the far-infrared, L1780 has a clearly visible brighter central core in the West, which coincides with the region of maximum optical extinction. On the opposite side, the cloud has an extended, tail-like structure, and an overall cometary shape.

The relation between the 100 µm and the 200 µm emission is shown in Fig. 2. The 100 µm emission is well correlated with the 200 µm emission, and the relation is linear up to the highest surface brightness values, where there is a slight flattening trend. The solid lines in the figure show the surface brightness ratios at the indicated temperatures, assuming a modified blackbody function with dust emissivity power law index $\beta = 2$.

As can be seen in Fig. 1f, the IRAS 60 µm maximum is distinct from the 100 µm/200 µm maximum, and is situated East of it. The 25 µm, the 12 µm and the 6.7 µm maxima are located still further to the East, reaching towards the SE edge of the cloud. The 100 µm and 200 µm maps do not show any structure at the locations of these maxima.

The $^{13}$CO core of L1780 is in virial equilibrium (Tóth et al. 1995). However, no point sources, neither those from the IRAS Point Source Catalog nor any new ones, are detectable in the ISO maps. Also, a $J - H$ vs. $H - K$ color excess plot made using 2MASS data reveals no stars with color excess $\geq 1.0$ mag in L1780. This leads to the conclusion that there is no (detectable) star formation activity in L1780.

3.2. Surface brightness ratios from ISO raster scans and IRAS observations

In Fig. 1f, the positions of the ISO raster scans, which go through the cloud from West to East and back, are shown.
Figure 3a shows the intensities of the raster scans averaged (using Gaussian beams with $FWHM = 4.5'$) at the positions marked with circles in Fig. 1f.

All the raster scans go through the high density core of L1780 and the regions of the maximum 12 $\mu$m, 25 $\mu$m and 60 $\mu$m emission. The maxima of the 120–150 $\mu$m emission coincide with the maximum of the 200 $\mu$m emission, whereas the positions of the 60 $\mu$m and the 80 $\mu$m maxima are shifted towards East. The shape of the 100 $\mu$m brightness profile is between the shapes of the 80 $\mu$m and the 120 $\mu$m, especially in the region of maximum emission.

Figure 3a also shows the values of the IRAS 12 $\mu$m and 25 $\mu$m observations calculated at the same positions as the raster scans. The maximum of the IRAS 25 $\mu$m emission is located between the 60 $\mu$m maximum and the 12 $\mu$m maximum on the Eastern side of L1780.

Figure 3b shows the intensity ratios 12 $\mu$m/60 $\mu$m; $I_6/100 \mu$m, where $I_6$ is 12 $\mu$m, 25 $\mu$m or 60 $\mu$m; and $I_6/200 \mu$m, where $I_6$ is 60 $\mu$m, 80 $\mu$m, 100 $\mu$m, 120 $\mu$m or 150 $\mu$m, plotted through the cloud from East to West (the intensities have been calculated as in Fig. 3a). The cold core of L1780 shows up as a minimum in all the curves. The ratios $I_6/100 \mu$m and 60 $\mu$m/200 $\mu$m rise steeply towards the Eastern side of the cloud, indicating an increased presence of the small-grain dust component. The ratio 12 $\mu$m/60 $\mu$m peaks at the maximum position of the 12 $\mu$m emission in L1780, indicating the presence of PAHs in this location. The ratios 80 $\mu$m/200 $\mu$m and 100 $\mu$m/200 $\mu$m show a deep minimum at the core of L1780, while the ratios 120 $\mu$m/200 $\mu$m and 150 $\mu$m/200 $\mu$m show only a slight drop at this location, the 150 $\mu$m/200 $\mu$m ratio being almost constant.

In Fig. 4, the 60–150 $\mu$m surface brightness values of the raster scans are plotted against the 200 $\mu$m scan values. All the wavelengths correlate well with the 200 $\mu$m intensity. However, with the exception of the 150 $\mu$m vs. 200 $\mu$m relation, all curves clearly show signs of flattening close to the 200 $\mu$m maximum. The solid line shows $FWHM$, and ISO maps. In the fitting, the statistical errors (from PIA) plus filter-to-filter errors of 10% have been used for emissivity law fitted to the 100 $\mu$m, 120 $\mu$m, 150 $\mu$m and 200 $\mu$m intensities. The error bars show the 1-$\sigma$ errors used in fitting (see the text).

### 3.3. Dust temperature and the spectral energy distribution

The temperature of dust has been derived, pixel by pixel, from the 60 $\mu$m and 200 $\mu$m ISO surface brightness maps by using a modified blackbody function

$$I(\lambda) \propto \lambda^{-\beta}B(\lambda, T_{dust}),$$

where $\beta$ is the dust emissivity power law index, and $B(\lambda, T_{dust})$ is the Planck function. We assume $\beta = 2$. For the temperature calculation, the 100 $\mu$m map was convolved to the resolution of the 200 $\mu$m map. The surface brightness values were iteratively color corrected, using the color correction coefficients based on previous temperature determination, until the differences between two consecutive iterations were below 0.1 K. The temperature map is shown in Fig. 1e. At the resolution of 1.5', the minimum temperature is 14.9 ± 0.4 K.

The temperature of L1780 has also been determined using the ISO raster scans. Figure 5 shows the SEDs at three positions along the scan: Figs. 5a–c correspond to the locations of the IRAS 12 $\mu$m, the IRAS 60 $\mu$m and the ISO 100 $\mu$m emission maxima, respectively (see Fig. 1f for the locations of these maxima in L1780). In addition to the ISO raster scan values at 60–200 $\mu$m, the IRAS 12 $\mu$m and 25 $\mu$m values are plotted in the figure. Modified blackbody curves with dust emissivity index $\beta = 2$ have been fitted to the four longest wavelengths, resulting in temperatures 15.0 ± 0.4 K, 15.0 ± 0.4 K and 14.1 ± 0.4 K, for Figs. 5a–c, respectively. These temperatures are in agreement with the values obtained using the large 100 $\mu$m and 200 $\mu$m ISO maps. In the fitting, the statistical errors (from PIA) plus filter-to-filter errors of 10% have been used for...
the ISO C200 values (120 µm, 150 µm and 200 µm). The error used for the 100 µm values is the statistical error plus a 10% error resulting from the uncertainty of the scaling of the 100 µm to DIRBE. The average $\chi^2$ value of all the fits was slightly below 2. In Fig. 5 the 80 µm are ~2σ above the fitted curves. The ratio of the mid-infrared intensity (average of the 12 µm and 25 µm intensities) to the FIR intensity (maximum of the blackbody fit, which is in agreement with values for diffuse ISM by Dwek et al. (1997) (1.4×10^{-25} cm² per H-atom). The relationship in Fig. 6a deviates from linearity in the region of highest density in L1780; see Sect. 4.3 for discussion.

The total mass (gas plus dust) of L1780 has been calculated using the equation

$$M_{\text{FIR}} = \frac{\tau(200 \, \mu m)}{\sigma^H(200 \, \mu m)} D^2 m_\text{H}_2,$$

where $\tau_{200 \, \mu m}$ is the 200 µm optical depth, $\sigma^H(200 \, \mu m)$ is the absorption cross section per H-nucleus for which we have used the value derived above, $D$ is the distance, $m_\text{H}_2$ is the hydrogen mass, and $\mu$ is the mean molecular weight. The mass has been derived by summing up the pixels of the $\tau(200 \, \mu m)$ map. The mass thus obtained for L1780 is 18 $M_\odot$.

### 3.5. Comparison of FIR and extinction data

At large scale, the far-infrared emission in L1780 correlates well with the optical extinction. The 100 µm, 200 µm and $A_V$ maps in Figs. 1a–c show that the 100 µm and the 200 µm emission maxima coincide with the location of the highest visual extinction. The relations between the 100 µm and the 200 µm emission and the visual extinction are linear (Fig. 7).

In the $A_V$ map, there seems to be another region of higher visual extinction, an arc-like structure, on the Eastern side of the 100 µm core. If real, this feature, together with the cometary shape of L1780, could result from the propagation of a shockwave from the SW direction through the cloud as has been suggested by Töth et al. (1995). In fact, the arc-like feature could also be a part of a ring-shaped structure, in which case an interesting analog of a possible dense-core formation would be found in the Globule 2 of the Coalsack cloud (Lada et al. 2004). However, the extinction values may be biased because of variations in the stellar density. This hampers the detection of morphological features in the $A_V$ map at this resolution, which is close to the detection limit ($\Delta A_V \approx 2\sigma$ in the contours in Fig. 1c).

Figures 6 and 8 show the relations between $A_V$, $\tau(200 \, \mu m)$ and $T_{\text{dust}}$. The values from the locations of the IRAS 12 µm, IRAS 60 µm and ISO 100 µm maxima are marked with triangles, diamonds and squares, respectively. The sizes of sky areas of the maxima have been chosen according to the highest-level contours visible in Fig. 1f, and are 12.5'×3.0', 11.3'×4.0', and 6.3'×4.0' for the 12 µm, 60 µm and 100 µm maximum, respectively. The error bars in the figures show typical errors. The errors of the temperature and the 200 µm optical depth get larger for the points near to the borders of the maps, since near the borders of the ISO FIR maps the background-subtracted surface brightness values, used for calculating $T_{\text{dust}}$ and $\tau(200 \, \mu m)$, are more uncertain. For the plots in Figs. 6 and 8, most of the near-border points have been removed.

Figure 6d shows the temperature decrease in the densest part of the cloud: as the optical depth increases, the temperature decreases from ~15.8 K in the regions of the 12 µm emission maximum (PAHs) and the 60 µm maximum (VSGs) to ~14.9 K in the 100 µm maximum region (big grains). In Fig. 6b, similar dependence is shown for the temperature as the function of the visual extinction. Figure 6a shows increased emissivity in the regions of high $A_V$ in L1780 (see Sect. 4.3 for discussion).

| Raster position 4 | Raster position 6 | Raster position 9 |
|-------------------|-------------------|-------------------|
| $\lambda$ | $I(\nu)$ [MJy/sr] | $\delta I(\nu)$ [MJy/sr] | $\lambda$ | $I(\nu)$ | $\delta I(\nu)$ | $\lambda$ | $I(\nu)$ | $\delta I(\nu)$ |
| 12 µm | 1.06 | 0.21 | 0.88 | 0.11 | 0.92 | 0.10 |
| 25 µm | 1.55 | 0.31 | 1.36 | 0.27 | 0.95 | 0.19 |
| 60 µm | 2.56 | 0.65 | 2.92 | 0.69 | 2.24 | 0.62 |
| 80 µm | 4.48 | 0.87 | 6.09 | 1.06 | 5.94 | 1.05 |
| 100 µm | 7.27 | 1.04 | 9.78 | 1.34 | 10.69 | 1.44 |
| 120 µm | 17.76 | 1.93 | 23.39 | 2.51 | 28.86 | 3.09 |
| 150 µm | 26.90 | 2.84 | 35.19 | 3.69 | 46.84 | 4.90 |
| 200 µm | 24.88 | 2.73 | 32.98 | 3.60 | 46.59 | 5.02 |

Table 2. The surface brightness values and corresponding errors used in Fig. 5. The three raster positions are given according to Fig. 3: the raster positions Nos. 4, 6 and 9 correspond to the 12 µm, 60 µm and 100 µm emission maxima of L1780, respectively.
4. Discussion

4.1. Different dust populations from FIR observations

The Southern side of L1780 is facing both the Galactic plane in the South and the Upper Scorpius (USco) association of OB stars in the SW direction, and is, therefore, subject to more intense ISRF. However, the variations in the emission of L1780 at different wavelengths are more prominent in the E-W direction than on the S-N axis. Figure 1f shows that the 12 µm emission maximum (indicating the presence of PAHs) is located on the SE side, in the “tail” of L1780. The 60 µm (VSGs) emission maximum is located to the West from the 12 µm maximum, and finally, the 100 µm maximum (big grain emission) is on the Western side of the cloud.

In Fig. 3a, the 60 µm emission curve clearly rises towards East and has its maximum on the Eastern side of the 200 µm maximum. Figure 3b shows that the 60 µm/100 µm ratio rises rather steeply from its minimum towards the East side of L1780. In Table 3, it can be seen that the minimum value of this color ratio (reached in the cold core of L1780) is the same as the solar neighborhood (SN) value by Boulanger et al. (1990). Laureijs et al. (1991), who made IRAS observations on the L134 complex, indicate in their study of L1780 that the 60 µm emission diminishes in a narrow transition layer around the 100 µm maximum. Our data do not show any abrupt change, but the decrease in the 60 µm/100 µm ratio is clear: the ratio is halved in the cold core region relative to the Eastern edge of the cloud. It is not likely that this reduction would be due to attenuation effects.
alone: in the model by Bernard et al. (1992) the effect of radiation attenuation on the ratio 60 $\mu$m/100 $\mu$m as $A_V$ increases from 1 to 4 mag (between different 1D models) is only half of the decrease of the ratio observed in L1780.

Laureijs et al. (1991) attribute the change in 60 $\mu$m/100 $\mu$m to the formation of icy mantles on grains. Stepnik et al. (2003) shows that the depletion of VSGs through grain-grain coagulation can reduce the 60 $\mu$m/100 $\mu$m ratio, and, in addition, cause an increased FIR emissivity of grains, which is also observed in L1780. Figure 6c shows the increased values of $\tau_{200}/A_V$ in the region of the 100 $\mu$m emission maximum (marked with squares in Figs. 6b and c). On the other hand, if taken to be traced by the $\tau_{200}/A_V$ ratio, no difference in the overall size distribution of the large grains between the 60 $\mu$m and 12 $\mu$m maxima is visible in Fig. 6c, although the 60 $\mu$m maximum is located deeper in the cloud.

Figures 3a and b show that the emission from VSGs and PAHs is concentrated on the Eastern side of L1780, and that the PAH emission clearly is distinct from the VSG emission. Also the MIR/FIR ratios from Fig. 5 indicate increase of the 12–60 $\mu$m emission toward the East. For the 12 $\mu$m/100 $\mu$m ratio, comparison with the results of the model of Bernard et al. (1992) suggests that radiative transfer effects account for less than one third of the decrease of the ratio in the L1780 core. Table 3 shows that the average colors 12 $\mu$m/100 $\mu$m and 25 $\mu$m/100 $\mu$m are more than twice the SN values. At the scan positions of the 12 $\mu$m and 25 $\mu$m maximum emission, the values of 12 $\mu$m/100 $\mu$m and 25 $\mu$m/100 $\mu$m are 0.15 and 0.18, corresponding to 3.6 and 3.3 times the SN value. The maximum 12 $\mu$m/100 $\mu$m and 25 $\mu$m/100 $\mu$m ratios observed in L1780 are both 4.8 times the SN value. These values can be compared with those of two clouds from Chameleon and $\rho$-Ophuchi, which are 5.5 and 3.3 times the SN value for PAHs (using the 12 $\mu$m/100 $\mu$m ratio), respectively, and 2.3 and 2.3 times the SN value for VSGs (using the 25 $\mu$m/100 $\mu$m ratio), respectively, (Bernard et al. 1993). The color ratios observed in L1780 indicate that there is an overabundance of PAHs and VSGs on the Eastern side of the cloud. Further support to our observations on PAH abundance is provided by the strong decrease of the 6.5/100 $\mu$m ratio in the FIR core of L1780 observed by Miville-Deschênes (2002) using ISOCAM and IRAS observations.

We conclude that, although attenuation effects may be involved, they are not sufficient to explain the observed color ratios, which indicate true variations in the abundances of dust grains from different populations. To estimate the effect of radiation attenuation on the observed color variations in L1780, model calculations are needed (Ridderstad et al., in preparation).

### 4.2. VSG contribution at the wavelengths above 80 $\mu$m

Radiative transfer modelling performed using the current ISM models (including PAHs, VSGs and big grains) indicates that the emission from VSGs is still significant above 60 $\mu$m, and contributes from 15% to 23% of the total emission at 100 $\mu$m when $A_V$ ranges from 1 to 4 mag (Désert et al. 1990). Laureijs et al. (1996) made ISOPHOT observations at 60 $\mu$m, 90 $\mu$m, 135 $\mu$m and 200 $\mu$m on a small cloud in Chameleon, which, like L1780, has a reduced 60 $\mu$m/100 $\mu$m ratio in the centre, and indicated that the 90 $\mu$m emission has an excess contribution from dust grains emitting at 60 $\mu$m. In Fig. 9, the 200 $\mu$m raster scan has been assumed to contain emission solely from the big-grain dust component, which then...
4.3. Increased FIR emissivity in the dense core of L1780

Many recent studies indicate a change in the emissivity of interstellar grains in dense molecular regions (Cambresy et al. 2001; del Burgo et al. 2003; Dupac et al. 2003; Kramer et al. 2003; Stepnik et al. 2003; Cambrésy et al. 2005). Also in our study, Fig. 6a shows that in the cold core of L1780 (the region of the FIR emission maximum and minimum temperature $T_{dust}$) above $A_V \approx 3.5$, the relation between $\tau(200 \mu m)$ and $A_V$ deviates from linearity, indicating an increased emissivity of the big grains. This increase in the ratio $\tau(200 \mu m)/A_V$ in the 100 $\mu m$ emission maximum area is also visible in Fig. 6c. The emissivity observed in the cold core of L1780 in Fig. 6a is $\sim 1.5$ times the values observed elsewhere in the cloud. This value is in agreement with the results of Cambresy et al. (2005), who considered the whole galactic anticenter hemisphere and found that, for regions with $A_V > 1$ mag, the ratio of FIR optical depth to NIR extinction is $A_V(FIR)/A_V(gal) = 1.31 \pm 0.06$.

Del Burgo et al. (2003) found FIR emissivity changes in their 60–200 $\mu m$ observations of eight regions mostly belonging to quiescent high latitude clouds with $A_V \sim 1$–6 mag. Since L1780 is also a translucent cloud, their results are of particular interest here. Del Burgo et al. (2003) presented a model with two big-grain dust components: a warm component at $T = 17.5$ K and a cold component at $T = 13.5$ K. A coefficient $\epsilon$ gives the factor by which the emissivity of the cold component is increased. In Fig. 8, the curves showing the emissivity change according to the model by del Burgo et al. (2003) are shown for comparison with our data. Comparison with the results of del Burgo et al. (2003) indicates that the emissivity in the core of L1780 is about twice that of for the diffuse ISM, which is in agreement with the value derived from the relation in Fig. 6a. Although the uncertainty in Fig. 8 increases with increasing temperature, it is clear from the average errors (shown by error bars in the figure) that there is an increasing trend towards high $T_{200}/A_V$ values. It must be noted that in this kind of plot, the dependance of the optical depth on the dust temperature (since the former is calculated using the latter) can cause false correlation similar to the supposed emissivity increase. However, the errors in the plot in Fig. 8 diminish towards high optical depth and low temperature. We also have the advantage that the measurements are from a single cloud, which eliminates the effects resulting from calibration errors between separately calibrated maps.

The ratio $T_{200}/A_V$ increases with grain size and porosity (Cambresy et al. 2001), and the change in FIR/submm emissivity has been attributed to the coagulation of grains into larger, fluffy particles in dense, cold molecular regions (Cambresy et al. 2001; Stepnik et al. 2003). It is interesting that an independent indicator, the decrease of the 60 $\mu m$/100 $\mu m$ ratio towards the dense core of many clouds, including L1780, has also been attributed to grain coagulation (Bernard et al. 1999; Stepnik et al. 2003). While the emissivity change in L1780 is seen above $\sim 3.5$ mag, Stepnik et al. (2003) derived the threshold value $A_V = 2.1 \pm 0.5$ for the possibly coagulation-induced changes (reduced 60 $\mu m$/100 $\mu m$ ratio and increased emissivity) in the properties of the grains to occur. They noted that these changes in the properties of dust grains may be part of a general transformation process that dust undergoes in the dense ISM. Moreover, Cambresy et al. (2005) indicate that large, fluffy grains may be common all over the galaxy wherever $A_V \geq 1$.

5. Conclusions

The analysis of the ISO 100 $\mu m$ and 200 $\mu m$ maps and 60 $\mu m$, 80 $\mu m$, 100 $\mu m$, 120 $\mu m$, 150 $\mu m$ and 200 $\mu m$ raster scans of L1780, combined with the IRAS 12 $\mu m$ and 25 $\mu m$ data and the visual extinction map (based on NIR $J, H$ and $K_s$ band color excess data), leads to the following conclusions:

- The 100 $\mu m$ emission is well correlated with the 200 $\mu m$ emission throughout the cloud. The cloud has a single core, revealed by the 100 $\mu m$ and 200 $\mu m$ emission, the FIR optical depth, and the visual extinction.
- The spatial distributions of the 12 $\mu m$, 25 $\mu m$ and 60 $\mu m$ emission differ significantly from the emission at longer wavelengths. This indicates the presence of separate dust components with different physical properties and spatial distributions.
- The maximum values of the color ratios $12 \mu m$/100 $\mu m$, 25 $\mu m$/100 $\mu m$ and 60 $\mu m$/100 $\mu m$, which are 4.8, 4.8 and
2.0 times the solar neighborhood values, indicate an over-abundance of PAHs and VSGs in L1780.
– The $A_V$ map gives a maximum visual extinction of 4 mag at 3.0° resolution. The visual extinction is well correlated with the FIR emission at large scale.
– The cold core of L1780 has the minimum temperature of $14.9 \pm 0.4$ K and the maximum 200 $\mu$m optical depth of $2.0 \pm 0.3 \times 10^{-3}$ at 1.5° resolution.
– The value of the absorption cross section per H-atom at 200 $\mu$m has been estimated to be $\sigma^H(200 \mu$m) $= 1.4 \times 10^{-25}$ cm$^2$ per hydrogen atom, which is in good agreement with values obtained for diffuse ISM in other studies. The mass obtained for L1780 is $18 M_\odot$.
– The relation between $A_V$ and $\tau(200 \mu$m) shows nonlinearity at high $A_V$ values, indicating that in the cloud core the far-infrared dust emissivity has increased by a factor of $\sim 1.5$.
– The comparison of the 80 $\mu$m and the 100 $\mu$m emission with the emission at longer wavelengths indicate that not only the 80 $\mu$m, but also the 100 $\mu$m and even the 120 $\mu$m emission may contain some small-grain contribution.

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References

Bakes, E. L. O., & Tielens, A. G. G. M. 1994, ApJ, 490, 258
Bernard, J. P., Boulanger, F., Desert, F. X., & Puget, J. L. 1992, A&A, 263, 258
Bernard, J. P., Boulanger, F., & Puget, J. L. 1993, A&A, 277, 609
Bernard, J. P., Abergel, A., Ristorcelli, I., et al. 1999, A&A, 347, 640
Bohlin, R. C., Savage, B. D., & Drake, J. F. 1978, ApJ, 224, 132
Boulanger, F., Falgarone, E., Puget, J. L., & Helou, G. 1990, ApJ, 364, 136
del Burgo, C., Laureijs, R., Abram, P., & Kiss, Cs. 2003, MNRAS, 346, 403
Cambrésy, L., Boulanger, F., Lagache, G., & Stephan, B. 2001, A&A, 375, 999
Cambrésy, L., Jarrett, T. H., & Beichman, C. A. 2005, A&A, 435, 131
Cernis, K., & Straizys, V. 1992, Baltic Astronomy, 1, 163
Clark, F. O., & Johnson, D. R. 1981, ApJ, 247, 104
Désert, F.-X., Boulanger, F., & Puget, J. L. 1990, A&A, 237, 215
Dupac, X., Bernard, J.-P., Boudet, N., et al. 2003, A&A, 404, L11
Dwek, E., Arendt, R. G., Fussen, D. J., et al. 1997, ApJ, 475, 655
Franco, G. A. P. 1989, A&A, 223, 313
Gabriel, C., Acosta-Pulido, J., Heinrichsen, I., et al. 1997, in Proc. of the ADASS VI conference, ed. G. Hunt, & H. E. Payne, ASP Conf. Ser., 125, 108
Good, J. C. 1994, in IRAS Sky Survey Atlas: Explanatory Supplement, ed. S. L. Wheelock et al., JPL Publication 94-11, G1-G14
Kessler, M. F., Steine, J. A., & Anderegg, M. E. 1996, A&A, 315, L27
Klaas, U., Laureijs, R. J., Radovich, M., Schultze, B., & Wilke, K. 2000, ISOPHOT Calibration Accuracies, Ver 3.0, January 2000
Kleinmann, S. G., Lysaght, M. G., Pughe, W. L., et al. 1994, Exp. Astron., 3, 65
Kramer, C., Reicher, J., Mookerjea, B., et al. 2003, A&A, 399, 1073
Kuntz, K. D., Snowden, S. L., & Vetter, F. 1997, ApJ, 484, 245
Lada, C. J., Huard, T. L., Crews, L. J., & Alves, J. F. 2004, ApJ, 610, 303
Lagache, G., Abergel, A., Boulanger, F., & Puget, J.-L. 1998, A&A, 333, 709
Lallement, R., Welsh, B. Y., & Vergely, J. L. 2003, A&A, 411, 447
Laureijs, R., 1989, Ph.D. Thesis, Rijksuniversiteit te Groningen, The Netherlands
Laureijs, R. J., Fisk, D., & Prusti, T. 1991, ApJ, 372, 185
Laureijs, R. J., Haikala, L., Burgdorf, M., et al. 1996, A&A, 315, L31
Lehtinen, K., Mattila, K., Russell, D., Lemke, D., & Haikala, L. K. 2001, in Proc. of the conference The Calibration Legacy of the ISO Mission, VIISpA, Spain, 5–9 February 2001, ESA SP-481, 2003, ed. L. Metcalfe, A. Salama, S. B. Pechke, & M. F. Kessler
Lehtinen, K., Mattila, K., Lemke, D., et al. 2003, A&A, 398, L571
Lemke, D., Klaas, U., Abelins, J., et al. 1996, A&A, 315, L64
Lombardi, M., & Alves, J. 2001, A&A, 377, 1023
Lynds, B. T. 1962, ApJS, 7, 1
Magnani, L., Blitz, L., & Murray, L. 1985, ApJ, 295, 402
Martin, E. L., & Kun, M. 1996, A&A Suppl. Ser., 116, 467
Mathis, J. S. 1989, ARA&A, 27, 37
Mattila, K. 1979, A&A, 78, 253
Mattila, K. 1986, A&A, 160, 177
Mattila, K., & Sandell, G. 1979, A&A, 78, 264
Miville-Dechênes, M.-A. 2002, in Proc. of the conference Chemistry as a Diagnostic of Star Formation, Univ. of Waterloo, Canada, 21–23 August 2002, ed. C. L. Curry, & M. Fich
Rawlings, M. G., Juvela, M., Mattila, K., Lehtinen, K., & Lemke, D. 2005, MNRAS, 356, 810
Schmidt, G. D., Cohen, M., & Margon, B. 1980, ApJ, 239, L133
Stepnik, B., Abergel, A., Bernard, J.-P., et al. 2003, A&A, 398, 551
Tóth, L. V., Haikala, L., Liljeström, T., & Mattila, K. 1995, A&A, 295, 755
Vetter, F., Magnani, L., Dwek, E., & Rickard, L. J. 2000, ApJ, 536, 831
War-Ward-Thompson, D., Scott, P. F., Hills, R. E., & André, P. 1994, MNRAS, 268, 276
War-Ward-Thompson, D., & André, P. 2004, in ISO Survey of a Dusty Universe, Proc. of a Ringberg Workshop, Tegernsee, Germany, 8–12 November 1999, ed. D. Lemke, M. Stickel, & K. Wilke, Lect. Notes Phys, 548, 309
Wheelock, S. L., Gauthier, T. N., Heiles, C., & Chillemi, J., et al. 1994, ISSA Explanatory Supplement at http://lambda.gsfc.nasa.gov/product/iras/docs/issa.exp.sap/