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Infrared Properties of Dust Grains Derived from IRAS Observations

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ABSTRACT The paper presents the analysis of several diffuse interstellar clouds observed by IRAS. The 60/100 µm flux ratios appear to be nearly constant in clouds with up to 1^m of visual extinction at the centre. Observations of a highly regular cloud in Chamaeleon show that the 12/100µm ratio peaks at an intermediate radial distance and declines towards the centre of the cloud. These observations indicate that non-equilibrium emission accounts only for the 12 and 25 µm bands; strong emission observed at 60 µm band is probably due to equilibrium thermal radiation. The correlation of 12 µm emission with a red excess observed for a high latitude cloud, L1780, is shown to be consistent with the assumption that both features are due to fluorescence by the same molecular species.

1. Introduction

The early analysis of IRAS observations of dust in the diffuse interstellar medium concentrated on the discovery of the infrared cirrus (Low et al., 1984) and the universal occurrence of strong emission at 12 and 25 µm. These observations provided a clear indication that existing grain models must be modified by including a contribution of particles emitting as a result of transient rather than equilibrium radiative heating. In order to provide more restrictive constraints on grain models, we have analyzed data for individual well-defined clouds and studied the dependence of IR emission on the visual optical depth. This paper summarizes the most important preliminary results of the study.

2. Data reduction

The data base used in this study consisted of IRAS HCON3 scans (IRAS Explanatory Supplement, 1985). The maps were corrected for detector sensitivity effects (striping) by two-dimensional Fourier filtering. The zodiacal light contribution was estimated by masking bright sources and fitting a cosecant law to the remaining extended emission. After these reductions, the background level was determined as the average of weak galactic emission surrounding each cloud.

3. A 'typical' diffuse cloud

The object, for which the data have been summarized in Fig. 1, does not appear in the catalogues of galactic clouds. Its IR emission, however, is seen clearly in the IRAS maps of the Chamaeleon area; the cloud can also be identified in the ESO/SERC J-plate. The cloud appears highly regular with nearly circular IR isophotes, particularly at 100 µm. The brightness distribution within the cloud derived by averaging intensities in concentric rings, has been shown in Fig. 1, which also presents pixel-to-pixel correlations between intensities in individual bands.

The results of our study of the Chamaeleon object can be summarized as follows:
(1) The 60/100 μm ratio remains constant over the entire radial extent of the cloud. The colour temperature implied by this ratio is 27K (assuming a λ^{-1} emissivity law). This number is somewhat higher than the temperatures obtained for several other clouds (Low et al., 1984; Laureijs et al., 1986); however, it may be due to the inaccurate calibration of HCON3, since the analysis of the cloud in HCON1 data yields a lower temperature of 24-25K (H. Walker, private communication). (3) The ratio of 12 and 25 μm intensities does not vary strongly but after improved background correction, the data imply a slight decrease towards the centre of the cloud. The value of the ratio is ~ 0.3. (3) The 12/100

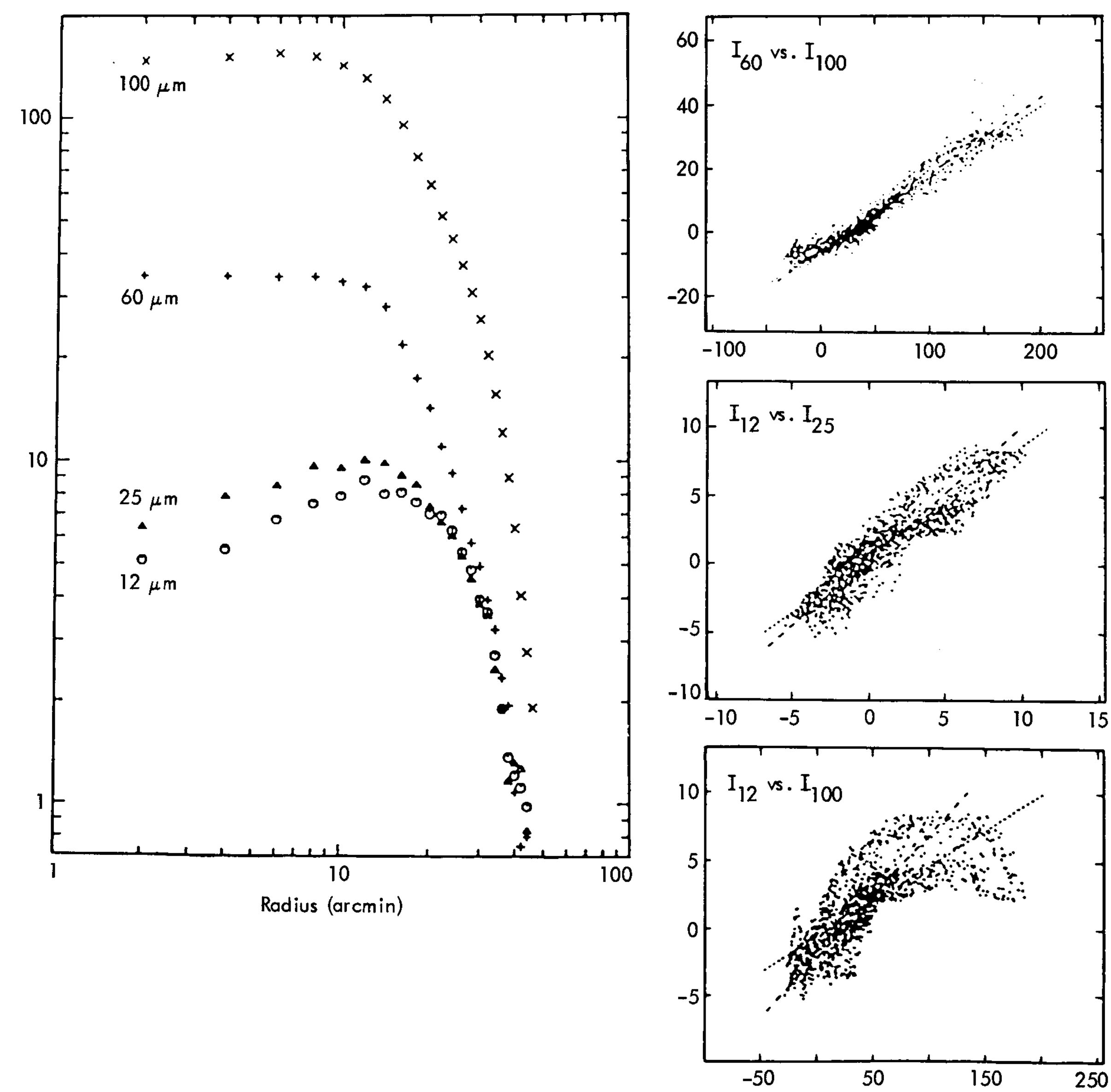

Fig. 1. Left: radial brightness distribution. Right: pixel-to-pixel correlations between individual IRAS bands. Intensities are in units of 105 Jy/sr.

μm ratio peaks at an intermediate radial position in the cloud and declines towards the centre.

The visual extinction at the centre of the cloud has not been measured (the work on star count analysis is in progress), but a comparison with L1642 (Laureijs et al., 1986) implies $A_V \approx 1^m$.

The high 60/100 μm temperature observed for the Chamaeleon object and almost all of the clouds so far extracted from the IRAS data base, cannot be explained by the current grain models, which predict equilibrium temperatures of less than 20K. The constant 60/100 μm ratio for the Chamaeleon object appears to contradict the suggestion that the additional emission at 60 μm is due to non-equilibrium emission from graphite particles with sizes of less than 0.005 μm (Draine and Anderson, 1985; the 60/100 μm ratio can be made to vary more slowly in this model if the power-law size distribution for the small particles is assumed to be steeper than λ^{-4}). The same argument appears to exclude the hypothesis which associates the 60 and 100 μm emission with fine structure lines of OI and OIII (Harwit et al., 1986), since the fall-off in the degree of fractional ionization with optical depth should lead to a rapid variation in the ratio of the two intensities.

As an alternative possibility, we have considered equilibrium emission from a population of particles whose temperatures are higher than those obtained in current grain models. The calculations related to this hypothesis have been carried out for thin graphite discs modelled as oblate spheroids with an axial ratio of ~10, for which the equilibrium temperature in the diffuse interstellar radiation field can be demonstrated to be ~25K (the increased temperature of spheroids with respect to spherical particles considered in current grain models is due to a combination of the properties of a conductor with a strong anisotropy, which is peculiar to graphite; Chlewicki, 1985). The required abundance of the additional particles is relatively low: with the distance to the cloud estimated at ~100 pc on the basis of its location with respect to the more extended cirrus emission, the volume concentration of the particles is only $\sim 10^{-6}$ cm^{-3}. The abundance of particles responsible for visual extinction is most easily derived from the three-population model (Hong and Greenberg, 1980), with the 'large' particles represented by 0.15 μm dielectric spheres. The extinction of 1^m at the centre of the cloud leads to a concentration of 'visual' particles of $\sim 5 \times 10^{-10}$ cm^{-3}. The volume ratio for the entire populations of 60 μm particles and large 'visual' grains is then ~0.1. The ratio is almost unchanged if the MRN (Mathis et al., 1977) model is used as a representation of the interstellar extinction curve, since both models impose similar requirements on the volume of material locked up in grains responsible for visual extinction. One of the most important implications of this hypothesis is that algorithms for estimating masses and volumes of interstellar clouds -such as the method described by Hildebrand (1983) - which are based on parameters derived from submillimetre data sensitive only to the IR properties of large particles, cannot always be used in the analysis of IRAS observations at significantly shorter wavelengths.

3. L1780: correlated visual and IR fluorescence?

L1780 appears to be the only interstellar cloud for which a red visual spectrum has been obtained (Mattila, 1979). The spectrum shows a pronounced peak at ~6500A, which cannot be explained by scattered light, unless substantial modifications in the optical properties of the grains are assumed (the intensities of the scattered diffuse galactic light predicted at these wavelengths by both the MRN and the three-population model are nearly constant). The position and shape of the feature (as far as they can be determined in the inevitably noisy spectrum) are almost identical with the broad-band emission observed in the Red Rectangle (Schmidt et al., 1980). Recent interest in the polycyclic aromatic hydrocarbons as a possible explanation for the unidentified IR features and the IRAS 12 μm emission (PAH's, Leger and Puget, 1984; Allamandola et al., 1985), has led to suggestions that the Red Rectangle feature is due to fluorescence by such molecules. We have analyzed the IR data for L1780 in order to test the hypothesis that both the short wavelength IRAS emission and the red feature observed by Mattila can be due to fluorescence from the same molecular species. Since the basic parameters of the cloud have been determined by Mattila ($A_B = 3^m$, $r = 100$pc, $n_H = 10^3$ cm^{-3}; $l = 359^o$, $b = 36^o$), the energies contained in both visual and IR features can be estimated. By subtracting a scattering component predicted by grain models from Mattila's spectrum, we have obtained a total energy in the red feature of $8*10^{32}$ erg s^{-1} = 0.2 $L_\odot$. Table 1 contains the fluorescence yields required to reproduce this number for molecules in the gas phase and species locked up in grain mantles. The core-mantle grains containing the molecules were assumed to be 0.15μm spheres with a normal gas-to-dust ratio, $n_{gr} = 10^{-12} n_H$. Gas phase molecules were assumed to consist of 20 carbon atoms and to have a UV absorption cross-section of 10^{-16} cm^{-2}; the total content of carbon in the species was taken to be 1% of the cosmic abundance.

For aromatic molecules, the energy of a typical exciting photon (~4 eV) should be distributed almost equally between visual and IR fluorescence (the IRAS 12 μm band). If both the visual excess and the 12 μm emission are associated with the PAH's, the ratio of the energy contained in each wavelength range should have a value close to the fluorescence yield. The 12 μm intensity in the part of the cloud observed by Mattila is $I_{12} = 9*10^{-5}$ ergcm^{-2}s^{-1}sr^{-1}. With the intensity of the red excess of $4*10^{-5}$, the intensity ratio is 0.45 in perfect agreement with fluorescence fields expected for aromatic species. A stronger confirmation of the PAH hypothesis for L1780 could only be obtained if more visual spectra of galactic clouds become available.

Table I
Fluorescence yields derived from the L1780 emission

Excitation threshold	Grain mantles	Free molecules
3.5 eV (UV)	0.03	~1
2 eV (UV+Vis)	0.01	0.4

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