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The Origin of the Diffuse Galactic IR/Submm Emission: Revisited after IRAS

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Abstract

In three previous papers we have investigated the origin of the diffuse galactic IR/Submm emission by fitting model computations to balloon-borne surveys. In this paper we compare the balloon observations with IRAS observations. For the longitude profiles we find good agreement. However, the dust emission observed by IRAS - contrary to balloon observations which show dust emission only within $|b| \leq 3°$ - extends all the way to the galactic pole. We repeat the model fits, using more recent parameters for the distribution of interstellar matter in galactic disk and central region. IR luminosities are derived for the revised galactic distance scale of $R_\odot$ = 8.5 Kpc. A total IR luminosity of 1.2 E10$L_\odot$ is obtained, which is about one third of the estimated stellar luminosity of the Galaxy.

The dust emission spectrum λI_λ attains its maximum at ~ λ100μm. A secondary maximum in the dust emission spectrum occurs at ~λ10μm, which contains ~ 15% of the total IR luminosity of the Galaxy. To this hot dust emission contribute both OH/IR stars (~ 1/3) and very small grains down to few Å size (~ 2/3). OH/IR stars are M giants with (for optical/NIR radiation) opaque dust shells. The very small grains could be polycyclic aromatic hydrocarbon (PAH) molecules.

We compare the galactic dust emission spectrum with the dust emission spectra of external IRAS galaxies. The emission spectra observed between λ30μm and 1300μm can be fitted by a minimum of two dust components: Cold dust with temperatures of ~14-25 K, which is associated with diffuse atomic hydrogen and with molecular hydrogen, respectively, and which is heated by the general interstellar radiation field; and warm dust with temperatures of ~30-50 K, located in HII regions and dense molecular cloud cores, which is heated by O and early B stars. The warm dust luminosity relates to the present OB star formation rate, while flux densities observed at longer submm wavelengths are dominated by cold dust emission and thus can be used to estimate gas masses.

I. The Galactic Disk between Galactic Radii 2 ≤ R/kpc ≤ 10

The diffuse galactic IR/Submm emission is due to stellar radiation, which is absorbed and reradiated by interstellar dust particles. About one third of the total stellar luminosity of the galactic disk is reemitted as IR emission. For an investigation of the origin of this dust emission three basic parameters must be known: i) The dust characteristics; ii) the spatial distribution of both

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Star Formation in Galaxies

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interstellar dust and stars of different luminosity and evolutionary stage; iii) the geometrical association between stars and interstellar dust, which determines dust temperatures and luminosity.

We have investigated the origin of the galactic submm/IR emission in three successive papers (Mezger, Mathis and Panagia, 1982. Mathis, Mezger and Panagia, 1983. Cox, Krügel and Mezger, 1986. This last paper is referred to in the following as Paper I). As input parameters to our model computations we use the distribution of the interstellar gas as derived from HIλ21cm and CO(J=1-0) line emission. The distribution of different stellar populations adopted for our model computations are discussed in Mathis et al., who also derive the intensity and spectral distribution of the interstellar radiation field (ISRF) as function of galactic radius R.

We use the Mathis, Rumpl and Nordsieck (MRN, 1977) dust model (which consists of graphite and silicate grains), as extended beyond $\lambda 10\mu m$ by Mezger et al. (1982), but with optical constants as revised by Draine and Lee, (1984; see also Paper I). We scale the gas-to-dust mass ratio as a function of R with the observed galactic O/H abundance gradient. The MRN grain size distribution has the form $f(a) \propto a^{-3.5}$, with a lower and higher cut-off at radii $a_{min} \sim 100$ Å (=0.01 μm) and $a_{max} \sim 0.25\mu m$. In dense molecular clouds one expects grains with radii $> a_{max}$ due to formation of ice mantles. In the diffuse atomic hydrogen (HI) recent observations suggest an extension of the grain size distribution to radii as small as a few Å (Boulanger et al., 1985). The existence of these very small grains (VSG) in interstellar space, probably polycyclic aromatic hydrocarbon molecules (PAH), was first suggested by Léger and Puget (1984).

We first compute the temperature of dust located in the diffuse HI and in quiescent giant molecular clouds (GMC) heated by the general ISRF. The dust emission predicted as a function of galactic longitude l and wavelength λ is then compared to observations. The spectrum of the dust emission within the solar circle (but without contributions from the region around the galactic center) is shown in Figs. 1a and 1b. Fig. 1a shows the spectrum taken from Paper I, which is based on a compilation of balloon observations by Pajot et al. (1986). Open circles relate to a preliminary evaluation of IRAS observations. The revised spectrum in Fig. 1b contains the final IRAS results (filled circles), which are obtained by integrating the IRAS maps after subtraction of the contributions by zodiacal dust. Very recently new and improved balloon observations at $\lambda 145\mu m$ and $\lambda 380\mu m$ became available (Caux and Serra, 1986). We cannot incorporate their surface brightness directly in the spectrum Fig. 1b, since their integration extends over $|b| < 1^\circ.25$ rather than over $|b| < 1^\circ$ used by us. However, we adopt their spectral shape for $\lambda \geq 100\mu m$.

It is found that the contributions from very cold dust (vcd) associated with quiescent molecular clouds and from cold dust (cd) associated with atomic hydrogen, as derived from our model computations (see Table 1), can account for only part of the spectrum between $\lambda 30\mu m$ and $1000\mu m$. Remember that both these dust components are heated by the ISRF, whose radiation density is primarily determined by contributions from stars with $T_{eff} < 10{,}000$ K. Subtraction of the contributions by (vcd) and (cd) leaves the dotted curves in Figs. 1a and b, which represent the contribution by warm dust (wd, T ~ 30-50K) to the diffuse galactic emission $\lambda \geq 30\mu m$. Detailed model computations

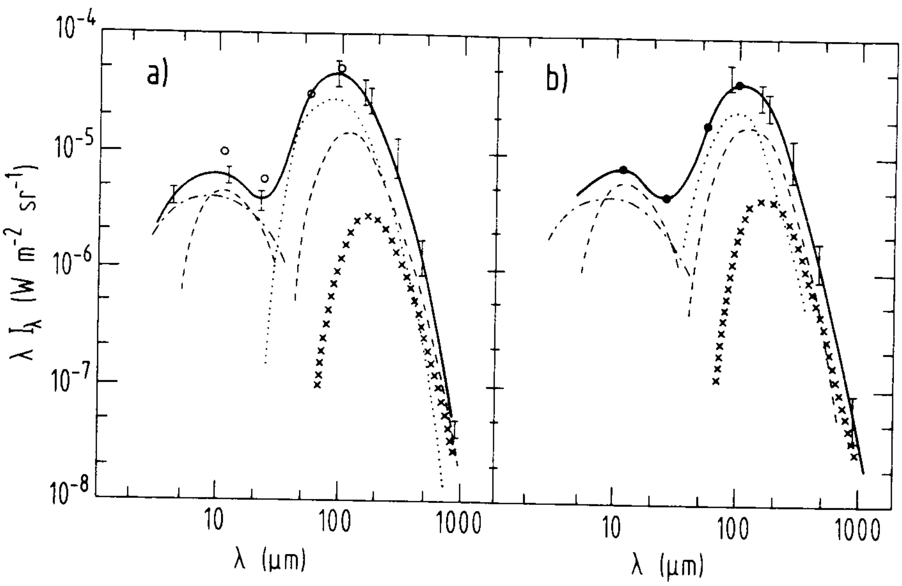

Figure 1. Spectrum of the dust emission between 4 and 900 μm from the inner part (R ≤ 8 kpc) of our galaxy,averaged over galactic longitudes 3 − 35° and latitudes |b| < 1°. a) This is *the spectrum reproduced from Paper I; open circles refer to preliminary IRAS results. b)* This is *the revised spectrum based on final IRAS data (filled circles). The three components which are used to fit both spectra for λ ≥ 30μm are: cold dust (dashed curve), very cold dust (crosses) and warm dust (dotted curve). Two components contribute to the* (hd) *spectrum in the middle IR λ ≤ 30μm, viz. very small grains (dashed curve) and OH/IR stars (dashed-dotted curve). The solid line shows the superposition of the five dust components.*

(Paper I) show that only O and early B stars located in HII regions and dense molecular cores can heat dust to these (wd) temperatures and provide the luminosity required to explain the observed galactic (wd) emission. These model computations further suggest that ~2/3 of the (wd) luminosity is due to heating by O stars and ~1/3 is due to heating by B stars. Comparison of the hydrogen masses associated with (wd) and (cd, vcd), respectively (see Table 1) shows, that only ~1% of the interstellar hydrogen is associated with warm dust, while the (wd) and (cd) luminosities are about equal. Of further interest is the fact that the submm part of the spectra shown in Figs. 1, for λ>500μm, is dominated by (cd) and (vcd) emission. Taking these facts together we arrive at the important conclusion that the (wd) luminosity of the diffuse galactic emission is related to the formation rate of O and early B stars during the past few million years; and that flux densities at submm wavelengths λ ≥ 500μm are dominated by contributions from (cd) and (vcd), which represent the bulk of the interstellar dust.

The emission between λ4μm and 20μm is due to hot dust (hd) of several hundred K. Our model computations, adjusted to the most recent IRAS results, suggest that ~ 1/3 of the total (hd) luminosity comes from normal MRN grains located in circumstellar shells of M giants, which are in their asymptotic giant branch (AGB) evolutionary stage, where heavy mass outflow occurs(the so-called OH/IR stars). The other 2/3 of the (hd) luminosity is contributed by very small grains (VSG) which are heated temporarily by absorption of single energetic photons to temperatures of several hundred K. If these grains are made of PAH molecules, they would emit the absorbed energy via a "forest of lines" at MIR wavelengths rather independent on the exact grain temperature, and thus could account for the MIR shoulder in the spectra Fig. 1.

While the basic heating sources of the galactic dust are the same as described in Paper I, some of the model parameters have been changed for the fit of the revised spectrum presented here in Fig. 1b. Original and modified model parameters are given in Table 1 for $R_\odot$ = 10 kpc.

Table 1 Parameters for the Model Fit to IR/submm Emission from our Galaxy within the Solar Circle ($2 \leq R/\mathrm{kpc} \leq 10$)

Dust component	used in Paper I and Fig.Ia	used here and in Fig.Ib	Reference
Very cold dust (vcd)			
$\langle T^{vcd} \rangle$ in K	14	14	(Puget, 1983)
L^{vcd}_{IR} in $L_\odot$	5 E 8	8 E 8	
M_{H_2} in $m_\odot$	9 E 8	1.5 E 9	(Puget, 1983)
Cold dust (cd)			
T^{cd} in K	15 - 25	15 - 25	
L^{cd}_{IR} in $L_\odot$	4.4 E 9	6.6 E 9	
M_{HI} in $m_\odot$	6 E 8	9 E 8	(Bloemen et al., 1986)
Warm dust (wd)			
T^{wd} in K	30 - 40	30 - 40	
L^{wd}_{IR} in $L_\odot$	7.3 E 9	6 E 9	
M^{wd}_{gas} in $m_\odot$	4 E 7	3 E 7	
Hot dust (hd)			
T^{hd} in K	200 - 500	200 - 500	
L^{hd}_{IR}(VSG) in $L_\odot$	1.3 E 9	2 E 9	
L^{hd}(OH/IR) in $L_\odot$	1.2 E 9	1.4 E 9	(Habing, 1986 priv. comm.)
A_V (10 - 2Kpc)			
$A_V{}^{tot}$ in mag	20	25	(Puget, 1983)
$A_V{}^{HI}$ in mag	9	13.5	
$A_V{}^{H_2}$ in mag	11	11.5	

The main difference of the parameters used in the revised model is an increase of the mass of interstellar matter associated with (vcd) and (cd) by factors of ~1.7 and ~1.5, respectively, accompanied by a corresponding increase in the IR luminosities. VSG appear to exist only in the diffuse interstellar matter (HI).Hence their contribution to the (hd) luminosity also increases by a factor 1.5. In paper I we adopted a luminosity ratio $L^{hd}(VSG)/L^{cd}$ ~ 0.25, which we here increase to ~ 0.30 based on the latest evaluation of IRAS results (Cox and Leene, 1986).

Ridge line intensities of the dust emission in the galactic plane as derived from IRAS observations are shown together with our model fits in Figs. 2a,b,c and d. Fits for surveys at other wavelengths can be found in Paper I. Ridge line intensities, derived from balloon and IRAS surveys, generally agree very well. Latitude profiles derived from IRAS surveys - contrary to balloon surveys - show dust emission at all latitudes. The extended IRAS latitude profiles are well reproduced by our model computations (see Paper I, Fig. 4). This high-latitude dust emission increases the radiation density contained in the FIR part of the ISRF by nearly an order of magnitude, as compared to the estimates by Mathis et al.(1983).

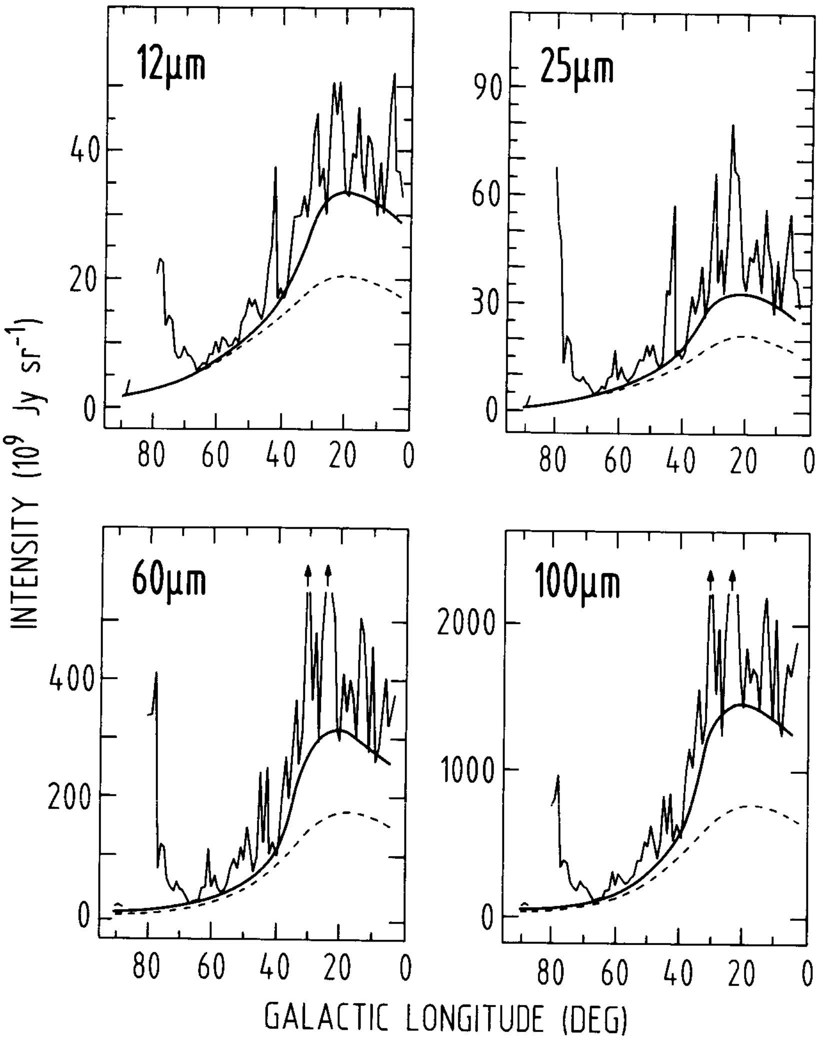

Figure 2. Ridge line intensities of the infrared emission for 3° ≤ l ≤ 90° in the four IRAS bands. The data are averaged over |b| ≤ 0°.5. The dashed curves represent at λ = 12μm and λ = 25μm the contributions of very small grains and show at λ = 60μm and λ = 100μm the contribution of cold dust. Solid curves are the sum of the contribution of cold, very cold and warm dust at 60μm and 100 μm, and of very small grains and hot dust in the shells of OH/IR stars at 12μm and 25μm.

II. The Galactic Center Region

The central regions of many external spiral galaxies are prominent IR sources. In analyzing their integrated dust emission one would like to know if and how the emission spectra of nuclear regions (R ≤ 1 kpc) deviate from those of the spiral arm regions, where most of the OB stars form. For most external galaxies the angular resolution of IRAS is not sufficient to resolve disk and nucleus. However, for the center region of our galaxy the IRAS data can be used to estimate the characteristics of its dust emission.

The surface density of both atomic and molecular hydrogen falls to a minimum between galactic radii R ~1–2kpc, then starts to increase again at R ≤ 0.7 kpc. The total mass of interstellar matter within this radius amounts to several 10E8 $m_\odot$. Free-free and warm dust emission, however, which indicate OB star formation, are only found within an area $\Delta l \times \Delta b$ ~ 2° x 0°.5, corresponding to ~ 350 x 90 pc surrounding the galactic center. The dust emission from this region will be investigated in this section.

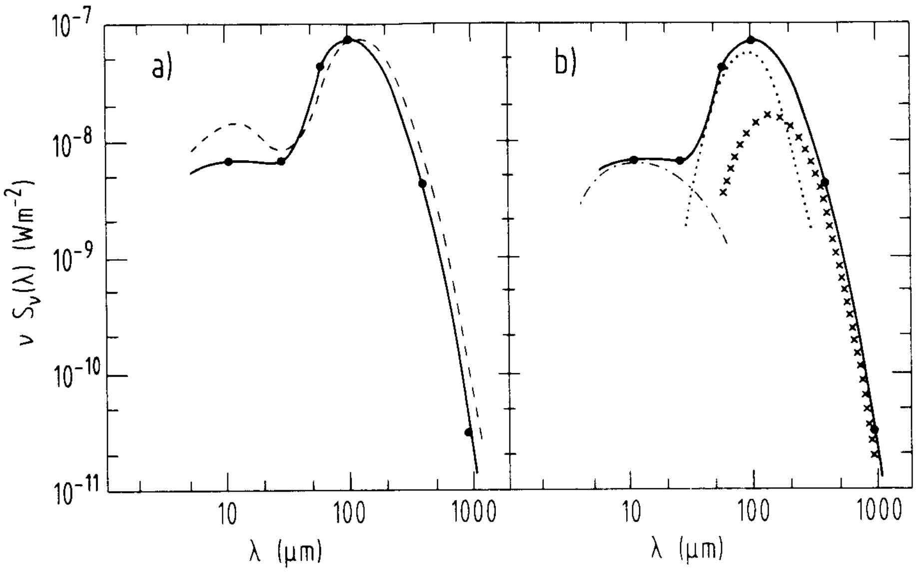

Figure 3. Average spectrum of the dust emission associated with the galactic center, integrated within an area $\Delta l \times \Delta b$ ~ 2° x 0°.5 (dots and full line). a) is a comparison with the spectrum of the galactic disk taken from Fig. 1b (dotted line); b) is a decomposition of the galactic center spectrum into the contributions of very cold dust (crosses), warm dust (dotted line) and hot dust (dash-dotted line), as described in the text.

In Fig. 3a we have plotted flux densities integrated within this area. The flux densities relate to the galactic center, i.e. an underlying extended component due to dust emission from the galactic disk has been subtracted. Flux densities at 900μm and 300μm are those estimated by Mezger et al. (1986, and references therein), flux densities at shorter wavelengths have been derived from IRAS data. The dashed curve in Fig. 3a represents the spectrum of the surface brightness of dust emission from the galactic disk as shown in Fig. 1b, but normalized to coincide with the galactic center flux density at λ100μm. The full curve connects the observed flux densities and represents the true IR/submm spectrum of the center region to the best of our present knowledge. Again, the spectral shape for λ ≥ 100 μm has been adopted from Caux and Serra (1986).

An investigation of the cold dust emission at λ300μm and λ900μm yielded a total mass of hydrogen of ~1.5E7 $m_\odot$ within 2° x 0°.5, comparable to the total mass of molecular hydrogen as estimated from CO observations. This led to the conclusion that most of the hydrogen in the central region is in form of molecules located in GMCs, whose average dust temperature of $\langle T^{vcd}\rangle$ ~ 20K, however, appears to be higher than in disk GMCs. Also, kinetic gas temperatures derived for the center GMCs are much higher than gas temperatures derived for disk GMCs (Mezger et al., 1986, and references therein).

The (vcd) spectrum, for M_H = 1.5E7 $m_\odot$ and $\langle T^{vcd} \rangle$= 20K, is shown by crosses in Fig. 3b. Subtraction of this (vcd) contribution from the observed spectrum leaves the dotted line, which corresponds to the emission from (wd) with T^{wd} ~ 35-45K. Due to the absence of atomic HI we consider the contribution from (cd) emission negligible. This also agrees with the considerably lower (hd) emission as compared to the galactic disk (Fig. 3a). **Since VSG dust is to be correlated with diffuse atomic hydrogen, which appears to be absent in the central 2°x0°.5, only OH/IR stars will contribute to the (hd) emission.**

Table 2

Parameters for the Model Fit to the IR/submm Emission from a Region Δl x Δb ~ 2°x $0^\circ.5$ surrounding the Galactic Center. Adopted Distance to the Galactic Center is $R_\odot$ = 10 kpc.

Dust component	Parameters	References
Very cold dust (vdc)		
$\langle T^{vcd} \rangle$ in K	20	
L^{vcd} in $L_\odot$	7E7	Mezger et al.: 1986
M_{H_2} in $m_\odot$	1.5E7	
Cold dust (cd)		
not considered		
Warm dust (wd)		
T^{wd} in K	35 - 45	Dent et al.: 1983
L^{wd} in $L_\odot$	2.3E8	
M^{wd}_{gas} in $m_\odot$	1E6	
Hot dust (hd)		
T^{hd} in K	200 - 500	
L^{hd}_{IR} (VSG) in $L_\odot$	—	
L^{hd}_{IR} (OH/IR) in $L_\odot$	3E7	

The parameters used for the model fit of the dust emission from the central 2°x0°.5 are given in Table 2. The corresponding dust luminosity amounts to ~ 2% of the total luminosity. Estimates of the formation rate of OB stars in the central 350 x 90 pc - based on free-free flux densities and warm dust luminosity - range from ~ 10-4% of the total OB star formation rate in the Galaxy. The nucleus of our Galaxy thus exhibits only mild star formation activity.

III. Comparison with external galaxies

The average spectrum of 18 Sb,c type galaxies, taken from Chini et al. (1986), is shown in Fig. 4. This spectrum can be decomposed into a minimum of three components, which we identify - in analogy to the dust emission from our Galaxy - with contributions from i) (vcd) + (cd) emission (which cannot be separated), ii) (wd) emission and iii) (hd) emission, respectively.

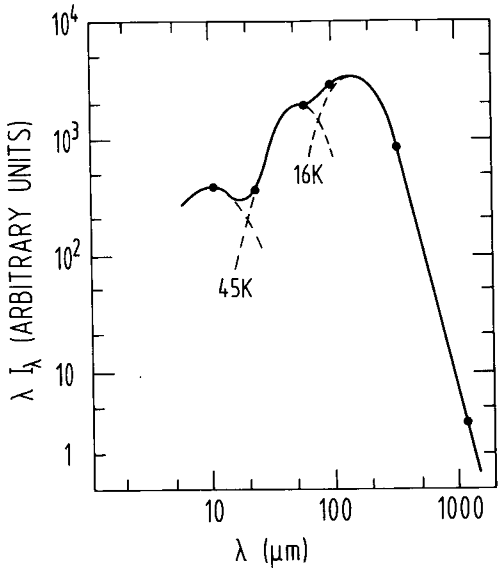

Figure 4. The average spectrum of 18 Sb,c type galaxies normalized at λ100μm (from Chini et al., 1986). The solid curve is the sum of the contributions from very cold dust and cold dust (16 K), warm dust (45 K) and hot dust (of a few hundred K).

Compared with the decomposition of the galactic dust emission spectrum in Fig. 1, which is based on model computations, the decomposition of the observed spectra of external galaxies in contributions from (cd) and (wd) is somewhat arbitrary and appears to represent a rather extreme solution, since the (wd) spectrum has been forced to fit the IRAS observations at λ25μm and 100μm, respectively. This is also born out by the fact that the ratio T^{wd}/T^{cd} ~ 2.9, derived for the external galaxies, is considerably higher than the ratio $T^{wd}/(\langle T^{cd}\rangle + T^{vcd})0.5$ ~ 2.1, obtained for our Galaxy (with temperatures taken from Table 1). It has been shown, however, by Chini et al. that this uncertainty in the decomposition barely affects the determination of L^{wd}. The uncertainty in the (cd) + (vcd) luminosity, on the other hand, does not affect estimates of the gas content of these galaxies, which are based on their λ1200 μm flux densities. The gas content of external galaxies estimated in this way (see e.g. Chini et al.) promises to be considerably more reliable than estimates based on the luminosity of the opaque ^{12}CO emission line. For the Sb,c galaxies a ratio L^{wd}/L^{cd} ~ 0.7 is found as compared to a ratio ~ 0.8 for our Galaxy (with luminosities taken from Table 3). The dust emission characteristics of our Galaxy appear to fit in with Sc galaxies (see Chini et al., 1986, Fig. 2).

IV. Dust luminosities of the Galaxy

Dust emission characteristics of the galactic disk as given in Table 1 extend to 10 kpc. In Paper I we have extended model computations beyond 10 kpc. Adding both the contributions for R >10 kpc (Paper I) and R <2 kpc (Table 2, this paper) to the luminosities given in Table 1 yields the total dust luminosities of the Galaxy, as given in the second column of Table 3. Note that the (hd) luminosities from Tables 1 and 2 have been decreased by a factor of 1.4 to account for opacities at MIR wavelengths (see Paper I). The absorbed MIR luminosity is reradiated at longer wavelengths.

Table 3

Total Dust and Stellar of the Galaxy

$R_\odot$ =	10 kpc	8.5 kpc
L_{IR}^{vcd} in $L_\odot$	1.0 E9	7.2 E8
L_{IR}^{cd} in $L_\odot$	7.3 E9	5.2 E9
L_{IR}^{wd} in $L_\odot$	6.5 E9	4.7 E9
L_{IR}^{hd} in $L_\odot$	2.5 E9	1.8 E9
L_{IR}^{tot} in $L_\odot$	1.7 E10	1.2 E10
L_{*}^{tot} in $L_\odot$	5 E10	3.6 E10

The total stellar luminosity in Table 3 comes from Mathis et al.(1983). All luminosities have been obtained for a distance $R_\odot$ = 10 kpc between solar system and galactic center. Recently, the Working Group on Galactic Constants of the IAU Commission 33 (see, e.g. Kerr and Lynden-Bell, 1986) has recommended to use the distance $R_\odot$ = 8.5 Kpc. In this case all luminosities are reduced by a factor $0.85^2 = 0.72$. These reduced luminosities are given in the third column of Table 3. The ratio $L_{IR}^{tot}/L_{*}^{tot} \sim 0.34$ means that one third of the stellar emission in the Galaxy is absorbed and reemitted by dust.

V. Dust Luminosities and Star Formation Rates

At present the most reliable way to estimate the global star formation rate (SFR) of O and early B stars, ψ_{OB}, is via the Lyman continuum (Lyc) photon production rate, which can be derived from the integrated free-free flux density of a galaxy. In a second step the OB SFR is connected to the total SFR, ψ, by adopting an initial mass function (IMF). It has first been suggested by Mezger and Smith (1977) that in our Galaxy (and in external galaxies probably as well) we deal with two different star formation processes, viz. "spontaneous SF", where stars form in the total mass range $0.1 \leq m/m_\odot \leq 100$ according to a rather general IMF, and "induced SF", where only stars form above a critical mass m_c. In our Galaxy induced SF appears to occur primarily in main spiral arms and (probably) in the center region, with $m_c \sim 3\ m_\odot$. The ratio of induced to spontaneous SF is $\alpha = \psi^{ind}/\psi^{spon} \sim 2-2.5$. This hybrid process of SF, also referred to as "bimodal SF", was put into a quantitative form by Güsten and Mezger (1983) in order to explain galactic abundance gradients. As a by-product it was found that bimodal SF also solves the problem of an apparently too high SFR, which is estimated on the basis of the Lyc-photon production rate.

From the Lyc-photon production rate in our Galaxy, using the IMF obtained by Miller and Scalo (1978), one derives a present-day SFR of $\psi(t_0)$ = 10.4 $m_\odot\ yr^{-1}$. The change of the galactic distance scale mentioned above reduces this value to ~ 7.5 $m_\odot\ yr^{-1}$. The contribution to the total SFR from the central region appears to be less than 10%, that from outside the solar circle accounts for ~ 10%. This leads to an estimated total present galactic SFR of $\psi(t_0)$ ~ $9m_\odot$, which is the value given in Table 4 for $\alpha = 0$. The corresponding lock-up rate in low mass stars m $\lesssim$ 1 $m_\odot$ and dead stellar remnants is $dM_*/dt = (1-r)\psi = 5.2 m_\odot yr^{-1}$, with r = 0.42 the fractional rate of "instantaneous return" to the interstellar space of matter transformed into a newly formed generation of stars. These values are close to the SFR and lock-up rate averaged over the lifetime of the Galaxy. In other words this would mean a time-independent SFR and lock-up rate, which - for various reasons - appears to be an unlikely situation. In the upper line of Table 4 is shown, for $m_c = 3m_\odot$ and two values of α, how bimodal SF reduces both ψ and $\dot{M}_*$ in our Galaxy. Analytical formulae to compute SFRs and lock-up rates in the case of bimodal SF are given by Mezger (1985).

Table 4

Present Star Formation Rates $\psi(t_0)$ and Lock-up Rates $(dM/dt)_t = \dot{M}$ in our Galaxy and in an IR Galaxy with L^{wd} = 1E12 $L_\odot$, computed for mc 3 $m_\odot$ and three values of $\langle\alpha\rangle = \langle\psi^{ind}/\psi^{spon}\rangle$.

$\langle\alpha\rangle$ =	0		2.5		∞	
Rates in $m_\odot yr^{-1}$	ψ	$\dot{M}_*$	ψ	$\dot{M}_*$	ψ	$\dot{M}_*$
Our galaxy L^{wd} = 4.7E9$L_\odot$	9.0	5.2	4.5	1.8	2.6	0.34
IR Galaxy L^{wd} = 1E12$_\odot$	1.9E3	1.1E3	9.5E2	3.8E2	5.5E2	7.2E1

For external galaxies a determination of the Lyc photon production rate is difficult, since in most cases for $\lambda \gtrsim$ 2mm synchroton emission, and for $\lambda \lesssim$ 2mm dust emission dominate over the free-free emission. It therefore would be desirable, if the easily observed total IR luminosity of a galaxy could be used to estimate its SFR. Most authors who have tried to do this, however, have oversimplified a rather complex problem. As pointed out above, it is only the warm dust luminosity which is directly linked to the number of recently formed 0 and early B stars. But a quantitative relation between L^{wd} and ψ_{OB} is difficult to establish. Factors f(m) enter into such a relation, which measure the fraction of the MS lifetime of a star of mass m, during which it is associated closely enough with dust in surrounding HII regions and shells to heat it to the (wd) temperatures (see the discussion in Paper I, Appendix A). Rather than using such a quantitative relation we combine values ψ and L^{wd} from Tables 3 and 4 to derive the empirical relation ψ ($\langle\alpha\rangle = 0$) = 1.9 10^{-9} L^{wd}, valid for our Galaxy and $\langle\alpha\rangle = 0$ (i.e. no induced SF). Here $L^{(wd)}$ is given in solar luminosities and ψ in $m_\odot yr^{-1}$. This empirical relation can be generalized for bimodal SF. Then, assuming that this relation also holds for external galaxies, we estimate the SFR and lock-up rate for a hypothetical IR galaxy with L^{wd} = 1E12$L_\odot$. Without bimodal SF a SFR of nearly 2000 $m_\odot$ yr^{-1} would be required to sustain the (wd) luminosity of 1E12$L_\odot$. In one million years this galaxy would transform 2E9 $m_\odot$ into stars and lock up one half of this mass in stellar remnants. Remember that the total gas content of our Galaxy is ~ 4E9 $m_\odot$.

Considerations like these have probably helped to popularize explanations of high IR luminosities of galaxies in terms of "bursts of star formation". If, however, in such actively star forming galaxies induced SF dominates (i.e. $\langle\alpha\rangle \rightarrow \infty$) both ψ and $\dot{M}_*$ are drastically reduced. E.g. in the case of the galaxy with L^{wd} = IE12$L_\odot$, as shown in the second line of Table 4, a SFR of 550 $m_\odot yr^{-1}$ is required to sustain this luminosity, of which only 64 $m_\odot yr^{-1}$ would be permanently locked up. This example shows that galaxies can derive their high IR luminosities for a long time without consuming extensive amounts of gas or piling up too much mass in dead stars. Moreover, as shown by Chini et al. (1986) high IR luminosities in Galaxies are not necessarily a sign of star burst, but rather of very massive galaxies, whose SFR is proportional to their gas content, i.e. $\psi \propto M_H$.

VI. Estimated Uncertainties

This paper and related previous papers were aimed to derive a model , which both explains the diffuse galactic IR/Submm emission correctly, and is consistent with observations pertaining to dust characteristics and the distributions of stars and interstellar matter. How accurate are these parameters known today?

Derived dust luminosities depend primarily on the quality of the IR surveys and on the galactic distance scale, but only marginally on a particular model. Provided $R_\odot$ = 8.5 Kpc is the correct distance to the galactic center, L^{tot} = 1.2E10$L_\odot$ should be correct within ~ 20-30%. There are indications that $R_\odot$ is still overestimated.

Model computations related to the emission from dust associated with HI and H_2, which is heated by the general ISRF, depend on i) the dust absorption cross section per H-atom; ii) the distribution of interstellar gas in the galactic disk; iii) the density and spectral distribution of the ISRF. At present, we believe that dust cross sections between λ0.1μm and ~ 40μm are known with uncertainties of a few 10%. At longer wavelengths absorption cross sections could be up to twice as high as those adopted here and in Paper I.
The intensity and spectral distribution of the ISRF in the solar vicinity and for wavelengths $\lambda \leq 2\mu$m appear to be rather well established. The FIR part of the ISRF, as given by Mathis et al. (1983), may be underestimated, however, by an order of magnitude and more, since contributions from dust at high galactic latitudes were neglected. This would affect primarily the temperature of dust deep inside GMCs. This is the reason why we adopted a rather uniform temperature $\langle T^{vcd}\rangle$ ~ 14 K of dust inside GMCs, rather than the lower values suggested by the model computations by Mathis et al. (1983). Extrapolation of the ISRF becomes more uncertain with increasing distance from the sun. We are nearly completely ignorant regarding the contribution of newly formed medium and low mass stars to the heating of dust in quiescent molecular clouds.
Estimates of the surface density of atomic and molecular hydrogen as a function of galactic radius appear slowly to converge. In the case of HI self-absorption of the λ21cm line appears to be the main source of uncertainty. The determination of H_2 surface densities based on ^{12}CO surveys is highly uncertain on a number of accounts. We refer to recent critical reviews by Puget (1983) and Bloemen et al.(1986).

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DISCUSSION

TELESCO:

For your Sbc galaxy energy distribution, what do you claim is the origin of the 10μm emission?

MEZGER:

Presumably OH/IR stars and small grains.

TELESCO:

Shouldn't one be able to separate out these contributions to some extent, since small grains and others associated with 'starbursts' should be spatially distributed differently from the OH/IR stars? The OH/IR stars should be more uniformly distributed since they are not necessarily starburst products.

MEZGER:

Yes.

GALLAGHER:

Which initial mass function did you use?

MEZGER:

We used the Miller/Scalo IMF.

GALLAGHER:

More recent results, from both the Milky Way and Large Magellanic Cloud, suggest a flatter slope for the upper IMF than adopted by Miller and Scalo. This will help remove some of the energetics problems that you discussed. Going from an upper IMF slope of $\sim$3 to the Salpeter value of $\sim$2.35 might gain a factor of 3-10 in predicted L_{IR} per $M_{\odot}$ of stars formed.

MEZGER:

I agree.

PUGET:

In your discussion of the Galactic Center region, you don't mention the fact that the heating is due mostly to an old disk population-type spectrum peaking at 1μm, which is quite different from what happens in the disk and could explain the low $12\mu m/100\mu m$ ratio.

MEZGER:

In the Galactic Center region, $\Delta l \times \Delta b \sim 2^{\circ} \times 0^{\circ}.5$, we identify OH/IR stars as the principal contributors to the MIR emission, while the warm dust ($\sim$ 35 – 45 K) is heated by O stars and early B stars. The contribution from cold dust associated with atomic hydrogen is absent, and the very cold dust associated with molecular hydrogen is warmer ($\sim$20K) than in the Galactic disk. Although I agree that the density of the interstellar radiation field in the central region is higher than in the disk and is dominated by M giants, I doubt if these stars contribute anything to the 12μm flux density. Apart, of course, from those M giants which happen to be in their AGB evolutionary stage. In fact, we believe that all MIR emission in the central region comes from such OH/IR stars.