INTERPRETATION OF THE LARGE-SCALE EMISSION FROM THE GALACTIC PLANE

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I. INTRODUCTION

To obtain information on the large-scale structure of our Galaxy, one has to investigate the radiation in the short-wavelength and long-wavelength portion of the electromagnetic spectrum where attenuation throughout the whole galactic disk is very low: gamma-radiation on the one-hand side and infrared and radio radiation on the other side. But since most of the different modes of radiation are generated by interaction of two or more basic galactic constituents one derives only indirect information on a specific component. To come as close to a unique solution as possible the results of as many different spectral regions as possible should be combined. From this point of view it is very encouraging that infrared astronomy has been entering the field and will continue to contribute in the years to come. While gamma-radiation presents mainly information about the cosmic rays and the interstellar gas and radio astronomy about early-type stars and the interstellar gas, infrared astronomy has opened a new way to investigate a major fraction of the stellar population and the inter-

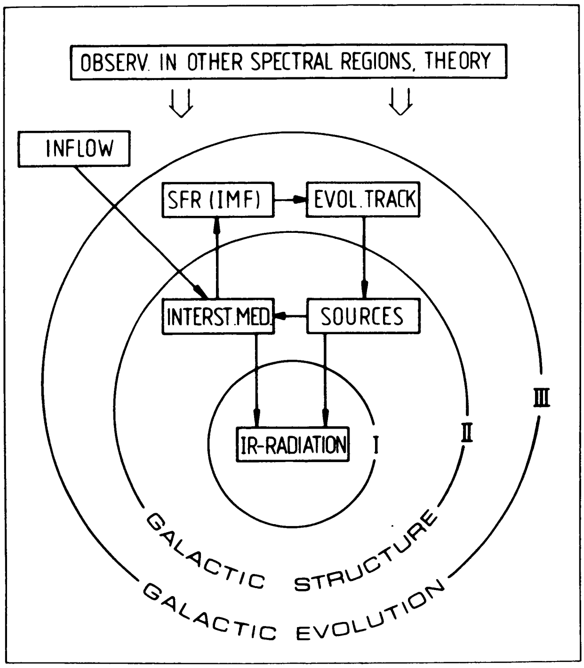

Figure 1: Concept of Interpretation of the Large-Scale IR-Emission

C. G. Wynn-Williams and D. P. Cruikshank (eds.), Infrared Astronomy, 261–274.

stellar dust. The information is contained in the diffuse galactic emission, which is observed at low galactic latitudes with a field of view large enough to discriminate against point sources, i.e. the emission is averaged over typical dimensions of some 100 pc.

A summary of the corresponding observations has been given in the previous talk (Okuda). In the following the interpretation of these data will be dealt with (Fig. 1). Firstly, the present state of the Galaxy will be described by modelling the distribution of stars, dust and radiation field on the basis of these observational results including data from other wavelength regions (Section II). In a next step first attempts will be reported to draw conclusions about the interaction of ISM and stars inferring basic parameters like star formation rate, initial mass function and chemical abundance (Section III). The galactic center will not be discussed, since it is the subject of another talk.

II. MODELLING OF THE LARGE-SCALE EMISSION

Simple models are used to investigate whether the experimental results fit into our overall picture of the Galaxy. The emission of the sources (mainly stars) is modified by the interstellar medium (treatment of radiative transfer) before it can be observed at the earth. In the models quoted it is generally assumed that the dust properties and the gas/dust ratio are the same throughout the Galaxy, so that these quantities can be scaled by the gas densities. Of course, the relative amount of dust could be smaller (e.g. thermal evaporation and sputtering of grains in hot regions) as well as larger (heavy element gradients). If the fraction of heavy elements locked up in grains and molecules is constant throughout the Galaxy, then the dust density scaled with the CO density is unaffected by heavy element gradients. While it is generally adopted that abundance gradients exist in the Galaxy (e.g. Janes 1979 and ref. therein), their precise nature remains to be determined (existence of more noticeable gradients in CNO elements than in heavier elements, local inhomogeneities, etc.).

1) Near-Infrared (NIR) and Middle-Infrared (MIR) Diffuse Emission

The interpretation of the NIR-radiation starts with the assumption that it is due to integrated light of late-type stars attenuated by interstellar extinction along the line-of-sight. For the solar neighborhood different authors deduce the 2.4 μm emissivity from star counts per spectral type and luminosity class (McCuskey 1969, Allen 1973) to be around $2 \cdot 10^{24}$W pc^{-3} μm^{-1} (Maihara et al. 1978, Hayakawa et al. 1978, Serra et al. 1980) in good agreement with the observed values. On the basis that in spiral galaxies there exists a homogeneous disk of stellar population with the same color as in the solar vicinity (Schweizer 1976) these data can be extrapolated using a conservative mass model of the Galaxy (e.g. Schmidt 1965). The extinction of interstellar dust is taken to be correlated with the gas density (e.g. Gordon and Burton

1976). The data at $l^{II} < 10^o$ and $l^{II} > 60^o$ can be explained in terms of a simple model, but one obtains a strong excess (factor 3) of the observed brightness over the predicted one in the region $10^o < l^{II} < 60^o$ (Hayakawa et al. 1977). Its association with spiral arms and local active regions (correlation with observations in other spectral regions, see Okuda-paper) implies young objects. For a determination of the corresponding emissivity several authors have discussed models where a Population I component is superimposed upon an 'old disk' component. Although the observations reveal that NIR sources are associated with spiral arms the axisymmetric approximation is assumed for simplicity in these models and no peculiar features are included in the discussion.

The Kyoto group (Maihara et al. 1978) has obtained numerical values for the excess emissivity so as to fit the observations for $l^{II} \sim 0° - 30°$. The distribution of dust is taken as comprising two components: a uniform component (A_V = 1.5 mag/kpc) and an additional concentration associated with the 5 kpc-ring (maximum A_V = 2.2 mag/kpc), where $A(2.4\ \mu m)/A_V = 0.08$. An exponential type dust density distribution with a scale height of 150 pc is used.

The Nagoya group has revised a previous model (Hayakawa et al. 1977) by improving on the treatment of extinction (Hayakawa et al. 1980). Including the clumpiness effect the optical depth is scaled with the column density of HI (scale height 120 pc) and CO (scale height 50 pc) as $A_V = 4 \cdot 10^{-22}\ N(HI) + 1.05 \cdot 10^{-17}\ N(CO)$ mag cm^2. It is shown that this optical depth is consistent with the observed longitude and latitude profiles of the 2.4 μm relative to the 3.4 μm observations (using model No. 15 of van de Hulst 1957). The excess luminosity is modelled by two rings (at R = 4.6 and 7.2 kpc) where the source function decreases exponentially with R and z. Since there exists no dip or flattening at the equator in the latitudinal brightness distribution, the emitting sources have to be highly concentrated to the galactic plane to compensate the absorption feature by dust grains associated with molecular clouds. According to the model, the scale height of the sources (z_o = 50 pc) is the same as for molecular clouds, i.e. they also seem to be extreme Population I objects. The volume emissivity averaged over 1 kpc in the radial direction of the 5 kpc-arm is $5 \cdot 10^{25}$ W pc^{-3} μm^{-1}.

The French group (Serra et al. 1980) uses three rings (one at 5 kpc and two additional ones). The radial and z-distribution are given by Gaussian profiles and calculations are done for different scale heights z_o. Finally z_o = 200 pc is selected, where the maximum emissivity at 5 kpc agrees with the value of the Kyoto group ($4 \cdot 10^{25}$W pc^{-3} μm^{-1}). This scale height implies objects of older Population I. The volume emissivity derived by all three groups is in good agreement; the corresponding surface flux density of the Nagoya group is smaller (factor ∿ 2) than for the other groups, since all models use nearly the same value for the optical depth in the galactic plane but different scale heights.

The mass of stars producing the infrared excess represents a minor fraction of the total mass since no mass excess at 5 kpc is observed. Evidence quoted above suggests that the sources are (extreme) Population I objects. Two candidate sources have been considered: (proto)stars embedded in circumstellar dust and late-type (super)giants.

The first alternative has been discussed by Hayakawa et al. (1977). They compare the 5 kpc region with a 'typical' dust cloud, the Ophiuchus dark cloud (located at a distance of ∿ 160 pc from the Sun). Triggered by a cloud-cloud collision the formation of a star cluster occurs in this region (Wilking et al. 1979). From its luminosity function (Vrba et al. 1975) an emissivity is derived which agrees with the emissivity in the 5 kpc region, if a reasonable filling factor of 10^{-2} for dust clouds is assumed. But the interpretation would require that practically all dust clouds are heated by newly born stars associated with them. Furthermore, a fraction of the stars in the Ophiuchus cloud seems to be either non-main sequence or background stars (Fazio et al. 1976). So, while dust-embedded stars seem not to be the dominant source of the NIR excess, they probably are responsible for a larger fraction of the MIR emission, since corresponding observations show a color temperature of about 500 K for the excess emission (Price 1980), a value characteristic of sources with circumstellar shells. The MIR emission is well correlated with the intensity distribution obtained in the 2.7 GHz Survey (Altenhoff et al. 1970). Rowan-Robinson (1979) finds the same correlation for the distribution of hot-centered molecular clouds. The cloud spectra are composed of a far-infrared peak (color temperature 50 K) and a weaker mid-infrared emission (color temperature 500 K). For the few nearby clouds, where far-infrared resolution is sufficient, one finds that the radiation comes from dust illuminated by sources embedded in the cloud, rather than by the stars responsible for the H II region.

The second alternative (red giants) has been put forward by Puget et al. (1979) and has been further discussed in connection with star formation rates (see Section III). Hayakawa et al. (1980), who find that the sources belong to extreme Population I, consider late-type supergiants. Assuming that the 5 kpc region has nearly the same spectrum of radiation as the Per OB 1 association, its surface brightness in blue light is obtained (21.3 mag arcsec^{-2}), which is in approximate agreement with corresponding values of other galaxies (M31, M51, M101). At 5 kpc the surface flux density at 2.4 μm corresponds to a surface density of $5 \cdot 10^{-4}$pc^{-2} M2 supergiants, whereas the Lyc-photon density (Mezger 1978) can be provided by $\sim 2 \cdot 10^{-3}$ pc^{-2} B supergiants. The ratio of the star densities of about 4 agrees with the corresponding ratio in Per OB1, where most of the early-type stars are of early B-type. But the Perseus cluster, which is located outside the solar circle (distance ∿ 2 kpc from the Sun), may have relatively more massive stars than the clusters in the 5 kpc region (Burki 1977). This will be discussed in Section III.

In summary the NIR excess seems to be due to late-type giants/supergiants, whereas some MIR-excess should be provided by circumstellar shells around young and/or evolved stars. From a theoretical point of view the two classes of sources are not easy to separate (Yorke and Shustov 1980). It is possible for cool late-type stars with high rates of mass loss to have infrared spectra similar to protostars with accretion envelopes, provided the same type of dust is present in each case. Information pertaining to the intrinsic spectra of the central source is not available in the resulting infrared continuum. Nevertheless, the product of luminosity and lifetime for protostars ($\sim 10^9\ L_\odot$yr) seems to be lower than for giants ($\sim 10^{10}\ L_\odot$yr), so that an unrealistically high number of protostars would be needed to explain the NIR brightness.

2) Far-Infrared (FIR) Diffuse Emission

The UV and visible radiation of (mainly) stellar objects is partly absorbed by interstellar grains and reradiated at FIR-wavelengths, where the dust is nearly transparent. For the prediction of the diffuse emission simple models have been used (Stein 1967, Fazio and Stecker 1976) on the basis of a uniform stellar radiation field throughout the Galaxy. The fact that the FIR radiation observed was more than one order of magnitude higher than predicted generated the interest in somewhat more refined models.

In a first step the total (wavelength-integrated) diffuse emission in the galactic equator has been derived as a function of longitude and compared to observational results. The basic idea in such a model (Drapatz 1979) is that the total FIR emissivity ε (which equals its total short-wavelength absorptivity) at location R in the galactic plane may be related to its value ε^o in the solar neighborhood by $\varepsilon(R) = \varepsilon^o\ S(R)\ D(R)$. Here S represents the stellar distribution in other regions of the Galaxy and D the influence of the dust distribution, which consists of two opposing effects: a larger amount of dust reduces the short wavelength radiation field by extinction but increases the emitting mass. The FIR intensity is then obtained by integrating the emissivity along the line-of-sight.

The quantity ε^o is derived using a compilation of observed optical properties of the interstellar medium and a mean interstellar radiation field in the solar vicinity, which is formally approximated by a sum of three dilute black-body spectra, each characterizing one group of stars (O/B, A/F, late-type stars). This procedure is justified by more sophisticated derivations of the interstellar radiation field (Henry 1977, Mattila 1980) and by good agreement with observations. One obtains $\varepsilon^o = 1 \cdot 10^{25} \mathrm{W pc}^{-3}$ with roughly an equal contribution of all three groups of stars. The distribution of young stars throughout the Galaxy is represented by a simple spiral model based on the work by Georgelin and Georgelin (1976). The radial distribution in the arms follows the relative distribution of giant H II regions (Mezger 1970); the arm/interarm contrast is obtained from the ratio of Lyc-photons of giant and small H II regions (Smith et al. 1978). The stars in the arm region obey the initial luminosity function, the stars in the interarm region the observed luminosity function (McCuskey 1966). The older stars (A-K) are not affected by the spiral structure and their scaling factors S are obtained from Schmidt's model (Schmidt 1965). The dust scaling factor D has been derived under certain assumptions for a homogenous medium with dust particles having either a completely forward or a totally isotropic scattering pattern and for a medium where dense clouds are superimposed upon a homogenous background. In all three cases the mean dust density $< n >$ averaged over cloud and intercloud regions is of moderate influence ($D \sim \sqrt{< n >}$). The calculated diffuse emission shows a maximum intensity around $l^{II} = 30^{o}$ ($I = 1.1 \cdot 10^{-8}$ W $cm^{-2} sr^{-1}$) and a slow decrease around $l^{II} = 45^{o}$ and is in quite good agreement with the observations. The total FIR luminosity of the Galaxy ($4 < R < 12$ kpc) is $\gtrsim 5 \cdot 10^{9}$ $L_{\odot}$.

Ryter and Puget (1977) have correlated the FIR emission of massive molecular clouds associated with well-known H II regions with their gas column densities to derive a luminosity normalized per hydrogen atom $L_H \sim 2 \cdot 10^{-30}$ W (H atom)$^{-1}$. It is argued that this quantity should prevail in most of the interstellar medium leading to an intensity $I \sim 3 \cdot 10^{-8}$ W $cm^{-2} sr^{-1}$ at $l^{II} \sim 30^{o}$, which is high. Here one should keep in mind that most of the H_2 resides in molecular clouds, where no massive stars are formed at present. A relation between FIR intensity and gas density can have a meaning on the basis of the good correlation of the longitude profiles of CO and FIR emission and the suggestion that the star formation rate varies with a certain power of the overall mean gas density (Schmidt 1959).

The French group has then built a model (Boissé et al. 1980) by discussing the efficiency of absorption of starlight by dust as a function of the mass of the star. One fraction of the stellar radiation is absorbed by the molecular cloud in which the star is formed, another fraction is absorbed by dust in the diffuse interstellar medium and a third one is absorbed by all other molecular clouds. An evaluation of the efficiency factors as a function of the mass of main sequence stars yields $f \sim 0.14 (M/M_{\odot})^{0.4}$ Averaging over the stellar population in the solar neighborhood gives $f \sim 0.25$, whereas $f \sim 0.4$ in the 5-kpc region. The corresponding efficiency factors in the model of Drapatz (1979) would have values 0.21 and 0.44 respectively.

An interpretation of the observed FIR intensity is given by Mezger (1978). He finds that the main portion (∿ 90%) of the early-type stars are located outside radio H II regions. The corresponding Lyc-photons either ionize an extended low-density (ELD) medium or are absorbed by the dust or escape from the Galaxy. The first fraction is determined from measurements of the diffuse thermal radio emission, the other two contributions are estimated. Of the number of Lyc-photons absorbed by the gas in the H II regions a fraction 2/3 is degraded into Lα-photons. Comparing this Lα intensity I(Lα) with the observed intensity I(FIR) by use of the relation $I(FIR) = IRE \cdot I(L\alpha)$ yields $IRE = 8$.

This value can be met, if either all non-ionizing photons from cluster stars get absorbed by grains inside the ELD H II regions and the neutral clouds or if only half of these photons is absorbed and absorption of photons of the general stellar radiation field (stars of later type) account for the other half.

All three models agree that all star classes contribute to some extent to the FIR emission, early-type stars being especially important in the 5 kpc arm. Since there exists a good correlation of the longitude profile of the FIR emission with the corresponding H 166α-observations (typical of diffuse radio H II regions with large spatial extent, e.g. Lockman 1976) as well as with CO-observations (molecular clouds, e.g. Solomon and Sanders 1979) different dust containing regions are assumed to be dominant in the transformation of star light into FIR radiation: Mezger stresses the ELD H II regions, the French group emphasizes parent clouds of newly born stars and Drapatz the ionized, atomic, and molecular component. When young massive stars form, they are located in or close to the edge of their parent cloud, which absorbes their radiation in this initial phase. Rowan-Robinson (1979) finds from observations that hot-centered clouds contribute roughly $\sim 8 \cdot 10^8 L_\odot$ to the total FIR luminosity of the Galaxy. The massive stars then form H II regions, which by the champagne effect (Tenorio Tagle et al. 1979) evolve into ELD H II regions and finally form associations. In the galactic plane (scale height $\sim$ 50 pc) the absorption due to dust in molecular clouds and in ELD H II regions is comparable (absorption-length $\sim$ 1 kpc), whereas absorption by dust located in diffuse H I and H II regions dominates in directions out of the plane. The short wavelength radiation penetrates into the molecular clouds heating up the grains in the outer shells (Flannery et al. 1980). These warm regions comprise some 10% of the volume and mass of the cloud fairly independent of grain parameters and cloud sizes.

So far the 'total' FIR radiation has been discussed, although observations do not cover the whole wavelength region (especially not the 30 - 60 μm range). Furthermore, the measurements have been carried through in certain bands, so that the general shape of the whole spectrum and the integrated total radiation has to be attained on the basis of theoretical models. They have to include the microscopic properties of the dust (chemical nature, size distribution). The spectrum for spherical dust particles is given by

$$I(\lambda) = \iint B\left[\lambda,\ T(a,\ U(\lambda,\ l))\right]\ Q(a,\ \lambda)\pi a^2\ n(a,\ l)\ da\ dl \qquad (1)$$

where B is the Planck-function (grain temperature T), U the stellar radiation field, Q the emission efficiency ($Q = \sigma/\pi a^2$), n the spatial and size distribution of grains and the integration is over all grain radii a and the line-of-sight l. Drapatz and Michel (1976) have carried through a specific model calculation. They first derive and discuss a certain grain model (grain-size distribution a^{-4}, chemical composition taken as silicates perturbed by impurities and radiation defects generating absorption maxima due to local lattice vibrations in the infrared and due to color centers in the UV). The high specific heat of the material reduces the appearance of temperature spikes of small grains (Drapatz and Michel 1977, Aannestad & Kenyon 1979). On the basis of this grain model the diffuse galactic emission is obtained, where the stellar radiation field is dealt with like in the work by Drapatz (1979) already quoted, but with a more qualitative treatment of radiative transfer. At $l^{II} = 30^o$ the maximum emission occurs around λ = 80 μm decreasing to half that value at 150 μm. The wavelength of the maximum intensity is determined by the absorption efficiency of grains $Q \sim \lambda^{-2}$ as $\lambda(\max) \sim 0.2/T$ cm. If the interstellar dust has a different composition the particle temperature will be higher for a larger ratio of short wavelength absorption to infrared emission and for smaller particles. So the color temperature of the diffuse emission will only indirectly be related to the dust temperature distribution. Also, more refined models have to include the small-scale distribution of the radiation sources as well as that of the interstellar matter, i.e. the spectrum of the radiation will show a spatial distribution. Some general remarks related to these problems will be given in the following.

The distribution of the dust temperature as induced by the random distribution of stars has been computed by Rouan (1980). The distribution is quite narrow (typically ΔT = 2K at half maximum) with a sharp cut-off on the low temperature side, reflecting the presence of a uniform starlight background. This is due to the fact that the absorption length in the interstellar medium is much larger than the mean distance of stars. Most of the mass of the dust has therefore the temperature T_m of the maximum of the distribution and emits at ≳ 100 μm. The temperature distribution P(T) has an extended wing on the high temperature side, however, due to the more scarcely distributed hot stars. It converges towards the nearest star approximation $P(T) \sim T^{-10}$ (for $Q \sim \lambda^{-2}$). Therefore, the small fraction of grains that is hotter (say $1.5 \cdot T_m$) will emit a fraction of the total energy (≳ 10%) at shorter wavelengths and determine the spectrum in that range ($\lambda \lesssim 80$ μm).

In the FIR/submm region the spectrum will be influenced by an additional component originating from the inner parts of giant molecular clouds, where the gas is heated to 10 K by cosmic rays, H_2 formation, gravitational collapse or magnetic ion-neutral slip heating (Goldsmith and Langer 1978). The dust is not in thermal equilibrium with the gas for small densities ($n < 10^4$ cm^{-3}); still the temperatures will be similar in the interiors of dense clouds (Leung 1975). The corresponding diffuse emission should be comparable in intensity with the emission in the long wavelength wing of the warm component (diffuse medium plus outer layers of molecular clouds). If the dust properties are similar, the optical depths through both regions along the line-of-sight will be comparable (τ(350 μm $\sim 10^{-2}$ at $l^{II} = 30°$). Recent observational results (Owens et al. 1979) are compatible with this interpretation.

III. IMPLICATIONS FOR GALACTIC EVOLUTION

One fundamental feature of galactic evolution is the conversion of interstellar matter into stars (formation of stars from the ISM) and the ejection of matter back into the ISM (during stellar evolution and after nuclear processing). The first process is described by the Star Formation Rate (SFR)

$$\mathrm{SFR} = \dot{\xi}(M,R,t) = d\dot{N}(M,R,t)/d\ln M \tag{2}$$

which is the number of stars arriving (per unit area of the galactic plane and per unit time) at the Main Sequence with a mass distribution given by the Initial Mass Function ξ. The description of the second process follows from that equation by taking into account the evolution and lifetime $\tau(M)$ of the stars formed. The observed surface flux densities F_i are connected with the above quantities as

$$F_i = \iint k(R,t) \cdot \dot{\xi}_o(M) \cdot L(M) \cdot f_i(M)\, d\ln M\, dt \tag{3}$$

Observations present values of F_i for the NIR (subscript 1), FIR, (subscript 2) and Lyc-radiation (subscript 3), the last one being deduced from radio continuum measurements. The integral includes stars of all ages, which have been formed during time t_a, the age of the stellar population. The upper time limit of the integration is t_a for $\tau(M) > t_a$ and $\tau(M)$ for $\tau(M) < t_a$. Integration limits for post main sequence stars have to be considered separately. The assumption is made that the SFR at other locations in the Galaxy and at other times equals its present value in the solar neighbourhood ξ_o multiplied by a dimensionless scaling factor $k(R,t)$. The quantities L (stellar luminosity), τ, and f depend on the star class. Serra et al. (1980) have defined the efficiency factors as follows: f_1 = fraction of the total energy of a star radiated in the NIR region, f_2 = fraction of the total energy of a star absorbed by dust and reemitted in the FIR-region (see Section II.2) and f_3 = fraction of the total energy of a star emitted by Lyc-radiation. Mean values $< f_i >$ can be defined as the ratio F_i/F_{tot} with $F_{tot} = F(f=1)$. Although equation (3) includes all stars, different F_i are dominated by different stellar populations: F_3 is due to high mass stars, while F_2 includes high and intermediate mass stars ($M \gtrsim 1 M_\odot$). F_1 is determined by evolved stars of intermediate mass ($1 \lesssim M \lesssim 5\, M_\odot$). The low mass stars ($M < 1\, M_\odot$) are not directly accessible to observations and are subject to present theoretical investigations (e.g. Zinnecker and Drapatz 1979, Zinnecker 1980). While stars of high and intermediate mass are formed in open clusters and OB associations (Mezger and Smith 1977) this seems not to be true for low mass stars. First quantitative arguments for the necessity for two modes of star formation are given by Talbot (1980). For the high mass mode Lequeux (1979) has recalculated the IMF for the solar vicinity following the method of Salpeter (1955) but using more recent catalogues. This IMF will be used in the following to discuss the results of Section II on the basis of equ. (3).

1) Old Disk Population

Calculating F_1 and F_2 from equ. (3) for t_a = 10 Gyr and a constant SFR(i.e. k=1) reproduces quite well the observed values of NIR (Serra et al. 1980) and FIR surface flux density (Boissé et al. 1980) in the solar neighbourhood. Since F_1 is dominated by older stars and F_2 by all the stars it implies that k cannot have changed much in time, if the IMF was the same during the lifetime of the Galaxy. This is in agreement with the work of Miller and Scalo (1979), who derive a constant SFR in the solar vicinity from a critical reanalysis of observational material and the condition that the IMF should be continuous. A physical interpretation of this constant SFR is given in the model of Kaufman (1979), where after a disk age $t \sim 10^9$ yr the decaying exponential birthrate for star formation by high mass stars (triggered by expanding H II regions and supernova shock waves) is dominated by a constant star formation rate triggered by a galactic spiral density wave. However, Cassé et al. (1979) show that gas flows, such as differential infall or radial flows, have to be included to reproduce the observed gas distribution in the Galaxy. These gas flows are also needed to explain the abundance of elements (difference in metallicity between young and old stars in the solar vicinity, heavy element gradients throughout the Galaxy). Corresponding models have been suggested (Tinsley and Larson 1978, Chiosi 1980). Also, a closed system seems unrealistic for a constant SFR, if the frequently used law should prevail that the SFR depends on a power m of the gas density. While Lockman (1979) states that this law is unlikely to be correct over scales of a few kpc, it can be used for parametrization purposes (Guibert et al. 1978).

For decreasing galactocentric distance the fraction of F_1 which is due to the old disk population (wide scale height) follows Schmidt's mass law, so that the same IMF holds with k proportional to the local mass density in stars: k (5 kpc, t) $\sim$ 5 and t_a = 10 Gyr, as before.

2) Population I Excess

The present integrated (over all masses) SFR in the arm region is obtained from the fact that the rate of formation of early-type stars is proportional to F_2. The result is $\sim 20 M_\odot (pc^2 Gyr)^{-1}$ since k(5 kpc,t) > 5 in good agreement with the values obtained from F_3 by Mezger (1978).

There have been undertaken first attempts to investigate the SFR as a function of time. Serra et al. (1980) solve equations (3) for a given region in the Galaxy (R = 5 kpc) by maintaining ξ_0 and representing k as a time step function (3 steps with $t_a \sim 10^7$, 10^8, 10^9 yr). These values take into account that the excess population is young (small scale height, no mass excess above Schmidt mass distribution). Since the F_i are of comparable size the system would have a trivial solution with a constant SFR, if the $< f_i >$ are also of comparable size. Not only are the $< f_i >$ different, but they also change in opposite directions when changing the age of the stellar population (< f_1 > increases,< $f_{2,3}$ > decrease with the age of the population). As the authors correctly state the derivation of the < f_i > depends crucially on the stellar parameters L, τ (mainly their product). While those parameters seem to be fairly well known for the main sequence stars a problem arises from the uncertainties in the evolutionary tracks of post main sequence stars which are severely affected by mass loss and the chemical abundance of elements. With comparison to recent theoretical investigations the authors seem to have overestimated the low mass contributions (see Schönberner 1979) and underestimated the high mass contribution (see Weaver et al. 1978). Still, accepting their parameters < f_i > at face value a relative increase of < f_1 > is necessary which could be obtained either by increasing the SFR by a factor of 5 - 10 about 10^9 years ago (to increase the number of red giants) or by steepening the IMF (changing ξ) or by decreasing the upper mass limit M_u. It should be kept in mind that the variation in heavy element abundances could also mimic a different M_u. For higher abundances,stars of a given mass have lower T_{eff} and therefore fewer Lyc-photons, as if they were less massive stars. But even taking that effect into account Panagia (1980) finds a deficiency of massive stars. Evidence for a lower rate of formation of massive stars with decreasing galactocentric distance is also obtained from other observations: from UBV photometry of very young clusters (Burki 1977) and from the determination of the IRE of large H II region associated with molecular cloud complexes (Boissé et al. 1980). Also Hayakawa et al. (see Section II.1) state that a larger number of B stars (rather than a few O stars) is compatible with their NIR observation. From a theoretical point of view the limiting mass of stars with $L \sim M^3$ is proportional to $Z^{-1/2}$ (Shields and Tinsley 1976) in agreement with the above results for higher abundances of heavy elements Z inside the solar circle. Each piece of evidence stated may not be fully convincing for itself, but taken together they seem to indicate a change of ξ or of M_u with galactocentric distance.

In conclusion, the investigation of the large-scale infrared emission of the Galaxy starts to deliver important input data for the development of models of galactic structure and evolution. The increasing accuracy,resolution,and completeness of observations will allow for more sophisticated models and better understanding of the parameters involved.

I want to thank my colleagues from the Max-Planck-Institut, especially H. Zinnecker, for interesting discussions and some colleagues from other institutes for communication of not yet published results.

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DISCUSSION FOLLOWING PAPER DELIVERED BY S. DRAPATZ

BLITZ: Is it possible to model the existing infrared data to determine what the radial exponential scale length of the Galaxy is, or are there too many free parameters in the models?

DRAPATZ: Most of the work to date has been concerned with the spiral or ring component of the disk rather than the exponential component. However, from near infrared data Hayakawa et al. estimate the scale length in the solar vicinity to be 1 kpc and the spheroidal component in the inner region of the Galaxy to be somewhat steeper than the Schmidt Law mass distribution. I find that far infrared data are compatible with a distribution of early-type stars following giant radio H II regions and of other stars following the Schmidt Law.

BLITZ: Are the near infrared data good enough to attempt to model the distribution of disk stars in the outer Galaxy to see if the warp in the gas is mimicked by a warp in the stellar disk? The maximum warp occurs toward $\ell = 60°$, and knowing whether the warp in the stars follows that of the gas has important implications for understanding the origin of the warp.

DRAPATZ: At present the sensitivity of surveys towards the outer region of the Galaxy is insufficient to show structure beyond 1-2 kpc. We cannot yet say if there are warps in the outermost regions of the Galaxy. However, for the inner regions the near infrared ridge shows the same deviations from the galactic plane as other Population I objects.

HABING: Can you characterize the difference in population at R = 4 kpc and R = 5 kpc?

DRAPATZ: Inside of the ring, say at 4 kpc, we can fit the data with a population of stars similar to that in the solar neighborhood, but with a deficiency of early-type stars. In the ring itself at 5 kpc, there is an extra population of younger age, possibly due to a higher star formation rate in the past.

T. JONES: How do you reconcile the use of a few luminous Population I stars to explain the IR excess above the old disk population with the fact that at 28° longitude the actual source counts are 2 to 3 times above the disk at adjacent longitudes?

DRAPATZ: Even if the 5 kpc ring did not exist, there would still be a factor of five more stars there than in the solar neighborhood, due to the Schmidt Law. Part of the problem you raise may also be due to anisotropies in the stellar distribution and to holes in the extinction.

AARONSON: The near-IR data for other spirals indicate that in general, old disk M giants dominate the light at 2 μm. Although there may be regions of our Galaxy dominated by supergiants, such regions are probably not typical of the Galaxy as a whole.

DRAPATZ: Though I agree that these are basically giants, I think that currently there are uncertainties in the evolutionary tracks of giants and supergiants, partly due to the previous omission of effects such as mass loss, which may lead to order-of magnitude changes in the luminosities of these stars.

KRISCIUNAS: Miller and Scalo (Ap.J. Suppl. 41, 513-547, 1979) note that a function whose slope smoothly steepens with increasing mass is more valid than the power law in star formation and the stellar mass function. They favor a half-Gaussian distribution in log $[M/M_{\odot}]$. This is important for models of star formation.

DRAPATZ: The interpretation of the infrared data given deals with stars of mass $\geq 1\ M_{\odot}$. In that mass range the power law and half-Gaussian distribution do not differ sufficiently to influence the results. For the shape of the complete initial mass function, however, different functions must be considered, also to prevent a divergence for low masses.