Radiative Transfer in Spiral Galaxies

Simone Bianchi

*Istituto di Radioastronomia/CNR - Sez. di Firenze, L.go E. Fermi 5, 50125, Firenze, Italy*

**Abstract.** The internal dust extinction in spiral galaxies can affect our understanding of their structure and morphology, as well as our perception of the distant universe in the background. The intrinsic properties of the stellar and dust components can be studied by comparing the observed appearance of a dusty spiral in the optical with a radiative transfer model. The absorbed starlight is re-radiated by dust in the FIR/sub-mm. Thus, observations at long wavelengths allow to put further constraints on the properties of the dust distribution. I present our Monte Carlo simulations for dust extinction and emission in galactic disks, discuss the basic ingredients and limitations and compare them with other solutions for the radiative transfer available in the literature. I review the current picture of dusty disks that emerges from radiative transfer studies.

1. Introduction

For many extragalactic astronomers, dust is a nuisance: intrinsic luminosities and morphology, star formation rates, face-on corrections and several other quantities characterizing a spiral galaxy may be affected by dust extinction, requiring a correction to retrieve them from observed data. Furthermore, dusty disks or dust ejected into the intergalactic medium could hamper our view of the distant universe. However, dust is also interesting for its own sake. Dust is the repository of a good fraction of the metals in a spiral, and any model for galaxy evolution and star formation history should be constrained by the present amount of grains. Dust plays an active role in the interstellar medium, e.g. as a site of molecule formation or as a source of heating photoelectrons, and it may play a significant role in the intergalactic medium as well, if dust grains can escape the potential well of a galaxy.

Before the advent of infrared observations, the amount of dust in a spiral galaxy was traditionally quantified by it extinction effects\(^1\). Starting from Holmberg (1958), statistical studies of the surface brightness in samples of galaxies offering different inclinations to the observers were taken as a proof for a substantial transparency of galactic disks (at least when not seen edge-on). However such studies, besides being possibly affected by subtle selection effects, also de-

\(^1\)For reviews, see Calzetti (2001) or the introductions in the radiative transfer papers listed in the next section (e.g. Witt, Thronson & Capuano 1992; Byun, Freeman & Kylafis 1994)
pend on the geometric model assumed for the relative distribution of dust and stars: in a provocative paper, Disney, Davies & Phillipps (1989) shook the traditional view by showing how the same galactic samples were compatible with models completely opaque to radiation.

Therefore, to assess the amount of dust and its effects in a spiral galaxy disk it is necessary to solve the radiative transfer problem for geometries as close as possible to those inferred from observations.

2. Radiative Transfer vs Geometry

For light traveling in a dusty medium along a path of length \( s \) and direction \( k \), the change in the intensity \( I_\lambda \) of radiation is described by the well known radiative transfer equation (Chandrasekhar 1960),

\[
\frac{dI_\lambda}{ds} = -\kappa_\lambda I_\lambda + j_\lambda + \kappa_\lambda \omega_\lambda \frac{1}{4\pi} \int I_\lambda(k')\Phi_\lambda(k, k')d\Omega.
\]  

(1)

The first term on the right hand side of the Eq. 1 represents the light that is removed from the beam, either because of absorption by or scattering off dust grains (both effects included in the extinction coefficient \( \kappa_\lambda \)). The opacity of a medium is in general characterized by the optical depth \( \tau_\lambda \), the integral of \( \kappa_\lambda \) along the whole radiation path. The other two terms in Eq. 1 are positive contributions to \( I_\lambda \), due to direct sources of radiation (the emission coefficient \( j_\lambda \)) or to light coming from different directions \( k' \) that is scattered into the direction \( k \). The last term depends on the dust phase function \( \Phi_\lambda \) (stating the directionality of the scattering) and the albedo \( \omega_\lambda \) (the fraction of extinguished light that is scattered).

It is relatively easy to solve the radiative transfer equation omitting the scattering term (at least numerically). Unfortunately, this is not justified a priori in the UV-Optical-NIR regime (where \( j_\lambda \) is mainly due to starlight), since a good fraction of the light impinging on each grain is scattered (for Milky Way dust, \( \omega_V = 0.6 \); Gordon, Calzetti & Witt 1997; Gordon, these proceedings)\(^2\).

To ease the solution of the radiative transfer equation inclusive of scattering, several authors have adopted a plane parallel geometry to describe the galactic disk (see Baes & Dejonghe 2001 for a review and a comparison between different methods). Two popular plane parallel models are the Slab, in which stars and dust are homogeneously mixed, and the Sandwich, in which the dust distribution is thinner than the stellar distribution.

However, the surface brightness distribution in spirals is better described by exponential disks (Freeman 1970; Wainscoat, Freeman & Hyland 1989). Two methods have been used to solve the radiative transfer problem in such geometry. The first is the one proposed by Kylafis & Bahcall (1987; Byun et al. 1994; Xilouris et al. 1999). Eq. (1) can be solved separately for \( I_0 \), the contribution due to directly emitted photons, \( I_1 \), the contribution due to photons that have

\(^2\)Conversely, solutions are simpler for FIR/submm radiation, where emission is mostly due to dust: for particles much smaller than the wavelength of light scattering is negligible (Rayleigh scattering; van de Hulst 1957).
scattered only once, $I_2$, the contribution due to photons that have scattered only twice, etc. The total intensity is the summation of all terms. In the Kylafis & Bahcall method $I_0$ and $I_1$ are computed exactly, while the contribution due to scattering events of order $n \geq 2$ is approximated assuming that $I_n/I_{n-1} = I_1/I_0$.

The second approach is the Monte Carlo method (Bianchi, Ferrara & Giovanardi 1996; De Jong 1996; Wood & Jones 1997; Baes et al. 2003). The life of each photon is followed as it moves through dust and its fate is derived in a probabilistic way by tossing random numbers. The position where the photon is emitted is drawn from the adopted distribution of sources; a path direction is assigned, in general assuming isotropic emission. On a given path of optical depth $\tau$, the probability for a photon to avoid absorption/scattering is $e^{-\tau}$; thus a probable optical depth along the path can be derived. If such optical depth is larger than the total optical depth along the photon traveling direction, the photon escape the dust distribution and can be recorded by an observer, otherwise it encounters a grain inside the dust distribution. Here the photon can be either absorbed or scattered along another direction. If the photon is scattered (a fraction $\omega$ of all photons impinging on a grain are scattered) the phase function $\Phi$ is used as the probability distribution for the angle between the old and new traveling direction. The process is then repeated on the new path. Several cycles (photons) are needed to produce high S/N results (integrated photometry or maps as in Fig. 1). This basic scheme can be optimized to reduce the number of cycles needed to achieve the same S/N (Gordon et al. 2001; Baes et al. 2003). The Monte Carlo procedure is quite general and has been used to study radiative transfer in other geometries, like spheroidals which may be appropriate for starburst galaxies and ellipticals (Witt et al. 1992; Gordon et al. 1997; Baes & Dejonghe 2002) or young stars in their birth environment (Whitney, these proceedings).

Several other works have adopted radiative transfer recipes to deal with dust extinction, especially when modeling the spectral evolution in galaxies (see, for example, Charlot & Fall 2000; Granato et al. 2000). I have limited the review here only to models focused on the radiative transfer problem.
3. Radiative Transfer in a Homogeneous Medium

In radiative transfer models, the stellar disk is usually reproduced by a double exponential,

$$\rho = \rho_0 \exp \left( -\frac{r}{\alpha_*} - \frac{|z|}{\beta_*} \right),$$

(2)

where $\alpha_*$ and $\beta_*$ are the radial and vertical scalelengths of the distribution. Observations in the Milky Way and in other spirals suggest $\alpha_*/\beta_* \approx 10^{-15}$ (Bahcall & Soneira 1980; De Grijs & Van Der Kruit 1996) with trends of smaller $\beta_*$'s (Mihalas & Binney 1981) and larger $\alpha_*$'s (de Jong 1996) for bluer starlight (although the radial color gradients can also be explained with extinction; Peletier et al. 1995). In analogy with stars, Eq. 2 is also adopted for the dust distribution, with independent scalelengths $\alpha_d$ and $\beta_d$. A common assumption is that $\alpha_d = \alpha_*$ and $\beta_d \approx 0.5\beta_d$ (the latter needed to reproduce the extinction lanes observed in edge-on galaxies; Fig. 1). I will call this the standard model and parametrise the amount of dust in the disk by assigning a value to $\tau_V$, the V-band optical depth along the face-on direction through the disk plane.

In Bianchi et al. (1996) we have described the behavior of standard models with different $\tau_V$, extending the study to a larger set of parameters in Ferrara et al. (1999). A spheroidal distribution was also included to simulate the bulge in late types. For our first work we have used the Draine & Lee (1984) model to derive the dust properties ($\omega_\lambda$, $\Phi_\lambda$ and extinction law; the last needed to scale the opacity of models at different $\lambda$'s to $\tau_V$). Later, we have preferred an empirical approach, with extinction laws, albedos and phase functions derived from observations of Milky Way dust (Gordon et al. 1997; these proceedings).

Once images of simulated galaxies are produced, the variations of observable quantities (e.g. total magnitudes, surface brightnesses, colour gradients) can be analyzed as a function of the inclination and opacity of the disk (Byun et al. 1994). An important quantity that can be computed from the models is the attenuation $A_\lambda$, i.e. the ratio between the flux observed from a galaxy and the flux that would be observed in the absence of dust. To illustrate the importance of scattering and its effects, we show in Fig. 2 the behavior of $A_\lambda$ for two standard disks of different opacities ($\tau_V = 1$ and 5) and seen at different inclinations and wavelengths (solid lines). When scattering is not included (dotted lines) the attenuation is clearly overestimated. The effect is more important for disks seen face-on: due to the higher optical depth of any path along the plane of the disk, light is more easily scattered above the plane than in the edge-on direction.

The trend of $A_\lambda$ with wavelength reflects the trend in the Milky Way extinction law, which has been used for the models of Fig. 2. The main feature in $A_\lambda$ is the footprint of the 2175Å bump, whose strength and width depend on the geometry, dust opacity and inclination. The feature’s $\lambda$ dependence is in general smoother than one would expect for a dust screen of the same opacity in front of the galaxy, since in a galaxy model the observed flux includes light coming from different regions and having suffered different absorption and scattering. For the same reason, further smoothing is possible when considering clumpy dust distributions (next section). However, it is usually believed that radiative transfer alone cannot smooth the bump out completely (Vijh, Witt & Gordon 2003; Clayton, these proceedings). Thus, the featureless Calzetti law (Calzetti
2001) derived on starburst galaxies implies a different dust composition or size distribution in those objects (but see Granato et al. 2000 for a different view).

The attenuation is larger for models with larger $\tau_V$ (and for larger inclinations) but it does not increase indefinitely with increasing opacity. For high optical depths a saturation is reached when stars high above the plane of the galaxy, and thus unstirred, become the dominant component of the galactic flux. For the same reason, the colour of a galaxy does not become indefinitely redder for increasing $\tau_V$, as it would be for a screen of dust in front of a light source (Witt et al. 1992).

In Bianchi et al. (1996) the study of radiative transfer was extended to polarization due to scattering off spherical grains. While in some peculiar cases it is possible to reproduce the linear polarization pattern parallel to the galactic plane observed in the Milky Way and in most spirals (Whittet, these proceedings), for normal dust size distributions the linear polarization due to scattering is perpendicular to the disk. Polarization due to aligned grains is needed (Wood & Jones 1997), but so far a proper treatment of radiative transfer including dichroic extinction and scattering by elongated grains has only been applied to circumstellar environments (Whitney & Wolff 2002).

4. Radiative Transfer in a Clumpy Medium

A smooth exponential model is only a first approximation for galactic disks, which are observed to have a complex clumpy structure. Clumping can be easily
Figure 3. V-band major axis profiles for a clumpy disk with dust mass equivalent to that of a $\tau_V=1$ homogeneous standard disk. Clumps have the same exponential distribution as the diffuse dust. Profiles are shown for inclinations $i=20^\circ$ (nearly face-on) and $90^\circ$ (edge-on). Solid lines refer to models with 25%, 50%, 75% of the dust mass in clumps, from bottom to top, respectively. For comparison, we also show profiles for homogeneous disks (dotted lines) with $\tau_V=0.25, 0.5, 0.75, 1$ (from top to bottom).

incorporated in Monte Carlo simulations by dividing the three dimensional space in cells and assigning to each of them a clumpy or smooth status. In Bianchi & al. (2000c) and Misiriotis & Bianchi (2002) we modelled the dust distribution as a two phase medium, including a smooth exponential disk and a distribution of clouds. We assumed that the clumpy dust medium is associated with the molecular gas component of a spiral disk and we allowed for different fractions of dust mass in clumps (25, 50 and 75%) analogous to the fraction of gas mass in the molecular component in late-type galaxies; the mass and dimension (size of each cell) of the clumps were derived from Milky Way giant molecular clouds; the distribution of clumps was taken to be a ring, as for HII in the Milky Way, or an exponential, as for the molecular gas of most late type spirals.

As expected, models in which the distribution of dust is clumpy have a higher transparency than models in which the same amount of dust is in a homogeneous disk. However, for the parameter range we have explored the effects of clumping are moderate, with changes in attenuation laws and in the amount of absorbed energy of less than 30% in the V-band. In Fig. 3 we show the radial surface brightness profiles of clumpy models with the same amount of dust as a $\tau_V = 1$ homogeneous model. The distribution of clumps is exponential. Because of the low optical depth, in the face-on case there is hardly any difference be-
tween homogeneous and clumpy models. Instead, profiles for edge-on disks with clumping look brighter than the corresponding homogeneous one: for instance, the model with 75% of the dust in clumps has the same profile as a more transparent, $\tau_V = 0.5$, model. This is interesting, since comparisons between models and observations are more easily done at high inclinations, where the effects of dust are maximized and the geometric components of a galaxy can be easily separated (next section): if clumping is not taken into account, the amount of dust in a galaxy may be underestimated.

Unfortunately, clumping depends on the adopted parameterization. In the galaxy models of Kuchinski et al. (1998), for example, homogeneous and clumpy models of edge-on galaxies are very similar. They follow the Witt & Gordon (2000) formalism for clumping, with constant cloud filling factors and density contrast with respect to the smooth medium. For the parameters they adopted (based on a comparison with the cloud mass spectra in the Galactic ISM) most of the dust mass ($\approx 95\%$) is in clumps. As a result, any line of sight along the galactic plane will intersect a larger number of clumps than in our models, making little difference between the clumpy and homogeneous case.

I recall here that these general considerations are valid when clumping affects only the extinguishing medium. If we allow for a fraction of the starlight to be emitted inside clouds (as it is the case for young stars), models with clumping could be less transparent than a homogeneous one, depending on the amount of embedded radiation (Bianchi et al. 2000c).

5. Radiative Transfer vs Observations

A direct comparison between radiative transfer models for homogeneous dusty disks and observations of edge-on galaxies was done by Xilouris et al. (1999). Using the Kylafis & Bahcall approach, they fitted the surface brightness distribution of seven galaxies observed in the optical/NIR and obtained the parameters for the dust (disk) and stellar (disk + bulge) components. They derived a mean optical depth for the sample, $< \tau_V > \approx 0.6$, with the opacities in the various optical/NIR bands showing an extinction law similar to that in the Milky Way. Moderate-to-low opacities are compatible with those obtained with a variety of methods for the diffuse dust component (Calzetti 2001): the dust disks, thus, would be almost transparent when seen face-on and unable to produce a significant obscuration of the distant universe (Alton et al. 2001). As for the relative dust/star geometry, Xilouris et al. found that: $< \beta_d/\beta_* > \approx 0.5$, necessary to explain the dark extinction lane; $< \alpha_d/\alpha_* > \approx 1.4$, the dust disk thus being more extended than the stellar disk.

Tests on mock data have shown how disk dishomogeneities cannot severely bias a fit made with homogeneous distributions: the neglect of spiral structure only affects the derived parameters by less than few percent (Misiriotis et al. 2000); clumping can produce a moderate dust underestimation by $\leq 30\%$ in mass (somewhat less than predicted on the sole basis of the major axis profile; Misiriotis & Bianchi 2002) or even less for the clumpy disks of Kuchinski et al. (1998).

Other studies support extended dust disks: a large dust disk is invoked by Peletier et al. (1995) to explain the change of B-K colour gradients with the
inclination in a sample of 37 galaxies; the FIR emission observed in the Milky Way by the COBE satellite can be explained with an exponential dust disk with \( \alpha_d/\alpha_*=1.5 \) (Davies et al. 1997); a dust spatial distribution less concentrated than the stellar is suggested by coadded IRAS 100\( \mu \)m images of spiral galaxies (Nelson, Zaritsky & Cutri 1998).

Even more striking were the results of Alton et al. (1998b). They observed a sample of seven nearby resolved spirals at 200 \( \mu \)m with the ISOPHOT camera on board of the ISO satellite. Large amounts of cold dust (\( T \approx 20K \)) could be detected, which were previously missed by the satellite IRAS operating at wavelengths below the peak of dust emission. The scalelength in 200\( \mu \)m maps was larger than that observed by IRAS at 100\( \mu \)m, as expected for diffuse dust heated by the Interstellar Radiation Field (colder dust at larger distances from the centre, where the ISRF is less intense). However, the ISO emission was also found to be as extended as or broader than the B-band emission, implying a dust intrinsic scalelength larger than the stellar (\( \alpha_d/\alpha_* > 1 \)). How much larger?

6. Models of FIR Emission

The increasing availability of FIR data allows a more direct study of the dust content of a galaxy than extinction measures. To be able to compare radiative transfer models with observation at longer wavelengths, in Bianchi, Davies & Alton (2000a) we extended our simulations to include emission from dust heated by the ISRF. In particular, we were interested in verifying if the large emission scalelengths observed by Alton et al. (1998b) were compatible with the values of \( \alpha_d \) derived by Xilouris et al. (1999) for the intrinsic dust distribution.

The first step in a model of dust emission is computing the local heating ISRF or, correspondingly, the amount of energy that is absorbed by dust grains as a function of position inside the galaxy. This is straightforward in a Monte Carlo simulation where, for each light-grain interaction, the amount of energy absorbed and the position of the event is known. Once a Spectral Energy Distribution (SED) for starlight is adopted, several monochromatic simulations are run and a final map of the total energy absorbed from starlight can be produced.

More complex is deriving the dust temperature resulting from the heating. Sophisticated approaches will consider both thermal equilibrium emission from large grains and stochastic heating of small grains and PAHs (Popescu et al. 2000; Misselt et al. 2001). Since we were interested mainly in emission at \( \lambda > 100\mu \)m, we only considered the former. As stellar radiation is absorbed by all kind of grains, we used the dust model of Desert, Boulanger & Puget (1990) to derive the amount of energy that goes into non equilibrium emission (about 20-30\% of the infrared dust output) and subtracted it from the map of total energy absorbed. Then, the dust temperature was computed using an emissivity law derived from observations of the Milky Way FIR emission (Bianchi, Davies & Alton 1999). The same emissivity also tells us that FIR opacities are very low, at least for the diffuse medium we are dealing with. Thus, the optically thin regime can be considered: maps of emission can be produced by simply integrating the emission coefficient (a modified blackbody) along the chosen line of sight (i.e. for the FIR/submm, only \( j_\nu \) is left in the right hand side of Eq. 1).
In Bianchi et al. (2000a) we produced simulations for the spiral galaxy NGC 6946, whose stellar SED is well covered by observations from the UV to the NIR. For each geometry and \( \tau_V \) we chose, we carried out the radiative transfer for several wavelengths and we normalized the simulations at each \( \lambda \) to produce the same output in radiation as observed. That is, we derived \textit{a posteriori} the intrinsic, dust-free, emission that would result in the observed, dust-extinguished, flux. As a result, the intrinsic dust-free stellar SED depends on the adopted geometry and \( \tau_V \). Dust in NGC 6946 is observed to emit \( \approx 30\% \) of the galaxy bolometric luminosity. In this, NGC 6946 is very similar to other late type spirals in the nearby universe (Popescu & Tuffs 2002). In a realistic simulation, then, dust needs to be able to absorb 30\% of the stellar radiation. Such comparison between stellar and dust energy outputs is usually referred to as \textit{energy balance}.

I show here the results for an optically thin (\( \tau_V = 0.5 \)) and thick (\( \tau_V = 5 \)) standard (\( \alpha_d/\alpha_*=1.0 \)) model and an optically thick (\( \tau_V = 5 \)) extended (\( \alpha_d/\alpha_*=1.5 \)) model. All models have homogeneous exponential stellar and dust distributions with \( \beta_d/\beta_* = 0.5 \) and it is assumed that the relative stellar/dust geometry do not change with the wavelength of the starlight. The results are not significantly different if \( \beta_* \) is allowed to decrease with \( \lambda \) or if a bulge is included (both cases having a slightly larger efficiency in absorbing starlight for the same \( \tau_V \) because more stellar emission is inside the dust distribution; Bianchi 1999).

The temperatures distributions are very similar from model to model, with values similar to those derived in other galaxies and gradients that are compatible with those derived in the Milky Way (Fig. 4). A look at the SED for dust emission (Fig. 5) shows that the optically thin standard model does not absorb enough stellar radiation (only 5\%) to match the observed emission. For dust to be able to absorb between 25 and 40\% of the total bolometric luminosity, a standard model with optical depth \( 5 \lesssim \tau_V \lesssim 10 \) is needed. For a disk as in Xilouris et al. (1999) slightly more radiation is absorbed than in a standard disk with the same \( \tau_V \); the extended \( \tau_V = 5 \) model fits reasonably well the observed data by absorbing 30\% of starlight (of which 70\% is emitted at thermal equilibrium). The optically thin models inferred from observations, instead, do not have the necessary FIR energy output. The need for high optical depths for the energy balance in spirals is confirmed by other authors (Evans 1992; Trewhella 1998; Radovich, Kaahanpää & Lemke 2001; in the first two works the neglect of scattering may result in an overestimate of the absorption; the last work is a Monte Carlo radiative transfer simulation very similar to our own).

Popescu et al. (2000) and Misiriotis et al. (2001) modelled the dust emission for 5 of the 7 galaxies whose parameters where derived by Xilouris et al. (1999). Since they lack data in the UV, they provide the fitted stellar distributions with an extra, UV emitting, disk thinner than the dust distribution (i.e. \( \beta_{UV}^d/\beta_* < 1 \)). The Star Formation Rate in the UV disk is derived by allowing the model to fit the FIR emission in the two IRAS bands at 60\( \mu \)m and 100\( \mu \)m. The fitted values for the SFR are consistent with SFR normally observed in spirals. Without such UV emitting disk, the stellar and dust distributions of Xilouris et al. (1999) are not able to emit enough FIR flux. Unfortunately only for two objects (namely, NGC 891 and NGC 5907) they have datapoints at \( \lambda \)'s beyond IRAS data. When these submm observations are considered, the model is not able to predict the
corresponding flux, unless a supplementary disk of dust is included. If the new disk is as thin as the UV disk, it would be undetected in fits of edge-on surface brightness profiles, being obscured by the more vertically extended dust disk. Neglecting the new dust disk, the fits of Xilouris et al. (1999) underestimate the total dust mass by a factor between 2 and 4.

Although the sample analysed is limited, a common trend seems to emerge: the dust disks implied by the surface brightness distributions of edge-on galaxies do not provide enough absorption to explain the FIR emission. The discrepancy cannot be easily explained with clumping, at least with the clumping discussed in Sect. 4. A different parametrization for clumping of dust and sources may be needed. For instance, the thin extra UV and dust disks introduced by Popescu et al. (2000) and Misiriotis et al. (2001) may hide a distribution of sources still embedded in giant clouds. While clumping of dust does not modify significantly the FIR SED (Misselt et al. 2001), preferential emission within dust clouds could increase the efficiency of a dust disk in absorbing (and emitting) radiation.

What about the spatial distribution of FIR emission? Because of the temperature gradient, emission at longer wavelength is characterized by a larger emission scalelength, approaching the intrinsic radial dust scalelength $\alpha_d$ as $\lambda$ increases. While the extended disk model for NGC 6946 has a 100$\mu$m scalelength

Figure 4. Temperature gradient along the galactic plane for three different models (see text). Data points show the radial gradient of temperature in the Galaxy (derived from Sodroski et al. 1997). The cross marks the temperature of 21K at the Sun distance from the galactic centre (Bianchi et al. 1999).
Figure 5. Observed and modelled SED of NGC 6946. The models are the same as in Fig. 4. The solid line is the stellar SED derived from the observations (data points), which is the common UV-optical-NIR output for all models. The intrinsic, dust-free, stellar SED (shown for each single model in the figure) is derived \emph{a posteriori} from the radiative transfer simulations. The spike visible in the intrinsic stellar SEDs is due to the 2175 Å extinction feature, which is present in the MW extinction law assumed for dust but absent in the observed SED. The SED of dust emission is shown for each model in the FIR. More details in Bianchi et al. (2000).

similar to that observed in IRAS data, the broad 200µm emission observed by Alton et al. (1998b) cannot be explained. Models that could reproduce the 200µm emission \emph{(only)} require too broad distributions that are ruled out by observations (Bianchi et al. 2000a). Recently, concern has been raised on the results of Alton et al. (1998b): the mapping procedure with which the galaxy sample was observed is known to artificially broaden the detected emission when scanning over a bright source (Popescu et al. 2002). However, the broadening should be less important across the scan direction, where Alton et al. measured essentially the same scalelengths as those along the scan.

7. The Future

Despite the progress in modelling, a clear picture of dust extinction and emission in \emph{real} spiral galaxies is not yet available. A better understanding of the
problem will be possible when a detailed wavelength coverage of a galaxy SED is available, for a large number of nearby objects well resolved at each $\lambda$. Data around the peak of dust emission are obviously needed. A move in this direction is the SIRTF Nearby Galaxy Survey (SINGS; Kennicutt et al. 2003). Future SIRTF observations of a sample of 75 nearby objects will be integrated with other data from archives and supplementary programs, providing an unprecedented view on both dust emission and stellar emission. The latter will extend down to the UV, which is very important to understand if FIR emission in local universe spirals is a good tracer of recent star formation (Walterbos & Greenawalt 1996). The radiative transfer models of Popescu et al. (2000) and Misiriotis et al. (2001) propend for this hypothesis, while in our work dust preferentially absorbs radiation from old stars emitting in the optical/NIR (Bianchi et al. 2000a).

Good resolution in observations of dust emission is an advantage, especially to define the influence of clumping. Available submm instruments like the camera SCUBA can provide an adequate resolution but they are not sensitive enough to detect emission from diffuse regions, thus limiting the study to dense regions in face-on galaxies or to the inner disk in edge-on objects: for instance in the face-on NGC 6946 only emission associated with dense molecular gas could be detected (Bianchi et al. 2000b), while cold dust could be observed up to $2/3$ of the optical disk in the edge-on NGC 891 (Alton et al. 1998a). More sensitive and high resolution observations in the submm and in the FIR will be possible in the nearby future, from a variety of planned ground-based or satellite-born instruments and facilities (SCUBA2, APEX, SOFIA, Herschel, ALMA).

Together with the improvements in the observing capabilities, more refined radiative transfer models have to be developed, also gaining insights on the dust/stellar geometry by analyzing other observables affected by extinction, like polarization and observed kinematics (for the last issue, see the recent radiative transfer studies by Matthews & Wood 2001 and Baes et al. 2002, 2003).

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