THE EXTINCTION IN GALACTIC DISKS FROM A MULTIWAVELENGTH STUDY

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Abstract

We present the results of a model constructed to estimate the extinction in galactic disks. This model is based on the comparison between the escaped light (UV-optical-NIR emission) and the dust re-radiation (FIR emission). A radiative transfer model with a plan-parallel geometry is used, stars and dust are assumed to be mixed. Most galaxies of a sample of 152 galaxies which contains 18 starbursting objects exhibit a rather low mean extinction with less than $\sim$ 60% of the stellar emission converted in FIR.

The mean optical depth deduced from the model is compared to the mean gas surface density of a sub-sample of 29 spiral galaxies with available UV, FIR, HI and CO data: the optical depth is found to correlate with the molecular gas surface density but not with the HI gas alone.

The case of starburst galaxies is emphasized: our model appears to be relevant to the global extinction of these galaxies whereas a model using a foreground screen of dust which seems to be appropriate for the central starbursting regions cannot be applied to the entire galaxies.

1 Introduction

We propose a method to estimate the extinction in disk galaxies based on an energetic balance [13], [2]. Indeed, the stellar emission is absorbed by the dust which re-emits this energy in the far-infrared. Therefore, the comparison between the FIR emission (dust re-radiation) and the UV and optical emission (escaped stellar light) must constrain the amount of extinction. Similar approachs have been already proposed (e.g. [7]) but without including the UV wavelengths which are known to be very efficient to heat the dust.

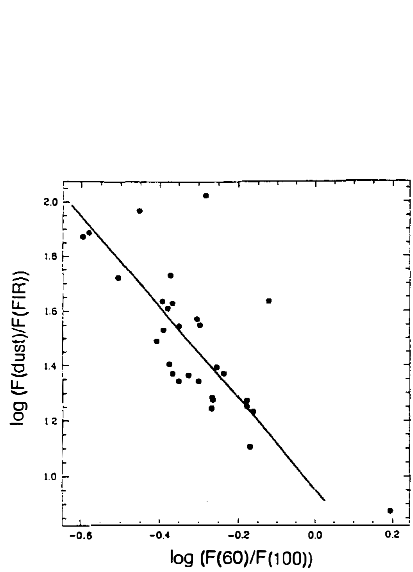

Figure 1: The ratio of the total dust to FIR (40-120 μm) fluxes as a function of the f_{60}/f_{100} color ratio for the galaxies studied in Andreani and Franceschini (1996)

2 Description of the model

The principle of our model is to calculate the ratio between the radiation absorbed by dust grains and re-emitted in the FIR-submm wavelength range to the stellar radiation escaping the galaxy as a function of the face-on optical depth (in the B band) and of the inclination of the galaxy. The comparison of the results of the model with the observed emissions of the dust and of the stars in galaxies leads to an estimate of the optical depth of these galaxies.

A detailed description of the model can be found in [13] and [2]: we use a radiative transfer in an infinite plan-parallel geometry where stars and dust are mixed. The model assumes a dust grain model as observed in the Solar Neighborhood. The stellar emission which heats the dust is divided in three components according to their wavelength range: the ionizing radiation ($\lambda < 91.2$ nm), the UV non-ionizing radiation ($91.2 - 365$ nm) and the optical-near infrared radiation ($\lambda > 365$ nm). A very sensitive parameter for the model is the scale height of the stars as compared to that of the dust [2]: our standard model assumes the same scale height for the dust and the UV non-ionizing radiation and twice this scale height for the optical-near infrared radiation.

3 The data

The disk galaxies are selected to be detected both in UV (around 200 nm [8] [6]) and in the FIR by IRAS (60 and 100 μm). The sample contains 152 spiral and irregular galaxies. Among them, 18 galaxies exhibit a far-infrared color $f_{60}/f_{100} > 0.55$, these galaxies are all reported as starburst galaxies in the literature.

The observed stellar emission of the galaxies is estimated from the UV (91.2 nm) to the NIR ($\sim 3\mu$m). It is splitted in a UV range ($91.2 - 365$nm) and an optical-NIR one ($\lambda > 365$ nm). Empirical spectra are used and scaled with the monochromatic fluxes at 200 nm for the

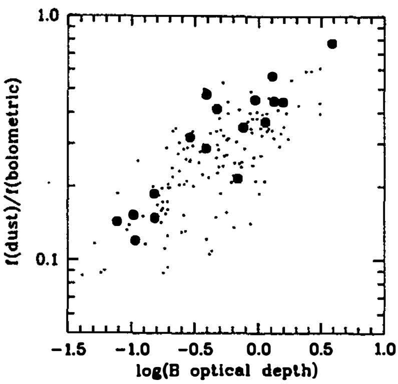

Figure 2: The ratio of the dust flux to the bolometric flux as a function of the B optical depth deduced from the model for the entire sample of 152 galaxies. Starburst galaxies are plotted with filled circles

UV range and with the blue fluxes for the optical-NIR one.

The dust emits from a few microns to around 1 mm whereas the combination of IRAS data at 60 and 100 μm is a reliable estimate of the dust emission only in the wavelength range 40-120 μm. Nevertheless it has been shown [13] that a strong anti-correlation exists between the ratio of the total dust emission to the FIR (40-120 μm) one and the FIR color ratio f_{60}/f_{100}. The relation is calibrated on the FIR/mm dust luminosities estimated by Andreani and Franceschini [1](figure 1, solid line): the ratio of the total dust emission and the FIR (40-120 μm) is roughly comprised between 1 and 1.4 for our sample galaxies.

4 Results and discussion

The results of our model on our sample of galaxies are presented in figure 2 where the ratio of the total dust emission to the bolometric (stars+dust) emission is plotted against the optical depth estimated in the B band. The quantity reported on the vertical axis does not depend on our model of radiative transfer. Except for some cases less than 60% of the stellar emission is re-emitted in the far-infrared even for starburst galaxies (plotted with filled circles); the more extinguished galaxy of our sample is Messier 82.

4.1 The importance of the UV non ionizing radiation to heat the dust

The contribution of the UV non ionizing radiation (91.2 − 365 nm) has been estimated for a sample of 152 spiral and irregular galaxies. In figure 3 the fraction of dust heating due to this radiation is plotted against the ratio of the UV (200 nm) to B flux. Except for very red Sa-Sbc galaxies, this fraction is found higher than 0.5: in most cases, the UV non ionizing radiation dominates the dust heating. Therefore the FIR emission of the dust and the UV non ionizing

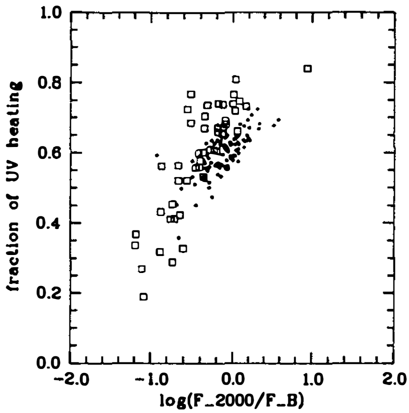

Figure 3: The fraction of dust heating due to the UV non ionizing radiation (91.2 – 365 nm) as a funtion of the UV (200 nm) to B flux for spiral and irregular galaxies,Sa-Sbc galaxies are plotted with squares, and Sc-Im galaxies with dots

radiation trace the star formation activity in these galaxies over similar timescales (some 10^8 years).

4.2 Optical depth and gas content

Is a correlation between the optical depth and the gas surface density like that found in the Milky Way valid for other galaxies? To answer this question we have used our model for a sample of 29 galaxies with CO and HI data available. Given the very different radial distributions of the atomic and molecular gas we only select galaxies for which HI profiles are available (V. Cayatte, private communication). Integrated CO fluxes are taken from [14] and [11]. The gas surface densities are estimated over half the optical diameter ($d_{25}/2$) assuming that all the molecular content is inside this diameter and using a standard CO to H_2 conversion factor [12]. A correlation is found between the optical depth estimated with our model and the molecular surface density (correlation coefficient R = 0.6) whereas no correlation at all is found with the HI surface density (R = 0) (figure 4). However it must be emphasized that 22 galaxies out of the 29 of the sample have a molecular surface density higher than the HI one.

4.3 The extinction in starburst galaxies

The validity of our model for the starburst galaxies is tested in figure 5 where the ratio of the dust flux to the observed UV flux at 200 nms is plotted against the ratio of the UV to B fluxes for the 18 starburst galaxies of our sample. As already found [6], a clear correlation is found between these two ratios, bluer galaxies having lower dust to UV flux ratios. Such a sequence can be due to the extinction or to the star formation history or both. We have investigated the effect of the extinction by using the generic spectrum for starburst galaxies proposed by Calzetti [3] which is equivalent to a star formation rate constant over 1-2 Gyr. For increasing optical

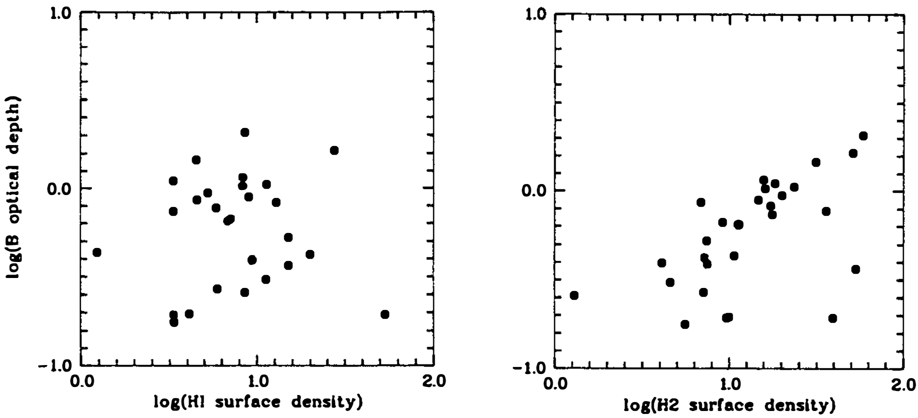

Figure 4: Optical depth on the B band as a function of the atomic and molecular gas surface densities estimated inside half the optical diameter

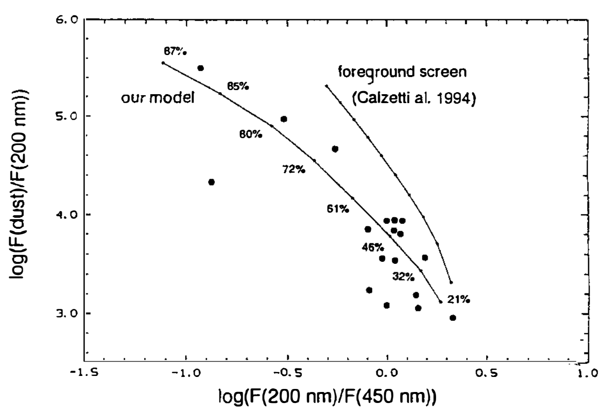

Figure 5: The ratio of the dust flux to the UV flux at 200 nms as a function of the ratio of the UV to B fluxes for the starburst galaxies of our sample

depths the two ratios have been calculated using our model, the percentage of the bolometric flux due to the dust is reported on the figure for each step. The model fits reasonnably the data leading to the result that the trend found in figure 5 is essentially due to the extinction at least for the starburst galaxies. We find again that in most cases less than $\sim 60\%$ of the stellar emission is converted in FIR-submm radiation(dust emission). The dispersion of the points can be easily explained by variations of the star formation history in these galaxies.

We have also used the empirical obscuration curve deduced for starburst galaxies with a foreground screen geometry [5] . This model does not fit at all the data. This is probably due to the fact that we use photometric data integrated over the entire galaxies whereas the obscuration curve [5] is obtained for the central parts of the galaxies (IUE diaphragm) where the starburst occurs. For the same reason the empirical obscuration curve is well adapted to the study of the central starbursts with HST [9]. However, when the emission over the entire galactic disk is concerned a model which assumes a mixing of stars and dust seems to be more appropriate.

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