

The observation of the nearby universe in UV and in FIR: an evidence for a moderate extinction in present day star forming galaxies

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Abstract. We study the FIR and UV-visible properties of star forming galaxies in the nearby Universe. This comparison is performed using the local luminosity functions at UV and FIR wavelengths and on individual starburst galaxies for which photometric data from UV to NIR and FIR are available.

The FIR and UV luminosity functions have quite different shapes : the UV function exhibits a strong increase for low luminosity galaxies whereas the FIR tail towards ultra luminous galaxies ($L > 10^{11} L_{\odot}$) is not detected in UV. The comparison of the FIR and UV local luminosity densities argues for a rather moderate extinction in nearby disk galaxies. The galaxies selected to be detected in FIR and UV are found to be located in the medium range of both luminosity functions.

An emphasis is made on starburst galaxies. For a sample of 22 of these objects, it is found that the UV (912-3650 Å), the visible (3600-12500 Å) and the NIR (12500-22000 Å) wavelength range contribute $\sim 30\%$, $\sim 50\%$ and $\sim 20\%$ respectively to the total emerging stellar emission (for a subsample of 12 galaxies for the NIR and visible light). The mean ratio of the dust to bolometric luminosity of these galaxies is 0.37 ± 0.22 similar to the ratio found for normal spiral galaxies. Only 4 out of the 22 galaxies exhibit a very large extinction with more than 60% of their energy emitted in the FIR-submm range. The mean extinction at 2000 Å is found to be ~ 1.2 mag although with a large dispersion. The UV, visible and NIR emissions of our sample galaxies are consistent with a burst lasting over ~ 1 Gyr. The conversion factor of the stellar emission into dust emission is found to correlate with the luminosity of the galaxies, brighter galaxies having a higher conversion factor. Since our sample appears to be representative of the mean properties of the galaxy population in FIR and UV, a very large conversion of the stellar light into dust emission can no longer be assumed as a general property of starburst galaxies at least in the local Universe. Instead a larger amount of energy emerging from the present starburst galaxies seems to come from the stars rather than from the dust.

We compare the UV properties of our local starburst galaxies to those of recently detected high redshift galaxies. The larger extinction found in the distant galaxies is consistent with

the trend we find for the nearby starburst galaxies namely the brighter the galaxies the lower the escape fraction of stellar light.

Key words: galaxies: starburst – galaxies: stellar content – galaxies: ISM – infrared: galaxies – ultraviolet: galaxies – dust, extinction

1. Introduction

One of the most important challenges of modern astronomy is the detection of young primeval galaxies. Indeed, very significant progress has been made with the detection of very high redshift galaxies either from ground based observations (Steidel et al. 1996b) or in the Hubble Deep Field (e.g. Steidel et al. 1996a, Lowenthal et al. 1997).

In order to understand the properties of high redshift galaxies and study the cosmological evolution of star-forming galaxies, it is crucial to properly characterize the properties of starburst galaxies in the local Universe. These nearby galaxies are forming stars with a very high rate and it is actually important to analyse their emission over the entire spectral range (from UV to FIR-submm) to study the efficiency of the dust extinction and to know what is the spectral range (UV, visible, NIR or FIR) where most of their energy is emitted. If high redshift star forming galaxies are similar to their low- z counterparts, studying the latter will bring some clues to detect the former. We can wonder whether the observation of the rest-frame UV continuum is the best way to detect high redshift galaxies or if the high obscuration from dust makes them emit more energy in the FIR.

IRAS discovered infrared bright galaxies with prodigious star formation rates, a very high extinction and therefore a low optical flux (Sanders & Mirabel 1996). The most luminous FIR galaxies are produced by strong interactions or merging of molecular gas-rich galaxies which induce enormous starbursts. Such objects might be the progenitors of elliptical galaxies (Kormendy & Sanders 1992). In a "bottom-up" scenario of galaxy formation, numerous starbursts induced by merging are expected and the bulk of their emission would be in the FIR redshifted in the submm (e.g. van der Werf & Israel 1996). Mazzei et al. (1994) predict that more than 90 % of the energy emitted by a starburst is in the FIR range during the first Gyr. This

percentage rapidly drops to reach $\sim 30\%$ for ~ 5 Gyr- old objects. Models aimed at explaining the galaxy counts in optical and FIR predict that during intense phases of star formation the quasi totality of the stellar light is absorbed and re-radiated in the FIR wavelength range (Franceschini et al. 1994, Pearson & Rowan-Robinson 1996).

Conversely, considerable effort has been carried out in the UV-optical study of star forming galaxies for some years. Calzetti, Kinney and co-workers have extensively used the IUE spectra of star-forming galaxies complemented with optical and IR data to characterize the star formation history and the extinction occurring in the central regions of these objects (Calzetti et al. 1994, Calzetti et al. 1995, Calzetti 1997a). Meurer et al. (1995) have used Faint Object Camera on board the *Hubble Space Telescope* HST-FOC observations to study the morphology of some starburst galaxies. From these studies, a foreground distribution of dust and a rather grey extinction curve seems to be able to explain the spectral distribution of the central regions of starburst galaxies. The extinction found by Meurer et al. (1995) for nearby starburst galaxies is rather low: at 2000 \AA it lies between 0.08 and 1.9 mag (excluding NGC7552 at 3.13 mag). Nevertheless these studies deal with the central parts of starburst galaxies and may well not be valid for the global emission of these objects at least when longer wavelengths than UV are concerned (Buat et al. 1997).

Analyses of the UV-optical and FIR global emissions of nearby spiral and irregular galaxies selected to be observed both in UV and in FIR led to a rather low extinction (Xu & Buat 1995, Buat & Xu 1996, Wang & Heckman 1996). An important result of these studies is that the UV non-ionizing stellar emission is likely to be the major cause of dust heating. The contribution of OB stars to the dust heating is estimated to amount to about 20% of the total FIR emission in the Milky Way (Cox & Mezger 1989), almost the same contribution of the ionizing radiation to the dust heating is found for spiral galaxies (Xu & Buat, 1995) and for starburst objects (Calzetti et al. 1995). The comparison between the FIR emission (dust re-radiation) and the UV and optical emission (escaped stellar light) constrains the extinction. As a consequence the FIR to UV continuum ratio is a powerful indicator of the extinction occurring in galaxies (Meurer et al. 1995, Buat & Xu 1996, Wang & Heckman 1996).

Recently, HST imaging of very high redshift galaxies complemented when possible by spectroscopic observations with the Keck Telescope have led to the discovery at high redshift ($z \sim 2 - 3$) of compact star forming galaxies with a moderate size and a strong rest-frame UV emission (Steidel et al. 1996a) with sometimes more diffuse extended structures (Lowenthal et al. 1997). Depending on the intrinsic UV spectrum adopted, the average extinction estimated at 1600 \AA from the rest-frame UV spectral energy distribution of these galaxies is of the order of 1.7 to 3 mag (Meurer et al. 1997, Calzetti 1997b). These significant average extinctions are therefore larger than the values estimated for nearby starburst galaxies. However, it must be noted that these high redshift galaxies are very luminous ($M_B < -21$) when compared to the mean luminosity of nearby starburst galaxies studied by Meurer et al. (1995) ($< M_B > = -18.6$)

and the extinction is known to correlate with the luminosity of galaxies (Giovanelli et al. 1995, Wang & Heckman 1997). Moreover, the selection biases are very strong towards very luminous galaxies with a strong UV continuum and it cannot be excluded that high redshift galaxies almost entirely hidden by the dust are missing from these observations in the rest-frame UV (Mobasher et al. 1996, Burigana et al. 1997).

The selection biases in the recent detections of high z galaxies are difficult or even impossible to quantify in the absence of similar observations at other wavelengths corresponding to longer than UV rest frame emissions (NIR or FIR). A first step is to estimate the importance of such a bias in the local Universe. Such a study is also crucial to compare the properties of high redshift galaxies to those in the nearby Universe.

At this aim we will adopt a global approach to study the local Universe which consists in comparing the luminosity functions and the luminosity densities in UV and FIR. The UV wavelength range is particularly interesting since it is a tracer of the recent star formation rate as already mentioned and observations in the visible range of high z (> 2) galaxies correspond to their UV rest frame emission. More specifically we will compare the amount of energy locked up in FIR to the amount of energy directly emitted in UV in the local Universe. The comparison of these global values with individual galaxies selected to be observed both in UV and FIR will allow to discuss how such samples of individual galaxies are representative of the mean properties of the local Universe.

We will also investigate the specific case of a sub sample of nearby starburst galaxies detected in UV, visible, NIR and FIR in order to compare their global dust and stellar emission and to estimate what fraction of the emission of stars is converted into dust emission as well as the relative contribution of the UV, visible and NIR spectral ranges to the observed stellar emission. Such estimates will lead to predict what spectral range is more favorable for the detection of high redshift starbursts under the hypothesis that they are similar to their nearby counterparts. The main limitation to this approach is that we deal with global fluxes integrated over the galaxies whereas the starburst often occurs in the central parts. Moreover the galaxies at high redshift so far detected seem to have compact morphologies. Nevertheless as it will be shown in section 4 a large fraction of the UV emission of a starburst galaxy is likely to come from the starburst itself making valid a study on the global fluxes as soon as this wavelength is concerned. It is also the case for the FIR emission since the UV (ionizing and non ionizing) emission is the major contributor to the dust heating, especially in starbursting objects. Obviously, more care must be taken when dealing with the visible and NIR emission: at these wavelengths the contribution of the underlying old stellar population present in local starburst galaxies is very large even dominant. Endly, available FIR fluxes on large samples are integrated over the galaxies due to the poor resolution of the IRAS satellite and dealing with global fluxes allows a reliable comparison of the emission of galaxies at different wavelengths.

Beyond the detection of high redshift star forming galaxies it is necessary to estimate a quantitative star formation rate

(SFR) for these galaxies. The deduction of such a quantity from the observed rest-frame UV continuum relies almost entirely on the amount of the extinction with only a moderate dependence on the star formation history (e.g. Meurer et al. 1997, Calzetti 1997). More specifically after $\sim 5 \cdot 10^7$ years of constant star formation rate the UV flux (912-3650 Å) reaches 80 % of its stationary value calculated for 10^{10} years of constant star formation (from Bruzual & Charlot 1993). From a global energetic budget, we will try to constrain the amount of extinction and bring some clues to this difficult problem.

2. The data on individual galaxies

Our study is based on samples of galaxies detected in UV and for which FIR data are available. We have used the UV observations ($\sim 2000\text{Å}$) of the balloon borne telescopes SCAP and FOCA (Donas et al. 1987, 1990, 1995) together with those obtained with FAUST (Deharveng et al. 1994). The FIR data come from the IRAS database.

First, we will re-consider a sample of 152 galaxies already compiled (Buat & Xu 1996) in order to investigate the selection biases inherent to our selection.

Second, we built a sample of starburst galaxies. These starburst galaxies are selected according to their far-infrared color: $f_{60}/f_{100} > 0.55$. It ensures a dust temperature larger than 36K assuming a single temperature thermal model and a dust emissivity index equal to 1 in agreement with the definition of starburst galaxies adopted by Pearson and Rowan-Robinson (1996). These starburst galaxies are selected to be observed in UV photometry and by IRAS at 60 and 100 μm . For galaxies belonging to the Coma, Abell 1367 or Virgo clusters, the visible and NIR data come from Gavazzi et al. (1996a,b), Gavazzi & Boselli (1996 and references therein), Boselli et al. (1997) and Boselli et al. (1998, in preparation); the FIR data are compiled by Gavazzi (private communication). The data for non cluster galaxies are from de Vaucouleurs et al. (1991, RC3) and the IRAS database. Active galaxies are excluded. 22 galaxies are selected and gathered in Table 1. Most of the galaxies of this sample (and all the nearest ones not belonging to Coma or Abell 1367 clusters) are reported in the literature as experiencing a starburst.

The distances of nearby galaxies are taken from Tully (1988). The distances to A1367 and Coma clusters are taken to 87 and 92 Mpc respectively. When the galaxies do not belong to a cluster and are not listed in Tully's catalog, their radial velocity are taken from the RC3 and the distances computed assuming $H_0 = 75\text{km/s/Mpc}$ in consistency with Tully; h is defined as $H_0/100$.

3. Comparison of the local luminosity functions at 60 μm and 2000 Å

3.1. The luminosity functions at 60 μm and 2000 Å

The local FIR luminosity function at 60 μm has been determined from IRAS observations (e.g. Soifer & Neugebauer 1991, Saunders et al. 1990, Koranyi & Strauss 1997). Saunders et al. used

Table 1. Starburst galaxies ($f_{60}/f_{100} > 0.55$) detected to be observed in FIR and UV. (1) Name NGC, IC or Zwicky by order of preference, (2) morphological type using the RC3 nomenclature, (3) absolute B magnitude, (4) 60 to 100 μm flux ratio and (6) ratio of the FIR (40-100 μm) to UV (defined as νF_ν at 2000 Å) luminosities

Name	Type	M_b	f_{60}/f_{100}	$L_{\text{FIR}}/L_{\text{UV}}$	NIR data
NGC3034	8	-19.52	0.64	172.72	
NGC3353	3	-17.92	0.78	3.98	
NGC3913	5	-19.01	0.59	2.72	H
NGC4194	10	-20.00	0.98	25.53	
NGC4383	1	-18.50	0.66	3.85	J H K
NGC4424	1	-18.71	0.56	8.19	H
NGC4519	5	-18.79	0.58	1.48	J H K
NGC4532	8	-18.81	0.58	2.46	J H K
NGC4670	8	-17.19	0.59	1.26	H
NGC4922	8	-19.72	0.81	107.85	H
NGC5253	8	-16.76	1.09	2.05	
NGC5477	9	-14.68	0.58	0.43	
NGC7673	5	-20.20	0.64	1.65	
NGC7677	4	-19.46	0.67	3.60	
IC732	8	-18.76	0.65	243.66	H
IC3258	10	-17.51	0.56	0.65	
IC3576	9	-17.12	0.60	0.47	
Z97068	4	-20.03	0.55	7.66	J H K
Z97079	8	-18.83	0.60	1.47	J H K
Z160076	5	-18.95	0.76	0.65	H
Z160106	8	-19.48	0.73	9.05	J H K
Z160139	8	-18.80	0.62	1.09	H

a compilation of samples and determined an analytical expression of the luminosity function at 60 μm . This analytical form will be used hereafter.

Recently, the spectroscopic follow-up of ultraviolet observations at 2000 Å allowed to estimate a local UV luminosity function (Milliard et al. 1997, Treyer et al. 1997). In spite of the small number of galaxies involved in the determination of the UV luminosity functions we compare the shapes of these functions at 60 μm and 2000 Å (Fig. 1). In this figure the UV luminosity function is represented by the Schechter function fitted by Treyer et al.. The largest observational errors quoted by Treyer et al. reach 0.8 in units of $\log(\Phi)$ (vertical axis in Fig. 1) at the faint and bright ends of the UV luminosity function whereas the error bars reported by Saunders et al. correspond to ~ 1 . in units of $\log(\Phi)$ at the faint end and ~ 0.5 at the bright end of the 60 μm luminosity function. Fig. 1 clearly shows that the two functions exhibit very different shapes at a high level of confidence : the UV luminosity function rises sharply for low luminosity galaxies while the tail of FIR bright galaxies has no counterparts in UV. Note however that Milliard et al. (1997) do not observe the knee in the UV luminosity function with a rather monotonic decrease towards large luminosity galaxies. A more thorough comparison of the luminosity functions is beyond the scope of this paper and devoted to a subsequent work.

The study of disk galaxies detected in UV and FIR led to a moderate extinction even in UV around 0.5-1 mag (Buat &

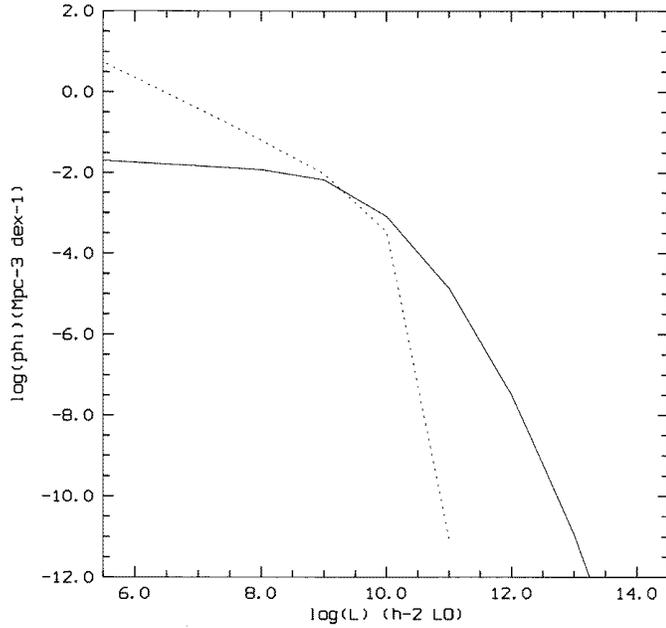


Fig. 1. Luminosity functions at $60\mu\text{m}$ (solid line) and 2000 \AA (dotted line) with $h=0.75$. The luminosity of the galaxies at the wavelength considered ($60\mu\text{m}$ or 2000 \AA) is reported on the x-axis. The luminosities expressed in solar units are defined as νL_ν

Xu 1996, Wang & Heckman 1996, Buat 1997). However, the impact of these studies is limited by the difficulty to estimate and understand the selection biases inherent to the fact that the galaxies must be detected in UV and FIR. We can test these potential biases by comparing the luminosity distributions of samples of galaxies selected to be detected in UV and FIR to more global luminosity functions. At this aim, we use the largest sample compiled by us which consists in 152 spiral and irregular galaxies (Buat & Xu 1996). In Fig. 2 are reported the luminosity distributions of these galaxies at $60\mu\text{m}$ and 2000 \AA . By a comparison with the luminosity functions of Fig. 1, we can see that we select galaxies near the "knee" of the luminosity functions. The sharp decrease at low luminosities is due to the detection limits. The luminosity distribution of our sample of starburst galaxies presented in Table 1 is also reported in Fig. 2. The distribution of their UV luminosity is consistent with that of the former sample. These galaxies appear to have in average a slightly larger luminosity at $60\mu\text{m}$ in agreement with the result of Saunders et al. (1990). In conclusion the galaxies we study have medium luminosities at each wavelength. As we may have expected, the effects due to the UV-based selection of galaxies are counterbalanced by the necessity to have these objects also detected in FIR. We can therefore conclude that *galaxies selected in such a way can be considered as representative of the mean population of galaxies.*

3.2. The UV and FIR local luminosity densities

It is important to know what fraction of the energy emitted by a star forming galaxy will fall in the UV or FIR range. This result

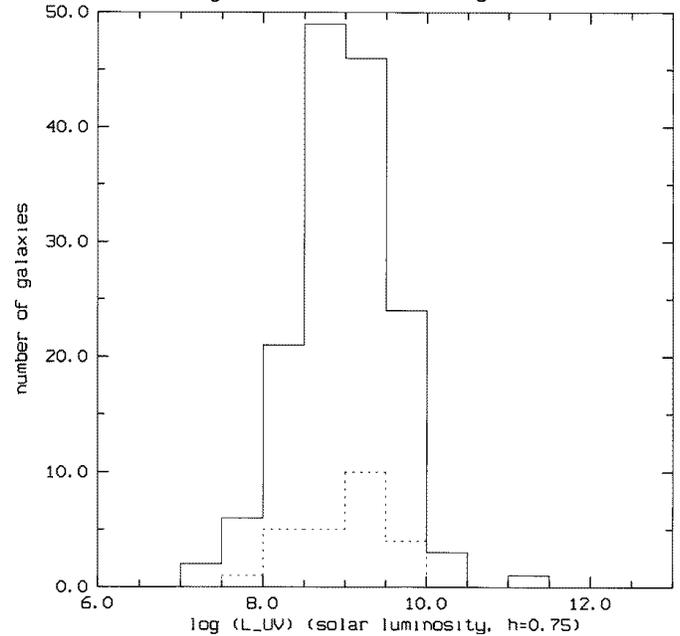
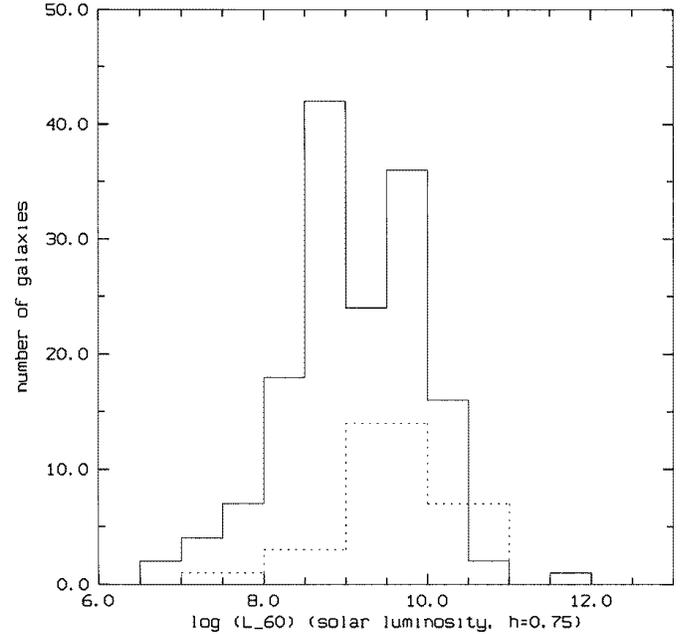


Fig. 2a and b. Luminosity distributions at **a** (upper panel) $60\mu\text{m}$ and **b** (lower panel) 2000 \AA for galaxies detected at both wavelengths. The distributions of starburst galaxies are plotted with a dotted line

will allow us to predict which of the two spectral domains is best suited to search for high- z star-forming objects. Moreover, the comparison of the FIR and UV emissions of galaxies has been recognized to be a powerful way to estimate the extinction (e.g. Meurer et al. 1995, Buat & Xu 1996, Wang & Heckman 1996), the UV non-ionizing flux being found to dominate the dust heating (Buat & Xu 1996 but see Trewhella et al. 1997). In the following, we will estimate this ratio deduced from local luminosity densities and for individual galaxies.

Saunders et al. (1990) estimate the local luminosity density at $60\mu\text{m}$ (defined as the product of the frequency ν by the

luminosity density per unit frequency at $60\ \mu\text{m}$) and in the FIR ($40\text{--}120\ \mu\text{m}$) range:

$$\rho_{60} = (4.2 \pm 0.4) \times 10^7\ h\ L_{\odot} / \text{Mpc}^3$$

$$\rho_{\text{FIR}} = (5.6 \pm 0.6) \times 10^7\ h\ L_{\odot} / \text{Mpc}^3$$

The local luminosity density at $2000\ \text{\AA}$, defined as the product of the frequency ν by the luminosity density per unit frequency at $2000\ \text{\AA}$, is found to be (Milliard et al. 1997, Treyer et al. 1997) :

$$\rho_{\text{UV}} = (6.3 \pm 2.7) \times 10^7\ h\ L_{\odot} / \text{Mpc}^3$$

From the values quoted above we deduce :

$$\rho_{\text{FIR}} / \rho_{\text{UV}} = 0.9 \pm 0.5$$

The global ratio of the luminosity densities can be compared to the ratio between the FIR and UV emissions of individual galaxies. First, we use the sample of 152 spiral and irregular galaxies (Buat & Xu 1996) for which we find :

$$\langle L_{\text{FIR}} / L_{\text{UV}} \rangle = 3$$

Given the very large dispersion ($\sigma = 5$) of the ratio we have also measured the median of the distribution which is found equal to 1.6. Second, the case of starburst galaxies is also explored. Table 1 lists the ratio between the FIR and UV luminosities for these galaxies. These values are also very dispersed extending from 0.4 to 244 with a median value equal to 2.5. Therefore from the comparison of the FIR to UV ratio the selected starburst galaxies seem to be slightly more obscured than the mean of spiral and irregular galaxies as already found from the luminosity distributions. Nevertheless such a conclusion must be taken with caution since the calibration of the FIR to UV ratio in terms of extinction might well depend on galaxy properties like the dust temperature or the star formation history.

An other way to compare the FIR and UV emissions of individual galaxies to the luminosity densities consists in estimating the local UV density using the luminosity function at $60\ \mu\text{m}$ and the L_{UV}/L_{60} ratio found for individual galaxies. Such an approach has the advantage to be independent of the shape of the UV luminosity function which is not yet very secure due to the small number of galaxies involved (Milliard, private communication). A correlation is found between the L_{UV}/L_{60} ratio and the L_{60} luminosity as shown in Fig. 3. A linear regression gives :

$$\log(L_{\text{UV}}/L_{60}) = 18.56 - 0.44 \log(L_{60})$$

where the independent variable L_{60} is expressed in erg/s . The local luminosity density at $2000\ \text{\AA}$ can be calculated as :

$$\rho_{\text{UV}} = \int_{L_{60\ \text{min}}}^{\infty} \phi(L_{60}) \cdot (\rho_{\text{UV}}/\rho_{60}) \cdot d(\log(L_{60}))$$

where $\phi(L_{60})$ is the present epoch $60\ \mu\text{m}$ luminosity function estimated by Saunders et al. (1990) and $\rho_{\text{UV}}/\rho_{60}$ is equal to L_{UV}/L_{60} .

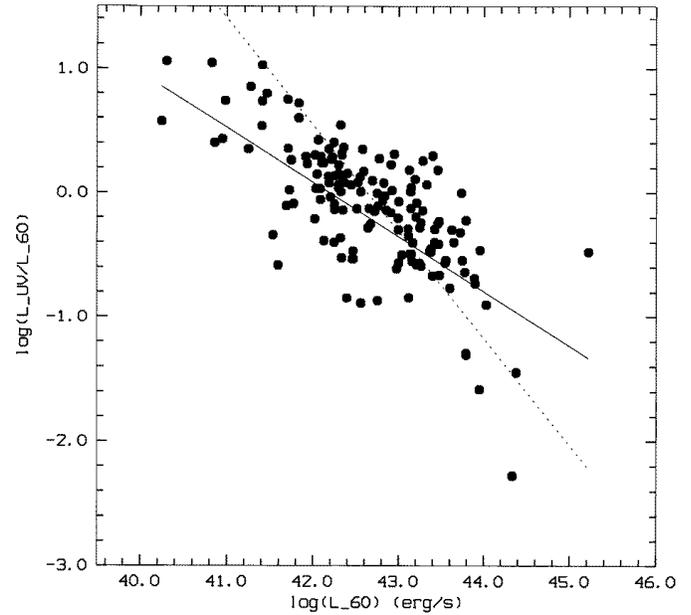


Fig. 3. L_{UV}/L_{60} luminosity ratio as a function of the L_{60} luminosity at $60\ \mu\text{m}$

The lower boundary of the integral $L_{60\ \text{min}}$ has to be estimated according to the limiting absolute UV magnitude used to evaluate the local luminosity density. Treyer et al. (1997) adopt $M_{\text{UV}} < -16$ for $H_0 = 100\ \text{km/s/Mpc}$ which translates to $M_{\text{UV}} < -16.6$ for $H_0 = 75\ \text{km/s/Mpc}$. Using the regression formula between $\log(L_{\text{UV}}/L_{60})$ and $\log(L_{60})$ we find $L_{60\ \text{min}} = 1.1 \cdot 10^{41}\ \text{erg/s}$. Milliard et al. (1997) have calculated the local luminosity density at $2000\ \text{\AA}$ with an extrapolation at fainter magnitudes. The difference between the two estimates of the local luminosity density is within the error bars estimated by Treyer et al. (1997). Therefore we will use the lower limit calculated above to calculate the local UV luminosity density.

We obtain :

$$\rho_{\text{UV}} = 1.3 \times 10^7\ L_{\odot} / \text{Mpc}^3$$

with $h = 0.75$. This value is lower than the observed one: $\rho_{\text{UV}} = 3.5 \times 10^7\ L_{\odot} / \text{Mpc}^3$ in agreement with the fact that the selected galaxies have a larger FIR to UV ratio than that found from the local luminosity densities. However the dispersion in Fig. 3 is large; we can estimate the uncertainty in our calculation by considering the regression taking $\log(L_{\text{UV}}/L_{60})$ as the independent variable, the corresponding regression line is plotted in Fig. 3 (dotted line). This leads to $\rho_{\text{UV}} = 3.5 \times 10^7\ L_{\odot} / \text{Mpc}^3$ similar to the observed value but the adopted regression clearly overestimates the UV flux of low luminosity galaxies in the sample.

Therefore, in spite of the uncertainties of our calculation the calculated UV luminosity density is lower than the observed one as expected since our selection lacks the low luminosity galaxies detected in UV but not in FIR (Fig. 1) and which largely contribute to the local UV density. Once again this analysis

leaves no much room for a lot of galaxies with a very high extinction missed by the UV observations.

From the analysis of the local luminosity densities, a similar amount of energy seems to be present in the UV and the FIR spectral range. We must note, however, that this estimate is very crude since the energies are defined as the product of a monochromatic flux per unit frequency by the observed frequency independently of the spectral distribution. For individual galaxies a larger amount of energy is found in FIR as shown in Fig. 3. We will re-discuss this result in the next section with a more careful analysis of the spectral energy distributions of individual starburst galaxies.

4. The stellar and dust emissions of starburst galaxies

We now focus on the case of starburst galaxies (Table 1). We have seen in the previous section that our sample can be considered as typical as far as the luminosity at both wavelengths is concerned.

A rather straightforward way to estimate the extinction in a bolometric sense (without a wavelength dependence) is to compare the total (stars+dust) emission of a galaxy to the dust emission alone. Models for dust extinction including geometry and radiation transfer are needed to estimate the extinction at each wavelength but not for such a global approach. Therefore we will not have to discuss the various sources of dust heating and their relative contribution to the dust emission.

At this aim we have to estimate the dust and stellar emissions emerging from the galaxies. The comparison of the FIR and stellar properties of galaxies has been intensively made in the literature (e.g. Disney et al. 1989, Trewhella et al. 1997) but without accounting for the emission in the UV spectral range. Actually, the UV non ionizing stellar light from 912 to 3650 Å is found to dominate the dust heating in most galactic disks (Buat & Xu 1996). Moreover, the contribution of the UV flux to the total stellar light produced in a galaxy can be estimated using synthetic spectra of galaxies. From population synthesis models (Bruzual & Charlot 1993) assuming a constant star formation rate over 1 Gyr, 2 Gyr and 20 Gyr and no extinction, the ratio of the UV (912-3650 Å) flux to the flux emitted from 912 Å to 1 μm is equal respectively to 0.66, 0.63 and 0.50. Therefore, an accurate estimate of the flux emitted by a galactic disk in UV is crucial for an analysis of the energy budget.

4.1. The total dust emission

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 40-120 μm wavelength range. Nevertheless, using the total dust emission calculated by Kwan & Xie (1992) for 11 galaxies, Xu & Buat (1995) showed 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} . Here, we re-calibrate the relation with the new FIR/mm dust luminosities reported by Andréani and Franceschini (1996). In Fig.4 is reported the ratio of the total dust emis-

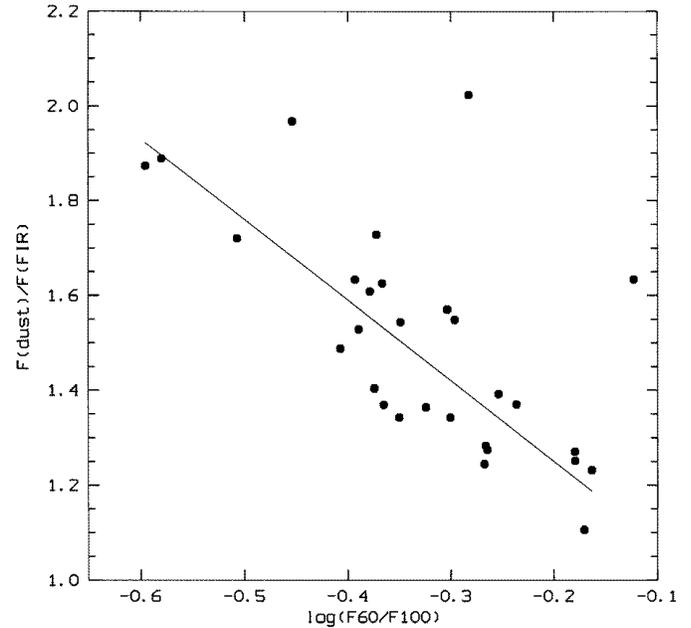


Fig. 4. The ratio of the total dust to FIR (40 - 120 μm) fluxes as a function of the F_{60}/f_{100} color ratio for the galaxies observed by Andréani & Franceschini (1996)

sion to the FIR one for the 29 galaxies studied by Andréani and Franceschini (we have excluded one Seyfert galaxy). A strong anti-correlation is found and a linear regression gives :

$$F_{\text{dust}}/F_{\text{FIR}} = -1.7(\pm 0.2) \cdot \log(F_{60}/F_{100}) + 0.91(\pm 0.11)$$

The ratio of the total dust emission and the FIR (40 - 120 μm) is found between 1 and 1.35 for the starburst galaxies of our sample. This results differs by only 30% from that obtained previously (Xu & Buat 1995). Andréani and Franceschini use two components (a cirrus and a dust component) to fit the fir-submm spectrum whereas Kwan and Xie (1992) introduced a dust model with a continuous dust temperature distribution. Modeling the FIR emission with a single temperature component leads to a ratio between the total dust flux (1-500 μm) to the FIR one also compatible with our estimate within the same uncertainty of 30% whatever the adopted emissivity law (Helou et al. 1998). Indeed whereas the determination of the dust mass is very dependent on the number of dust components and of their characteristics (temperature, emissivity) the total dust emission is not very sensitive to the adopted dust model (e.g. Devereux & Young 1992).

4.2. The total stellar emission

The stellar light emerging from a galaxy covers a large spectral range from the Lyman limit to a few microns. Therefore the total observed emission of stars must be estimated over this spectral range. Since we deal with global fluxes only photometric data at different wavelengths are available : UV fluxes at 2000 Å, U, B, V and in some cases J, H, and K data. These data constitute

broad band spectra which can be used to estimate the global stellar emission emerging from the galactic disks.

In previous works (Xu & Buat 1995, Buat & Xu 1996) we estimated this observed stellar emission using empirical spectra indexed on the morphological type of the galaxies. Although valid for normal galaxies which are the bulk of the objects sampled in these papers, such an approach is not valid for starburst galaxies since the UV light distribution in these objects is likely to be dominated or at least largely influenced by the starburst and is therefore probably not representative of the morphological type of the galaxy.

The method adopted here consists in integrating the observed broad band spectra. However we have to consider all the emission longward the Lyman limit with only 7 photometric data in the best cases. The situation is particularly difficult in the UV range with only one flux at 2000 Å to cover the wavelength range 912-3650 Å. Nevertheless Calzetti et al. (1994) have shown that the UV spectrum of central regions of starburst galaxies can be fitted by a power law $F_\lambda \propto \lambda^\beta$ from 912 to 2600 Å; the slope β is supposed to depend only on the extinction. The extension of this study to the emission of the entire galaxies is not straightforward because of the contribution of the non starbursting regions to the total UV emission. A first way to estimate the contribution of the starburst to the integrated UV emission is to use population synthesis models. Using the models of Bruzual and Charlot (1993) we have added a starburst lasting 10^7 years and involving a fraction of the total stellar mass to a constant star formation rate over 10^{10} years (underlying disk population). For a fraction of 10% of the total stellar mass created in the burst (Satyapal et al. 1988, Wright et al. 1997) more than 80% of the flux at 2000 Å comes from the starburst. Another way to estimate the contribution of the starburst is to consider the observations of resolved galaxies. Indeed the central starburst regions of two galaxies in our sample (NGC 4670 and NGC 5253) have been observed with the HST at 2200Å (22" × 22" field, Meurer et al. 1995). The integrated UV fluxes over the entire galaxies at 2000 Å reported in table 1 are 1.2 times larger than the flux measured in the HST field: 80 % of the total flux at 2000Å of these galaxies comes from the central starburst region. However these galaxies are classified as irregular galaxies and the contribution of an underlying old population could be expected to be negligible for such objects. Therefore we have also to envisage the case of earlier type galaxies. To this aim we have considered the starburst SBbc galaxy NGC 3310 observed both with the Ultraviolet Imaging Telescope (Smith et al. 1996) and with HST (Meurer et al. 1995). The central region observed with HST is found to contain 35% of the total UV flux (Smith et al. 1996). Nevertheless, a large part of the remaining UV emission of NGC3310 is located in compact sites of recent star formation (Smith et al. 1996) as it is also the case for other disk galaxies like Messier 33 for example (Buat et al. 1994). Therefore except perhaps in the case of very early type galaxies (only 3 galaxies of our sample have a morphological type earlier than Sbc) where the contribution of a population outside the sites of recent star formation might be quite important, applying the results found for the UV emission

of starbursting regions to the entire galaxies is likely to be a good approximation.

To estimate the slope of the UV spectrum we use the correlation found by Meurer et al. (1995) between β and the FIR to UV flux ratios. More precisely, we use the curve calculated by Meurer et al. (their Fig. 6) using a foreground screen model and the extinction curve of Calzetti et al. (1994). The unreddened slope of the UV spectrum adopted by Meurer et al. is $\beta = -2.5$ corresponding to a starburst younger than 100 Myr. We have also tried the case of a constant star formation rate over 1 Gyr which implies $\beta = -2$ for the unreddened UV spectrum and we have checked that the difference in both estimates of the fraction of energy emitted in the UV range reaches only a few percents.

Beyond 2600 Å, we directly integrate the spectral energy distributions obtained with the U, B, V, J, H and K data and no model fitting. Only 6 galaxies have been observed at every wavelength. From V to K the shape of the SED in log-log units is almost linear. 7 galaxies have an H magnitude (without J and K data) and for these objects we assume a linear spectral energy distribution from V to K. The error due to this approximation is estimated for the 6 galaxies for which all the data are available and is found to be 7% for the estimate of the energy contained between the J and K band and only 2% for the estimate of the total stellar flux. The case of the 9 remaining galaxies not observed at all in the NIR is more difficult. Nevertheless for the 12 galaxies for which at least one NIR band is available a very tight correlation (correlation coefficient equal to 0.99) with a slope equal to 0.98 ± 0.02 is found between the logarithm of the total stellar flux and the logarithm of the flux emitted in the visible range from U to V (the latter being chosen as the independent variable). The correlation is more dispersed when the UV range is accounted for. Therefore the total stellar flux is calculated from the flux emitted in the (U-V) range by forcing the slope of the linear regression to 1. We obtain $\log(F_{\text{star}}) = \log(F_{\text{U-V}}) + 0.90$. The error is estimated to be 12 % using the 15 galaxies for which NIR data are available.

In Table 2 are reported the stellar and dust fluxes estimated for each starburst galaxies together with the contribution of the UV (912-3650Å), visible (3650-12500Å) and NIR (12500-22000 Å) wavelength ranges. The major contribution to the total stellar flux is from the visible wavelengths (from U to J) with $51 \pm 11\%$, $32 \pm 19\%$ of the emitted energy comes from the UV and $19 \pm 11\%$ from the NIR. Note however that the very large contribution of the visible wavelengths is mainly due to the fact that the range is extended up to 12500 Å due to the lack of data between the V and J band.

4.3. *The comparison between the dust and stellar emission of the starburst galaxies*

The ratio of the dust luminosity to the bolometric (stars+dust) one may be taken as a global measure of the extinction at least in a crude way (e.g. Xu & Buat 1995, Andréani & Franceschini 1996). In Fig. 5a the logarithm of this ratio is plotted against the absolute B magnitude of the galaxies. A clear trend is found for

Table 2. Stellar and dust emissions of the selected starburst galaxies. The fluxes are in $\text{erg}/\text{cm}^2/\text{s}$. F_{star} is the total stellar flux emerging from the galaxies, F_{UV} is the stellar flux between 912 and 3650 Å, F_{vis} between 3650 and 12500 Å and F_{NIR} between 12500 and 22000 Å. F_{dust} is the total dust flux of the galaxies.

Name	$\log(F_{\text{star}})$	$\log(F_{\text{dust}})$	$\frac{F_{\text{UV}}}{F_{\text{star}}}$	$\frac{F_{\text{vis}}}{F_{\text{star}}}$	$\frac{F_{\text{NIR}}}{F_{\text{star}}}$
NGC3034	-10.63	-10.22	0.03		
NGC3353	-12.31	-12.53	0.28		
NGC3913	-13.36	-13.74	0.25	0.56	0.19
NGC4194	-12.28	-11.93	0.14		
NGC4383	-12.09	-12.28	0.24		
NGC4424	-12.10	-12.61	0.07	0.69	0.24
NGC4519	-12.03	-12.54	0.37	0.49	0.14
NGC4532	-12.00	-12.19	0.42	0.44	0.14
NGC4670	-12.21	-12.66	0.50	0.41	0.09
NGC4922	-13.00	-12.48	0.05	0.65	0.30
NGC5253	-11.35	-11.83	0.36		
NGC5477	-12.77	-13.69	0.56		
NGC7673	-12.27	-12.52	0.61		
NGC7677	-12.58	-12.61	0.39		
IC732	-13.34	-12.61	0.03	0.57	0.40
IC3258	-12.48	-13.43	0.33		
IC3576	-12.63	-13.68	0.38		
Z97068	-12.92	-12.83	0.20	0.55	0.25
Z97079	-13.28	-13.57	0.60	0.32	0.08
Z160076	-13.35	-14.15	0.54	0.40	0.06
Z160106	-13.23	-13.40	0.12	0.62	0.26
Z160139	-13.09	-13.62	0.51	0.45	0.04

brighter galaxies to be more obscured as already known (e.g. Giovanelli et al. 1995, Wang & Heckman 1996). Except for 4 objects, less than 60% ($\log(F_{\text{dust}}/F_{\text{bol}}) < -0.2$) of the total stellar emission is re-emitted in the FIR range and the fraction is very low (less than 15% or $\log(F_{\text{dust}}/F_{\text{bol}}) < -0.8$) for 5 galaxies. The same variation is found when the ratio of the dust luminosity to the UV one alone is considered (Fig. 5b) as expected since this ratio is closely related to the extinction (Buat & Xu 1996, Wang & Heckman 1996). No trend is found with the morphological type of the galaxies.

The mean and the median of the ratio of the dust to bolometric luminosity is 0.35 ($\sigma = 0.22$) similar to that found for normal spiral galaxies like the Milky Way (around 30%, Cox & Mezger 1989, Xu & Buat 1995). Therefore, in average a larger amount of energy is emitted by the stars than by the dust. However the dispersion is very large due to two groups of extreme cases discussed in the previous paragraph for which the dust emission exceeds 70% or is lower than 15 %.

The amount of energy in the UV spectral range (912-3650 Å) is in average comparable to the dust emission with $\langle F_{\text{UV}}/F_{\text{dust}} \rangle = 1.19 \pm 1.38$ although the dispersion is very large; the median of $F_{\text{UV}}/F_{\text{dust}}$ is 0.6. For the 12 galaxies for which NIR data are available (at least in the H band), the mean ratio of the visible (3650-12500Å) to the dust emission is $\langle F_{\text{vis}}/F_{\text{dust}} \rangle = 1.10 \pm 0.75$ with a median equal to 0.9. The

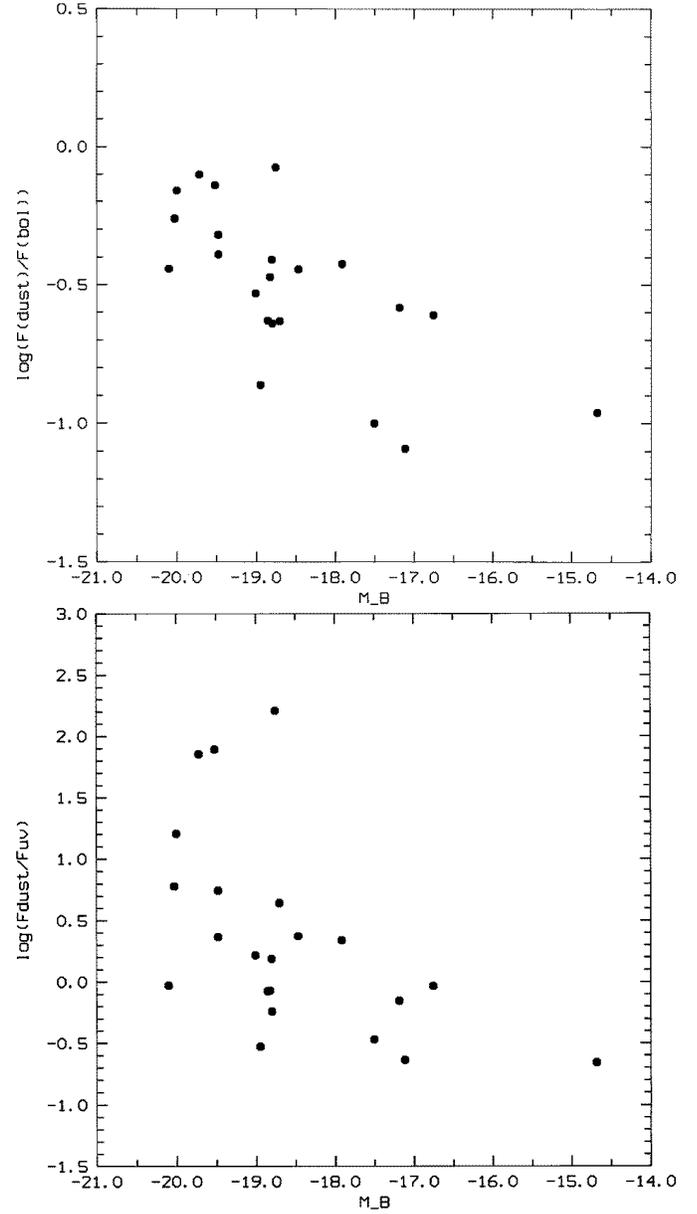


Fig. 5a and b. The logarithm of the ratio of the dust to bolometric luminosities (a upper panel) and of the dust to UV luminosities (b lower panel) for the 22 starburst galaxies as a function of their absolute B magnitude

energy of the NIR range (12500-22000 Å) is only one third the energy emitted by the dust : $\langle F_{\text{NIR}}/F_{\text{dust}} \rangle = 0.31 \pm 0.20$ with a median equal to 0.22. Once again, this low value found for the NIR contribution is due to the truncation between the visible and NIR ranges at 12500 Å.

One must be cautious in the interpretation of these results: the spectral energy distribution of a galaxy is governed by the star formation history and the effects of the extinction, both being poorly known. More specifically, the old underlying population in nearby galaxies is expected to be the major component of the visible and NIR emission in nearby disk galaxies. On the other hand as soon as a significant star formation is currently

Table 3. The relative contribution of the UV, visible and NIR wavelength range to the total star emission for different scenarios of star formation: a starburst (SB) lasting since 10 Myr, a constant star formation (CSF) over 1 Gyr and 10 Gyr and an old burst which occurred 5 Gyr ago and lasted 1 Gyr. Four combinations of these scenarios are also considered: in each case the newly formed population created during the SB of 10 Myr or during the CSF over 1 Gyr accounts for 10 % of the stellar mass. The quantities computed are the same as in table 2

Star formation scenario	$\frac{F_{UV}}{F_{star}}$	$\frac{F_{vis}}{F_{star}}$	$\frac{F_{NIR}}{F_{star}}$
SB (10 Myr)	0.83	0.14	0.03
CSF (1 Gyr)	0.58	0.34	0.08
CSF (10 Gyr)	0.43	0.43	0.13
old SB (5 Gyr)	0.01	0.69	0.30
old SB (5 Gyr) and SB (10 Myr)	0.82	0.15	0.03
old SB (5 Gyr) and CSF (1 Gyr)	0.43	0.44	0.14
CSF (10 Gyr) and SB (10 Myr)	0.82	0.15	0.03
CSF (10 Gyr) and CSF (1 Gyr)	0.50	0.40	0.10

occurring in a galaxy the intrinsic UV emission (i.e. without accounting for the extinction) is dominated by this star formation as discussed in section 4.2. Therefore any estimate of the extinction on the F_{dust}/F_{bol} ratio is always very crude since the UV and visible emitting stars are not located in the same regions of a galaxy, it is particularly true for starburst galaxies. The use of the F_{dust}/F_{UV} ratio is probably more meaningful to estimate the extinction.

To estimate more quantitatively the relative contribution of the UV, visible and NIR range to the total stellar emission, different scenarios of star formation have been considered using the evolutionary models of Bruzual & Charlot (1993) (table 3). Different cases have been chosen to test the influence of an old population compared to that due to the stars newly formed in the starburst. The old disk population has been described by a constant star formation over 10 Gyr and by an old starburst which occurred 5 Gyr ago and lasted 1 Gyr, there are referred as CSF(10 Gyr) and old SB(5 Gyr) respectively in table 3. For the current starburst we have used two extreme cases: a very recent starburst lasting since 10 Myr (Meurer et al. 1995) or a star formation constant over 1 Gyr (Calzetti 1997a). The models are referred as SB(10 Myr) and CSF(1 Gyr) respectively in table 3.

One can check that the fraction of stellar light emitted in the UV range is large as soon as a recent star formation occurs in the galaxy. If we exclude the scenario of the old burst alone which cannot describe a current starburst, F_{UV}/F_{star} from the models is larger than the mean value $\langle F_{UV}/F_{star} \rangle = 0.32 \pm 0.19$ found for our sample (table 2) by a factor ranging from 1.3 to 2.6.

The contribution of the visible-NIR range becomes significant as soon as the galaxy is not experiencing a large burst with a short duration (described as SB(10 Myr) in table 3 and involving 10% of the stellar mass). Although the statistics is poor (only 12 objects) the mean value found in table 2 for F_{vis}/F_{star} (0.51 ± 0.11) is slightly larger than those obtained in table 3

for the models with a current starburst described by a constant star formation over 1 Gyr (CSF(1 Gyr)) by a factor 1.2-1.5. The difference is much larger when a more recent starburst is considered (SB(10 Myr)) with a factor 3.4 between the mean value of the observations and the result of the models.

The comparison in the UV range of the observations and the few models presented here seems to favor a rather moderate extinction in our sample of starburst galaxies. Under the hypothesis of such a moderate extinction, the analysis of the visible-NIR range argues for a starburst lasting more than 10 Myr (at the scale of the entire galaxy) to explain the rather large fraction of visible light emerging from these galaxies.

4.4. Estimate of the extinction

A large fraction of the light emitted by the nearby starburst galaxies studied here is found in the UV wavelength range, at least in average. This might imply a moderate extinction. As discussed below, a reliable estimate of the extinction must account for the true spectral energy distribution of the stellar emission as well as assuming a realistic geometry for the repartition of dust and stars.

To estimate this extinction we first use a radiation transfer model in an infinite plan parallel geometry where stars and dust are mixed, different scale heights are assumed for stars emitting in UV or visible. This model treats the dust grains as frequency converters, converting the UV and optical radiation to the FIR one. Details on the model are given in Xu & Buat (1995) and Buat & Xu (1996). A main result of this model based on an energy balance is that the UV non ionizing radiation dominates the dust heating in disk galaxies (with starbursts or not, (Buat & Xu 1996)). Applying this model to our sample of starburst galaxies leads to a mean extinction at 2000 \AA $A_{2000} = 1.33 \pm 1.38$ mag. Therefore the extinction is effectively found to be moderate.

Actually, it has been found that the foreground screen geometry favoured by Calzetti et al. (1994) does not fit our data probably because we deal with integrated fluxes over the entire galaxies whereas the model of Calzetti et al. is suited to the central regions of the galaxies where the starburst occurs (Buat et al. 1997). Nevertheless, for the sake of comparison with the high redshift objects (see below) we also use the extinction curve of Calzetti et al. using an unreddened spectrum with a star formation rate constant over 1 Gyr. Since the UV light is likely to be the major source of dust heating, especially in starburst galaxies, we have considered the F_{dust}/F_{UV} ratio. Excluding the three galaxies with a F_{dust}/F_{UV} ratio larger by a factor 30 or more than the ratios of the other sample galaxies (see Fig. 5b), the mean value is $\langle F_{dust}/F_{UV} \rangle = 2.5 \pm 3.7$. For comparison the median value of F_{dust}/F_{UV} for the entire sample is 1.6. The mean value of this ratio corresponds to an extinction of 1.2 mag at 2000 \AA in full agreement with our previous estimate. The extinction we find in our sample of starburst galaxies is also consistent with the values estimated by Meurer et al. (1995) from the UV spectral slope for a sample of 9 nearby starburst galaxies. Such a consistency is expected

since our sample exhibits the same range of FIR to UV ratios as that of Meurer et al.

5. Discussion and concluding remarks

5.1. The local Universe

We have considered galaxies selected to be detected photometrically both in UV and FIR. An analysis of the local luminosity functions at both wavelengths shows that the galaxies selected in this way have a FIR and a UV emission representative of the mean population of galaxies in the local Universe. From a sample of 22 starburst galaxies, the mean escape fraction of the stellar light (ratio of the stellar luminosity to the bolometric one) is found to be $63\% \pm 22\%$, i.e. similar to what is found for normal galaxies. This escape fraction exhibits a strong decrease with increasing galaxy luminosity ranging from $\sim 80\%$ at faintest B magnitudes ($M_B > -17$) to $\sim 10\%$ for $M_B \sim -20$. This result is quite different to that of Pearson & Rowan-Robinson (1996) who found that the escape fraction of the stellar light in starburst galaxies cannot exceed 5-10% from an analysis of deep counts in visible and NIR and assuming a very strong cosmological evolution for the starburst population. Such a low fraction of escaped light is consistent with the studies of FIR bright galaxies but seems not to be a generic property of starbursting objects, at least in the local Universe.

5.2. Comparison with high redshift galaxies

We can compare our results found for nearby starbursts to high redshift galaxies recently detected. A limitation to this comparison might be that we deal with integrated fluxes on nearby galaxies which contain an underlying stellar population pre-existing to the starburst. To our knowledge, there is no evidence for the presence or not of such an older population in high redshift starburst galaxies ($z \sim 3$). Nevertheless, as discussed in the paper, the UV range is largely dominated by the emission of the newly formed stars and the comparison of the high redshift galaxies to present-day starburst ones in this wavelength range is justified.

From an analysis of the slope of the rest-frame UV continuum, an extinction has been estimated for high z galaxies (Meurer et al. 1997, Calzetti 1997b, Pettini et al. 1997). A mean extinction of 1.65 mag at 1650 Å is found by Calzetti for a star formation rate constant over ~ 1 Gyr which implies an unreddened slope for the UV continuum $\beta = -2$. This value is in agreement with Pettini et al.'s estimates. Meurer et al. have adopted a different star formation law with a starburst lasting 10 Myr, leading to a larger proportion of very young stars and a steeper UV slope ($\beta = -2.5$). Such a very extreme scenario gives an extinction as large as 3 mag. at 1600 Å which can be considered as a very upper limit. The extinction found for nearby starburst galaxies is lower than the value found by Calzetti or Pettini et al. at high redshift. But the galaxies observed at high redshift are much more luminous than the nearby starburst galaxies studied by us or by Meurer et al. (1995) (Meurer et al. 1997,

Lowenthal et al. 1997, Pettini et al. 1997). As an example, an extinction of 1.6 mag at 1600 Å gives $F_{\text{dust}} / F_{\text{bol}} = 0.6$ and $F_{\text{dust}} / F_{\text{UV}} = 4.5$ using the extinction curve of Calzetti et al. (1994), a foreground screen and a star formation rate constant over 1 Gyr. Extrapolating Fig. 5, these ratios correspond to the brightest galaxies with $M_B \leq -20$. If the trends found in Fig.5 are mainly due to the extinction, the extinction estimated in high redshift star forming galaxies is in agreement with the values found for nearby starburst galaxies when the galaxy luminosity is accounted for. We must point out, however, that low luminosity galaxies ($M_B \sim -16$) would be detectable with a NGST-type telescope in a reasonable amount of time as far as $z \sim 9$ (if they exist). In a hierarchical scenario for the formation of the galaxies, it is likely that such galaxies would outnumber the large luminous galaxies presently detected (Ellis 1997).

Obviously the knowledge of the local Universe properties in terms of the extinction occurring in galaxies as well as their spectral energy distribution, especially in the UV range, is essential to interpret the observations of the Universe at high redshift. It is also crucial to predict the best way to detect young galaxies during a phase of intense star formation. We show that a comparison of the FIR and UV emissions in nearby galaxies can bring some clues since these two emissions are very sensitive to the current star formation rate and to the extinction. A more straightforward method would be a systematic comparison of deep fields in UV and FIR. Such a preliminary comparison was already performed (Buat & Xu 1996) using FAUST (Deharveng et al. 1994) and IRAS observations on two 7.6° -wide fields in the central region of the Virgo cluster. Although the UV observations of FAUST were not very deep (limiting flux $10^{-14} - 10^{-15}$ erg/cm²/s/Å at 1600 Å), we have searched for galaxies detected by IRAS without any UV detected counterpart. Given the low sensitivity of the FAUST experiment, the lower limits obtained for the ratio of the FIR to UV luminosity are within the range of values found for the galaxies detected at both wavelengths (fig. 4 in Buat & Xu 1996). This is in agreement with the results found in this paper but needs to be confirmed with deeper observations. The UV observations carried out with the large field ($\sim 2^\circ$) FOCA telescope (e.g. Donas et al. 1990) reach the magnitude 18 at 2000Å. Unfortunately up to now the FIR observations (made by the IRAS satellite) are not deep enough to be compared to these UV observations and we have to wait for new FIR large field instruments like WIRE to perform such a comparison.

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