Abstract. We discuss the dust attenuation and the star formation rates in the nearby universe obtained from a comparison of far-infrared (IRAS) and ultraviolet (GALEX) observations. The ratio of the dust to UV flux ratio is used to derive the dust attenuation: this dust attenuation is found to increase with the luminosity of the galaxies and from z=0 to z=1. The slope of the UV continuum is found to be a very poor tracer of the dust attenuation in "normal" galaxies. Galaxies selected by their UV emission are found to be rather quiescent with a recent star formation rate equal to only 25-30% of the past averaged one. Galaxies selected in FIR appear slightly more active in star formation.

INTRODUCTION

The measure of the star formation rate (SFR) in galaxies is based on the analysis of the emission from young stars which escapes the galaxies or is absorbed and re-emitted by the gas or the dust. It might be thought that the most direct tracer is the UV light emitted by young stars but the attenuation of this UV light by the dust absorption prevents from any quantitative estimate of the SFR with the UV emission if no correction for this attenuation is applied. To estimate this dust attenuation has long been recognized as a crucial issue. Calzetti, Meurer and collaborators showed that the UV continuum from $\sim 1200 \text{ Å}$ to $\sim 2500 \text{ Å}$ can be fitted by a power-law in starburst galaxies ($f_\lambda \propto \lambda^{\beta}$) ([5]); the slope $\beta$ of the UV continuum was found to be tightly related to the dust attenuation in nearby starburst galaxies (e.g.[16]). Nevertheless, it appeared that the method was not valid for all types of galaxies: nearby spirals as well as Ultra Luminous Infrared Galaxies do not follow the starburst relation ([1] [11]).

Another way to estimate the dust attenuation is to perform an energetic budget: the UV light which does not escape the galaxy is absorbed by the interstellar dust and re-emitted in the far-IR. Therefore both emissions originate from the same stellar populations and their comparison is a powerful tracer of the dust attenuation ([3] [12]). They are also closely related to the recent star formation rate over similar timescales ([3] [14]).

In this paper, we will combine the UV and IR emissions and we will combine the new GALEX data together with the existing far-IR data from IRAS to discuss the dust attenuation and star formation activity of galaxies.
THE GALEX AND IRAS DATA

We have worked on 600 deg$^2$ observed by GALEX in NUV ($\lambda = 2310$ Å) and FUV ($\lambda = 1530$ Å) to build two samples of galaxies. The first one, called the NUV selected sample includes all the galaxies brighter than $m(\text{NUV}) = 16$ mag (AB scale), among the 88 selected galaxies (excluding ellipticals and active galaxies) only 3 are not detected by IRAS at 60 µm. The second sample, called the FIR selected sample is based on the IRAS PSCz ([17]): 118 galaxies from this catalog lie within our GALEX fields, only 1 is not detected in NUV.

DUST ATTENUATION IN GALAXIES

Mean values of the dust attenuation

For both samples we measure the dust attenuation using the dust to UV flux ratio. This ratio is a quantitative measure of the dust attenuation at UV wavelengths. It has been shown to be robust against variations of the dust properties and of the star formation rate as long as stars are formed actively in galaxies (e.g. [3] [5] [12]). The formulae used here are obtained for the GALEX bandpasses ([5]).

$$A(\text{FUV}) = -0.0333y^3 + 0.3522y^2 + 1.1960y + 0.4967$$ (1)

where $y = \log(F_{\text{dust}}/F_{\text{FUV}})$. and

$$A(\text{NUV}) = -0.0495y^3 + 0.4718y^2 + 0.8998y + 0.2269$$ (2)

where $y = \log(F_{\text{dust}}/F_{\text{NUV}})$. The total (8-1000 µm) dust emission is calculated from the fluxes at 60 and 100 µm using the Dale et al. ([9]) recipe. The NUV fluxes are calculated as $\nu \times f_{\nu}$ and therefore $F_{\text{dust}}/F_{\text{FUV}}$ and $F_{\text{dust}}/F_{\text{NUV}}$ are unitless.

A moderate attenuation is found in the NUV selected sample with $0.8^{-0.3}_{+0.4}$ mag in NUV and $1.1^{-0.5}_{+0.4}$ mag in FUV. As expected the dust attenuation is higher in the FIR selected sample with $2.1^{-0.8}_{+1.2}$ mag in NUV and $2.9^{-1.2}_{+1.2}$ mag in FUV.

Dust attenuation & bolometric luminosity of galaxies

Hereafter the dust and the NUV luminosities are added to give an estimate of the bolometric luminosity of the galaxies in Fig 1. This luminosity is plotted against the dust attenuation in NUV for the NUV selected and the FIR selected samples. A clear increase of the dust attenuation with the luminosity of the galaxies is obtained although the trend is dispersed for the IR selected sample.
The slope of the UV continuum as a tracer of the dust attenuation

The FUV-NUV color from the GALEX observations is directly linked to $\beta$ ([15]). We have plotted this color versus F(dust)/F(FUV) for our two samples of galaxies in Fig. 2 and compared to the predictions for starburst galaxies [16]. Obviously $\beta$ is not a reliable tracer of the dust attenuation in our NUV and FIR selected samples. Moreover, different behaviors are found within both samples: whereas the FIR selected galaxies spread over a large area of the diagram most of the NUV selected galaxies lie below the starburst relation.

The NUV selected sample

Let us focus on the behavior of galaxies from the NUV selected sample. Kong et al. [15] have explored the effect of various star formation histories on the correlation found originally for starburst galaxies. They showed that assuming a decrease of the global star formation activity lead to redder FUV-NUV colors for a similar dust attenuation as compared to a constant star formation rate or a current star burst. In Fig 2 we reproduce the results of their model obtained for a ratio of the present to the past averaged SFR (the so called b parameter) equal to 0.25. The model is consistent with our data: the NUV
FIGURE 2.  \( \log(F_{\text{dust}} / F_{\text{FUV}}) \) against the FUV-NUV color for NUV and FIR selected samples. The dashed line is the mean relation expected for starburst galaxies, the solid line is the locus of Kong et al. models with b=0.25 (see text).

The effect of the dust properties

Two factors are expected to have a large effect on the FUV-NUV color: the star formation history and the dust properties. Kong et al [15] have explored the first factor (see above) but a variation of the dust attenuation curve has also to be explored. We have used the Charlot and Fall [7] formalism and assumed a power law variation of the optical depth of the dust: \( \tau(\lambda) \propto \lambda^{-n} \) allowing n to vary from 2 to 0.5 (whereas Charlot and Fall fixed n to 0.7 from an analysis of starburst galaxies). The NUV bandpass of GALEX is well centered on the Galactic bump at 2175 Å, therefore if such a bump exists in external galaxies it may have a strong effect on the FUV-NUV color. Therefore we also simulate the bump by adding a Gaussian curve centered on 2175 Å(amplitude variable and \( \sigma =200 \) Å) to the power law variation of the optical depth and simulating the bump. In Fig 3 are presented the results of this model for a continous star formation rate (using the PEGASE synthesis model [10]). The solid line is the locus of starburst galaxies and the dashed one the prediction of Kong et al for b=0.25. Whereas the only
way to obtain redder FUV-NUV colors with a low dust attenuation seems to assume a quiescent current star formation, a variable dust attenuation curve alone (with a constant star formation rate) can also explain the behavior of many galaxies in Fig. 2. Therefore a complete interpretation of the data will need to consider both temporal variations of the star formation history and spectral variation of the dust attenuation among galaxies (Burgarella et al. in preparation).

**The mean dust attenuation from z~0 to z~1**

A comparison of the FIR and UV luminosity densities from IRAS ([18]) and GALEX ([20]) leads to a mean dust attenuation at z~0 of 1.1 mag in NUV and 1.5 mag in FUV: the nearby universe is not very obscured [5]. With the recent results of GALEX we can also perform the analysis from z=0 to z ~ 1. The dust emission is derived from Chary & Elbaz [8]: we translate the results of their model for the evolution of the obscured star formation rate in dust luminosity density using the formulae given in their papers. The rest-frame FUV luminosity density as a function of z is taken from [19]. The dust to FUV luminosity density ratios thus calculated are translated in dust attenuation using the relation (1). The results are gathered in Tab. 1. A clear increase of the mean dust attenuation with the redshift is observed: the dust luminosity density increases more than the UV one with the redshift leading to an increase of the global dust attenuation by ~ 1 mag from z=0 to z>0.5.
TABLE 1. Evolution of the mean dust attenuation, the luminosity densities are taken from [19] in FUV and [8] for the dust emission.

| redshift | \(\rho(\text{dust})\) \(L\odot\,Mpc^{-3}\) | \(\rho(\text{FUV})\) \(L\odot\,Mpc^{-3}\) | \(\rho(\text{dust})/\rho(\text{FUV})\) | A(FUV) \(\text{mag}\) |
|----------|---------------------------------|---------------------------------|----------------|----------------|
| 0.06     | \(910^7\)                       | \(1.810^7\)                    | 5              | 1.5            |
| 0.3      | \(2410^7\)                      | \(3.810^7\)                    | 6.3            | 1.7            |
| 0.5      | \(6510^7\)                      | \(4.210^7\)                    | 15.7           | 2.4            |
| 0.7      | \(16010^7\)                     | \(7.710^7\)                    | 20.8           | 2.6            |
| 1        | \(20410^7\)                     | \(6.910^7\)                    | 29.6           | 2.9            |

RECENT STAR FORMATION RATE & STAR FORMATION ACTIVITY

The measure of the recent star formation rate

UV and total dust emissions can be calibrated in a recent star formation rate assuming a star formation history over \(\sim 10^8\) years and an initial mass function [3] [14]. When using the dust luminosity one must add an additional hypothesis about the absorption of the stellar light by the dust. The classical hypothesis (also made in this work) is that all the stellar light from the young stars is absorbed by the dust [14]. In this paper we also assume a Salpeter IMF from 1 to 100 \(M\odot\). Using Starburst99 synthesis models we obtain:

\[
\log(L_{\text{NUV}})(L\odot) = 9.73 + \log(SFR)(M\odot\,yr^{-1})
\]

and

\[
\log(L_{\text{dust}})(L\odot) = 10.168 + \log(SFR)(M\odot\,yr^{-1})
\]

In Fig 4 are plotted the SFR estimated from the NUV luminosity against the SFR from the dust luminosity. In both samples, the observed NUV luminosity strongly underestimates the SFR the effect being worse for the FIR selected sample. When the UV fluxes of the FIR selected sample are corrected for dust attenuation the agreement is very good (as expected) between both estimates of the SFR since we are dominated in each case by the dust emission. Conversely in the NUV selected sample the SFR estimated from the dust luminosity alone is found to underestimate systematically the SFR as compared to the NUV corrected luminosity. The discrepancy increases towards the low SFRs to reach a factor 3 for SFR of \(\sim 0.3\,M\odot\,yr^{-1}\). Therefore, using the dust emission alone to measure the total SFR in all galaxies can be misleading, the best way being to combine UV and IR emissions to estimate reliable SFRs [13].

Star formation activity

We can compare the strength of the star formation in the NUV and FIR selected samples by plotting the SFR per unit area in both samples as a function of the total star formation rate. For the NUV selected sample the SFR is obtained from the NUV fluxes
FIGURE 4. SFR deduced from the dust luminosity versus the SFR deduced from the NUV luminosity directly observed (crosses) and corrected for dust attenuation (points) for the NUV selected sample (left panel) and the FIR selected one (right panel). The lines correspond to equal quantities on both axes corrected for dust attenuation and using the formula (3); for the FIR selected sample we use the total dust emission and formula (4). The results are shown in Fig 5. The FIR selected galaxies appear more active than the NUV selected ones both in terms of total SFR and surface density of star formation. No strong starbursts is selected in either sample: starbursts are characterized by a SFR per unit area larger than 0.1 $M\odot$ yr$^{-1}$ (Kennicutt 2004, in Starbursts-From 30 Doradus to Lyman Break Galaxies) and only two galaxies selected in FIR exhibit such a value.

We can also calculate the $b$ parameter (the ratio of the present SFR to the past averaged one) by using the H magnitude from the 2MASS survey. Using the calibration from [2] we obtain a mean $b$ parameter of $0.3 \pm 0.4$ for the NUV selected sample and $0.4 \pm 0.5$ for the FIR selected sample (Fig. 6). Once again the FIR selected galaxies seem to be slightly more active than the NUV selected ones. The $b$ parameters found for the NUV selected sample are consistent with the value of the model of Kong et al. ([15]) used to fit our data in Fig 2.
FIGURE 5. The star formation rate per unit area plotted against the total SFR for NUV selected galaxies (filled circles) and FIR selected galaxies (open circles)

FIGURE 6. The ratio of the present to past average SFR as a function of the SFR per unit area for NUV selected galaxies (filled circles) and FIR selected galaxies (open circles)
CONCLUSIONS

FIR and UV emissions are complementary to obtain reliable estimates of the dust attenuation and of the star formation rate in galaxies. Using the FIR or the UV alone can lead to errors: on one hand the star formation rate of galaxies selected in UV is under-estimated by a factor which can reach ~3 using the FIR alone, on the other hand for the vast majority of the galaxies the UV must be corrected for dust attenuation before any quantitative use. Therefore the best estimate of the star formation rate is probably to add the observed FIR and UV contributions.

A FIR or a NUV selection in the nearby universe does not select starbursts, FIR selected galaxies are found slightly more active in SFR than the NUV selected ones. NUV selected galaxies have a mean ratio of the present SFR to the past averaged one of 0.2-0.3

The dust attenuation measured by comparing the dust and UV emissions is found to increase with the total luminosity of the galaxies. The interpretation of the F(dust)/F(NUV) vs FUV-NUV diagramm (i.e. the dust attenuation vs the slope of their UV continuum) is difficult and depends on the dust properties and the star formation history in a complex way.
The mean dust attenuation appears to increase from z=0 to z~1 by more than 1 mag.

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