DUST EXTINCTION IN THE UNIVERSE UP TO Z=1

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Abstract

The comparison of the far-infrared and far ultraviolet emissions of galaxies in the local universe has demonstrated that these two emissions are very complementary star formation tracers and that the ratio of the FIR to FUV fluxes is a very powerful and robust tracer of the dust extinction. The next years will see the launch of the GALEX satellite which will observe in the far and near uv both in imagery and spectroscopy. By a cross-correlation between the FIRST (PACS & SPIRE) surveys and the GALEX survey we will be able to construct large samples of galaxies FUV limited and FIR limited which can be used as templates for the high redshift observations in a single wavelength range.

Key words: Dust: extinction, Ultraviolet: galaxies, Far-infrared: galaxies, Galaxies: statistics

1. How to estimate the dust extinction?

The problem of dust extinction in galaxies is crucial in the study of galaxy formation and evolution. Indeed the light emitted by the stars is partly absorbed by the interstellar dust before escaping galaxies: the determination of the true stellar content and of the star formation activity inside galaxies can only be done once the amount of dust extinction is known. Hence, a proper estimate of the internal dust extinction is crucial for understanding the results of the surveys at low, medium and high redshift and at different wavelengths (e.g. Steidel et al. 1999, Meurer et al. 1999 , Flores et al. 1999). The situation is dramatic at ultraviolet (UV) wavelengths which are observed in the visible for high redshift objects and where the extinction is severe. The shape of the distribution of the mean metal production rate as a function of redshift is strongly dependent on the assumptions made on the internal extinction (e.g. Rowan-Robinson et al. 1997, Steidel et al. 1999).

Since the works of Calzetti, Kinney and collaborators the slope of the UV continuum (1300–2500 Å) has been identified as a powerful tracer of the extinction and used as a quantitative estimate of this extinction (e.g. Calzetti et al. 1994, Calzetti 1997). This method is intensively used because the rest-frame UV spectra of high z galaxies is redshifted in the visible and therefore often available. Nevertheless the method has been tested on the central parts of nearby starburst galaxies and the generalization to the entire galaxies and to all types of objects may well not be valid (Buat & Burgarella 1998, Buat et al. 1999). Moreover, theoretical calculations of the extinction for various galactic environments have shown that the variation of the spectral index with the extinction depends strongly on the geometrical distribution of the emitting stars relative to that of the absorbing dust and also on dust characteristics (Witt & Gordon 2000, Granato et al. 2000). The empirical trends found by Meurer et al. 1999 between the amount of extinction and the slope of the UV continuum may only be consistent with specific assumptions which would be characteristics for starbursts.

An alternative approach to overcome these difficulties and to obtain better information of the dust extinction is to perform a global energetic budget in galaxies: the dust emission, measured in the far-infrared (FIR) is due to the absorption of the stellar photons. This absorption is very efficient in UV and the comparison of the FIR and UV emissions is very powerful to measure the extinction (Buat & Xu 1996, Meurer et al. 1999, Gordon et al. 2000). Indeed, the FIR to UV flux ratio has been found to be very robust and rather insensitive either to the stength of the star formation (strong starburst or "normal" star forming galaxies (Buat & Xu 1996, Buat & Burgarella 1998) or to the dust properties (SMC or MW type, geometrical distribution of the emitting stars and the absorbing dust (Witt & Gordon 2000, Granato et al. 2000).

In figure 1 and 2 is plotted the extinction in the far UV as a function of the ratio of $F_{\rm dust}$ (1-1000 μm) to $F_{\rm UV}$ (defined as νf_ν). The FIR data all originate from IRAS. In figure 1 the extinction is calculated using a radiation transfer model in a plane parallel geometry in an homogeneous dusty medium (Buat & Xu 1996). The data consist in star forming galaxies for which total UV fluxes are available (Buat & Xu 1996). A polynomial fit on the data is plotted as a red curve. The green curve is the result of the model of Gordon et al. 2000. In figure 2 are reported the results of Meurer et al. 1999 for a sample of nearby starburst galaxies observed whose central parts have been observed by IUE. The extinction is calculated from the spectral shape of the UV continuum.The blue curve is obtained by the authors using a model of dust heating with

Proc. Symposium *'The Promise of the Herschel Space Observatory'* 12–15 December 2000, Toledo, Spain
ESA SP-460, July 2001, eds. G.L. Pilbratt, J. Cernicharo, A.M. Heras, T. Prusti, & R. Harris

a screen geometry. In both figures the green curves are the result of the model of Gordon et al. 2000.

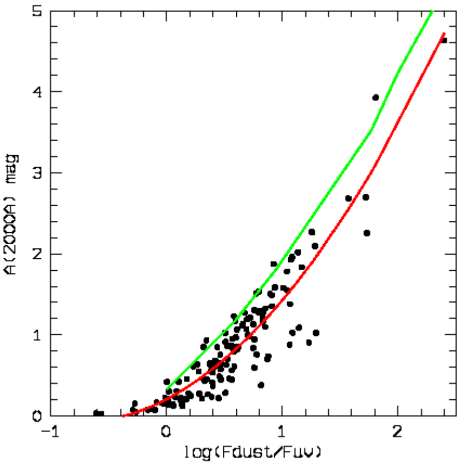

Figure 1. The dust extinction at 2000 Å is plotted as a function of the F_{dust}/F_{UV} ratio from a sample of nearby star forming galaxies

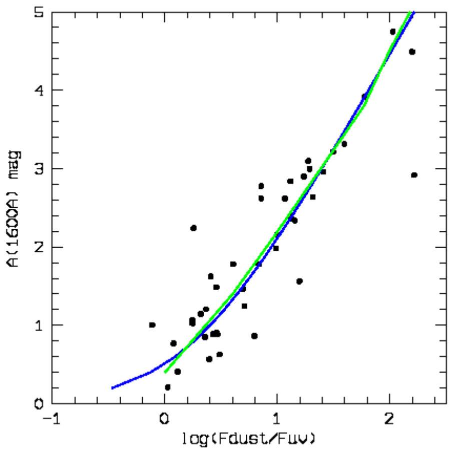

Figure 2. The dust extinction at 1600 Å is plotted as a function of the F_{dust}/F_{UV} ratio from a sample of nearby starburst galaxies

2. The future FIR and FUV surveys

Until now all the work has been made using the all sky survey of IRAS and relatively scarce samples of galaxies detected in UV either by IUE or by small satellites and balloon-borne experiments. The next years will see the launch of FIR (SIRTF, ASTRO-F, FIRST) and FUV (GALEX) telescopes. We will be able to make a statistical significant analysis of the extinction as a function of different galactic properties such as the morphology, the environment, the star forming activity or the bolometric luminosity, all these quantities being directly extracted from the UV and FIR data.

Hereafter we will focus on a cross-correlation between the FIRST (PACS & SPIRE) and GALEX photometric data

- The Galaxy Evolution Explorer (GALEX)is a NASA project, the launch is scheduled for 2002. It will perform a full sky imaging survey at a limiting flux at 5σ of 15.5 μJy at 1600 Å and 8.5 μJy at 2200 Å. A deeper survey covering 160 deg^2 will reach 0.1 μJy in both bands. These limits (at 1600 Å) are reported in figures 3 and 4 as vertical blue lines and right arrows. The mean redshift of the galaxies detected by GALEX is estmated to be $\sim$ 0.2 for the All Sky Survey and $\sim$ 1 for the Deep Sky Survey.
- The PACS and SPIRE intruments of the FIRST satellite will perform imaging surveys over substantial areas of the sky. For the purpose of our study we have adopted rather conservative limits: 10 mJy for the shallow PACS survey at 75, 110 and 170 μm and 5 mJy for the deep survey at 170 μm; 15 mJy for the SPIRE detections at 250, 350 and 500 μm.

2.1. PACS $\bigcap$ GALEX surveys

In this section we will try to estimate what is expected from a cross-correlation of the PACS and GALEX surveys (figure 3).

To make these predictions we assume that the sample of local galaxies IRAS/FOCA is representative of the properties of the galaxies in the nearby universe in terms of FIR to UV flux ratio (cf Buat et al. 1999. This sample is reported as black dots in figure 3. The diagonal lines are the locus of constant FIR to UV flux ratio i.e. of constant extinction (cf. figures 1 & 2).

The PACS detection limits are translated to 60 μm in order to be compared to the IRAS data. The extrapolation from 75, 110 and 170 μm to 60 μm has been made using generic FIR emission curve of normal and active (starbursting) galaxies (Siebenmorgen 2000). The such obtained different limits are reported in figure 3.

- A pure UV selected sample: such a sample purely selected in UV with a FIR detection for each galaxy can be built. Indeed roughly all the galaxies detected in the all sky survey of GALEX will have a counterpart in the PACS survey (shallow survey at 75 and 110 μm, deep survey at 170 μm). Since this sample will be UV limited we can estimate the expected number of galaxies used the UV counts (Gardner et al. 2000. We find $\sim$ 300gal/deg^2.
- A pure FIR selected sample: from fig.3 it can be seen that we can also build a sample purely selected in FIR by cross correlating the PACS survey with the

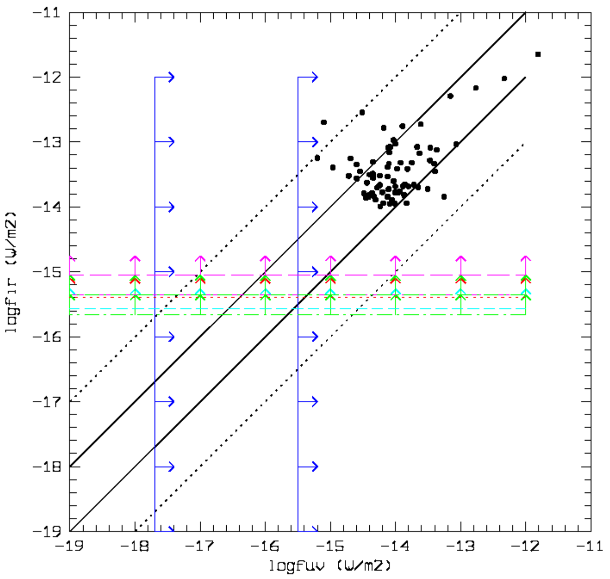

Figure 3. Expected limits of the PACS and GALEX surveys. The axis are in $\nu \cdot f_\nu$ (W/m^2), the UV fluxes are taken at 1600 Å. The IRAS/FOCA sample is reported as black dots. The blue vertical lines & right arrows: expected limits of GALEX at 1600 Å deep survey and all sky survey. The horizontal lines & arrows up: expected limits of PACS; 75 µm: red dotted line, 110 µm: cyan dashed line, 170 µm shallow survey: magenta long dashed line (upper line: starburst galaxies, lower line: normal galaxies), 170 µm deep survey: green (upper line: starburst galaxies, lower line: normal galaxies). The diagonal lines correspond to log(F_{FIR}/F_{UV}) $= -1, 0, 1, 2$

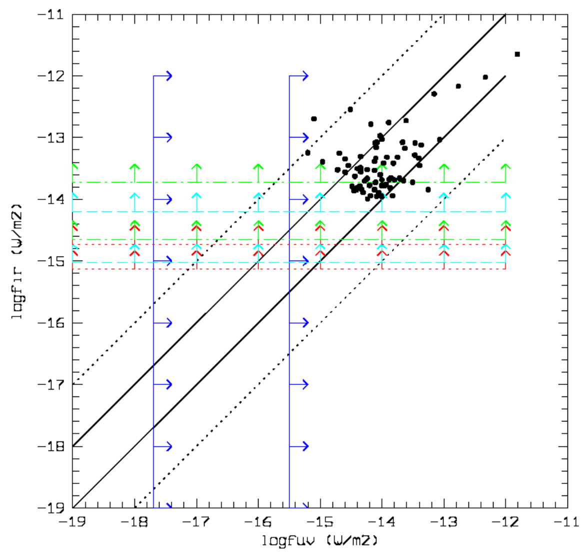

Figure 4. Same as fig.3 but for the expected limits of the SPIRE and GALEX surveys. The horizontal lines & arrows up: expected limits of SPIRE at 250 µm (red, dotted), 350 µm (cyan, dashed) and 500 µm (green, dash-dotted), for each wavelength the upper line corresponds to the starburst case and the lower line to normal galaxies

deep sky survey of GALEX. The number of objects expected can be roughly estimated with the predicted number counts for PACS (PACS Science Meeting 1, http://pacs.ster.kuleuven.ac.be)and the predicted redshift distribution of the galaxies (Malkan & Secker 2000). We find few hundreds galaxies per square degrees at $z < 1$.

2.2. SPIRE $\bigcap$ GALEX surveys

1. The Local Universe
   The cross-correlation of GALEX with SPIRE is less favorable for the nearby universe than with PACS and only performant at 250 µm. This is due to the fact that in the rest-frame of the galaxy 350 and 450 µm correspond the Rayleigh-Jeans part of the emission with a low flux as compared to the 60-150 µm range.
   At 250 µm the cross-correlated sample of the all sky survey of GALEX with the SPIRE survey will give a sample not strongly biased against or towards very extincted galaxies (figure 4). From the UV counts (Gardner et al. 2000) and the FIR/UV values found in nearby galaxies (Buat et al. 1999) we estimate the expected sample to 200 gal/deg^2.

2. Quantifying the extinction up to z=1
   More interestingly, with SPIRE and GALEX we will be able to quantify the effects of the extinction up to z=1. Indeed the observed fluxes at 2200 Å (GALEX) 250 and 350 µm (SPIRE) will correspond to rest frame fluxes at 1100 Å, 125 and 175 µm and will be well suited to perform an energetic budget between the rest-frame FIR and UV emissions of the galaxies.
   In order to make some predictions, once again we assume that the sample of IRAS/FOCA galaxies is representative of what is expected at z=1. Such an assumption is crude since we can expect some evolution from z=0 up to z=1.
   As previously, the rest frame emissions at 125 and 175 µ are translated to 60 µm according to Siebenmorgen 2000. In UV the extrapolation from 1100 Å 2000 Å (FOCA observations) is made adopting a power-law spectral energy distribution in the far UV (Calzetti et al. 1994). We adopt a power-law index β ($f_\lambda \propto \lambda^\beta$) from -2 to 0 which corresponds to an extinction for starbursting galaxies varying from 0.5 to 4 mag (Meurer et al. 1999). Such a range of values corresponds to the case of nearby galaxies (fig 1 & 2).
   Combining these wavelength extrapolations we predict the ratios:

$$\nu \cdot \mathrm{f}_\nu(250\mu\mathrm{m})/\nu \cdot \mathrm{f}_\nu(2200\text{Å}) = 2 - 50$$

and

$$\nu \cdot \mathrm{f}_\nu(350\mu\mathrm{m})/\nu \cdot \mathrm{f}_\nu(2200\text{Å}) = 0.5 - 20$$

We now compare these ratios to the expected limits of GALEX and SPIRE. For the deep survey the GALEX limit at 2200 Å (5σ) is 1.4 10^{-18} W/m^2 whereas the SPIRE limits of 15 Jy lead to 1.8 10^{-16} W/m^2 at 250 μm and 1.3 10^{-16} W/m^2 at 350 μm. Therefore all the galaxies detected by SPIRE at z=1 will be detected in the GALEX deep survey if their properties are similar to those of nearby galaxies.

3. Conclusion

The cross-correlation of the FIRST and GALEX imaging surveys will give us the opportunity of studying the extinction and recent star formation in the Nearby Universe in a statistical way. The selection of pure FIR selected and UV selected samples of galaxies will allow to quantify and understand the effects of selection when only one wavelength range is used as it is often the case especially at high redshift.
Up to a redshift near 1 the galaxies detected by SPIRE will also be observed by GALEX provided that their properties are not very different from the galaxies of the nearby universe. Hence the evolution of the extinction from now up to z=1 will be measured.

Given the sensitivity of PACS, SPIRE and GALEX it would be very valuable to perform the deep surveys within the same areas of the sky. The deep survey GALEX will cover 160 deg^2 and the satellite will be launched in 2002. Low resolution spectrocopy will be also performed by GALEX in this sky area.

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