Tracing the Ancestry of Galaxies (on the land of our ancestors)
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Hidden and Visible Star Formation: new insights from Herschel

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Abstract. Herschel opens a large field of investigations on the hidden star formation in galaxies. Combining UV and far-IR rest-frame data allows us to measure all the star formation in galaxies and to estimate the net dust attenuation. The analysis can be performed from the local universe using far-IR and GALEX surveys to high z (up to $z < 2$) by combining deep U data with the *Herschel* observations of the HerMES project.

The calibration of dust attenuation, and then star formation rate, is reinvestigated. We present the results of the first analyses performed with Herschel data obtained in the Lockman and COSMOS fields as part of the HerMES project and discuss the reliability of dust attenuation corrections.

Keywords. galaxies: evolution-galaxies: stellar content-infrared: galaxies-ultraviolet: galaxies.

1. Introduction

To quantify star formation activity from low to high redshift, we need as accurate an estimate as possible of the current star formation rate (SFR) in galaxies. The far-infrared (IR) and ultraviolet (UV) luminosities are commonly used since both emissions are expected to come from young stars. The physical process linking UV and IR emissions is absorption and re-emission by dust of a significant fraction of the light coming from newly formed stars: the luminosity ratio L_{IR}/L_{UV} is a robust and quantitative tracer of dust attenuation (e.g. Gordon *et al.* (2000), Buat *et al.* (2005)). SFR derivations as well as the energetic budget between stellar and dust emission rely on the bolometric luminosity (L_{IR}) of dust. This quantity is accurately measured in the nearby universe since *IRAS*, *ISO* and *Spitzer* sampled wavelengths close to the peak emission of the dust. At higher z ($z > 1$) *Spitzer* observed galaxies in the mid-IR and the extrapolation to the total IR luminosity becomes uncertain. By observing the IR rest-frame of galaxies *Herschel* (Pilbratt *et al.* (2010)) allows us to measure accurately this IR bolometric luminosity over a continuous and large range of redshift and consequently to study star formation and dust attenuation.

2. Data

The results presented here are based on the observations conducted as part of the *Herschel* Multi-Tiered Extragalactic Survey (HerMES) †.). All the HerMES data will be available in HeDaM, the *Herschel* Database in Marseille ‡.
The Lockman field was observed with SPIRE (Griffin *et al.* (2010)) during the Science Demonstration Phase. Roseboom *et al.* (2010) produced cross-identified catalogues with

† hermes.sussex.ac.uk
‡ http://hedam.oamp.fr/HerMES

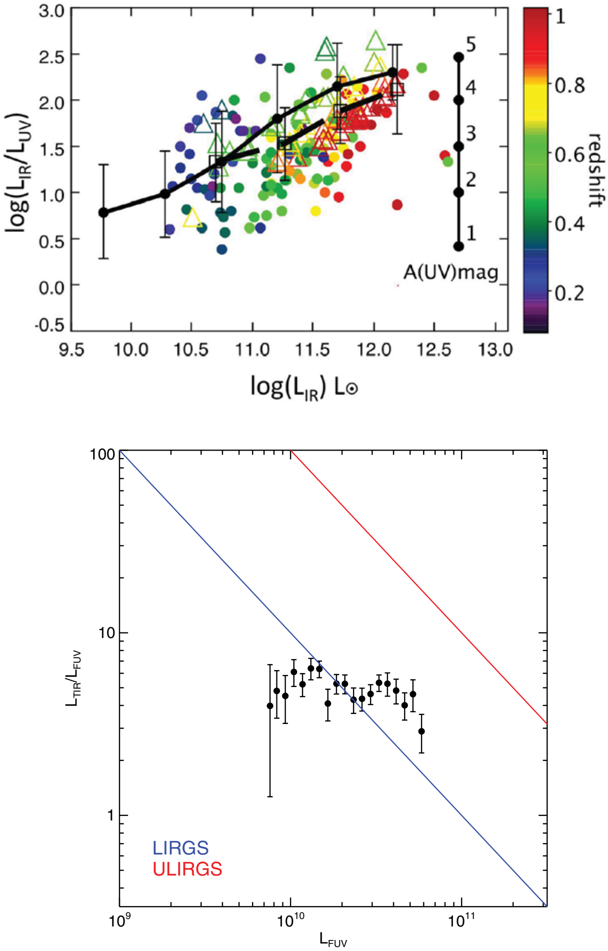

Figure 1. *Top*:L_{IR}/L_{UV} versus L_{IR} for sources detected in the Lockman North in the redshift range 0-1(colour coded in redshift). Lower limits of L_{IR}/L_{UV} are plotted as triangles for galaxies not detected in UV. The filled circles and solid line correspond to the relation found for local IR selected galaxies (Buat *et al.* (2007a)), the empty squares and dashed line to the mean values per bin of IR luminosity obtained in the Lockman North study.*Bottom*: L_{IR}/L_{UV} versus L_{UV} for stacked sources in the COSMOS field. 250 μm images are stacked at the UV positions per bin of L_{UV}

SPIRE sources extracted on the prior positions at 24 μm. These sources were then cross-matched with the *GALEX* Deep Imaging Survey to study IR and UV properties of galaxies from z=0 to 1. Details can be found in Buat *et al.* (2010).

The COSMOS field was also observed with SPIRE and data are available as part of the first internal data release of HerMES data. Combining these data with the U images and photometric redshifts available from the COSMOS web site¶ we are able to extend the study of IR and UV (rest-frame) properties of galaxies up to z=1.5 (Heinis *et al.* in preparation).

¶ http://cosmos.astro.caltech.edu/index.html

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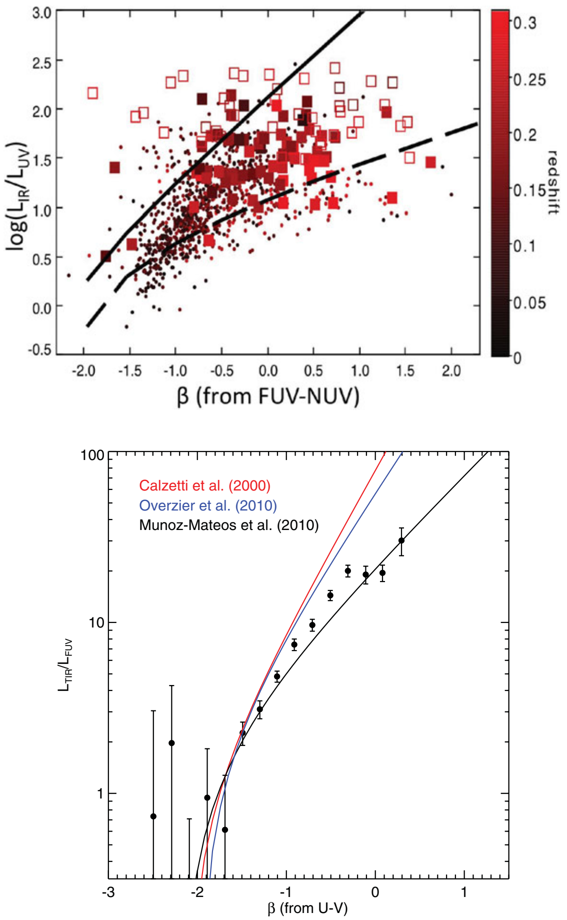

Figure 2. *Top:* L_{IR}/L_{UV} versus the slope β of the UV continuum for galaxies of the Lockman SWIRE field ($z < 0.3$, colour coded in redshift). The dots represent galaxies with $\mathrm{L_{IR}} < 10^{11}\mathrm{L}\odot$ and a reliable measure of β; LIRGs ($\mathrm{L_{IR}} > 10^{11}\mathrm{L}\odot$) with a reliable measure of β are plotted with filled squares, LIRGs with less reliable β values with empty squares. The lines correspond to the relations found for local starburst galaxies (upper red line) and for local star forming galaxies selected in UV and optical (lower blue line). *Bottom*: L_{IR}/L_{UV} versus the slope β of the UV continuum for stacked sources at $z = 1.5$ in the COSMOS field, per bin of β. The lines correspond to the local relations found for normal galaxies (black lines from Munoz-Mateos *et al.* (2009)) and starburst galaxies (blue and red lines from Overzier *et al.* (2010) and Calzetti *et al.* (2000))

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3. L_{IR}/L_{UV} variations with L_{IR} and L_{UV} (Fig. 1)

L_{IR}/L_{UV} (with L_{UV} defined as νL_ν) is a reliable and quantitative tracer of dust attenuation in galaxies forming stars. This ratio is used to follow the evolution of dust attenuation with redshift in UV and IR selected samples of galaxies.

IR selected galaxies up to z=1 in the Lockman North field.
Galaxies are selected at 250μm. L_{IR} is estimated by combining Spitzer and Herschel data and using the CIGALE code (http://cigale.oamp.fr, Noll et al. (2009)). L_{IR}/l_{UV} increases with L_{IR}, as also found at z=0. There is a hint for a slight decrease of dust attenuation in UV (~ 0.5 mag) at $z > 0.5$ for a given L_{IR}, confirming earlier results obtained with *Spitzer* and GALEX at $z = 0.7$ (Buat *et al.* (2007b)).

UV selected sample at z=1.5.
The galaxies are selected down to U=24.5 ABmag and with a redshift comprised between 1.2 and 1.7, only 4% of these sources are tentatively detected at 250 μm. So we stack all the 250 μm images at the U positions, per bin of L_{UV} using the IAS stacking library (Bethermin *et al.*). Total IR luminosities are deduced using the Chary & Elbaz(2001) library. We obtain a flat distribution of L_{IR}/L_{UV} as a function of L_{UV} with $< L_{IR}/L_{UV} >\simeq 5$ which corresponds to $A_{UV} = 1.5$ mag (with the calibration of Buat *et al.* (2005)). Mean dust attenuation for a complete UV selection at $z \simeq 1.5$ is found moderate and independent of the observed UV luminosity of the galaxies.

4. L_{IR}/L_{UV}-β relation. (Fig. 2)

Dust attenuation diagnostics based on UV data alone must be used when far-IR data are not available. Meurer *et al.*(1999) found a relation between the slope of the rest-frame UV continuum β (defined as $f_\lambda \propto \lambda^\beta$ for $\lambda > 120$ nm)) and L_{IR}/L_{UV} for local starburst galaxies. Local star forming galaxies do not follow this relation (e.g. Munoz-Mateos *et al.* (2009), Boissier *et al.* (2007)) and the spectral slope β is found to depend on various parameters not entirely related to dust attenuation. Checking the reliability of β as a tracer of dust attenuation on large samples of galaxies at different redshifts is therefore a key to understand dust attenuation processes in galaxies and perform accurate corrections.

We consider an IR selected sample up to z=0.3 in the Lockman-SWIRE field (Fig. 2, top panel), β is calculated with the FUV-NUV colour (Buat *et al.* (2010)) and the U (UV (rest-frame)) selected sample at $z = 1.5$ in the COSMOS field (Fig 2. bottom panel), β is calculated with U-V, U and V data are extracted from the public COSMOS U and V images, 250 μm images are stacked at the U positions, per bin of β. L_{IR}/L_{UV} is plotted against β: galaxies from both samples are found lying between the relations found for local starbursts and normal star forming galaxies. As a consequence, using the starburst relation to correct UV fluxes for dust attenuation leads to an over-estimate of the SFR by a factor 2-3 for the IR selection at $z < 0.3$ and up to $\simeq 5$ for the UV selected sample at $z \simeq 1.5$.

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