The impact of dust attenuation laws on the stellar mass of galaxies – based on 170 million galaxies from HELP survey

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The *Herschel* Extragalactic Legacy Project (HELP) focused on the data from ESA's *Herschel* mission, which covered around 1300 deg^2 on the sky. HELP systematically combines data from 23 of the premier extragalactic survey fields. It compiles all the ancillary data that are available across the HELP fields into a catalogue with consistent photometry, from the best photometric catalogues that are available. We performed the spectral energy distribution (SED) fitting of millions of HELP galaxies across a wide redshift range to obtain homogeneous estimates of the main physical parameters of detected infrared (IR) galaxies. Here we are going to present the results of the SED fitting, based on the pilot HELP field: ELAIS N1, and and the very well known COSMOS field. We deliver the main physical parameters such as stellar mass, star formation rate, and dust luminosity by assuming three different dust attenuation laws, separately. This exercise allows us to test the impact of the assumed attenuation law on estimated physical parameters. We find that the attenuation law has almost no impact on derived star formation rate (if the far IR data is used for the SED fitting) and the dust luminosity, but it has an important impact on the stellar mass estimate. We find a systematic shift between stellar masses obtained with different attenuation laws. We derive the relation between stellar mass estimates obtained by three different attenuation laws.

1 Introduction

The presence of dust in a galaxy causes the reddening, a consequence of the highest attenuation occurring in the ultraviolet and decreasing towards longer wavelengths, and is dependent on both the dust properties and its geometry within the galaxy. The simple interaction between the emitting star and the dust is described by the extension curve, measured along the line of sight of a single star. The extinction law combines information about the absorption and scattering of electromagnetic radiation by dust and gas between the light provided by a background point source (i.e. star) and the observer. The law became more complicated when large regions of galaxies as a whole are considered, then the effect of dust on the stellar populations depends not only on the amount and properties of dust but also on its distribution relative to the stars. The complexity of the mixture of birth clouds and surrounding dust and gas results in an attenuation law - the grid effect of dust in a complex geometrical distribution. The attenuation law taking into account the light emitted by sources which are located behind and in front of dust clouds. This law is generally very different from that of the extinction curve, with a general flattening (e.g. Witt & Gordon, 2000). The shape of the attenuation curve effects the interpretation of the galaxy fundamental quantities such as the stellar population age, stellar mass ($M_{\rm star}$), and star formation rate (SFR) (i.e. Mitchell et al., 2013; Lo Faro et al., 2013).

To test the hypothesis that different attenuation laws can lead to the different stellar masses we use data from an FP7 project called the *Herschel* Extragalactic Legacy Project (HELP, Vaccari, 2016, Oliver et al., in preparation), funded by the European Union. This project removed the barriers to multi-λ statistical survey science by providing homogeneously calibrated catalogues, covering roughly 1300 deg^2 of the *Herschel* Space Observatory (Pilbratt et al., 2010) survey fields. The detailed description of the catalogue can be found in Shirley et al. (2019) and Oliver at al. (in prep). The presence of IR data together with ultraviolet (UV) – optical counterparts makes the HELP multi-λ catalogue a perfect data set for statistical studies of attenuation laws impact for the main physical parameters of galaxies across wide redshift range. We perform three SED-fitting runs with three different dust-attenuation laws: we use the Charlot & Fall (2000) model as the main dust attenuation recipe, and then we redo the whole analysis with the popular attenuation law of Calzetti et al. (2000), and we also test the attenuation law for z$\sim$2 ULIRGs derived by Lo Faro et al. (2017).

Here we present the results obtained from 42 047 galaxies from the pilot HELP field ELAIS N1 (HELP-ELAIS N1), and 22 321 galaxies from COSMOS field (HELP-COSMOS).

2 Data

In our analysis, first we focus on the pilot HELP field: European Large Area ISO Survey North 1 (hereafter ELAIS N1), 9 deg^2 area centred at $16^h10^m01^s$ $+54^o30^{'}36^{''}$ (Oliver et al., 2000). ELAIS N1 is one of 20 fields making up the European Large Area ISO Survey (ELAIS, Oliver et al., 2000; Rowan-Robinson et al., 2004). It is representative of moderately deep fields for future HELP catalogues. We already published our results of SED fitting and the analysis of the physical properties of $\sim$40 000 galaxies from that field in Małek et al. (2018). The second field we used here for the comparison is COSMOS (Scoville et al., 2007). It is a smaller, 5.1 deg^2 area, but deeper than ELAIS N1. The *Herschel* data in ELAIS N1 and COSMOS were obtained as part of the HerMES project (Oliver et al., 2012). The detailed description of the *Herschel* source deblending and extraction can be found in Hurley et al. (2017). We stress that all galaxies used for our analysis have detection in far IR bands, which makes possible a correct estimation of the star formation rate and parameters related to the amount of dust (as dust luminosity).

In this paper we briefly summarise the data used for ELAIS N1 and COSMOS. A detailed description of the data used for the HELP project (both far IR and ancillary data), the open source pipeline, which was developed for HELP, and the cross-matching procedure, astrometry corrections, and full data diagnostics are presented in Shirley et al. (2019); Małek et al. (2018), and Małek et al. (2019).

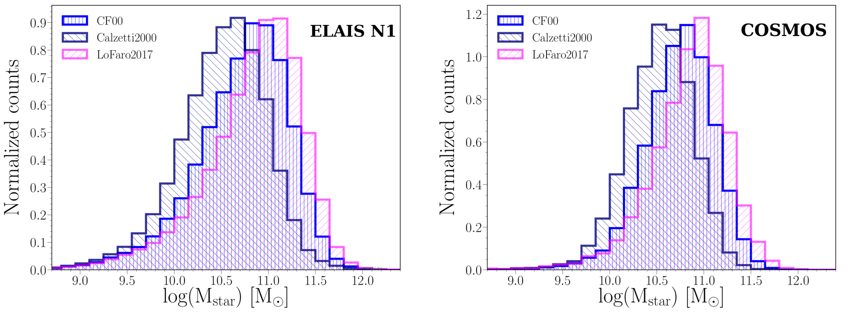

Fig. 1: Comparison of stellar masses obtained with three different dust attenuation laws: Charlot & Fall (2000) – blue vertical striped histogram, Calzetti et al. (2000) - navy right hatched histogram, and Lo Faro et al. (2017) - magenta left hatched histogram, for ELAIS N1 field (*left panel*) and COSMOS field(*right panel*).

3 Spectral Energy Fitting procedure

Taking advantage of the very dense coverage from the broadband pass bands both for ELAIS N1 and COSMOS fields, from far UV (0.15 μm) in case of COSMOS field and u band (0.38 μm) for ELAIS N1, to 500 μm, we use Code Investigating GALaxy Emission (CIGALE, Boquien et al., 2019) to estimate the physical parameters of observed galaxies (i.e. SFR, $M_{\rm star}$, dust luminosity, dust attenuation). We refer to Boquien et al. (2019) for a detailed description of the code, here we want to stress that this tool conserves the energy balance between dust absorption in the domain from UV to near IR and emission in the mid and far IR. We use 19 and 21 broad bands to fit the SED for HELP-ELAIS N1 and HELP-COSMOS field, respectively. The HELP project provides well-calibrated photometric redshifts (Duncan et al., 2018a,b) which were also used for the SED fitting.

4 Results

Fig. 1 shows $\log(M_{\rm star})$ distributions obtained for runs with three different attenuation laws. It is clearly visible that stellar masses obtained with the Calzetti et al. (2000) law are on average lower than those estimated from Charlot & Fall (2000) and Lo Faro et al. (2017). We find the relation between $\log(M_{\rm star})$ obtained with different attenuation laws with agreement to those from the HELP-ELAIS N1 field (Małek et al., 2018). The relation obtained for Calzetti et al. (2000) and Charlot & Fall (2000) for HELP-COSMOS field is:

$$\log(M_{\rm star})_{\rm Calzetti} = 0.89 \times \log(M_{\rm star})_{\rm CF00} + 0.95, \tag{1}$$

and for Lo Faro et al. (2017) and Charlot & Fall (2000):

$$\log(M_{\rm star})_{\rm LoFaro} = 1.00 \times \log(M_{\rm star})_{\rm CF00} + 0.12. \tag{2}$$

The ratio between mean $M_{\rm star}$ obtained from Calzetti et al. (2000) and Charlot & Fall (2000) for COSMOS field (0.98±0.12) is also very similar to that one estimated

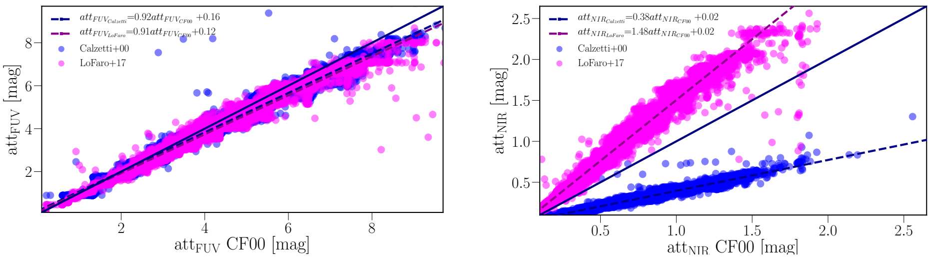

Fig. 2: Total dust attenuation in far UV (*left panel*) and in near IR (*right panel*) band estimated under the assumption of the Charlot & Fall (2000) dust attenuation curve with the Calzetti et al. (2000) dust attenuation law (*full blue dots*) and Lo Faro et al. (2017) model (*full magenta dots*). The navy solid line corresponds to the 1:1 relation.

for the ELAIS N1 field. Similar goes with the M_{star} ratio between Lo Faro et al. (2017) and Charlot & Fall (2000) attenuation laws.

We check the main differences for attenuation curves defined by Calzetti et al. (2000), Charlot & Fall (2000) and Lo Faro et al. (2017) and we found that the main driver of the obtained different stellar masses through the SED fitting is the shape of attenuation laws for the wavelengths longer than 0.5 μm. The Lo Faro et al. (2017) attenuation law is the flatter one, then Charlot & Fall (2000) is less flatter, while the Calzetti et al. (2000) is the most steeper between all of them. Figure 2 shows the difference between the total dust attenuation in far UV and near IR bands for all the attenuation laws used in our analysis. The left panel of Figure 2 shows clear consistency between all models for far UV bands. The right panel of the same figure 2 shows the difference of the amount of the attenuation for near IR bands. We find that attenuation in the near IR range is not preserved between different attenuation laws, and is on average larger for Lo Faro et al. (2017) and Charlot & Fall (2000) than for Calzetti et al. (2000). Figure 3 summarises the global relations between attenuation in near IR band and far UV band for all three laws.

5 Conclusions

In this work we have checked the influence of the dust attenuation laws on the estimated M_{star} of galaxies. We presented the new analysis based on the 22 321 galaxies from the HELP-COSMOS field and compared them with the results published by Małek et al. (2018) for 42 047 galaxies from the HELP-ELAIS N1 field. We find a very good agreement between both analyses.

We compared results using Charlot & Fall (2000), Calzetti et al. (2000), and Lo Faro et al. (2017) recipes of the attenuation law. We conclude that using different attenuation laws has non negligible influence on the calculation of stellar masses, which we find to be a direct result of the shape of the adopted attenuation curves in near IR wavelengths.

We provided relations between M_{star} estimations obtained under those three assumptions of attenuation curves. We found that on average the values of M_{star} for the HELP-COSMOS, the same as for HELP-ELAIS N1 sample, can vary up to a factor of approximately two when calculated with different attenuation laws. We conclude that the dust attenuation law has an important impact on the estimation

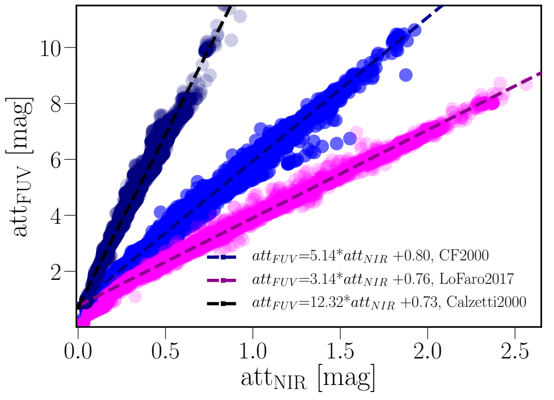

Fig. 3: Total dust attenuation in NIR filter versus the total dust attenuation in the FUV filter estimated under the assumption of the Calzetti et al. (2000) dust attenuation curve (navy circles), Charlot & Fall (2000) (blue circles) and the Lo Faro et al. (2017) attenuation law (magenta circles).

of the main physical parameter of the galaxy, which is the M_{star}, as and it should be take in to account comparing results from different SED fitting techniques.

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