HELP project - a dreamed-of multiwavelength dataset for SED fitting: The influence of used models for the main physical properties of galaxies

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Abstract. The Herschel Extragalactic Legacy Project (HELP) focuses to publish an astronomical multiwavelength catalogue of millions of objects over 1300 deg² of the Herschel Space Observatory survey fields. Millions of galaxies with ultraviolet–far infrared photometry make HELP a perfect sample for testing spectral energy distribution fitting models, and to prepare tools for next-generation data. In the frame of HELP collaboration we estimated the main physical properties of all galaxies from the HELP database and we checked a new procedure to select peculiar galaxies from large galaxy sample and we investigated the influence of used modules for stellar mass estimation.

Keywords. galaxies: fundamental parameters, infrared, methods: statistical, catalogs

1. Introduction

The primary objective of the Herschel Extragalactic Legacy Project (HELP project, Shirley et al. (2019)) founded by FP7 European Union is to provide homogeneously calibrated multiwavelength catalogues covering roughly 1300 deg² of the extragalactic Herschel Space Observatory surveys (HSO, Pilbratt et al. (2010)) at wide redshift range. Millions of galaxies with good coverage of ultraviolet–far infrared spectral range make HELP a perfect sample to prepare tools for next-generation data. The detailed description of a final master list creation of 170 million objects, selected at 0.36—4.5 μm from HSO, depth maps etc. can be found in Shirley et al. (2019). The catalogues supported by spectroscopic (if possible) or photometric redshift (Duncan et al. (2018)) will allow for colour-colour/colour-flux analysis, multi-wavelength spectral energy distribution (SED) fitting and many more statistical studies of the low-to-intermediate redshift galaxy population formation and evolution over cosmic time.

Tab. 1 shows the list of the HSO fields used for HELP project. It demonstrates that HELP not only created a huge multiwavelength, homogenized database, but also focuses
both on wide and deep fields, with different area on the sky. This careful selection and the final data product can remove the barriers to multiwavelength data studies on the statistical level.

2. Data and short overview of the method

The European Large Area ISO Survey North 1 (ELAIS N1, 13.51 deg$^2$ area centred at $16^\text{h}10^\text{m}1^\text{s} +54^\circ30'36'', \text{Oliver et al. 2000}$) was a pilot field for HELP. The HELP homogenized catalogue of ELAIS N1 includes 50 135 galaxies with good ultraviolet (UV)–far infrared (IR) measurements (quality criterion requires at least two optical – near IR measurements and at least two of five Herschel measurements with signal to noise ratio $\geq 2$). We used the sample of 50 135 galaxies and we estimated the key physical parameters (i.e. stellar mass, star formation rate, dust luminosity) by fitting SED to all of them using Code Investigating GALaxy Emission (CIGALE, Burgarella et al. 2005, Noll et al. 2009, and Boquien et al. 2019).

CIGALE is designed to estimate the physical parameters by comparing modelled galaxy SEDs to observed ones. CIGALE conserves the energy balance between the dust-absorbed stellar emission and its re-emission in the IR. A more detailed description of the code can be found in Boquien et al. (2019).

All adopted parameters used for modules are presented in Table 2. More detailed discussion of used parameters and description of addition quality tests for SED fitting procedure for ELAIS N1 field can be found in Malek et al. (2018). An exemplary fit of SED, showing typical photometric coverage of the spectra is shown in Fig. 1.

3. Impact of the dust attenuation law on the stellar mass

Based on the statistically significant sample of $\sim 50\,000$ galaxies we check the influence of different dust attenuation recipes on the main physical parameters calculated for all HELP galaxies; stellar mass, star formation rate and dust luminosity. We perform the SED fitting of ELAIS N1 galaxies by assuming three different dust attenuation laws

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### Table 1. Overview of 23 fields used for HELP project.

| HELP field name | number of objects | area [deg$^2$] |
|-----------------|-------------------|----------------|
| AKARI-NEP       | 531 746           | 9.2            |
| AKARI-SEP       | 844 172           | 8.7            |
| Bootes          | 3 367 490         | 11             |
| CDFS-SWIRE      | 2 171 651         | 13             |
| COSMOS          | 2 599 374         | 5.1            |
| EG5             | 1 412 613         | 3.6            |
| ELAIS-N1        | 4 026 292         | 14             |
| ELAIS-N2        | 1 783 240         | 9.2            |
| ELAIS-S1        | 1 655 564         | 9.0            |
| GAMA-09         | 12 937 982        | 62             |
| GAMA-12         | 12 369 415        | 63             |
| GAMA-15         | 14 232 880        | 62             |
| HDF-N           | 130 679           | 0.67           |
| Herschel-Stripe-82 | 50 196 455   | 363            |
| Lockman-SWIRE   | 4 366 298         | 22             |
| HATLAS-NGP      | 6 759 591         | 178            |
| SA13            | 9 799             | 0.27           |
| HATLAS-SGP      | 29 790 690        | 295            |
| SPIRE-NEP       | 2 674             | 0.13           |
| SSDF            | 12 661 903        | 111            |
| xFLS            | 977 148           | 7.4            |
| XMM-13hr        | 38 629            | 0.76           |
| XMM-LSS         | 8 704 751         | 22             |
| **Total:**      | **171 570 436**   | **1270**       |
Table 2. Main modules and input parameters used in CIGALE for the analysis of the high-z sample. The first column lists the CIGALE model, the second provides a brief description of the main parameters, and the third one shows the range of the selected values.

| CIGALE module                                       | main parameter                        | description                      |
|-----------------------------------------------------|---------------------------------------|----------------------------------|
| SFH delayed + additional burst                       | \( \tau \) of the main stellar population model [Myr] | 3 000                            |
|                                                     | \( \tau \) of the late starburst population model [Myr] | 10 000                           |
|                                                     | mass fraction of the late burst population | 0.001–0.300                      |
| SSP: Bruzual & Charlot (2003)                       | initial mass function                 | Chabrier (2003)                  |
| dust attenuation: Charlot & Fall (2000)             | \( A_V \) in the BCs                  | 0.3–3.8                          |
|                                                     | power law slopes (BC and ISM)          | –0.7                             |
|                                                     | minimum radiation field (\( U_{\text{min}} \)) | 5.0, 10.0, 25.0                  |
|                                                     | mass fraction of PAH                   | 1.12, 2.5, 3.19                  |
|                                                     | power law slope \( dU/dM (U^\alpha) \) | 2.0, 2.8                         |
|                                                     | fractional contribution of AGN         | 0.0, 0.15, 0.25, 0.8              |

Figure 1. An example of SED fitting result. Open squares represent observed fluxes, while filled circles correspond to the model fluxes. The final model is plotted as a solid black line. The relative residual fluxes are plotted at the bottom of the spectra.

We check that the differences in obtained stellar masses are closely related to the shape of each attenuation law at near IR wavelengths. Fig. 2 shows relation between attenuation
in near IR band and far UV band for all three attenuation laws used in our analysis. This figure presents that the range and distribution of attenuation in ultraviolet band is similar for Charlot & Fall (2000), Calzetti et al. (2000), and Lo Faro et al. (2017), however the attenuation obtained in near infrared band is meaningly different. Similar result, showing that Calzetti recipe leads to steeper slopes, not consistent with radiation transfer models results, was found by Buat et al. (2018) based on the infrared complete sample of galaxies in the COSMOS 3D-HST CANDELS field at $0.6<z<1.6$. Similar impact of the attenuation law on the stellar mass was found by Mitchell et al. (2013) based on the semi-analytic galaxy formation model GALFORM (Cole et al. 2000).

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Figure 2. Relation between attenuation in near infrared band and attenuation in ultraviolet band for all three laws used in the analysis. Open black squares represent Calzetti et al. (2000) recipe, blue dots – Charlot & Fall (2000) law, and orange stars correspond to the Lo Faro et al. (2017) law.
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**Discussion**

**ADAM CARNALL:** When you fit your galaxies with the Charlot & Fall (2000) dust law what do you assume for the slope?

**KATARZYNA MALEK:** The birth cloud slope is fixed to -0.7, the ISM slope is also fixed to -0.7. Those values were obtained by Charlot & Fall (2000).

**MAARTEN BAES:** You have demonstrated that the choice of the attenuation law is important for the $M_\star$ determination. But which one is the best one?

**KATARZYNA MALEK:** For most of the galaxies, the Charot & Fall attenuation law was giving the best fits (in terms of the lowest $\chi^2$).

**TOMOTSUGU GOTO:** What are 30% of possible lensed objects which do not satisfy Rowan-Robinson *et al.* (2014) criteria?

**KATARZYNA MALEK:** Could be opt-IR mismatches.