Challenges in Panchromatic Modelling with Next Generation Facilities
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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 deg^2 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 deg^2 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

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	2 171 051	13
COSMOS	2 599 374	5.1
EGS	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

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 $16^h10^m01^s$ $+54^o30'36''$, 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 two of five Herschel measurements with signal to noise ratio $\geqq$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 Małek *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 ∼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 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	τ of the main stellar population model [Myr]	3 000
	τ 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
dust emission Draine & Li (2007)	minimum radiation field (U_{min})	5.0, 10.0, 25.0
	mass fraction of PAH	1.12, 2.5, 3.19
	power law slope dU/dM (U^{α})	2.0, 2.8
AGN emission: Fritz *et al.* (2006)	fractional contribution of AGN	0.0, 0.15, 0.25, 0.8

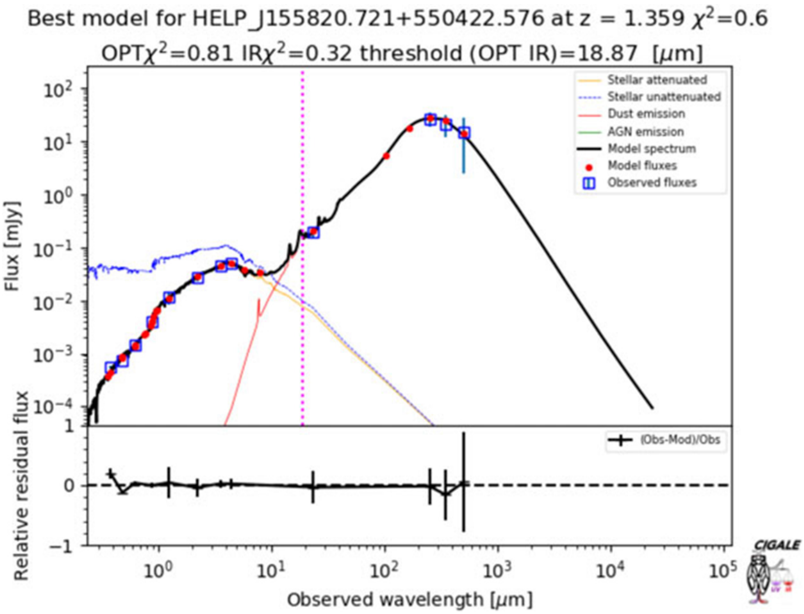

Figure 1. An example of SED fitting result. Open squares represent observed fluxes, while filled circles correspond to the model fluxes. The final model is plotted as a solid black line. The relative residual fluxes are plotted at the bottom of the spectra.

separately: Charlot & Fall (2000), widely used in the literature Calzetti *et al.* (2000), and Lo Faro *et al.* (2017) – dust attenuation recipe created in the framework of the HELP project for Ultra Luminous Infrared Galaxies at redshift > 2. This test allows us to analyze the impact of the assumed law on estimated physical parameters. We find that the attenuation law has an important impact on the stellar mass estimation (on average leading to disparities of a factor of 2), and we derived the relation between stellar mass estimates obtained by those three different attenuation laws. Found recipes (published in Małek *et al.* 2018) can help to homogenize estimated stellar masses from different attenuation laws, and allow to make more precise comparisons, sample selection or study of so called main sequence (stellar mass versus star formation rate relation) between different SED fitting procedures.

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

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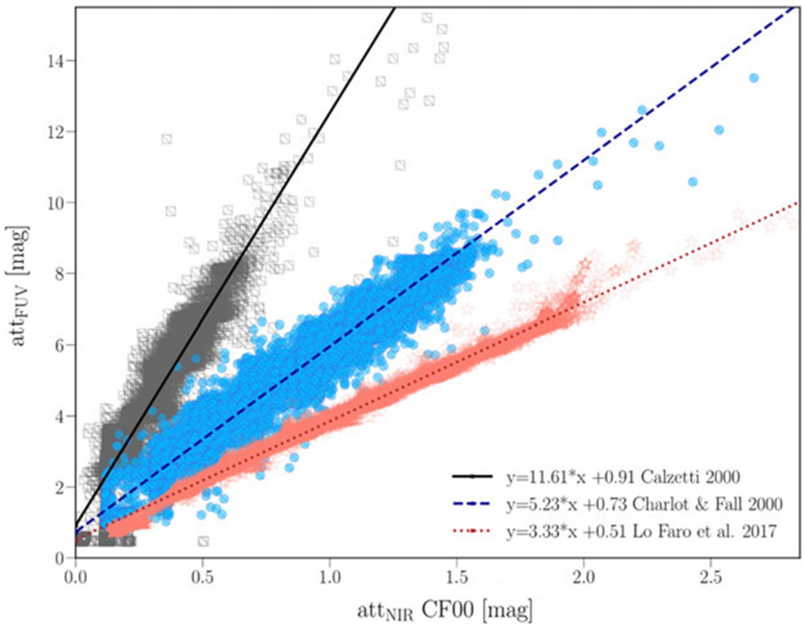

Figure 2. Relation between attenuation in near infrared band and attenuation in ultaviolet band for all three laws used in the analysis. Open black squares represent Calzetti *et al.* (2000) recipe, blue dots – Charlot & Fall (2000) law, and orange stars correspond to the Lo Faro *et al.* (2017) law.

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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Discussion

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

Katarzyna Małek: 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 Małek: For most of the galaxies, the Charot & Fall attenuation law was giving the best fits (in terms of the lowest χ^2).

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

Katarzyna Małek: Could be opt-IR mismatches.

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