MAGPHYS

Multi-wavelength Analysis of Galaxy Physical Properties

maintained by

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MAGPHYS – Multi-wavelength Analysis of Galaxy Physical Properties – is a self-contained, user-friendly model package to interpret observed spectral energy distributions of galaxies in terms of galaxy-wide physical parameters pertaining to the stars and the interstellar medium, following the approach described in *da Cunha, Charlot & Elbaz (2008)*. The present document provides a brief tutorial on MAGPHYS.

Section 1 below gives a concise overview of MAGPHYS. Instructions to download and install the code can be found in Section 2. Section 3 provides a detailed description of the way in which to use MAGPHYS to interpret observed spectral energy distributions of galaxies.

Note on proper referencing: when using MAGPHYS to interpret galaxy spectra, please refer to the original article of da Cunha, Charlot & Elbaz (2008, MNRAS 388, 1595). **For applications not making use of the mid- and far-infrared ($\lambda \gtrsim 2.5\ \mu$m, rest-frame) capabilities of the models**, please refer to, instead, Bruzual & Charlot (2003, MNRAS 344, 1000) and Charlot & Fall (2000, ApJ 539, 718).

For inquiries and feedback about MAGPHYS, please contact both `cunha@mpia.de` and `charlot@iap.fr`.

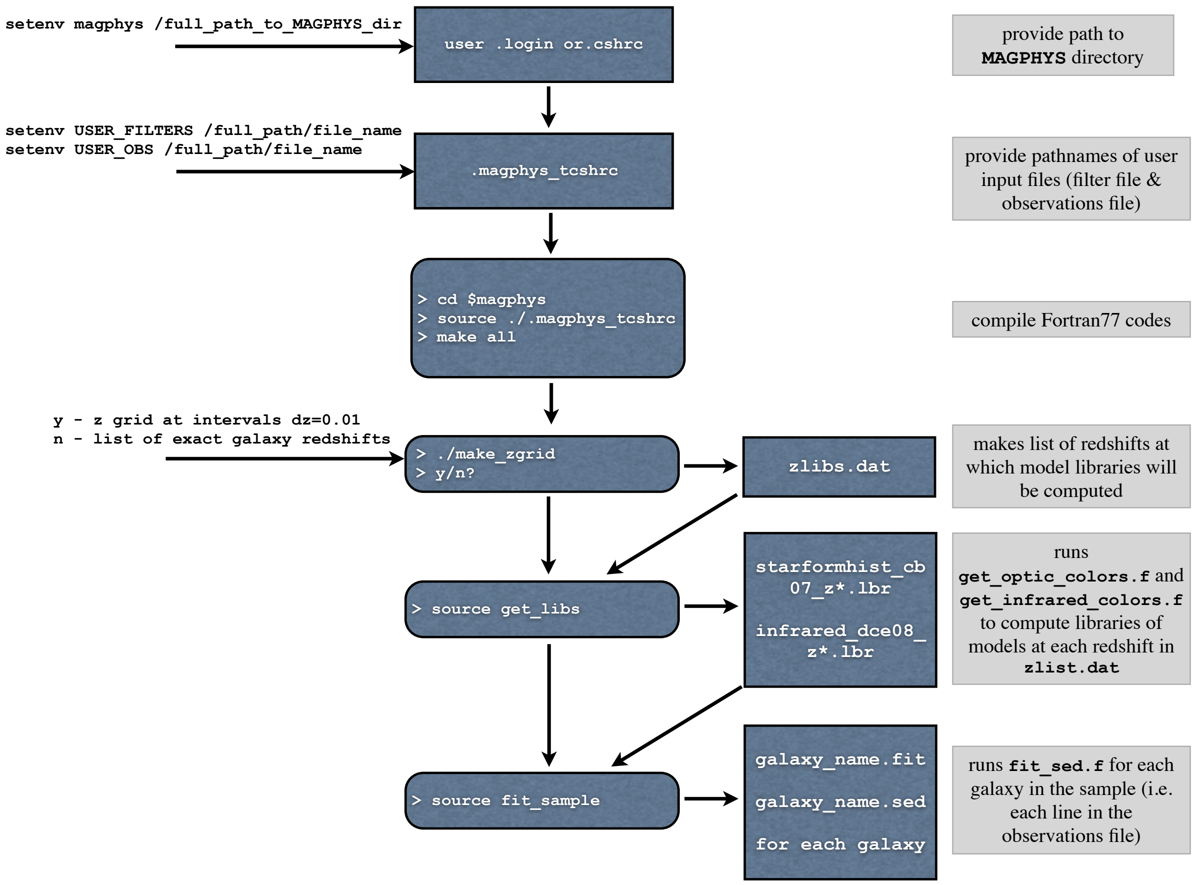
1 MAGPHYS in a nutshell

MAGPHYS is a self-contained model package allowing a user to interpret multi-wavelength observations of galaxies (at rest wavelengths in the range $912\,\text{Å} \lesssim \lambda \lesssim 1\,\text{mm}$) in terms of galaxy-wide physical parameters pertaining to the stars and the interstellar medium. At the moment, the package is limited to the analysis of galaxy spectral energy distributions defined by a set of multiband photometric observations.

The analysis of the spectral energy distribution of an observed galaxy with MAGPHYS is done in two steps (see da Cunha et al. 2008 for detail):

1. The assembly of a comprehensive library of model spectral energy distributions at the same redshift and in the same photometric bands as the observed galaxy, for wide ranges of plausible physical parameters pertaining to the stars and the interstellar medium.
2. The build-up of the marginalized likelihood distribution of each physical parameter of the observed galaxy, through the comparison of the observed spectral energy distribution with all the models in the library.

The MAGPHYS package is intended to be user-friendly. The code can be run by simply following the installation instructions given in Section 2 below and by editing two input files, as described in Section 3.2. No previous knowledge of the language in which the code is written (FORTRAN77) is required.



```
setenv magphys /full_path_to_MAGPHYS_dir
setenv USER_FILTERS /full_path/file_name
setenv USER_OBS /full_path/file_name
> cd $magphys
> source ./.magphys_tcshrc
> make all
> ./make_zgrid
> y/n?
> source get_libs
> source fit_sample
```

Figure 1: The main steps of usage of the MAGPHYS package.

2 Download & Installation

MAGPHYS can be set up on a UNIX machine as follows:

1. Download the file **http://www.iap.fr/magphys/magphys.tar.gz**.
2. In your **.cshrc** or **.login** file, define the environment variable **magphys** as the directory that contains the MAGPHYS code:

   setenv magphys /full_path_to_MAGPHYS_directory
3. In the **.magphys_tcshrc** file in the MAGPHYS directory, provide the pathnames of the two user-defined input files (Section 3.2) as arguments of the variables USER_FILTERS and USER_OBS.
4. Then type the following commands:

   source ~/.cshrc (or ~/.login)

   cd $magphys

   source ./.magphys_tcshrc

   make all

3 MAGPHYS How-To

The basic elements of MAGPHYS are:

- a large library of reference galaxy spectra (at wavelengths from the far ultraviolet to the far infrared) sampling wide ranges of star formation histories, metallicities and dust contents; these correspond to the prior distributions of galaxy physical parameters (see Section 3.1 below);
- two ASCII files elaborated by the user: one listing the observed fluxes of the sample of galaxies to be analyzed; and the other providing information about the specific photometric bands (Section 3.2);
- a simple FORTRAN77 program to compare models with observations and build up the marginalized likelihood distributions of the different physical parameters of each galaxy (Section 3.4).

Figure 1 provides a global overview of the main steps of usage of the MAGPHYS package, which are described in detail in the following subsections.

3.1 Model libraries

The library of reference galaxy spectra is assembled from two types of binary files: those containing the 'optical models', i.e. the emission from stellar populations in galaxies, computed using the Bruzual & Charlot (2003, see also Bruzual 2007) models and including the effects of dust attenuation as prescribed by Charlot & Fall (2000); another type of binary file contains the 'infrared models', i.e. the emission from dust, computed as described in da Cunha et al. (2008). The optical and infrared libraries are linked together in a physically consistent way (see Section 3.1.3 below) to provide the full spectral energy distributions of model galaxies at wavelength from the far ultraviolet to the far-infrared.

Detailed information about the computation of these spectra and the prior distributions of galaxy physical parameters can be found in Appendix A below and in da Cunha et al. (2008).

3.1.1 Description of the optical model files

The file **OptiLIB_cb07.bin** is a binary file containing 25 000 stellar population spectra. Each spectrum was computed by randomly drawing the various adjustable model parameters from the prior distributions described in Appendix A below (see also da Cunha et al. 2008). The parameters drawn for each model are stored in a formatted file, **OptiLIB_cb07.params**. The file **OptiLIBis_cb07.bin** contains 25 000 additional stellar population spectra generated in the same way.

The content of the file **OptiLIB_cb07.bin** can be read using the FORTRAN77 code **read_optilib_bin.f**. This code can be adapted to print formatted files containing the various quantities stored in the file **OptiLIB_cb07.bin**:

- Spectral energy distributions:

`niw`	number of wavelength points
`wl`	wavelength (in Å)
`fprop`	attenuated stellar spectrum (L_λ in $L_\odot$ Å^{-1})
`fprop0`	unattenuated stellar spectrum (L_λ in $L_\odot$ Å^{-1})

- Star formation history:

`nage`	number of time steps
`age`	age (in yr)
`sfr`	star formation rate (in $M_\odot$ yr^{-1})
`sfrav`	star formation rate averaged over the last 10^6, 10^7, 10^8, 10^9 and 2×10^9 yr

- Physical parameters:

`tform`	age of the oldest stars in the galaxy (in yr)
`gamma`	star formation timescale γ (in Gyr^{-1})
`zmet`	metallicity Z (in solar units)
`tauv0`	total V-band optical depth of the dust seen by young stars in their birth clouds, $\hat{\tau}_V$
`mu`	fraction of $\hat{\tau}_V$ contributed by dust in the ambient (diffuse) ISM, μ
`nburst`	number of random bursts experienced by the galaxy since t_{form}
`mstr1`	effective stellar mass, accounting for the fraction of mass returned to the ISM (in $M_\odot$)
`mstr0`	total mass of stars ever formed (in $M_\odot$; integral of the star formation rate)
`mstry`	mass of young stars in their birth clouds (in $M_\odot$)
`tlastburst`	time since the last burst of star formation ended
`fburst`	fraction of `mstr1` formed in bursts over the last 10^6, 10^7, 10^8, 10^9 and 2×10^9 yr
`age_wm`	mass-weighted age
`age_wr`	r-band light-weighted age
`lha`	Hα line luminosity (in $L_\odot$)
`lhb`	Hβ line luminosity (in $L_\odot$)
`ldtot`	total stellar luminosity absorbed by dust (birth clouds + ambient ISM, in $L_\odot$)
`fmu`	fraction of `ldtot` accounted by dust in the ambient ISM, f_μ
`fbc`	fraction of $\hat{\tau}_V^{\mathrm{BC}} (= [1-\mu]\hat{\tau}_V)$ contributed by dust in the HII region

3.1.2 Description of the infrared model files

The file **InfraredLIB.bin** is a binary file containing 50 000 dust emission spectra. These infrared spectra are normalized to a total luminosity of $1\,L_\odot$. Each spectrum was computed by randomly drawing the various adjustable model parameters from the prior distributions described in Appendix A below (see also da Cunha et al. 2008). The parameters drawn for each model are stored in a formatted file, **InfraredLIB.params**.

The content of the file **InfraredLIB.bin** can be read using the FORTRAN77 code **read_irlib_bin.f**. This code can be adapted to print formatted files containing the various quantities stored in the file **InfraredLIB.bin**:

- Spectral energy distributions:

`niw`	number of wavelength points
`wl`	wavelength (in Å)
`irsed`	dust emission spectrum (L_λ in $L_\odot$ Å^{-1})

- Physical parameters:

`fmu`	fraction of total dust luminosity contributed by dust in the ambient (diffuse) ISM, f_μ
`xic_ism`	fractional contribution by cold dust to the dust luminosity of the ambient ISM, $\xi_{\mathrm{C}}^{\mathrm{ISM}}$
`tw_bc`	equilibrium temperature of warm dust in stellar birth clouds, $T_{\mathrm{W}}^{\mathrm{BC}}$
`tc_ism`	equilibrium temperature of cold dust in the ambient ISM, $T_{\mathrm{C}}^{\mathrm{ISM}}$
`xipah_bc`	fractional contribution by PAHs to the dust luminosity of stellar birth clouds, $\xi_{\mathrm{PAH}}^{\mathrm{BC}}$
`ximir_bc`	fractional contribution by the hot mid-infrared continuum to the dust luminosity of stellar birth clouds, $\xi_{\mathrm{MIR}}^{\mathrm{BC}}$
`xiw_bc`	fractional contribution by warm dust in thermal equilibrium to the dust luminosity of stellar birth clouds, $\xi_{\mathrm{W}}^{\mathrm{BC}}$
`mdust`	total mass of dust (in $M_\odot$)

3.1.3 Combined ultraviolet-to-infrared spectra

A main feature of MAGPHYS is the consistent interpretation of ultraviolet, optical and infrared spectral energy distributions of galaxies. This is achieved by accounting consistently for the total energy absorbed by dust in stellar birth clouds and in the ambient ISM, and for the re-distribution of this energy at infrared wavelengths. In this approach, the main underlying assumptions are that the energy reradiated by dust is equal to that absorbed (i.e. the energy is conserved), and that starlight is the only significant source of dust heating in the galaxies under study (e.g. any contribution by an active galactic nucleus is ignored).

Different combinations of star formation histories, metallicities and dust contents can lead to the same energies absorbed by dust in the stellar birth clouds ($L_{\rm d}^{\rm BC} = [1 - f_\mu] L_{\rm d}^{\rm tot}$) and the ambient ISM ($L_{\rm d}^{\rm ISM} = f_\mu L_{\rm d}^{\rm tot}$) in a model galaxy. Furthermore, these energies can be distributed in wavelength using different combinations of dust parameters in the stellar birth clouds ($\xi_{\rm PAH}^{\rm BC}$, $\xi_{\rm MIR}^{\rm BC}$, $\xi_{\rm W}^{\rm BC}$ and $T_{\rm W}^{\rm BC}$) and the ambient ISM ($\xi_{\rm C}^{\rm ISM}$ and $T_{\rm C}^{\rm ISM}$). Therefore, a wide range of spectra in the **OptiLIB_cb07.bin** library can be associated to a wide range of spectra in the **InfraredLIB.bin** library, at fixed $L_{\rm d}^{\rm BC}$ and $L_{\rm d}^{\rm ISM}$ (or equivalently, at fixed f_μ and $L_{\rm d}^{\rm tot}$; see more details in da Cunha et al. 2008). In practice, this combination of the models is executed in the code **fit_sed.f** (see Section 3.4 below).

3.2 User input files

This section provides a description of the two input files that must be prepared by the user, and for which examples can be found in the folder **$magphys/eg_user_files/**. The pathnames of these files should be entered as arguments of the environment variables USER_FILTERS and USER_OBS in the file **$magphys/.magphys_tcshrc**, as explained in Section 2 above.

3.2.1 Preamble on filters

The first step toward using MAGPHYS to compare the models in the spectral libraries described in Section 3.1 above with photometric observations of galaxies at different redshifts is to select the filters used in these observations. The names of 243 widely used filters implemented in the MAGPHYS package are listed in the file **filters.log** (if additional filters are required, please contact the authors). The response functions of these filters are stored in the binary file **FILTERBIN.RES**. Table 1 lists a subset of the most widely used available filters.

Table 1: Examples of available filters (for other filters, check the **filters.log** file).

#	**filter name**	#	**filter name**	#	**filter name**
123	GALEX FUV	153	Spitzer IRAC 3.6μm	172	Herschel SPIRE 250μm
124	GALEX NUV	154	Spitzer IRAC 4.5μm	173	Herschel SPIRE 350μm
12	U Buser	155	Spitzer IRAC 5.8μm	174	Herschel SPIRE 500μm
14	B3 Buser	156	Spitzer IRAC 8.0μm	162	SCUBA 450μm
15	V Buser	157	Spitzer MIPS 24μm	163	SCUBA 850μm
32	R Johnson	158	Spitzer MIPS 70μm		
33	I Johnson	160	ISO 6.75μm		
115	SDSS u	161	ISO 15μm		
116	SDSS g	71	IRAS 12μm		
117	SDSS r	72	IRAS 25μm		
118	SDSS i	73	IRAS 60μm		
119	SDSS g	74	IRAS 100μm		
120	2MASS J	169	Herschel PACS 75μm		
121	2MASS H	170	Herschel PACS 110μm		
122	2MASS Ks	171	Herschel PACS 170μm		

3.2.2 USER_FILTERS (see example: **$magphys/eg_user_files/filters.dat**)

The file associated to the environment variable USER_FILTERS specifies the set of photometric filters for which the observations must be compared with the models. This is a simple ASCII file with 4 columns:

(1) *name*: filter name – this should be a string with no more than 10 characters;

(2) *lambda_eff*: effective wavelength of the filter (in μm; for model selection purposes only)

(3) *filt_id*: filter index in the **filters.log** file (see Section 3.2.1);

(4) *fit?*: if set to 1 – use this filter in the fits; if set to 0 – do not use this filter in the fits.

The first line of this file must contain the header. Each line after the header corresponds to a separate filter (up to 50 filters may be entered). **The filters must be sorted in order of increasing effective wavelength.**

3.2.3 USER_OBS (see example **$magphys/eg_user_files/observations.dat**)

The file associated to the environment variable USER_OBS contains the observed fluxes (in the filters defined in the file **filters.dat**) of the sample of galaxies to be analyzed. An ID (name) and a redshift must also be indicated for each galaxy. This is a simple ASCII file with the following columns:

(1) *ID*: galaxy name – this should be a string with no more than 25 characters;

(2) *redshift*: galaxy redshift;

($2i$+1,$2i$+2) (flux(i), sigma(i), for i=1,`NF`), where `NF` is the total number of filters: flux(i) is the flux observed through the i^{th} filter (in Jy) and sigma(i) the associated uncertainty (also in Jy). **These fluxes must be sorted in order of increasing effective wavelength of the corresponding filter. For non-detections, both flux(i) and sigma(i) should be set to 0 or any negative number.**

The first line of the file must contain the header. Each line after that corresponds to a separate galaxy.

3.3 Computation of model magnitudes

The analysis of a set of photometric observations of galaxies at different redshifts with MAGPHYS requires the computation of model magnitudes at the same redshifts and in the same filters as the observations. For each galaxy in the file $USER_OBS (Section 3.2.3), the fluxes observed through the filters specified in the file $USER_FILTERS (Section 3.2.2) must be compared with the fluxes predicted by the models at the same redshift as the galaxy. To this goal, MAGPHYS generates two files named **starformhist_cb07_z∗.lbr** and **infrared_dce08_z∗.lbr** (Section 3.3.2 below) containing the predictions of, respectively, the stellar and dust emission models at different redshifts ('∗' stands for the redshift rounded to 4 decimal places).

3.3.1 The redshift list

The **starformhist_cb07_z∗.lbr** and **infrared_dce08_z∗.lbr** libraries can be computed at the exact redshifts of the observed galaxies (as appropriate for small samples of galaxies) or for a grid of redshifts from which the closest to the observed redshift will be chosen for comparisons with an observed galaxy (as may be more efficient for the analysis of large galaxy samples).

The list of redshifts at which the model magnitudes will be computed is stored in the ASCII file **zlibs.dat**, which is built using the code **make_zgrid.f**. When running this code, the user is asked whether he/she wants to compute a redshift grid or not. If the answer is 'yes', the code generates a grid of redshifts spaced at regular 0.01 intervals; otherwise, the file **zlibs.dat** will contain the exact redshifts of the galaxies, as listed in the file $USER_OBS. It is usually acceptable to generate a grid of redshifts if the grid is fine enough that, in a given photometric band, the difference in flux between two consecutive redshifts is smaller than the photometric uncertainty. For typical applications, $\Delta z = 0.005$ should be sufficient.

3.3.2 Computation of model fluxes through the selected filters

After building a list of redshifts as described in the previous section, the codes **get_optic_colors.f** and **get_infrared_colors.f** can be used to compute model fluxes through the desired filters from the optical and infrared spectral libraries (Section 3.1) at each redshift in the list.

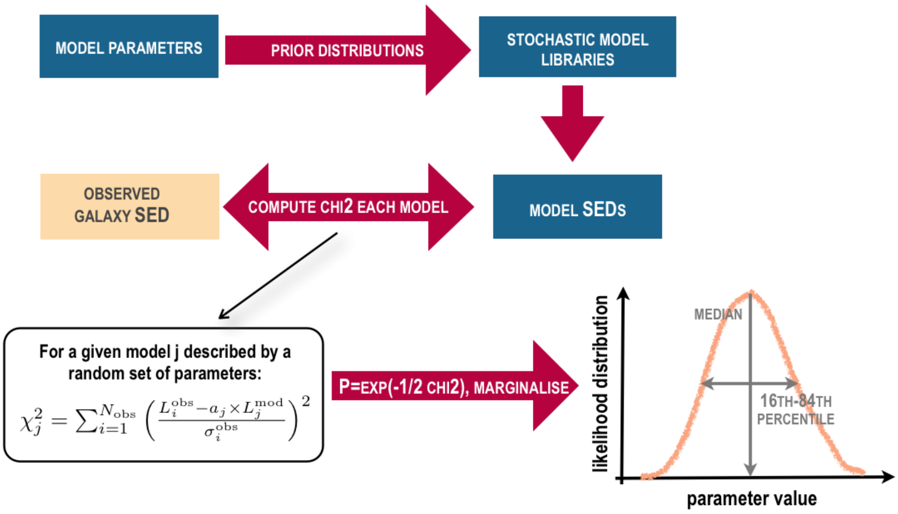


Figure 2: Summary of the methodology used to derive statistical estimates of galaxy physical parameters (see da Cunha et al. 2008 for more detail).

Specifically, the code **get_optic_colors.f** reads the optical spectral library in the files **OptiLIB_cb07.bin** and **OptiLIBis_cb07.bin** (Section 3.1.1). It also computes the age of the universe $t_{\rm u}(z)$ corresponding to each redshift z in the list (for a default set of cosmological parameters, which can be altered).

Then, the code computes the absolute (observer-frame) AB magnitudes of all the models with age $t_{\rm form}$ (Section 3.1.1) younger than $t_{\rm u}(z)$ through the filters specified in the file \$USER_FILTERS. The apparent AB magnitude of a model galaxy with spectral energy distribution L_λ at redshift z with age $t(z)$ is

$$m_{\rm AB}[z,t(z)] = -2.5 \log \left[\frac{\frac{1}{c} \int d\lambda \lambda \frac{L_\lambda[\lambda(1+z)^{-1},t(z)]}{(1+z) 4\pi d_L^2(z)} R_\lambda}{\int d\lambda \frac{R_\lambda}{\lambda}} \right] - 48.6 \,, \qquad (1)$$

where R_λ is the response function of the filter. The *observer-frame* absolute AB magnitude $M_{\rm AB}$ is the apparent magnitude obtained by assuming $d_L = 10$ pc in eq. (1),

$$M_{\rm AB}[z,t(z)] = -2.5 \log \left[\frac{\frac{1}{c} \int d\lambda \lambda \frac{L_\lambda[\lambda(1+z)^{-1},t(z)]}{(1+z) 4\pi (10\ {\rm pc})^2} R_\lambda}{\int d\lambda \frac{R_\lambda}{\lambda}} \right] - 48.6 \,. \qquad (2)$$

The magnitudes in all selected bands are written in the output file **starformhist_cb07_z∗.lbr** (where '∗' stands for the redshift rounded to 4 decimal places), along with the physical parameters of the model.

The program **get_infrared_colors.f** reads the infrared spectral library in the file **InfraredLIB_cb07.bin** and computes the absolute (observer-frame) infrared AB magnitudes of the models at each redshift z in the list in a similar way. The magnitudes are written in the output file **infrared_dce08_z∗.lbr** (where '∗' stands for the redshift rounded to 4 decimal places), along with the physical parameters of the model.

3.4 Comparison of models with observations

The libraries of model magnitudes generated at different redshifts (files **starformhist_cb07_z∗.lbr** and **infrared_dec08_z∗.lbr** above) can be compared directly with the photometric observations of galaxies to build the likelihood distributions of different physical parameters. This comparison is performed by means of the program **fit_sed.f**. The main steps of this program are as follows (see also Fig. 2):

- Read the user-controlled input files containing the photometric bands to fit (e.g. **filters.dat**), the catalog with galaxy redshifts and observed fluxes (e.g. **observations.dat**) and the list of redshifts at which model magnitudes have been computed (**zlist.dat**).

- Ask for the galaxy to be fitted – this is usually labelled by its position index `i_gal` in the input file.
- Find the optical and infrared photometric libraries (**starformhist_cb07_z*.lbr** and **infrared_z*.lbr** files) with redshift closest to that of the galaxy.
- Based on the galaxy redshift, decide which filters sample 'pure stellar' emission, 'pure dust' emission, or a mix of 'stellar+dust' emission. Emission at rest wavelengths shorter than 2.5 μm is considered to be purely stellar (hence represented by model fluxes in the **starformhist_cb07_z*.lbr** library); emission at rest wavelengths longer than 10 μm is considered to be purely from dust (hence represented by model fluxes in the **infrared_dce08_z*.lbr** library); and emission at rest wavelengths between 2.5 and 10 μm is considered to be a mix of stellar and dust emission (hence represented by the sum of model fluxes from **starformhist_cb07_z*.lbr** and **infrared_dce08_z*.lbr**).
- Open the file **starformhist_cb07_z*.lbr** and read, for each model `i_sfh`: the parameters `fmu_sfh` (f_μ), `mstr1` (M_*), `ldust` ($L_{\rm d}^{\rm tot}$), `mu` (μ), `tauv` ($\hat{\tau}_V$) and `ssfr` (ψ_S);[1] and the model magnitudes in all selected bands from the ultraviolet to the near infrared, `flux_sfh`. Convert absolute observer-frame AB magnitudes to L_ν in $L_\odot$ Hz^{-1} and normalize mass-dependent quantities to unit stellar mass.
- Open the file **infrared_z*.lbr** and read, for each model `i_ir`: the parameters `fmu_ir` (f_μ), `fmu_ism` ($\xi_{\rm C}^{\rm ISM}$), `xi1` ($\xi_{\rm PAH}^{\rm BC}$), `xi2` ($\xi_{\rm MIR}^{\rm BC}$), `xi3` ($\xi_{\rm W}^{\rm BC}$), `tbg2` ($T_{\rm C}^{\rm ISM}$), `tbg1` ($T_{\rm W}^{\rm BC}$); and the model magnitudes in all selected infrared bands, `flux_ir` (these correspond to fluxes normalized to a total infrared luminosity $L_{\rm d}^{\rm tot} = 1\,L_\odot$; see Section 3.1.2). Compute the corresponding contributions by PAHs ($\xi_{\rm PAH}^{\rm tot}$), the hot mid-infrared continuum ($\xi_{\rm MIR}^{\rm tot}$), warm dust ($\xi_{\rm W}^{\rm tot}$) and cold dust ($\xi_{\rm C}^{\rm tot}$) to the total infrared emission (as described in Section A.2).
- Perform the fit: for each model in the optical library, find all the models in the infrared library with `fmu_ir` = `fmu_sfh` ± `df`, with `df = 0.15`. For each combination, compute the goodness of fit parameter χ^2 by comparing the observed fluxes with the model fluxes, as described in da Cunha et al. (2008). Compute the corresponding probability as $\exp(-\chi^2/2)$ and use this to build the likelihood distribution of each parameter by marginalizing over all other parameters.
- Compute the 2.5th, 16th, 50th, 84th and 97.5th percentiles of the likelihood distribution of each parameter using the routine `get_percentiles`. Degrade the resolution of each likelihood distribution using the routine `degrade_histogram` (to make the output files smaller and the histograms easier to plot and visualize).
- Write the output file containing the fit residuals and parameter likelihood distributions (**galaxy_id.fit**).
- Select and store the best-fit spectral energy distribution using the subroutine **get_bestfit_sed**. This extracts the stellar and dust spectra from the files **OptiLIB_cb07.bin** (or **OptiLIBis_cb07.bin**) and **InfraredLIB_cb07.bin**, adds them together and stores the unattenuated stellar spectrum and the total (attenuated stellar + dust) spectrum in the output file **galaxy_id.sed**.

3.5 Output files

Description of the output file galaxy_id.fit

`line 3`	observed flux through each filter listed on line 2 (L_ν in L$_\odot$ Hz^{-1})
`line 4`	observational uncertainty in each flux of line 3 (same units as flux)
`line 9`	index of the best-fit optical model, infrared model, best-fit χ^2, z
`line 11`	values of the best-fit model parameters listed on line 10
`line 13`	flux of best-fit model through each filter listed on line 2 (L_ν in L$_\odot$ Hz^{-1})
`lines 17-36`	likelihood distribution of ${f_\mu}^{\rm SFH}$ (bin, probability)
`line 38`	2.5th, 16th, 50th, 84th, 97.5th percentiles of the ${f_\mu}^{\rm SFH}$ distribution
`lines 40-59`	likelihood distribution of ${f_\mu}^{\rm IR}$ (see footnote [2])

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[1] Additional physical parameters may be selected by altering the code.

[2] Note that the f_μ of a combined optical+infrared model is defined as $f_\mu = \frac{1}{2}\left[{f_\mu}^{\rm SFH} + {f_\mu}^{\rm IR}\right]$

`line 61`	2.5th, 16th, 50th, 84th, 97.5th percentiles of the $f_{\mu}{}^{\mathrm{IR}}$ distribution
`lines 63-82`	likelihood distribution of μ
`line 84`	2.5th, 16th, 50th, 84th, 97.5th percentiles of the μ distribution
`lines 86-133`	likelihood distribution of $\hat{\tau}_V$
`line 135`	2.5th, 16th, 50th, 84th, 97.5th percentiles of the $\hat{\tau}_V$ distribution
`lines 137-206`	likelihood distribution of ψ_{S} (in $M_{\odot}$ yr^{-1})
`line 208`	2.5th, 16th, 50th, 84th, 97.5th percentiles of the ψ_{S} distribution
`lines 210-269`	likelihood distribution of M_* (in $M_{\odot}$)
`line 208`	2.5th, 16th, 50th, 84th, 97.5th percentiles of the M_* distribution
`lines 273-332`	likelihood distribution of $L_{\mathrm{d}}^{\mathrm{tot}}$ (in $L_{\odot}$)
`line 334`	2.5th, 16th, 50th, 84th, 97.5th percentiles of the $L_{\mathrm{d}}^{\mathrm{tot}}$ distribution
`lines 336-345`	likelihood distribution of $T_{\mathrm{C}}^{\mathrm{ISM}}$
`line 347`	2.5th, 16th, 50th, 84th, 97.5th percentiles of the $T_{\mathrm{C}}^{\mathrm{ISM}}$ distribution
`lines 349-378`	likelihood distribution of $T_{\mathrm{W}}^{\mathrm{BC}}$
`line 380`	2.5th, 16th, 50th, 84th, 97.5th percentiles of the $T_{\mathrm{W}}^{\mathrm{BC}}$ distribution
`lines 382-401`	likelihood distribution of $\xi_{\mathrm{C}}^{\mathrm{tot}}$
`line 403`	2.5th, 16th, 50th, 84th, 97.5th percentiles of the $\xi_{\mathrm{C}}^{\mathrm{tot}}$ distribution
`lines 405-424`	likelihood distribution of $\xi_{\mathrm{PAH}}^{\mathrm{tot}}$
`line 426`	2.5th, 16th, 50th, 84th, 97.5th percentiles of the $\xi_{\mathrm{PAH}}^{\mathrm{tot}}$ distribution
`lines 428-447`	likelihood distribution of $\xi_{\mathrm{MIR}}^{\mathrm{tot}}$
`line 449`	2.5th, 16th, 50th, 84th, 97.5th percentiles of the $\xi_{\mathrm{MIR}}^{\mathrm{tot}}$ distribution
`lines 451-470`	likelihood distribution of $\xi_{\mathrm{W}}^{\mathrm{tot}}$
`line 472`	2.5th, 16th, 50th, 84th, 97.5th percentiles of the $\xi_{\mathrm{W}}^{\mathrm{tot}}$ distribution
`lines 474-553`	likelihood distribution of $\mu\hat{\tau}_V$
`line 555`	2.5th, 16th, 50th, 84th, 97.5th percentiles of the $\mu\hat{\tau}_V$ distribution
`lines 557-616`	likelihood distribution of M_{d} (in $M_{\odot}$)
`line 618`	2.5th, 16th, 50th, 84th, 97.5th percentiles of the M_{d} distribution

Note: this format will change if the likelihood distributions of additional parameters are printed or if the binning of the likelihood distributions is altered using the code **fit_mwsed.f**.

Description of the output file galaxy_id.sed

`lines 4 & 7`	main parameters of the best-fit model
`lines 11 - 12 826`	spectral energy distribution of the best-fit model: column (1): λ; column (2): L_{λ} (attenuated); column (3): L_{λ} (unattenuated)

Plotting results

MAGPHYS includes a simple IDL code, **plot_sed.pro**, for a quick visualization of the results.

4 Concluding remarks

- The constraints derived on the physical parameters of a galaxy strongly depend on the available observations (please read section 3.2.2 of da Cunha et al. 2008). For example, meaningful constraints on the dust temperatures and dust mass can be obtained only if sufficient (rest-frame) far-infrared observations are available.
- Please do not hesitate to contact the authors if you have comments, suggestions, or if you would like to apply the model beyond what the default code provides (e.g., constraints on other physical parameters; inclusion of extra filters; change in the prior distributions of physical parameters, etc.).

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A Complementary notes on spectral libraries & priors

The material presented in this section is described in detail in da Cunha et al. (2008) and references therein.

A.1 Stellar population spectra (dust-free and attenuated)

The stellar population spectra across the full wavelength range from 91 Å to 160 μm are stored in the binary file **OptiLIB_cb07.bin**.

These spectra were generated using the 2007 version of Bruzual & Charlot (2003, see Bruzual 2007) stellar population synthesis code. For each model galaxy, both the dust-free spectrum and the spectrum attenuated using the simple two-component dust model of Charlot & Fall (2000) are provided.

The spectral energy distribution at time t of a stellar population characterized by a star formation rate $\psi(t)$ is given by:

$$L_\lambda(t) = \int_0^t dt'\,\psi(t-t')\,S_\lambda(t',Z)\,\mathrm{e}^{-\hat{\tau}_\lambda(t')}\,, \tag{3}$$

where $S_\lambda(t',Z)$ is the power radiated per unit wavelength per unit initial mass by a simple stellar population (SSP) of age t' and metallicity Z, and $\hat{\tau}_\lambda(t')$ is the 'effective' absorption optical depth of the dust seen by stars of age t'.

The main adjustable parameters of these models are described below:

- Star formation history

  The star formation rate as a function of time, $\psi(t)$, is described by an underlying continuous model, characterized by an age t_{form} and a star formation timescale parameter γ,

  $$\psi(t) \propto \mathrm{e}^{-\gamma t}\,, \tag{4}$$

  and random bursts superimposed to this continuous model.

  The adjustable parameters are randomly drawn from prior probability distributions:

  - *Age of the galaxy* t_{form}: uniformly distributed over the interval from 0.1 to at most 13.5 Gyr.

    Note: at any redshift, the age of the universe provides an upper limit on the age of the galaxy.
  - *Star formation timescale* γ: to avoid oversampling galaxies with negligible current star formation (at $z=0$), γ is distributed according to the probability density function $p(\gamma) = 1-\tanh(8\,\gamma-6)$, which is approximately uniform over the interval from 0 to 0.6 Gyr^{-1} and drops exponentially to zero around $\gamma = 1$ Gyr^{-1}.

    Note: The prior distribution of γ should probably be altered for studies of high-redshift galaxies (see e.g. Walcher et al. 2008).
  - *Bursts of star formation*: random bursts occur with equal probability at all times until t_{form}. The burst probability is set so that 50 per cent of the galaxies in the library have experienced a burst in the past 2 Gyr. The amplitude of each burst is parameterized as $A = M_{\mathrm{burst}}/M_{\mathrm{cont}}$, where M_{burst} is the mass of stars formed in the burst and M_{cont} is the total mass of stars formed by the continuous model over the time t_{form}. This ratio is distributed logarithmically between 0.03 and 4.0. During a burst, stars form at a constant rate over the time t_{burst}, which is distributed uniformly between 3×10^7 and 3×10^8 yr.

- Metallicity

  The models are uniformly distributed in metallicity Z between 0.02 and 2 times solar.

- Attenuation by dust

The attenuation by dust is computed using the simple, angle-averaged model of Charlot & Fall (2000). This accounts for the fact that stars are born in dense molecular clouds, which dissipate typically on a timescale of 10^7 yr. Thus, the time dependence of the effective absorption optical depth $\hat{\tau}_\lambda$ reflects the different attenuation affecting young and old stars in galaxies:

$$\hat{\tau}_\lambda(t') = \begin{cases} \hat{\tau}_\lambda^{\mathrm{BC}} + \hat{\tau}_\lambda^{\mathrm{ISM}} & \text{for } t' \leq 10^7 \text{ yr,} \\ \hat{\tau}_\lambda^{\mathrm{ISM}} & \text{for } t' > 10^7 \text{ yr.} \end{cases} \tag{5}$$

Here $\hat{\tau}_\lambda^{\mathrm{BC}}$ is the effective absorption optical depth of the dust in stellar birth clouds and $\hat{\tau}_\lambda^{\mathrm{ISM}}$ that in the ambient ISM.

The shape of the effective absorption curve depends on the combination of the optical properties and spatial distribution of the dust. The following dependence of $\hat{\tau}_\lambda^{\mathrm{BC}}$ and $\hat{\tau}_\lambda^{\mathrm{ISM}}$ on wavelength is adopted:

$$\hat{\tau}_\lambda^{\mathrm{BC}} = (1-\mu)\hat{\tau}_V \left(\lambda/5500\,\text{Å}\right)^{-1.3}, \tag{6}$$

$$\hat{\tau}_\lambda^{\mathrm{ISM}} = \mu\hat{\tau}_V \left(\lambda/5500\,\text{Å}\right)^{-0.7}, \tag{7}$$

where $\hat{\tau}_V$ is the total effective V-band absorption optical depth of the dust seen by young stars inside birth clouds, and

$$\mu = \frac{\hat{\tau}_V^{\mathrm{ISM}}}{\hat{\tau}_V^{\mathrm{BC}} + \hat{\tau}_V^{\mathrm{ISM}}} \tag{8}$$

is the fraction of this contributed by dust in the ambient ISM.

The attenuation by dust in the spectral library is sampled by drawing randomly $\hat{\tau}_V$ and μ from the following probability distributions:

- *Total effective V-band absorption optical depth of the dust seen by young stars inside birth clouds,* $\hat{\tau}_V$: this parameter is distributed according to the probability density function $p(\hat{\tau}_V) = 1 - \tanh(1.5\,\hat{\tau}_V - 6.7)$, which is approximately uniform over the interval from 0 to 4 and drops exponentially to zero around $\hat{\tau}_V = 6$.

  Note: The prior distribution of $\hat{\tau}_V$ should probably be altered for studies of extremely dusty (e.g. ULIRG, submm) galaxies, to include a higher fraction of models with high optical depths.
- *Fraction of* $\hat{\tau}_V$ *contributed by dust in the diffuse ISM,* μ: the same probability density function as for γ above, i.e. $p(\mu) = 1 - \tanh(8\,\mu - 6)$, is adopted.

A.2 Dust emission spectra

The mid- and far-infrared emission from dust in galaxies is computed using the model of da Cunha et al. (2008). The full dust emission spectra are stored in the binary file **InfraredLIB.bin**.

The total dust emission from a galaxy is the sum of the dust emission originating from the stellar birth clouds and the dust emission originating from the ambient (i.e. diffuse) ISM.

- Birth Clouds

  The spectral energy distribution of the power reradiated by dust in the stellar birth clouds is computed as the sum of three components: a component of polycylic aromatic hydrocarbons (PAHs); a mid-infrared continuum characterizing the emission from hot grains at temperatures in the range 130–250 K; and a component of grains in thermal equilibrium with adjustable temperature in the range 30–60 K.

  In summary, the infrared spectral energy distribution of stellar birth clouds can be written

$$L_{\lambda,\mathrm{d}}^{\mathrm{BC}} = \left(\xi_{\mathrm{PAH}}^{\mathrm{BC}}\, l_\lambda^{\mathrm{PAH}} + \xi_{\mathrm{MIR}}^{\mathrm{BC}}\, l_\lambda^{\mathrm{MIR}} + \xi_{\mathrm{W}}^{\mathrm{BC}}\, l_\lambda^{T_{\mathrm{W}}^{\mathrm{BC}}}\right)(1-f_\mu)\, L_{\mathrm{d}}^{\mathrm{tot}}, \tag{9}$$

  where $L_{\mathrm{d}}^{\mathrm{tot}}$ is the total infrared luminosity reradiated by dust, f_μ is the fraction of this contributed by the ambient ISM, l_λ^{PAH}, l_λ^{MIR} and $l_\lambda^{T_{\mathrm{W}}^{\mathrm{BC}}}$ are the (normalized) spectral energy distributions of the emission by PAHs, hot mid-infrared continuum and warm dust in thermal equilibrium, and $\xi_{\rm PAH}^{\rm BC}$, $\xi_{\rm MIR}^{\rm BC}$ and $\xi_{\rm W}^{\rm BC}$ are the relative contributions by PAHs, the hot mid-infrared continuum and grains in thermal equilibrium to the total infrared luminosity of the birth clouds. These satisfy the condition

$$\xi_{\rm PAH}^{\rm BC} + \xi_{\rm MIR}^{\rm BC} + \xi_{\rm W}^{\rm BC} = 1\,. \tag{10}$$

As in the case of the library of stellar population spectra, the main adjustable parameters are randomly drawn from prior probability distributions:

- *Fraction of $L_{\rm d}^{\rm tot}$ contributed by the diffuse ISM, f_μ*: uniformly distributed over the interval from 0 to 1.
- *Contribution by warm dust in thermal equilibrium to the infrared luminosity of birth clouds, $\xi_{\rm W}^{\rm BC}$* : uniformly distributed between 0 and 1.
- *Contribution by the hot mid-infrared continuum to the infrared luminosity of birth clouds, $\xi_{\rm MIR}^{\rm BC}$* : drawn from a uniform distribution between 0 and $1 - \xi_{\rm W}^{\rm BC}$.
- *Equilibrium temperature of warm dust in birth clouds, $T_{\rm W}^{\rm BC}$* : uniformly distributed between 30 and 60 K.
- *Contribution by PAHs to the infrared luminosity of birth clouds, $\xi_{\rm PAH}^{\rm BC}$* : drawn from a uniform distribution between 0 and $1 - \xi_{\rm W}^{\rm BC} - \xi_{\rm MIR}^{\rm BC}$.

- Ambient ISM

  In the ambient ISM, the relative proportions of these three components are fixed, for simplicity, to reproduce the spectral shape of diffuse cirrus emission in the Milky Way, and a component of cold grains in thermal equilibrium with adjustable temperature in the range 15–25 K is included.

  The adjustable parameters are randomly drawn from the following prior probability distributions:

  - *Contribution by cold dust in thermal equilibrium to the total luminosity of dust in the diffuse ISM, $\xi_{\rm C}^{\rm ISM}$* : distributed uniformly between 0.5 and 1.
  - *Equilibrium temperature of cold dust in the diffuse ISM, $T_{\rm C}^{\rm ISM}$* : uniformly distributed between 15 and 25 K.

- Contribution of different components to the total dust emission

  For some purposes, it is also convenient to define the global contribution by a specific dust component, including stellar birth clouds and the ambient ISM, to the total infrared luminosity of a galaxy. This can be written

$$\xi_{\rm PAH}^{\rm tot} = \xi_{\rm PAH}^{\rm BC}\,(1-f_\mu) + 0.550\,(1-\xi_{\rm C}^{\rm ISM})\,f_\mu\,, \tag{11}$$

$$\xi_{\rm MIR}^{\rm tot} = \xi_{\rm MIR}^{\rm BC}\,(1-f_\mu) + 0.275\,(1-\xi_{\rm C}^{\rm ISM})\,f_\mu\,, \tag{12}$$

$$\xi_{\rm W}^{\rm tot} = \xi_{\rm W}^{\rm BC}\,(1-f_\mu) + 0.175\,(1-\xi_{\rm C}^{\rm ISM})\,f_\mu\,, \tag{13}$$

$$\xi_{\rm C}^{\rm tot} = \xi_{\rm C}^{\rm ISM}\,f_\mu\,, \tag{14}$$

  for PAHs, the hot mid-infrared continuum and warm and cold dust in thermal equilibrium, respectively.