

# Le PHARE

## PHotometric Analysis for Redshift Estimations

Stéphane ARNOUITS & Olivier ILBERT

CFHT and Laboratoire d'Astrophysique de Marseille

## Contents

<b>1</b>	<b><i>le PHARE package</i></b>	<b>3</b>
<b>2</b>	<b>Package installation</b>	<b>3</b>
2.1	downloading the package . . . . .	3
2.2	environment variables . . . . .	3
2.3	installation . . . . .	3
2.4	compilation . . . . .	4
2.5	size declaration . . . . .	4
<b>3</b>	<b>How to run the programs ?</b>	<b>5</b>
3.1	structure . . . . .	5
3.2	Syntax . . . . .	5
<b>4</b>	<b>A quick start with an example</b>	<b>7</b>
<b>5</b>	<b>Filters</b>	<b>8</b>
5.1	description and outputs . . . . .	8
5.2	syntax and parameter values . . . . .	8
5.3	parameter descriptions . . . . .	8
5.4	Filter informations . . . . .	9
5.4.1	standard filter informations . . . . .	9
5.4.2	extinction informations . . . . .	10
5.5	Application to long wavelengths . . . . .	11
5.6	requirement to create a new filter . . . . .	13

<b>6</b>	<b>SED libraries and sedtolib</b>	<b>14</b>
6.1	SED libraries . . . . .	14
6.2	<b>sedtolib</b> program . . . . .	14
6.2.1	syntax and parameter values . . . . .	14
6.2.2	building libraries from a list of SEDs . . . . .	15
6.2.3	Physical informations for the galaxies . . . . .	16
6.2.4	adding librairies . . . . .	16
6.3	example . . . . .	16
<b>7</b>	<b>Magnitude for stellar libraries : mag_star</b>	<b>18</b>
7.1	description and outputs . . . . .	18
7.2	syntax and parameter values . . . . .	18
<b>8</b>	<b>Magnitudes for galaxy/qso libraries : mag_gal</b>	<b>19</b>
8.1	description and outputs . . . . .	19
8.2	syntax and parameter values . . . . .	19
8.3	The extinction laws . . . . .	20
8.4	The Emission lines . . . . .	20
8.5	ASCII ouput file . . . . .	21
8.6	Resizing the library . . . . .	21
8.7	Example . . . . .	21
<b>9</b>	<b>The photometric redshift program: zphota</b>	<b>23</b>
9.1	description . . . . .	23
9.2	Input catalog, context and main parameters . . . . .	23
9.2.1	Input Catalog . . . . .	23
9.2.2	Context . . . . .	24
9.2.3	Main parameters . . . . .	24
9.3	SED fitting keywords for photo-z . . . . .	25
9.4	adding prior informations . . . . .	27
9.5	Additional SED fitting libraries . . . . .	28
9.5.1	FIR libraries . . . . .	28
9.5.2	Stochastic BC07 libraries . . . . .	29
9.6	Ouputs . . . . .	29
9.6.1	Absolute magnitudes . . . . .	29
9.6.2	additional output files . . . . .	30
9.7	Adaptive method . . . . .	30
<b>10</b>	<b>The output files and parameters</b>	<b>32</b>
10.1	the parameters . . . . .	32
10.2	the output files . . . . .	34
<b>11</b>	<b>Appendice A : Content of the main tar file (lephare_main.tar.gz)</b>	<b>35</b>

# 1 *le PHARE* package

Le PHARE is a set of fortran programs to compute photometric redshifts using SED fitting technique. The package is composed of three parts:

- A preliminary phase to select the SED models, the set of filters and to compute the template magnitudes, using stand-alone programs. They allow to extract basic informations relative to the filters( $\lambda_{mean}$ , AB-corrections, attenuation, ...) and SEDs (k-correction vs  $z$ , color-color diagrams, ...).
- The photometric redshift code, based on a simple  $\chi^2$  fitting method.
- A generator of realistic multicolour catalogues taking into account observational effects.

## 2 Package installation

### 2.1 downloading the package

The basic package is available from the website:

**[http://www.oamp.fr/people/arnouts/LE\\_PHARE/lephare\\_main.tar.gz](http://www.oamp.fr/people/arnouts/LE_PHARE/lephare_main.tar.gz)**

The content of the main file **lephare\_main.tar.gz** is briefly described in Appendice A.

Additional SED libraries (in tar.gz) can also be found in this webpage :

**[http://www.oamp.fr/people/arnouts/LE\\_PHARE.html](http://www.oamp.fr/people/arnouts/LE_PHARE.html)**

### 2.2 environment variables

Before running the programs, two environment variables have to be defined on your machine:

- **LEPHAREDIR** is the location where the package will be installed. This path will be used to get all the ingredients required to run the programs.
- **LEPHAREWORK** is the location where all the intermediate products, that are generated by the code, will be saved. This path can be the same as **LEPHAREDIR** but it is recommended to put your own working files somewhere else. Note that the requested subdirectories in the **LEPHAREWORK** directory will be created automatically during the compilation (see section 2.4).

As an example, depending on your shell, the syntax to define the two variables is:

```
% setenv LEPHAREDIR /your-path/lephare (or export LEPHAREDIR='/your-path/lephare')
```

```
% setenv LEPHAREWORK /your-path/lpwork (or export LEPHAREWORK='/your-path/lpwork')
```

### 2.3 installation

To install Lephare package, you must first put the tar file in directory one level up, where the code will be installed :

```
% cd /your-path
```

```
% tar -zxvf lephare_main.tar.gz
```

If you want to use other SED libraries from the website, you have to proceed in the same way :

```
% cd /your-path
```

```
% tar -zxvf lephare_sed_gissel.tar.gz
```

```
% tar -zxvf lephare_sed_pegase2.tar.gz
```

```
% tar -zxvf lephare_sed_hyperz.tar.gz
```

## 2.4 compilation

For the compilation, you can follow the instructions in the file called “INSTALL” or do the following steps :

```
% cd $LEPHAREDIR/source
```

```
% make (or make -f Makefile)
```

You may need to change options in the upper part of the Makefile. If you have to recompile the sources, you should first clean the files: `% make clean`.

When typing make, the subdirectories required under the **LEPHAREWORK** directory are automatically created (`/filt`, `/lib_bin`, `/lib_mag`). It can also be done separately with : `% make work`.

## 2.5 size declaration

The maximal dimension of some vectors are declared in files called : `dim_*.decl`. Their sizes can be changed. To be effective, the programs must then be recompiled ( with `%make clean` and `%make`).

## 3 How to run the programs ?

### 3.1 structure

The structure of the package is illustrated in Fig 1:

1. Selection of a list of SEDs
2. Selection of a set of filters
3. Computation of magnitudes, in those filters, for each SED and redshifts.
4. When these steps are done, the photo-z code can be run on a catalog.
5. The first three steps can be used to generate simulated multi-colour catalogs.

### 3.2 Syntax

The list of commands can be run from unix shell with the following syntax:

% **prog-name -c** *configuration-file* [-**Parameter** *value*] ...

where **prog-name** is the name of the program, followed by a configuration file called with **-c** *configuration-file* and a list of parameters. Any **-Parameter** *value* statement in the command-line overrides the values written in the configuration file. The part enclosed within brackets is optional, if not specified they are taken from the configuration file.

An help on-line is also available with the syntax : %**prog-name** -h (or -help)

All the parameters associated to the various programs are put in the configuration file *\$LEP-HAREDIR/config/zphot.para* with exception of the simulation program.

The format for the configuration file is ASCII.

- Only one parameter must be set per line.
- Values for the keywords can be : String, Float or Integer.
- Parameters can accept one or several values, which must then be separated by comma.
- Environment variable, written as \$VARIABLE in the configuration file, should be recognized and expanded.
- All parameters do not play the same role. The important ones have to be explicitly defined while the others have been assigned a default value and can be omitted ( with a “#”).

In the next sections the different parameters required for each program are described. The crucial parameters are followed by (\*)

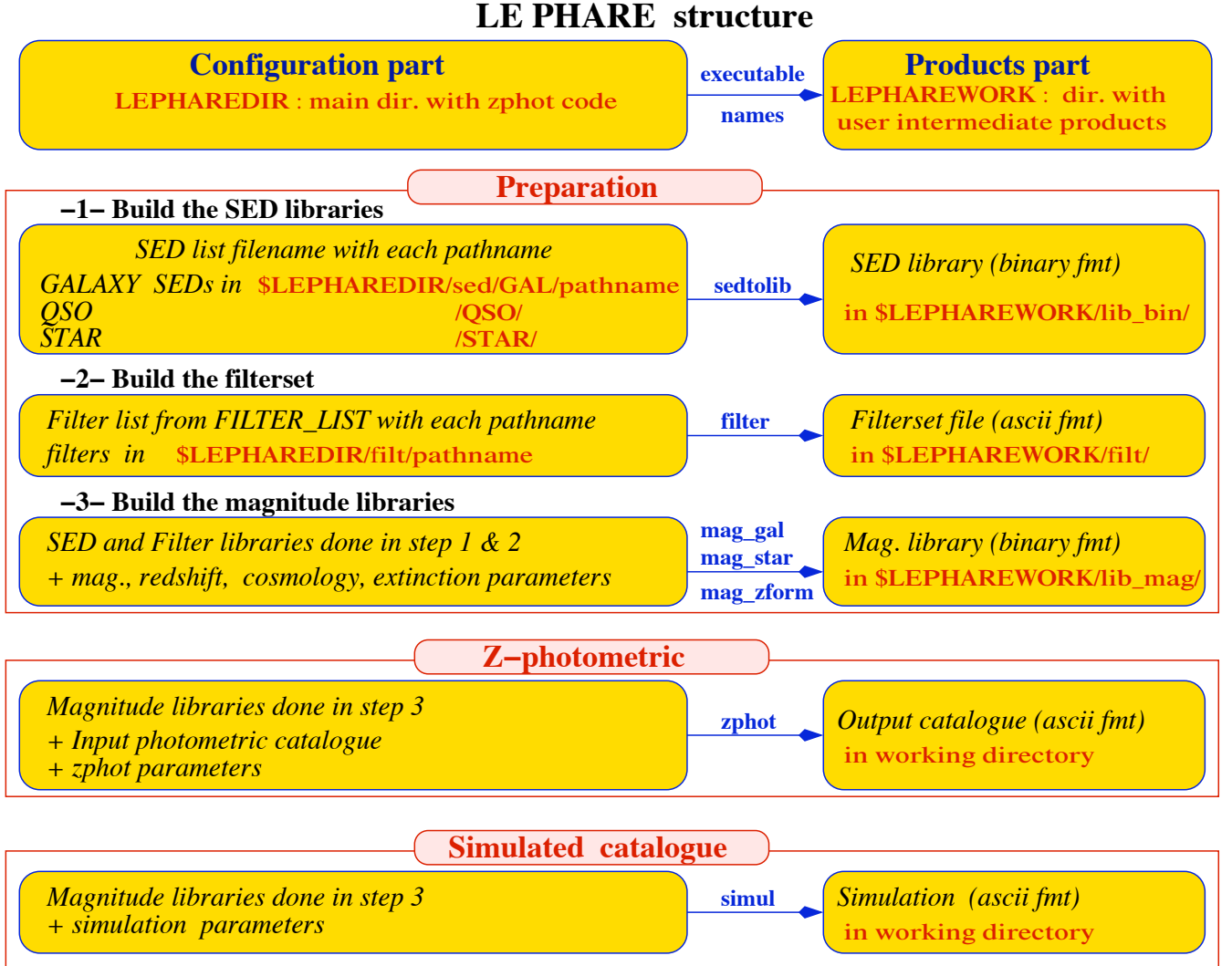





Figure 1: Illustration of the package structure

## 4 A quick start with an example

As an example, a catalog is available in \$LEPHAREDIR/test/. This catalog (hdfn\_lanzetta.in) is the HDF-North from Fernandez-Soto et al. (1999, ApJ 513) and include the flux and errors for 1067 sources with HST photometry and NIR.

The default configuration file (in \$LEPHAREDIR/config/zphot.para) is ready to be used for this example. Below are all the steps up to the output photo-z catalog:

1. cd \$LEPHAREDIR/test
2. create the star library :  
\$LEPHAREDIR/source/sedtolib -t S -c ../config/zphot.para
3. create the QSO library :  
\$LEPHAREDIR/source/sedtolib -t Q -c ../config/zphot.para
4. create the galaxy library :  
\$LEPHAREDIR/source/sedtolib -t G -c ../config/zphot.para  
check the GALAXY models used with : more \$LEPHAREWORK/lib\_bin/LIB\_CWW.doc
5. create the filter set :  
\$LEPHAREDIR/source/filter -c ../config/zphot.para
6. compute star magnitudes :  
 \$LEPHAREDIR/source/mag\_star -c ../config/zphot.para
7. compute QSO magnitudes and do not allow extinction for these SEDs (-EB\_V=0):  
 \$LEPHAREDIR/source/mag\_gal -t Q -c ../config/zphot.para -EB\_V 0.
8. compute galaxy magnitudes and apply extinction for models between 4 to 8 with E(B-V) values read from the configuration file. Create an ASCII file (CWW\_HDF.dat) to check the color tracks with redshift :  
 \$LEPHAREDIR/source/mag\_gal -t G -c ../config/zphot.para -MOD\_EXTINC 4,8 -LIB\_ASCII YES
9. run the photo-z code on the input catalog. :  
\$LEPHAREDIR/source/zphota -c ../config/zphot.para  
It creates the output file zphot.out with the output parameters selected in ../config/zphot\_output.para



## 5 Filters

A predefined set of filters are available in the directory `$LEPHAREDIR/filt/`. New set of filters can be added there.

### 5.1 description and outputs

The program **filter** puts together a list of filter response curves, and applies some transformations according to the nature of the filters. The resulting file in the directory `$LEPHAREWORK/filt/`. Additional programs (**filter\_info** and **filter\_extinc**) can be used to get more information about the filters.

### 5.2 syntax and parameter values

The syntax is : `% filter -c zphot.para`

The following parameters are considered:

Parameters	type	default	description
<code>FILTER_LIST(*)</code>	string (n≤100)	—	filter files separated by a comma.
<code>TRANS_TYPE</code>	float (n≤100)	0	Filter transmission type: 0= Energy; 1= Photon
<code>FILTER_CALIB</code>	integer (n≤100)	0	Filter calibration for long wavelengths [0-def].
<code>FILTER_FILE(*)</code>	string (n=1)	—	Name of the file with all combined filters . It is saved in <code>\$LEPHAREWORK/filt/</code> .

### 5.3 parameter descriptions

**FILTER\_LIST** : all the filter names must be separated by a comma. We assume that all the filter files are located in the directory `$LEPHAREDIR/filt/`. When writing the set of filters to be used, only the pathname after the common string `$LEPHAREDIR/filt/` should be specified.

**TRANS\_TYPE** : Type of the transmission curve for each filter, separated by a comma. The number of arguments should match the number of filter but if only value is given, which will be use for all the filters.

The transmissions ( $T_\lambda$ ) are dimensionless (in % ), however they refer either to a transmission in Energy or Photon which will slightly modify the magnitude estimates. The magnitude is :

$$mag(*) = -2.5 \log_{10} \frac{\int F_\lambda(*) R_\lambda d\lambda}{\int F_\lambda(Vega) R_\lambda d\lambda}$$

If the transmission curve ( $T_\lambda$ ) corresponds to energy then  $R_\lambda = T_\lambda$ ,

If the transmission curve ( $T_\lambda$ ) corresponds to number of photons ( $N_\varphi$ ) then  $R_\lambda = \lambda T_\lambda$  :

$$N_\varphi = \frac{F_\lambda d\lambda}{h \nu} = \frac{F_\lambda \lambda d\lambda}{h c} \rightarrow mag(*) = -2.5 \log_{10} \frac{\int F_\lambda(*) \lambda T_\lambda d\lambda}{\int F_\lambda(Vega) \lambda T_\lambda d\lambda} \rightarrow R_\lambda = \lambda T_\lambda$$



When building the filter library, the filter shape is changed with respect to the original one as follows :

$$R_\lambda = T_\lambda \left( \frac{\lambda}{\langle \lambda \rangle} \right)^{tt}$$

, where  $tt$  is the value of TRANS\_TYPE parameter and  $\langle \lambda \rangle$  is the mean wavelength of the filter. The modification of filter shape can be significant for long wavelength filters. Nevertheless it is often not the dominant source of errors with respect to other uncertainties relative to QE-CCD, telescope transmission, atmospheric extinction shape etc...

In the output filter file specified by the keyword **FILTER\_FILE**, we save the values  $(\lambda(\text{\AA}), R_\lambda)$ .

**FILTER\_CALIB** : This keyword allow to consider specific calibrations at long wavelengths in order to apply a correction factor to the original flux estimated by LEPHARE (see section 5.5 for more details).

We define the correction factor as  $\text{fac\_corr} = \frac{\int \frac{R_\nu}{B_{\nu_0}} R_\nu d\nu}{1/\lambda_0^2 \int \frac{B_\lambda}{B_{\lambda_0}} R_\lambda d\lambda}$ , where  $B_\nu$  is the reference

spectrum used to calibrate the filters and  $\lambda_0$  is the effective wavelength defined as  $\lambda_0 = \frac{\int R_\lambda B_\lambda \lambda d\lambda}{\int R_\lambda B_\lambda d\lambda}$ .

The value of **FILTER\_CALIB** allows to describe different combinations of  $\nu_0$  and  $B_\nu$ :

**FILTER\_CALIB= 0** :  $\frac{B_\nu}{B_{\nu_0}} = 1$  or  $B_\nu = ctt$ . This is the default value used in LEPHARE.

**FILTER\_CALIB= 1** :  $\nu B_\nu = ctt$ . This describes the SPITZER/IRAC, ISO calibrations.

**FILTER\_CALIB= 2** :  $B_\nu = \nu$ . This describes the sub-mm calibrations.

**FILTER\_CALIB= 3** :  $B_\nu$  =black body at T=10,000K.

**FILTER\_CALIB= 4** : A mix calibration with  $\nu_0$  defined from  $\nu B_\nu = ctt$  and the flux estimated as  $B_\nu$  =black body at T=10,000K. This appears to be the adopted scheme for the SPITZER/MIPS calibration.

**FILTER\_CALIB= 5** : Similar mix calibration with  $\nu_0$  defined from  $\nu B_\nu = ctt$  and the flux estimated as  $B_\nu = \nu$ . This may reflect the SCUBA calibration.

## 5.4 Filter informations

### 5.4.1 standard filter informations

As an example, using default values listed in the configuration file zphot.para.

---

FILTER_LIST	tmp/f300.pb,tmp/f450.pb,tmp/f606.pb,tmp/f814.pb,tmp/Jbb.pb,tmp/H.pb,tmp/K.pb
TRANS_TYPE	0
FILTER_CALIB	0
FILTER_FILE	HDF.filt

---

Run the program :% **filter -c** zphot.para.

It generates the file HDF.filt by combining all filters and saved it in \$LEPHAREWORK/filt.

It returns informations about the filters on screen . Another stand alone program allows also to read informations about existing filter list (with % **filter info -f** HDF.filt).

The following informations are written on the screen :

#NAME	ID	$\lambda_{mean}$	$\lambda_{eff}^{Vega}$	FWHM	ABcor	TGcor	VEGA	$M_{\odot}^{AB}$	CAL	$\lambda_0$	Fac
F300W	1	0.2999	0.2993	0.0864	1.398	99.99	-21.152	7.433	0	0.2999	1.000
F450W	2	0.4573	0.4513	0.1077	-0.074	-0.339	-20.609	5.255	0	0.4573	1.000
F606W	3	0.6028	0.5827	0.2034	0.095	0.161	-21.367	4.720	0	0.6028	1.000
F814W	4	0.8013	0.7864	0.1373	0.417	0.641	-22.322	4.529	0	0.8013	1.000
Jbb	5	1.2370	1.2212	0.2065	0.890	99.99	-23.748	4.559	0	1.2370	1.000
H	6	1.6460	1.6252	0.3377	1.361	99.99	-24.839	4.702	0	1.6460	1.000
K	7	2.2210	2.1971	0.3967	1.881	99.99	-26.012	5.178	0	2.2210	1.000

where :

Col 1 : Name put in the first row of the filter file

Col 2 : incremental number

Col 3 : Mean wavelength ( $\mu m$ ) :  $\int R_{\lambda} \lambda d\lambda / \int R_{\lambda} d\lambda$

Col 4 : Effective wavelength with Vega ( $\mu m$ ) :  $\int R_{\lambda} F_{\lambda}(Vega) \lambda d\lambda / \int R_{\lambda} F_{\lambda}(Vega) d\lambda$

Col 5 : Full Width at Half of Maximum ( $\mu m$ )

Col 6 : AB Correction where  $m_{AB} = m_{VEGA} + ABcor$

Col 7 : Thuan Gunn correction where  $m_{TG} = m_{VEGA} + TGcor$ . (99.99 if undefined)

Col 8 : VEGA magnitude :  $2.5 \log_{10}(\int R_{\lambda} F_{\lambda}(Vega) d\lambda / \int R_{\lambda} d\lambda)$

Col 9 : AB absolute magnitude of the sun ( $M_{\nu, \odot}^{AB}$ )<sup>1</sup>

Col 10: value of the calibration used for ( $B_{\nu}/B_{\nu_0}, \nu_0$ ) in **FILTER.CALIB**

Col 11: Effective wavelength ( $\mu m$ )  $\lambda_0^{B_{\nu}} = \frac{\int R_{\lambda} B_{\lambda} \lambda d\lambda}{\int R_{\lambda} B_{\lambda} d\lambda}$ .

Col 12: Correction factor to be applied to the original flux measured by LEPHARE. This correction is included in the programs **mag\_gal** and **mag\_star** as  $flux^{cor} = flux^{LePhare} \times fac_{cor}$

## 5.4.2 extinction informations

The stand alone program ( **filter\_extinc**) returns informations about atmospheric extinctions and galactic extinctions.

A set of atmospheric extinction curves and galactic extinction laws are available in \$LEPHAREDIR/ext/ directory. It includes the LMC (Fitzpatrick); Milky Way (Allen; Seaton ); Starburst (Calzetti) extinction laws with some variations around the 2170Å bump. The Cardelli law is hardcoded in the programs and is the default law for the galactic extinction.

```
% filter_extinc -f HDF.filt -e extinc_eso.dat -g SB_Calzetti.dat -o HDF.extinc
```

It returns :

```
#####
# Computing the ATMOSPHERIC/GALACTIC EXTINCTION #
# with the following OPTIONS #
# FILTER_FILE (-f): /data/arnouts/lepharework/filt/HDF.filt
# EXT_CURVE (-e): $LEPHAREDIR/ext/extinc_eso.dat [default:NONE]
# GAL_CURVE (-g): $LEPHAREDIR/ext/SB_calzetti.dat [default: Cardelli law]
# OUTPUT (-o): HDF.extinc [default:NONE]
#####
```

<sup>1</sup>conversion from absolute magnitude to luminosity: by combining the distance modulus ( $m - M = 5 \log D[pc] - 5$ ) and the luminosity ( $L_{\nu}[erg.s^{-1}.Hz^{-1}] = A \pi D^2[cm^2] f_{\nu}[erg.s^{-1}.cm^{-2}.Hz^{-1}]$ ) you get:  $L_{\nu, \odot}[erg.s^{-1}.Hz^{-1}] = 10^{-0.4(M_{\nu, \odot}^{AB} - 51.605)}$

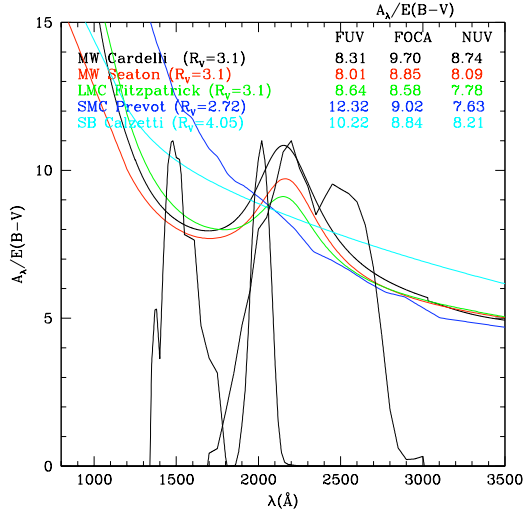


Figure 2: Example of attenuation ( $A_\lambda/E(B-V)$ ) for different filters in UV wavelength (GALEX :FUV, NUV and FOCA) and for different galactic extinction laws.

Filters	Ext(mag/airmass)	Albda/Av	Albda/E(B-V)
F300W	1.854	1.717	6.956
F450W	0.253	1.210	4.902
F606W	0.113	0.913	3.697
F814W	0.045	0.639	2.587
Jbb	0.092	0.335	1.356
H	0.100	0.197	0.799
K	0.100	0.089	0.358

Col 2 : Mean atmospheric extinction (mag/airmass) using (EXT\_CURVE):  $A_\lambda = \int R_\lambda Ext(\lambda) d\lambda / \int R_\lambda d\lambda$ .  $Ext(\lambda)$  comes from any atmospheric extinction curve that is put in \$LEPHAREDIR/ext/.

Col 3 : Mean galactic attenuation (in  $A(\lambda)/A_V$ ) using the galactic extinction law (GAL\_CURVE). Col 4 : Mean galactic attenuation (in  $A(\lambda)/E(B-V)$ ) as a function of color excess ( $E(B-V)$ ) assuming  $A_V = R_V \times E(B-V)$ .

For  $R_V$  coefficients, we assume  $R_V = 3.1$  for most extinction laws but Calzetti ( $R_V = 4.05$ ) and Prevost ( $R_V = 2.72$ ).

Others extinction laws can be added by following the format  $(\lambda(\text{\AA}), k_\lambda)$ .

## 5.5 Application to long wavelengths

LEPHARE has been developed for the optical-NIR domain but can be used at shorter (UV) and longer wavelengths (FIR, submm and radio). In particular extensive tests have been performed in the long wavelength domain by E. Le Floc'h to evaluate the photometric accuracy. Some issues have to be considered :

- the Vega spectrum is not defined at  $\lambda \geq 160\mu m$ . Thus, AB magnitudes should be used as standard when combining a large wavelength domain.

- The bandpass in radio domain is very narrow and does not require to convolve through the filter. However the structure of LEPHARE requires to implement a transmission curves for the radio frequencies in similar way as in shorter wavelengths.

More important, at long wavelengths the equivalent fluxes are taken as the monochromatic flux density calculated at the effective wavelength of the filter and for a reference spectrum that would result in the same energy received on the detector:

$$\langle F_\nu \rangle = \frac{\int F_\nu R_\nu d\nu}{\int \frac{B_\nu}{B_{\nu_0}} R_\nu d\nu}$$

where  $B_\nu$  is the reference spectrum and  $\nu_0$  the effective frequency of the filter. In LEPHARE, the flux estimates are equivalent to consider  $\frac{B_\nu}{B_{\nu_0}} = 1$  ( $B_\nu = ctt$ ). Therefore there is a correction factor to account for with respect to the original flux estimated by LEPHARE. This correction is :

$$\langle F_\nu \rangle^{COR} = \langle F_\nu \rangle^{LePhare} \times \frac{\int R_\nu d\nu}{\int \frac{B_\nu}{B_{\nu_0}} R_\nu d\nu}$$

At long wavelengths, different conventions have been used for the reference spectrum. As an example: SPITZER/IRAC uses a flat spectrum ( $\nu B_\nu = ctt$ ) as well as ISO; SPITZER/MIPS uses a blackbody with temperature  $T=10000K$  while SCUBA uses planets which have SEDs in submillimeter very close to  $B_\nu = \nu$ . The keyword **FILTER\_CALIB** is used to account for these different calibration scheme (see section 5.3).

One additional effect is the way the effective wavelength is defined. In the case of MIPS, the effective wavelength seems to be defined, according to the MIPS handbook, as  $\nu B_\nu = ctt$  while the reference spectrum is a black body. This mix definition can be described with **FILTER\_CALIB=4**.

In the table below we report the effective wavelengths and the correction factors that are applied to LEPHARE fluxes for a set of filters spanning from NIR (K band), MIR (SPITZER/IRAC), FIR (SPITZER/MIPS), sub-mm (SCUBA) to radio (VLA: 1.4GHz).

#NAME	$\lambda_{mean}$	$M_\odot^{AB}$	CAL	$\lambda_0^{B_\nu}$	Fac	CAL	$\lambda_0^{B_\nu}$	Fac
K	2.2210	5.178	0	2.2210	1.000	0	2.2210	1.000
IRAC_1	3.5634	6.061	1	3.5504	1.004	1	3.5504	1.004
IRAC_2	4.5110	6.559	1	4.4930	1.004	1	4.4930	1.004
IRAC_3	5.7593	7.038	1	5.7308	1.005	1	5.7308	1.005
IRAC_4	7.9595	7.647	1	7.8723	1.011	1	7.8723	1.011
24mic	23.8437	9.540	4	23.6750	0.968	3	23.2129	1.006
70mic	72.5579	12.213	4	71.4211	0.932	3	68.4725	1.013
160mic	156.9636	13.998	4	155.8945	0.966	3	152.6311	1.007
850mic	866.7652	nan	5	865.3377	0.997	2	862.4710	1.000
VLA_1.4GHz	214300	nan	5	214248.3782	1.000	2	214145.1645	1.000

As can be seen from this table :

- For K band, we use **FILTER\_CALIB=0**, so no correcting factor is applied.
- For IRAC bands , we adopt  $\nu B_\nu = ctt$  (**FILTER\_CALIB=1**). The correction factors are less than 1% and can be neglected.

- For MIPS bands (24, 70, 160 $\mu m$ ), we adopt  $B_\nu = BB(T = 10,000K)$  and  $\lambda_0$  defined as  $\nu B_\nu = ctt$  (FILTER\_CALIB=4), which seems to better reflect the current MIPS calibration. In this case, correction factors between 3% to 7% are applied to the theoretical magnitudes estimated with **mag\_gal** and **mag\_star** programs. However, we also compare the correction factors when both  $\lambda_0$  and  $B_\nu$  refer to a black body at T=10,000K (FILTER\_CALIB=3). In this case, the corrections become negligible with  $\sim 1\%$ .
- For sub-mm (SCUBA, 850 $\mu m$ ) and radio (VLA: 1.4GHz) wavelengths, no correction is required

As a general conclusion, the flux measured by LEPHARE appear accurate at a level of 1% with respect to most of the calibration scheme considered at long wavelength and thus no correction is required. A special warning for MIPS calibration, where depending on the calibration scheme, a correction up to 7%, may be applied.

## 5.6 requirement to create a new filter

- Filters are ASCII files with the following format :

In first row : # SHORT\_NAME\_of\_FILTER    ADD\_COMMENTS

In next rows :  $\lambda(\text{\AA})$  Transmission

Wavelengthes must be in increasing order. It is better to put the lowest and highest  $\lambda$  with Transmission=0 The units of Transmission are not considered

As an exemple : I create filter pippo.pb and put it in \$LEPHAREDIR/filt/pippo.pb :

```
# PIPPO    This is close to window function
5000       0
5001       1
5999       1
6000       0
```

## 6 SED libraries and sedtolib

### 6.1 SED libraries

A set of libraries for stars, galaxies and quasars are available in \$LEPHAREDIR/sed/STAR, \$LEPHAREDIR/sed/GAL, \$LEPHAREDIR/sed/QSO directories and spread in different subdirectories. Each subdirectory contains the SED files, a README file and one file with all the SED to be used (\*.list). This file can be changed and used as input for **sedtolib**.

For star and QSO and most of the galaxies, SEDs are written in ASCII format with  $(\lambda(\text{\AA}), F_\lambda)$ . For Galaxy, in addition to empirical SEDs, output files from stellar synthesis population models (Pegase and GISSEL) with more complex format can also be used with the add of a special character after the file name in the SED list file.

### 6.2 sedtolib program

The program **sedtolib** is used to build the different STAR, QSO and GALAXY libraries from a list of SED files. The goal of this program is to generate from different kind of SEDs (star/qso/galaxy) with different original formats (ascii, binary) a unique binary file with direct access that can be easily read in the next steps. The binary output file (\*.bin) is saved in the directory \$LEPHAREWORK/lib\_bin/ with an attached doc file (\*.doc) and for galaxy a file with physical informations (\*.phys). The new SED format is  $(\lambda(\text{\AA}), \text{flux}[erg/s/\text{\AA}/cm^2])$ . For models with input SEDs expressed in luminosity or energy  $(L_\odot/\text{\AA}, \nu L_\nu, \dots)$ , like PEGASE, GISSEL or the FIR libraries, the SED are converted in flux  $(erg/s/cm^2/\text{\AA})$ .

#### 6.2.1 syntax and parameter values

The usual syntax : % **sedtolib** -t G [or Q or S] -c zphot.para

To simplify the use of this section, specific parameters have been duplicated for the STAR, QSO and GALAXY categories with different names. The option -t allows to specify if galaxy (G) or star (S) or QSO (Q) parameters have to be read.

The parameter values : If XXX means either GAL or QSO or STAR :

parameter	type	default	description
XXX_SED(*)	string (n=1)	—	Full pathname of file with the list of selected SED files
XXX_LIB(*)	string (n=1)	—	Name of the output binary library (with no extension) Files \$XXX_LIB.bin, \$XXX_LIB.doc and \$XXX_LIB.phys saved in \$LEPHAREWORK/lib_bin/
XXX_FSCALE	float (n=1)	1.0	Flux scale to be applied to each SED in the list
SEL_AGE	string (n=1)	NONE	Full pathname of file with a list of ages (yr) to be extracted from GISSEL or PEGASE seds.
AGE_RANGE	float (n=2)	—	Range of age (yr)

### 6.2.2 building libraries from a list of SEDs

The easiest is just to take predefined list of SEDs in the existing subdirectories and look at the README file.

For stars (`$LEPHAREDIR/sed/STAR`), SEDs are available in those subdirectories :

- `PICKLES/` : 131 stellar SEDs from Pickles (1998)
- `BD/`: Low mass stars library from Chabrier et al. (2000)
- `WD/`: 4 white dwarfs from Bohlin et al. (1995)
- `SPEC_PHOT`: Spectro-Photometric standards from Hamuy et al. (1992, 1994)

For QSOs (`$LEPHAREDIR/sed/QSO`), there is a list of observed spectra from different authors and some synthetical QSOs listed in the subdirectory (`synth/`). TO BE CLEAN UP!

For galaxies (`$LEPHAREDIR/sed/GAL`), SEDs are available in those subdirectories :

- `42GISSEL/` : 42 SEDs with a single age extracted from GISSEL96
- `AVEROI_NEW/` : 62 empirical SEDs based on CWW and starburst galaxies
- `CFHTLS_SED/` : 66 SEDs used for CFHTLS photo-z paper (Ilbert et al.)
- `COSMOS_SED/` : 32 SEDs used for COSMOS photo-z paper (Ilbert et al.)
- `CWW_KINNEY/` : original CWW and Kinney spectra
- `POGGIANTI/`: 8 SEDs
- `VIRGO/`: 10 SEDs from VIRGO cluster analysis (Boselli et al.)
- `GISSEL/`: list of SEDs with GISSEL96
- `BC03_CHAB/` : list of SEDs with BC03 library
- `PEGASE2/` : list of SEDs with PEGASE2 library

For FIR galaxy SEDs (`$LEPHAREDIR/sed/GAL`), different SEDs are available :

- `CHARY_ELBAZ/` : 105 FIR templates with different luminosity
- `DALE/` : 64 FIR templates
- `LAGACHE/`: 46 FIR templates
- `SK06/` : different set of starburst models based on Siebenmorgen & Krugel (2006)

Note that for the first 3 libraries (`CHARY-ELBAZ`, `DALE`, `LAGACHE`), we have subtracted a stellar component to their SEDs in order to get only the dust contribution at the shortest wavelengths.

In order to know the format of the SEDs that are used in your list, an additional character must be specified after each sed file allowing to mix in one list different type of galaxy SEDs. For example you can prepare a list with :

```
COSMOS_SED/Ell3_A_0.sed
PEGASE2/spectra2_RB_B_SW_aver.sed  F
BC03_CHAB/bc03_chab_zo_tau3.ised    BC03
GISSEL/tau_070_00200_sp.ised        B
```

The character **F** is used for PEGASE2 models, **B** for the GISSEL96 models and **BC03** for the Bruzual and Charlot 2003 models. For ASCII SED file no character is required. For the list with FIR SEDs, the character **LW** is required.

### 6.2.3 Physical informations for the galaxies

For the galaxy templates, an additional file is generated with some physical properties (\*.phys). This information will be used when running the photo-z code. It contains the following parameters :

Model Age  $L_{UV}$   $L_R$   $L_K$   $L_{IR}$  Mass SFR Metallicity Tau  $D_{4000}$

where

Age is expressed in yr

$L_{UV}$  is NUV monochromatic luminosity ( $\text{Log}([\text{erg/s/Hz}])$ ) ( $\int_{2100}^{2500} L_{\lambda} d\lambda / 400 * 2300^2 / c$  )

$L_R$  is optical r monochromatic luminosity ( $\text{Log}([\text{erg/s/Hz}])$ ) ( $\int_{5500}^{6500} L_{\lambda} d\lambda / 1000 * 6000^2 / c$  )

$L_K$  is NIR K monochromatic luminosity ( $\text{Log}([\text{erg/s/Hz}])$ ) ( $\int_{21000}^{23000} L_{\lambda} d\lambda / 2000 * 22000^2 / c$  )

$L_{IR}$  is the IR luminosity ( $\text{Log}([L_{\odot}])$ )

Mass is the stellar mass ( $M_{\odot}$ )

SFR is the ongoing star formation rate ( $M_{\odot}/\text{yr}$ )

Metallicity Gas metallicity of the galaxy

Tau is the e-folding parameter for a star formation history with  $\text{SFH}=\exp(-t/\text{tau})$  (yr)

$D_{4000}$  is the 4000A break measured as Bruzual 1983 ( $D_{4000} = \int_{4050}^{4250} F_{\lambda} d\lambda / \int_{3750}^{3950} F_{\lambda} d\lambda$ )

if non available the parameters are set to -99.

The IR luminosity ( $L_{IR}$ ) is derived as :

- For the Infra-red libraries ( LW : Dale, Lagache, Chary-Elbaz, Siebenmorgen & Krugel) the IR luminosity is measured from 8 to 1000 microns. These luminosity may be slightly different than the ones quoted by the authors due to the different definition of the  $L_{IR}$  integration limits and because we have subtracted the underlying stellar component from the original SEDs (for Dale, Lagache and Chary-Elbaz).
- For the Pegase models (F) the IR luminosity is given as input if internal extinction is applied
- For the stochastic Bruzual and Charlot library ( BC\_STOCH ) the IR luminosity is estimated from the ratio between the extinguished and unextinguished flux over the entire wavelength domain.

### 6.2.4 adding librairies

New SEDs can be easily added to the current ones. They have to be located in the appropriated directory (GAL/STAR/QSO). If they are ASCII files they must be in  $\lambda(\text{\AA}), \text{flux}[\text{erg/s/\AA/cm}^2]$ , with increasing  $\lambda$ . New GISSEL or PEGASE models can be included if the format did not changed.

## 6.3 example

```
sedtolib -t G -c zphot.para -GAL_SED $LEPHAREDIR/sed/GAL/CFHTLS_SED/CFHTLS_MOD.list  
-GAL_LIB LIB_CFHTLS
```

This command reads the list of galaxy templates given by the keyword **-GAL\_SED** (as indicated by **-t G**).

A binary file LIB\_CFHTLS.bin with a LIB\_CFHTLS.doc and LIB\_CFHTLS.phys files are saved in \$LEPHAREWORK/lib\_bin/.

```
sedtolib -t S -c zphot.para -STAR_SED $LEPHAREDIR/sed/STAR/STAR_MOD.list -STAR_LIB
```



## LIB\_STAR

This command reads the list of star templates given by the keyword **-STAR\_SED** (as indicated by **-t S**).

A binary file LIB\_STAR.bin and a LIB\_STAR.doc file are saved in \$LEPHAREWORK/lib\_bin/.

**sedtolib -t Q -c zphot.para -QSO\_SED \$LEPHAREDIR/sed/QSO/QSO\_MOD.list -QSO\_LIB LIB\_QSO**

This command reads the list of QSO templates given by the keyword **-QSO\_SED** (as indicated by **-t Q**).

A binary file LIB\_QSO.bin and a LIB\_QSO.doc file are saved in \$LEPHAREWORK/lib\_bin/.

An example of misleading command :

**sedtolib -t S -c zphot.para -GAL\_SED \$LEPHAREDIR/sed/GAL/CWW\_KINNEY/CWW\_MOD.list -GAL\_LIB LIB\_CWW**

This command will work but it does not read the galaxy template given by **-GAL\_SED** but rather the star list given in the keyword **-STAR\_SED** in the zphot.para file, as specified by the option : **-t S !!**

## 7 Magnitude for stellar libraries : **mag\_star**

### 7.1 description and outputs

A specific program is used to derive magnitudes for the STAR sample (**mag\_star**). This program reads first the filter information and the stellar library and compute the magnitudes. The binary output file is saved in *\$LEPHAREWORK/lib\_mag/*. with an attached doc file.

### 7.2 syntax and parameter values

The usual syntax : % **mag\_star** -c zphot.para

The keywords for this program are :

Parameters	type	default	description
FILTER_FILE(*)	string (n=1)	—	Name of the filter file. This filter file must already exist in <i>\$LEPHAREWORK/filt/</i>
STAR_LIB_IN(*)	string (n=1)	—	Name of the stellar library (with no extension) The files <i>\$STAR_LIB_IN.bin</i> (.doc) should exist in <i>\$LEPHAREWORK/lib_bin/</i>
STAR_LIB_OUT(*)	string (n=1)	—	Name of the library file with the magnitudes (no extension) The files <i>\$STAR_LIB_OUT.bin</i> (.doc) are saved in <i>\$LEPHAREWORK/lib_mag/</i>
MAGTYPE(*)	string (n=1)	—	Magnitude type (AB or VEGA)
LIB_ASCII	string (n=1)	NO	Build an ASCII file with magnitudes in the working directory. Name of the file <i>\$STAR_LIB_OUT.dat</i>

## 8 Magnitudes for galaxy/qso libraries : mag\_gal

### 8.1 description and outputs

This program measures the magnitudes for the GALAXY or QSO sample (**mag\_gal**).

For a set of filters given by **-FILTER\_FILE** and an input SED library defined by **-GAL\_LIB\_IN**, the magnitudes are computed at different redshifts defined by **-Z\_STEP**. Extinctions can be applied as specified by the three keywords (**-EXTINC\_LAW**, **-MOD\_EXTINC**, **-EB\_V**). If evolving stellar population models are used, the cosmology (**-COSMOLOGY**) will allow to reject models older than the age of the universe. The magnitude in VEGA or AB (defined by **-MAGTYPE**) are saved in the binary file defined by **-GAL\_LIB\_OUT** in \$LEPHAREWORK/lib\_mag/ with an attached doc file. An output file (**-LIB\_ASCII YES**) is written to check the magnitudes, color tracks with redshift ....

### 8.2 syntax and parameter values

The usual syntax : % **mag\_gal -t G** (or **Q**) **-c** zphot para

The parameters values :

(XXX means either GAL or QSO and are selected with **-t G** or **-t Q**)

Parameters	type	default	description
FILTER_FILE(*)	string (n=1)	---	Name of the filter file file must exist in \$LEPHAREWORK/filt/
XXX_LIB_IN(*)	string (n=1)	---	Name of the QSO or GALAXY binary library (with no extension) files must exist in \$LEPHAREWORK/lib_bin/
XXX_LIB_OUT(*)	string (n=1)	---	Name of the magnitude binary library (with no extension) files \$GAL[QSO]_LIB_OUT.bin (.doc) are saved in \$LEPHAREWORK/lib_mag/
MAGTYPE(*)	string (n=1)	---	Magnitude type (AB or VEGA)
Z_STEP(*)	float (n=3)	---	dz,zmax,dzsup: linear redshift step (dz) and redshift max (zmax). if zmax>6, new step can be used (dzsup)
COSMOLOGY(*)	float (n=3)	---	$H_0$ , $\Omega_0$ , $\Lambda_0$ . Used for age constraints.
EXTINC_LAW	string (n≤10)	NONE	Extinction laws to be used (in \$LEPHAREDIR/ext/*) several files separated by comma
MOD_EXTINC	integer (n≤20)	0,0	Range of models for which extinction will be applied The numbers refer to the models in the \$GAL_SED list Number of values must be twice the number of extinction laws.
EB_V	float (n≤100)	0.	Reddening color excess E(B-V) values to be applied values separated by comma.
EM_LINES	string (n=1)	NO	Add contribution of emission lines
LIB_ASCII	string (n=1)	NO	ASCII file with magnitudes saved in the working directory called \$GAL[QSO]_LIB_OUT.dat

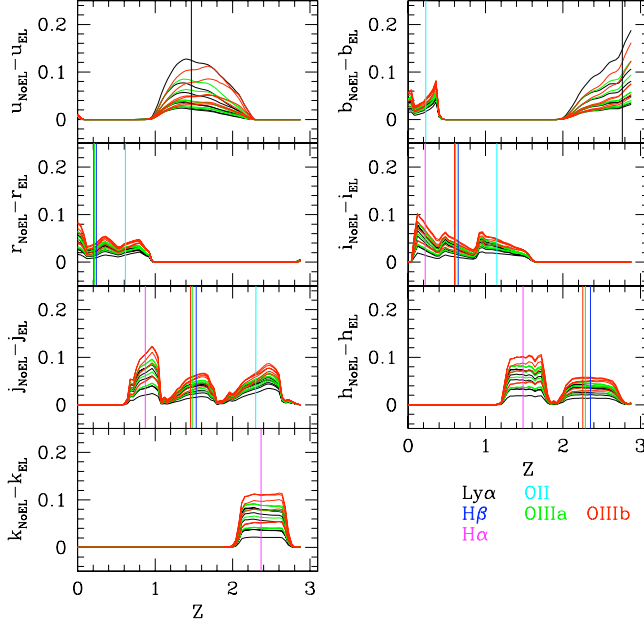


Figure 3: Flux contribution of the different Emission lines in the HDF filters for CWW galaxy types with  $NUV_{ABS} = -20$  and  $E(B-V) = 0$  (black) 0.1 (green) 0.3 (red)

### 8.3 The extinction laws

A set of extinction laws are available in the directory (\$LEPHAREDIR/ext/). Several extinction laws can be used and set up in the keyword **-EXTINC\_LAW**. Each extinction law will be applied to a range of SED models specified by the keywords **-MOD\_EXTINC**. The model number corresponds to the rank in the list of SEDs used in **-GAL\_SED**. The number of models must be twice the number of extinction laws. The different values of reddening excess  $E(B-V)$  are given in the keyword **-EB\_V** and will apply to all extinction laws. The extinguished flux is :  $F_{\lambda}^e = F_{\lambda}^0 10^{-0.4A_{\lambda}} = F_{\lambda}^0 10^{-0.4k_{\lambda}E(B-V)}$

If extinction is applied, a new estimate of the IR dust luminosity is computed by measuring the amount of light absorbed.

### 8.4 The Emission lines

Changing the option **-EM\_LINES YES**, the contribution of the emission lines in the different filters will be included. The role of emission lines in medium width filters can be significant as shown by Ilbert et al. (2007). LePhare accounts for the contribution of emission lines with a simple recipe based on the Kennicutt relations (1998) between the SFR and UV luminosity,  $H_{\alpha}$  and [OII] lines. The following lines are included in this treatment:  $Ly_{\alpha}$ ,  $H_{\alpha}$ ,  $H_{\beta}$ , [OII], OIII[4959] and OIII[5007] with different ratio with respect to [OII] line as described in Ilbert et al. 07. Emission lines are considered only for galaxies with dust free color bluer than  $(NUV - r)_{ABS} \leq 4$ . The intensity of the lines will be scaled according to the intrinsic UV luminosity of the galaxy. An example of the emission lines contribution to the flux in the broad band filters used in the HDF dataset is shown in Fig 3.

This option is not appropriated for the quasars samples.

## 8.5 ASCII output file

An output file is produces in the current directory if **-LIB\_ASCII YES**. It has the same root name as the binary file with extension .dat and contains the following informations :

Model, Extinc-law, E(B-V),  $L_{TIR}(L_{\odot})$ , Z, DMod, Age(yr), nrec, n , (mag(i),i=1,n),(kcor(i),i=1,n)  
where Model is the number of models based on the original list, Extinc-law refers to the number of the extinction laws used,  $L_{TIR}$  the new estimate of the IR luminosity, DMod is the distance modulus, nrec is a record (internal use), n the number of filters, mag(i) the magnitudes in all filters and kcor(i) the k correction in all filters.

## 8.6 Resizing the library

You must be aware that the size of the library becomes quickly huge if you do not pay attention. You can estimate its size by considering the following numbers :

# of models x # of age x # of z steps x # of extinction law x # of EB-V

For exemple, 10 SEDs with 60 ages, 2 extinction laws and 6 E(B-V) and 150 z steps will exceed 1,000,000 rows.

The maximal size of the libraries is declared in the file \$LEPHAREDIR/source/dim\_lib.decl. If you need to increase its size, you have to recompile the sources with **make clean** and **make**.

## 8.7 Example

**mag\_gal -t Q -c zphot.para -FILTER\_FILE HDF.filt -QSO\_LIB\_IN LIB\_QSO -QSO\_LIB\_OUT QSO.HDF -EXTINC\_LAW NONE**

It will generate the magnitudes for the QSO library (LIB\_QSO.bin) through the filters HDF.filt. Those two files have been created during the two previous steps. No extinction will be applied. The output QSO.HDF.bin and QSO.HDF.doc are saved in \$LEPHAREWORK/lib\_mag/

**mag\_gal -t G -c zphot.para -FILTER\_FILE HDF.filt -GAL\_LIB\_IN LIB\_CWW -GAL\_LIB\_OUT CWW.HDF -EXTINC\_LAW SMC\_prevot.dat,SB\_calzetti.dat -MOD\_EXTINC 3,6,4,8 -EB\_V 0.,0.05,0.1,0.2,0.3 -LIB\_ASCII YES**

It will generate the magnitudes for the galaxy library (LIB\_CWW) and HDF.filt. The library LIB\_CWW is built with the following option in sedtolib:

**sedtolib -t G -c zphot.para -GAL\_SED \$LEPHAREDIR/sed/GAL/CWW\_KINNEY/CWW\_MOD.list -GAL\_LIB LIB\_CWW**

CWW\_MOD.list contains the following SEDs : 1:Ell, 2:Sbc, 3:Scd, 4:Im, 5:SB1, 6:SB2, 7:SB3, 8:SB4.

The two extinction laws are applied as follows :

- SMC\_prevost is used for models Scd (3), Im(4), SB1(5), SB2(6)
- SB\_calzetti is used for models Im(4), SB1(5), SB2(6), SB3(7), SB4 (8)

The overlapping models (Im, SB1 and SB2) will be extinguished with the 2 extinction laws.

For both extinctions, the same values of E(B-V) are used.

The files CWW\_HDF.bin and CWW\_HDF.doc are saved in \$LEPHAREWORK/lib\_mag/ and the ASCII file CWW\_HDF.dat is written in the current directory.

## 9 The photometric redshift program: zphota

### 9.1 description

The program zphota performs the  $\chi^2$  fitting analysis between the template and observed flux. Analysis of the  $\chi^2$  minimization function for the different type of libraries (GAL/STAR/QSO) is performed to get the best models and to estimate the redshifts and uncertainties. Different options are available to improve the photo-z measurements (prior informations, adaptive photometric adjustments, emission lines).

The program can be used as a template fitting code to fit multi-wavelength dataset (from UV to sub-mm) to extract physical informations on individual galaxies from absolute luminosities to stellar mass, star formation rate,..., with SEDs based on Stellar Population Synthesis models and dust extinction with empirical FIR libraries.

As previous commands the syntax is : `% zphota -c zphot para`

### 9.2 Input catalog, context and main parameters

A small set of primary options has to be specified which describes the characteristics of your input catalog, the libraries you wish to use for the fitting and the output file parameters.

#### 9.2.1 Input Catalog

The most important overall steps, is the **preparation of the input catalog** !

Here are some requirements :

- The basic format for the catalog (**CAT\_TYPE=SHORT**) is :  
**ID mag1 err1 mag2 err2 ... magN errN**  
the expanded format (**CAT\_TYPE=LONG**) is :  
**ID mag1 err1 mag2 err2 ... magN errN CONTEXT Z-SPEC STRING**  
where the CONTEXT indicates which passbands can be used for this object (see below), Z-SPEC any input redshift and STRING all the remaining columns in the file (can be empty)
- **Magnitudes must be in Vega or AB system** and **flux must be in ( $\text{erg}/\text{s}/\text{cm}^2/\text{\AA}$  or  $\text{erg}/\text{s}/\text{cm}^2/\text{Hz}$ )**.  
If magnitudes are used as input, they are first converted in flux in the code.
- **The filters in the input catalog must follow the same order as in the library !**
- **The input catalog must include the same number of couple (mag, error) values as the number of filters used to create the libraries.** If not observed in a specific band, negative values (-99,-99) can be used for (mag,error). The context parameters allow you to handle these sparse data sampling .
- You can consider any band as an **upper-limit** if the **error=-1.0** and the **flux is positive**. If the band is used in  $\chi^2$  fitting, then **all the SEDs with flux above this upper-limit are discarded**. Be careful about your upper-limit flux value !

### 9.2.2 Context

The Context is an integer value which specify the filter combination to be used. It is defined as the sum of powers of 2 :  $\text{Cont} = \sum_{i=1}^{i=N} 2^{i-1}$ , where i is the filter number as ordered in the input catalog (and in the library), and N is the total number of filters.

As an example, let's consider a catalog with the following passbands:

Passband	U	G	R	I	Z	J	H	K
Filter number (i)	1	2	3	4	5	6	7	8
Filter Context ( $2^{(i-1)}$ )	1	2	4	8	16	32	64	128

- If the context is included in the catalog (CAT\_TYPE= LONG), you can specify a context for each object. One context value corresponds to a unique filter combination:
  - if an object is observed in all passband but H : Context=191
  - if an object is observed in UGRIZ : Context=31
  - if an object is observed in GRIZK : Context=158
- If the context is absent in the input catalog (CAT\_TYPE =SHORT), it is equivalent to use all the passbands for all the objects, so Context=255. However, the code checks the error and flux values. If both values are negative, the band is not used.

In practice, the context specified in the input catalog can include all the passbands where the object has been observed even the bands where it is not detected (upper-limit). Additional options in the configuration file will allow to restrict the use of the catalog to some specific filter combinations.

Note : In the configuration file, some options refer to a sum of filter context:  
BD\_SCALE, GLB\_CONTEXT, FORB\_CONTEXT, ADAPT\_CONTEXT, MABS\_CONTEXT, FIR\_CONT, FIR\_SCALE  
and some others refer to the filter number :  
NZ\_PRIOR, MAG\_REF, MABS\_REF, MABS\_FILT, ADAPT\_BAND, PDZ\_MABS\_FILT.

### 9.2.3 Main parameters

The keywords, in the table below describes the informations in the input catalog, the libraries for the photo-z and the output catalog. Keywords with (\*) must be defined, all the other keywords are optional.



PRIMARY & IN/OUTPUT CATALOG KEYWORDS			
Parameters	type	default	description
Input catalog			
CAT_IN(*)	string (n=1)	---	Name of the input photometric catalogue (full path)
INP_TYPE(*)	string (n=1)	---	Input values: Flux (F) or Magnitude (M)
CAT_MAG(*)	string (n=1)	---	Input magnitude type : AB or VEGA
CAT_FMT(*)	string (n=1)	---	Input format for the list of Mag (or Flux) and Errors : MEME : Mag1,Err1,Mag2,Err2,... = (Mag,Err) <sub>i=1,N</sub> MMEE : Mag1,...,MagN , Err1,..ErrN = (Mag) <sub>i</sub> , (Err) <sub>i</sub>
CAT_LINES	integer (n=2)	-99,-99	min and max rows read in input catalog
CAT_TYPE	string (n=1)	SHORT	Input format catalogue information if SHORT: Id,(mag,err)1→N if LONG : Id,(mag,err)1→N, context, z-spec, string
LePhare main libraries			
ZPHOTLIB(*)	string (1≤n≤3)	---	Library names (with no extension) like XXX.LIB.OUT Files should exist in \$LEPHAREWORK/lib_mag/ 3 libraries : one per type (GAL, QSO, STAR)
Output catalog			
PARA_OUT(*)	string (n=1)	---	Name of the file with selected output parameters (full path)
CAT_OUT	string (n=1)	zphot.out	Name of the output file (full path) by default saved in working directory

### 9.3 SED fitting keywords for photo-z

To measure the photometric redshift we use a  $\chi^2$  fitting procedure by comparing the observed flux ( $F_{obs}$ ) and its corresponding uncertainties ( $\sigma$ ) with the flux from templates ( $F_{temp}$ ) defined as ::

$$\chi^2 = \sum_i \left[ \frac{F_{obs,i} - sF_{temp,i}}{\sigma_i} \right]^2$$

where i refers to the band used for the analysis and s the scaling factor that is chosen to minimize the  $\chi^2$  values ( $d\chi^2/ds = 0$ ):

$$s = \sum_j \left[ \frac{F_{obs,j} F_{temp,j}}{\sigma_j^2} \right] / \sum_j \left[ \frac{F_{temp,j}^2}{\sigma_j^2} \right]$$

where j refers to the band used for the scaling (j can be different from i).

The choice of the filters is defined by the context value for each object. You can also force the analysis to some specific filter combination for the whole catalog with GLB\_CONTEXT ( $\chi^2$  analysis) and BD\_SCALE (scaling factor) keywords. If GLB\_CONTEXT is used, it supersedes the individual context.

BD\_SCALE will use only passbands that are also included in individual context or GLB\_CONTEXT.

You can also reject some bands with FORB\_CONTEXT keyword.

These Context keywords are used for the standard libraries defined with ZPHOTLIB. Those empirical and stellar population synthesis libraries only account for the stellar light. It is strongly suggested to only use filters where the stellar light is dominant. Typically we suggest to authorize only the filters with  $\lambda \leq 5\mu m$ .

Longer wavelength informations should be treated separately with the FIR libraries.

			FITTING PROCEDURE KEYWORDS
Parameters	type	default	description
Passband selection			
BD_SCALE	integer (n=1)	0	Band used for scaling the models to the observations defined as : $\sum_{i=0}^{nbd-1} 2^i$ 0 (default) means that all bands are used
GLB_CONTEXT	integer (n=1)	-1	Forces the context of all objects for $\chi^2$ analysis defined as : $\sum_{i=0}^{nbd-1} 2^i$ 0 means that all bands are used -1 (default) means that context per object is used
FORB_CONTEXT	integer (n=1)	-1	context for forbidden bands defined as : $\sum_{i=0}^{nbd-1} 2^i$
CHI2_RM_BD	integer (n=2)	—	(X,Y): Contribution to global $\chi^2(X\%)$ and $\Delta F/\sigma > Y$ reject one band if $\chi^2(bd)/\chi^2 > X\%$ and $\Delta F > Y\sigma$
error adjustments			
ERR_FACTOR	float (n=1)	1.0	Scaling factor to the errors (in flux)
ERR_SCALE	float (n≤100)	-1.	Systematic errors (in mag) add in quadrature to the observations must match number of bands, not used otherwise
Emission lines			
ADD_EMLINES	string (n=1)	NO	Add Emission lines contribution
Fixing redshift			
ZFIX	string (n=1)	NO	Fixed redshift (as defined in CAT_TYPE LONG) and search for best model
Analysis of $F(z)$ function			
Z_INTERP	string (n=1)	NO	Parabolic interpolation between original step (dz)
DZ_WIN	float (n=1)	0.25	“smoothing” window function for 2nd peak search in F(z) (value between 0 to zmax)
MIN_THRES	float (n=1)	0.1	threshold for the detection of 2nd peak in normalised F(z) (value between 0 to 1)
PROB_INTZ	float (n≤ 100)	0.	redshift intervalles to compute probability from F(z) (even number of values), output vectors from 0 to 100% 0.-default : not used

By definition the  $\chi^2$  procedure is sensitive to the photometric errors, so it is important to pro-

vide reliable uncertainties. Users must account for a possible underestimation (when noise correlation is present in the data) or zero-point calibration uncertainties. The keywords `ERR_FACTOR` and `ERR_SCALE` allow to tune the individual errors. Note that `ERR_FACTOR` will not change the best photo-z solution but just the estimates of the errors, while `ERR_SCALE` can change the relative contribution of the bands and thus the best redshift.

In the  $\chi^2$  analysis, the best  $\chi^2$  at each redshift step is saved to build the function  $F(z) = \exp[-\chi_{min}^2(z)/2]$ . This function is used to refine the photo-z solution (`Z_INTERP YES`) with a parabolic interpolation (Bevington, 1969), and to search for secondary solutions (`DZ_WIN`, `MIN_THRES`) and probability distribution (`PROB_INTZ`).

When fitting procedure is performed with option `ZFIX=YES`, no  $F(z)$  analysis is extracted for objects with input redshifts in  $0 \leq z_{spec} \leq 6$  but normal mode is used when input redshift is out of this range.

Note : when using auto adaptive mode (`AUTO_ADAPT YES`) the redshift, for objects that meet the criteria from `ADAPT_LIM` and `ADAPT_ZBIN`, is automatically fixed to the spectroscopic value during the adaptation, and will be let free when adaptation is finished. Do not use `ZFIX YES`.

## 9.4 adding prior informations

Additional constraints can be applied to the  $\chi^2$  fitting procedure with the options below. You can restrict the redshift, extinction ranges, the expected mass and absolute luminosity ranges. A prior on the redshift distribution, following a similar procedure than Benitez et al. (2000), can be applied (`NZ_PRIOR`). We used the  $N(z)$  prior by type computed from the VVDS survey in I band and detailed in Ilbert et al. (2006).

PRIOR KEYWORDS			
Parameters	type	default	description
<code>Z_RANGE</code>	float (n=2)	0.,99.	Z min and max allowed in the <code>GALAXY</code> library
<code>EBV_RANGE</code>	float (n=2)	0,9	E(B-V) min and max allowed in the <code>GALAXY</code> library
<code>NZ_PRIOR</code>	integer (n=3)	—	N(z) prior as function of I band and (B-I) restframe colors Reference filters for (I, B, I)
<code>MASS_SCALE</code>	float (n=2)	0.,0.	Log(scaling factor) range acceptable 0.,0. (default) means not used
<code>MAG_ABS</code>	float (n=2)	0.,0.	Absolute magnitude range acceptable (computed from the model) 0.,0. (default) means not used
<code>MAG_REF</code>	integer (n=1)	0	Reference filter for <code>MAG_ABS</code> (1 to $N_{bd}$ ) 0 (default) means not used
<code>ZFORM_MIN</code>	float (n $\leq$ 100)	0.	Minimum redshifts of formation (lower age constraints) must match with the number of model in $\{GAL\_LIB\}$ list 0. (default) means not used

## 9.5 Additional SED fitting libraries

After computing the photometric redshifts, other SED fittings can be applied to derive FIR properties or to get physical parameters based on a large stochastic BC07 library with 100000 spectra (as described in Kauffman et al., 2004). Those libraries only work with a predefined redshift information. They are not intended for improving the photo-z !

Additional Libraries KEYWORDS			
Parameters	type	default	description
FIR_LIB	string ( $n \leq 5$ )	NONE	Far-IR libraries separated by comma
FIR_LMIN	float ( $n = 1$ )	7.0	$\lambda$ min for FIR analysis (in $\mu m$ )
FIR_CONT	integer ( $n = 1$ )	-1	Context for bands to be used in Far-IR
FIR_FREESCALE	string ( $n = 1$ )	NO	Allows for free scaling
FIR_SCALE	integer ( $n = 1$ )	-1	Context for bands to be used for scaling
FIR_SUBSTELLAR	string ( $n = 1$ )	NO	Removing stellar component from best optical fit
PHYS_LIB	string ( $n = 1$ )	NONE	BC07 library
PHYS_NMAX	integer ( $n = 1$ )	100000	Number of models used in the BC07 library

### 9.5.1 FIR libraries

A set of four FIR libraries are available, and can be used to characterize the FIR emission of galaxies assuming that the emission is dominated by radiation of dust component heated by star formation activity. No implementation of hot dust heated by an AGN component has been included yet !

- The user defined the minimal rest-frame wavelength for the FIR analysis (FIR\_LMIN, default is  $\lambda = 7\mu m$ ). The global FIR context (FIR\_CONT) specifies the set of filters to be used. However, the final context will depend on the redshift of the source and only filters with  $\lambda/(1+z) \geq \text{FIR\_LMIN}$  will be considered.
- The contribution from the stellar component can be subtracted (FIR\_SUBSTELLAR) based on the best galaxy template (used in ZPHOTLIB). We arbitrarily add in quadrature the subtracted stellar flux in the flux error in a given band, and if the stellar component is too large ( $F_{obs} - F_{\star} \leq 3\sigma_{obs}$ ) we discard the passband in the analysis. When activated, the stellar flux is subtracted only if  $\lambda/(1+z) \leq 25\mu m$ , we neglect stellar component at longer  $\lambda$ .
- For each library, we estimate the infrared luminosity  $L_{IR} = \int_{8\mu m}^{1000\mu m} L_{\lambda} dL_{\lambda}$ . In most of the case the SED's distribution is attached to a luminosity. However when several FIR bands are available, it can be interesting to allow for a free rescaling in order to optimize the SED fitting (FIR\_FREESCALE , FIR\_SCALE).
- the FIR output parameters are described in Section 10.1. The total IR luminosity  $L_{IR}$  and its

uncertainties are derived from the maximum likelihood function :  $F(L_{IR}) = \sum \exp(-\chi^2(L_{IR})/2)$ . If only one passband is available, the FIR parameters luminosity is derived from the models with closest predicted flux (no rescaling allowed). The median and  $\sigma$  in  $L_{TIR}$  is estimated from the best models of each library.

### 9.5.2 Stochastic BC07 libraries

In progress....

## 9.6 Ouputs

### 9.6.1 Absolute magnitudes

This set of parameters allows the user to specify different methods to compute the absolute magnitudes. The absolute magnitudes are computed automatically in all the filters of `FILTER_LIST`. Different methods are available :

- **MABS\_METHOD=0** : A direct method to compute the absolute magnitude in a given filter from the apparent magnitude measured in the same filter (example:  $B_{ABS} = B_{obs} - DM(z) - kcor(B)$ ). This method is extremely sensitive to k-correction and to systematic effects in the apparent magnitude measurement. This method is likely to be less accurate.
- **MABS\_METHOD=1** : The less template dependent method. For example, the absolute magnitude in the filter B is computed using the observed apparent magnitude in the filter I, which is chosen to be  $\lambda(I) = \lambda(B) * (1 + z)$  at  $z \sim 0.7$  :  $B_{ABS} = I_{obs} - DM(z = 0.7) - (kcor(I) + (B - I)_{ABS}^{temp})$ . We used this method in Ilbert et al. (2005) and shown in Appendix A the advantage of this method to limit template dependency. The drawback of this method is that a systematic effect in the observed band will be directly propagated to the absolute magnitude (like zero-point calibration, or a band systematically with a lower S/N). For this reason, a context associated to each filter (`MABS_CONTEXT`) allow to reduce the filter set used for the observed apparent magnitudes (for instance, you don't want to keep in the subset a filter having a large offset between observed and predicted magnitude in `AUTO_ADAPT`).
- **MABS\_METHOD=2** : used to measure the absolute magnitudes in all the rest-frame bands using the observed apparent magnitudes always taken in the same observed filter (given by `MABS_REF`). It's not optimized but you know exactly which filter is used to compute the absolute magnitudes. As example if `MABS_REF` is defined as B filter and A could be any filter:  $A_{ABS} = B_{obs} - DM(z) - (kcor(B) + (A - B)_{ABS}^{temp})$
- **MABS\_METHOD=3** : The absolute magnitudes are directly measured from the best-fit template. This method is strongly model dependent.
- **MABS\_METHOD=4** : imposes the filter depending on the redshift. The filters are given in `MABS_FILT` for the corresponding redshift bins listed in `MABS_ZBIN`.

Note: Different methods can be applied for each filter. Number of values should match the number of filter in `FILTER_LIST`. If only one value is given, the same method is applied to all filters.

ABSOLUTE MAGNITUDE KEYWORDS			
Parameters	type	default	description
MABS_METHOD	integer (n≤100)	0	Method used for absolute magnitudes in each filter 0 (default): $\text{mag}(\text{filter}) \rightarrow M_{ABS}(\text{filter})$ 1 : $\text{mag}(\text{best filter}) \rightarrow M_{ABS}(\text{filter})$ 2 : $\text{mag}(\text{fixed filter}) \rightarrow M_{ABS}(\text{filter})$ defined with MABS_REF 3 : best SED $\rightarrow M_{ABS}(\text{filter})$ 4 : MABS(filter) derives according to a fixed filter in a fixed redshift interval as given by MABS_FILT and MABS_ZBIN
MABS_CONTEXT	integer (n≤100)	-1	Context for the bands used to derive $M_{ABS}$ -1 : used same context as for photo-z
MABS_REF	integer (n≤100)	0	Fixed filter (if MABS_METHOD=2) 0 (default) means not used
MABS_FILT	integer (n≤100)	—	List of fixed filters chosen to derive $M_{ABS}$ in all bands according to the redshift bins (if MABS_METHOD=4)
MABS_ZBIN	float (n≤200)	—	List of Redshift bins associated with MABS_FILT Even number of values (if MABS_METHOD=4)

### 9.6.2 additional output files

OUTPUT KEYWORDS			
Parameters	type	default	description
SPEC_OUT	string (n=1)	NO	Output files with Gal/Star/QSO spectra (one file per object) (if YES: can take a lot of disk space !)
CHI2_OUT	string (n=1)	NO	Output files with all $\chi^2$ for galaxy library (one file per object) (if YES: can take a lot of disk space !)

An output file for each objects with the various SEDs (star/QSO/GALs) is produced and can be plotted with the supermongo macro (\$LEPHAREDIR/tools/speclog.sm)

## 9.7 Adaptive method

This set of parameters deals with the adaptation. This procedure requires to have galaxies with a spec-z within the catalogue (format should be LONG with -99 when no spec-z available). This code will first fit the best-fit templates to the objects with a spec-z. Then, it will measure for each filter the systematic offset which minimizes the differences between the predicted and observed magnitudes. This procedure is applied iteratively until convergence of the systematic offset values (maximum of 10 iterations). If the photometric catalogue contains a large number of objects, you can save times by doing the training only on a sub-catalogue with spec-z and then apply the offsets by hand to the full catalogue (APPLY\_SYSSHIFT).

ADAPTIVE METHOD KEYWORDS			
Parameters	type	default	description
APPLY_SYSSHIFT	float ( $n \leq 50$ )	—	Apply systematic shifts in each bands number of values must fit number of filters
AUTO_ADAPT	string ( $n = 1$ )	NO	ZP adaptive method with spectro
ADAPT_BAND	integer ( $n = 3$ )	—	Reference bands : band + ( band1, band2) for color
ADAPT_LIM	float ( $n = 1$ )	18.,24.	Mag range for spectro in Ref band
ADAPT_POLY	integer ( $n = 1$ )	1	Number of coef in polynom (max=4)
ADAPT_METH	integer ( $n = 1$ )	1	Fit as a function of color [1], redshift [2], models [3]
ADAPT_CONTEXT	integer ( $n = 1$ )	-1	Context for bands used for training -1 : used context per object
ADAPT_ZBIN	float ( $n = 2$ )	0.01,6	Redshift's interval used for training
ADAPT_MODBIN	integer ( $n = 2$ )	1,1000	Model's interval used for training
ERROR_ADAPT	string ( $n = 1$ )	NO	Add error in quadrature according to difference between observed and predicted magnitudes

## 10 The output files and parameters

### 10.1 the parameters

IDENT	Original IDENT
	Best Galaxy model
Z_BEST	Zphot Best
Z_BEST68_LOW	Zphot min from $\Delta\chi^2 = 1.0$ (68%)
Z_BEST68_HIGH	Zphot max from $\Delta\chi^2 = 1.0$ (68%)
Z_BEST90_LOW	Zphot min from $\Delta\chi^2 = 2.71$ (90%)
Z_BEST90_HIGH	Zphot max from $\Delta\chi^2 = 2.71$ (90%)
Z_BEST99_LOW	Zphot min from $\Delta\chi^2 = 6.63$ (99%)
Z_BEST99_HIGH	Zphot max from $\Delta\chi^2 = 6.63$ (99%)
Z_ML	Zphot from Median of ML distribution
Z_ML68_LOW	Zphot min at 68% of ML distribution
Z_ML68_HIGH	Zphot min at 68% of ML distribution
CHI_BEST	lowest galaxy $\chi^2$ for galaxy
MOD_BEST	galaxy model for best $\chi^2$
EXTLAW_BEST	Extinction law
EBV_BEST	E(B-V)
PDZ_BEST	Probability distribution : $\int F(z)dz$ between $z_{best} \pm 0.1(1+z)$
SCALE_BEST	Scaling factor
DIST_MOD_BEST	Distance modulus
NBAND_USED	Number of band used in the measurement
NBAND_ULIM	Number of band used as upper-limit
	Galaxy Secondary solution from F(z) function
Z_SEC	
CHI_SEC	
MOD_SEC	
AGE_SEC	
EBV_SEC	
ZF_SEC	
MAG_ABS_SEC	
PDZ_SEC	
SCALE_SEC	
	QSO solutions
Z_QSO	
CHI_QSO	
MOD_QSO	
MAG_ABS_QSO	
DIST_MOD_QSO	
	Star solutions
MOD_STAR	
CHI_STAR	



	Best models magnitudes
PDZ()	Probability per Z bins
MAG_MOD()	magnitudes from best models
K_COR()	K-corrections
MAG_ABS()	absolute magnitudes
MABS_FILT()	Filter used for each absolute magnitude
K_COR_QSO()	
MAG_ABS_QSO()	
	PHYSICAL PARAMETERS from ZPHOTLIB galaxy library (from file .phys) with XXX=BEST, MED, INF, SUP
AGE_XXX	Age (yr)
MASS_XXX	rescaled Mass ( $M_{\odot}$ )
SFR_XXX	rescaled SFR ( $M_{\odot}/yr$ )
SSFR_XXX	SSFR ( $yr^{-1}$ )
LDUST_XXX	rescaled $L_{dust}$ ( $L_{\odot}$ )
LUM_NUV_BEST	rescaled $L_{UV}$ ( $L_{\odot}$ )
LUM_R_BEST	rescaled $L_R$ ( $L_{\odot}$ )
LUM_K_BEST	rescaled $L_K$ ( $L_{\odot}$ )
	Input informations
CONTEXT	
ZSPEC	
STRING_INPUT	
MAG_OBS()	input observed magnitudes
ERR_MAG_OBS()	input errors

Parameters from FIR_LIB library	
LUM_TIR_BEST	$L_{IR}$ from the best model
LIB_FIR	best library
MOD_FIR	best model in this library
CHI2_FIR	$\chi^2$
FSCALE_FIR	Scaling factor applied to the best model
NBAND_FIR	Number of bands used in the analysis
LUM_TIR_MED	median $L_{IR}$ from $F(L_{IR})$ function
LUM_TIR_INF	$L_{IR}$ inf at 68%
LUM_TIR_SUP	$L_{IR}$ sup at 68%
MAG_MOD_FIR()	FIR best model magnitudes
MAG_ABS_FIR()	$M_{ABS}$ from best model
K_COR_FIR()	K-corrections
PHYSICAL PARAMETERS derived from PHYS_LIB library	
PHYS_CHI2_BEST	best $\chi^2$ value
PHYS_MOD_BEST	best model
PHYS_MAG_MOD()	model magnitudes for the best models
PHYS_MAG_ABS()	absolute magnitudes
PHYS_K_COR()	k-corrections
PHYS_PARA <sub>x</sub> _BEST	value at the minimum $\chi^2$ value
PHYS_PARA <sub>x</sub> _MED	median value from ML analysis
PHYS_PARA <sub>x</sub> _INF	16% lower value on the ML analysis
PHYS_PARA <sub>x</sub> _SUP	16% higher value of the ML analysis

## 10.2 the output files

## 11 Appendice A : Content of the main tar file (lephare\_main.tar.gz)

\$LEPHAREDIR/source/ :	fortran source files (*.f)
\$LEPHAREDIR/vega/ :	SEDs for reference stars: VegaLCB.dat from Lejeune et al., (1997) BD+17°4708 from Oke & Gunn, (1983)
\$LEPHAREDIR/doc/ :	documentation files
\$LEPHAREDIR/config/ :	configuration files for photometric redshifts
\$LEPHAREDIR/ext/ :	extinction curves for internal galaxy extinction (see README.extinc)
\$LEPHAREDIR/opa/ :	Lyman absorption files produced by intergalactic medium as function of redshift from Madau (1995).
\$LEPHAREDIR/filt/ :	individual filter response curves sorted by directories: (ex : ./std/*.pb, ./sdss/*.pb, ./hst/*.pb, ...)
\$LEPHAREDIR/sed/STAR/:	SED files for STARS sorted by directories: ./BD/*.sed : Brown Dwarves and low mass stars from Chabrier & Baraffe (2000) ./PICKLES/*.sed: Atlas from Pickles (1998) ./WD/*.sed : 4 White dwarves from IRAF ??
\$LEPHAREDIR/sed/QSO/:	SED files for QSO ./qsol.dat : composite template from Cristiani (?) ./qso-*.dat: SEDs based on simulated slope and strengthes of emission lines (Warren ?) (see README.model_qso) ./a*.sed : SEDs from Eva Hatziminaoglou (?)
\$LEPHAREDIR/sed/GAL/:	SED files for GALAXY sorted by directories: CWW_KINNEY/*.sed: observed SED by Coleman etal(1980) + 2 starburst from Kinney (1996) extended in UV and IR by GISSEL CE/*.sed : 72 SEDs based on interpolation between the 4 CWW SEDS + 3 young star-forming galaxies from GISSEL (Arnouts et al., 1999) 42GISSEL/*.sed : 42 selected SEDs from GISSEL Additional directories with the other SED tar-files: GISSEL/*.sed : 27 theoretical SEDs including ages from GISSEL96 PEGASE2/*.sed : SEDs including ages from PEGASE2 (Fioc et al., 2000) HYPERZ/*.sed : SEDs from the HYPERZ package (Bolzonella et al., 2000)
\$LEPHAREDIR/tools/ :	macros for plotting filterset (filterplot) and extracted SED (spec.sm)
\$LEPHAREDIR/test/ :	test cases : photometric catalogs for the HDFN (Lanzetta, 1996) and HDFS (Vanzella et al., 2002)
\$LEPHAREDIR/simul/ :	configuration files for the simulations and predefined input files