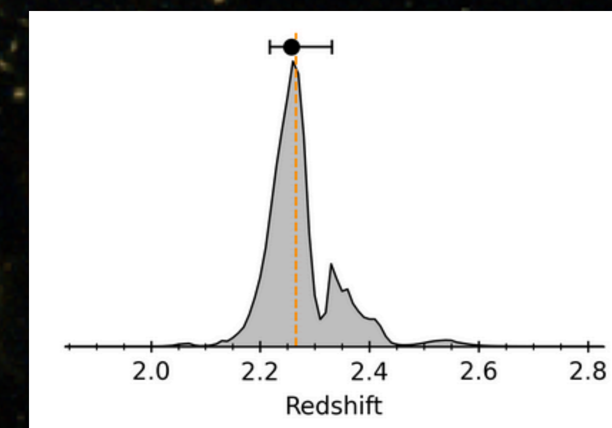
PHOTOMETRIC REDSHIFTS

O. Ilbert, R. Shirley, M. Treyer

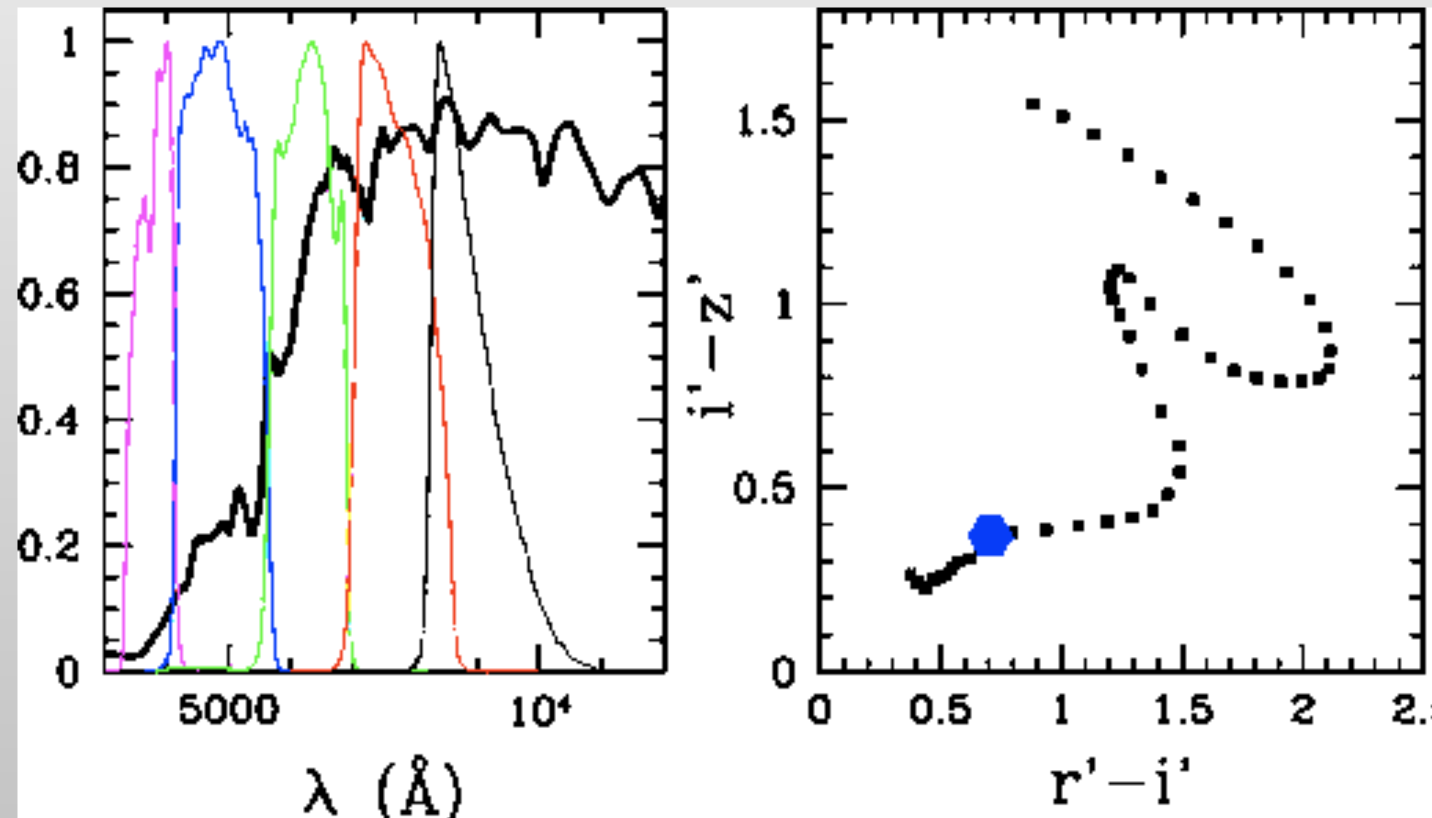


GDR CoPhys meeting
3-5 November 2025, Marseille

LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE
MPE
MAX-PLANCK-INSTITUT FÜR EXTRATERRESTRISCHE PHYSIK

Basic principle

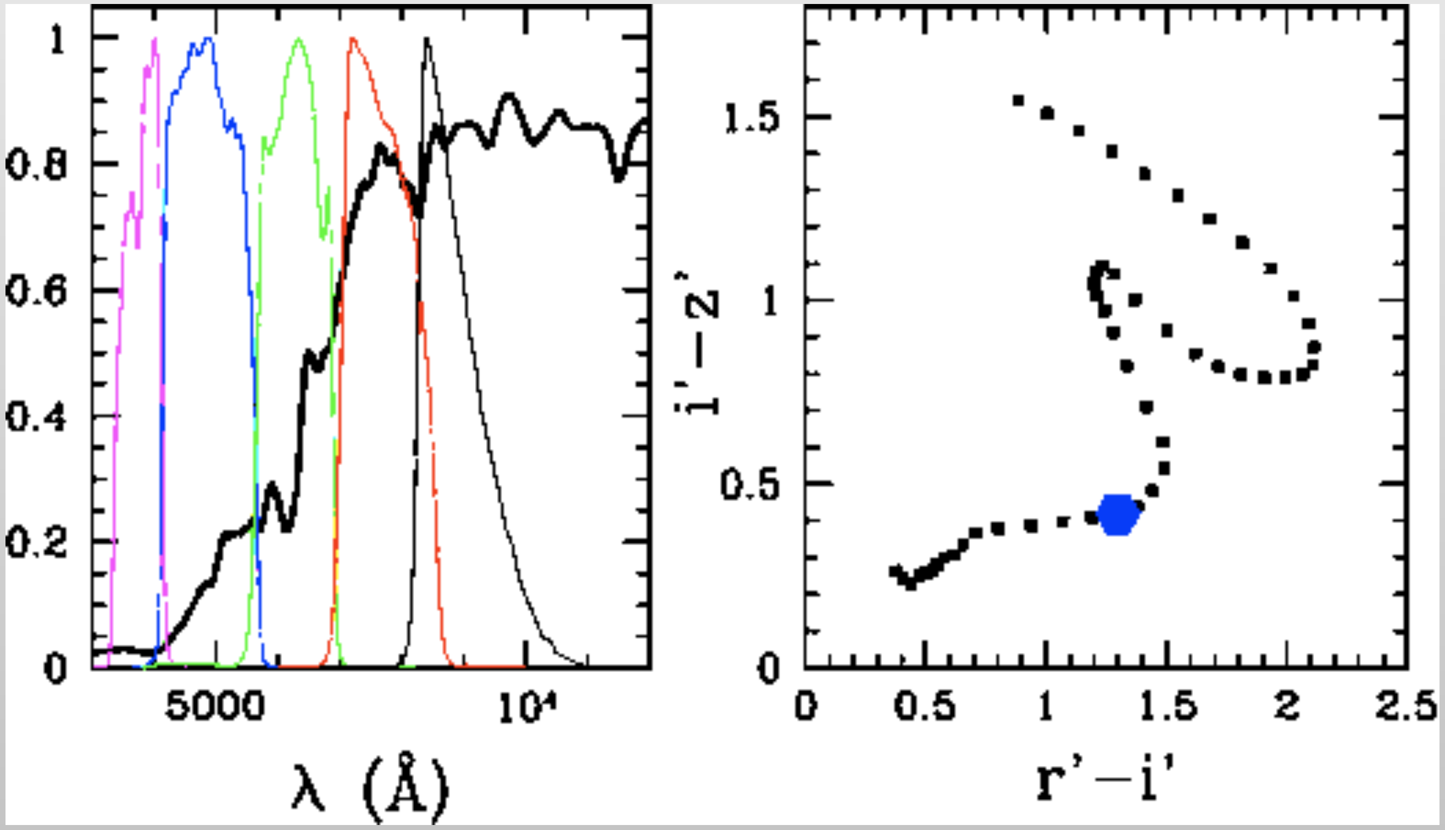
Observed colors change with redshift



Z=0.4

Basic principle

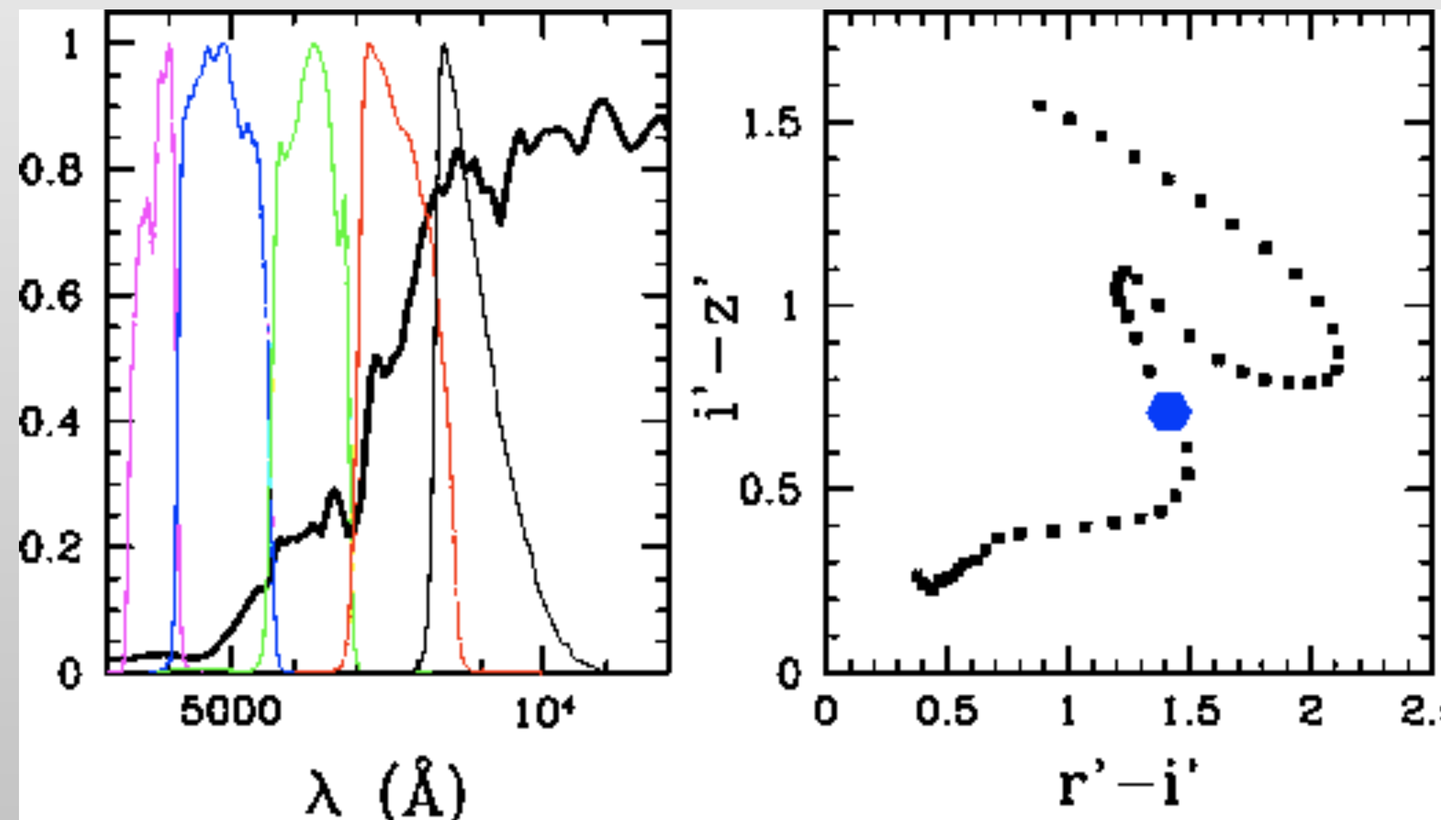
Observed colors change with redshift



Z=0.6

Basic principle

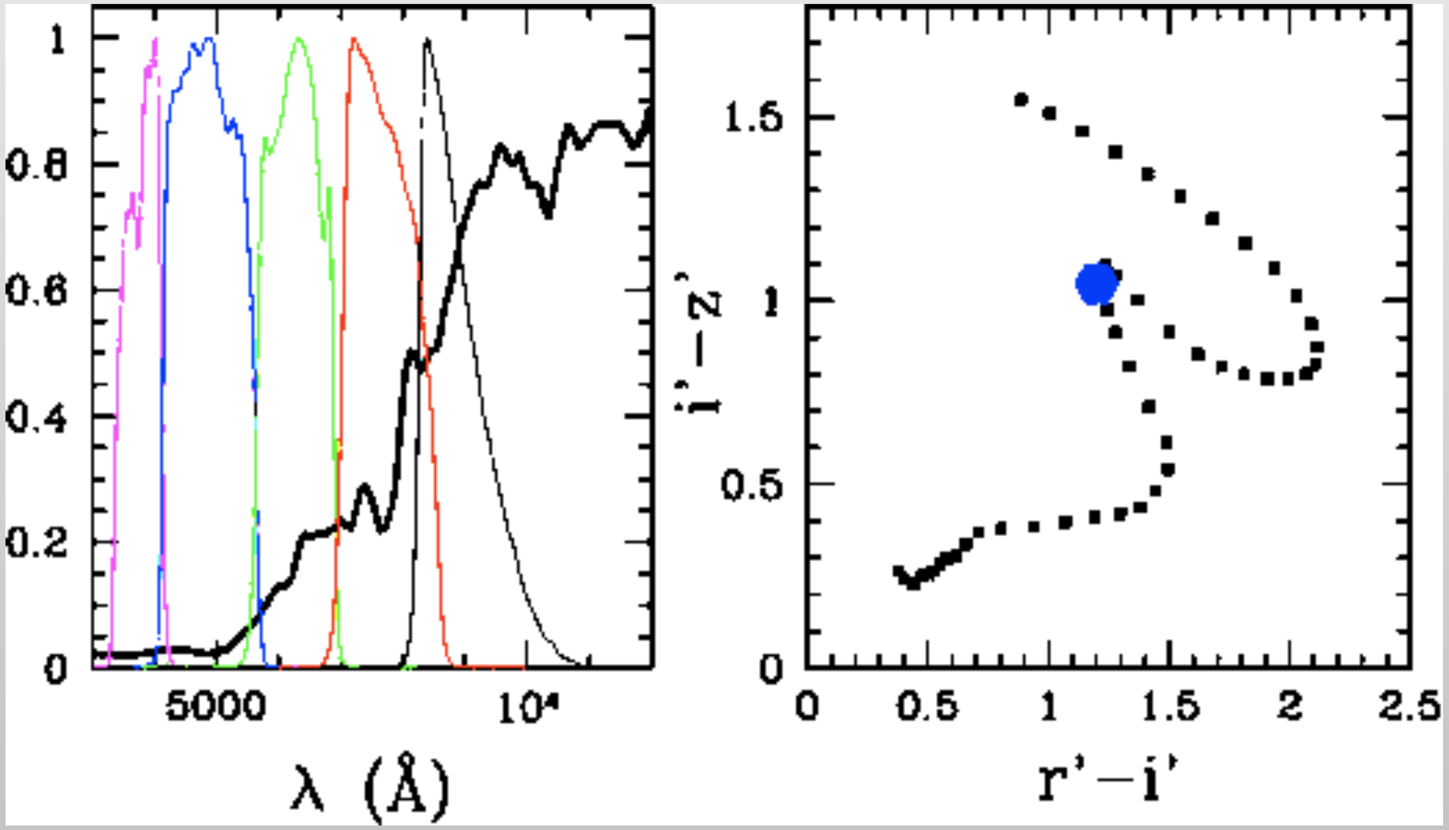
Observed colors change with redshift



z=0.8

Basic principle

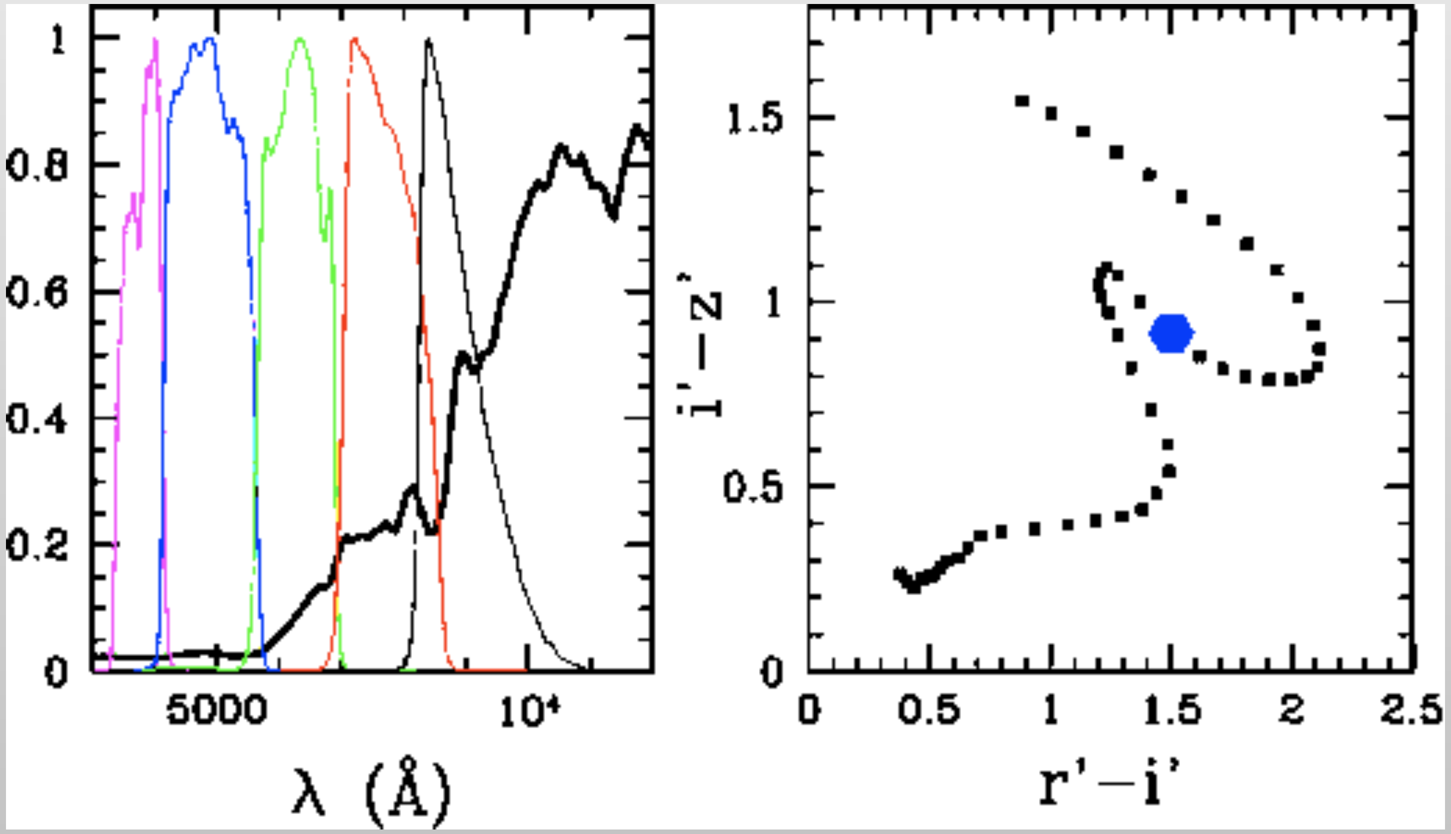
Observed colors change with redshift



z=1.0

Basic principle

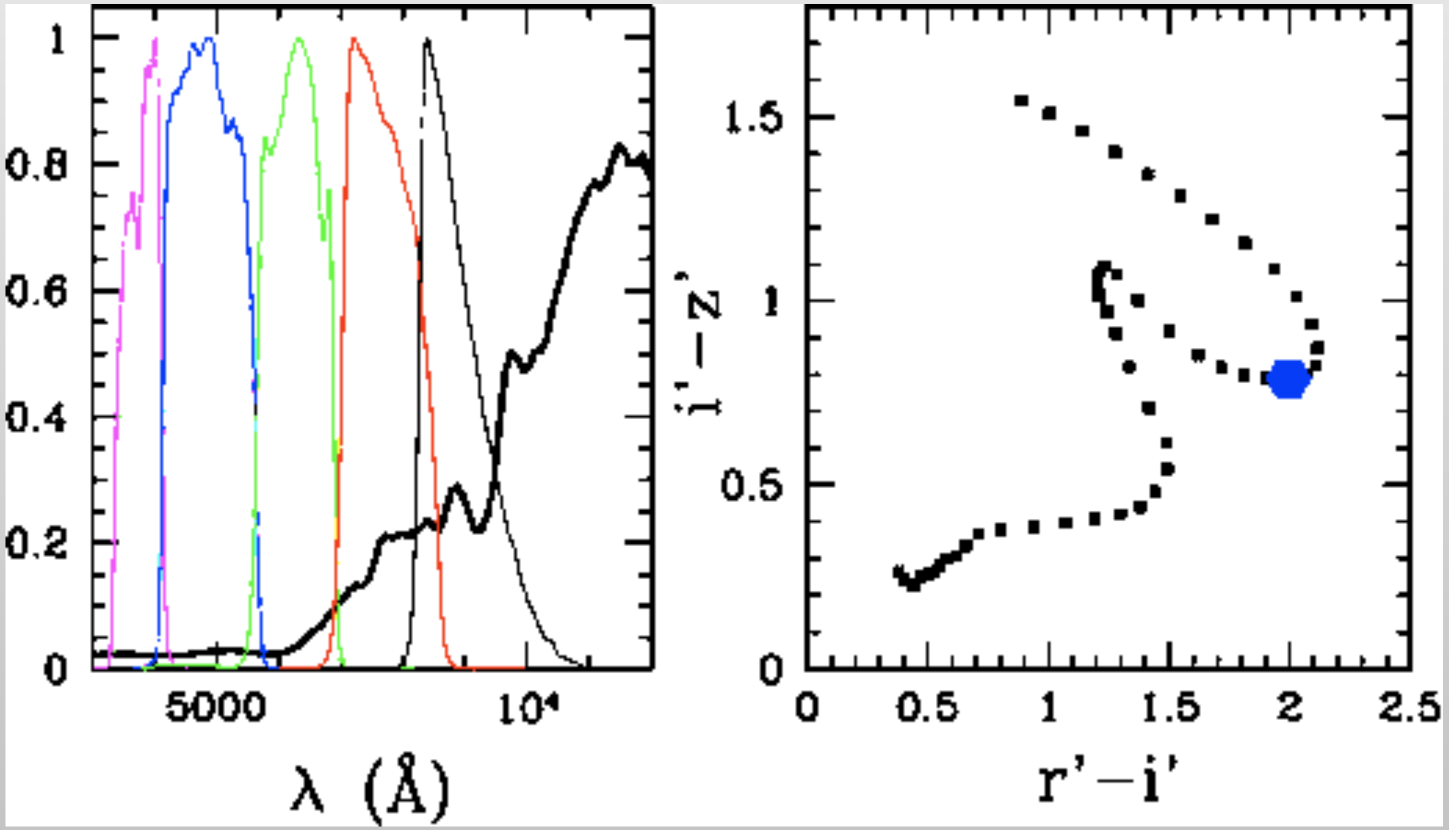
Observed colors change with redshift



z=1.2

Basic principle

Observed colors change with redshift



Z=1.4

Basic principle

Observed colors change with redshift

➢ redshift inference based on the multi-color images

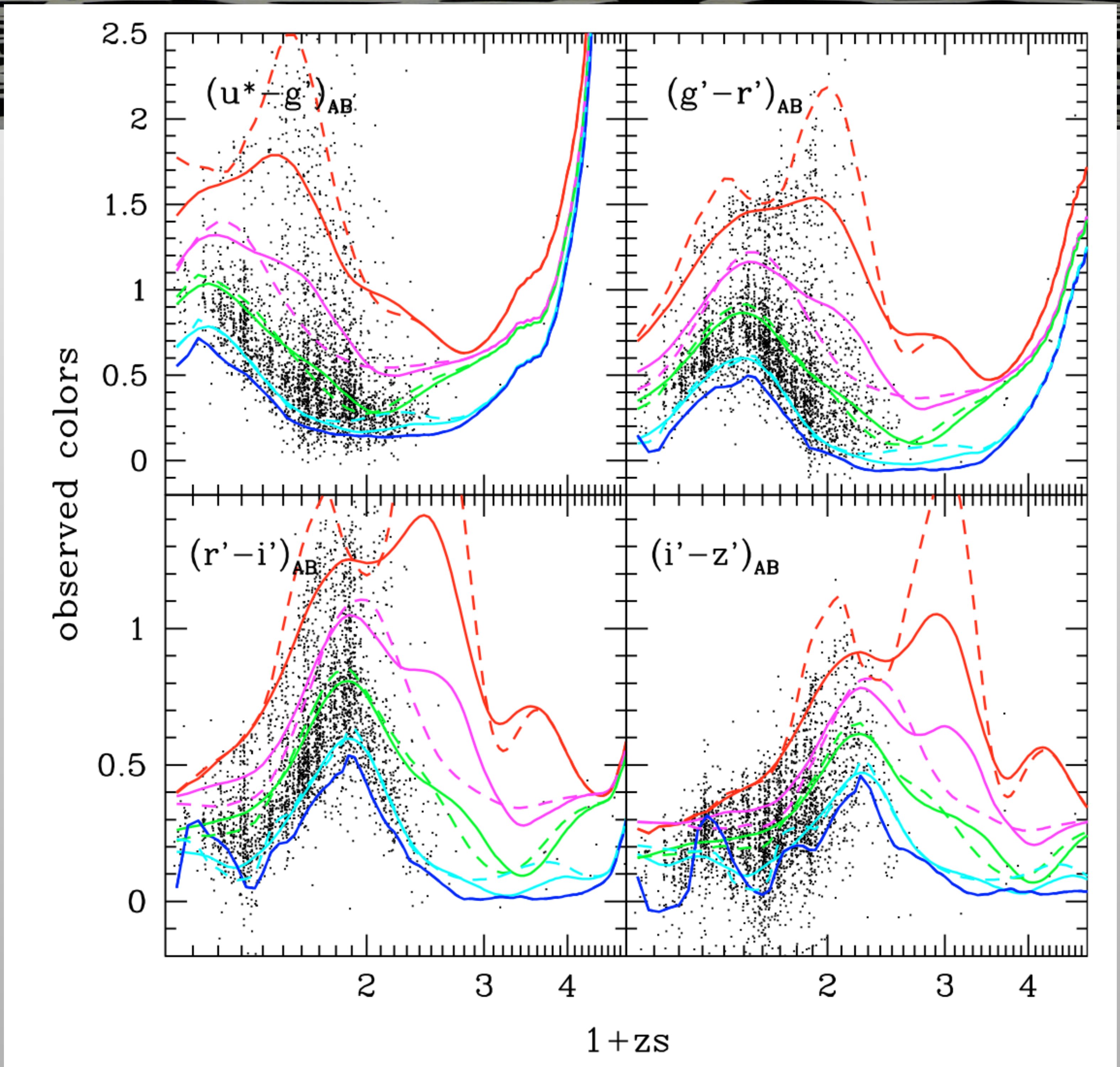


Photo-z or spec-z

Photo-z

Pro: all sources (reaching billions), faint, high-z, no problem of incompleteness

Con: degraded accuracy, catastrophic failures, need to be tested, difficult to estimate their errors

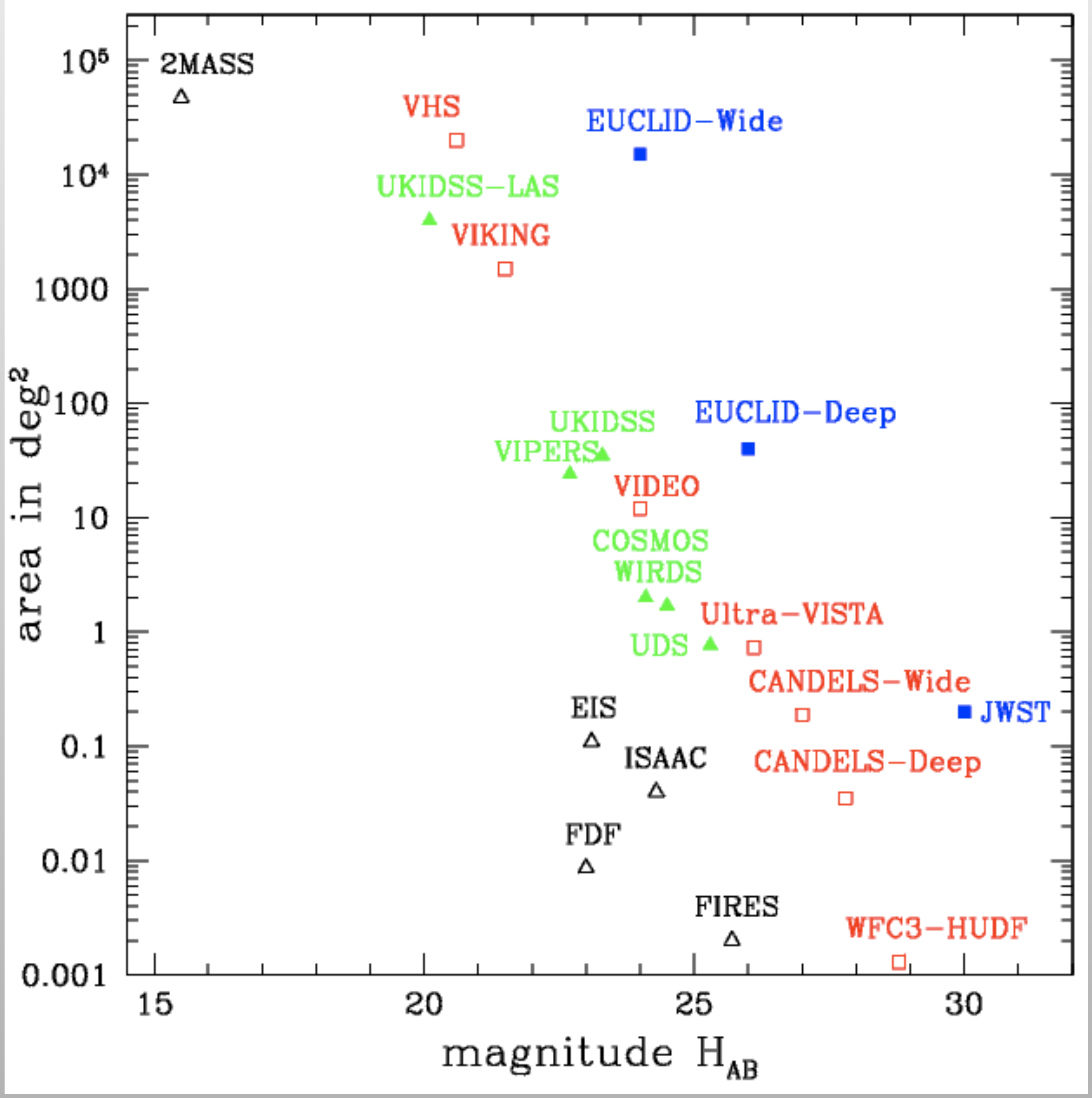


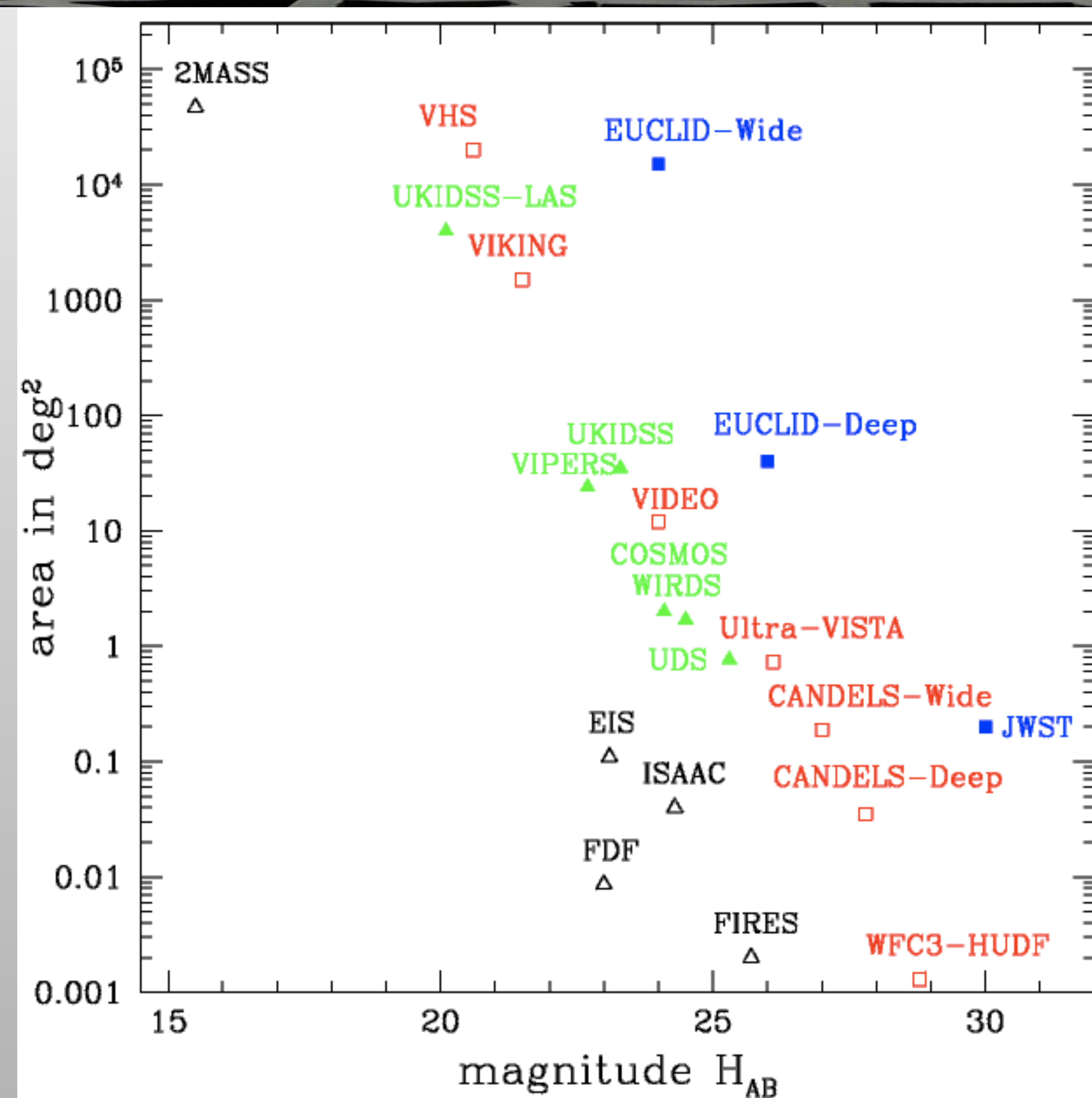
Photo-z or spec-z

Spec-z

Pro: accurate, easy to select the most robust

Con: time consuming, only for the brightest sources (<5% of a photometric catalogue), incompleteness difficult to assess

➢ photo-z/spec-z complementary



Two branches

Machine learning : data-driven

⇨ **The color-flux mapping is learned from an existing spec-z sample**

Template fitting : physically motivated

⇨ **The color-flux mapping is modeled from our builded knowledge**

Salvato+2018 for a short review

Outline of our today's presentations

14h30-16h
Template-fitting for galaxies with LePHARE tool / O. Ilbert - R. Shirley

16h30-17h
Template-fitting for AGN with LePHARE tool / R. Shirley

17h-18h
Photo-z with machine-learning / M. Treyer

Basic principle of template-fitting

First template-fitting from Puschell, Owen, Laing 1982

Data
multi-color photometric catalogue

Model
Models of source SED with the redshift as one dimension

Fit the model over the data

➢

Redshift Probability Distribution Functions

and associated redshift point-estimates

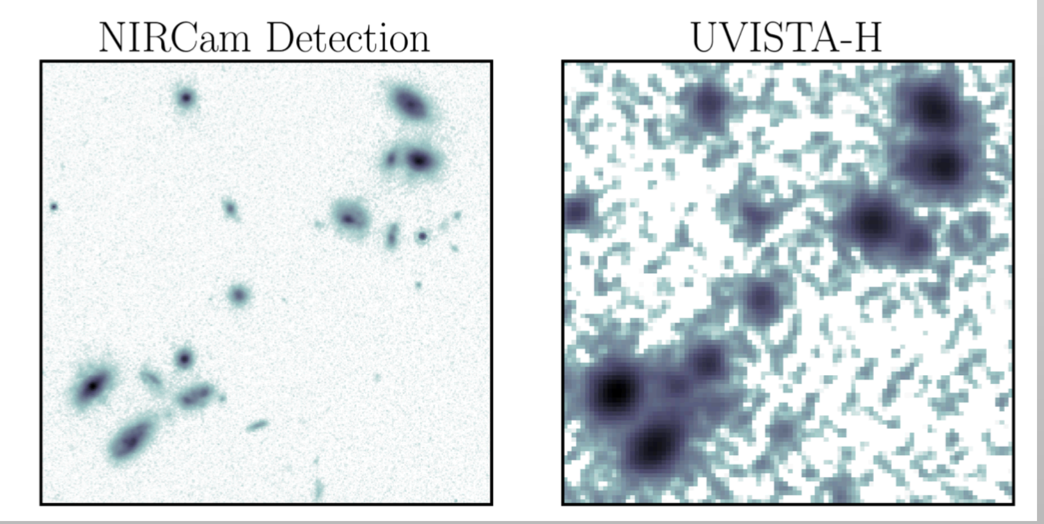
It seems pretty simple…

The data

Data
multi-color photometric catalogue

→ **Many difficulties behind this step**

- **Combine images with different PSF**
- **Blending of the sources**
- **Flux extraction method to limit the noise**
- **Identify unreliable regions on the images**
- **Photometric calibration**
- **…**

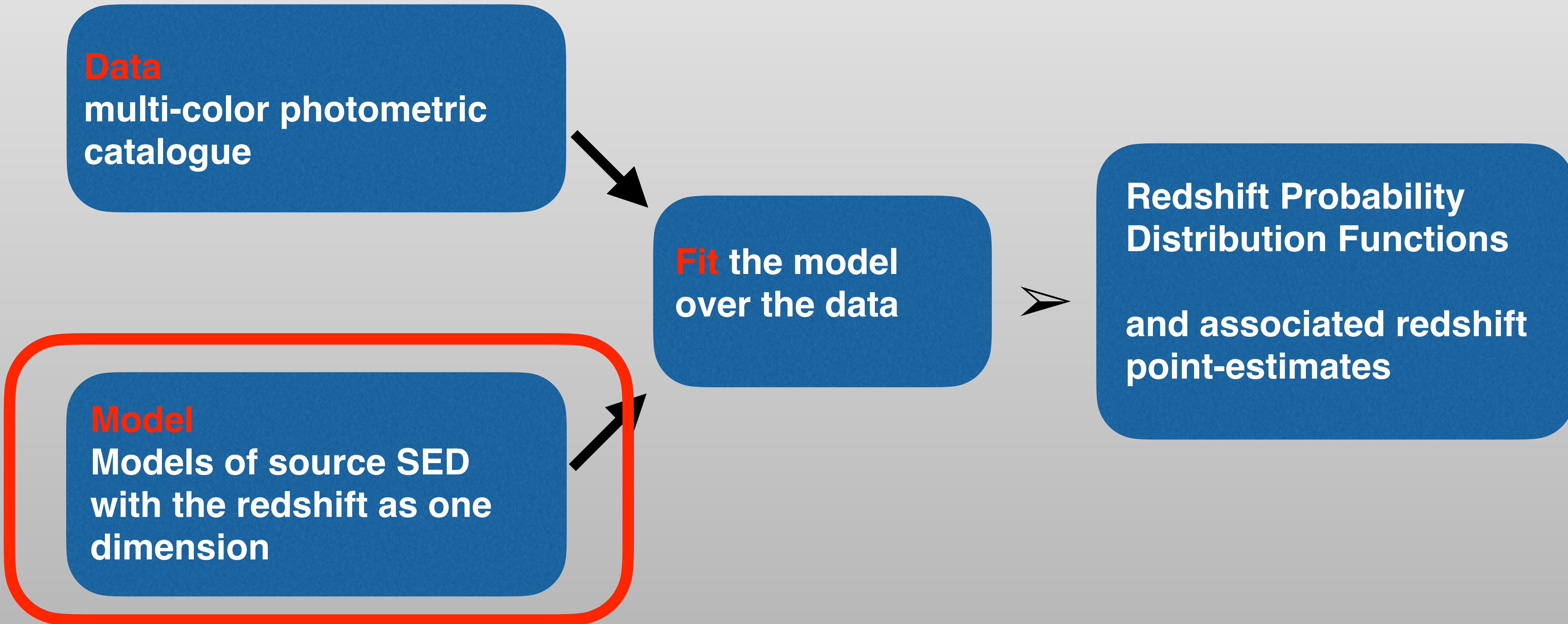


Shuntov+25

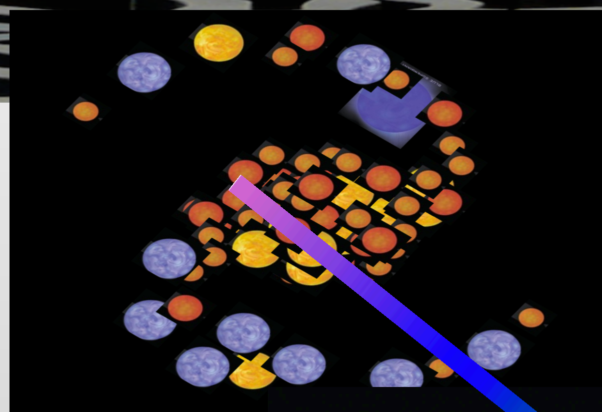
➢ **Crucial impact on the quality of the photo-z**

Basic principle of template-fitting

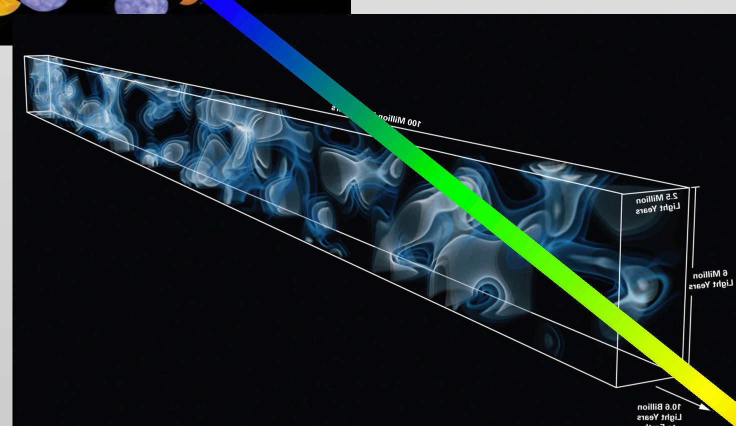
First template-fitting from Puschell, Owen, Laing 1982



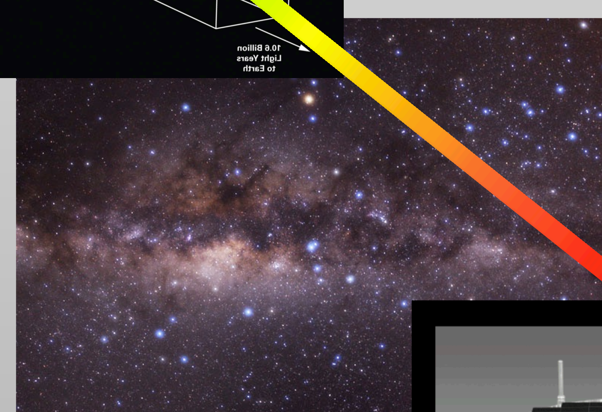
The model



Model the source emission

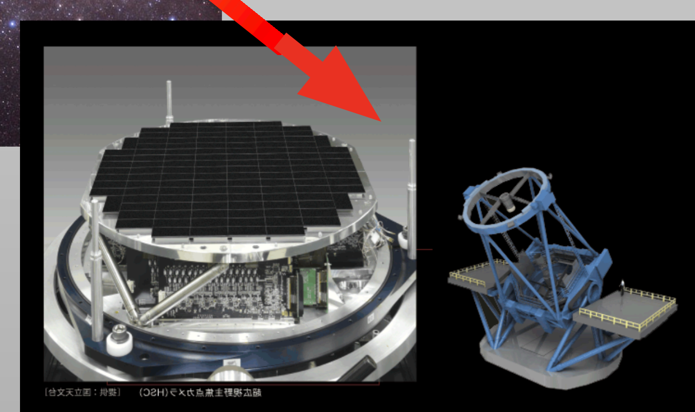


Neutral gas in the IGM



Dust in the Milky Way

- large vs. small library
- Empirical vs. physical
- Galaxy/AGN/Stars



The instrument (CCD, filters)

➢ These choices represent the core of the template-fitting method

Basic principle of template-fitting

First template-fitting from Puschell, Owen, Laing 1982

Data
multi-color photometric catalogue

Model
Models of source SED with the redshift as one dimension

Fit the model over the data

➢

Redshift Probability Distribution Functions

and associated redshift point-estimates

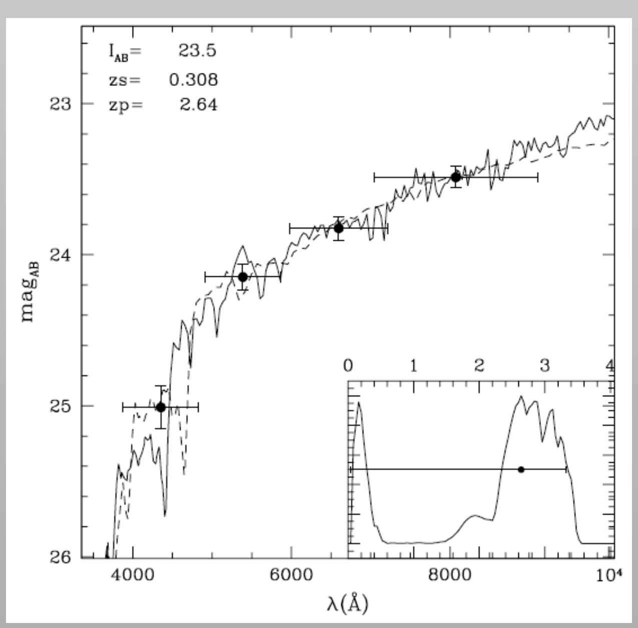
The fit

observed flux and error

Theoretical flux

$$\chi^2(z,T,A) = \sum_{f=1}^{N_f} \left(\frac{F^f_{\rm obs} - A \times F^f_{\rm pred}(z,T)}{\sigma^f_{\rm obs}} \right)^2$$

Outputs
Probability Distribution Function PDF(z)



- Possible training
- Different way to build the PDF(z)
- Prior
- Different methods to associate a point estimate to the PDF(z)
- …

That's why so many codes exist

2000 2006 2012 2018

HyperZ — Bolzonella, Miralles, Pello 2000

BPZ — Benitez 2000

LePhare — Arnouts+2002, Ilbert+06

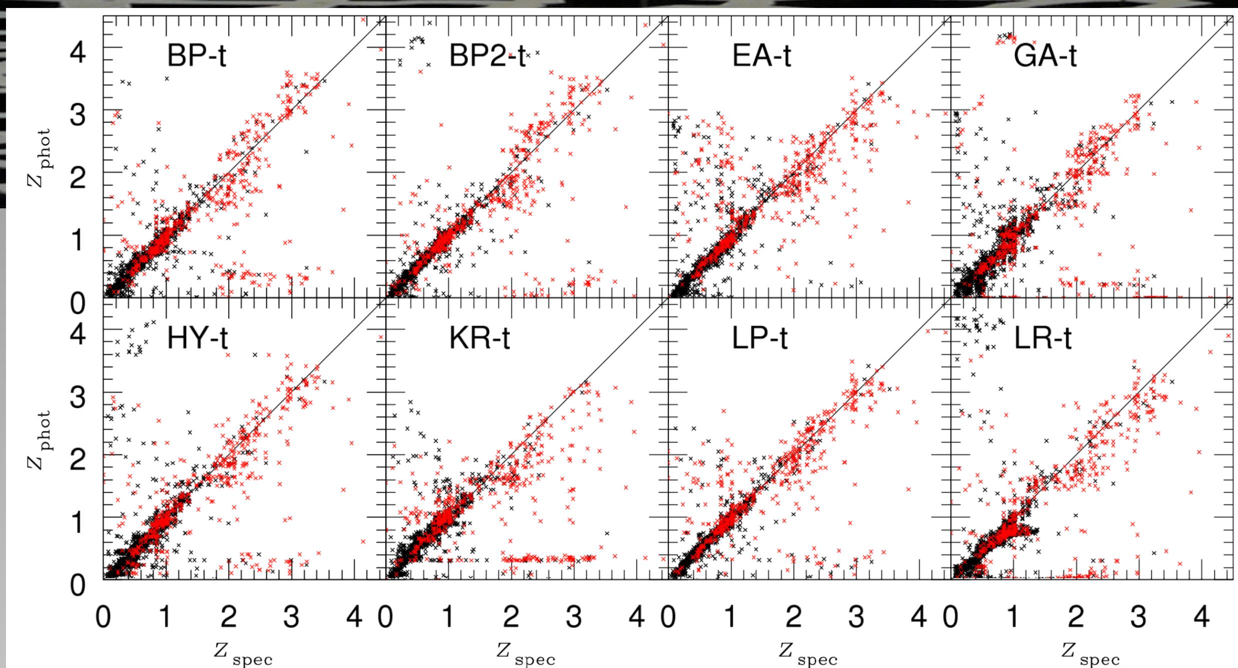
Zurich Extragalactic Bayesian Redshift Analyzer ZEBRA — Feldmann+2008

Easy and Accurate Zphot from Yale — Brammer+ 2008

BEAGLE — Chevallard & Charlot 2016

Phosphoros for Euclid

Numerous challenges to test the codes with real data

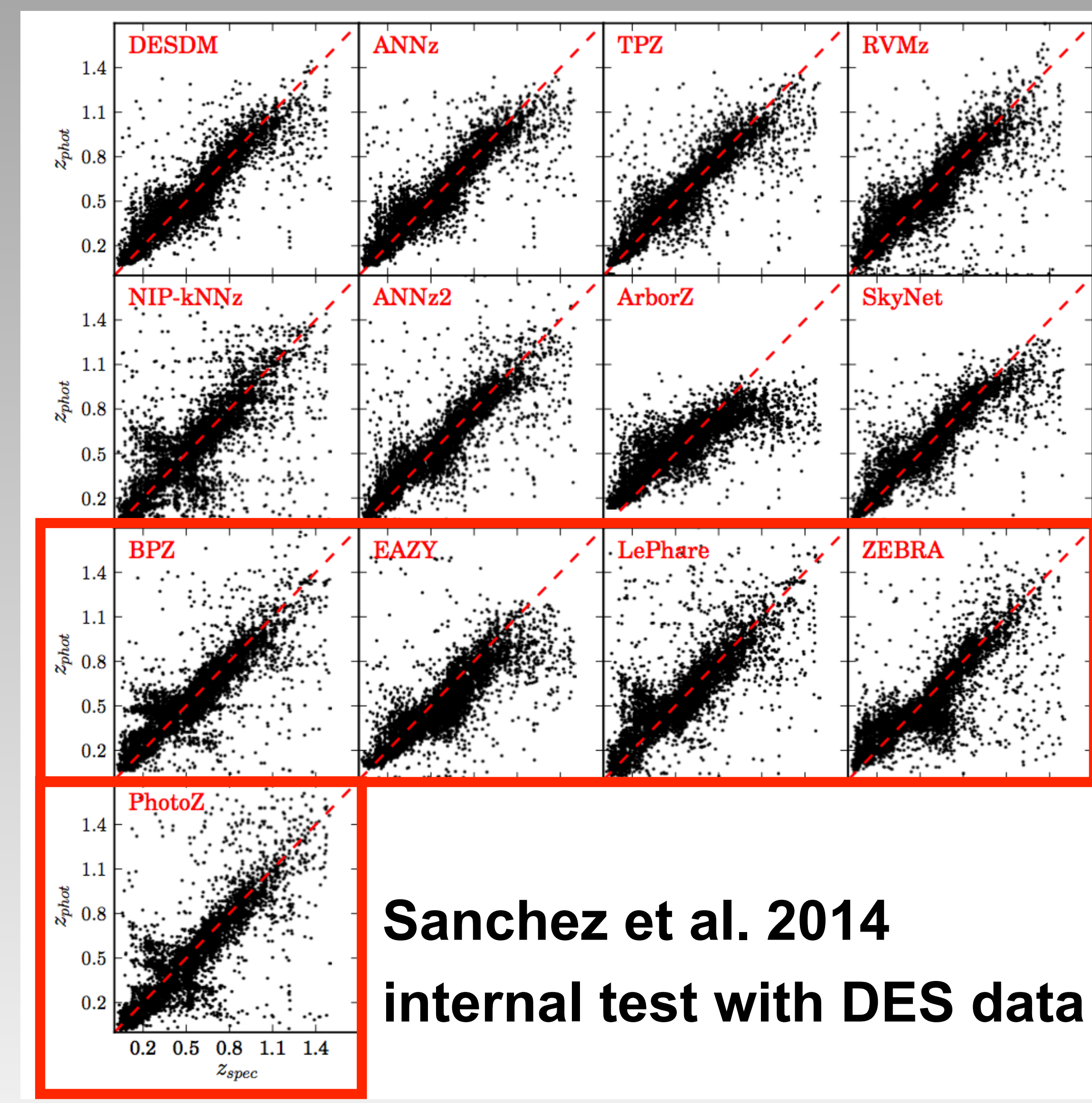


Hildebrandt+2010, PHAT,
blind test with GOODS data

TABLE 1
CODES INCLUDED IN THE CANDELS SED TEST FOR CALCULATING PHOTOMETRIC REDSHIFTS.

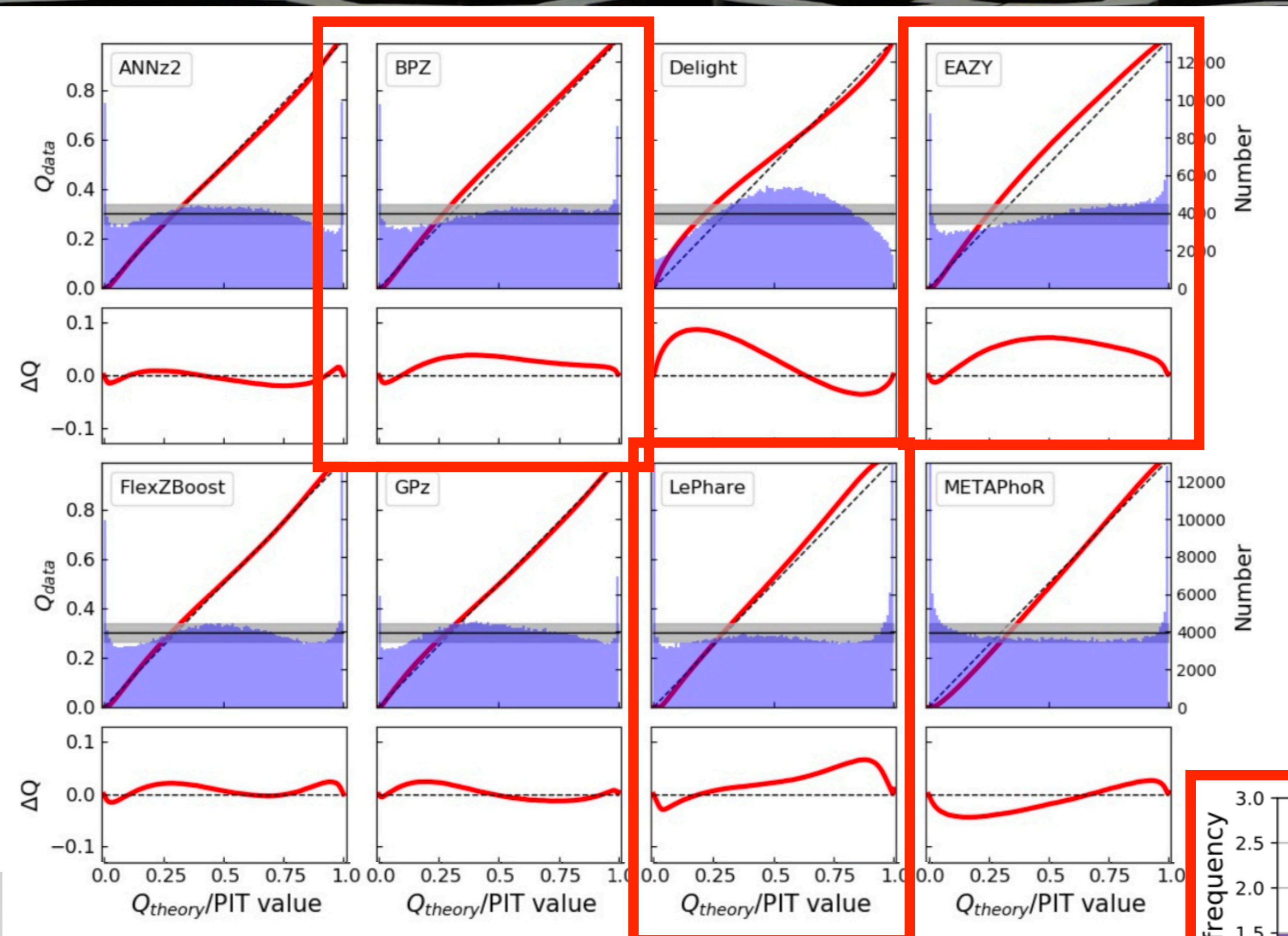
ID[a]	PI	Code	Code ID	Template set	Em lines	Flux shift	Δerr	ΔSED	Inter	ref.
2	G. Barro	Rainbow	A	PEGASE[b]	yes	yes	no	no	no	*j*
3	T. Dahlen	GOODZ	B	CWW[c], Kinney[d]	yes	yes	yes	yes	yes	*k*
4	S. Finkelstein	EAZY	C	EAZY[e]+BX418[f]	yes	no	no	no	yes	*l*
5	K. Finlator	SPOC	D	BC03[g]	yes	no	no	no	no	*m*
6	A. Fontana	zphot	E	PEGASEv2.0[b]	yes	yes	yes	no	no	*n, o*
7	R. Gruetzbauch	EAZY	C	EAZY[e]	yes	yes	yes	no	yes	*l*
8	S. Johnson	SATMC	F	BC03[g]	no	no	no	no	yes	*p*
9	J. Pforr	HyperZ	G	Maraston05[h]	no	no	yes	no	no	*q*
11	M. Salvato	LePhare	H	BC03[g]+Polletta07[i]	yes	yes	yes	no	no	*r*
12	T. Wikind	WikZ	I	BC03[g]	no	no	yes	no	no	*s*
13	S. Wuyts	EAZY	C	EAZY[e]	yes	yes	yes	no	yes	*l*

Dahlen+2013, internal tests
using CANDELS data



Sanchez et al. 2014
internal test with DES data

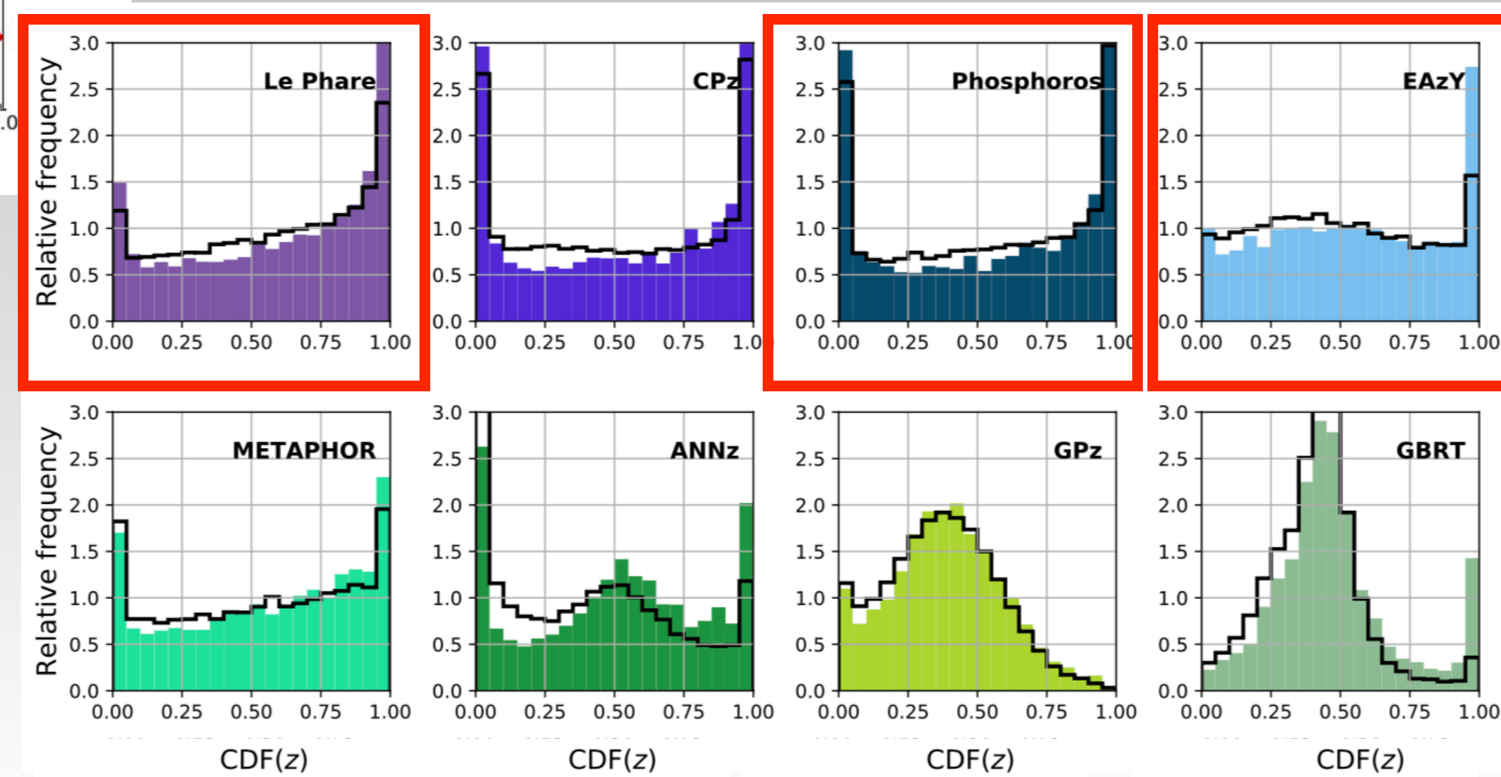
Numerous challenges to test the codes with simulations



Schmidt, Malz et al. 2020 for LSST

$$PIT_i = CDF_i(zs_i) = \int_0^{zs_i} PDF_i(z)dz$$

Euclid, Deprez et al. 2020



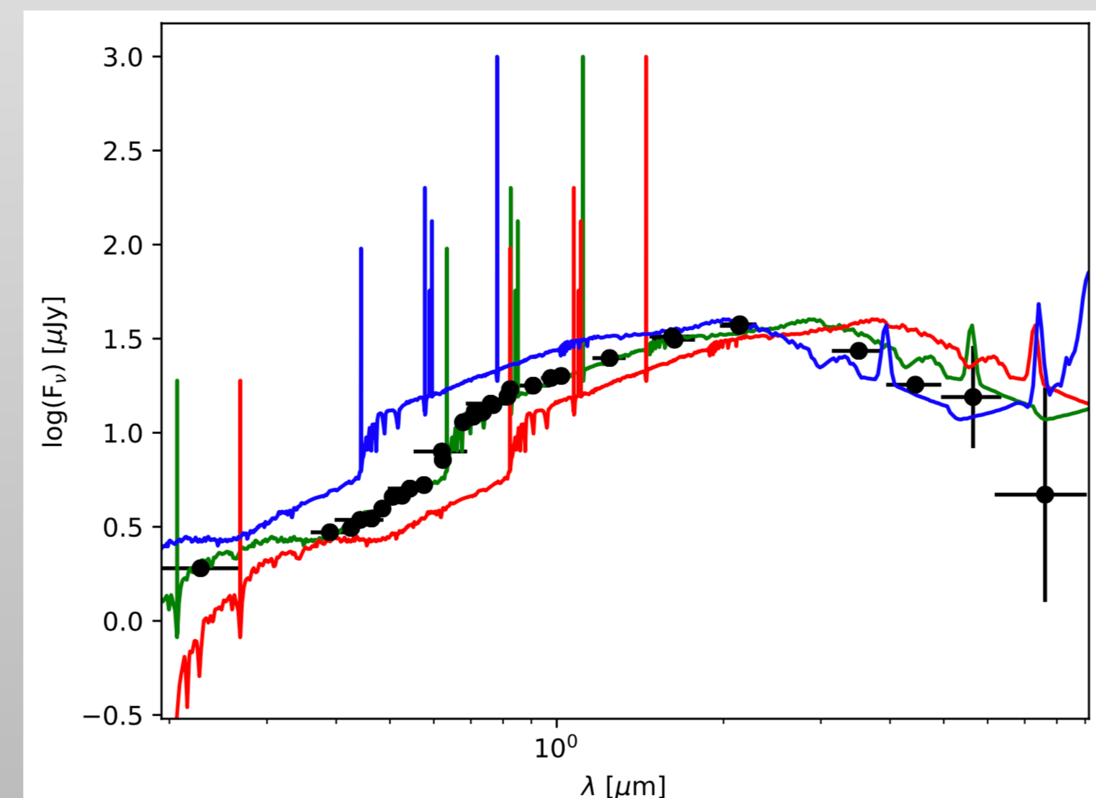
Recent papers also investigate the quality of the PDF

LePHARE

Olivier Ilbert, Johann Cohen-Tanugi, Raphael Shirley,
Mara Salvato, Stephane Arnouts

Template-fitting code based on a χ^2 minimisation

- **several set of templates, dust attenuations, emission lines recipes, …**
- **Stars, galaxies, and AGN fit seperately**
- **Possible priors**
- **Photo-z and physical parameters in output, as well as associated PDF**
- **…**



Originally a fortran code

(Arnouts+2002, Ilbert+2006)

New c++ version

Olivier Ilbert, Johann Cohen-Tanugi, Rafaël Shirley with the help of several others

Completely re-writen in c++

https://github.com/lephare-photoz/

- **Parallelized**
- **Better optimized**
- **Python interface using pybind**
  - **C++ classes can be used as library**
  - **The code can be fully run through notebooks**
  - **Allow to manipulate any input/output format available in python**
  - **Initial way to run the code still available**

Installing LePHARE

Installation

LePHARE is distributed with the Python Package Index (PyPI), and thus the simplest way to install it is with pip:

```
pip install lephare
```

We also reccommend using a conda environment to control Python version and isolate your installation:

```
# We recommend using Python 3.12
conda create -n <env_name> python=3.12
conda activate <env_name>
pip install lephare
# We have prepared a number of introductory notebooks. In order to run them
# you must install jupyterlab with the following commands.
conda install -c conda-forge jupyterlab
# And create a kernel which has access to this environment
python -m ipykernel install --user --name <kernel_name>
```

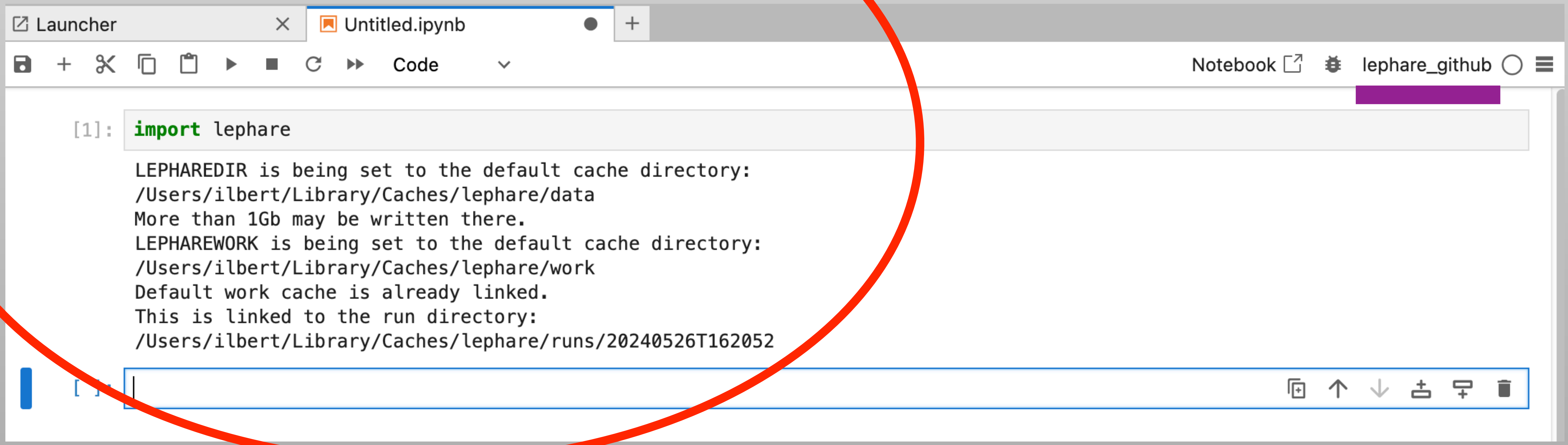
Documentation
https://lephare.readthedocs.io/en/latest/

Running LePHARE

Two methods

1. Same method as initial version of the code using command line in the terminal

2. Open a notebook (e.g. jupyter-lab)



Structure of the code

github.com/lephare-photoz

github repository lephare

Sources, documentation, tests.

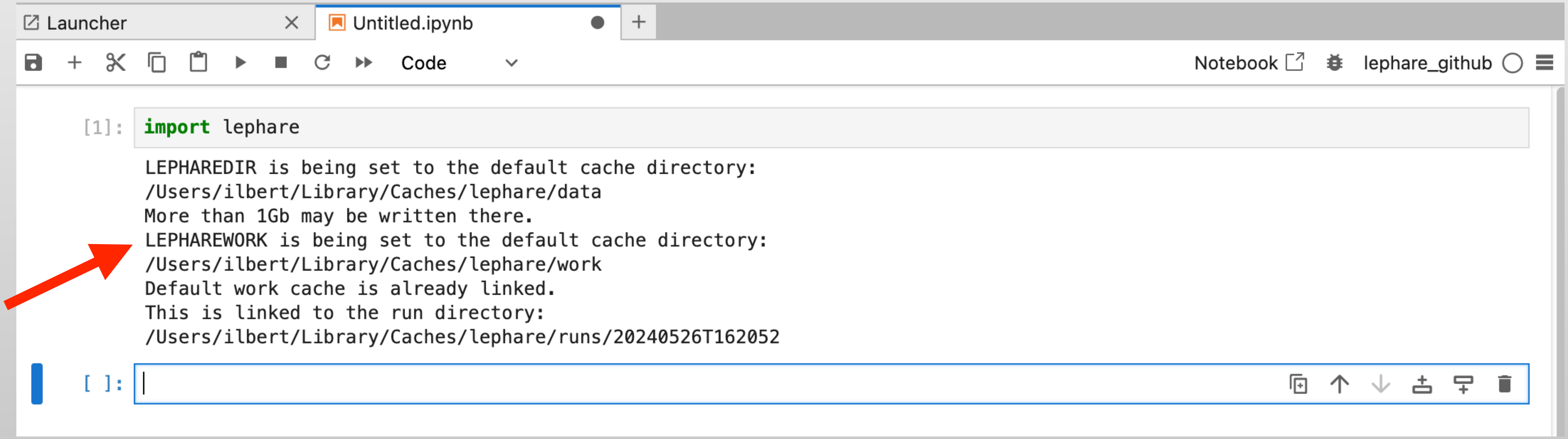
Used by pip install

github repository lephare-data

Auxiliary data (SEDs, attenuation curves, etc)

- **loaded locally on your computer depending on your parameter file**
- **OR cloned once for all, the environment variable LEPHAREDIR set the location**

Structure of the code

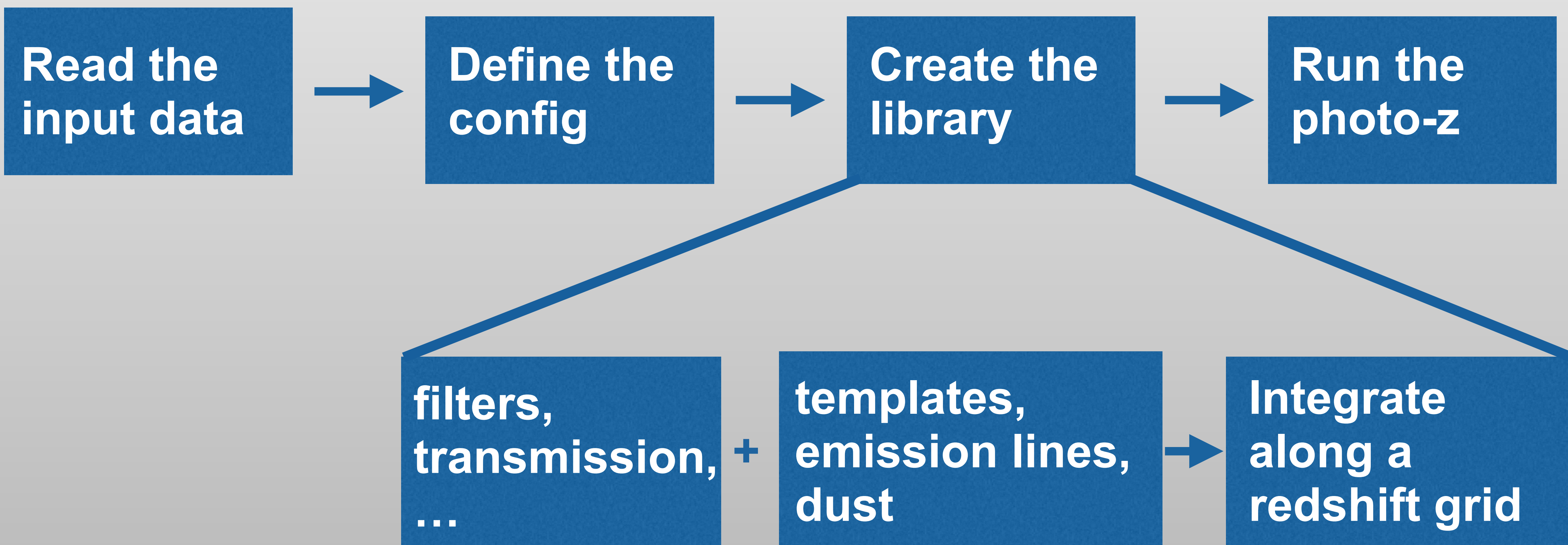


Intermediate files will be generated during your run.
You can specify their location with the environment variable LEPHAREWORK

By default, LEPHAREDIR and LEPHAREWORK are set up in your cache

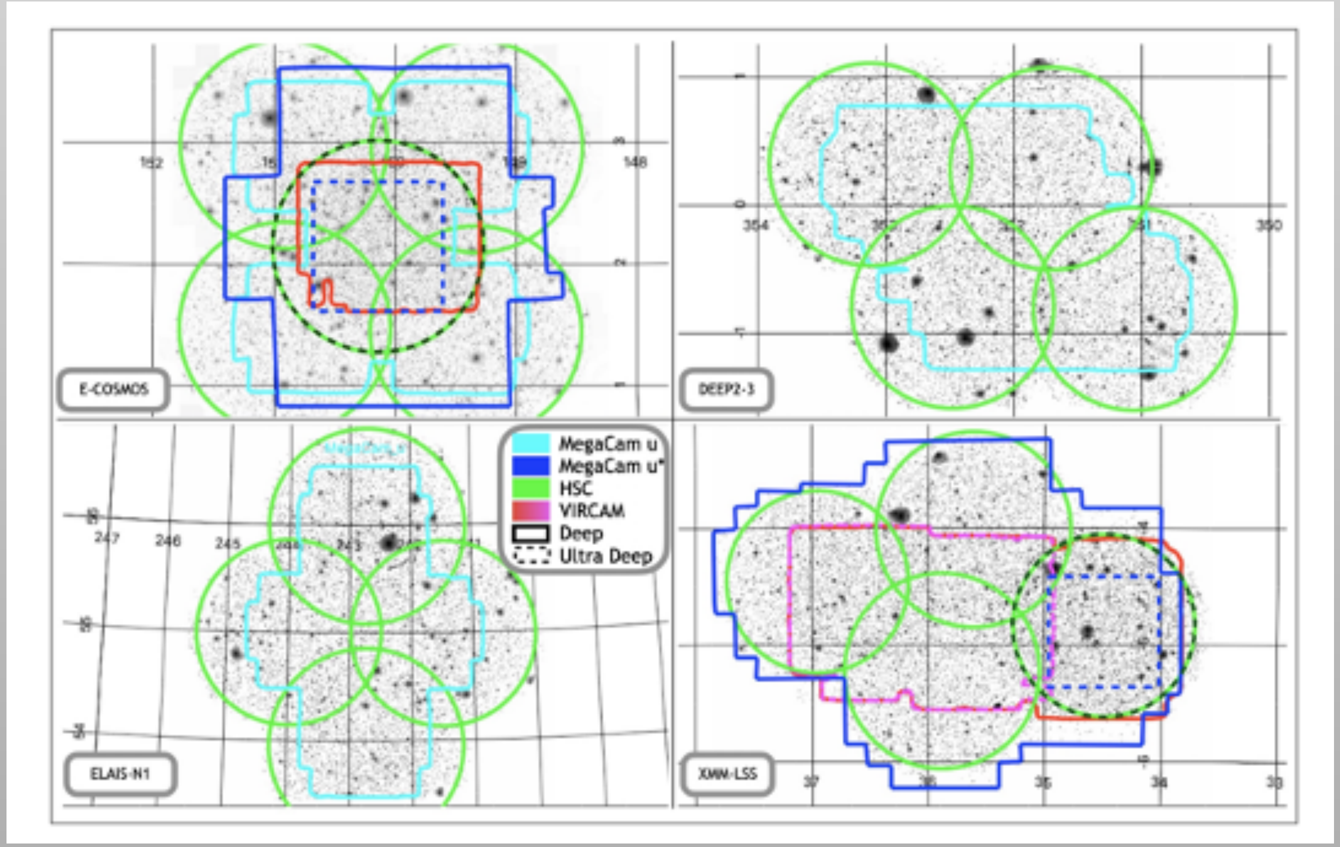
An example of notebook

We start with GDR_gal_photoz.ipynb

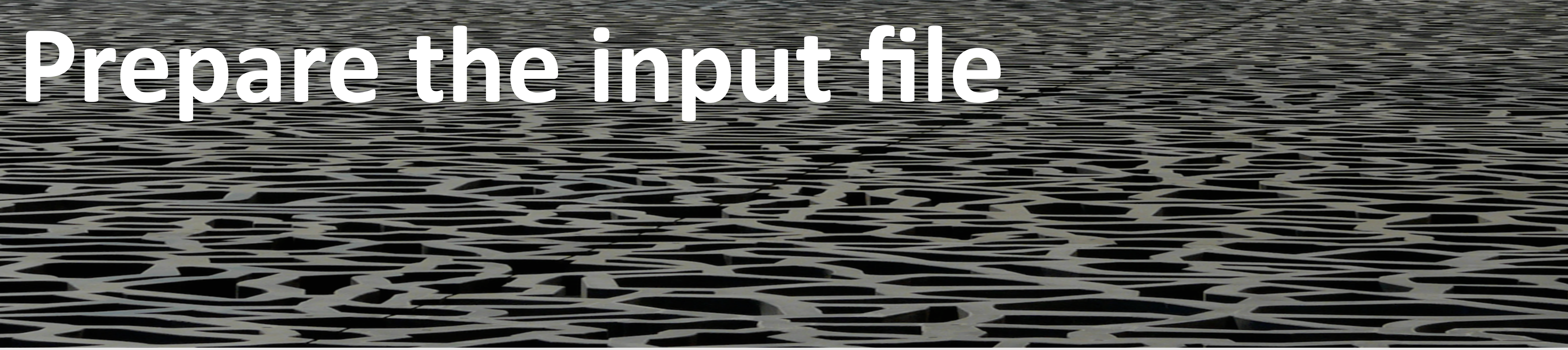


An example of notebook using CLAUDS data (Desprez+2023)

- CLAUDS (CFHT Large Area U-band survey) ugrizy data
- We concentrate on the COSMOS field for testing
- Deep spectroscopic sample from Khostovan et al. (2025) for testing
- Deep Chandra x-ray sample from Marchesi et al. (2016) (for the AGN part)



Prepare the input file



Flux Flux_err
in erg/s/cm2/Hz

Id

context

: Cont= $\sum_{i=1}^{i=N} 2^{i-1}$

Spec-z
(or -99)

id	LUX_APER_2s_u	FLUXERR_APER_2s_u	FLUX_APER_2s_g	FLUXERR_APER_2s_g	LUX_APER_2s_r	FLUXERR_APER_2s_r
	erg / (Hz s cm2)	erg / (Hz s cm2)	erg /	cm2)	erg / (Hz s cm2)	erg / (Hz s cm2)
int64	float32	float64	float32	float64	float32	float64
4808959	5.7268773e-31	5.518034975301129e-32	3.4033537e-30	4.974347995710069e-32	2.0249247e-29	6.132702554394253e-32
4142497	4.6692144e-30	8.35349039749749e-32	1.0584889e-29	7.032562540965531e-32	1.3118917e-29	1.1283534924838458e-31
4810688	7.382787e-29	6.9711521514209e-32	6.4941014e-28	9.675751207640002e-32	1.8728434e-27	1.6347614145883166e-31
3817033	3.5629857e-29	6.659804406999169e-32	2.0267107e-28	7.570278434616451e-32	5.8696846e-28	1.0176130568965198e-31
4424478	3.417857e-31	6.044610740664273e-32	8.763036e-31	4.354743801808737e-32	1.1540443e-30	5.741448872486873e-32

id	FLUX_APER_2s_i	FLUXERR_APER_2s_i	FLUX_APER_2s_z	FLUXERR_APER_2s_z	FLUX_APER_2s_y	FLUXERR_APER_2s_y	context	specz	string_input
	erg / (Hz s cm2)	erg / (Hz s cm2)	erg / (Hz s cm2)	erg / (Hz s cm2)	erg / (Hz s cm2)	erg / (Hz s cm2)			
int64	float32	float64	float32	float64	float32	float64	int64	float64	bytes6
4808959	6.3775256e-29	7.164708382869701e-32	1.3603414e-28	1.1793449142542687e-31	1.6035619e-28	2.1691132524251114e-31	63	0.97289	galaxy
4142497	1.6121168e-29	1.280090547837343e-31	1.7818013e-29	1.9356842451688993e-31	1.7054021e-29	4.143978765013208e-31	63	3.74973	broad
4810688	3.8103014e-27	3.20878394975566e-31	5.4658897e-27	3.831841571658854e-31	6.654268e-27	3.98548194889167e-31	63	0.0	galaxy
3817033	9.194632e-28	1.0529419782610294e-31	1.2421681e-27	1.6188882139810722e-31	1.3697514e-27	2.7597109946110087e-31	63	0.19567	galaxy
4424478	1.3336459e-30	6.5000303656972e-32	2.1873349e-30	1.0494809229310376e-31	2.3111705e-30	1.974837319678105e-31	63	2.09735	galaxy

A string with any information you want

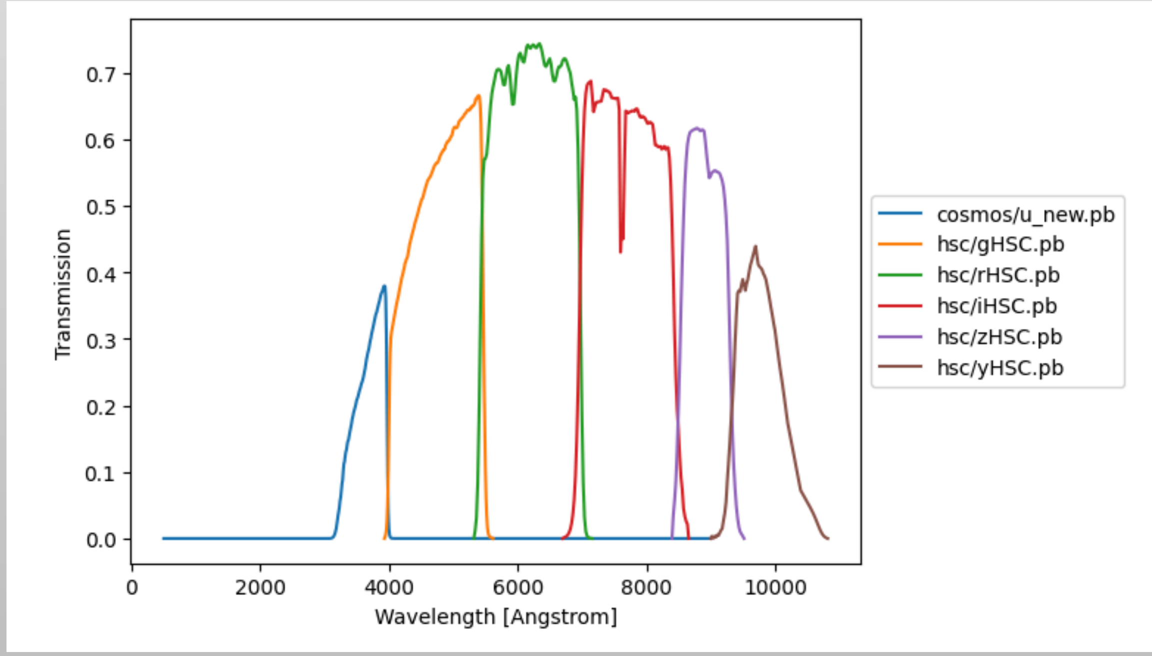
For more information on the format:
https://lephare.readthedocs.io/en/latest/detailed.html#input

!! The filters need to be sorted exactly in the same way in the catalogue and in the filter library !!

Generate the model library

The filters

All the filters already included in LePHARE can be browse at
https://github.com/lephare-photoz/lephare-data/tree/main/filt



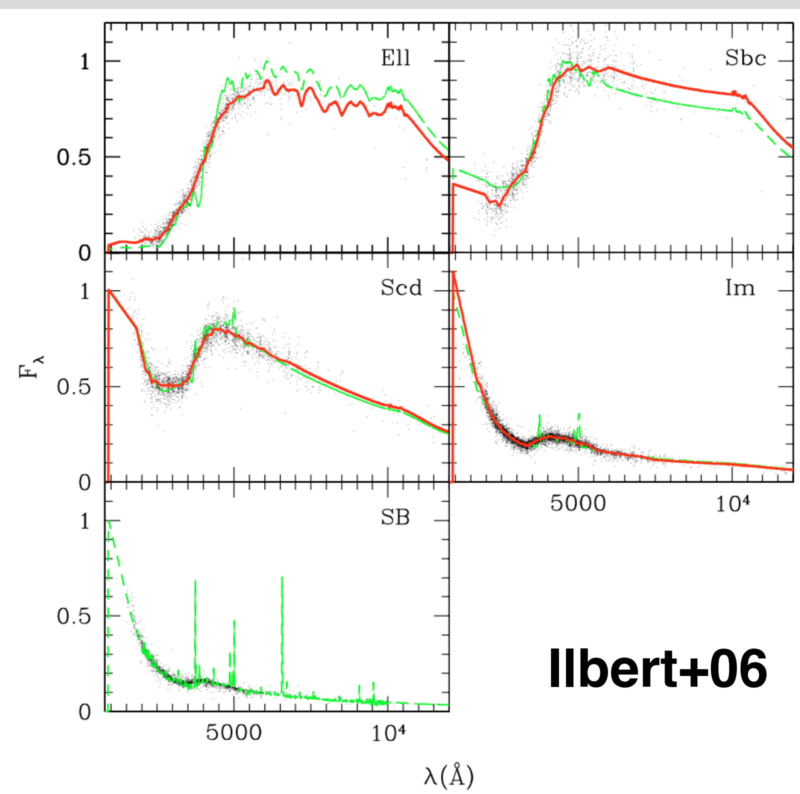
Another method allow you to import directly new filters from svo service
lephare.readthedocs.io/en/latest/detailed.html#adding-a-new-filter

Generate the model library

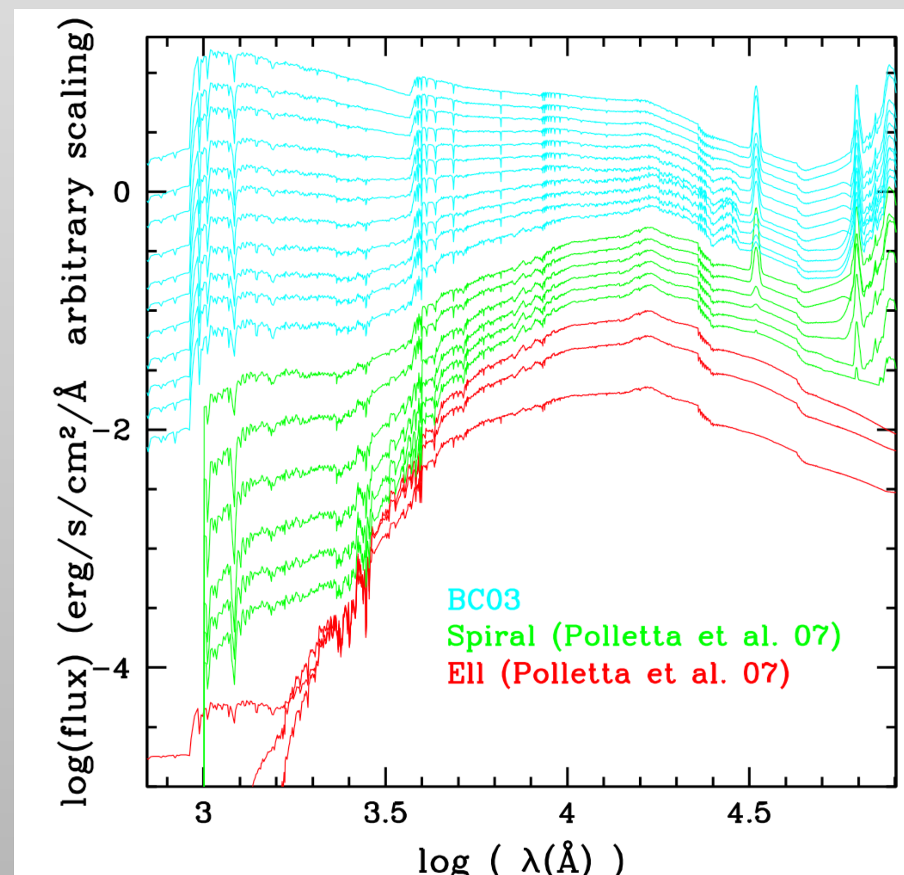
The set of galaxy templates

Various set of galaxy templates to be chosen

https://github.com/lephare-photoz/lephare-data/tree/main/sed

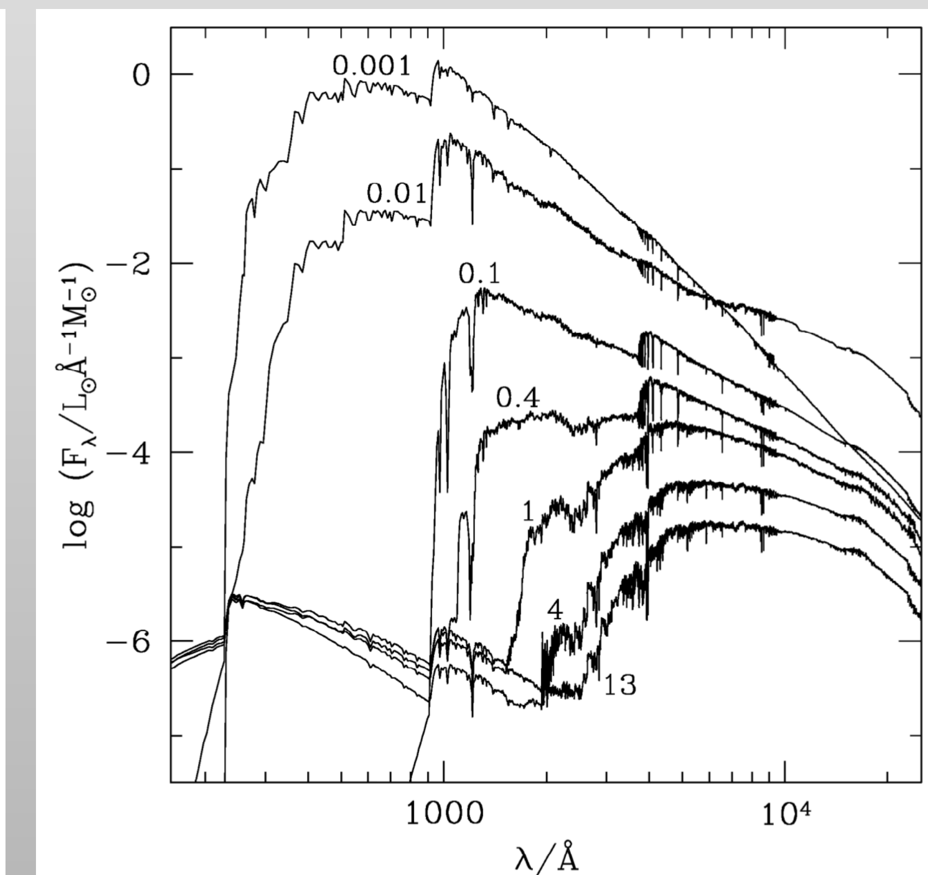


Simple empirical templates as CWW+Kinney



Limited set of models (GRASIL + BC03) Ilbert+09

Bruzual & Charlot 2003



Physical models
- **Complex Stellar Populations**

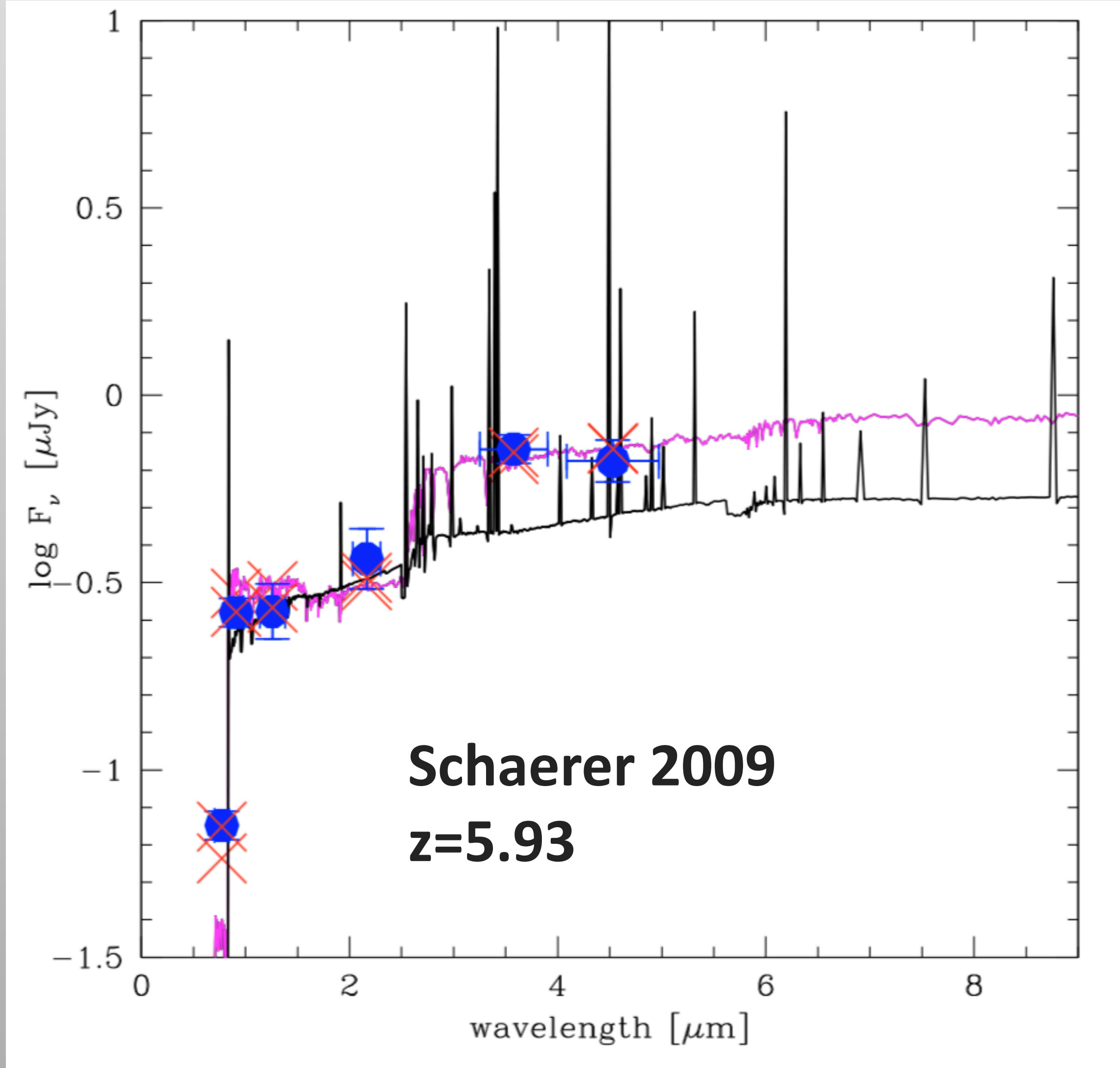
Large library

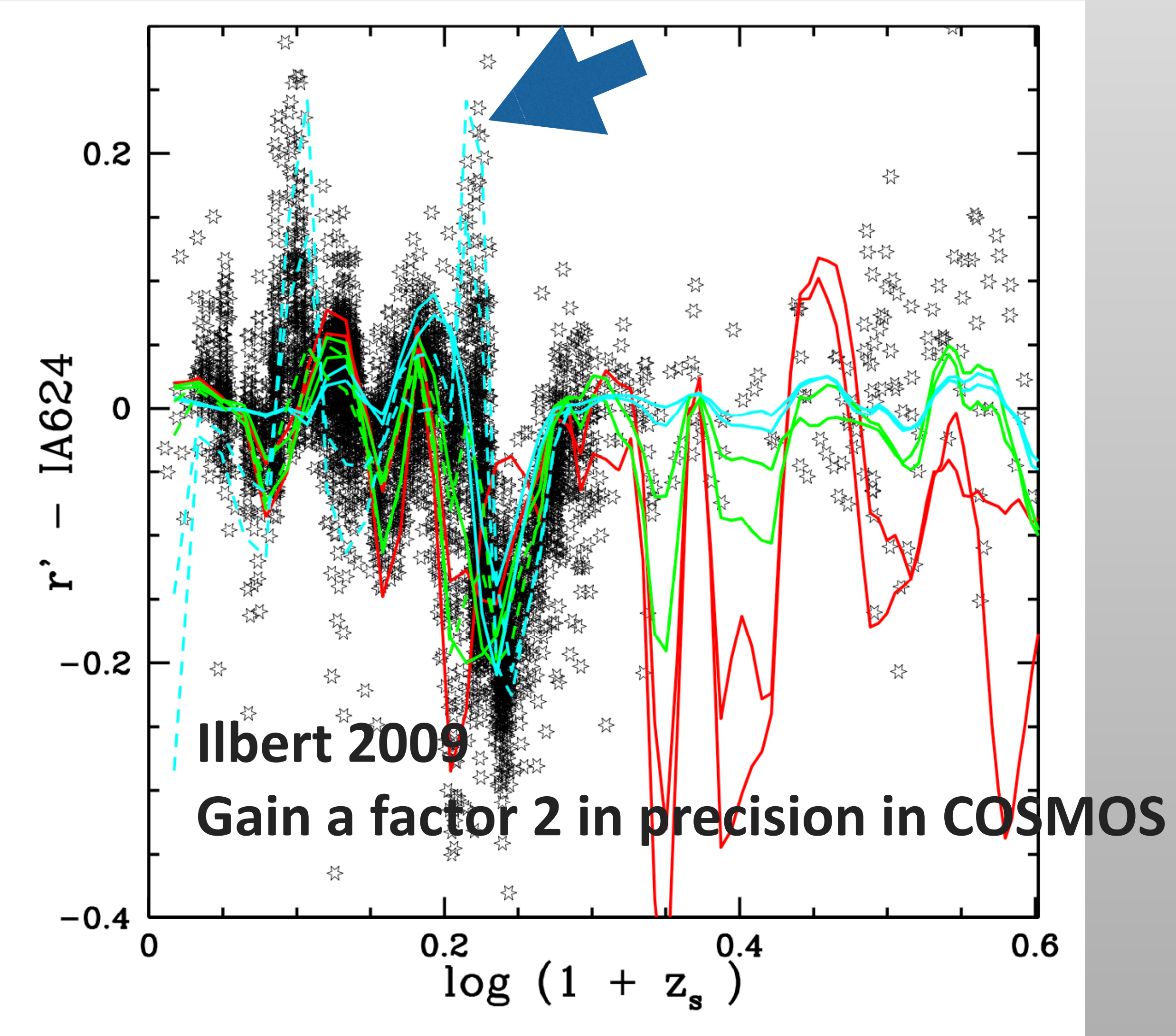
Generate the model library

Emission lines

Not trivial given the diversity of line ratios

Absolutely necessary, even with broad bands





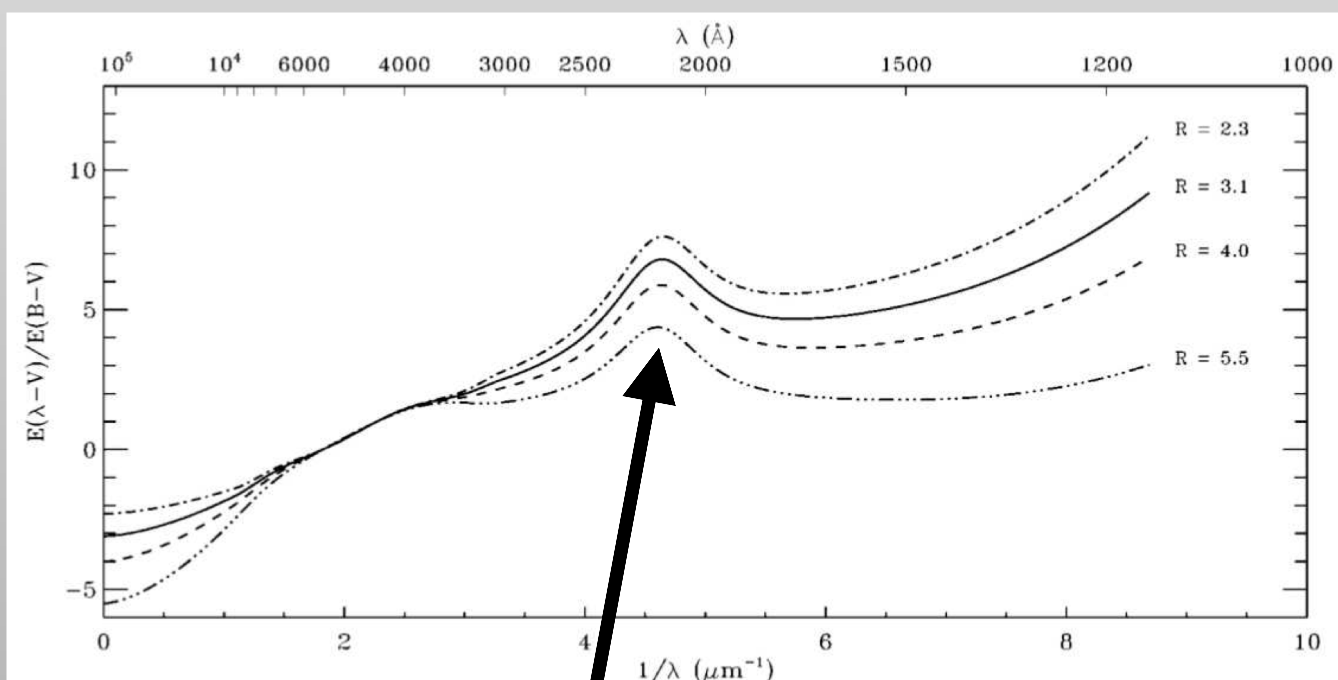
Generate the model libray

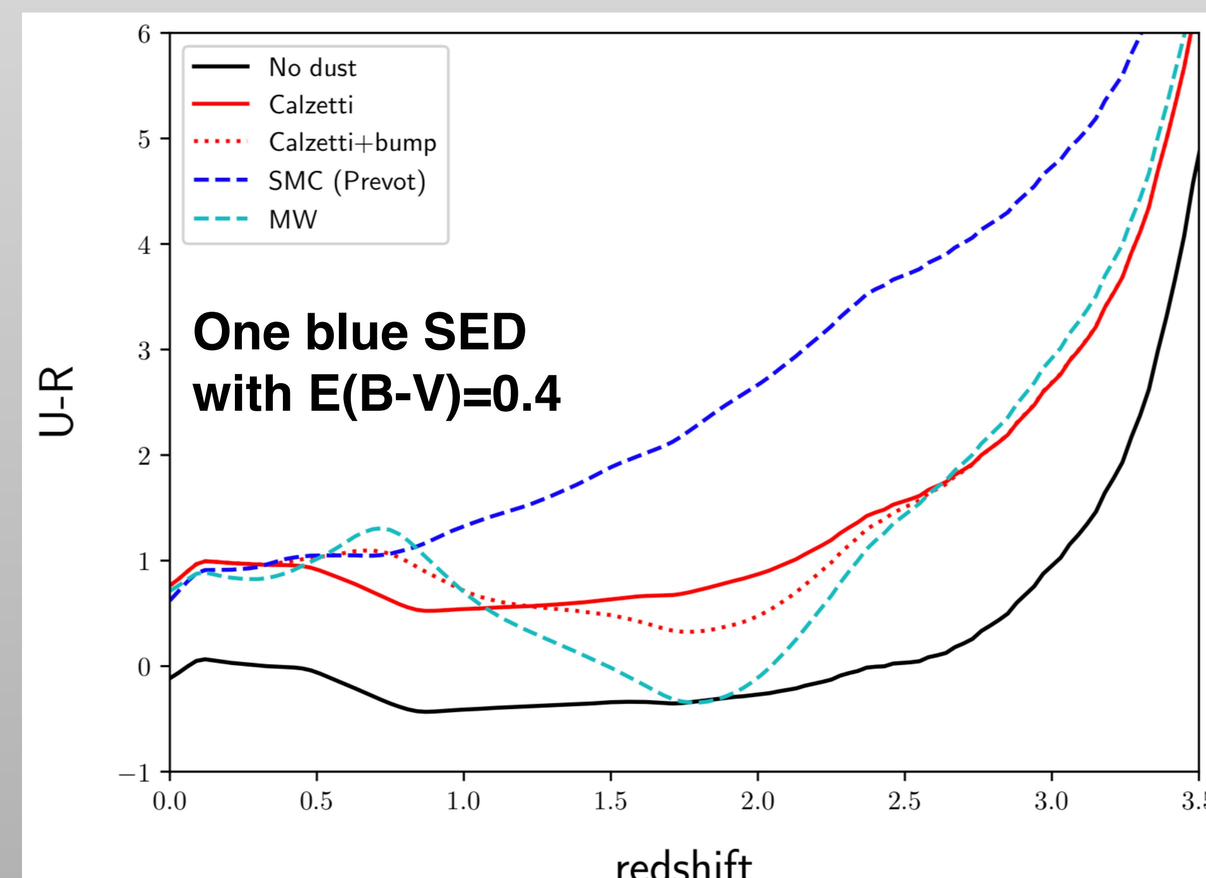
Dust attenuation

Dust attenuation depends on galaxy SFH, geometry, metallicity …

➢ **Several dust attenuation laws can be considered in the same run**

➢ **Define a grid of E(B-V)**





bump at 2175Å
Not always present

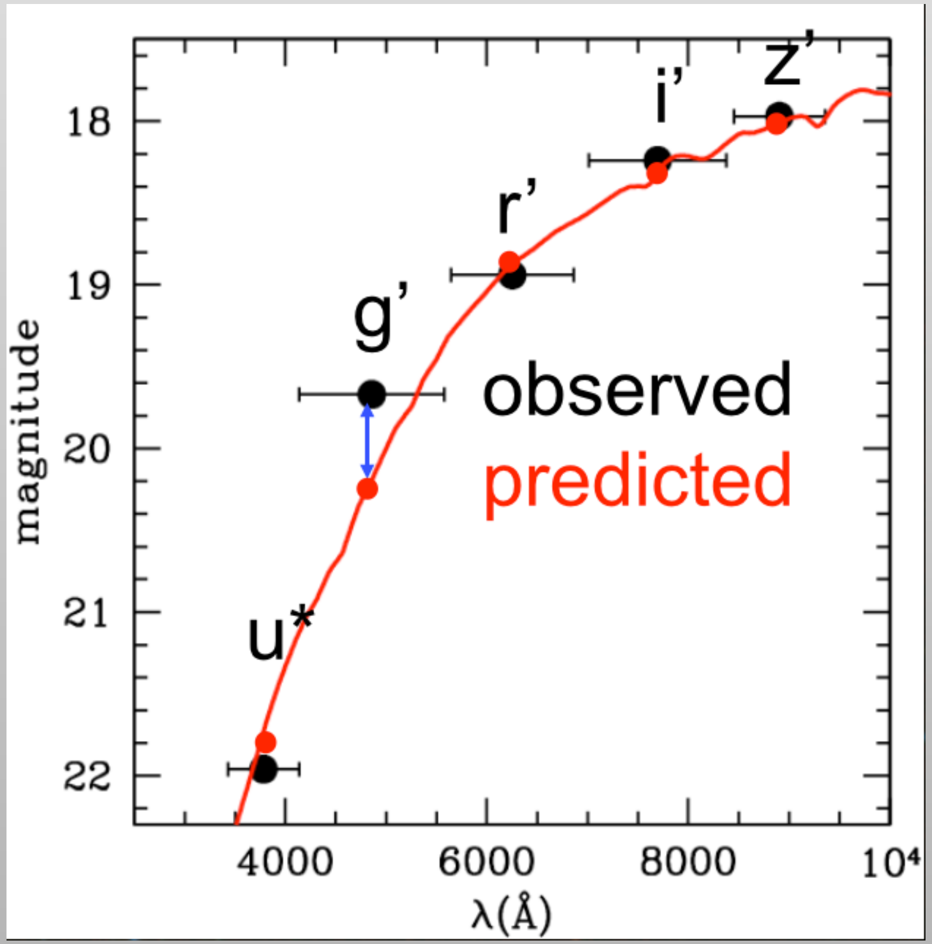
Notebook: create the library

photo-z run

Fine-tune the photomety

Correct the systematic differences between observed and predicted mag

Ilbert, Arnouts et al. 2006



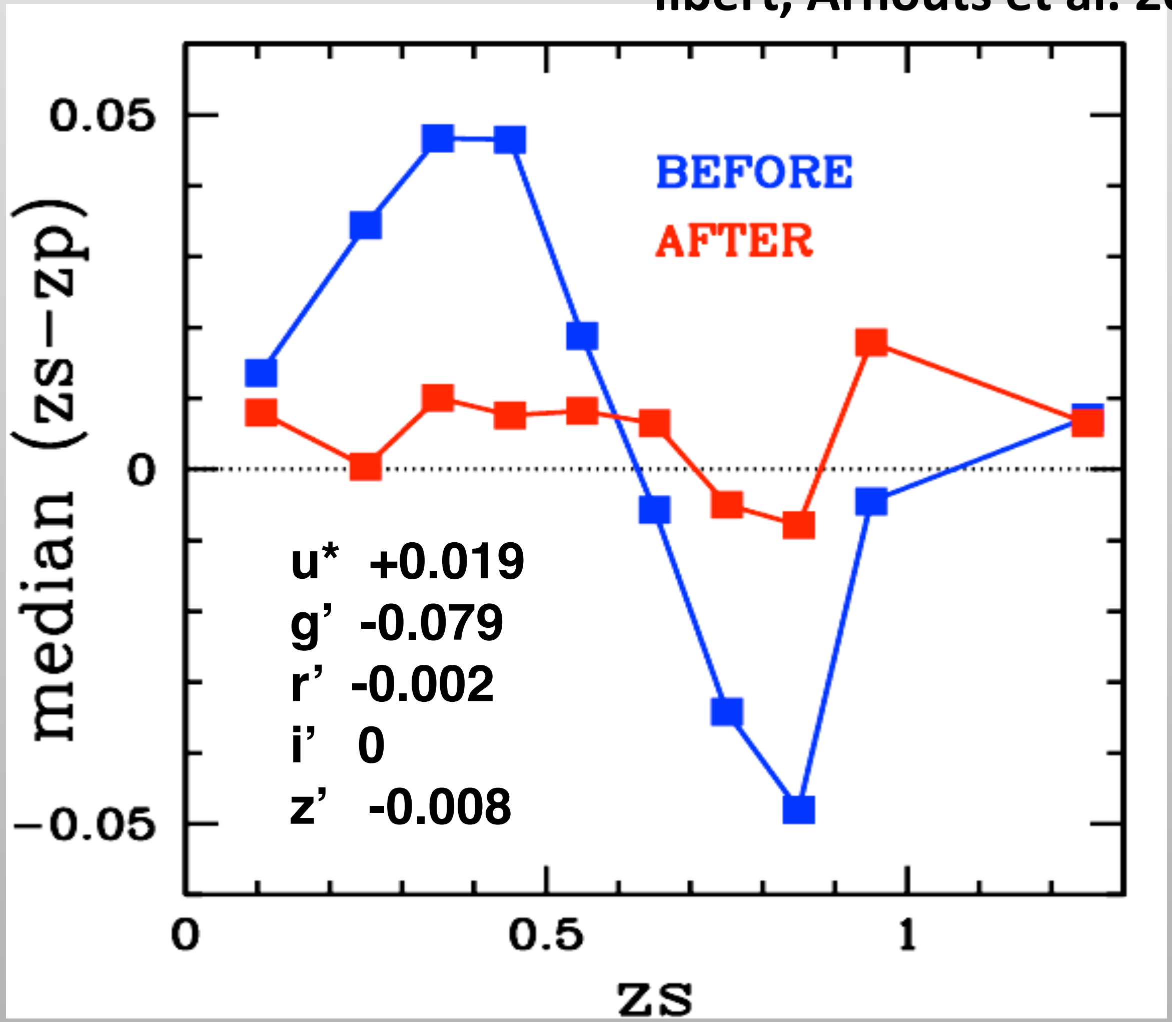


photo-z run

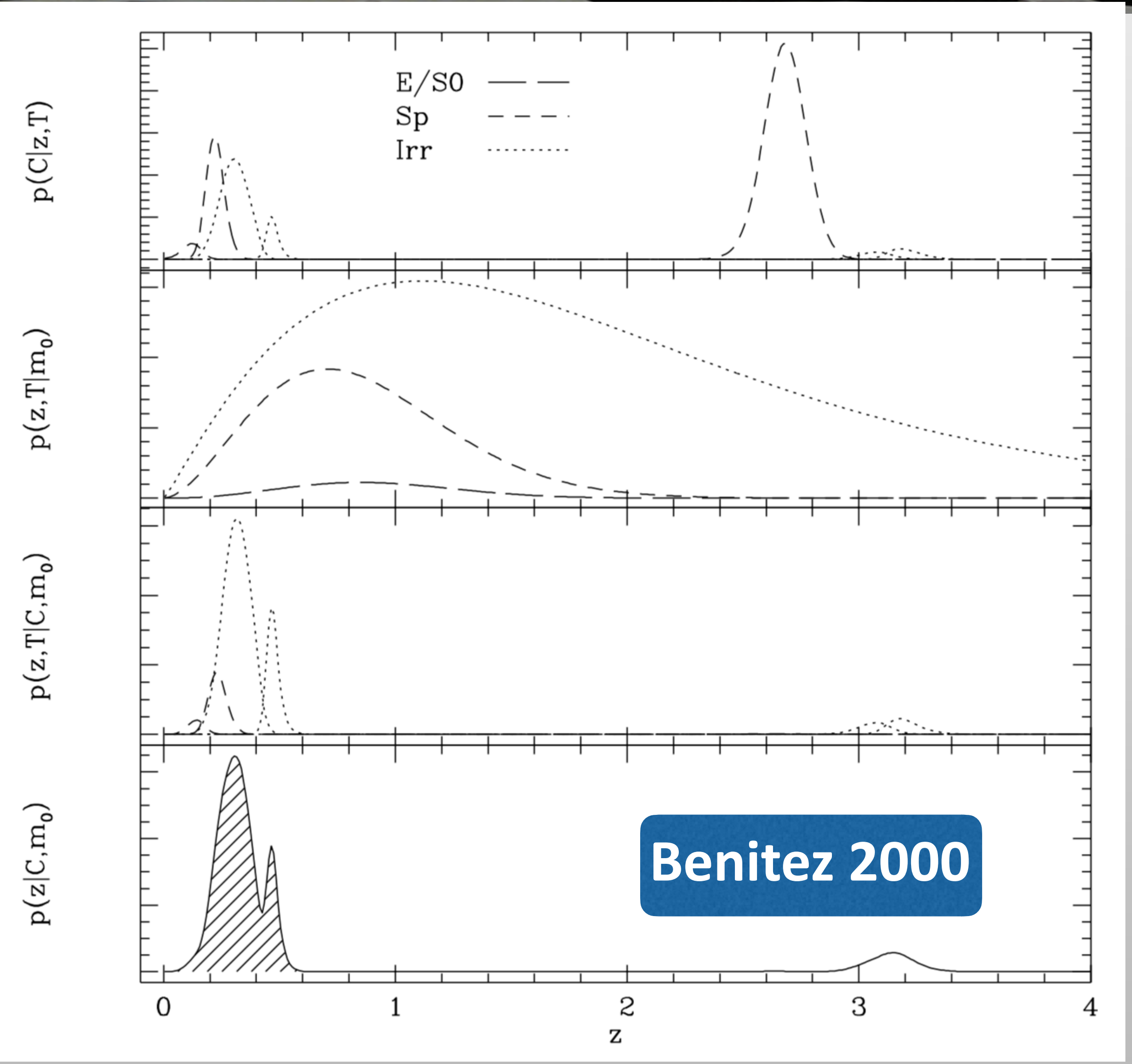
Priors

Bayesian approach could be chosen to derive the PDF and then the photo-z

$$p(z\,|\,C, m_0) = \sum_T p(z, T\,|\,C, m_0) \propto \sum_T p(z, T\,|\,m_0) p(C\,|\,z, T)$$

the contrary, Bayesian probability averages over all the likelihoods after weighting them by their prior probabilities, $p(z, T\,|\,m_0)$. In this way, the estimation is not affected by spurious likelihood peaks caused by noise (Fig. 2; see also

And simple priors on the absolute magnitude range



N(z) prior from Benitez 2000 but improved in Ilbert+2006

Notebook: running the photoz and play with calibration+prior

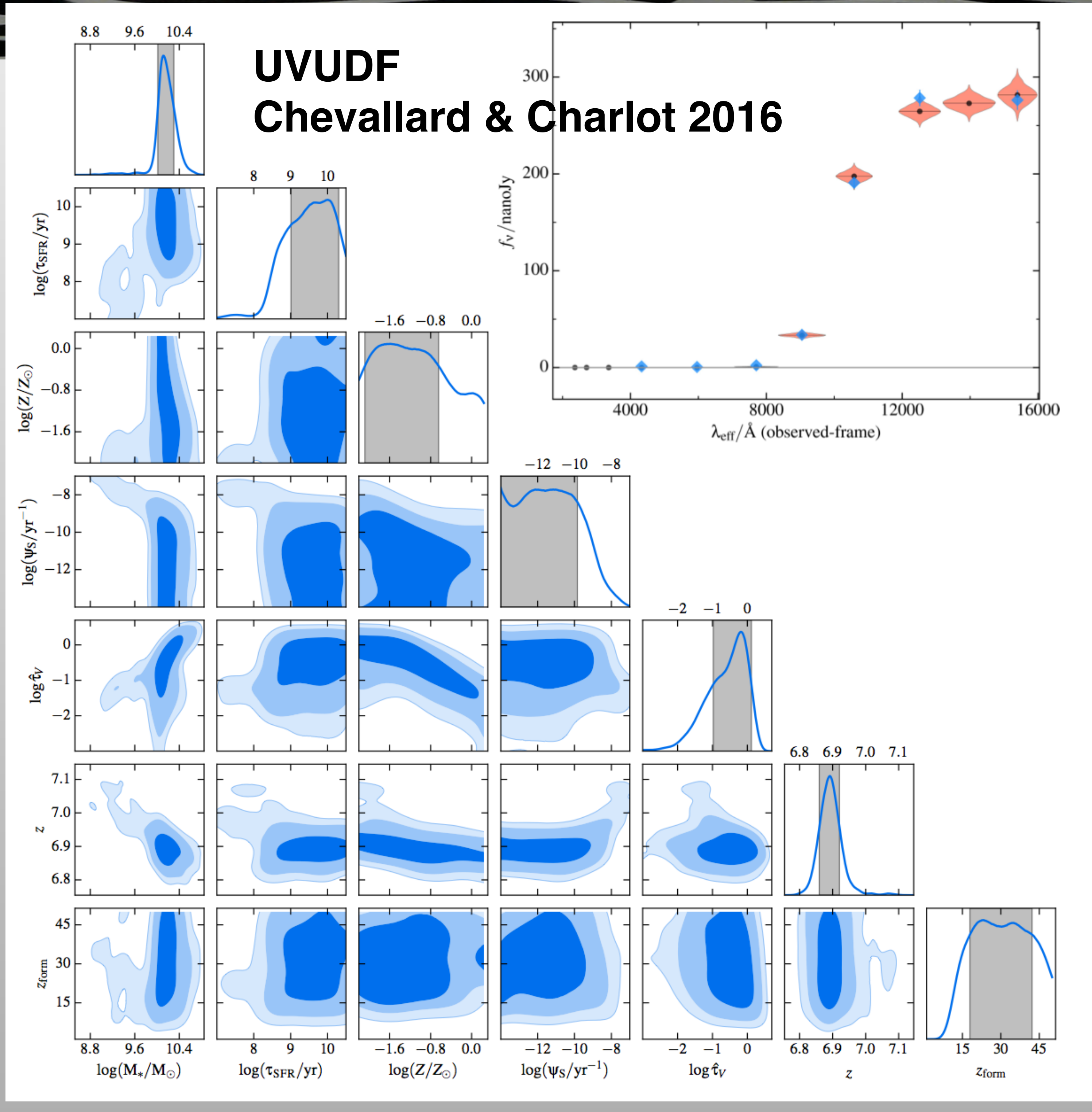
Suplementary slides

Physical parameters

Adding value of template fitting ➢ physical parameters

If the templates have a physical meaning, the physical parameters could be measured simultaneously

ex: Chevallard & Charlot 2016, Tanaka 2015

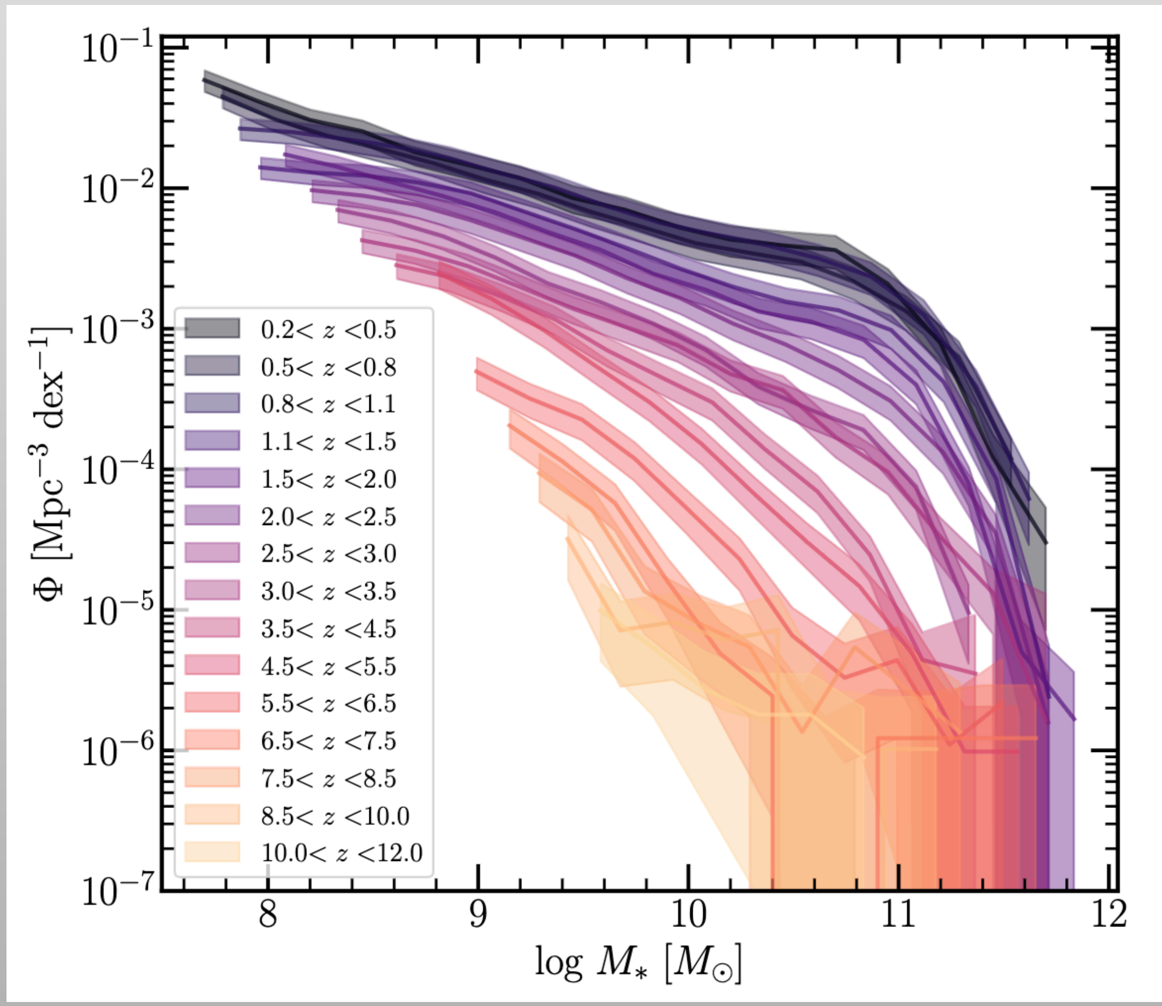


The output of LePHARE

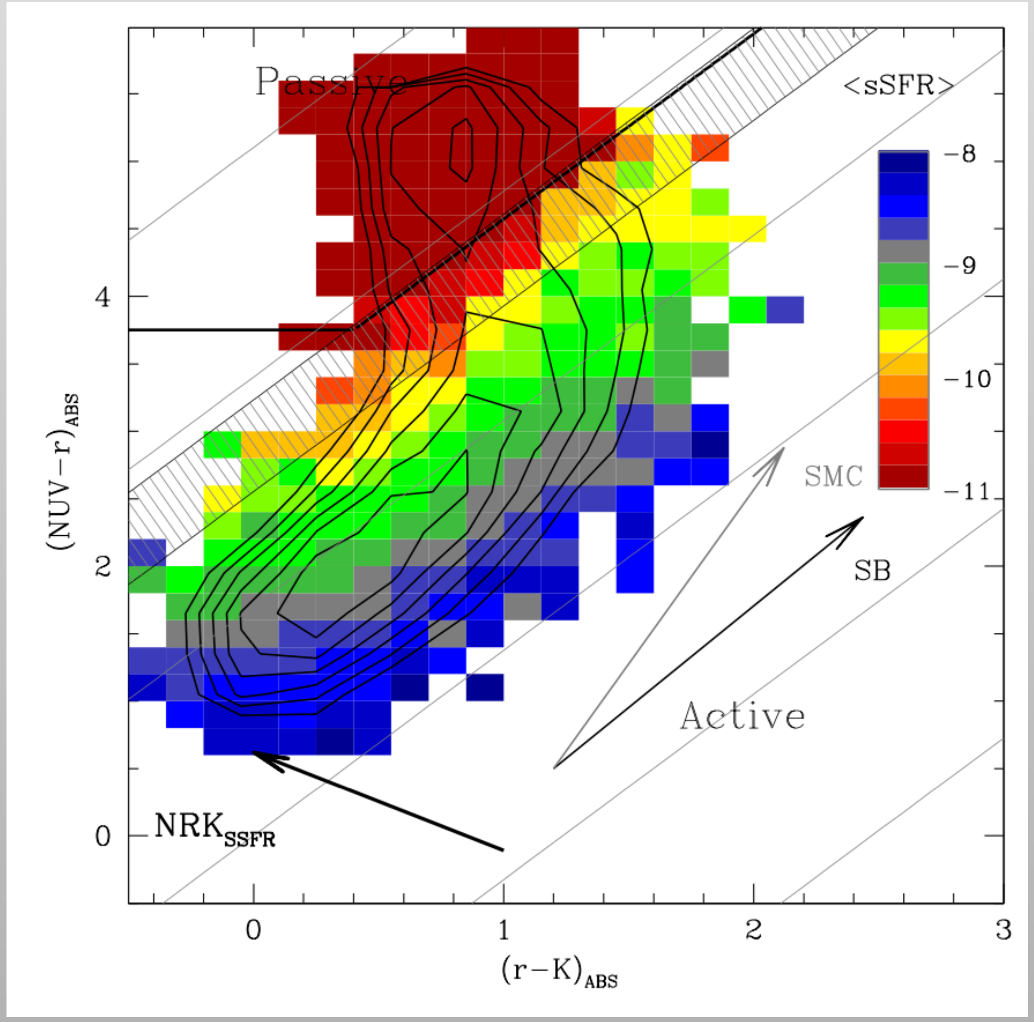
Physical parameters

Extract of the physical properties and associated PDF

For instance: stellar masses, rest-frame colors, SFR, specific SFR, E(B-V), …



Shuntov+24



Arnouts+13

Notebook

https://lephare.readthedocs.io/en/latest/notebooks/Typical_use_case_physicalParameters.html

Suplementary slides

Typical photo-z quality

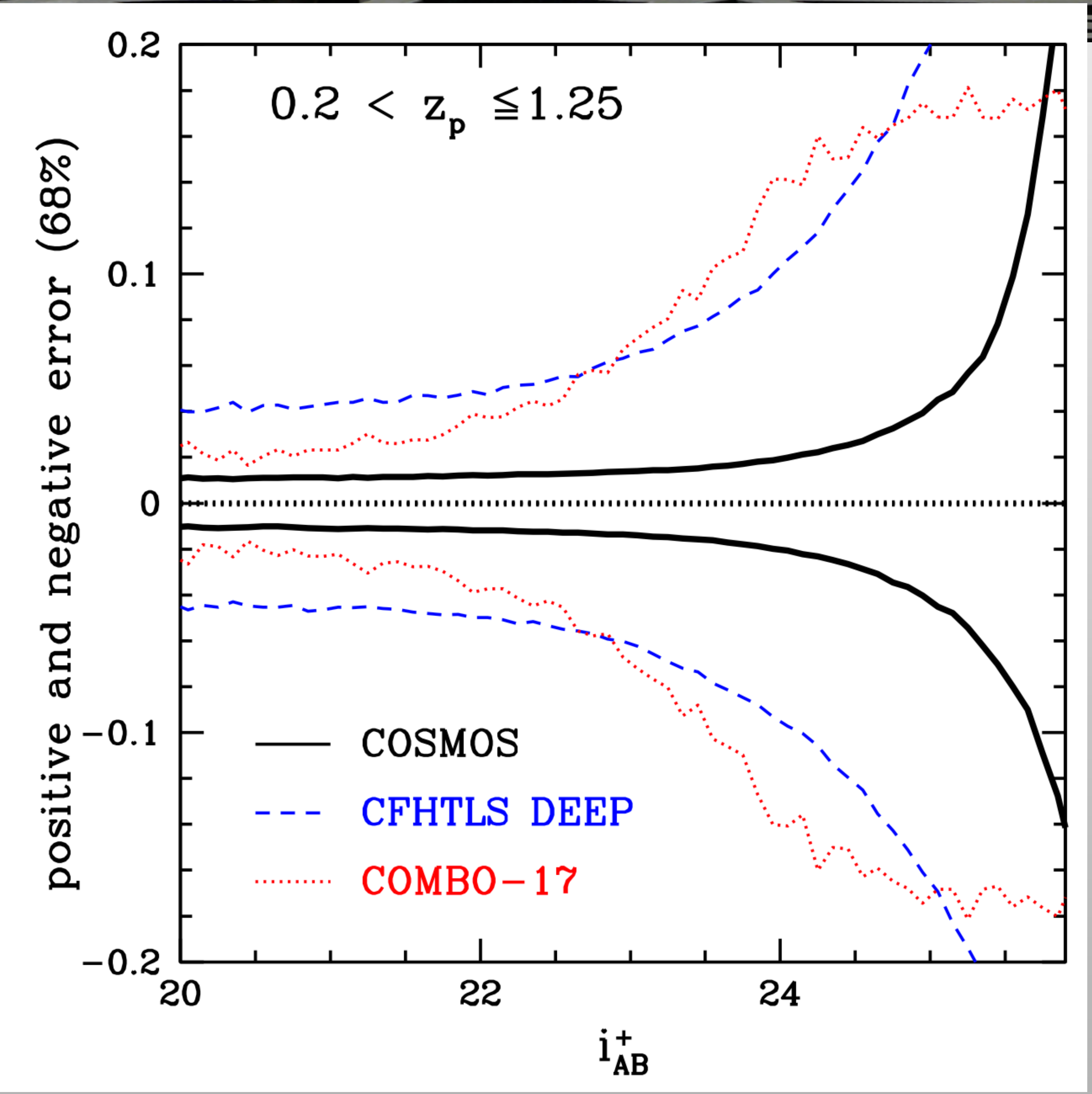
How properties of the photometric survey determine the photo-z accuracy

The quality of the photo-z depends on

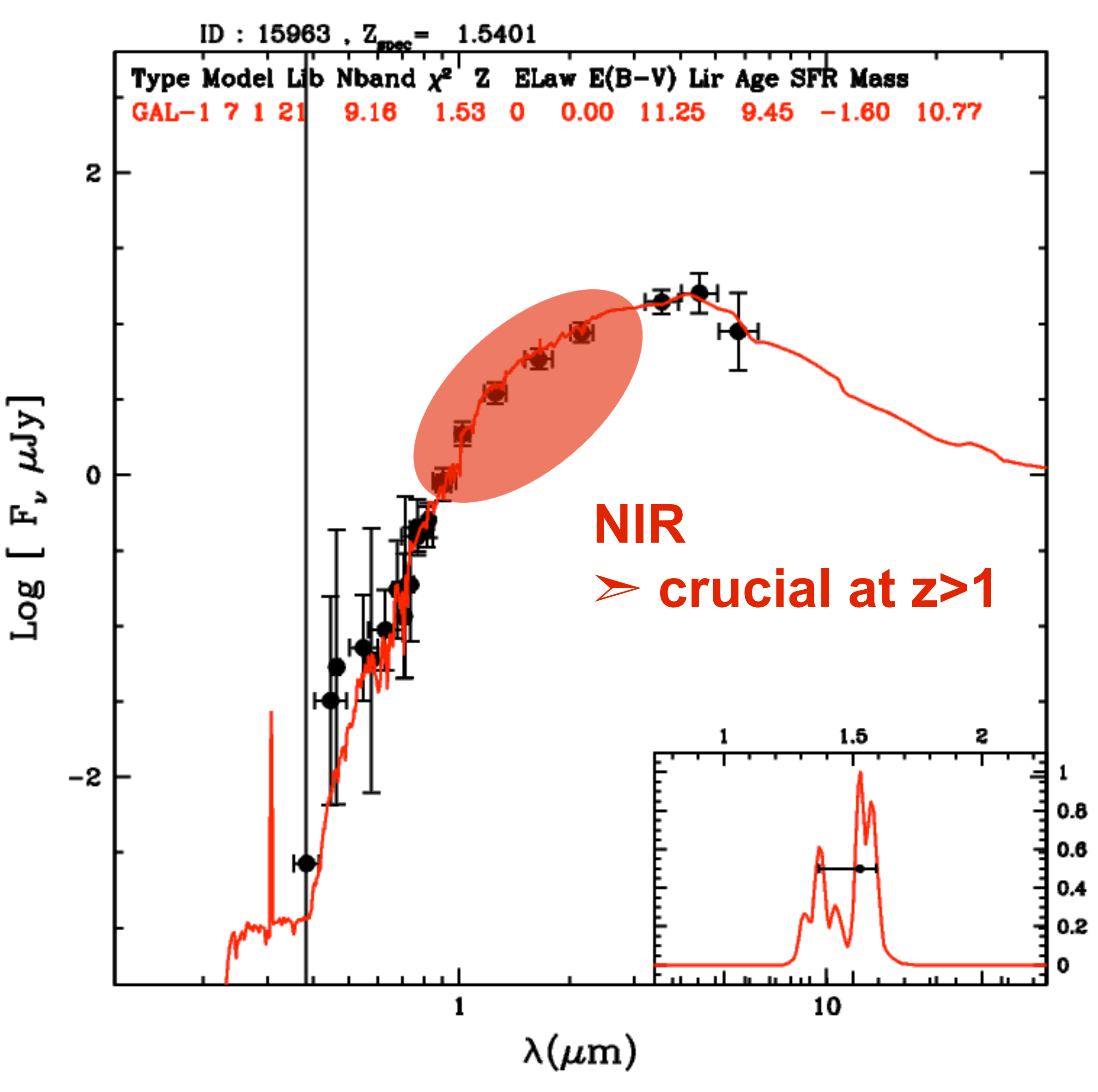
- **the S/N of the photometry, i.e. constraint on the fit**
- **the filter wavelength coverage, i.e. how well we can encompass the Balmer/Lyman break**
- **the resolution of the filter set**

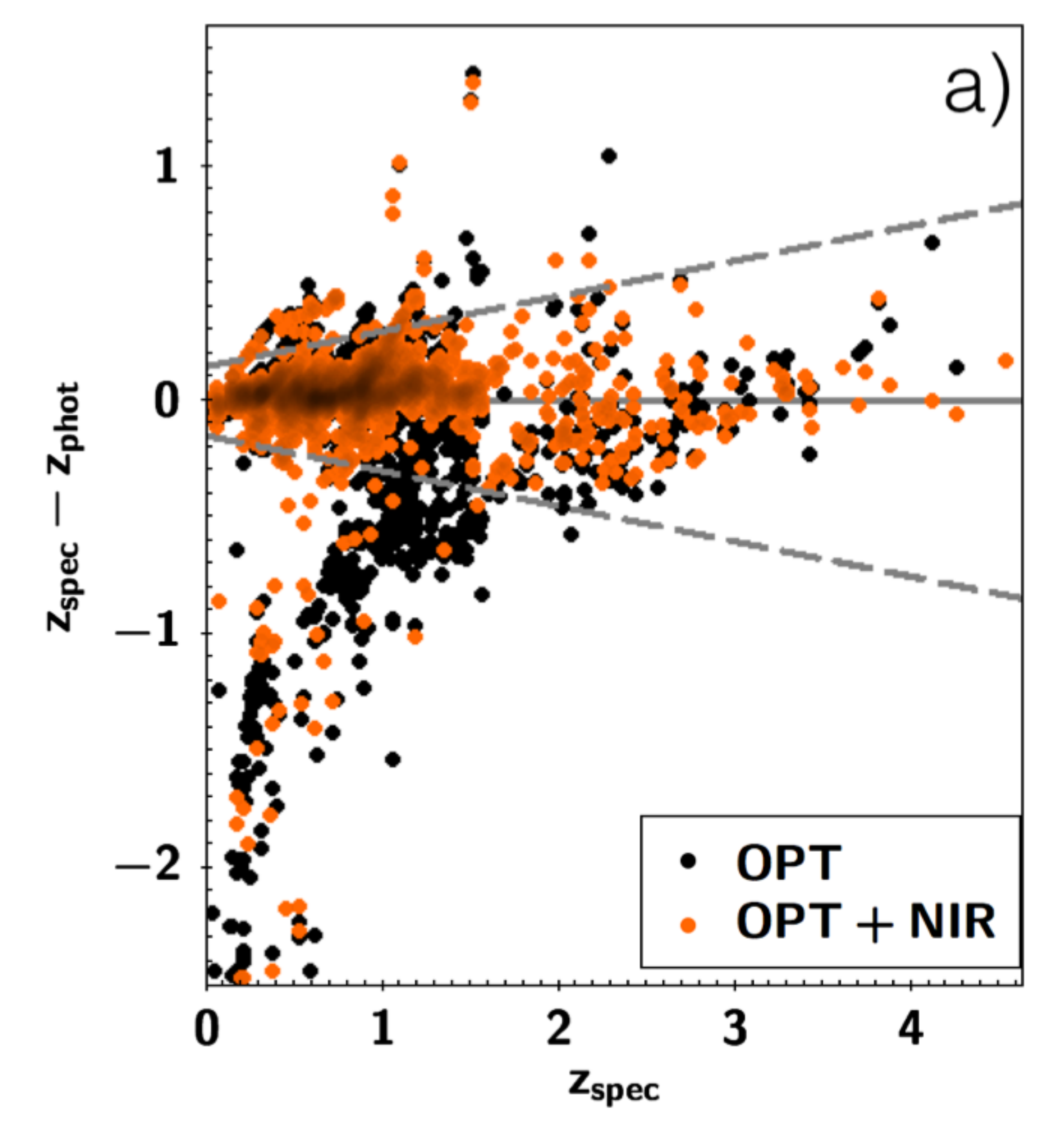
S/N of the photometry

Photo-z accuracy is degraded at faint S/N



Filter coverage



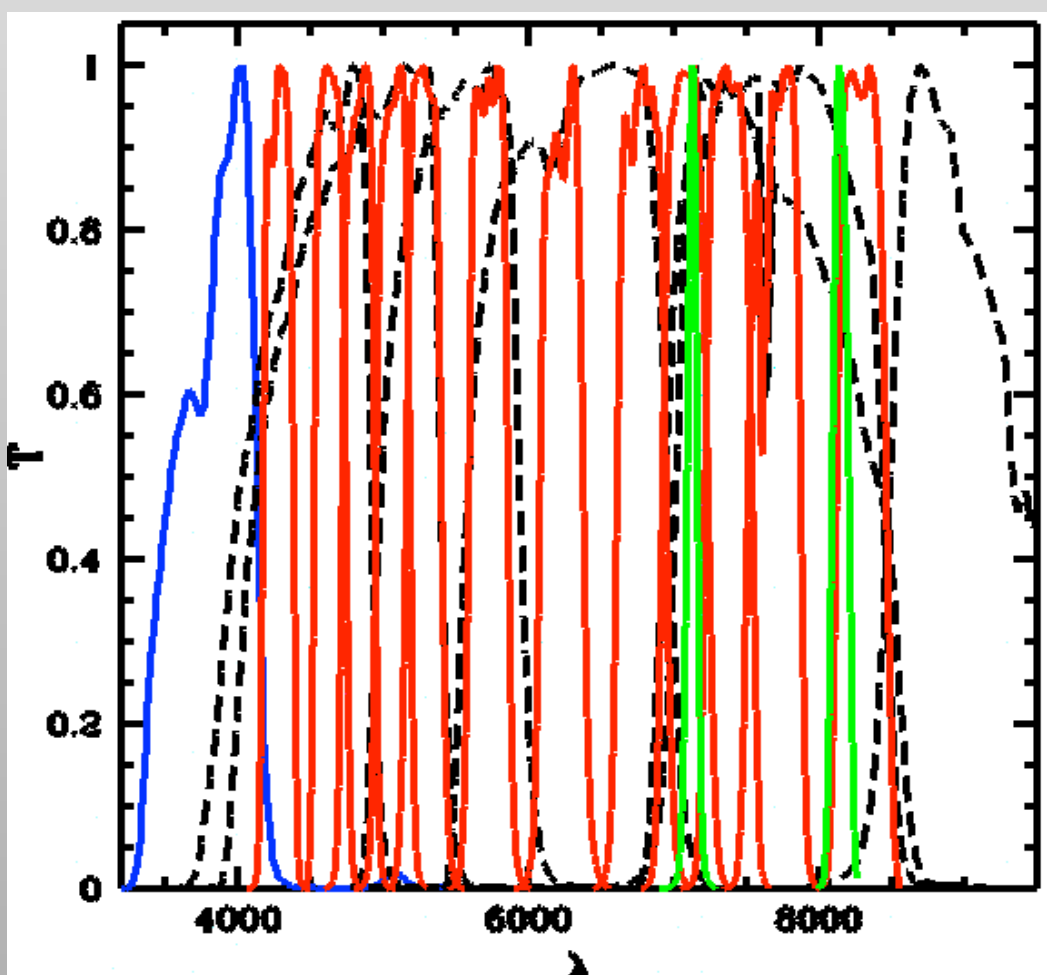


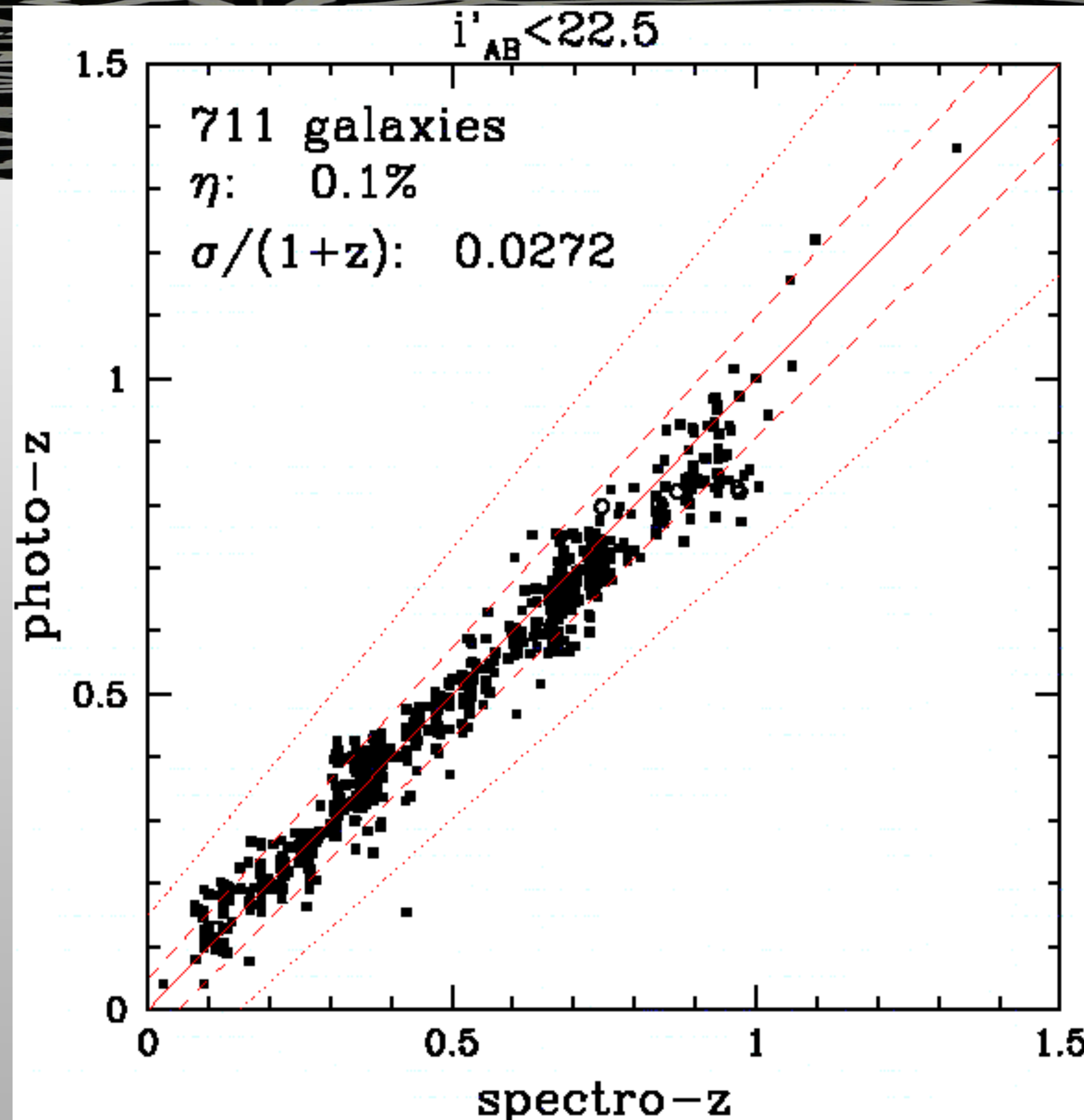
Wavelength resolution

Accuracy at i'<22.5

σ [(zp-zs)/(1+zs)] ~ 0.03

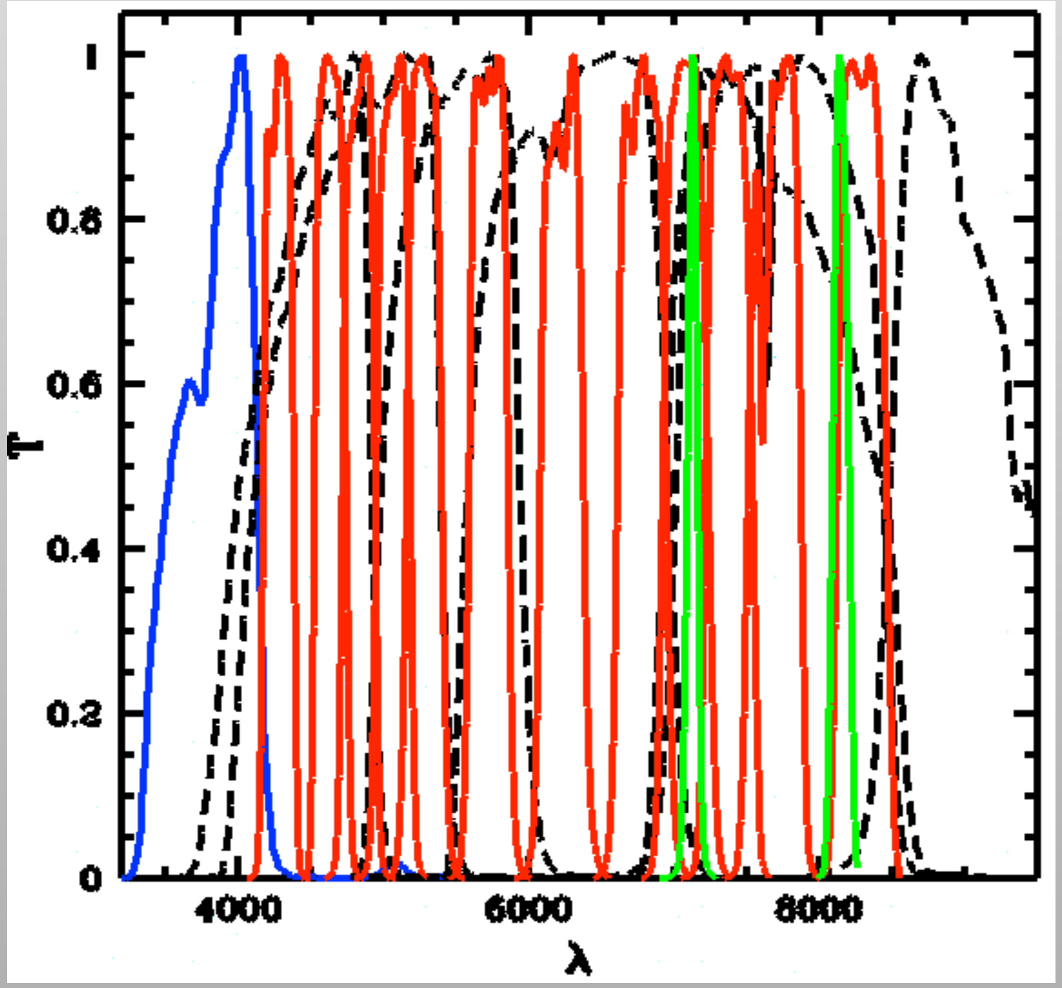
5 broad bands

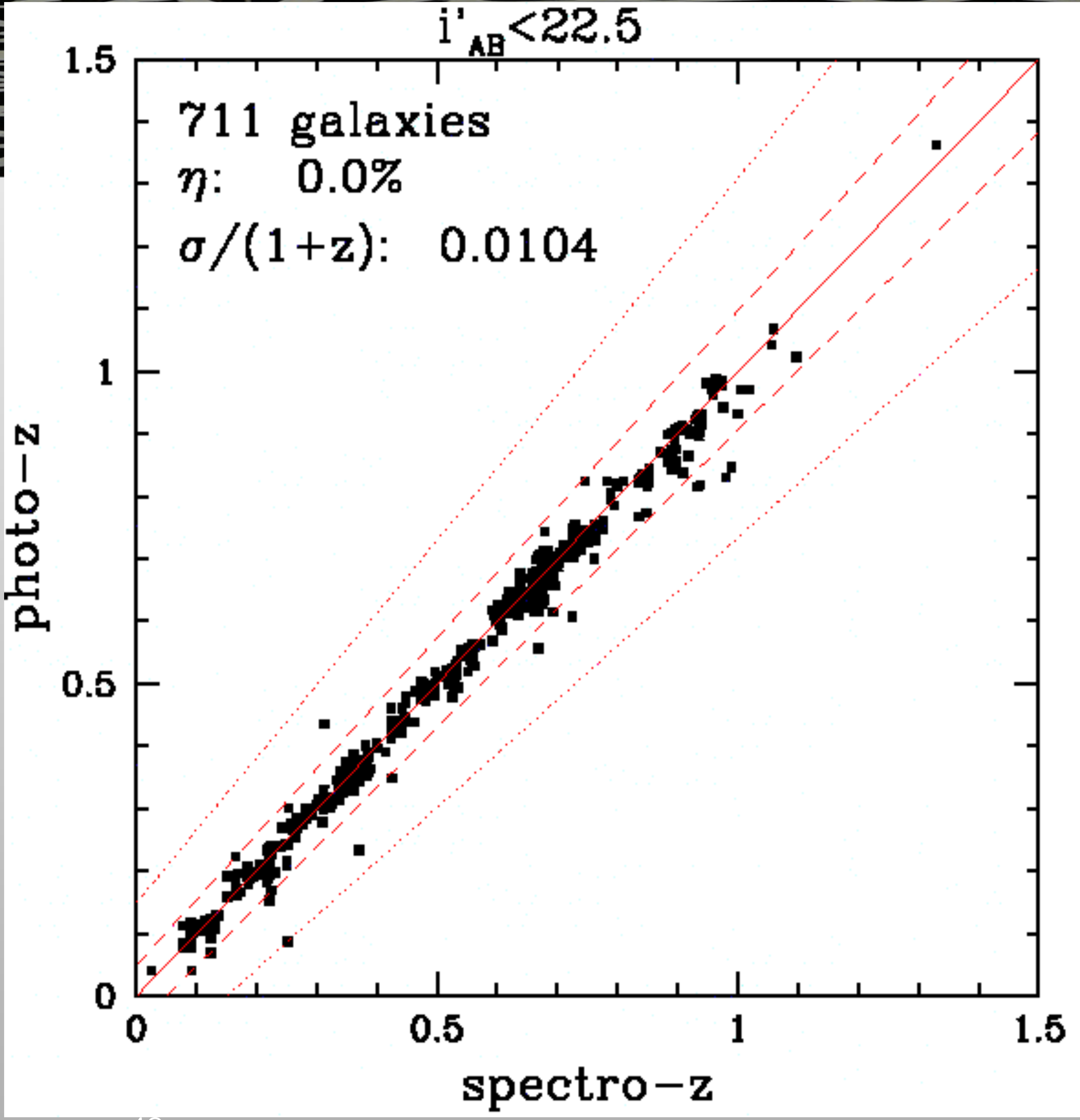




Wavelength resolution

Accuracy at i'<22.5
σ [(zp-zs)/(1+zs)] ~ 0.01
5 broad + 12 medium bands



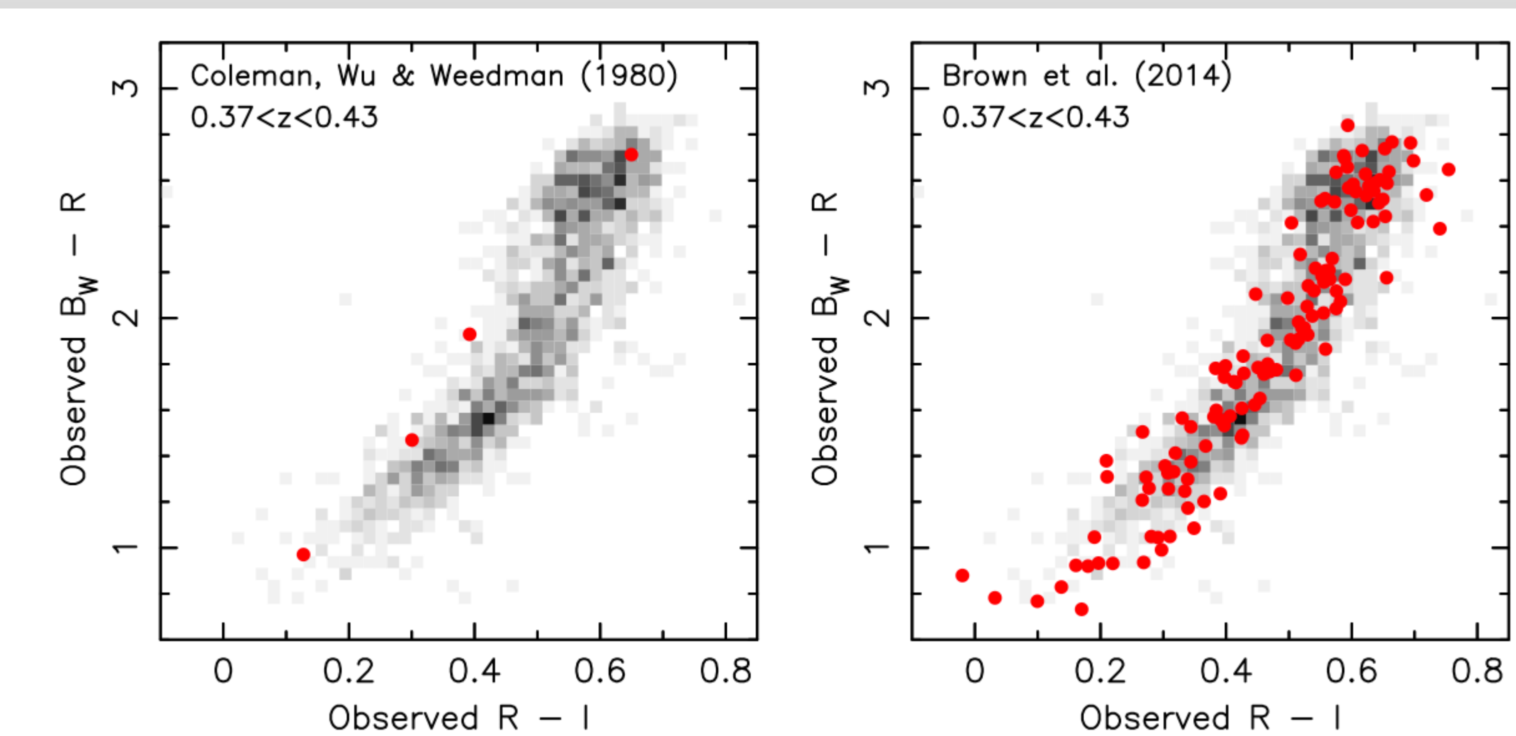


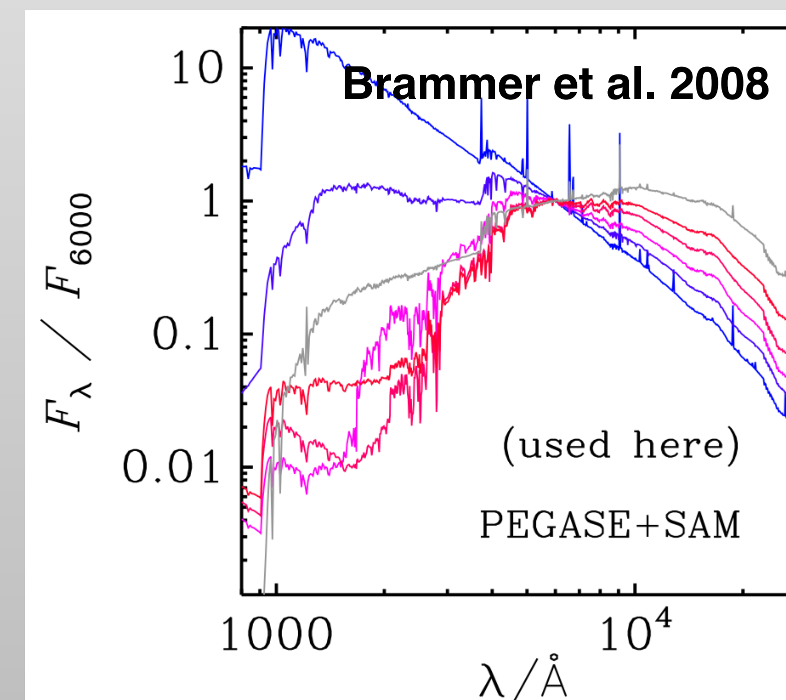
Suplementary slides

Selection the set of templates

The set of templates (now start the messy part)

Could decide to use few observed spectra or/and generate templates with stellar population synthesis models





Easy and Accurate Zphot from Yale

Brammer+(2008) allow for linear combination between templates and associate an error function to the templates

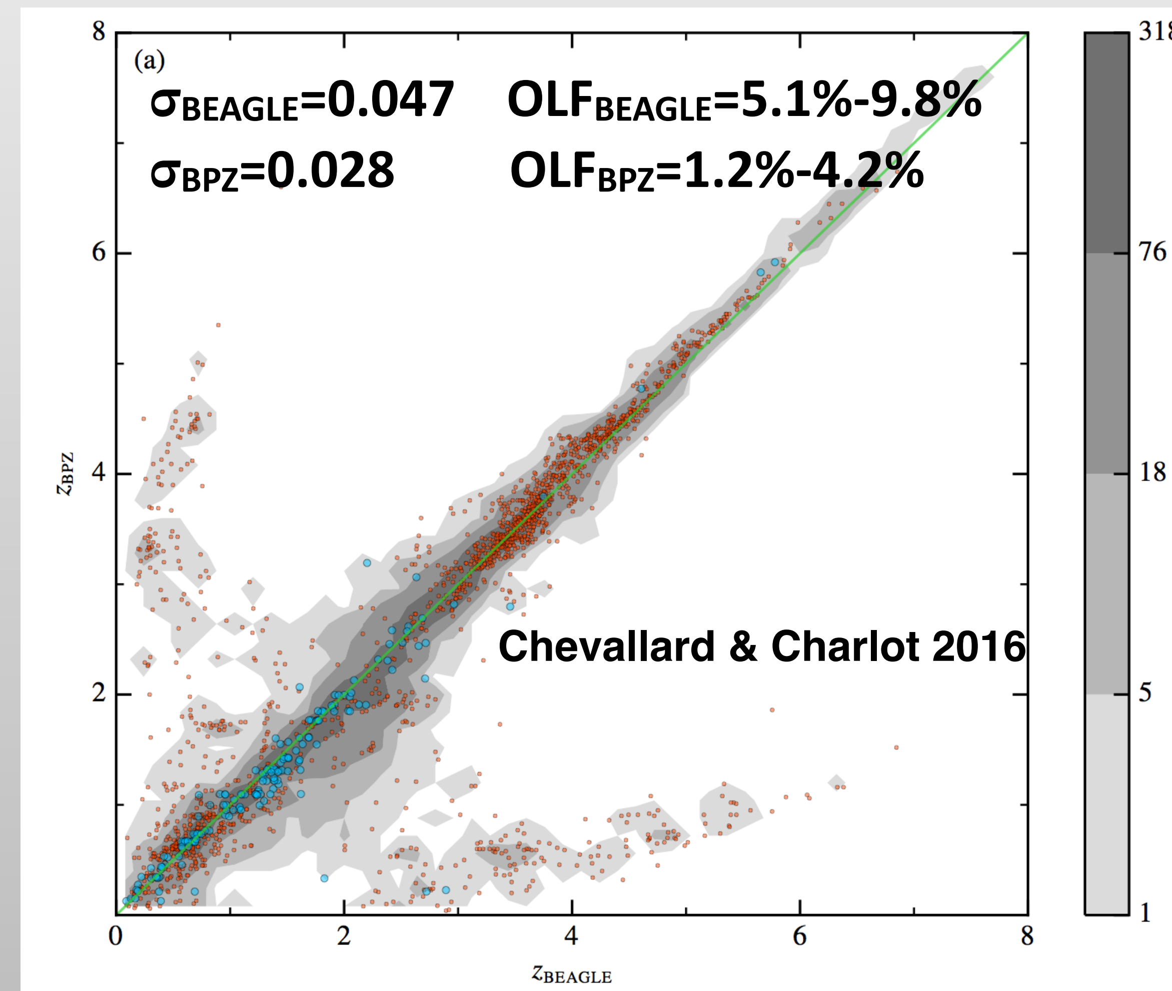
The set of templates (now start the messy part)

Or large libraries with complex star formation histories

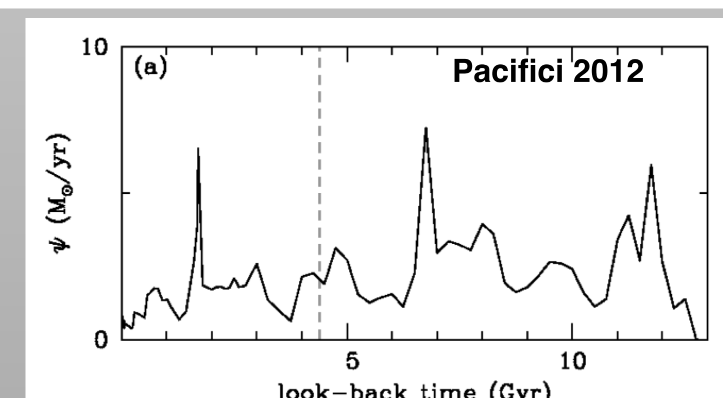
- ➢ **millions of templates**

the emission from a galaxy. Thus, in our approach, a large number of templates corresponding to different sets of parameters can potentially be consistent with the observed fluxes within the errors, which tends to increase the dispersion in the photometric redshifts derived for a galaxy at a given spectroscopic redshift. In return, the

Chevallard & Charlot 2016



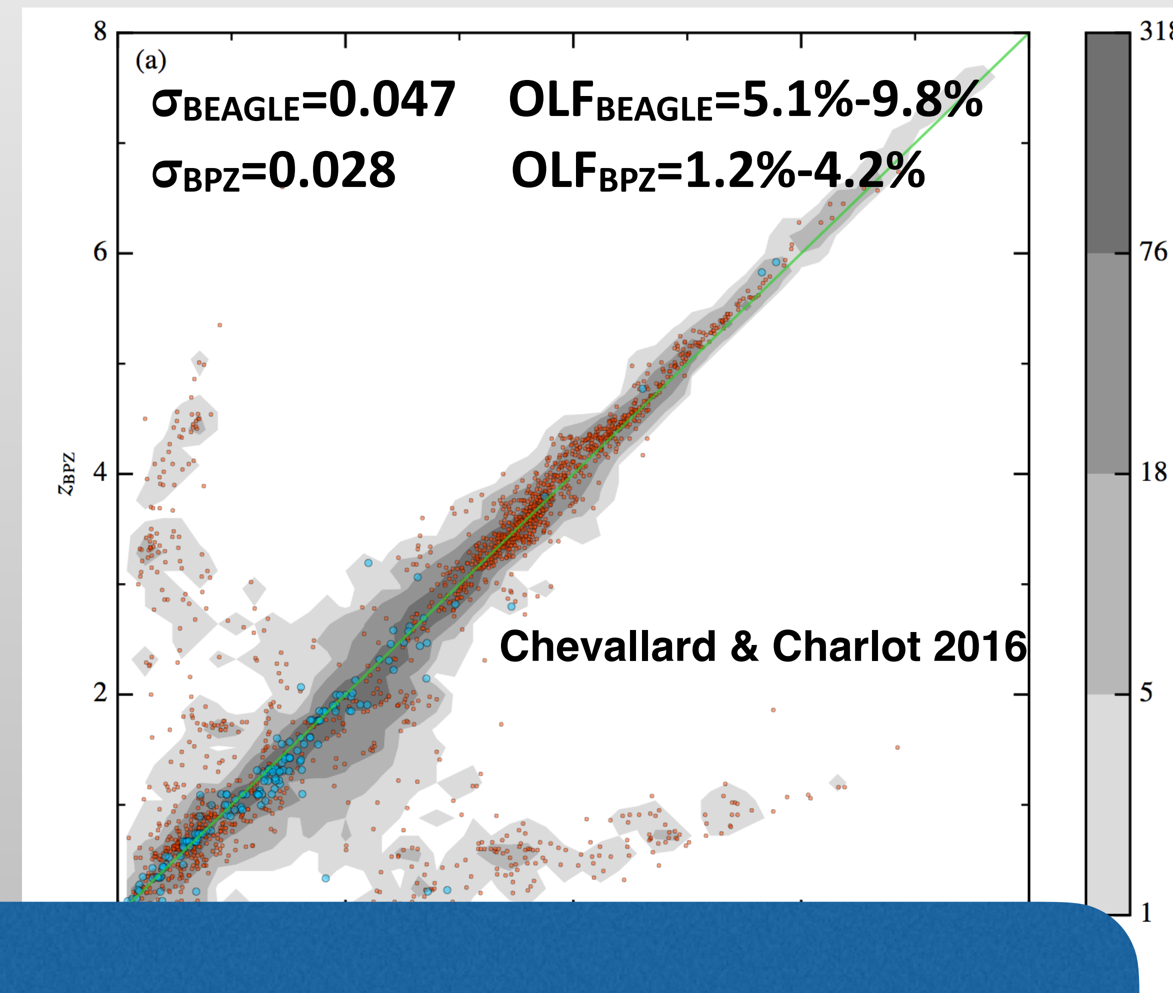
BEAGLE



The set of templates (now start the messy part)

Or large libraries with complex star formation histories
➢ millions of templates

the emission from a galaxy. Thus, in our approach, a large number of templates corresponding to different sets of parameters can potentially be consistent with the observed fluxes within the errors, which tends to increase the dispersion in the photometric redshifts derived for a galaxy at a given spectroscopic redshift. In return, the



As many set of templates as existing codes
➢ No consensus on a common set of templates, or even on the method to establish such set of templates

Suplementary slides

GASPIC

cesam.lam.fr/aspic

gazpar.lam.fr

Archive of spectro-photometric galaxy surveys

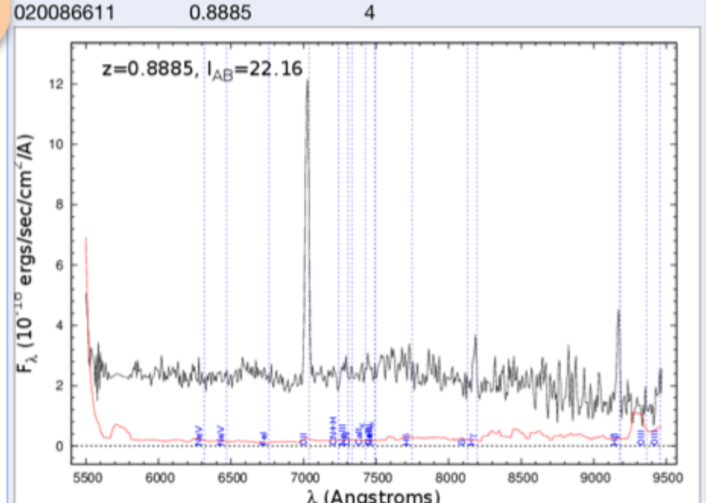
Photo-z and physical parameter estimates

ask to integrate your data!

Spectroscopic Data

Retrieve Spectra

Ident	Redshift	Redshfit quality flag
020086611	0.8885	4



Photometric Data

MAG_I_CFH12K	
MAG_U_CFHTLS	
MAG_G_CFHTLS	
MAG_R_CFHTLS	
MAG_I_CFHTLS	
MAG_Z_CFHTLS	22 ± 0.01

CFH12K [5"x5"]

Select the ASPIC datasets

VUDS
- VUDS-COSMOS (DR1)
- VUDS-ECDFS (DR1)

VVDS
- VVDS2h Ultra Deep
- VVDS2h Deep
- VVDS-CDFS Deep
- VVDS10h Wide
- VVDS14h Wide
- VVDS22h Wide

zCOSMOS
- zCOSMOS 20k BRIGHT (DR3)

GAMA
- GAMA LT (DR2)
- GAMA AAT (DR2)

6dFGS
- 6dF Galaxy Survey (DR3)

+ added-values from GAzPAR

Upload your data

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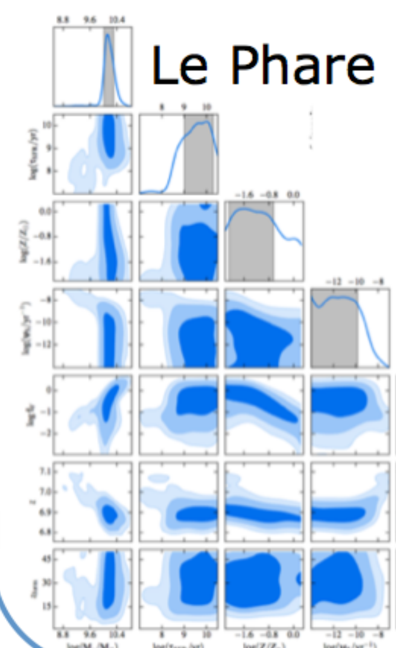
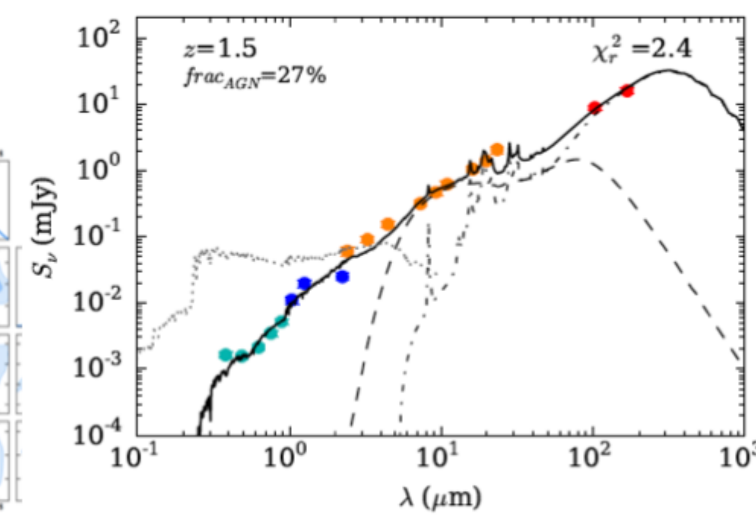
we do it for you!

Le Phare

CIGALE

BEAGLE





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