Review on photometric redshifts

- ➢ template-fitting methods / O. Ilbert
- ➢ deep learning / S. Arnouts

LAM
LABORATOIRE D'ASTROPHYSIQUE
DE MARSEILLE

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 photometric catalogue

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**
- **…**

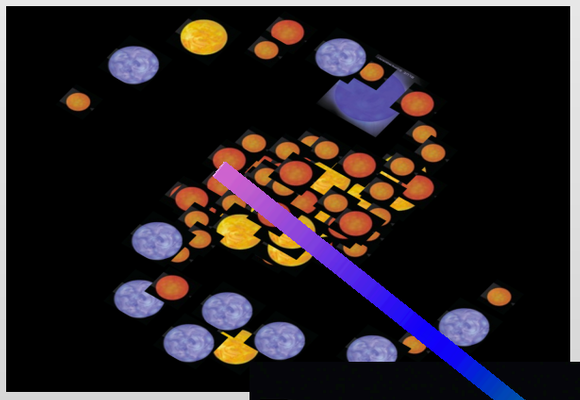
➢ **Real impact on the quality of the photo-z**

Physical model of SED

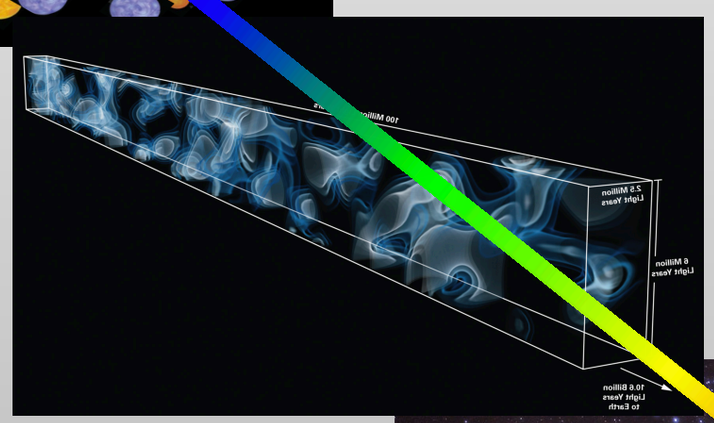
Model
Models of source SED with the redshift as one dimension

→ **What we discuss here**

Physical model of SED



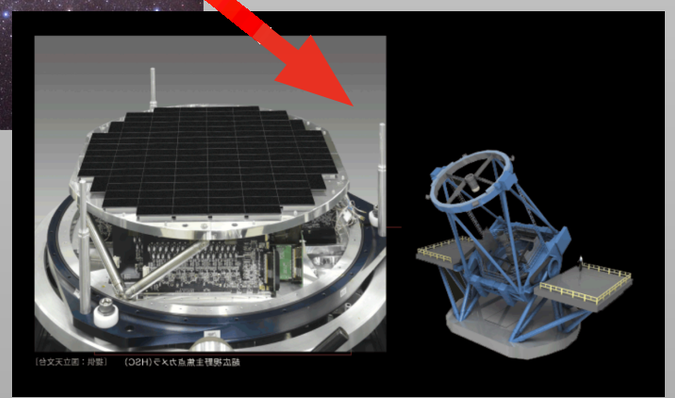
Model the galaxy emission



Neutral gas in the IGM

Dust in the Milky Way

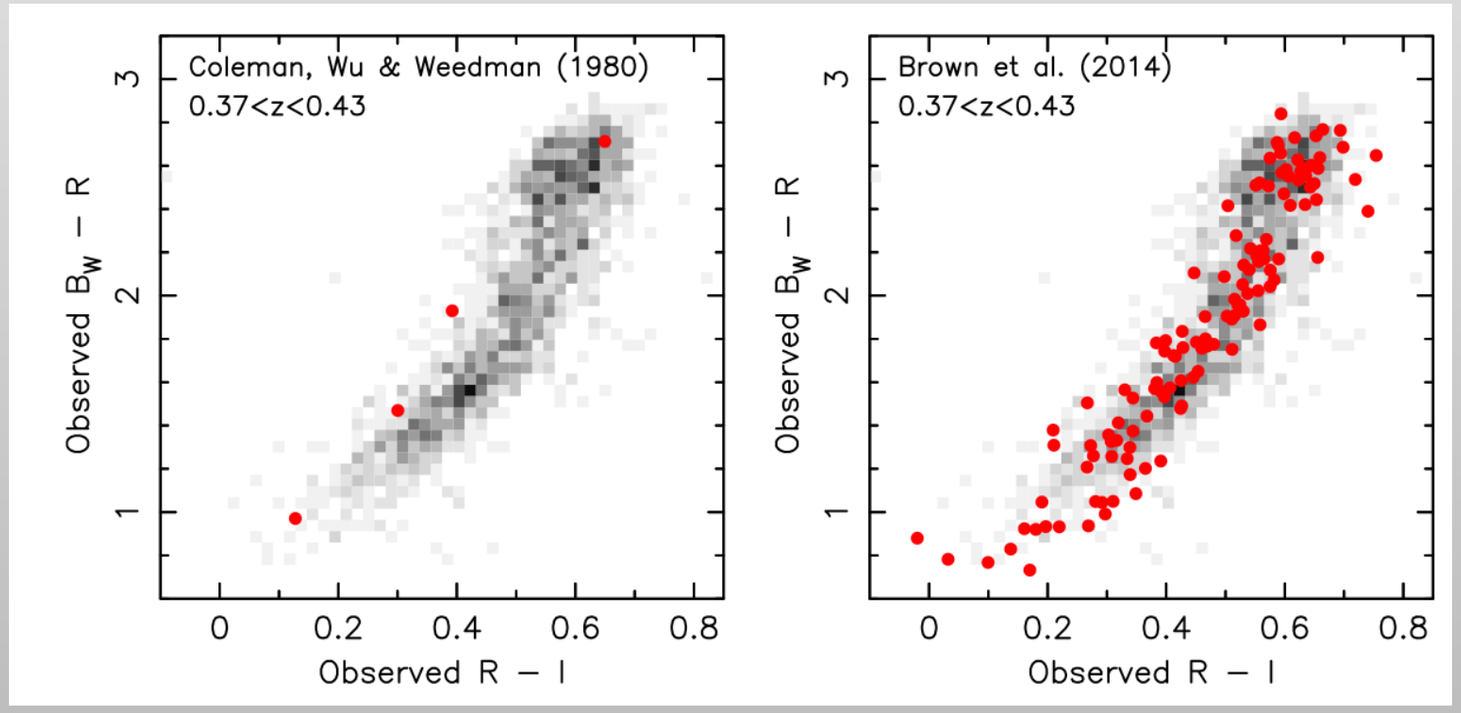
Reproduce everything from the photon emission to the researcher

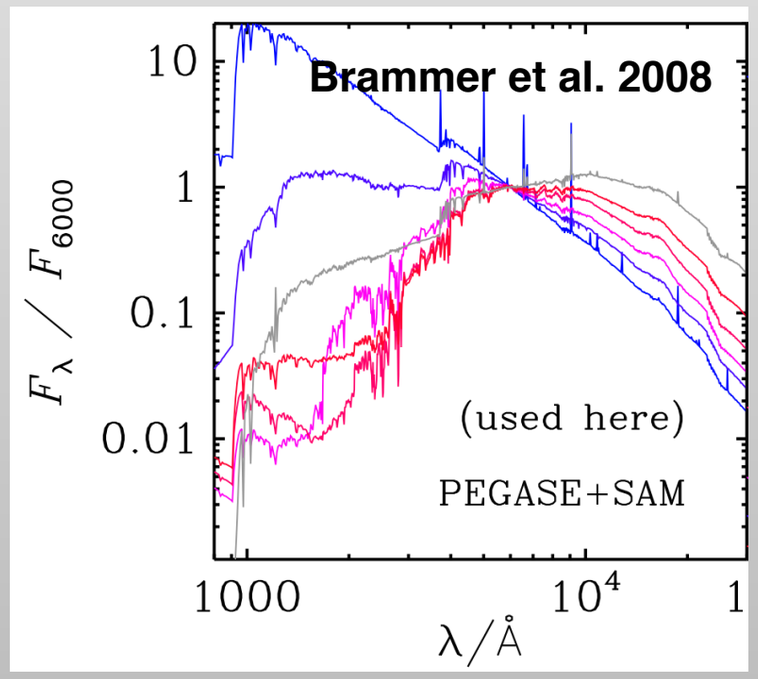


The instrument (CCD, filters)

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





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

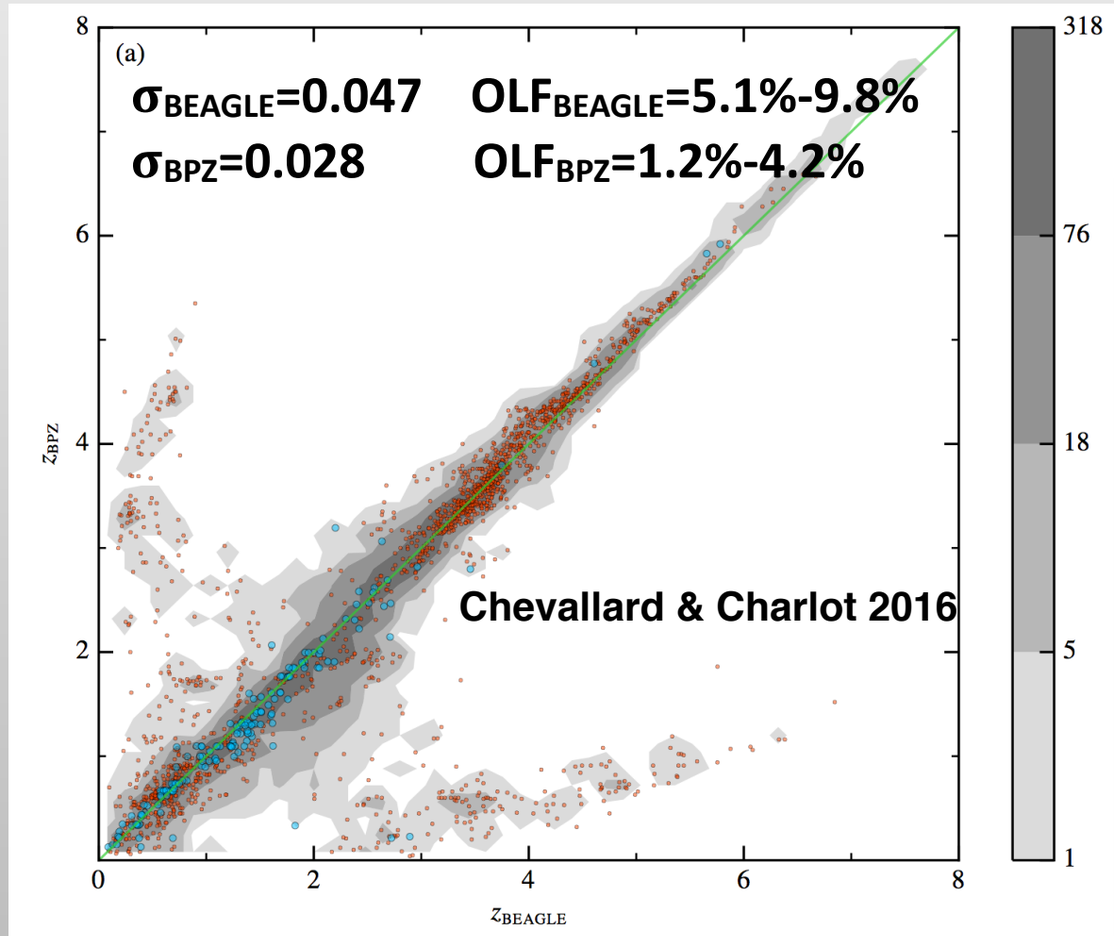
The set of templates (now start the messy part)

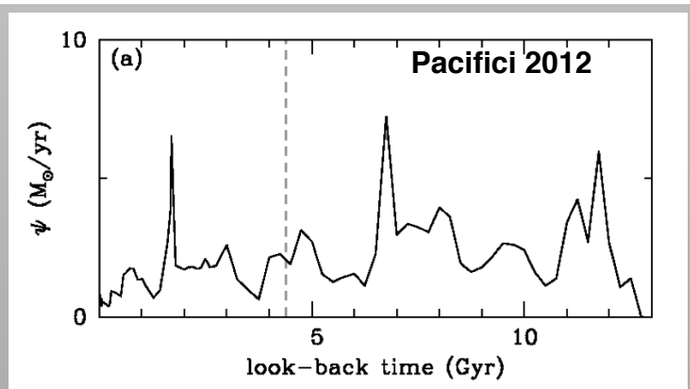
Or large libraries with complex star formation histories

➢ **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



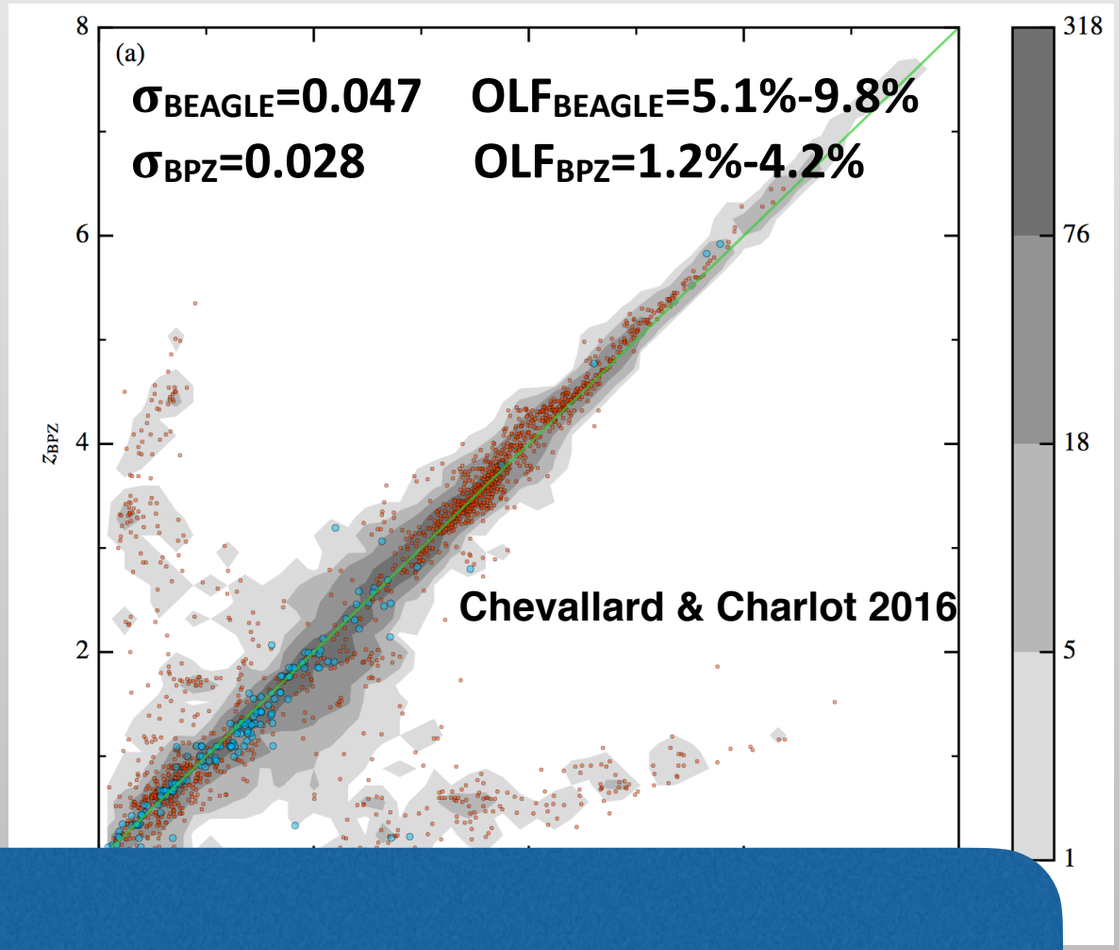


The set of templates (now start the messy part)

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



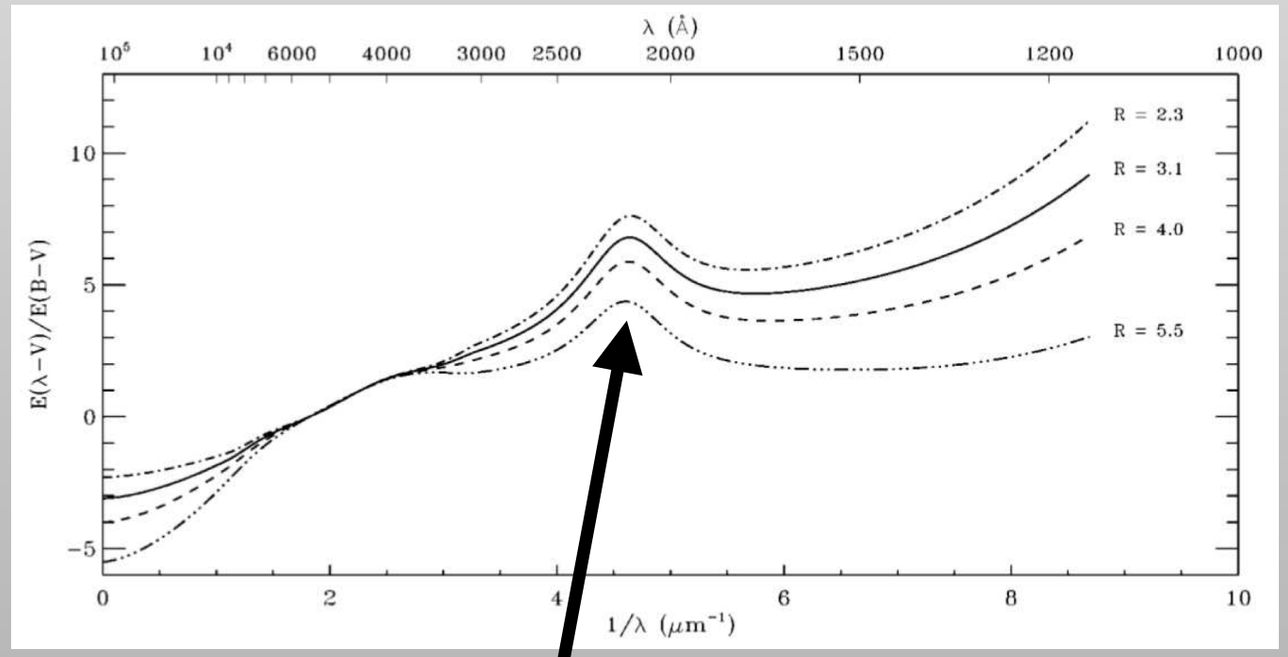
As many set of templates as existing codes

➢ **No consensus on a common set of templates, or even on the method to establish such set of templates**

Introducing the dust (admit even more ignorance…)

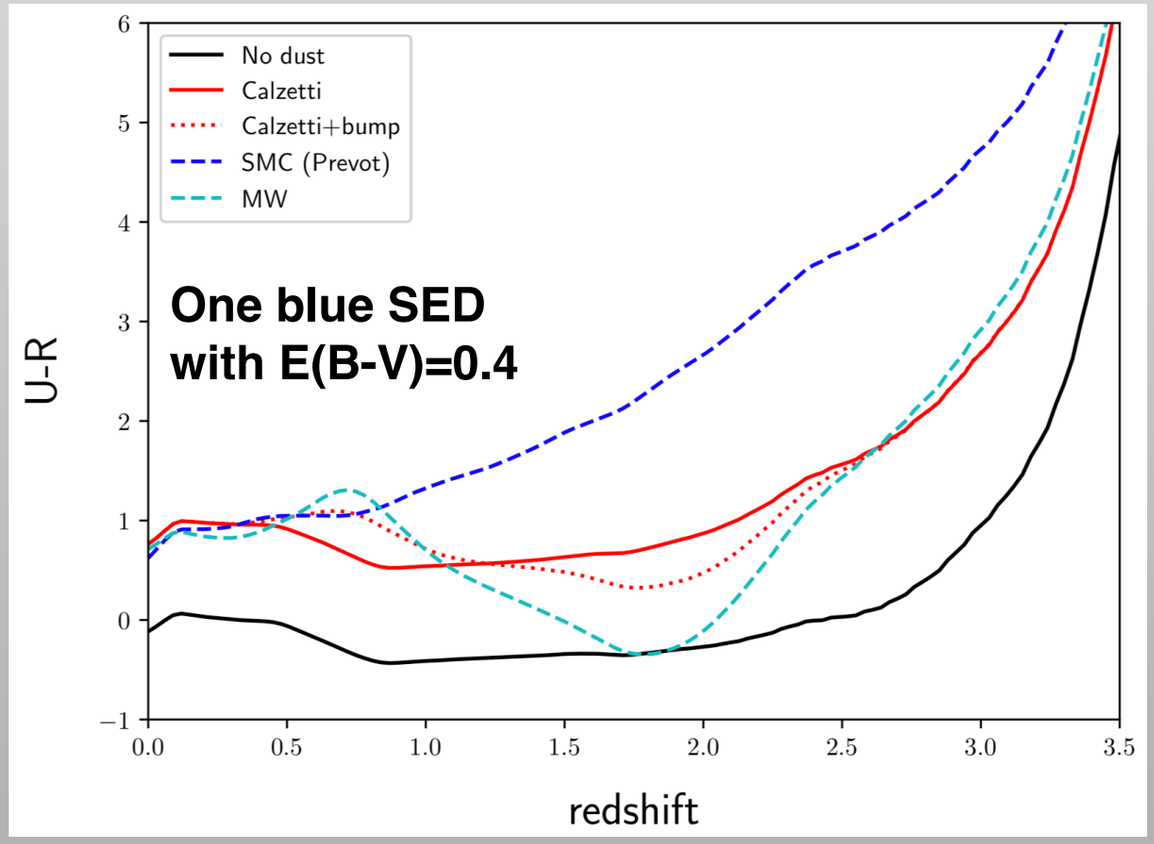
Dust attenuation depends on galaxy star formation history, geometry of the galaxy, metallicity …

➢ We don't know the dust attenuation law in the studied galaxy



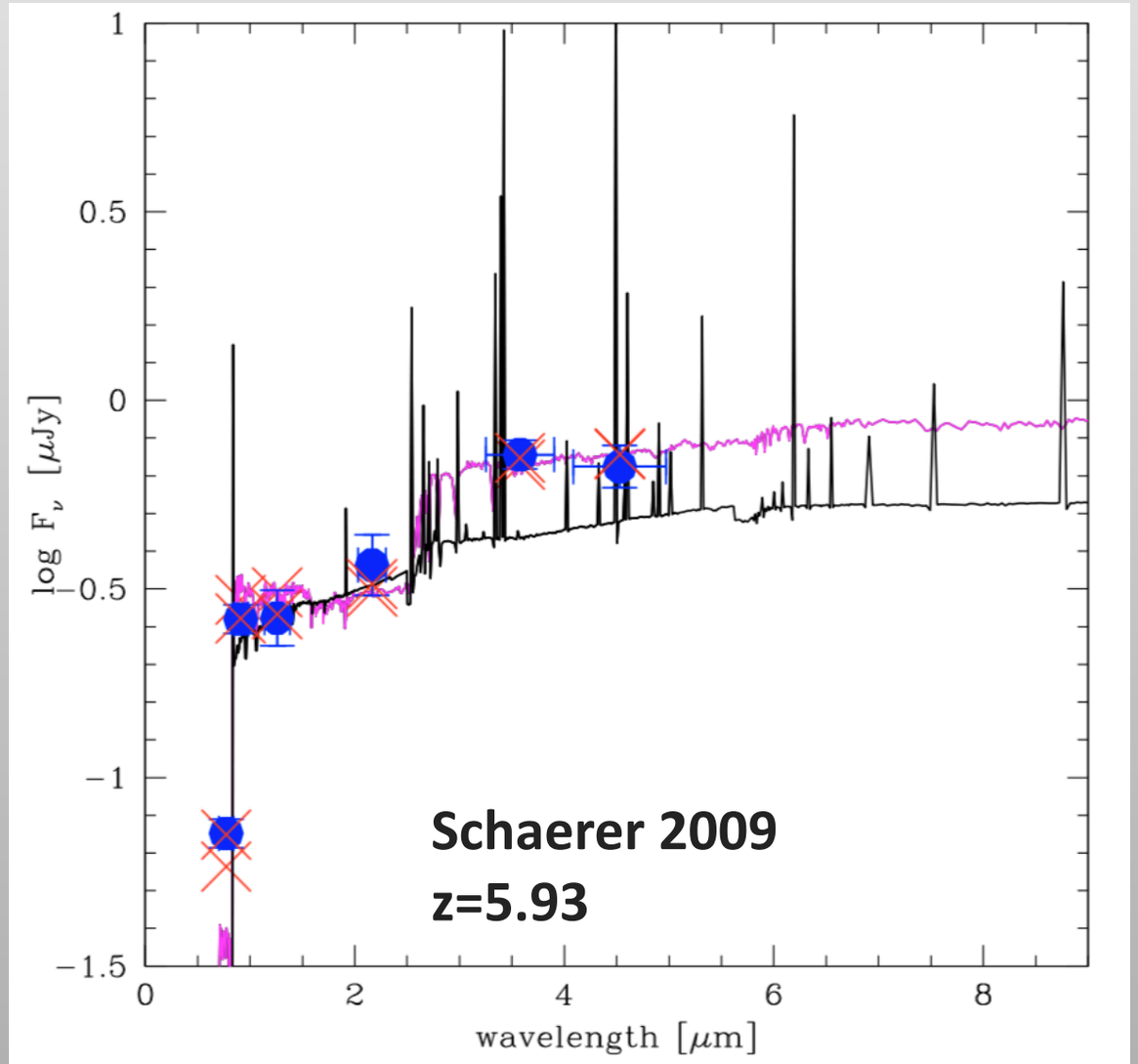
bump at 2175Å

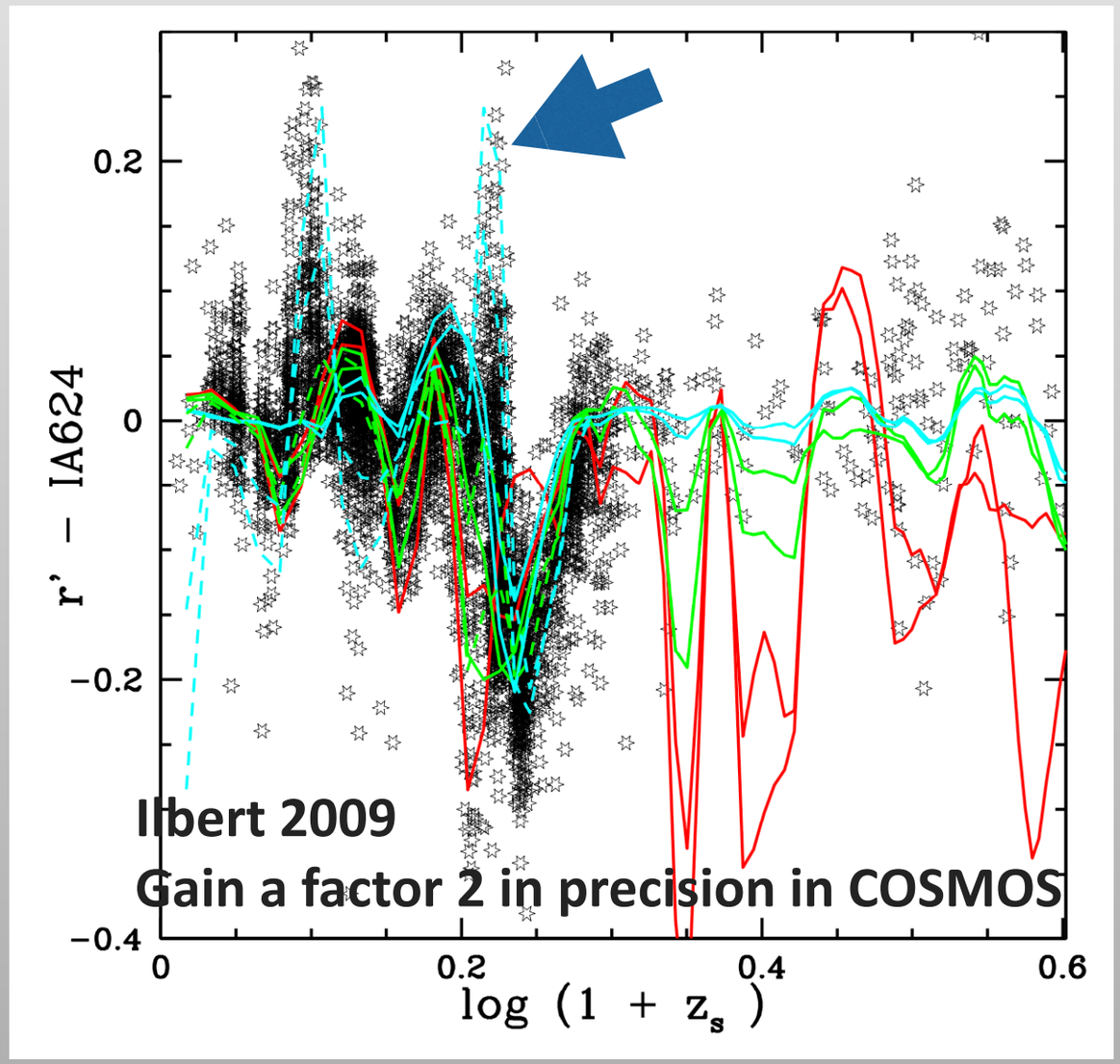
Not always present



On a top of that, emission lines should be considered seriously

Not trivial given the diversity of line ratios





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

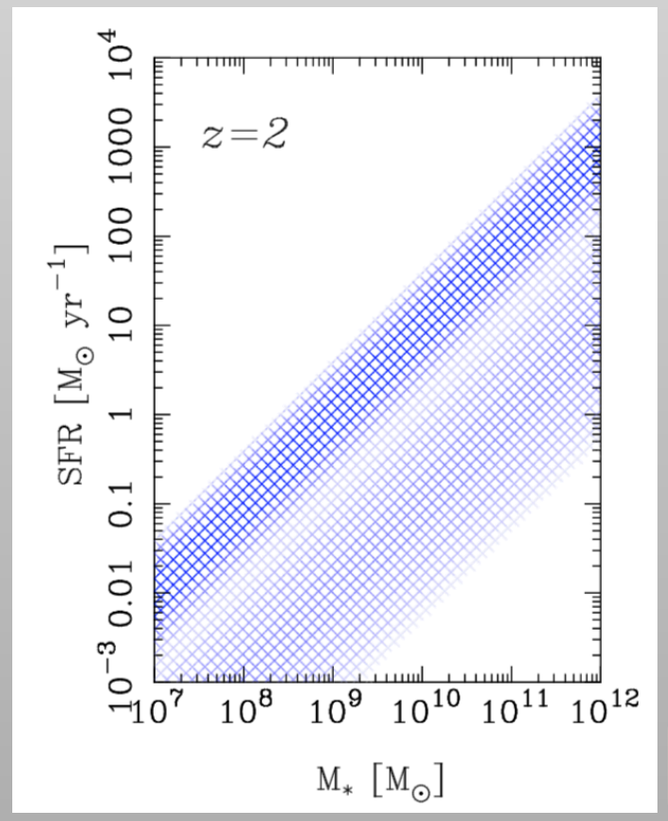
and associated redshift point-estimates

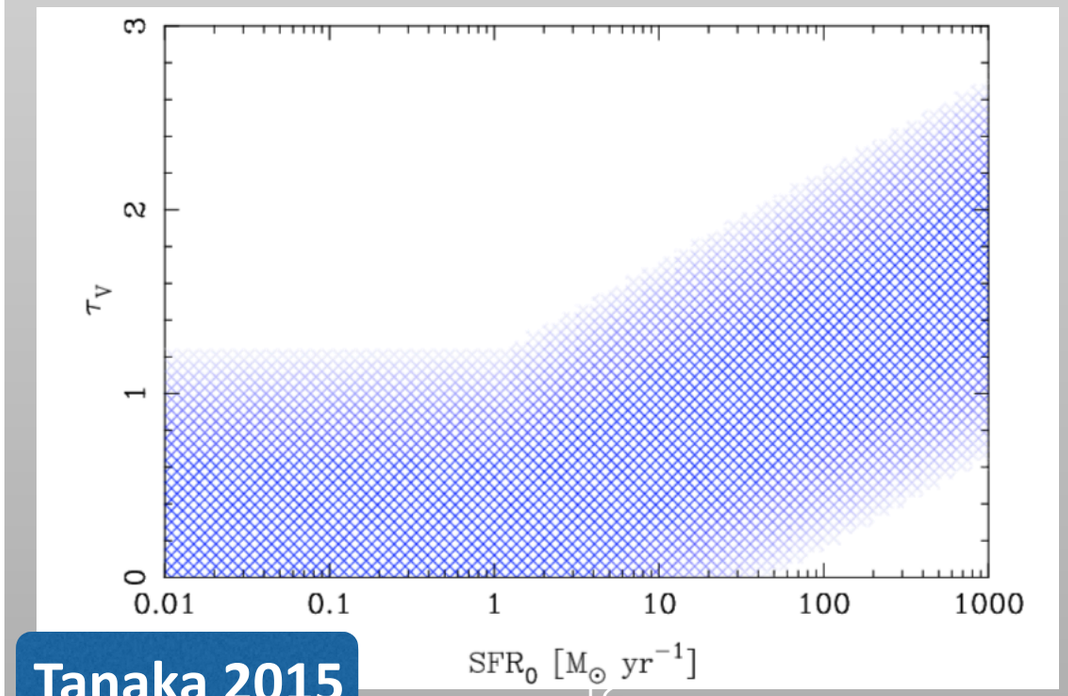
Different approaches also present in this step

Compensate our lack of data by adding some prior

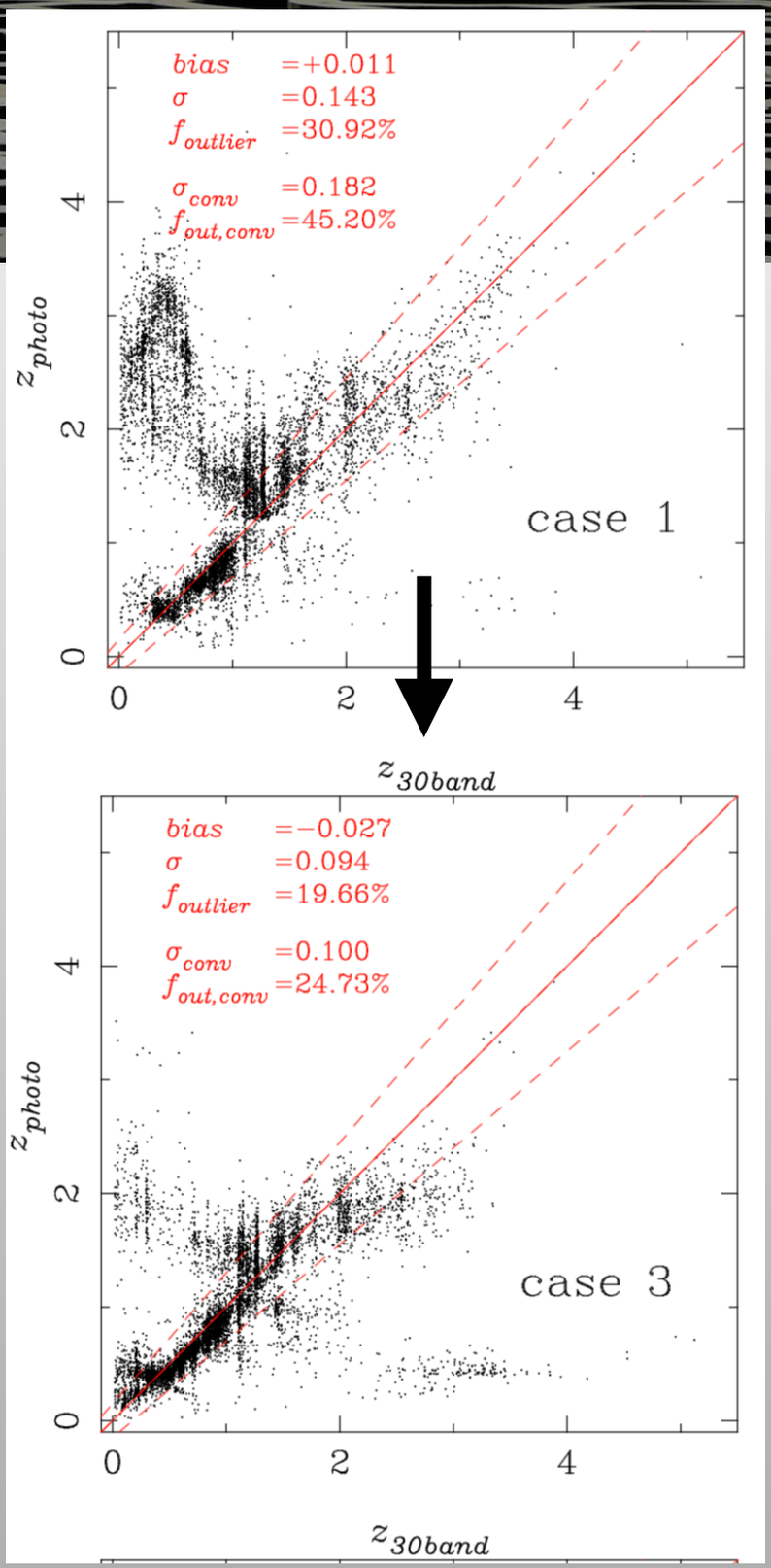
Could introduce external information as the N(z), the luminosity function, the mass-SFR relation, etc (Benitez 2000)

$$P(z, \vec{G}, \alpha) = P(z)P(SFR|M_*, z)P(\tau_V|SFR, z) \\ P(age|M_*, z).$$





Tanaka 2015



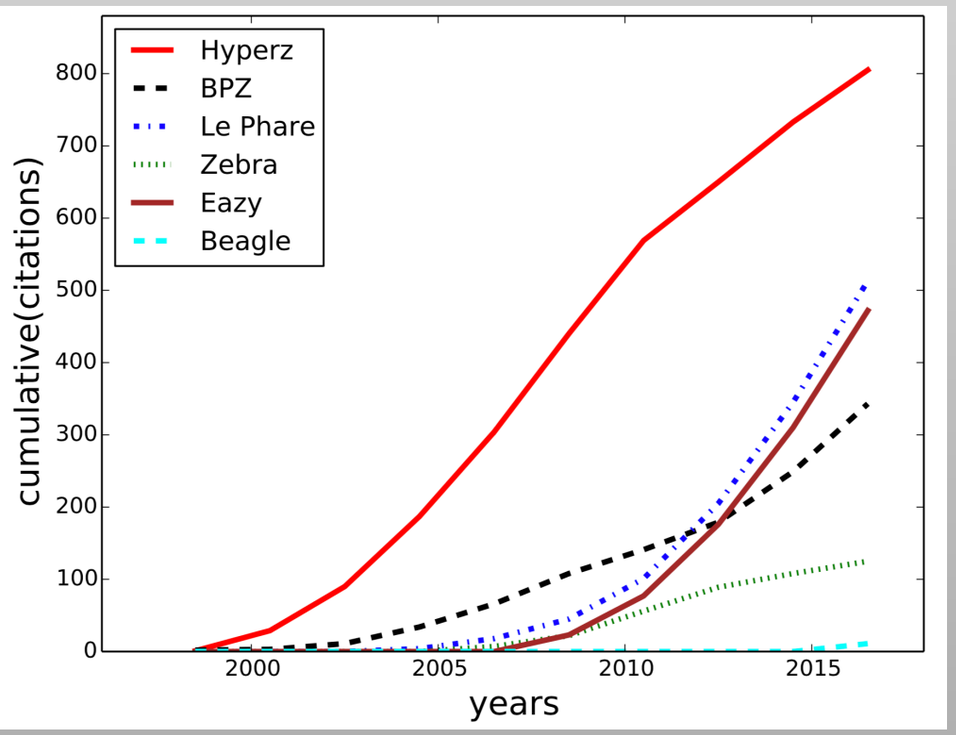
That's why so many codes exist

2000 2002 2004 2006 2008 2010 2012 2014 2016

HyperZ **Bolzonella, Miralles, Pello 2000**

BPZ **Benitez 2000**

Le Phare **Arnouts+2002, Ilbert+06**



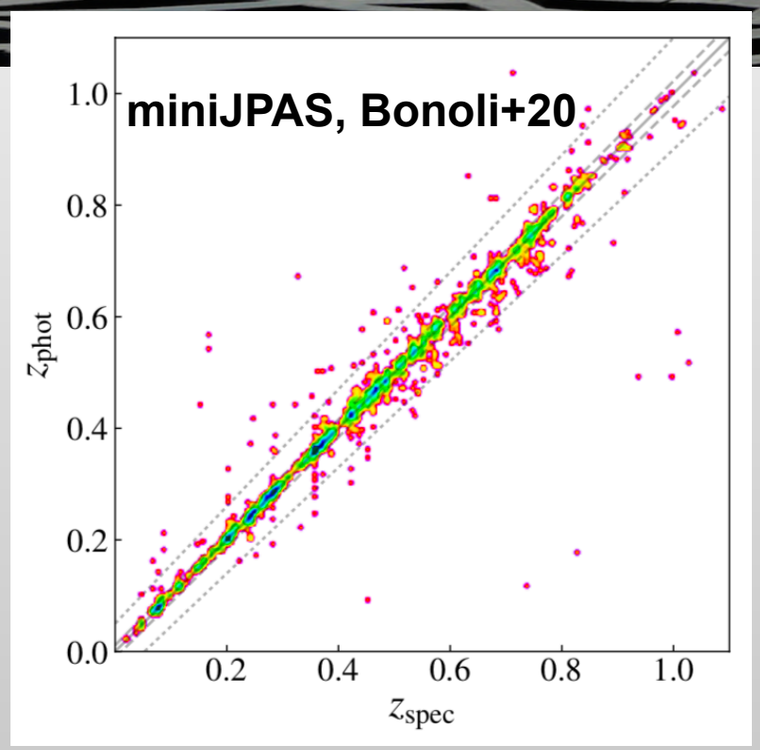
Zurich Extragalactic Bayesian Redshift Analyzer ZEBRA **Feldmann+2008**

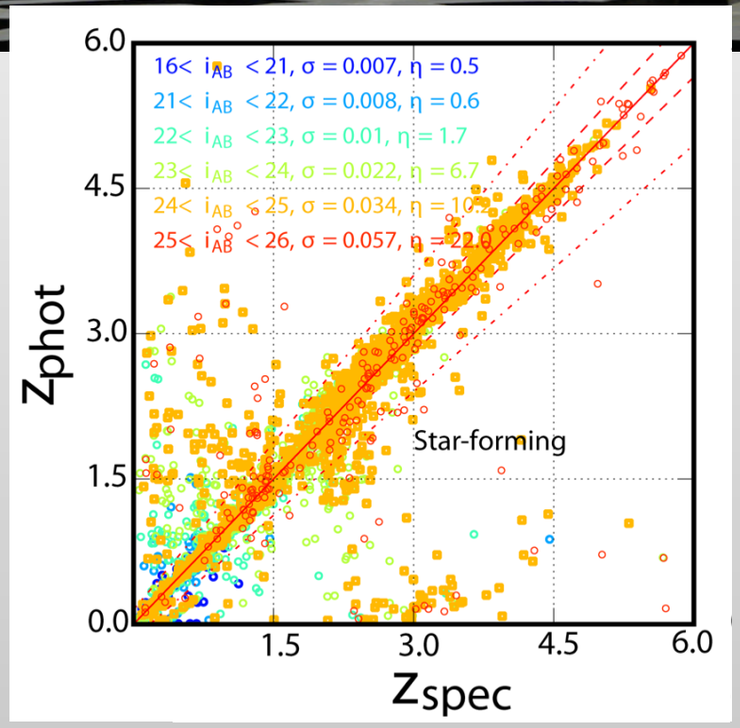
Easy and Accurate z_{phot} from Yale **Brammer+ 2008**

BEAGLE **Chevallard & Charlot 2016**

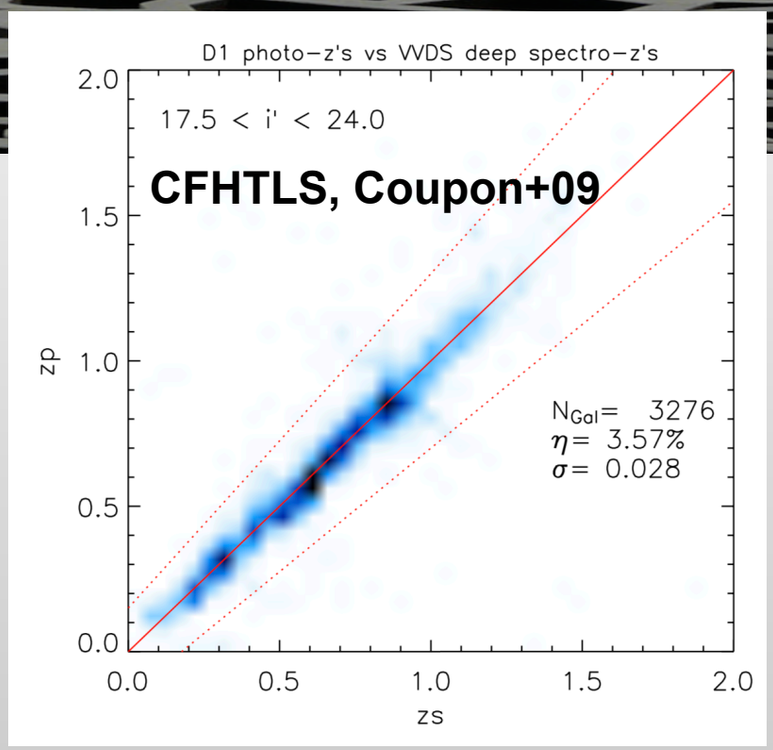
New codes developed within larges projects e.g. PHOSPHOROS for Euclid

Template-fitting used intensively since >20 years



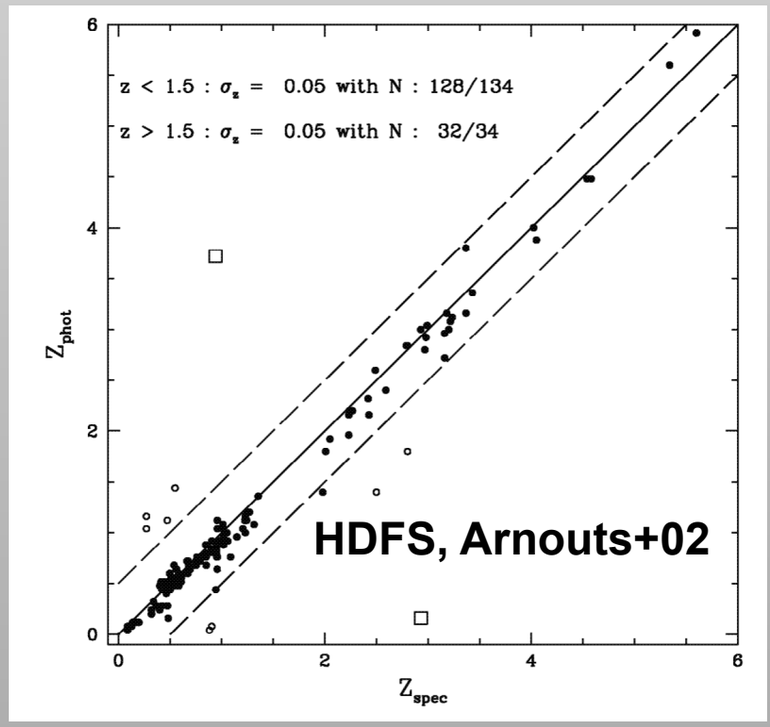


COSMOS, Laigle+2016

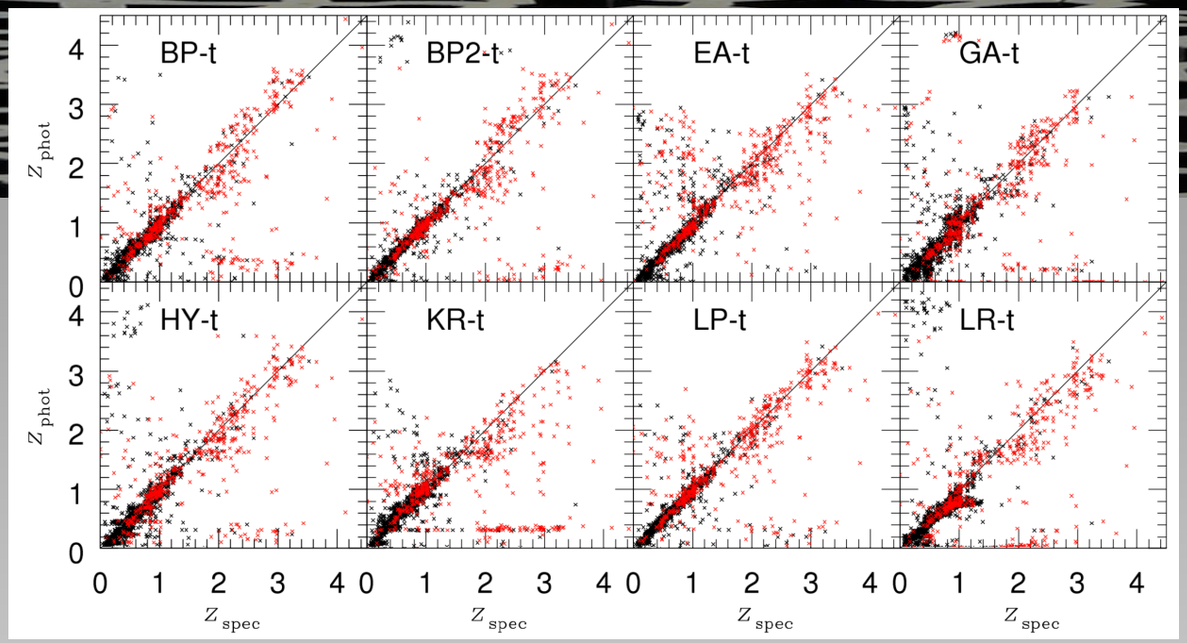


Validation through photo-z / spec-z comparison
But:

- **biased spec-z samples**
- **PDF are rarely checked in detail**



Numerous challenges to test the codes with real data

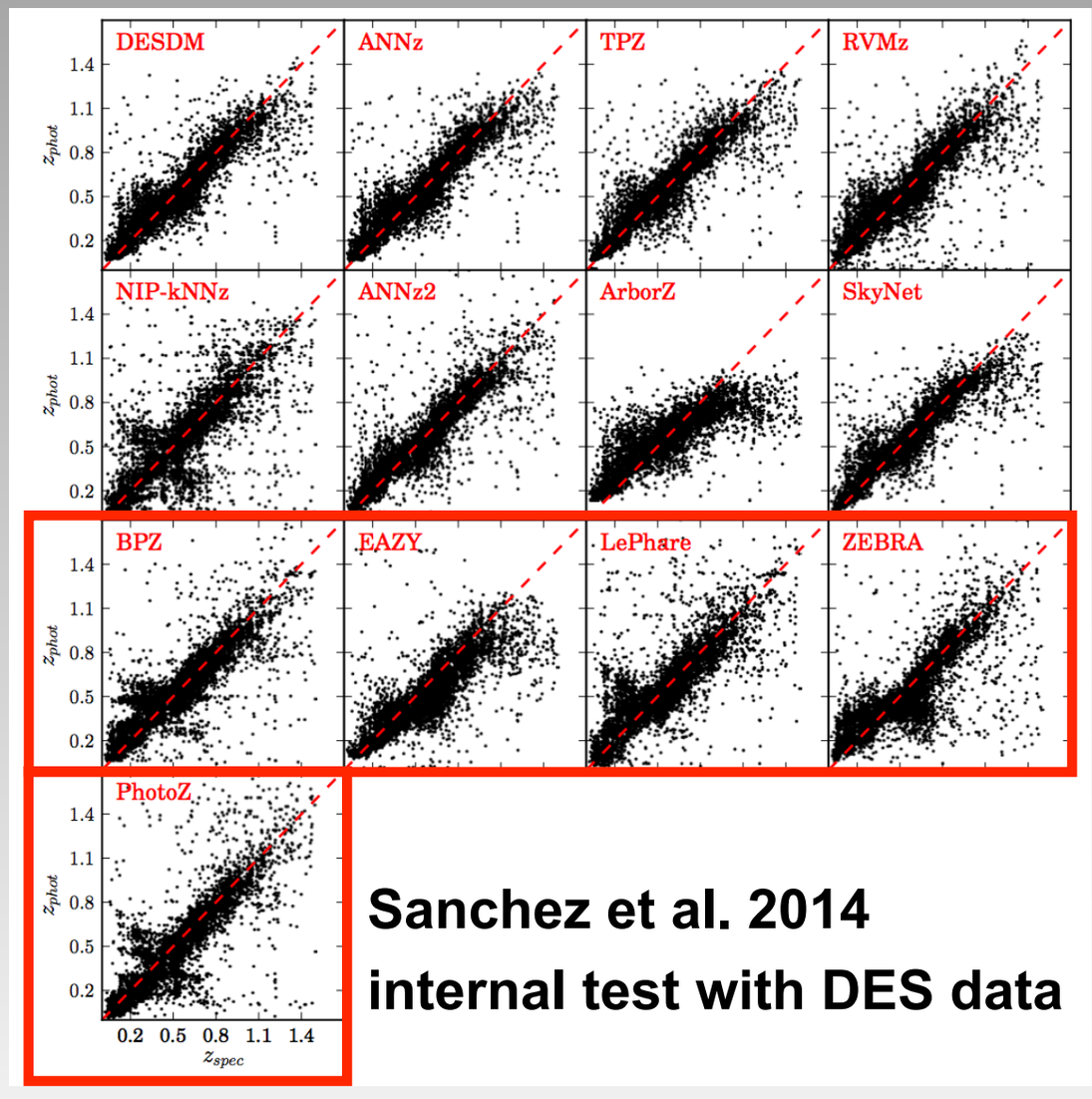


Hildebrandt+2010, PHAT, blind test with GOODS data

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

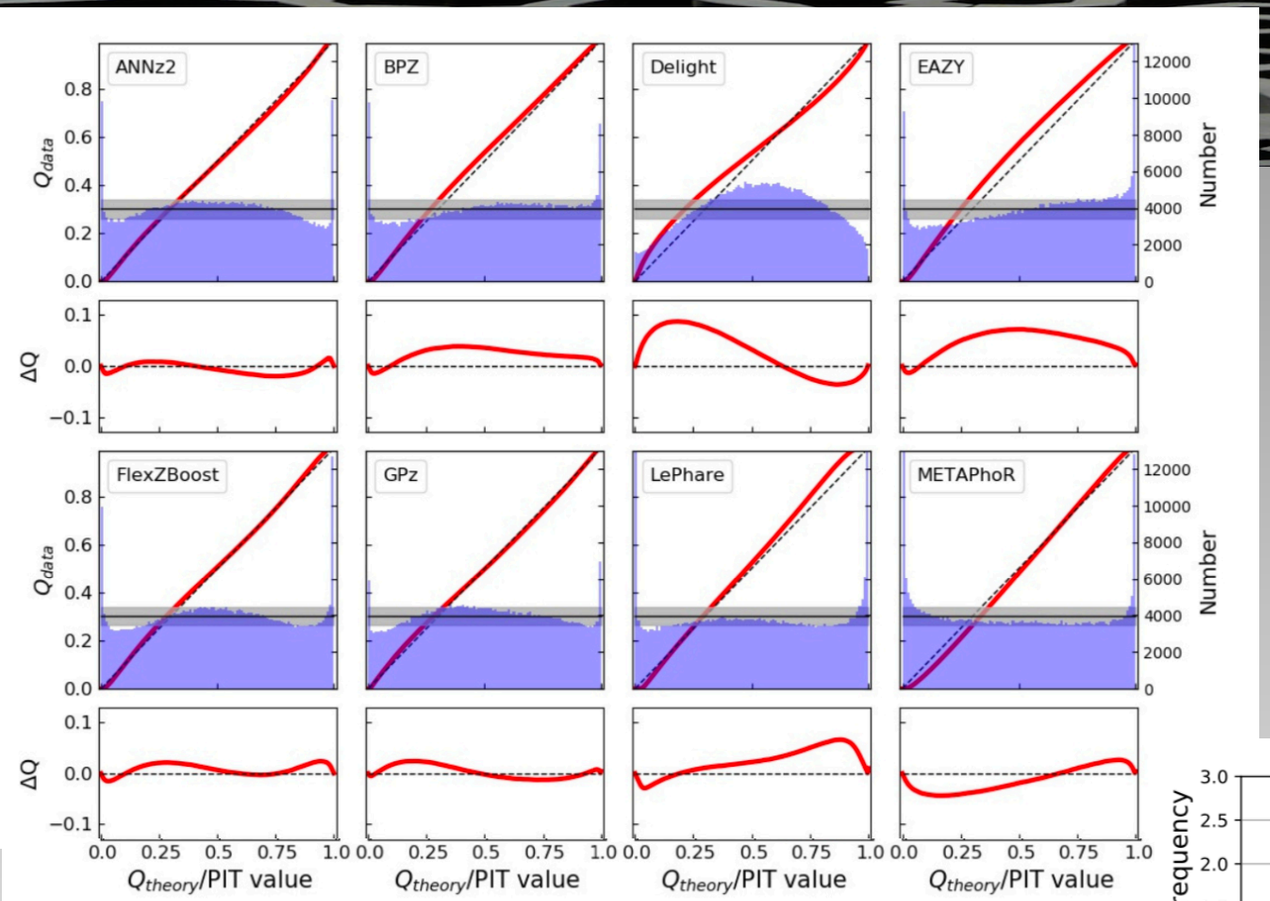
ID[a]	PI	Code	Code ID	Template set	Em lines	Flux shift	Δerr	ΔSED	Inter	ref.
2	G. Barro	Rainbow	A	PEGASE[b]	yes	yes	no	no	no	*j*
3	T. Dahlen	GOODZ	B	CWW[c], Kinney[d]	yes	yes	yes	yes	yes	*k*
4	S. Finkelstein	EAZY	C	EAZY[e]+BX418[f]	yes	no	no	no	yes	*l*
5	K. Finlator	SPOC	D	BC03[g]	yes	no	no	no	no	*m*
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

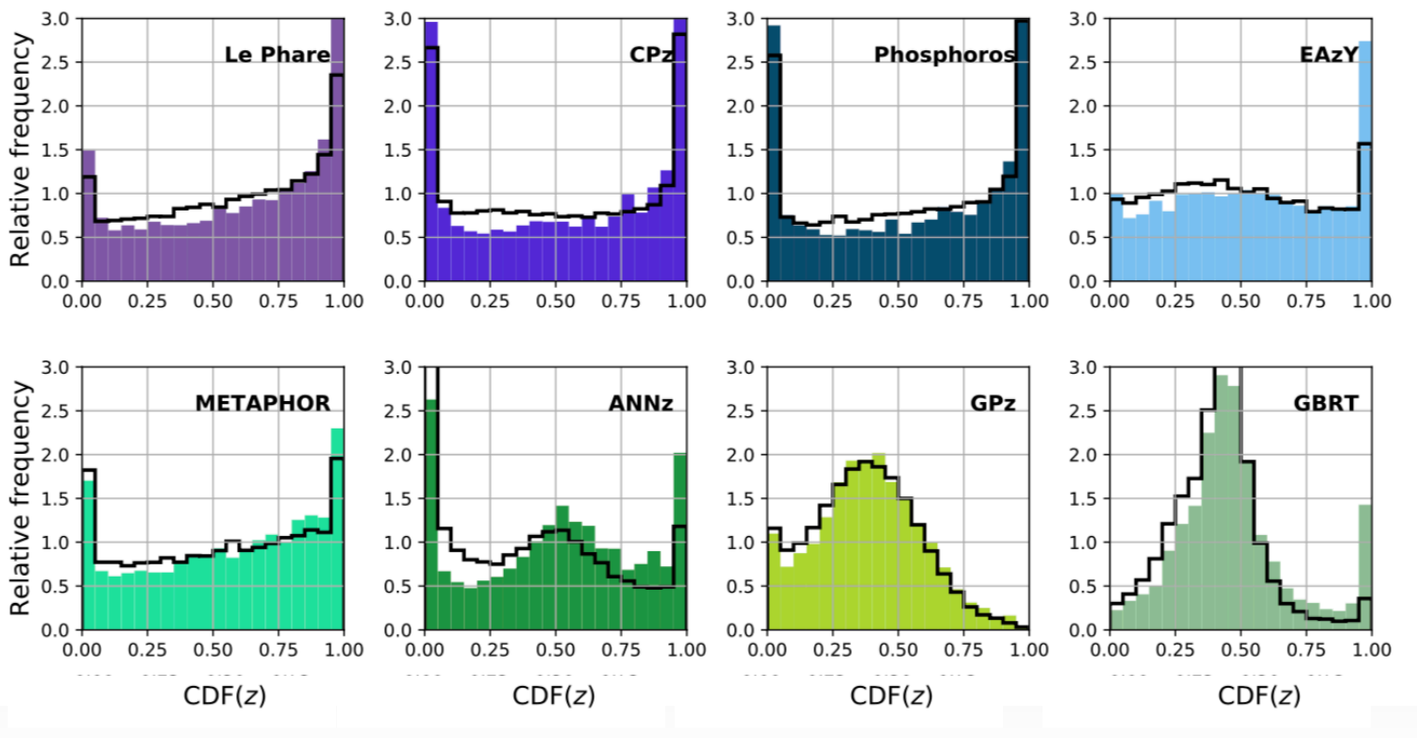


Schmidt, Malz et al. 2020

for LSST

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

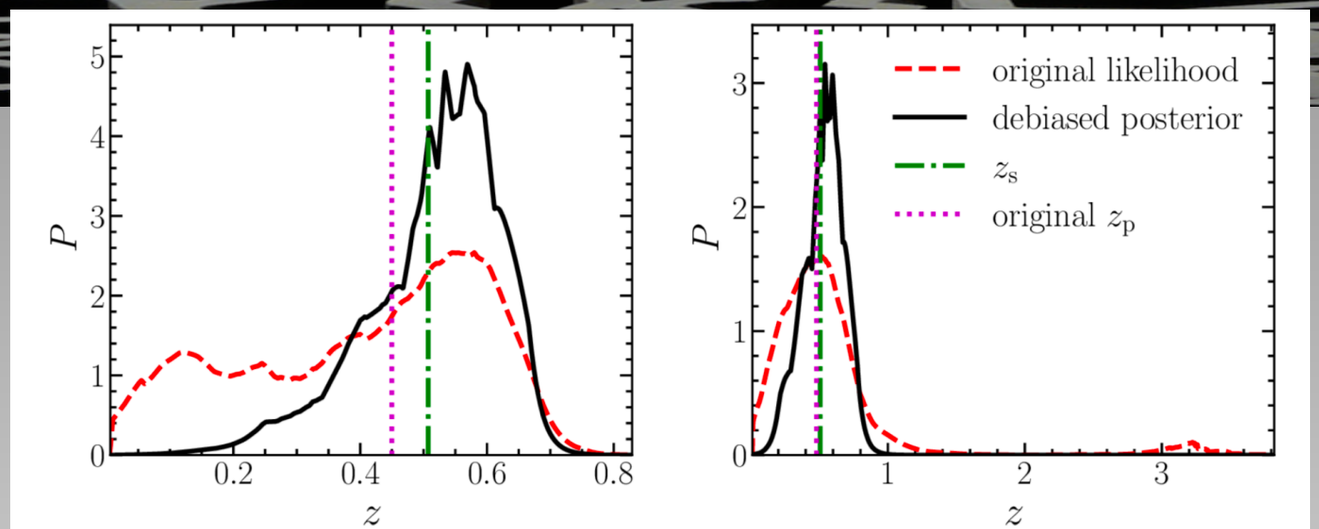
Euclid, Deprez et al. 2020



Recent papers start to investigate the quality of the PDF

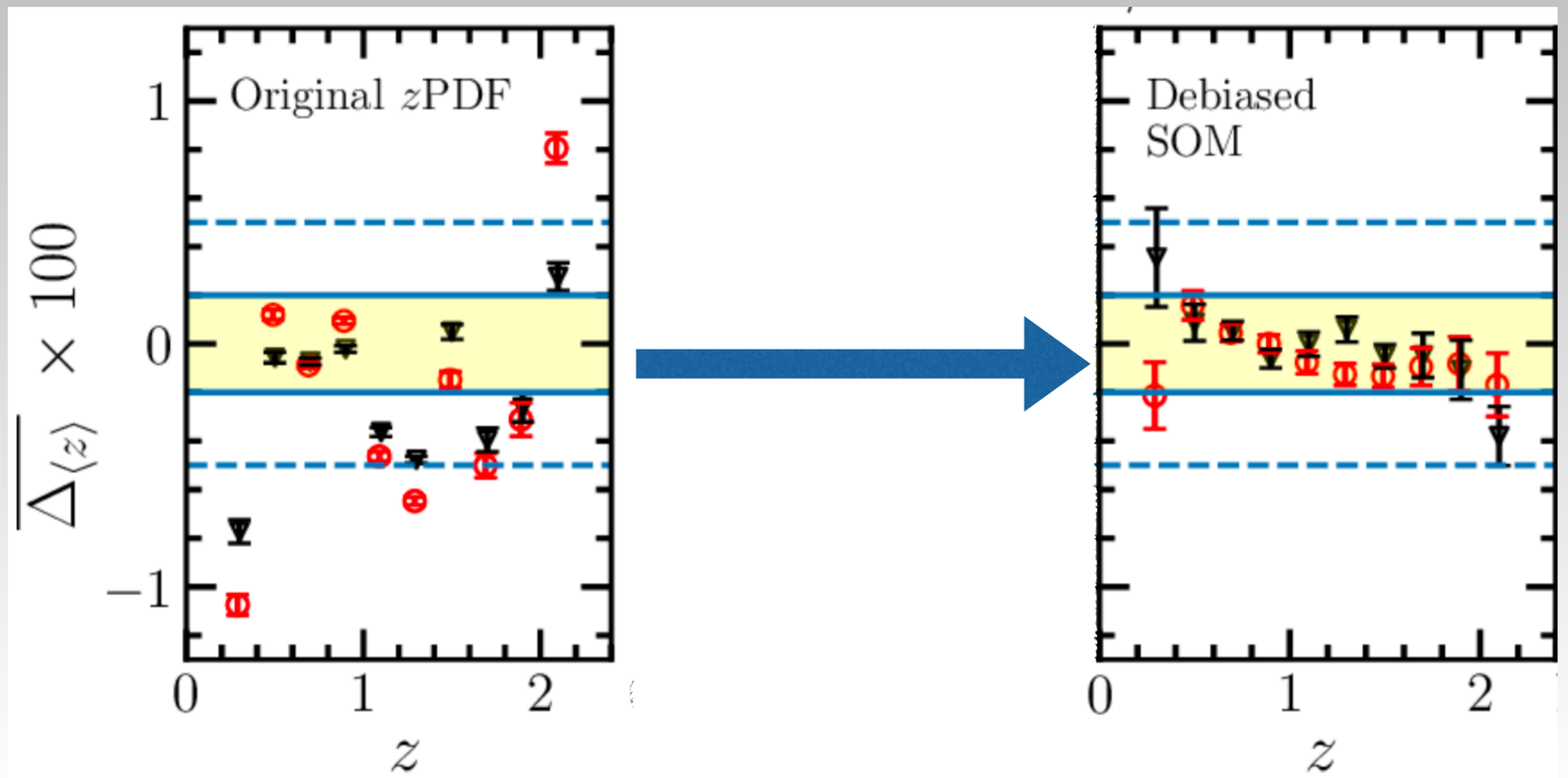
Mean redshift from the PDF
Test with a cosmological simulation

Euclid, Ilbert et al. 2021



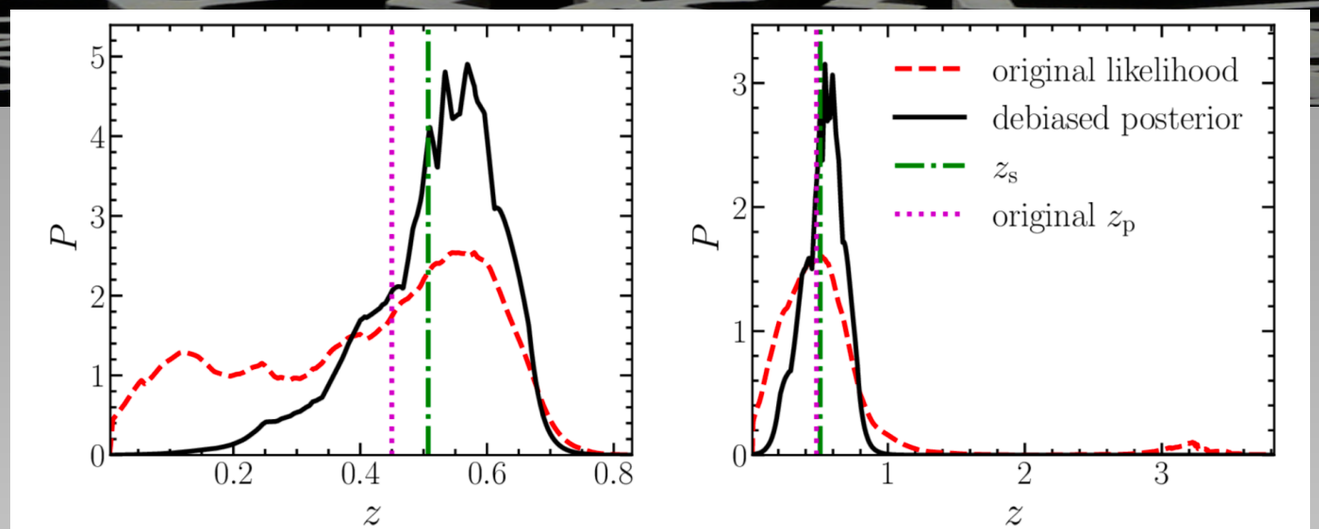
Use the PIT distribution to correct the PDF

bias on the mean redshift

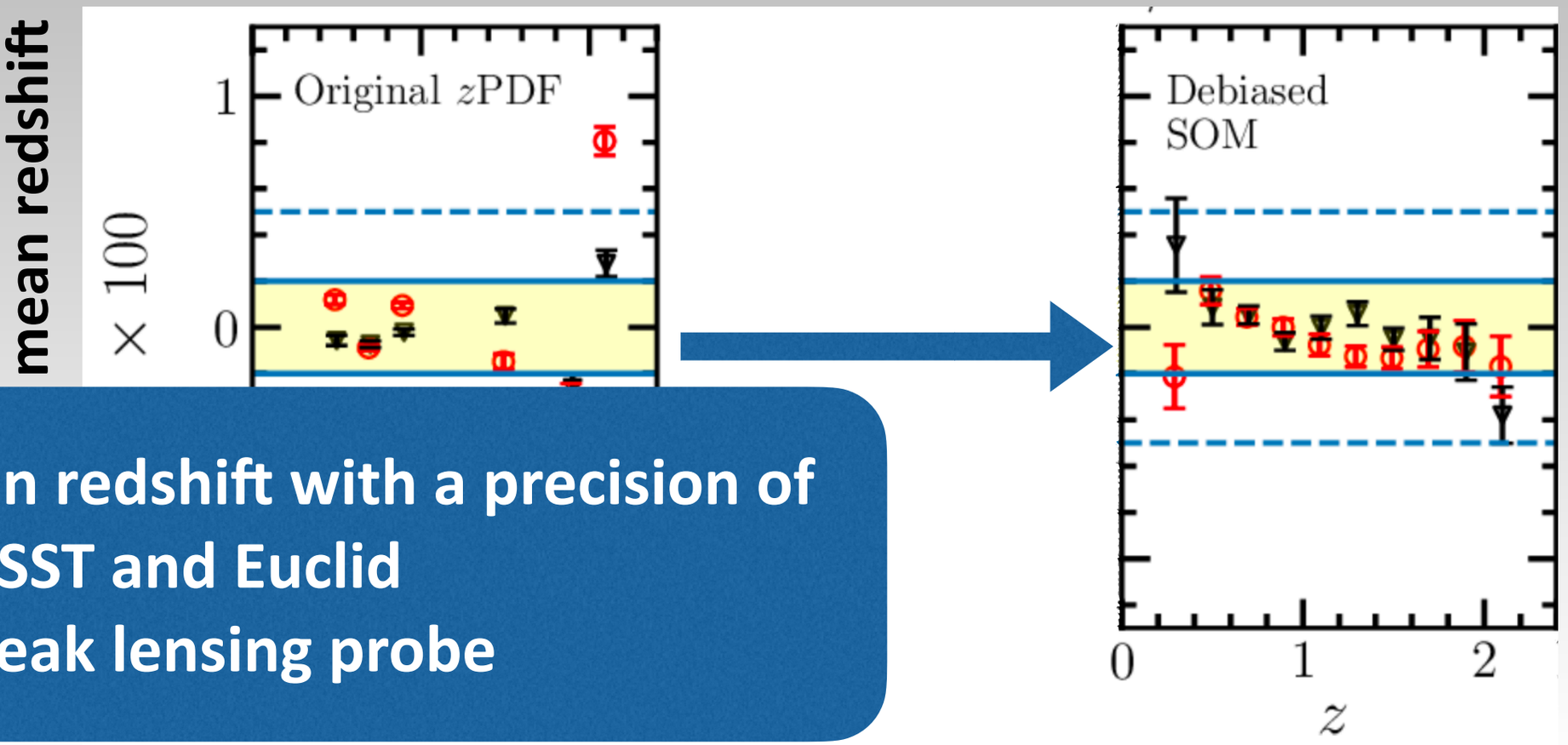


Mean redshift from the PDF
Test with a cosmological simulation

Euclid, Ilbert et al. 2021



Use the PIT distribution to correct the PDF



Measure the mean redshift with a precision of 0.2% combining LSST and Euclid

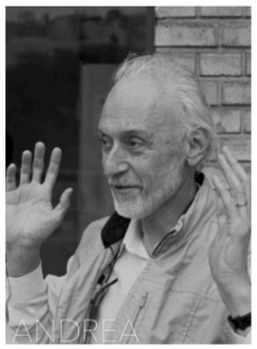
➢ **essential for weak lensing probe**

COSMOS2020 catalogue

Weaver, Kauffmann et al. 2021, submitted


MARKO SHUNTOV


HENRY McCRACKEN


ANDREA MONETI


CLOTILDE LAIGLE

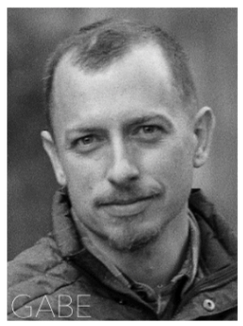
CANDIDE HPC CLUSTER

DAWN


JOHN WEAVER


IARY DAVIDZON


BO MILVANG-JENSEN


GABE BRAMMER


SUNE TOFT

LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE


OLIVIER KAUFFMANN


OLIVIER ILBERT


PETER CAPAK

COSMOS

... & MANY MORE!

COSMOS

cosmic evolution survey

{10:00:28.6 +02:12:21.0}

2020 CATALOG

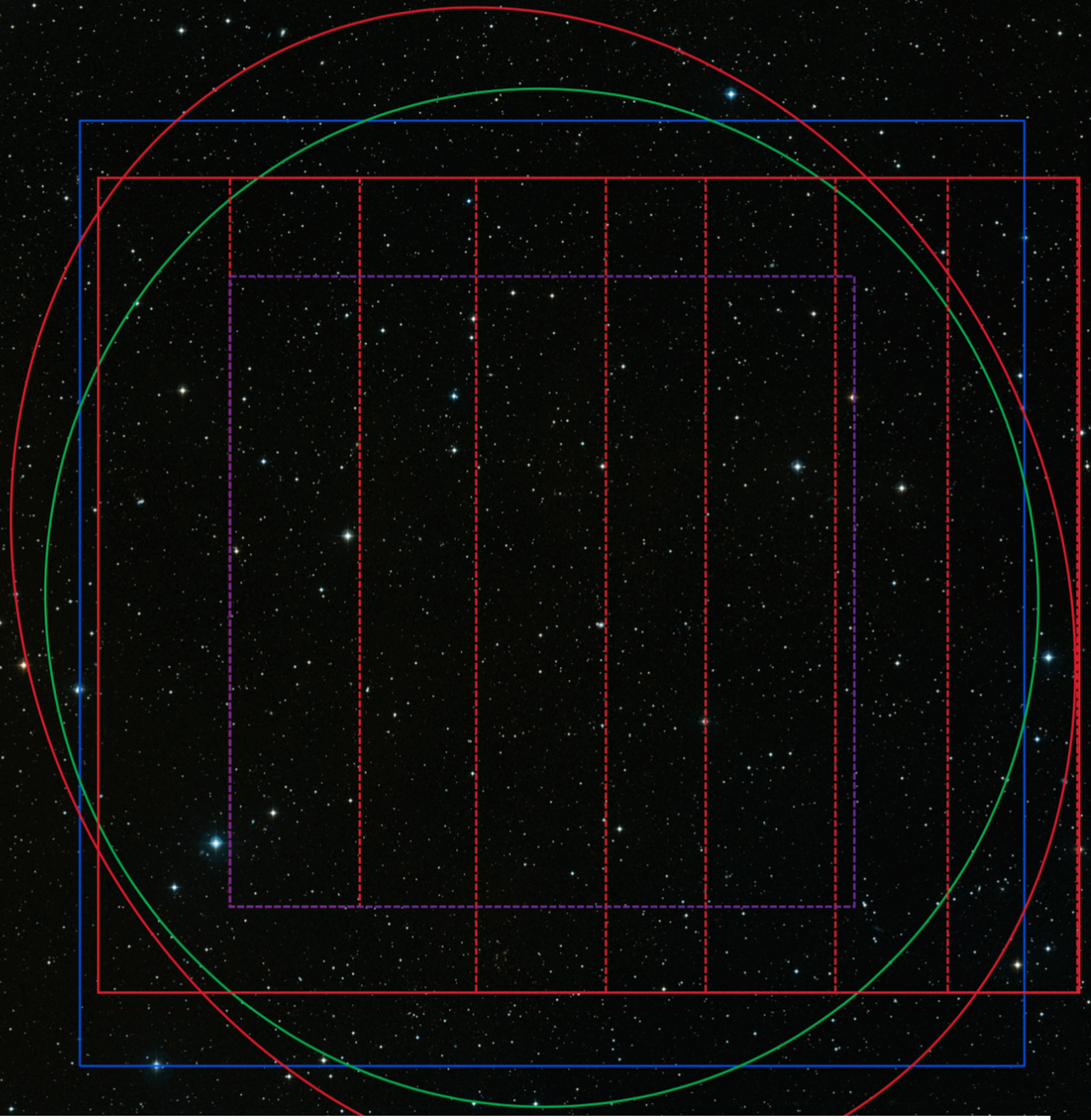
CFHT/**CLAUDS**

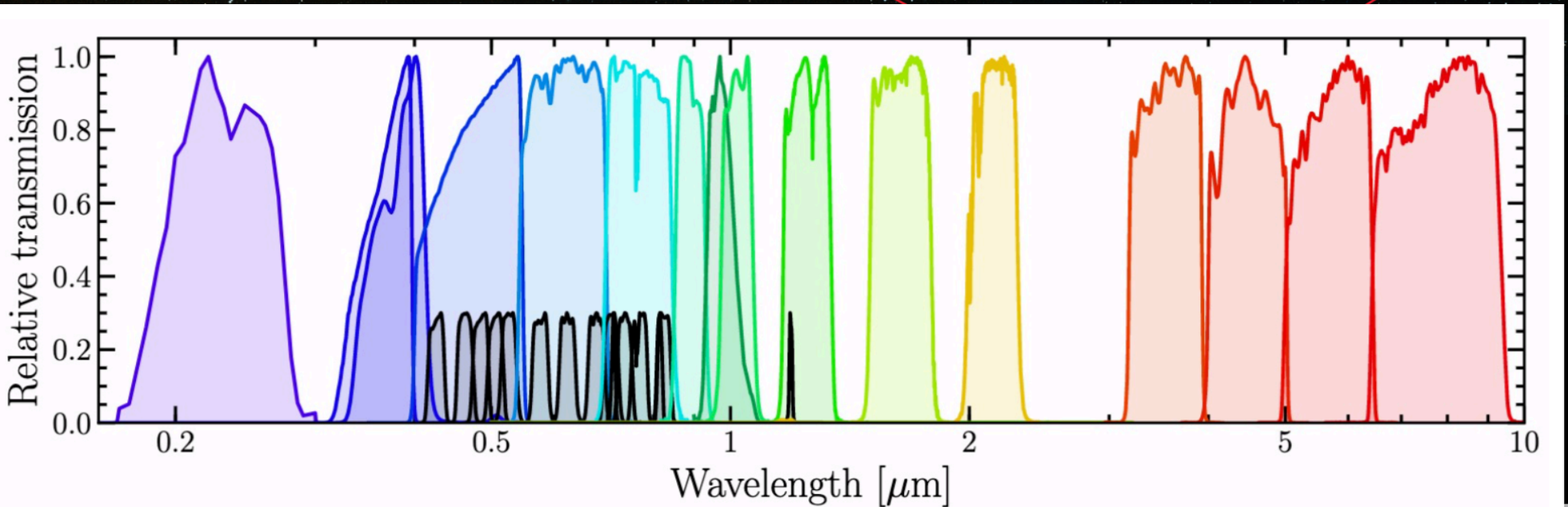
Subaru/**HSC PDR2**

Subaru/**SuprimeCam**

UltraVISTA DR4

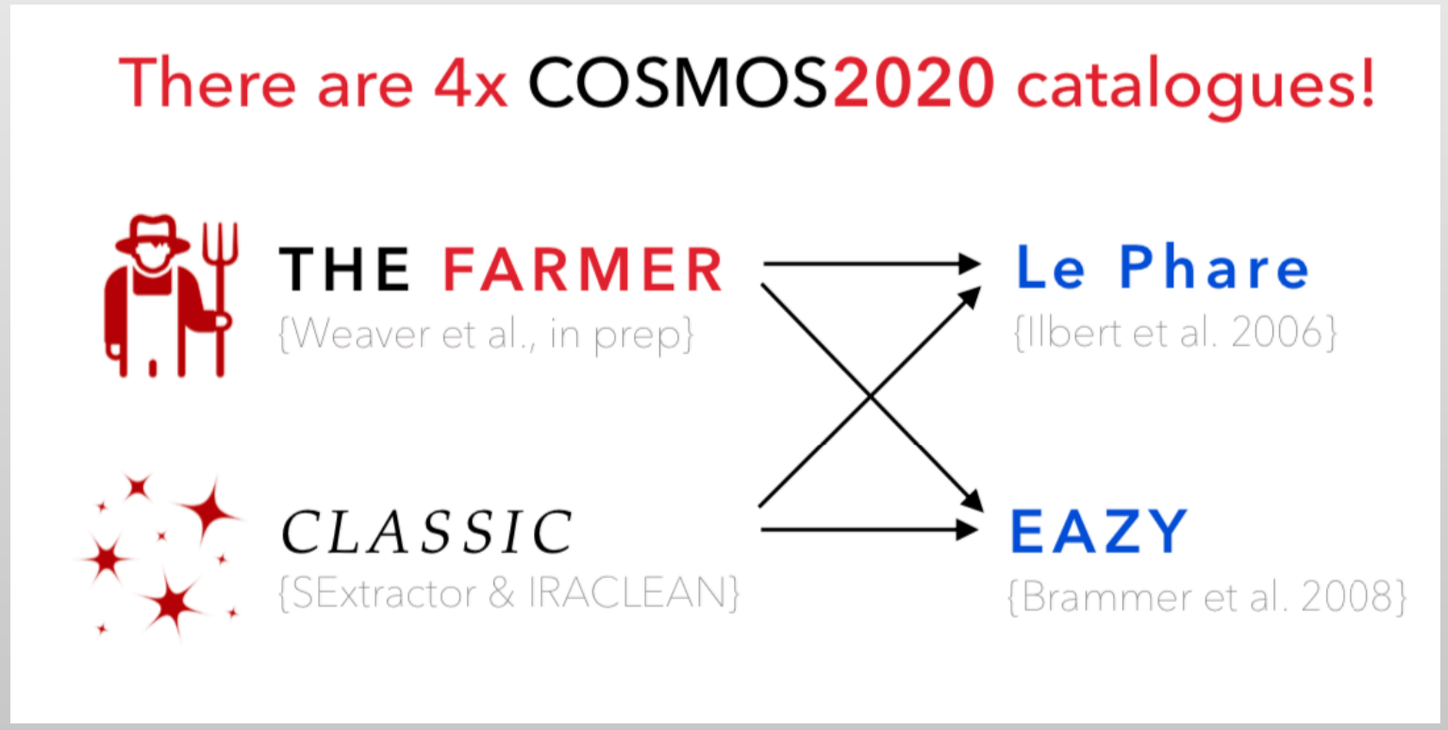
Spitzer/**IRAC**

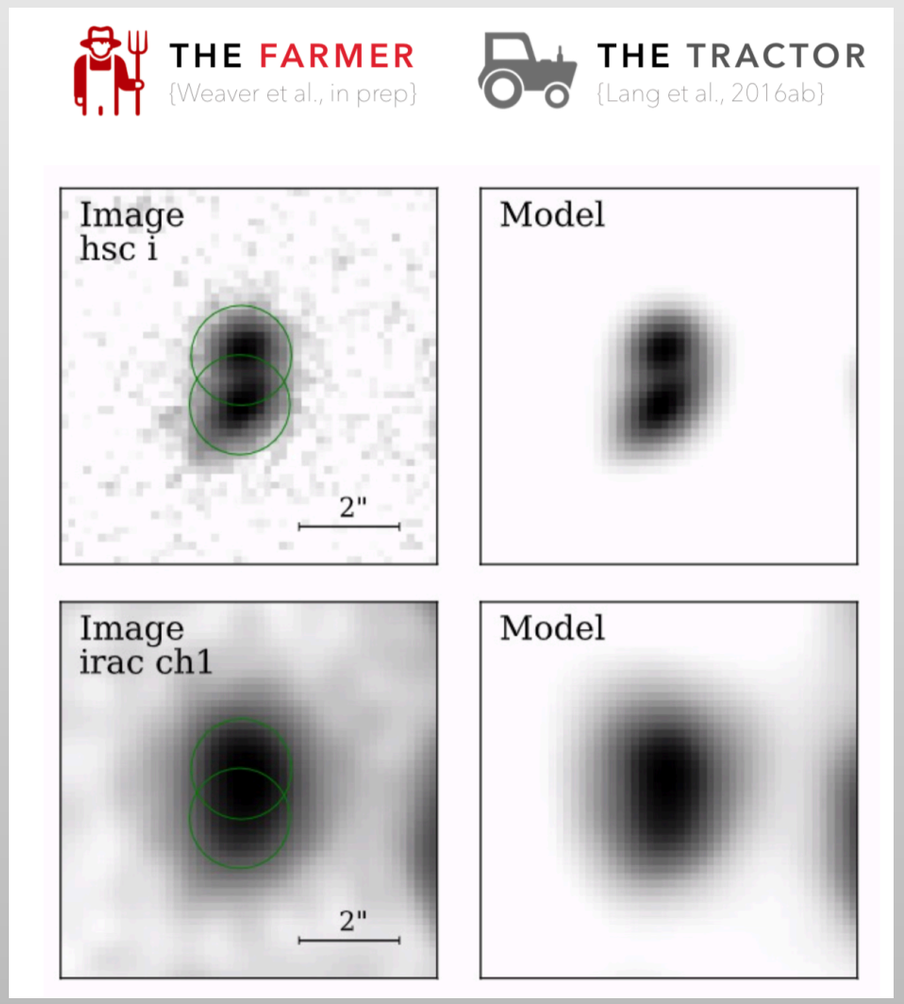




COSMOS2020 catalogue

Weaver, Kauffmann et al. 2021, submitted



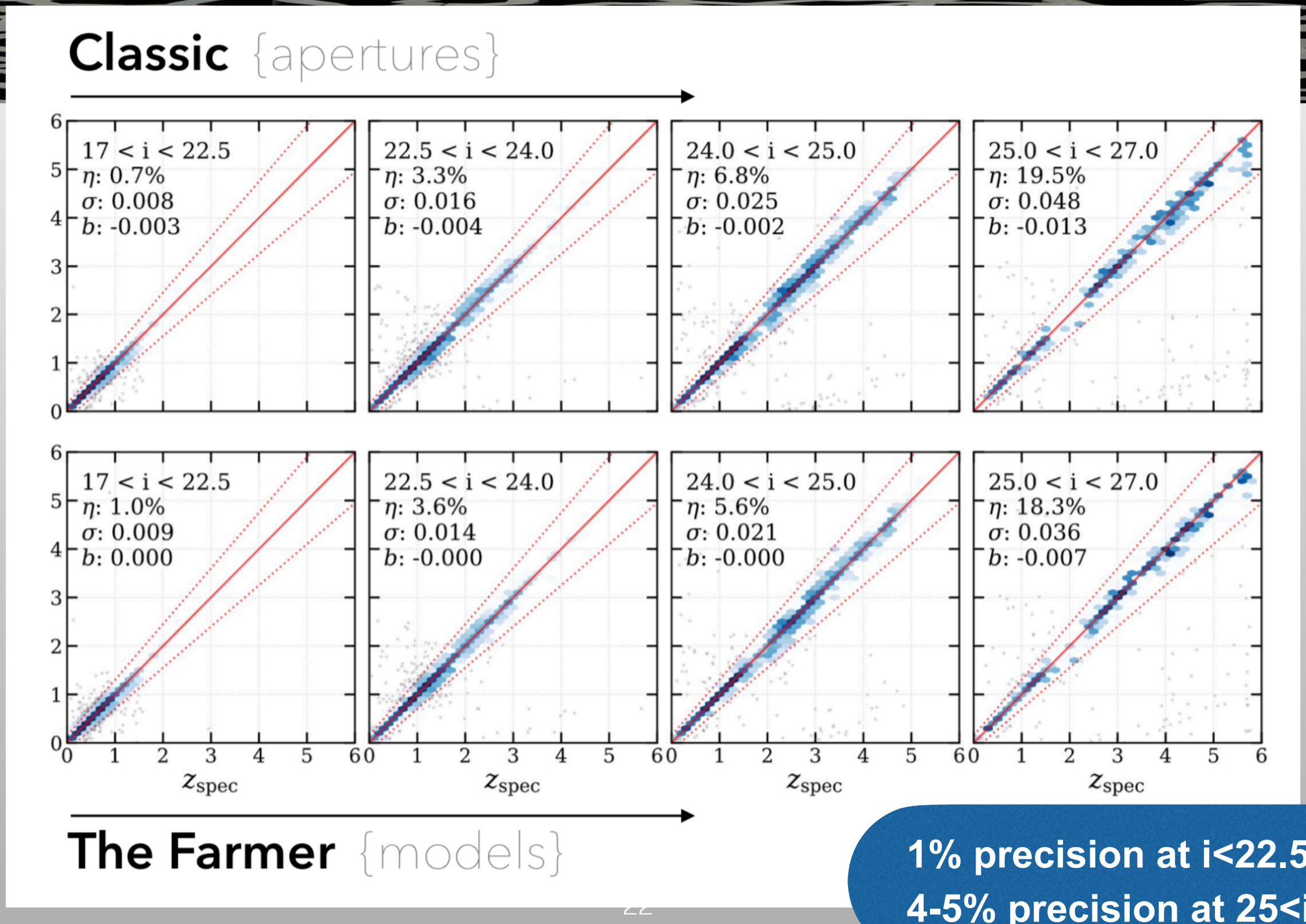


Classic : aperture photometry

The Farmer : profile-fitting photometry

COSMOS2020 catalogue

Weaver, Kauffmann et al. 2021, submitted



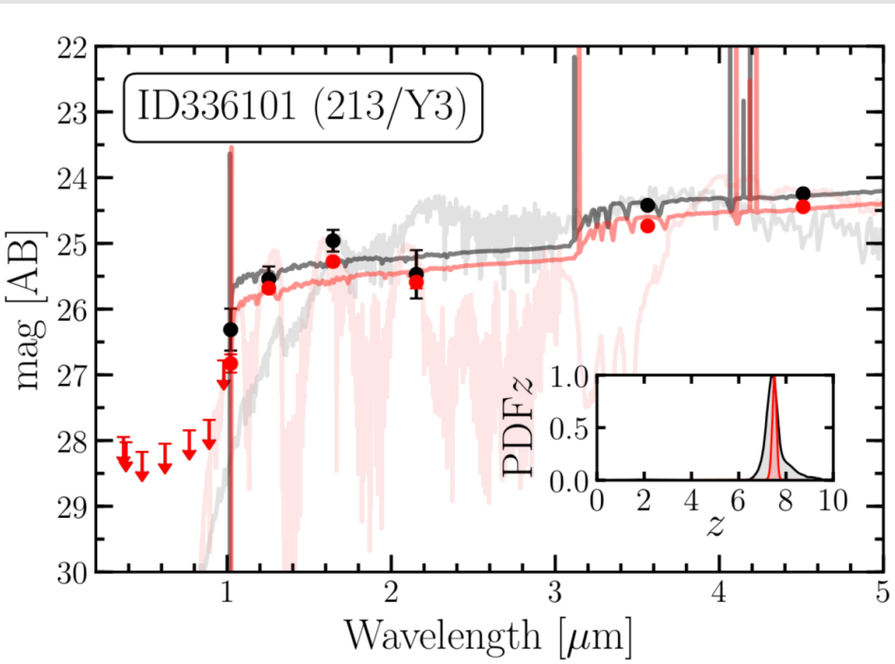
1% precision at i<22.5

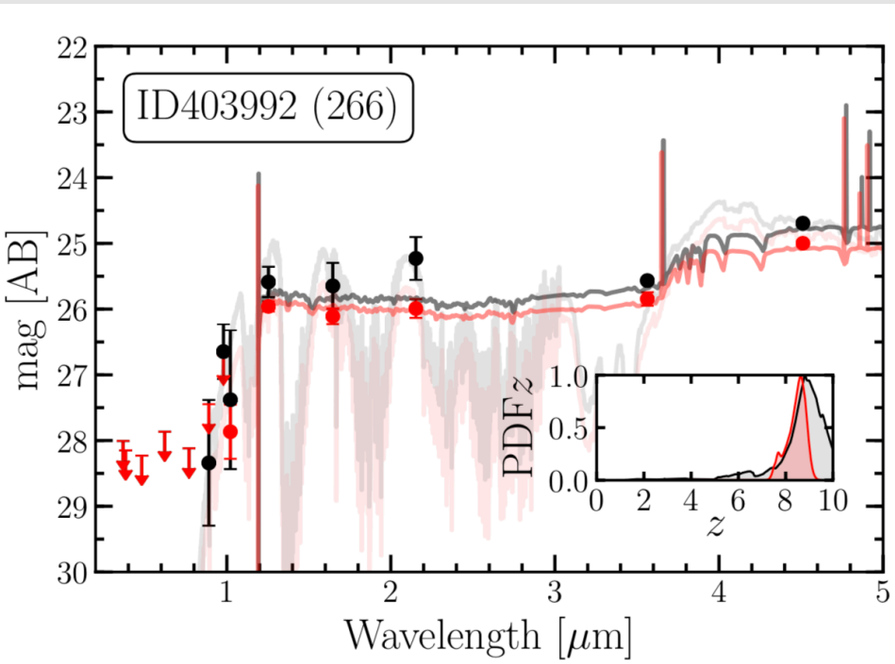
4-5% precision at 25<i<26

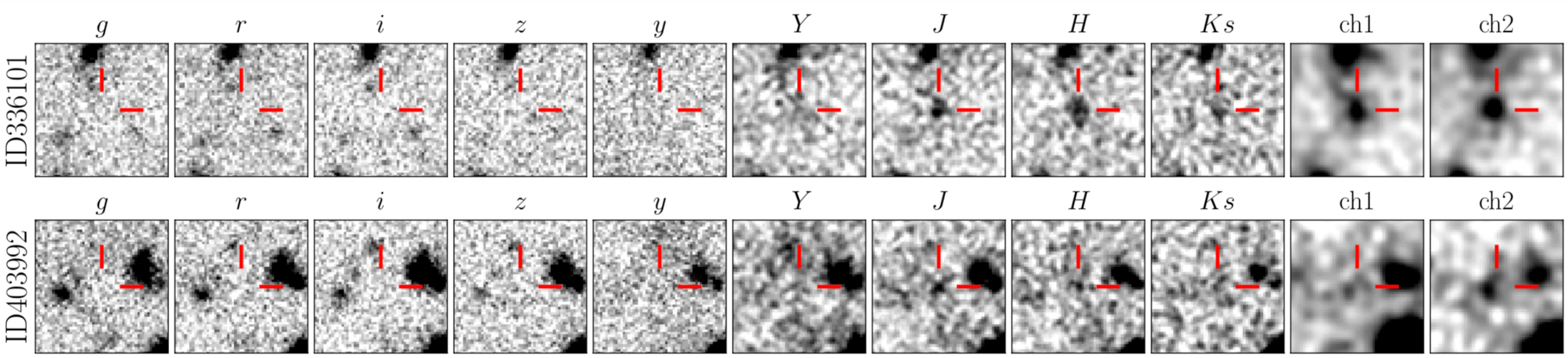
COSMOS2020 z>7 candidates

Kauffmann et al. 2021, in prep

31 candidates







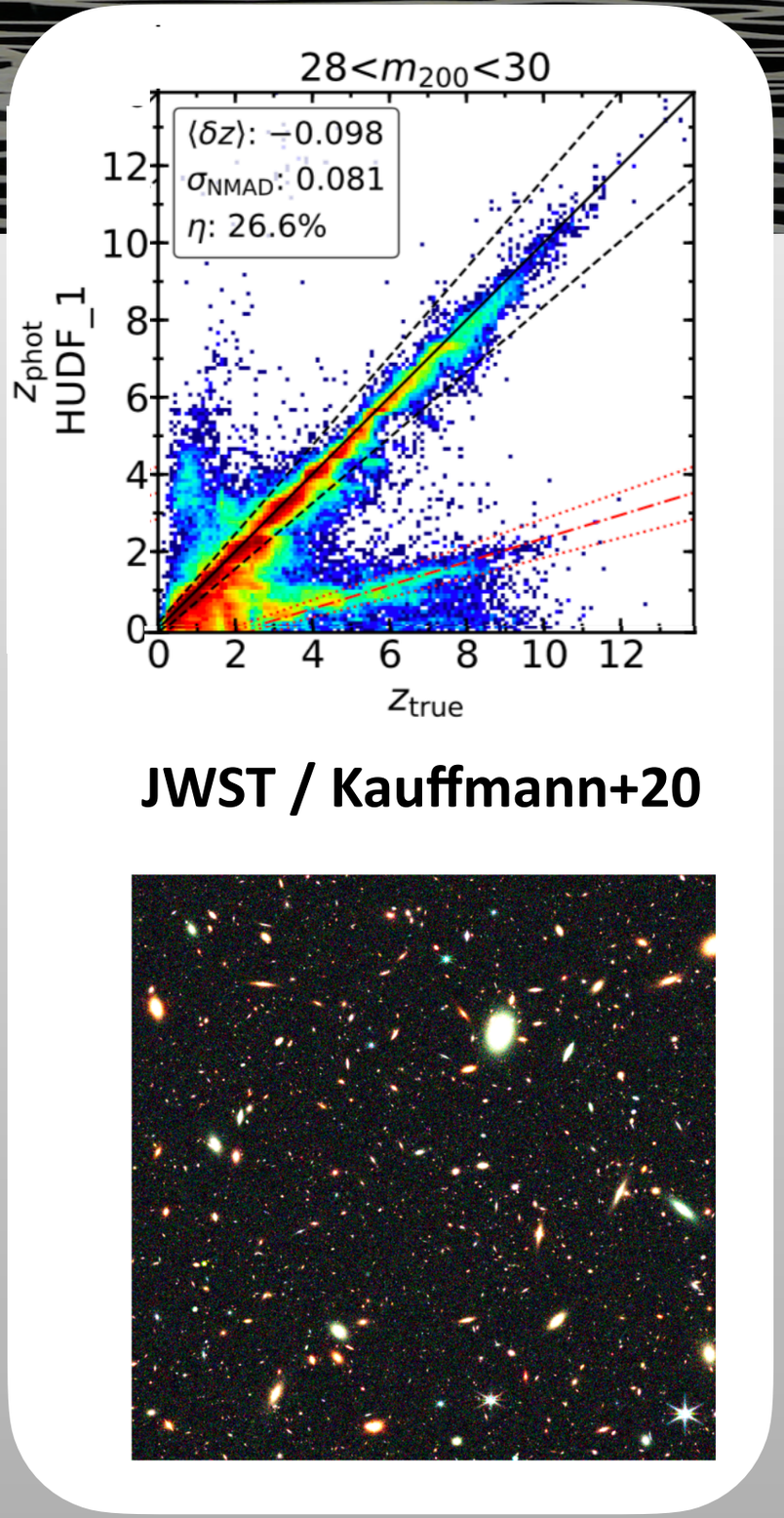
Conclusions on template-fitting

Template-fitting is a robust method

It will remain essential in case of sparse spectroscopic coverage (e.g. JWST)

The PDF could be use to measure the mean redshift with deep imaging

Salvato+2018, review on photo-z

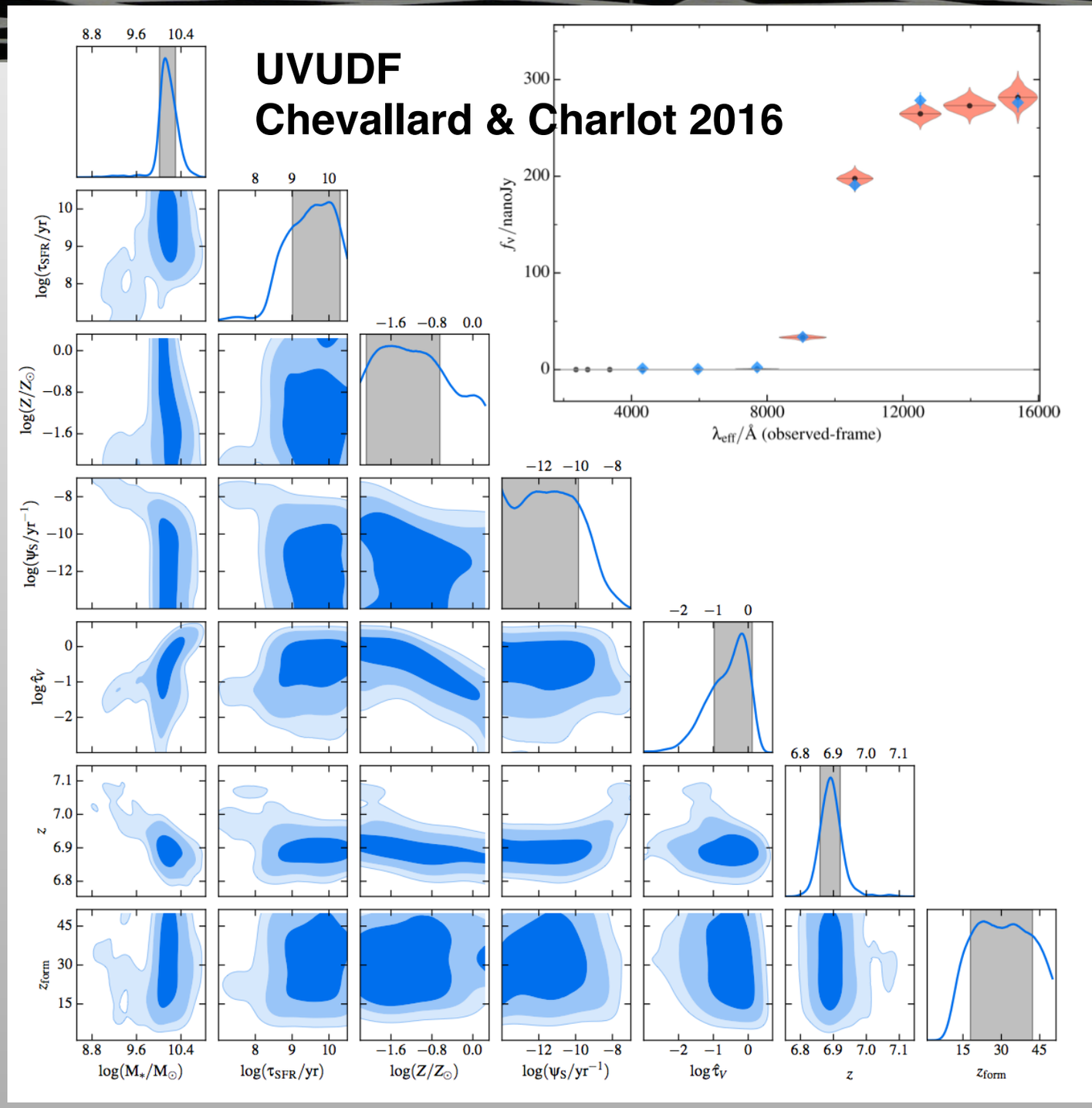


JWST / Kauffmann+20

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



ASPIC

cesam.lam.fr/aspic

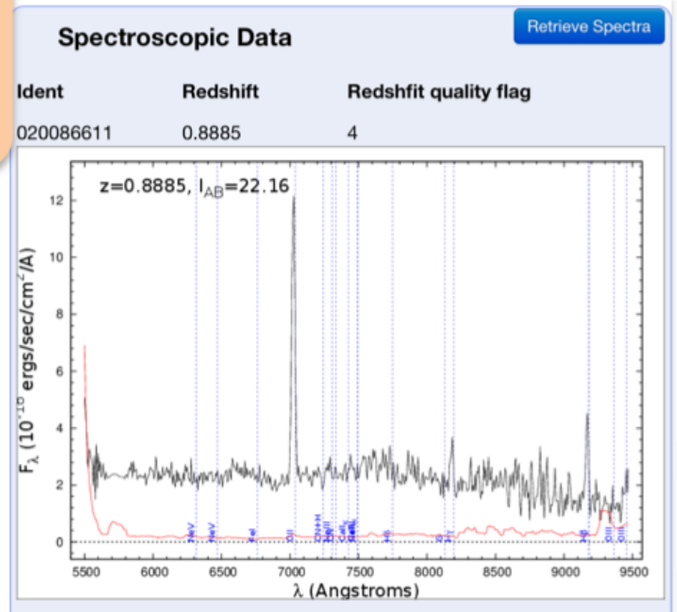
GAZPAR

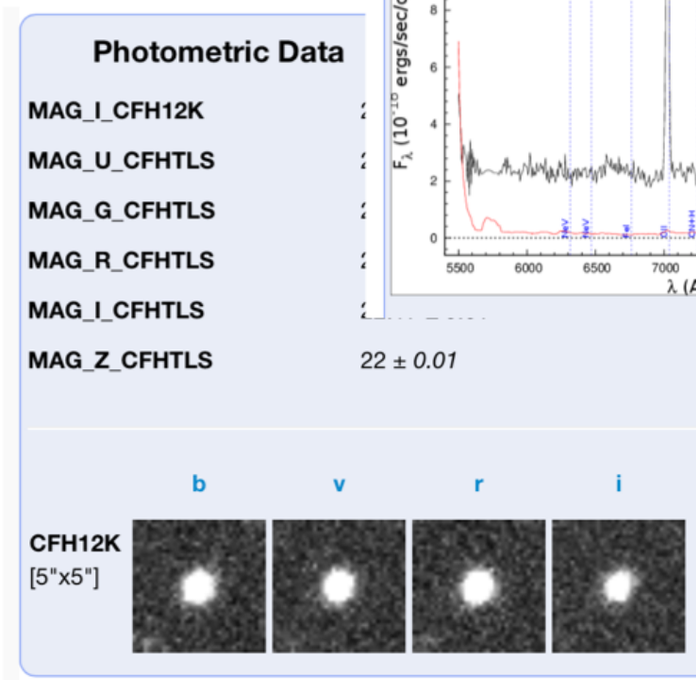
gazpar.lam.fr

Archive of spectro-photometric galaxy surveys

Photo-z and physical parameter estimates

ask to integrate your data!





+ added-values from GAzPAR

Upload your data

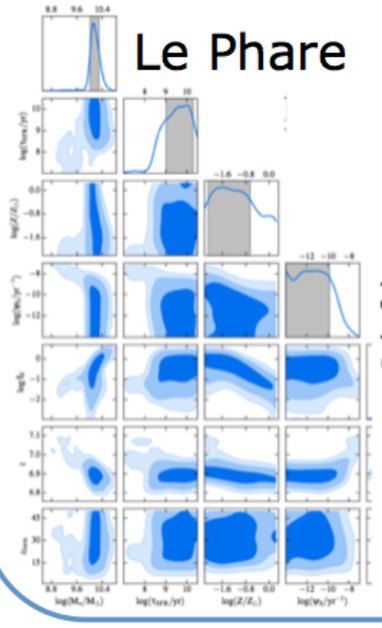
safe and private!

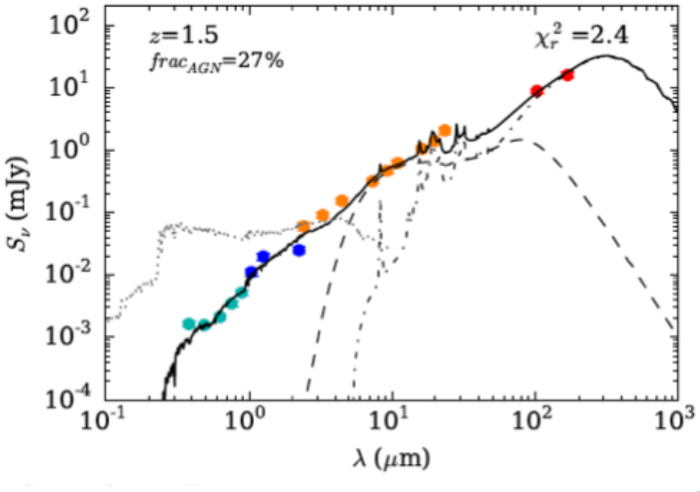
we do it for you!

Le Phare

CIGALE

BEAGLE





Receive your results + quality tests + report

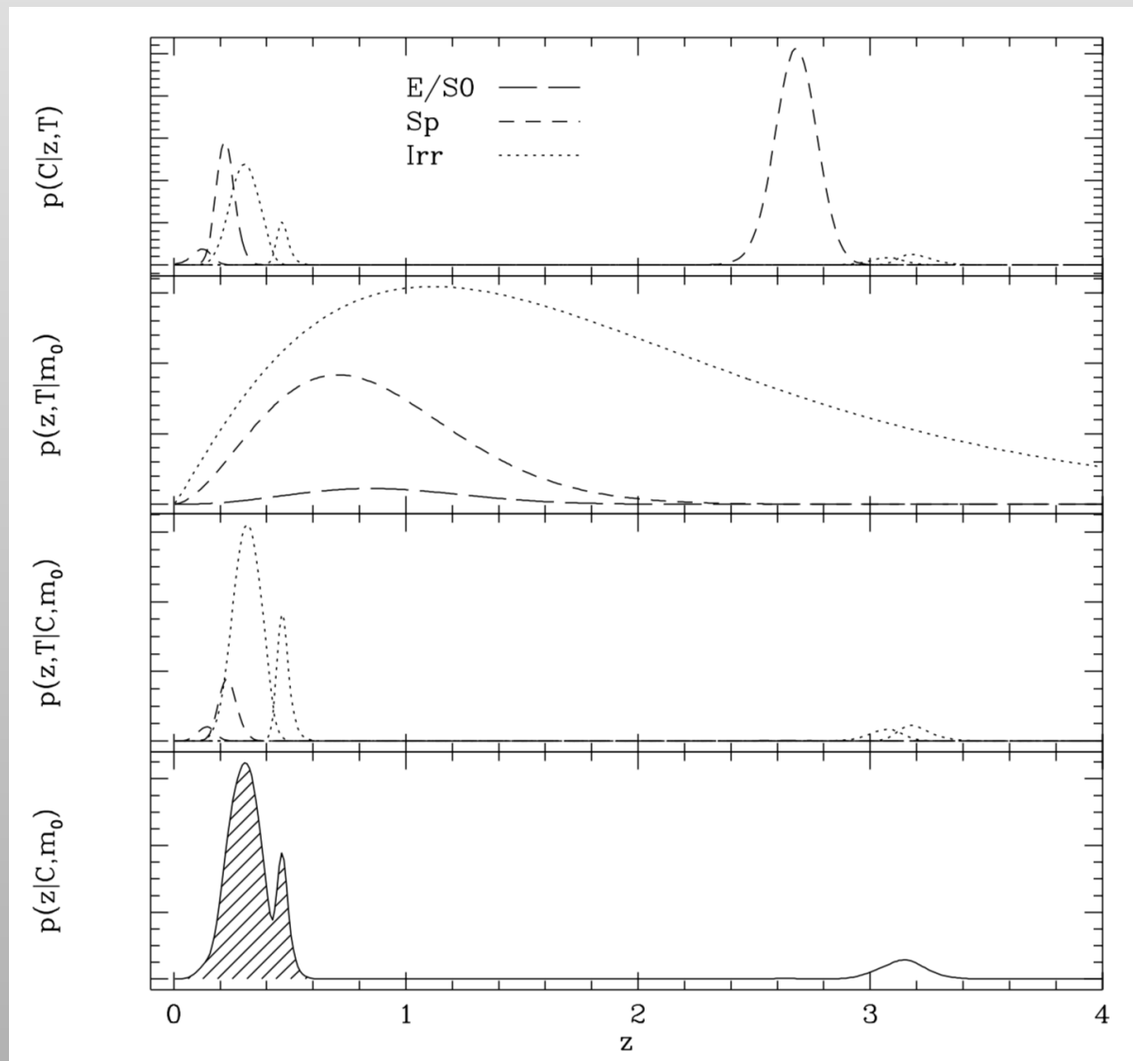
Compensate our lack of data by adding some prior

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

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

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

Benitez 2000

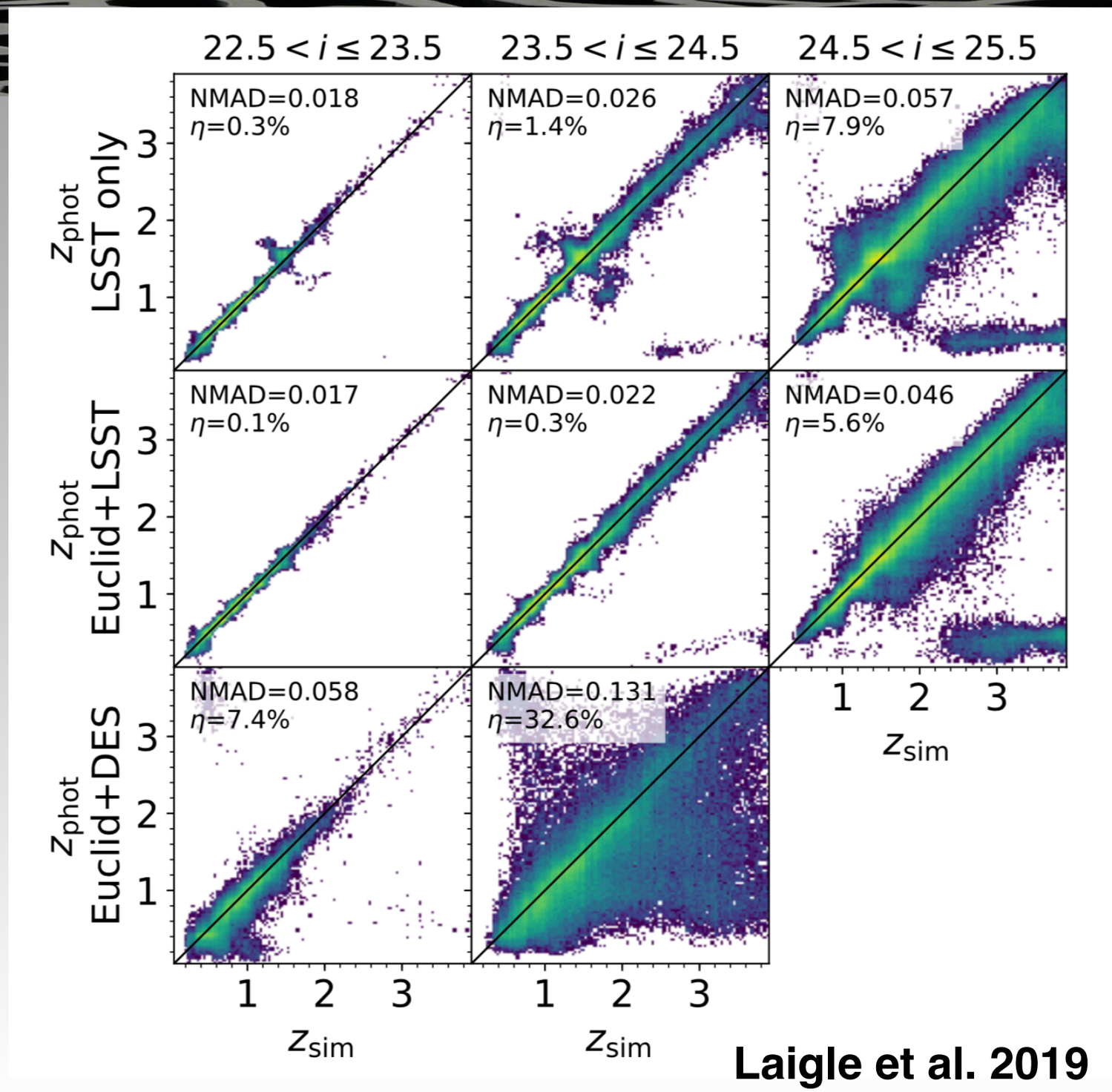


Test template-fitting with hydrodynamical simulations

Follow DM and baryonic particules in Horizon-AGN
➢ complex histories and diversity of galaxies

Run Le Phare with standard configuration
➢ excellent with LSST+Euclid

Ongoing work: generate image and source extraction for Horizon-AGN



Laigle et al. 2019