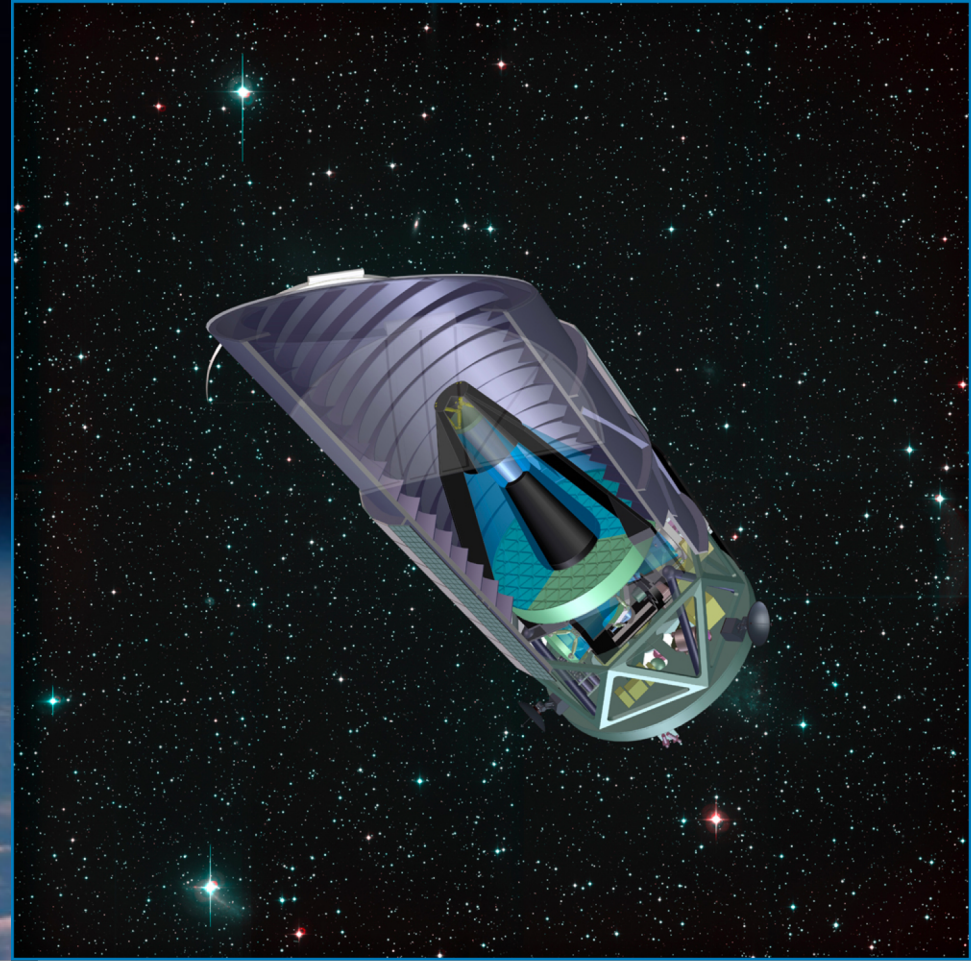


PHOTO-Z CHALLENGES FOR WL SPACE MISSIONS

JEAN-PAUL KNEIB
EPFL

Jouvel et al 2009, 2011

MOTIVATION

Imaging survey: shapes of $\sim 10^9$ -10^{10} galaxies (WL)

$$\langle \gamma^2 \rangle \sim 0.01^2 \, \sigma_8^{\,2} \, \Omega^{1.6} \, z_s^{\,1.4} \, \theta^{-(n+2)/2}$$

Redshift survey: bring 3rd dimension

- **Photo-z:** (useful for WL, clusters => DE, MG)
  - (-) less accurate => need calibration
  - (+) larger number of galaxies
- **Spectro-z:** (SN, calibration, BAO, clusters =>Cosmography)
  - (+) More accurate => provide calibration to photo-z
  - (-) Smaller number of galaxies

PHOTO-Z HOW-TO?

- Start with a telescope
- Define/Use a filter set with N filters
- Observe a fraction of sky in N multi-bands – (possibly adjust the exposure time for each filter)
- Identify objects – observed in M bands (3<M<N)
- Compute photometric redshift (template fit, neural network, CNN, …)
- Compare to spectroscopic redshift => improve photo-z

PHOTO-Z SURVEY OPTIMISATION

Aim: optimize (imaging, spectro survey) for the best DE experiment. For Photo-z:

- minimize catastrophic redshift fraction
- Minimize photo-z dispersion
- Minimize photo-z bias

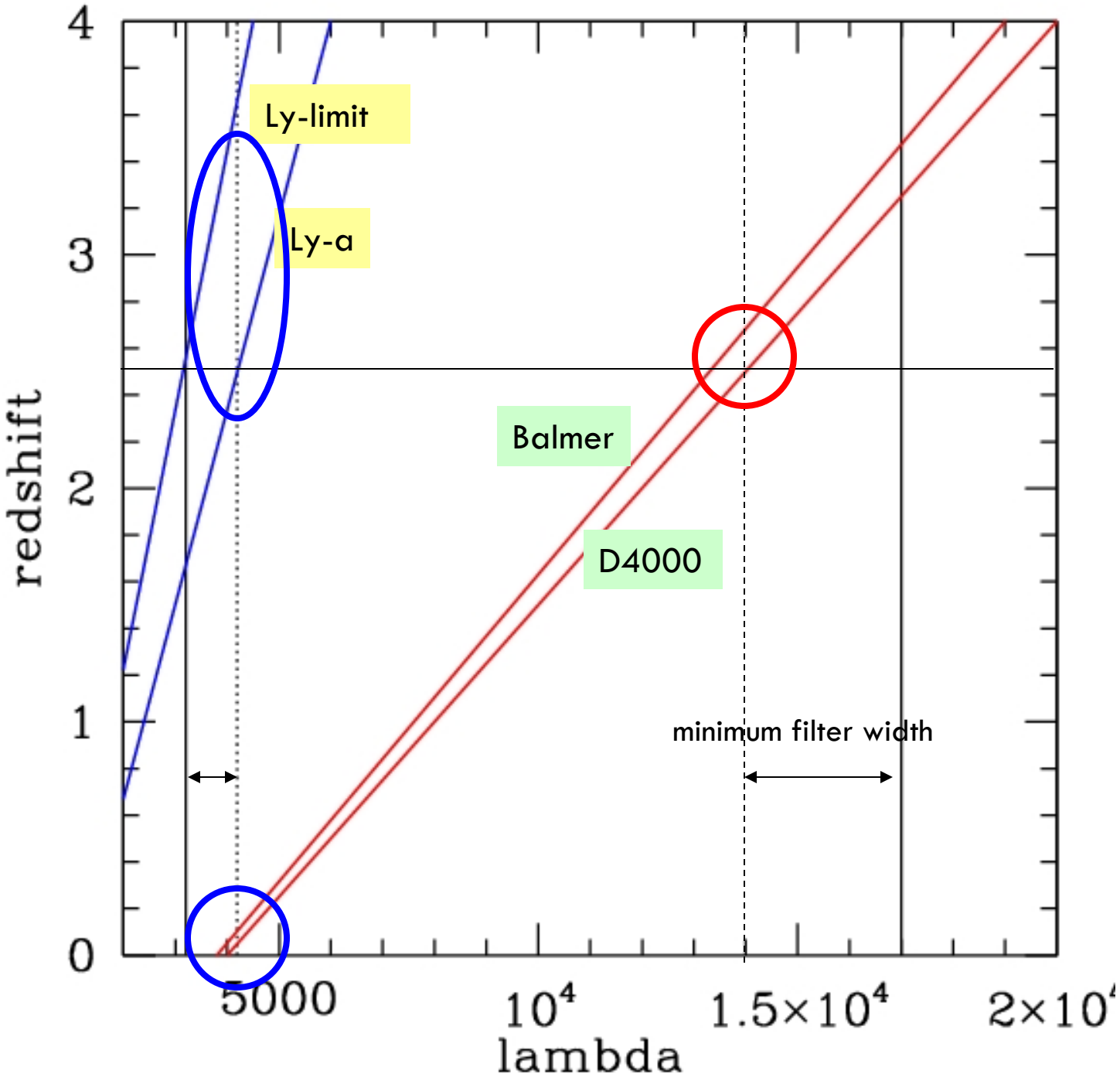
Photo-z: sensitive on color gradients

e.g: « breaks »: Lyman, D4000

Important parameters:

- **Wavelength coverage:** cover at least one "break" at any redshift (catastrophic z)
- **Number of filters** (photo-z precision)
- **Filter resolution (Image depth)** (photo-z precision)
- **Size of spectroscopic redshift survey** (photo-z bias)

Ideally have the 2 breaks in the wavelength range



QUICK ESTIMATE OF PHOTO-Z ACCURACY

Photometric Redshift accuracy relies on the combination of **color gradients**:

It can be expressed by considering all the color gradients : (Capak et al)

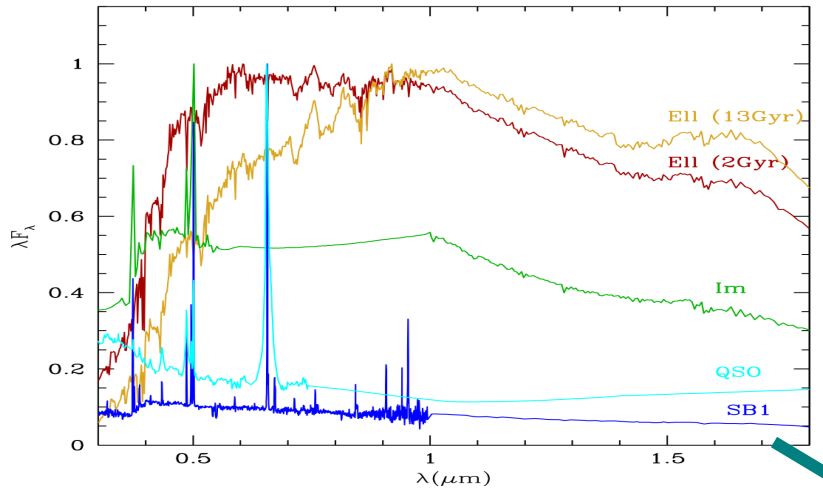
$$\frac{1}{\Delta z^2} = \sum_{i=0}^{i=n} \sum_{j=i+1}^{j=n} \left(\frac{\Delta C_{i,j}}{\Delta z} \frac{1}{dC_{i,j}}\right)^2 \qquad \text{(Equation 1)}$$

$\frac{\Delta C_{i,j}}{\Delta z}$ is the color gradient $C_{i,j}$ with z : depends on SED

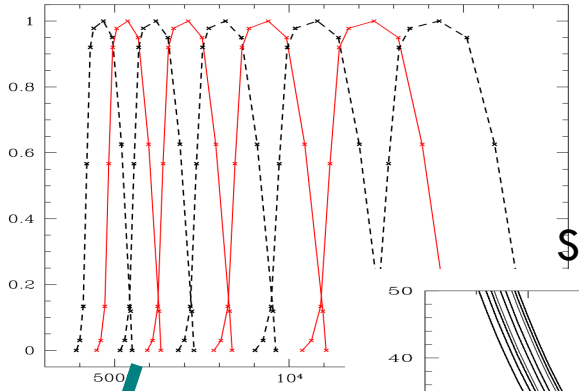
$dC_{i,j}$ is the photometric error : depends on survey performance

Allow to estimate the performance for a given survey Depending on the filter set and the SED templates.

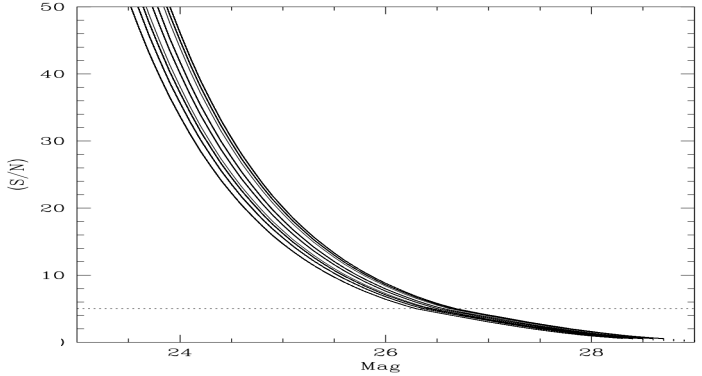
SEDs



Filters



S/N per filter



Eq 1

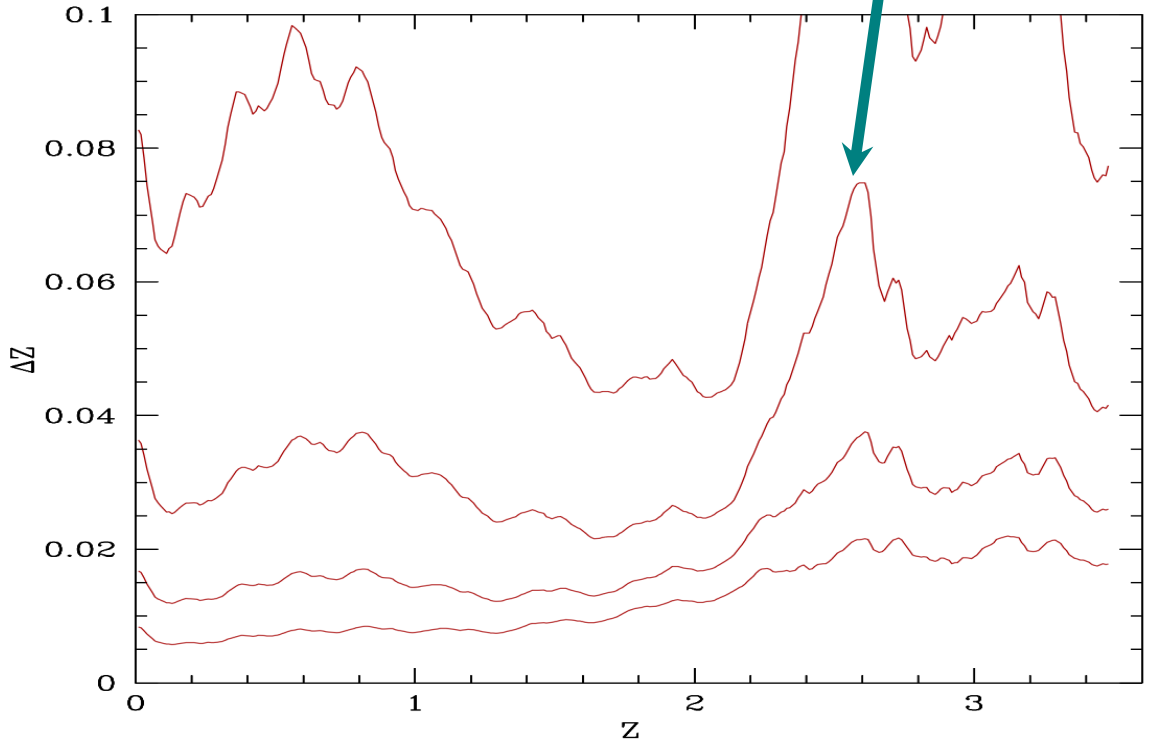
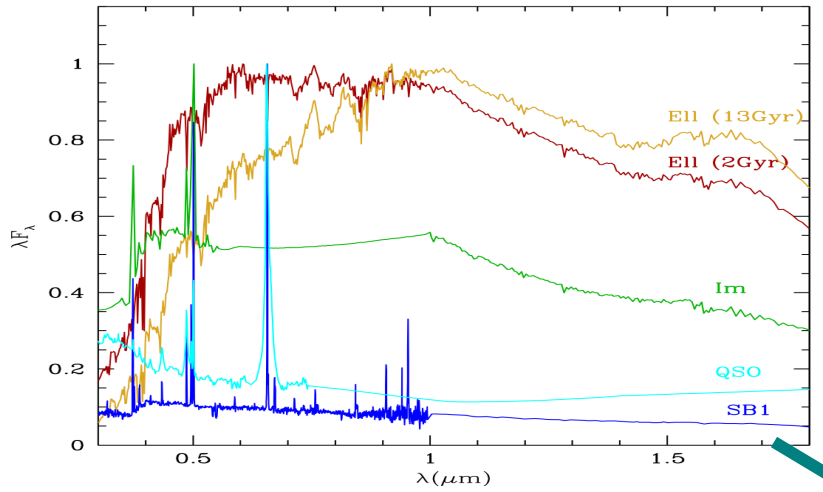


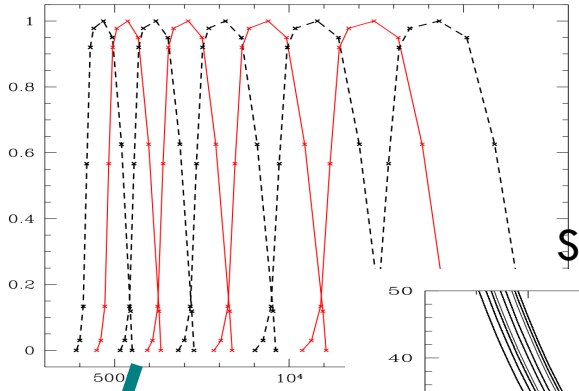
Photo-z accuracy
(Δz vs z)

for ELL with
I=27, 26, 25, 24

SEDs

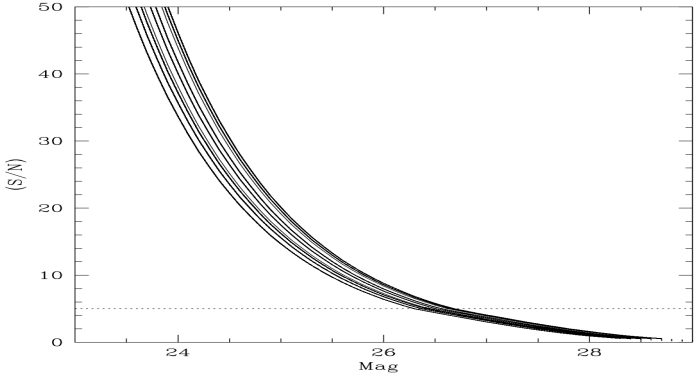


Filters



Eq 1

S/N per filter



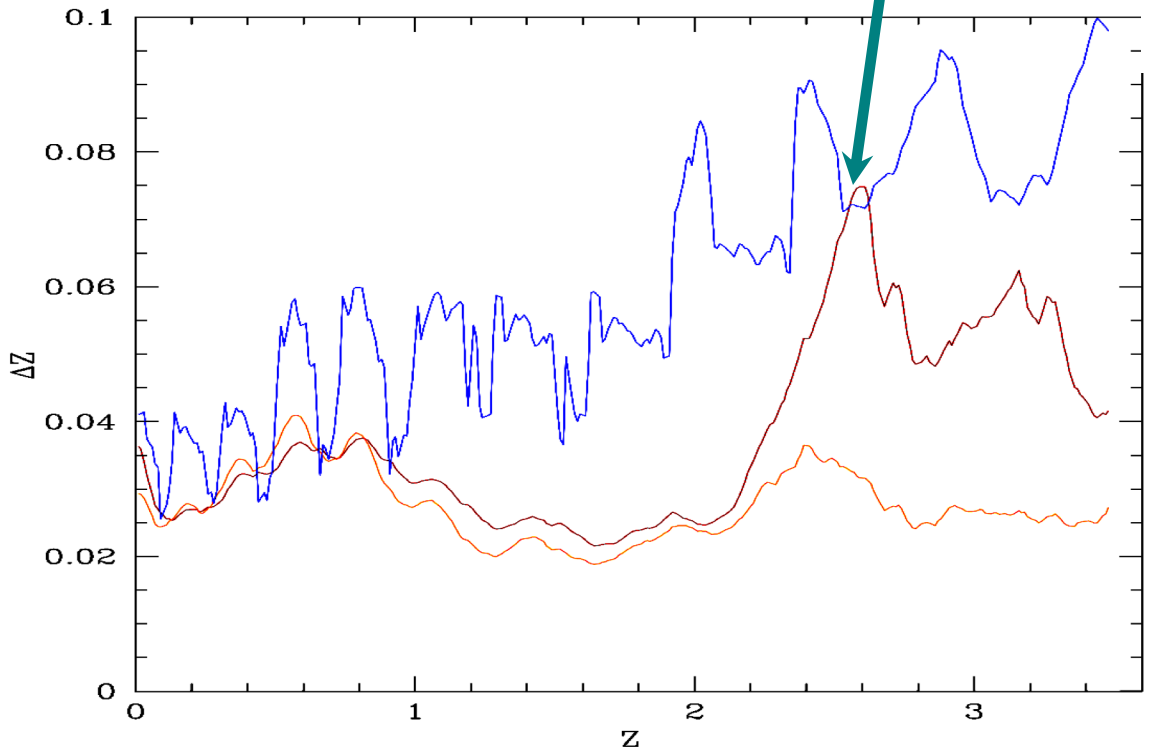
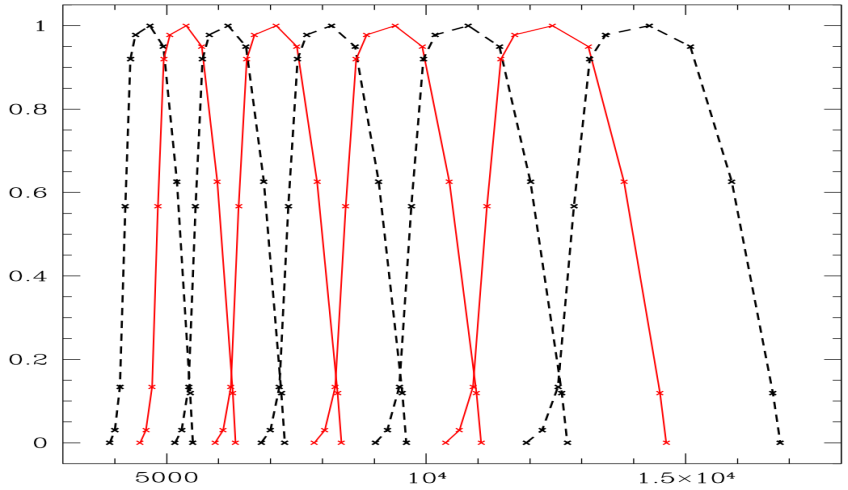


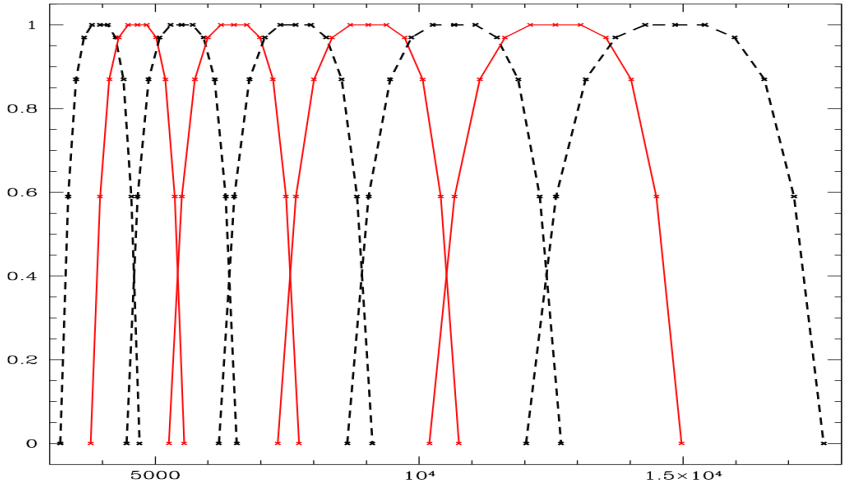
Photo-z accuracy
(Δz vs z)

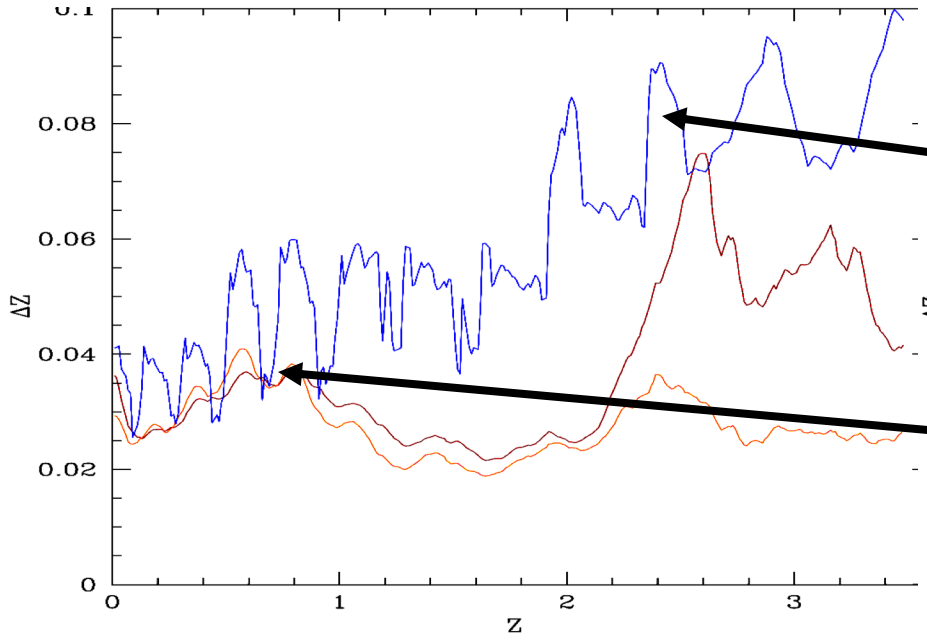
for ELL-1, ELL-2, SB1
with I=26

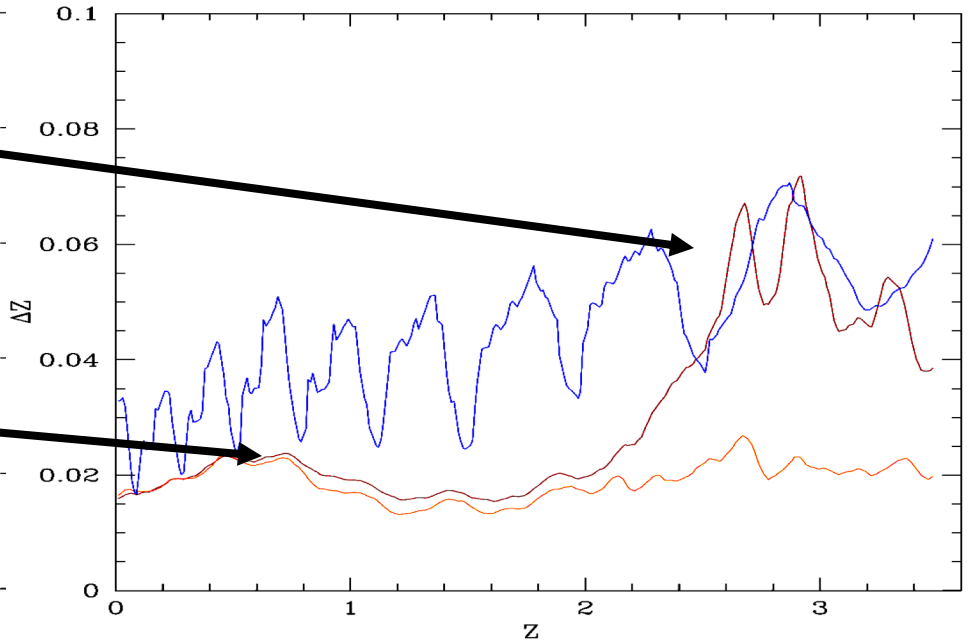
9 Standard and log scaling



9 with U filter and log scaling



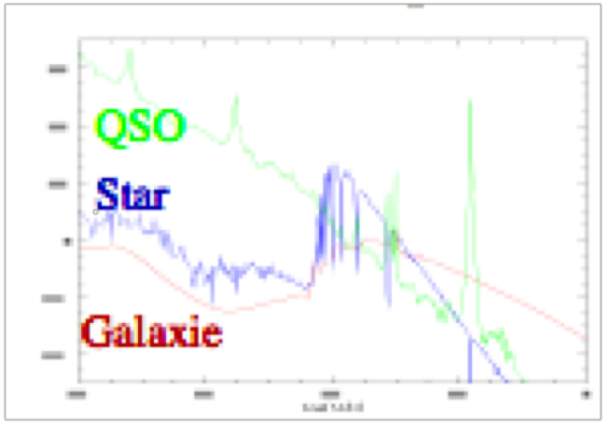




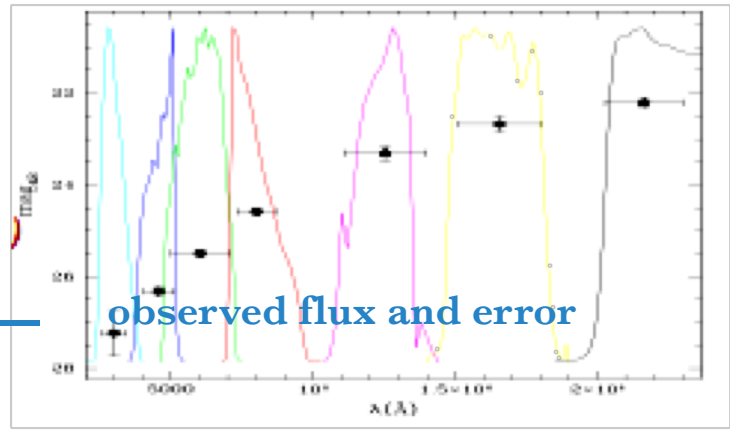
Gain to add a U band filters which depends on (z, SED)

PHOTO-Z BY FITTING TEMPLATE SED (LE PHARE)

SED's Library



Set of Filters



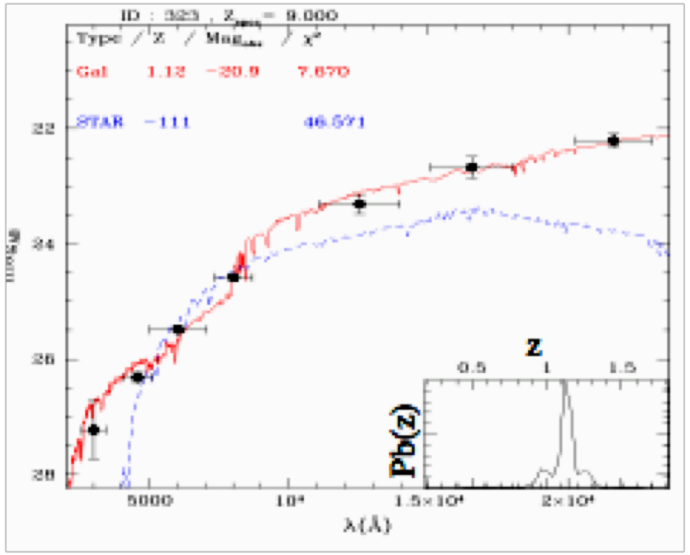
\+ Extinction IGM

Theoretical flux

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

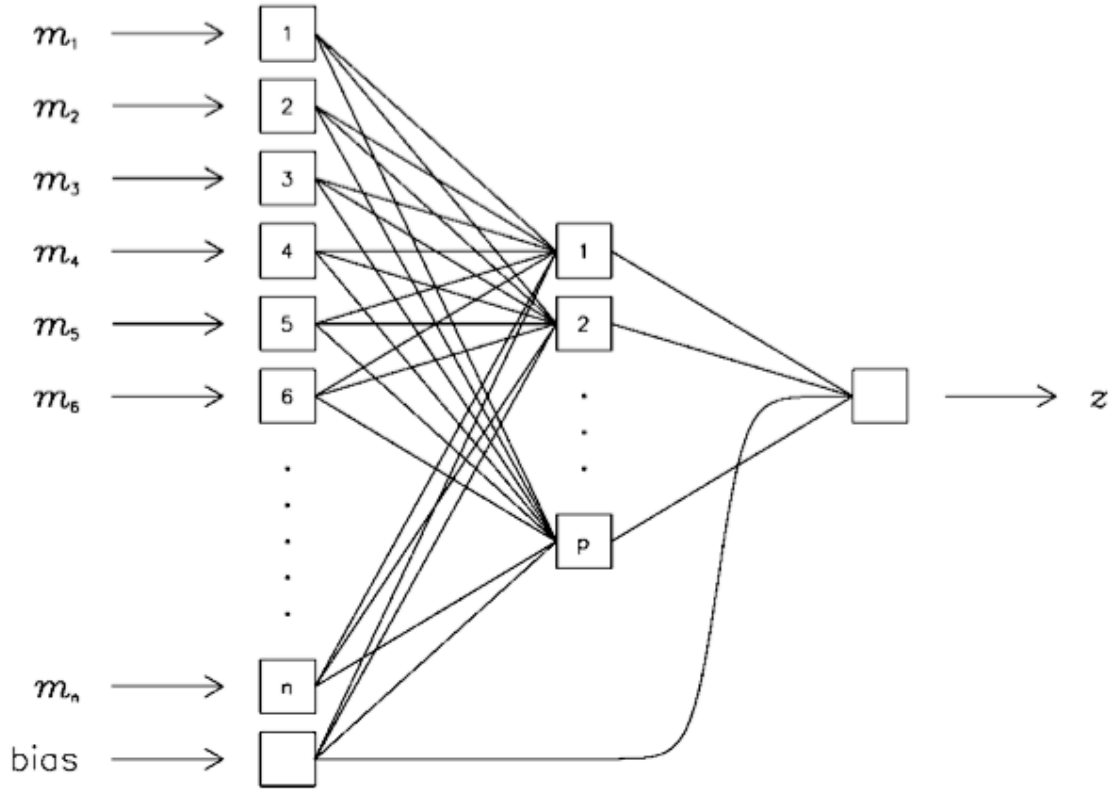
Outputs

Best Redshift z
z uncertainties, Pdz
Types , E(B-V)
Abs Magnitudes
Physical parameters:
Masses, Mean Age, SFR, Zo,…



NEURAL NET/(NOW CNN) TRAINED BY DATA

Pseudo-PDF from
- 'Gaussian input ensemble'
- 'Committee' of networks
- no prior knowledge of SED, all the information is in the training sample
- available neural-net output only photo-z



$$E = \sum_k [z_{\text{phot}}(\boldsymbol{w}, \boldsymbol{m}_k) - z_{\text{spec},k}]^2$$

Firth, Lahav & Somerville 2003

PHOTO-Z METHOD COMPARISON

Fitting with SED model:

Predictive method (lower luminosity, higher-z …)

Calibration of SED template with spectro-z

More difficult to evaluate size of spectro-z sample (how extended are the galaxy population?)

Neural Net model:

Training with spectro-z galaxy sample

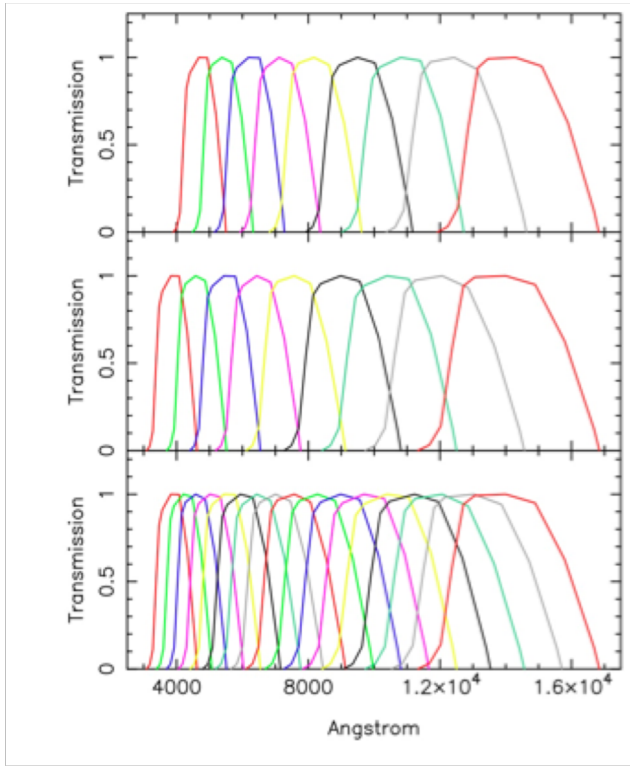
Best results if working sample « similar » to training set sample

Powerful to use to estimate size of spectro-z calibration sample

Possibly the ultimate method is an hybrid one

INVESTIGATING THE SNAP PHOTO-Z

Dahlen et al 2007



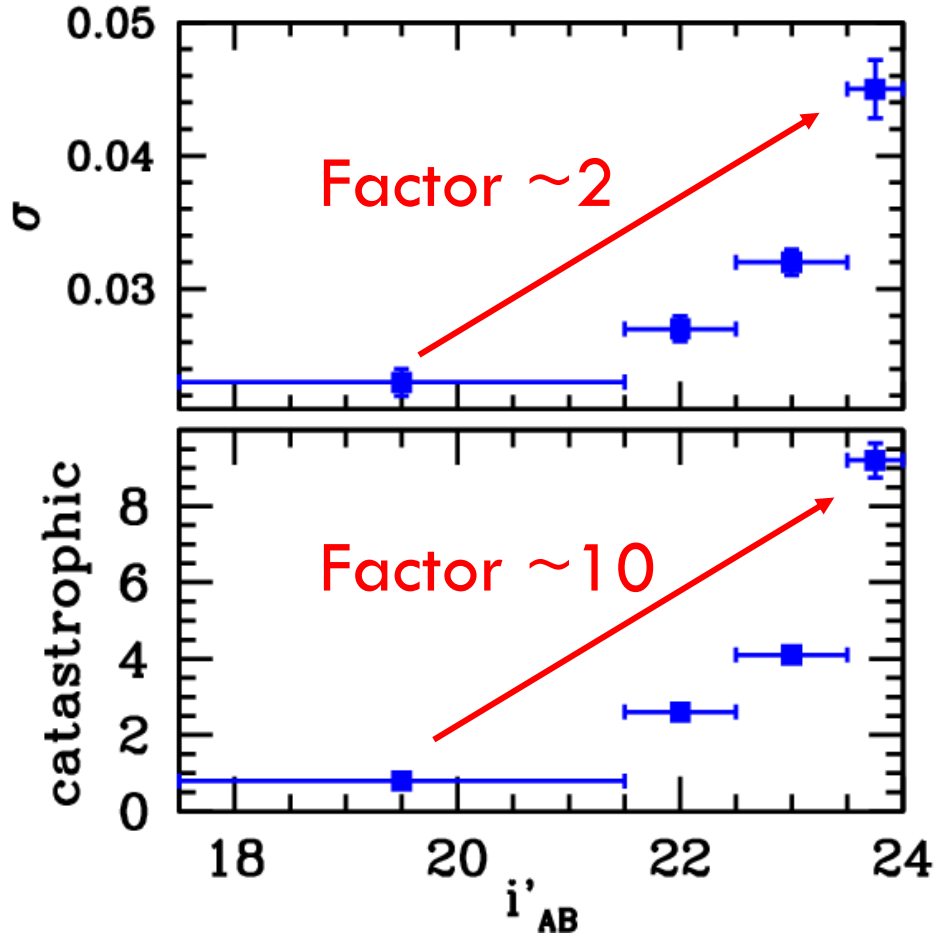
Method:

We create a mock galaxy catalog and use the *template fitting method* to calculate photo-z and compare with input 'spec-z'.

Conclusion:

- 9-filter set extended to U-band is preferred
- Phot-z accuracy highly dependent on limiting magnitude (S/N)
- Outlier fraction can be reduced using D95 while "maximizing"number of objects

ACCURACY PER MAGNITUDE BINS



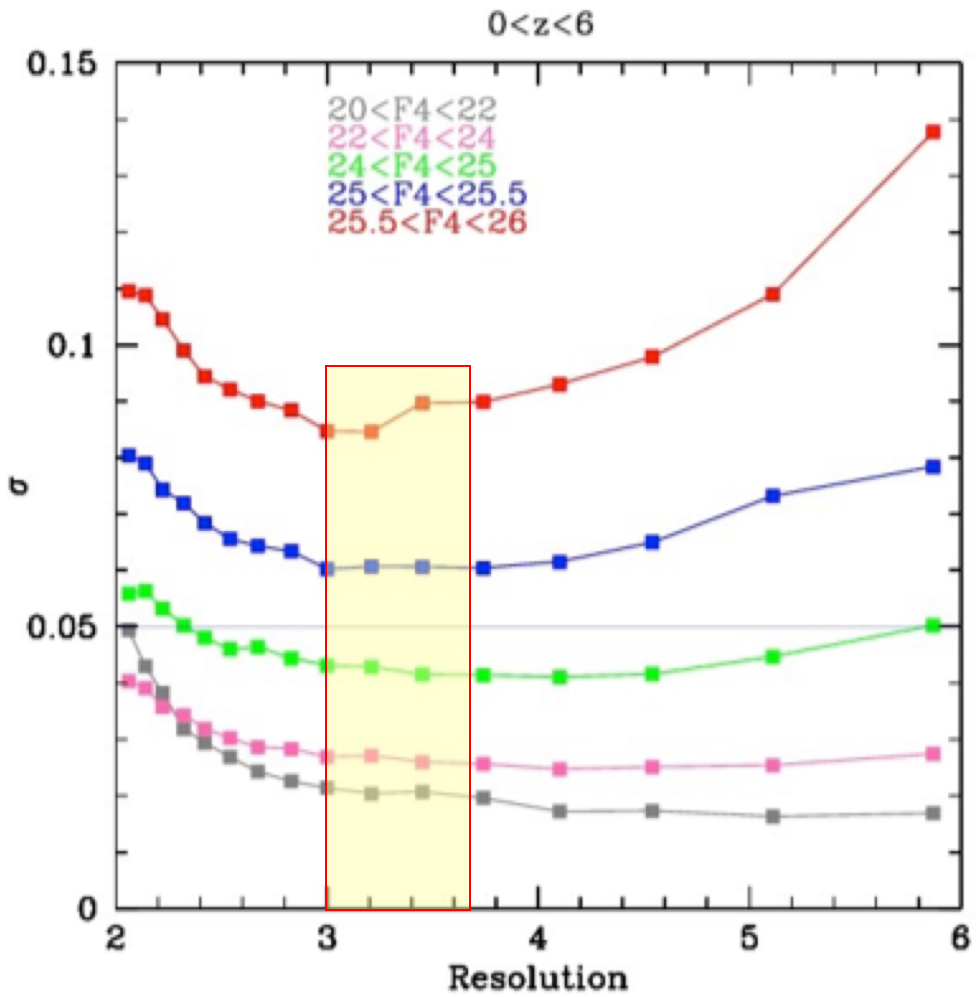
- Apparent magnitude (S/N) is a key parameter in photo-z accuracy
- Improve depth by optimization of filter shape and resolution:
- Square-ish filters preferred
- Need to optimize resolution of filter

OPTIMISATION OF FILTER RESOLUTION

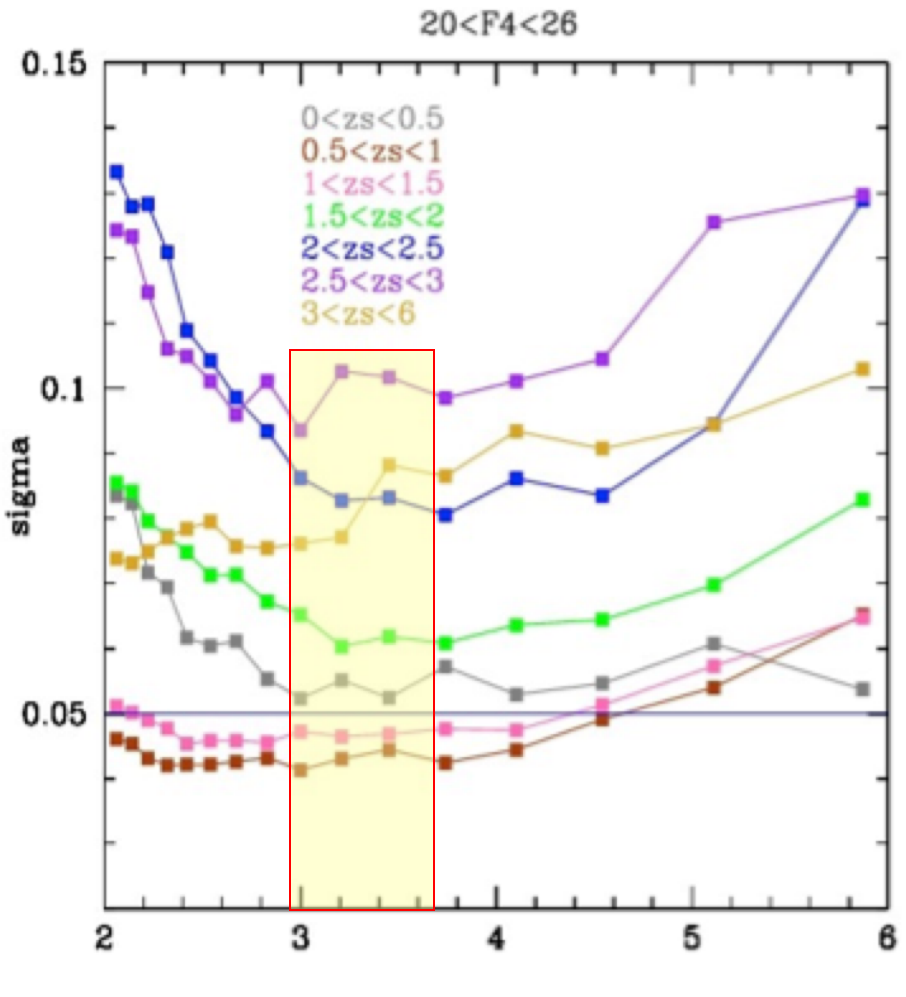
Square filters

Jouvel et al 2009

sig/mag bin



sig/z bin

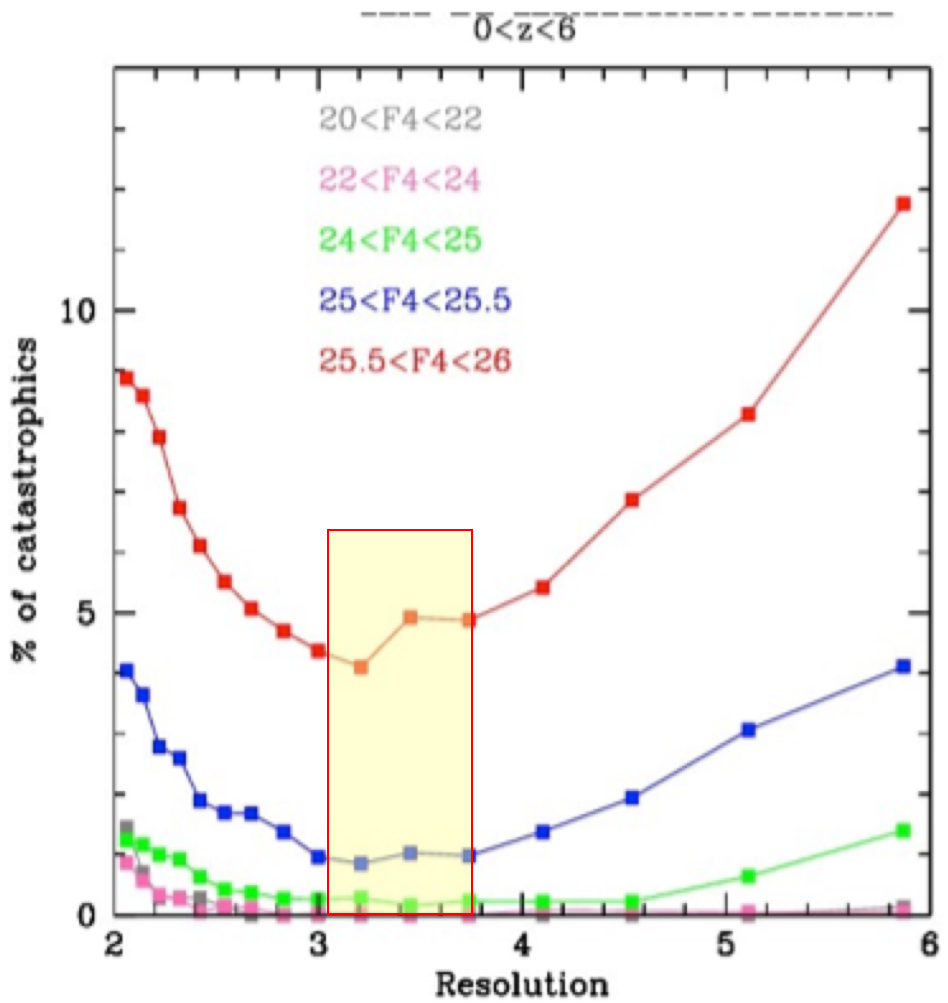


OPTIMISATION OF FILTER RESOLUTION

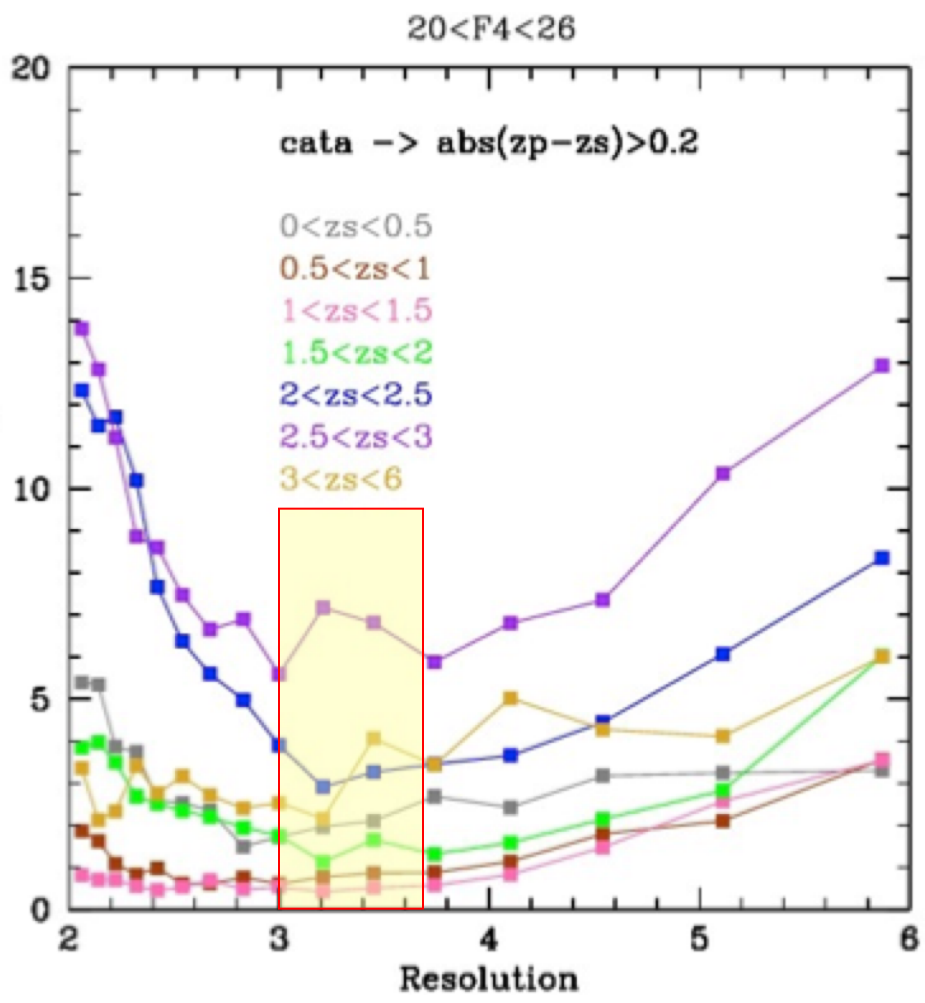
Square filters

Jouvel et al 2009

cata/mag bin

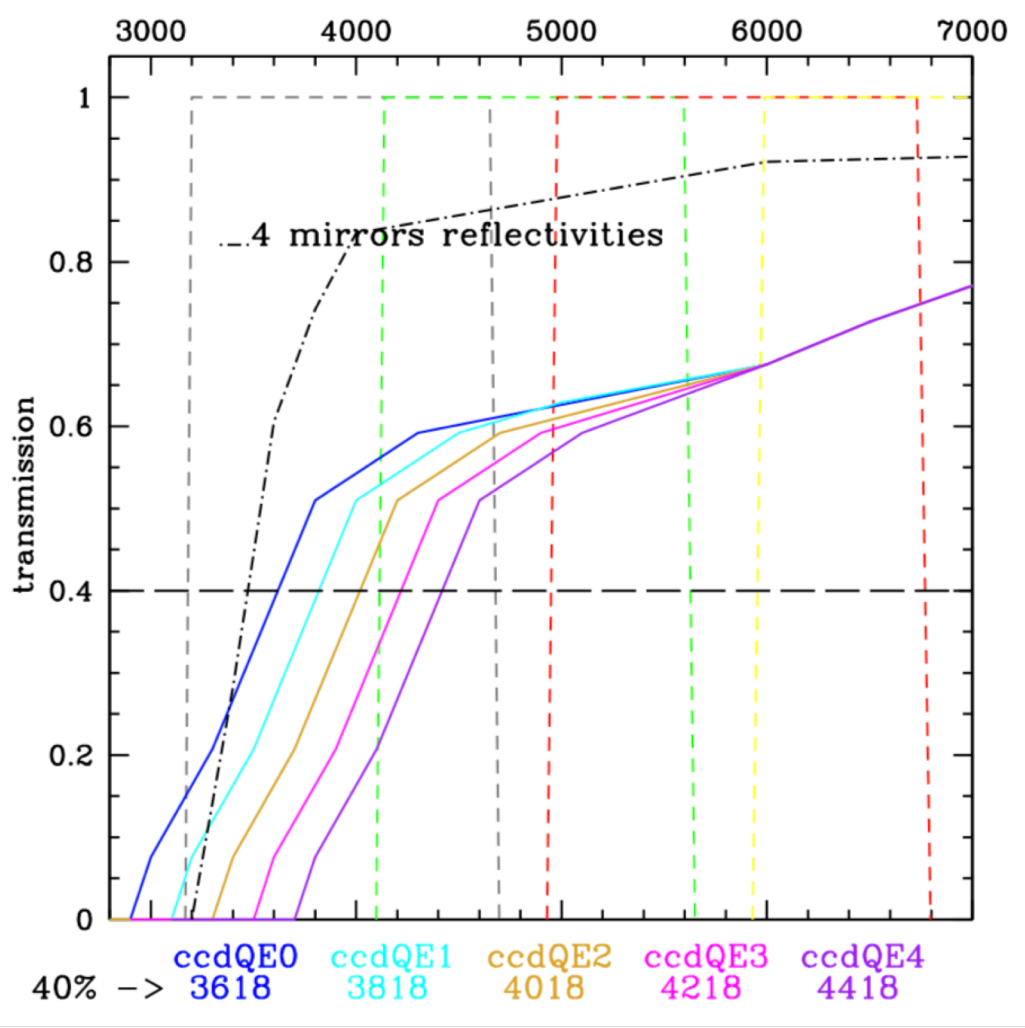


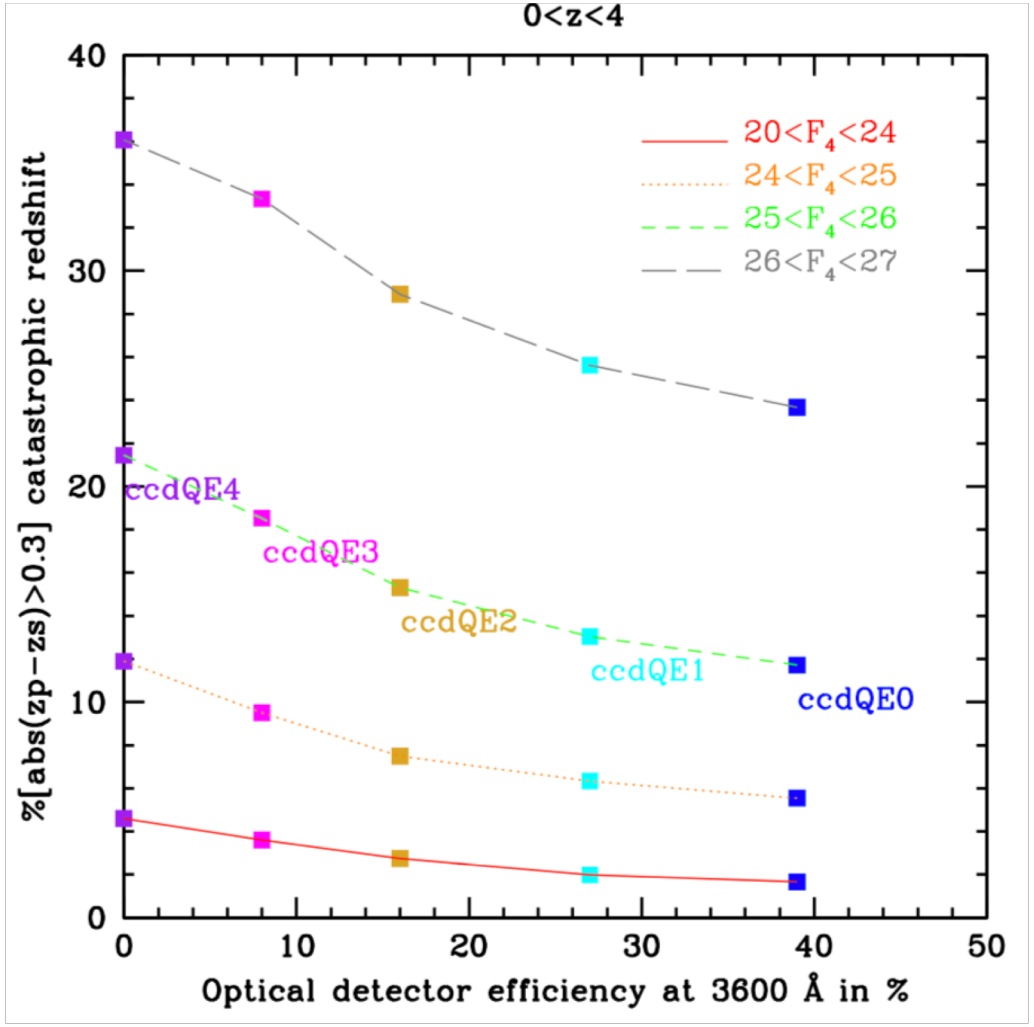
cata/z bin



BLUE SENSITIVITY

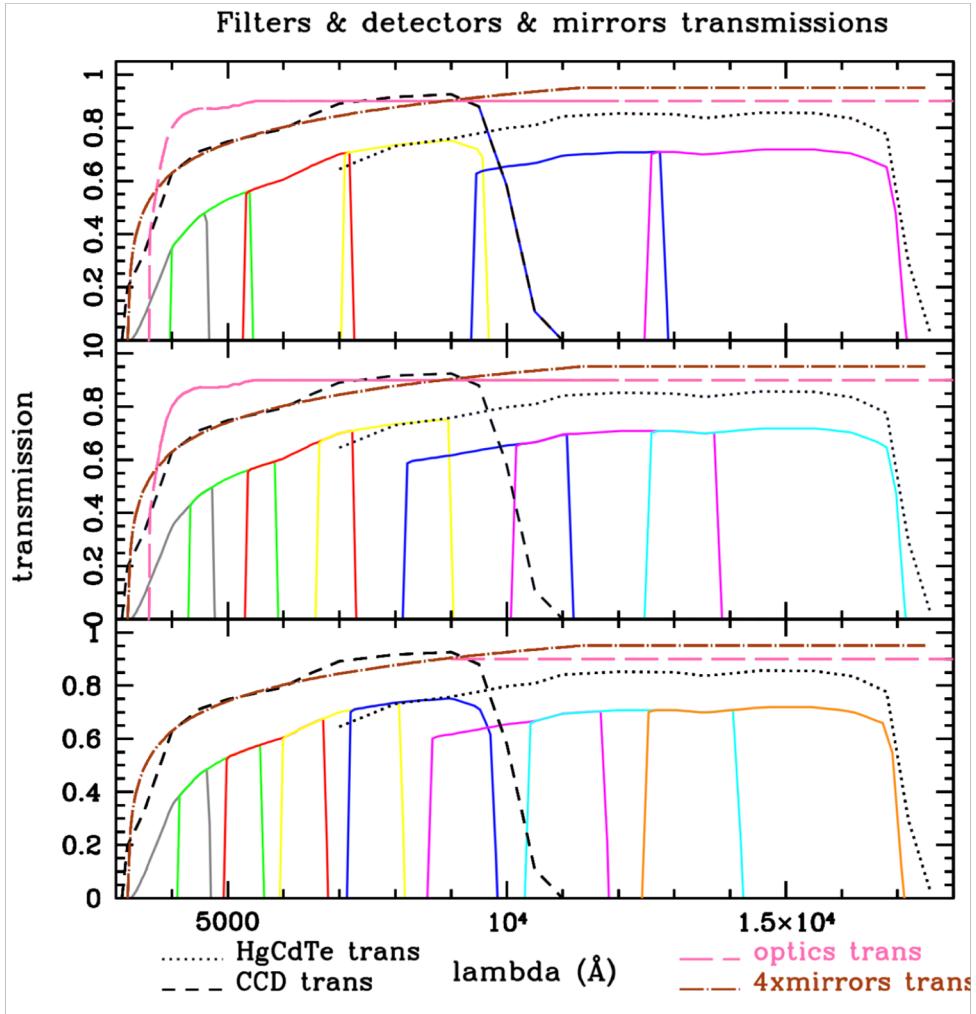
Jouvel et al 2011





NUMBER OF FILTERS

Jouvel et al 2011



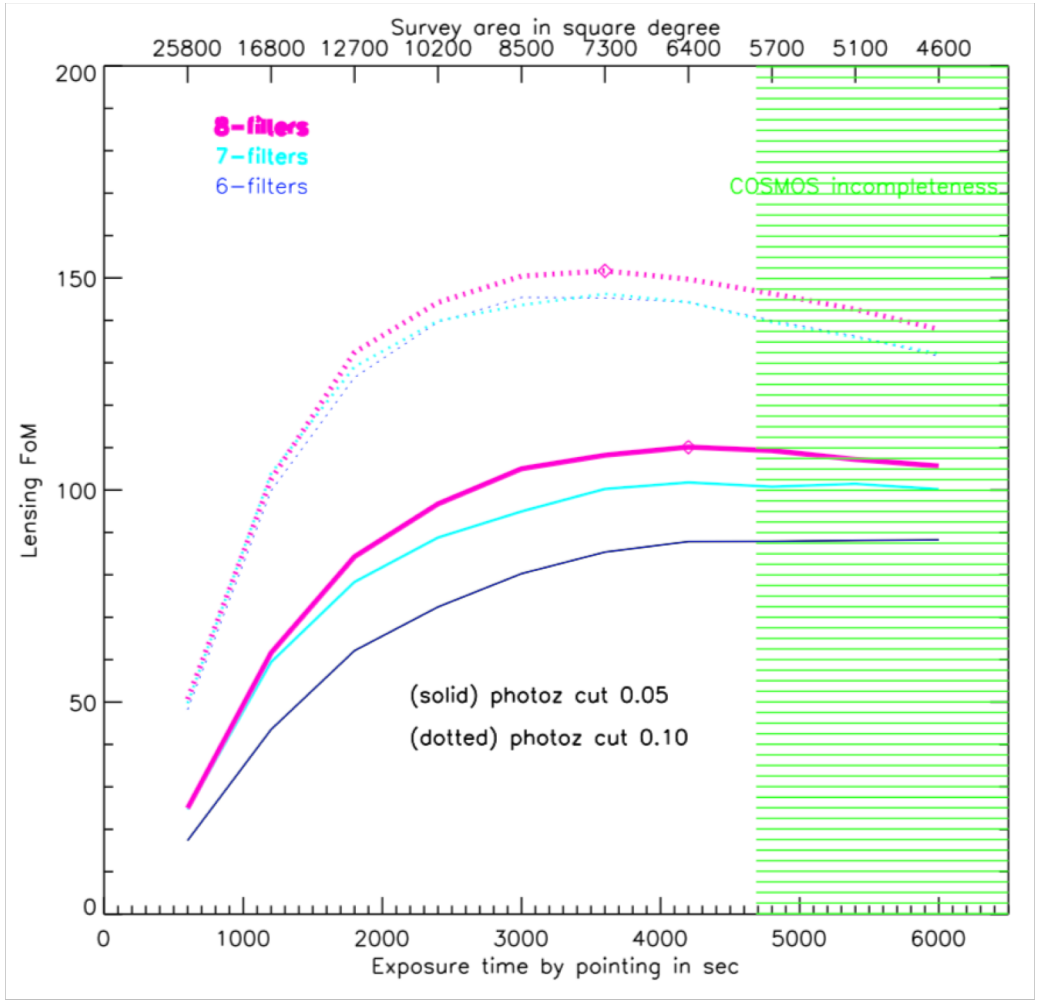


PHOTO-Z SED CALIBRATION

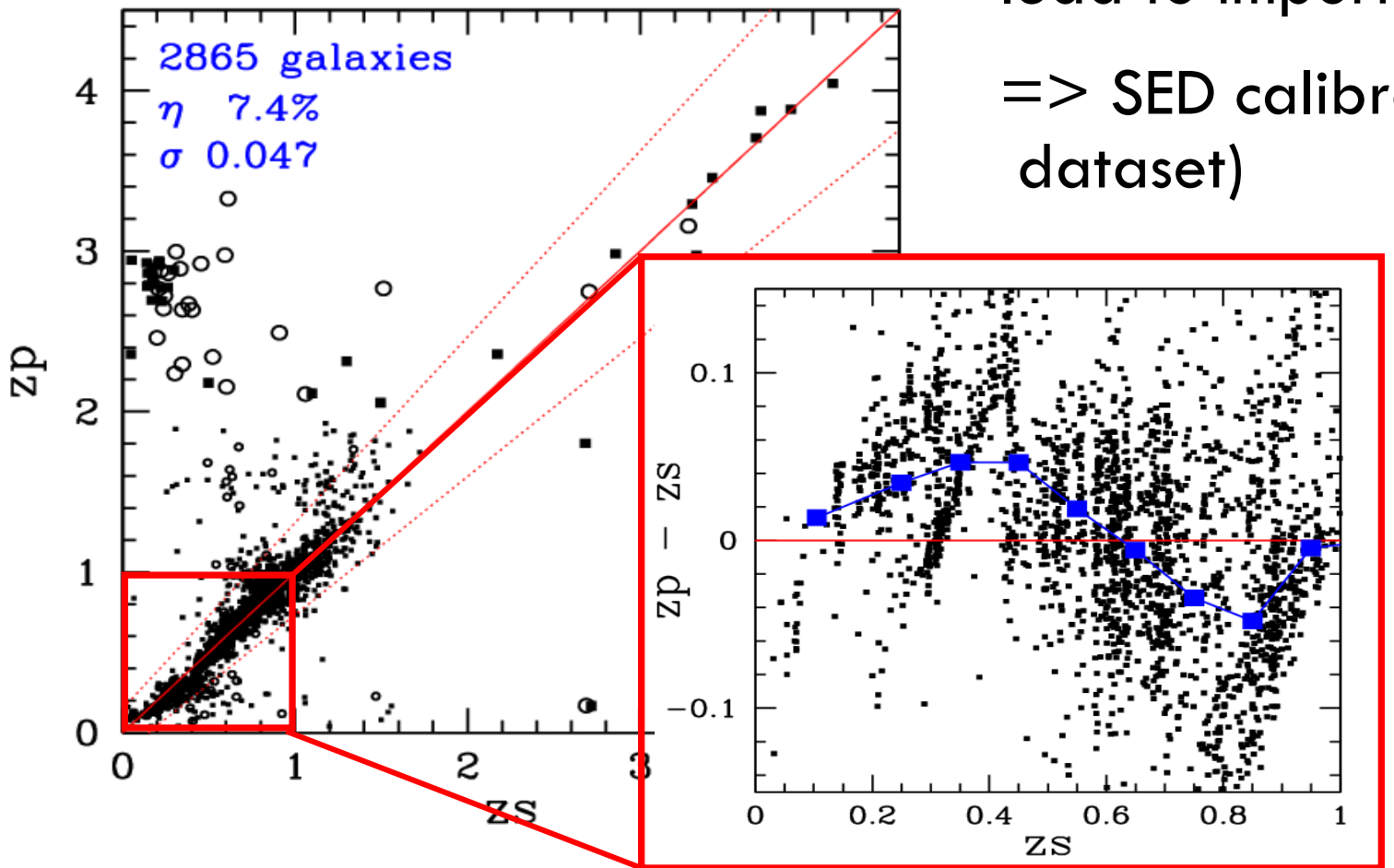
- **Need spectroscopic redshifts !!!** Indeed galaxies SEDs likely evolves with type, redshift, *age, luminosities, metallicity* …
- Redshift calibration should be done ideally on a representative population set: *i.e. similar magnitude, redshift covering galaxy diversity* => implication for the spectro survey
- One may be able to optimize spectroscopic sample [*i.e. one should spend less time on elliptical galaxies than starburst galaxies, one should spend sometime in calibrating e.g. the relatively rare objects such as type-2 AGNs*].

CALIBRATION PROBLEM

SED knowledge limited:

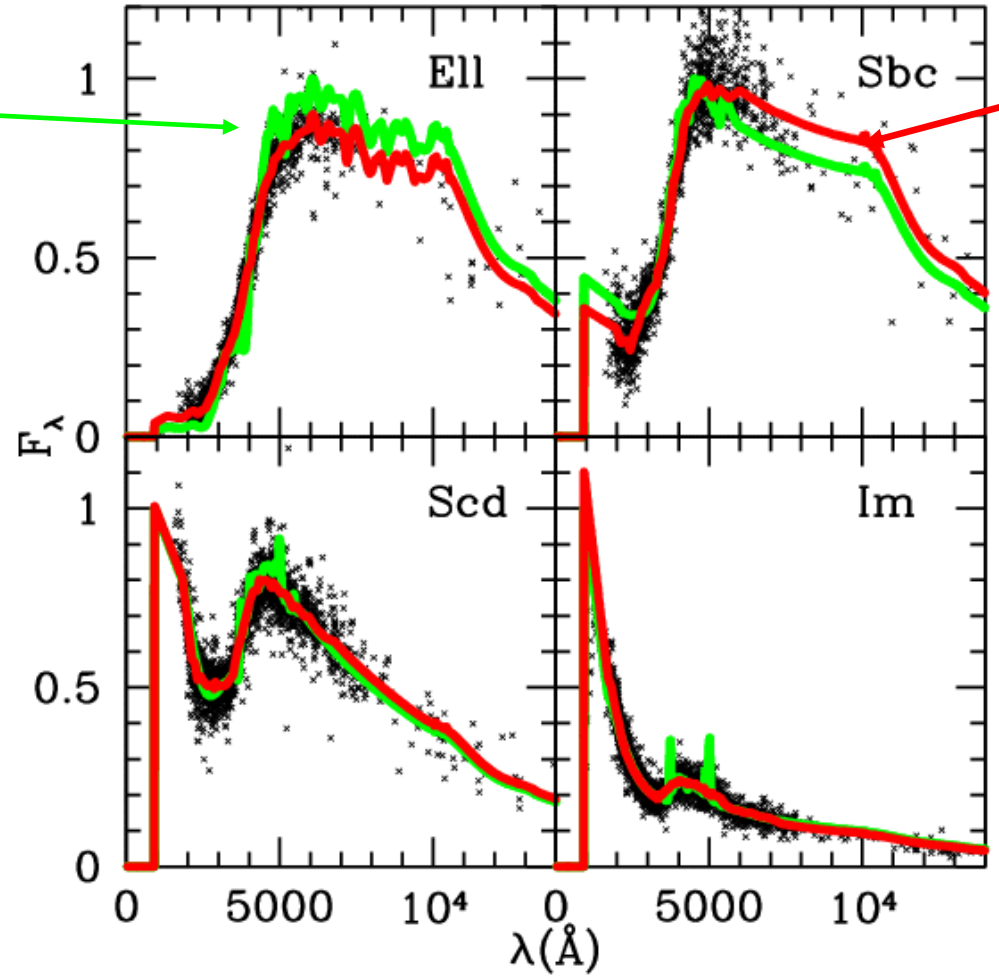
lead to important systematic

=> SED calibration (e.g. CFHT dataset)



CALIBRATION - TEMPLATE OPTIMIZATION

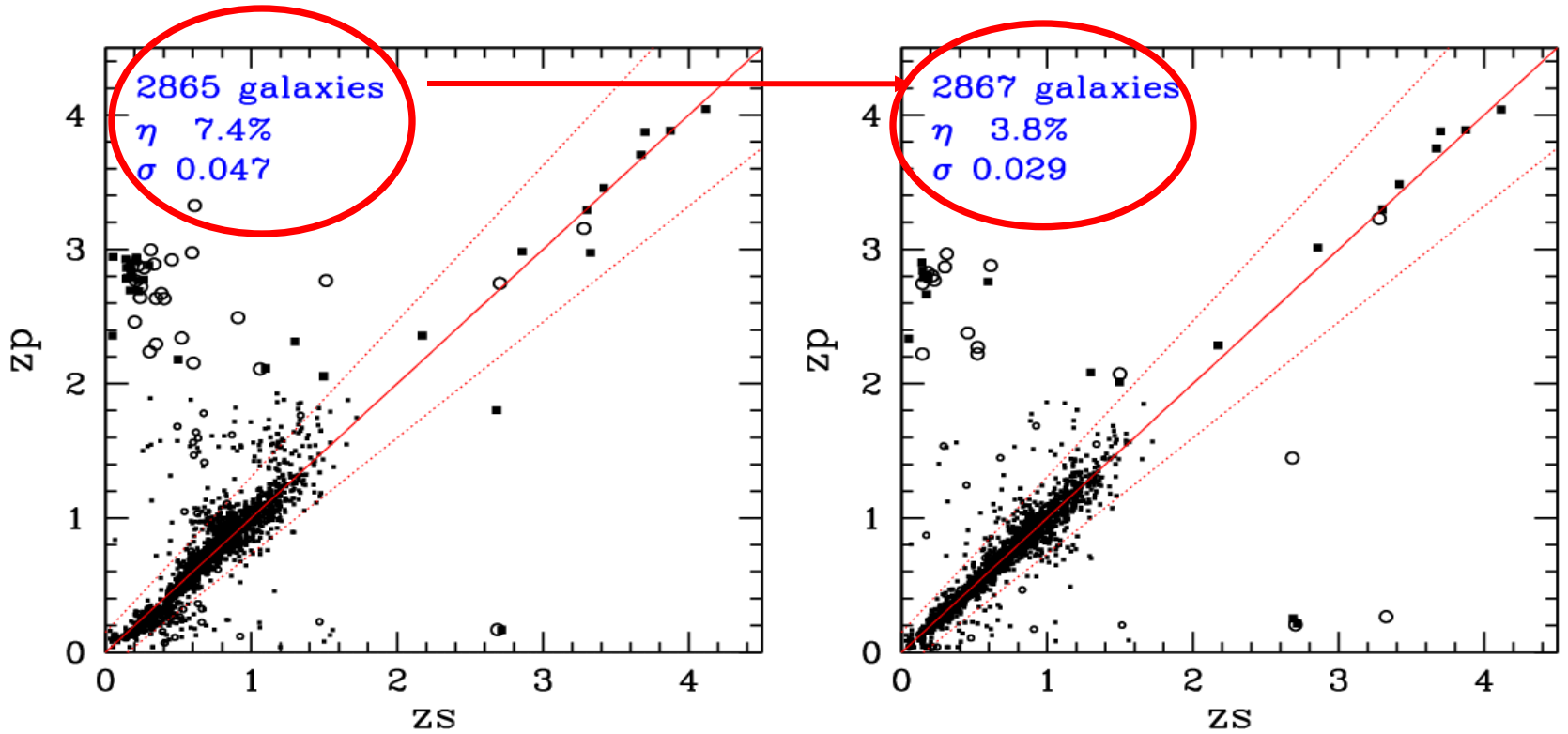
Initial templates



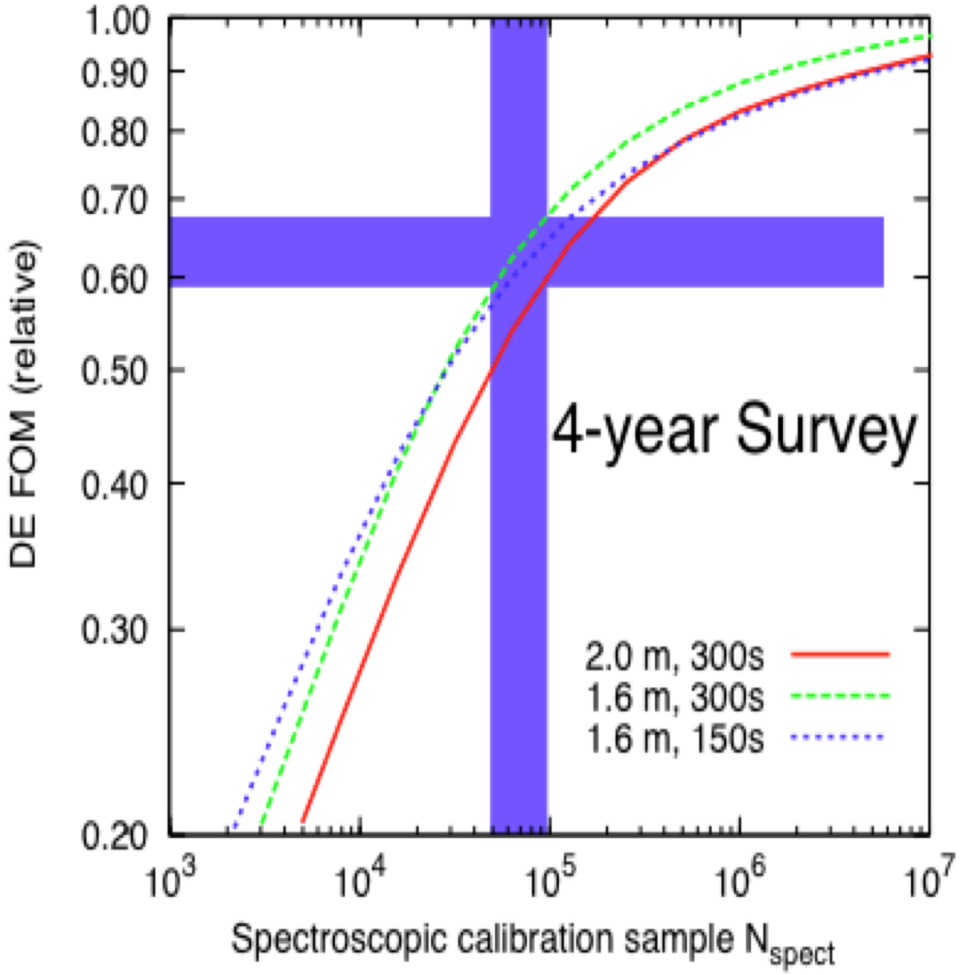
Optimized templates

Example: Optimize the 4 templates with 2800 spectroscopic z (CFHT-LS+VVDS)

CALIBRATION - IMPROVEMENT



SIZE OF SPECTROSCOPIC SAMPLE



Analysis by Zhaoming Ma

Shear tomography only

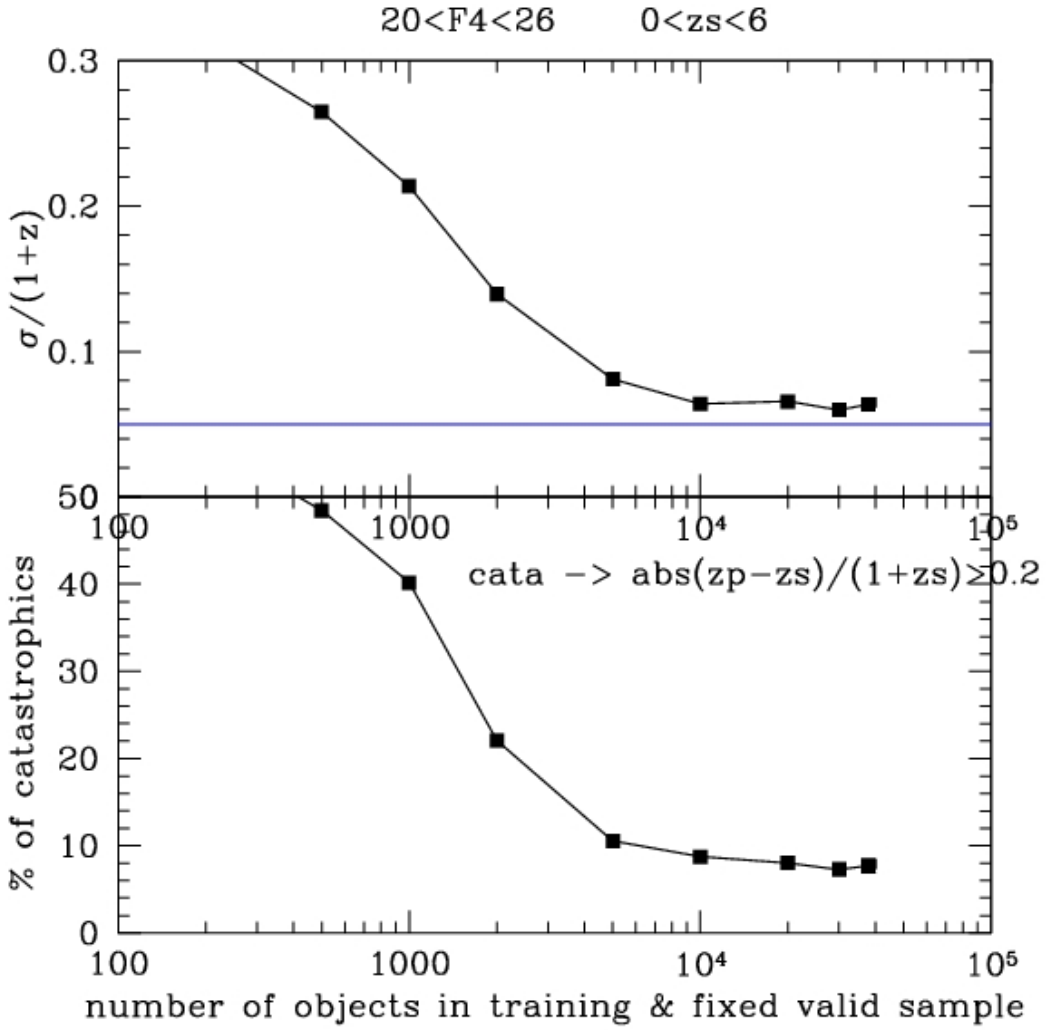
No other systematics

Z survey is only info about photo-z error distribution

Core distribution is double Gaussian with 4 free parameters per 0.1 redshift interval; fiducial distribution is the one generated by LePhare

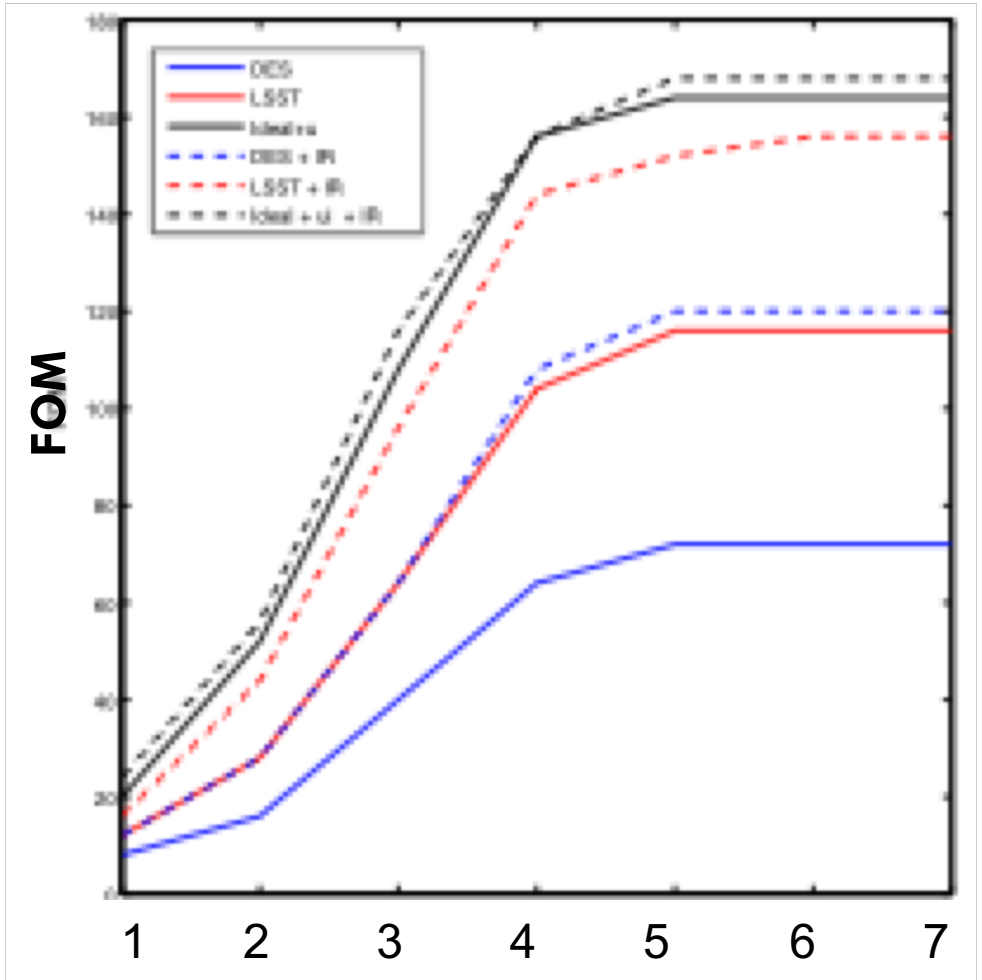
Deeper survey appears to need more redshifts.

NEURAL NET ESTIMATION OF SPECTRO-Z



- COSMOS-SNAP simulation - with limited number of SEDs (8), **requires a minimum 10^4 galaxies with redshift**
- **BUT likely a lower limit, because of simple SED model**

NEURAL NET ESTIMATION OF SPECTRO-Z



Abdalla et al 2007

- Competitors analysis
- Number of redshift for training set of neural-net photo-z ~ number of spectro-z
- DE FOM reach a plateau at **10^5 redshift**

WHAT WE LEARNED FROM SNAP STUDIES

Photo-z accuracy/bias and number of catastrophic depend on:

- Number of filter, filter set, detectors efficiency (blue)
- Photometry calibration
- Spectro-z calibration
- **Survey strategy**

Tools for filter optimisation are ready and recommend:

- **"U-band filter"** => blue sensitivity below 400nm (>30%@400nm, >20%@350nm)
- **Square-ish filter, log scaling, with resolution ~3.2 (for 6-8 filters)**

Crucial need of spectro-z for photo-z calibratrion

- Low dispersion spectroscopy OK
- Need to cover the full population of galaxies probe (mag, z), importance of λ coverage of spectrograph
- N~10^4-10^5 spectroscopic sample needed (NN number) – **possibly N~10^6-10^7**
- importance of spectrograph field of view and **survey strategy**

WHAT WE LEARNED IN THE LAST YEARS

- ***SNAP* was not selected – died in 2008**
- ***Euclid* too small to do photo-z from space – do only IR, rely on LSST for Photometric redshift**
- But having 2 facilities with different timescale, objectives, survey strategy, collaboration, systematics … will not make things simple … and we will have to wait the end of both experiments to make the best of the two measurements
- *Self-contained experiment better!*
- Lots of improvement in photo-z techniques (**but intrinsic limitations are given by the observations/survey strategy**)
- **Important to optimize the telescope/filter-set for best photo-z measurement**
- Spectroscopic survey important for calibration (BOSS/eBOSS, MUSE, DESI, PFS, MOONS, SDSS-V … are all these enough? Or not?)