Paris DUEL Summer School 2009

Lecture III: Photometric Redshifts and the `BPZ` code

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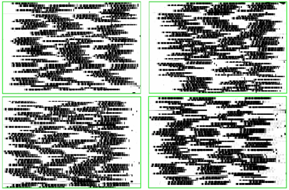
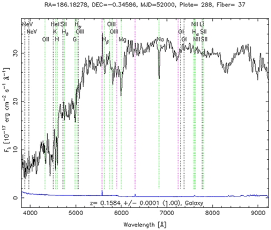
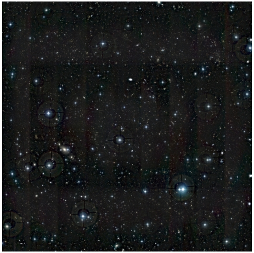
Spectroscopy vs. Photometry

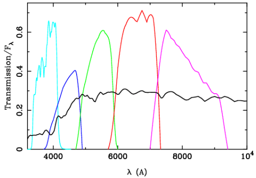
VIMOS@VLT (8m)





MEGAPRIME@CFHT (4m)





$\sim$ 500 objects in one shot,
$t_{\mathrm{exp}} \approx 4\mathrm{h}$ for $I_{\mathrm{AB}} < 24$

$\sim$ 50 000 objects in one shot,
$t_{\mathrm{exp}} \approx 5\mathrm{h}$ for $I_{\mathrm{AB}} < 24$ in *ugriz*

The idea and motivation for photo-*z*s is quite old

This situation has led us to consider alternative methods by which redshifts beyond the present spectrographic range can be adequately estimated. There are, in fact, at least four magnitudes of unexplored territory between the spectrographic limit and the faintest galaxies detectable by direct photography, and it is now clear that observations within that territory will be vital to any definitive cosmological result. In addition, the high precision of spectrographic redshifts is not needed; we can well afford to trade a factor 10 in precision for the opportunity of reaching galaxies at larger distances.

Baum 1957, AJ 62, 6

Main characteristics of photo-zs

- We obtain redshift estimates from *broad- and medium-band* multi-colour photometry. Usual are five optical bands, but many more in exceptional cases (COMBO-17 with 5 broad and 12 medium band filters, COSMOS with 30 filters)
- We accept the lower redshift accuracy of photo-zs ($\Delta z_{\rm phot} \approx 0.1$; $\Delta z_{\rm spec} \approx 0.001$) for individual objects
- We have to deal with *catastrophic outliers*
- We gain considerably in depth and number density of objects

Photo-zs are ideal for large, statistical studies which do not require high-precision on a per object basis. Since 1996 well calibrated and deep multi-waveband surveys together with representative spectroscopic complements are available.

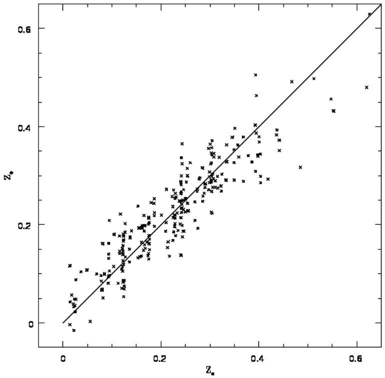
Approaches to photo-zs - Training methods

Polynom fit

$$
\begin{aligned}
z \;=\;& 0.396 + 0.121U - 0.0990B_J - 0.868R_F + 0.803I_N \\
& -0.346UB_J - 0.452UR_F + 0.0914UI_N \\
& +1.256B_JR_F - 0.263B_JI_N + 0.169R_FI_N \\
& -0.008246U^2 - 0.636B_J^2 - 0.485R_F^2 - 0.0177I_N^2
\end{aligned}
$$

- requires a training sample
- establish relation between magnitudes/ colours and spec-z
- systematic photometric errors are absorbed in the training
- high precision possible
- extrapolates badly to *untrained territory*

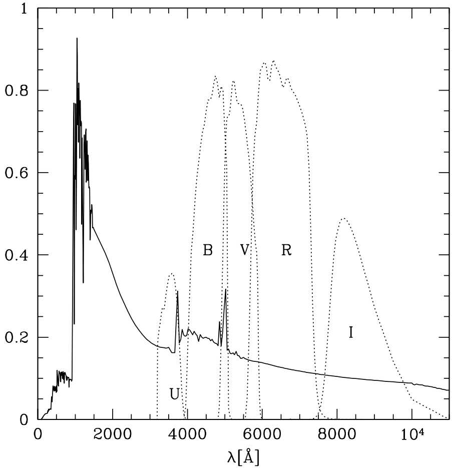
Photo-z vs. Spec-z



(Connolly et al. 1995)

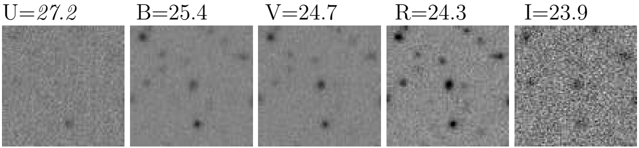
$\Delta z \approx 0.05$!
$B \leq 22.5$; $\Delta m \leq 0.5$!

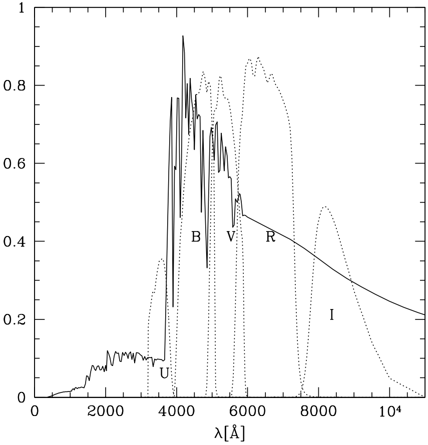
Approaches to photo-zs - Physical Motivations



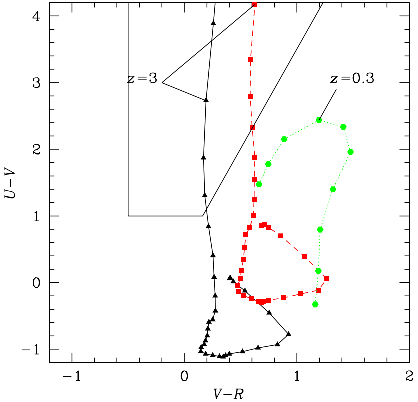
For certain types of galaxies we can identify strong spectral features with *very low resolution* observations in two/three broad-band filters.

Lyman-Break Galaxies

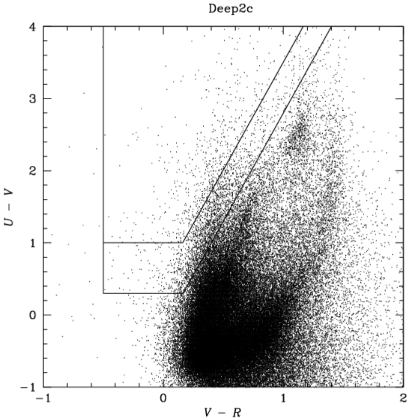




Colour-Selection of Lyman-Break Galaxies



Hildebrandt et al. 2005



Hildebrandt et al. 2007

Characteristics of Lyman-Break Galaxy Searches

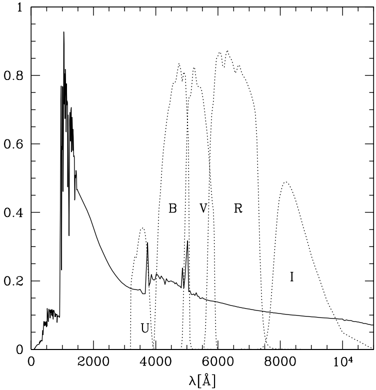
- Highly efficient and cheap method to obtain large samples of high-z sources; the CFHTLS/CARS Deep Fields yield the largest candidate samples to date (80000 candidates with $z = 3 - 5$ in four sq. degrees)
- contamination; you get a certain *probability* that a galaxy is at high z (selection box, magnitude errors).
- *very* accurate photometry required
- Works only for star forming galaxies with high flux in the blue - not representative for the high-z universe

Similar conclusions apply for cluster redshift estimates with RCS.

Approaches to photo-zs - Full Template Fitting

- Templates, Filters, observed fluxes and errors
- 3D model library (templates, filters, z) of theoretical fluxes
- Probability that our observed fluxes belong to a model library point (chi-square function)
- Optional: Inclusion of priors
- Most probable redshift and template!

Filters, SEDs and Fluxes

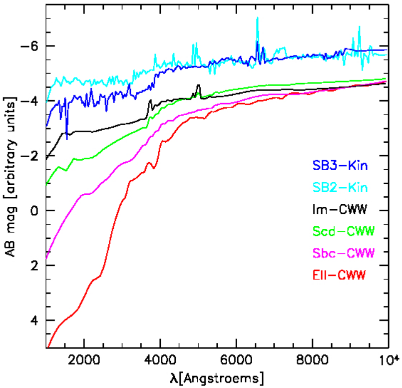


Publicly available codes for template fitting: `EAZY`, `BPZ`, `Hyperz`, `LePhare`, `ZEBRA`, ..

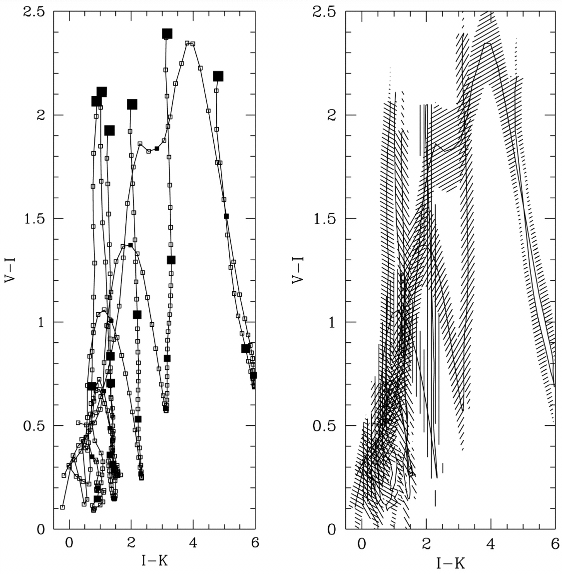
The template set

- Observed galaxy populations should be well represented
- Most widely used templates are spectro-photometric SEDs from Coleman, Wu & Weedman (1980)!
- Considerable improvements by *recalibration* of the CWW templates
- The largest uncertainty for template fitting

CWW template set

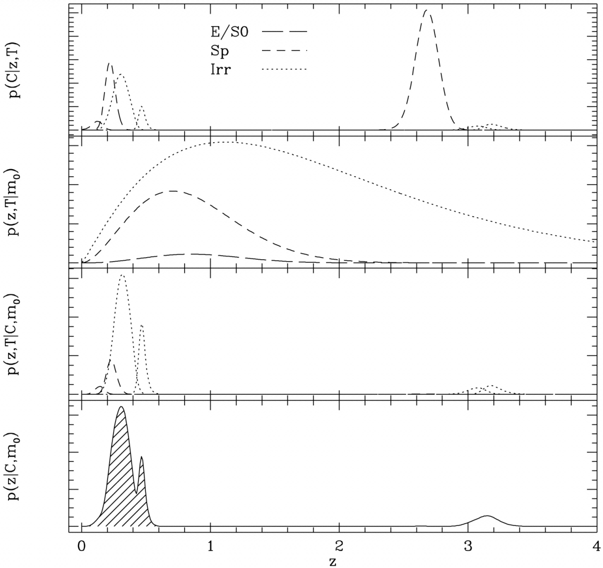


Why use priors priors?



Benitez 2000, ApJ 536, 571

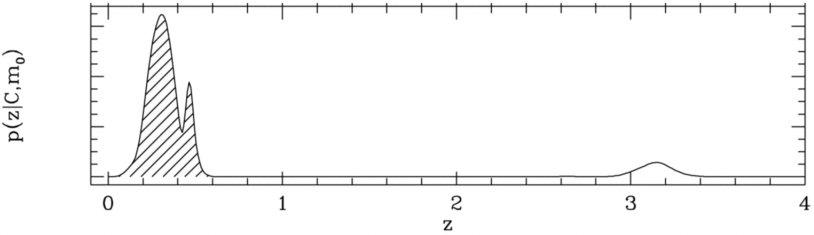
BPZ redshift estimation



Benitez 2000, ApJ 536, 571

BPZ- Empirical ODDS

Besides reporting the most probable (in a Bayesian sense) redshift as Z_B, BPZ also puts out the empirical odds of this redshift solution.

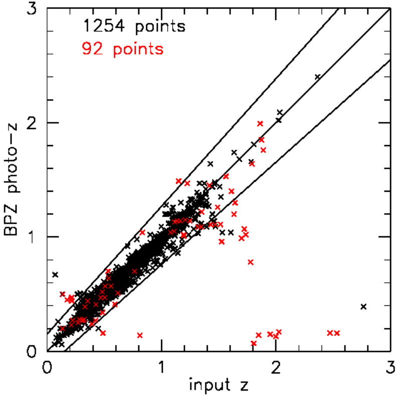


from Benitez 2000, ApJ 536, 571

This ODDS output parameter is a very robust measure of the redshift quality. Low ODDS is a sign for double-peaked posterior probability functions.

Quality assessment with spectro-z

Simulation in g'r'i'z'



ODDS distribution in real data

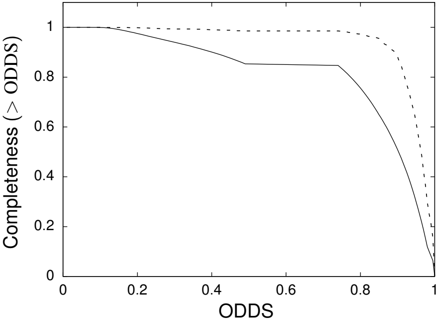
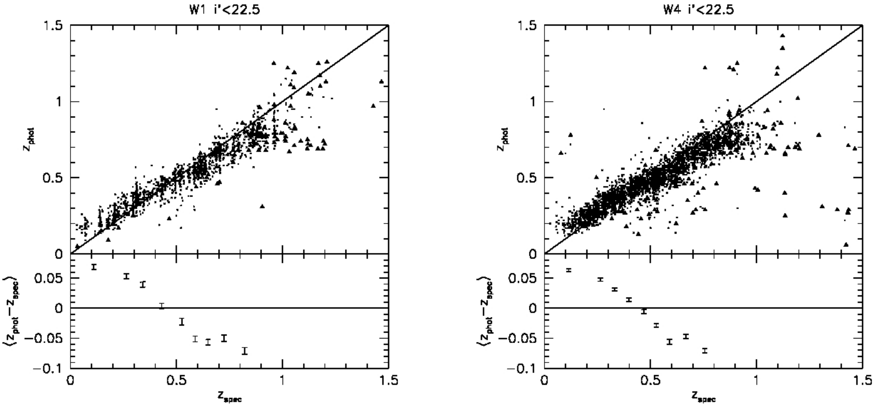


Photo-z error quantities: outlier rate: $|\Delta z/(1+z)| > 0.15$; $\sigma_{\Delta z/(1+z)} \approx 0.03 - 0.05$ (after rejecting outliers!)

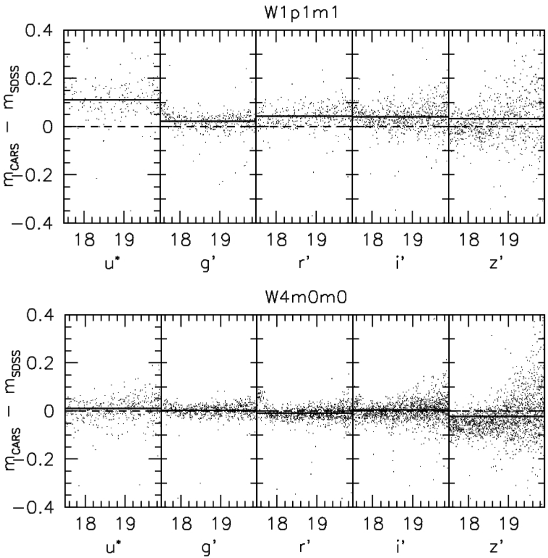
Probably 20% of our *real* galaxies are not well represented by the CWW template set.

Our first try with BPZ on the CFHTLS/CARS data

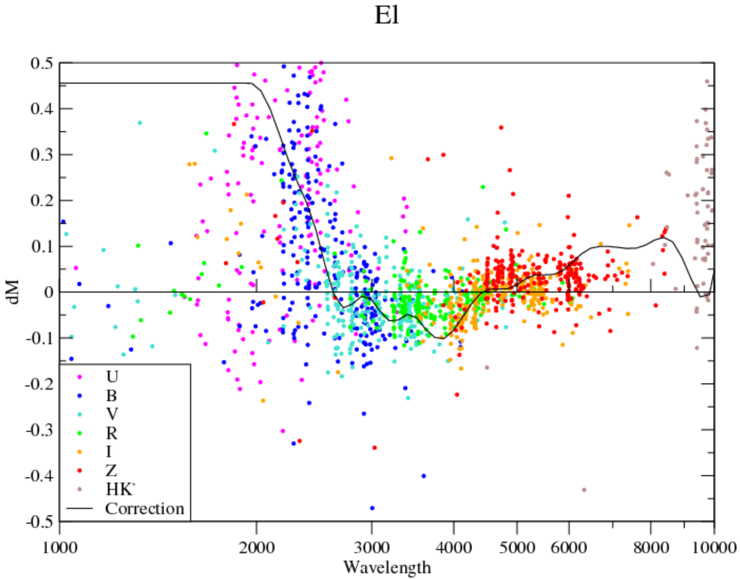


Good average agreement ($\sigma_{\Delta z/(1+z)} \approx 0.04 - 0.05$); a few percent outliers) but clear systematics visible!

Verification of Photometric Calibration



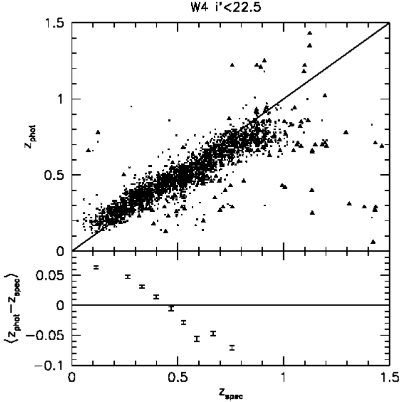
Verification and Recalibration of Templates



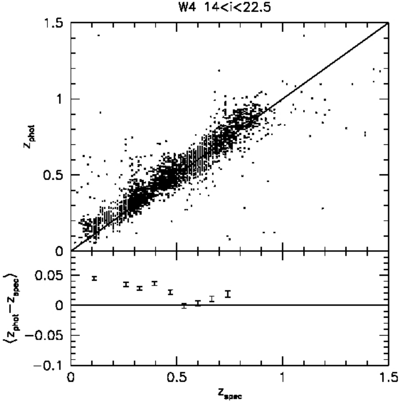
from Capak 2004, Ph.D. Thesis, AA (University of Hawai'i)

Our second try with `BPZ` on the CFHTLS/CARS data

We can determine photo-z's with about $\sigma_{\Delta z/(1+z)} \approx 0.03 - 0.04$ and an outlier rate of about 4%.

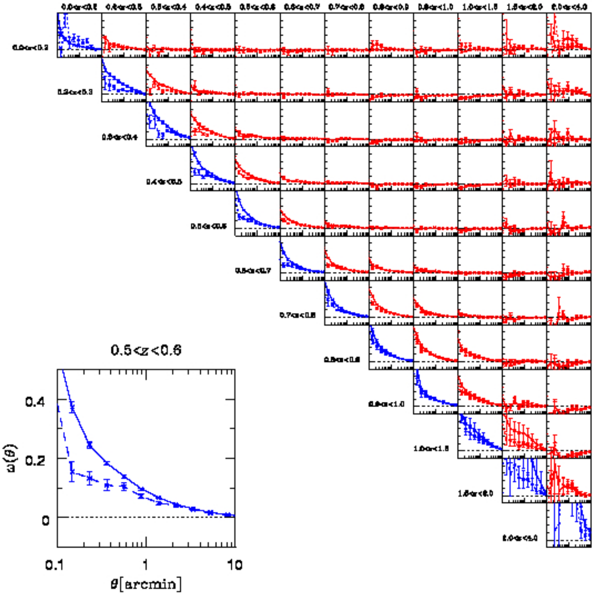


first try: photo-z with zeropoint recalibration (spectro-z)



second try: photo-z after template optimisation, prior adjustment - NO zeropoint recalibration!

Internal Photo-z quality checks



Other important technicalities

- How are not detected - not observed filters treated; estimation of limiting magnitudes. We treat all problematic filters as not observed - `BPZ` does not use them in template fitting
- Various forms of dust (in the observed galaxies, Milky Way, intergalactic dust). We use a mean correction for dust in the Milky Way
- Photo-z codes typically *increase* the basic template set by interpolation or taking into account dust. In `BPZ` we use five interpolations
- magnitude error estimates (Zeropoint errors, convolution to the same seeing). We add an error of 0.05 in quadrature to `SExtractor` error estimates