METAPHOR

Machine-learning Estimation Tool for Accurate Photometric Redshifts

V. Amaro[1], S. Cavuoti[2], M. Brescia[2], C. Vellucci[1], G. Longo[1,3]

1 - University of Napoli Federico II, Naples
2 - INAF- Astronomical Observatory of Capodimonte, Naples
3 - California Institute of Technology-Center for data driven discovery, Pasadena, USA

A reliable PDF should be able to:

1) evaluate photometric error distributions;

2) assess the correlation between spectroscopic and photometric errors;

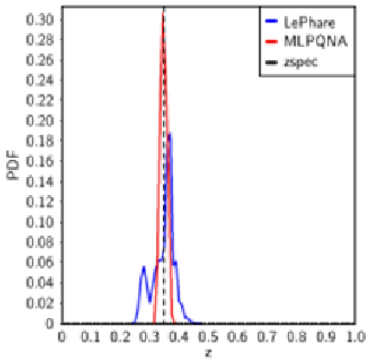
3) disentangle photometric uncertainties from those intrinsic to the ***method*** itself.

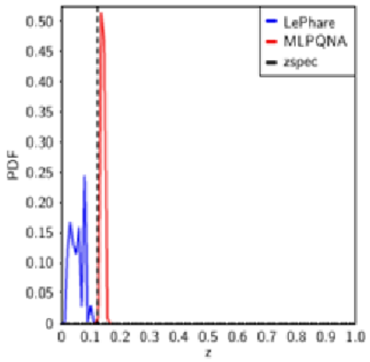
Source PDFs contain more information than simple redshift estimates. PDF's are able to improve the accuracy of cosmological measurements (Mandelbaum et al. 2008-2015).

Many PDF methods for ML have been developed over the past years, mostly based on:

- Supervised methods (ANN, RF, MLP, used both as regressors and classifiers)
- Unsupervised methods (SOMs, random atlas)

Rau et al. 2015, MNRAS, 452
Carrasco & Brunner 2013, MNRAS, 442
Bonnet 2013, MNRAS, 449
Sadeh et al. 2015, arXiv:1507.00490
Speagle et al. 2015, arXiv:1510.08073



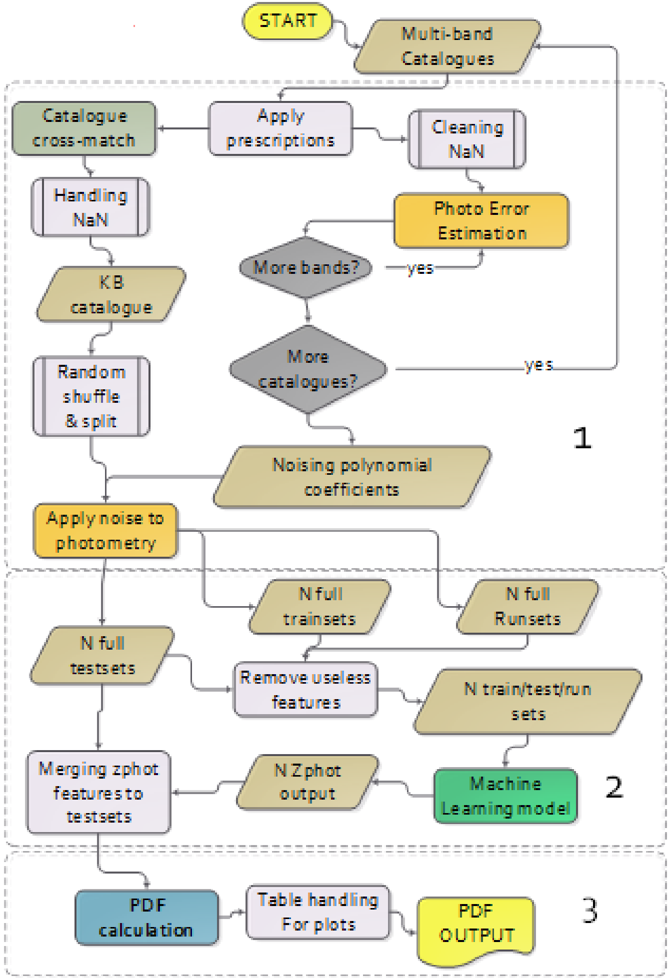


METAPHOR workflow

Data pre-processing:
KB preparation +
Photometry perturbation

Photo-z Prediction: train/test phase by means of any arbitrary ML model (in our case the multi-threading MLPQNA)

Probability Density Function Estimation



Cavuoti et al., 2017

MLP+ (QNA)/(LEMON)

METAPhoR embeds a multi-thread version of MLPQNA, made by a Python wrapper, to improve training computational performance

The model architecture is a standard 4-layers Multi Layer Perceptron trained by:

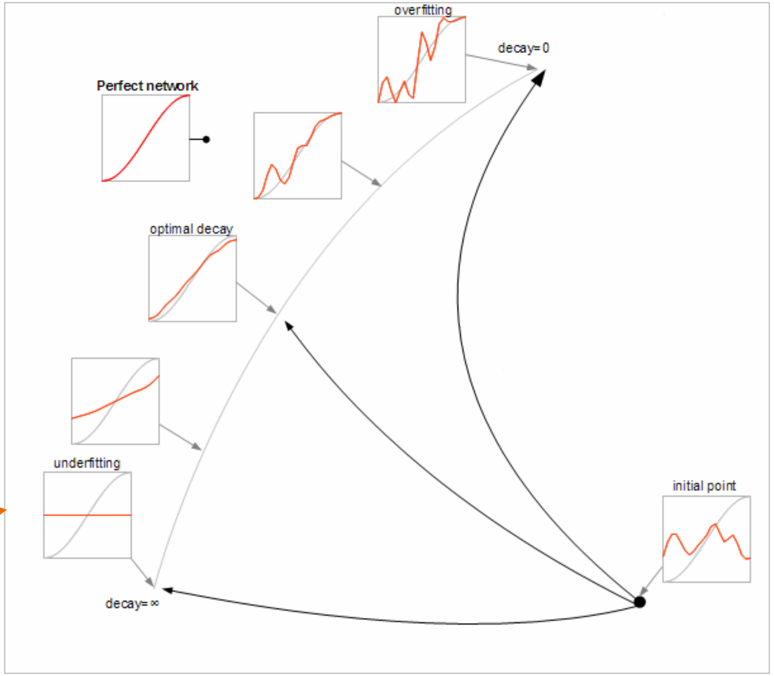
QNA rule, based on the L-BFGS algorithm (limited memory BFGS), implementing the Quasi-Newton algorithm

One command-line parameter may switch to the use of an alternative learning rule, called **LEMON** (Levenberg-Marquardt Optimization Network)

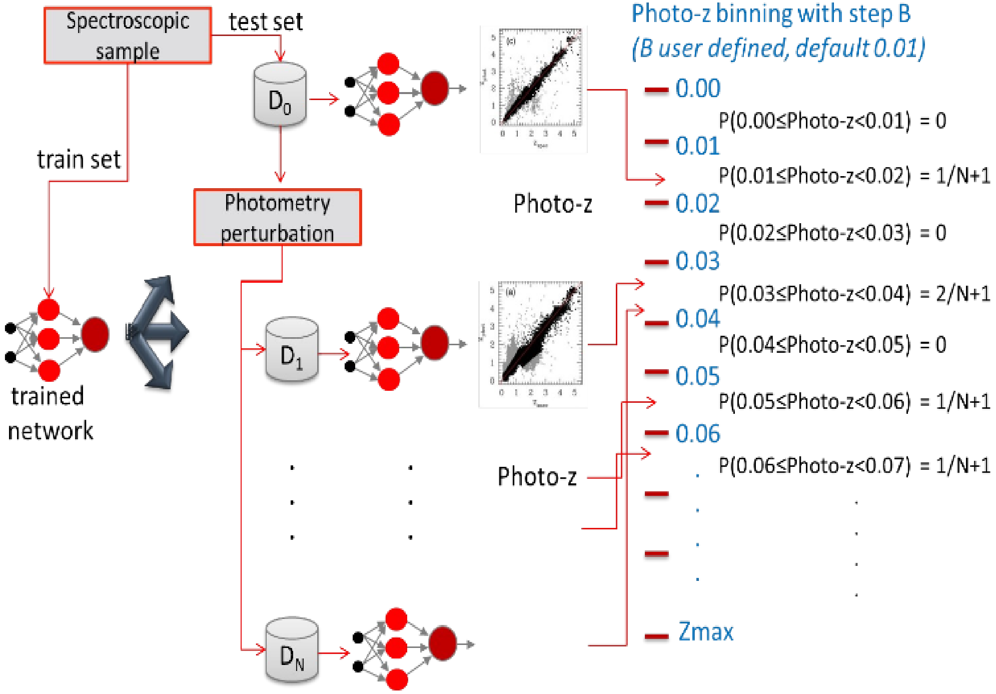
Regression error: Least Square error + Tikhonov regularization

$$E = \sum_{i=1}^{Npatterns} \frac{(y_i - t_i)^2}{2} + \frac{\|W\|^2 \lambda}{2}$$

decay



PDF estimation algorithm scheme



1. INPUT: the KB (train + test sets), the photo-z binning step B (by default 0.01) and the zspec Region of Interest (RoI) [Z_{min}, Z_{max}] (*a typical use case is [0,1]*);
2. Produce N photometric perturbations, thus obtaining N additional test sets;
3. Perform 1 training (or N +1 trainings) and N +1 tests;

$PDF(photo\text{-}z) = (P(Z_i \leq photo\text{-}z < Z_{i+B}) = C_{B,i}/N+1)_{[Zmin,Zmax]}$;

4. Derive: number of photo-z bins (Z_{max}-Z_{min})/B; N+1 photo-z estimations; the number of photo-z $C_{B,i} \in [Z_i, Z_{i+B}[$;

The photometry perturbation procedure

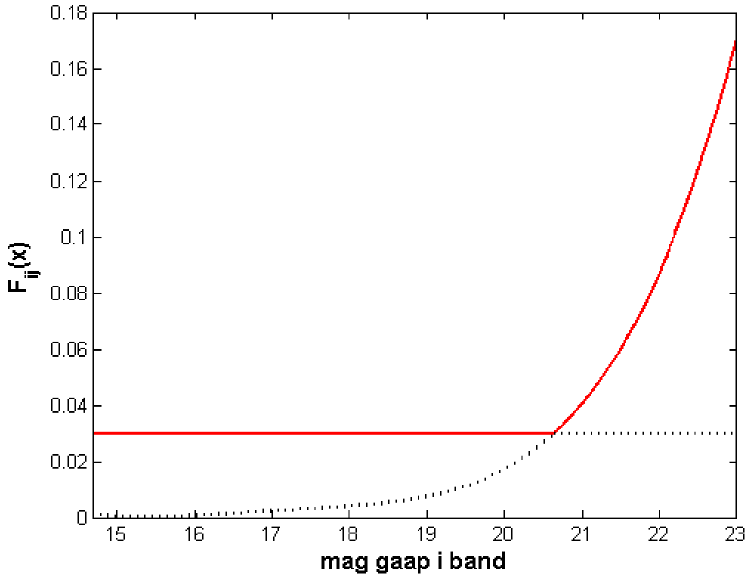
At the very base of the capability to determine a PDF in ML there is a photometry perturbation law

$$m_{ij} = m_{ij} + \alpha_i F_{ij} * \ gaussRandom_{(\mu=0,\sigma=1)}$$

- α_i is a multiplicative constant defined by the user;
- $F_{ij}(x)$ is the weighting associated to each specific band used to weight the Gaussian noise contribution to magnitude values;
- $gaussRandom\ (\mu=0, \sigma=1)$ is the random value from the normal standard;
- In particular $\alpha_i F_{ij}$ is the term used to generate the set of perturbed replicates of the blind test set.

Generally, we can identify and test different types of weighting coefficients:

- **constant weight (flat);**
- **individual magnitude errors (indiv.);**
- **polynomial fitting (poly.);**
- **bimodal function (bimod.).**



$\alpha_i = \underline{0.9}$; $thresh = 0.03$; $Npert = 1000$ for all the bands

The photometry perturbation procedure

At the very base of the capability to determine a PDF in ML there is a photometry perturbation law

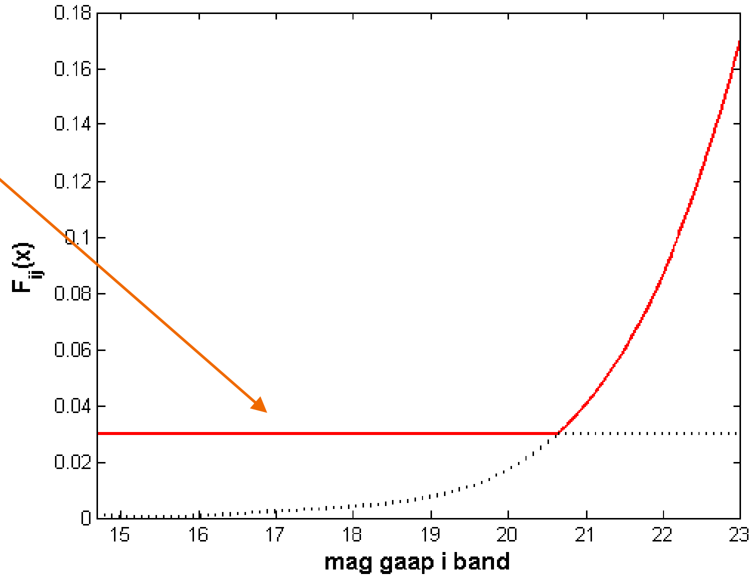
$$m_{ij} = m_{ij} + \alpha_i F_{ij} * \; gaussRandom_{(\mu=0, \sigma=1)}$$

- α_i is a m
- $F_{ij}(x)$ is
  used to
  magnitu
- *gaussRa*
  the norm
- In partic
  set of p

F_{ij} has been chosen as a bimodal function, i.e. with a constant value representing a threshold under which the polynomial function is considered too low to provide a significant noise contribution to the perturbation

Generally, we can identify and test different types of weighting coefficients:

- **constant weight (flat);**
- **individual magnitude errors (indiv.);**
- **polynomial fitting (poly.);**
- **bimodal function (bimod.).**



The photometry perturbation procedure

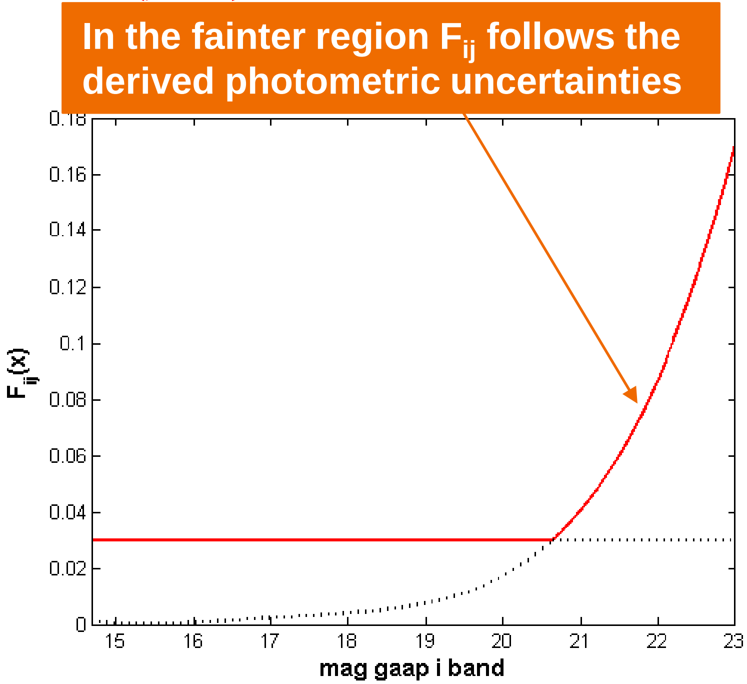
At the very base of the capability to determine a PDF in ML there is a photometry perturbation law

$$m_{ij} = m_{ij} + \alpha_i F_{ij} * \ gaussRandom_{(\mu=0, \sigma=1)}$$

- α_i is a multiplicative constant defined by the user;
- $F_{ij}(x)$ is the weighting associated to each specific band used to weight the Gaussian noise contribution to magnitude values;
- *gaussRandom* $(\mu=0, \sigma=1)$ is the random value from the normal standard;
- In particular $\alpha_i K_{ij}$ is the term used to generate the set of perturbed replicates of the blind test set.

Generally, we can identify and test different types of weighting coefficients:

- **constant weight (flat);**
- **individual magnitude errors (indiv.);**
- **polynomial fitting (poly.);**
- **bimodal function (bimod.).**



METAPHOR statistics output

Statistics provided for Δz=(zspec-zphot)/(1+zspec) on the blind test set:

bias, standard deviation, NMAD, σ_{68} (*radius of the region including 68% of residuals close to 0*), $\eta_{0.15}$ (*fraction of outliers with* $|\Delta z| > 0.15$), skewness (asymmetry);

for the cumulative PDF performance, three estimators on the stacked residuals of the PDFs:

$f_{0.05}$: percentage of residuals within 0.05;

$f_{0.15}$: percentage of residuals within 0.15;

$< \Delta z >$: weighted average of all residuals of stacked PDFs.

METAPHOR for KiDS DR3

For the training , we used a KB prepared as follows:

- 214 tiles of KiDS cross-matched with SDSS DR9 and GAMA DR2; → **#120,047 objects** before the mag distribution tails cuts and NaN removal
- Parameter Space: a total of **12 magnitudes**, in four bands *ugri* (4",6" apertures + GAaP), and **9 derived** natural colours, for a total of **21 features**;
- Two experiments performed with two KBs :
- *i)* $0.01 \leq zspec \leq 1$;
- *ii)* $0.01 \leq zspec \leq 3.5$

Band	lower cut limit	upper cut limit
MAG_APER_20_U	16.8	28.5
MAG_APER_30_U	16.8	28.1
MAG_GAAP_U	16.8	28.8
MAG_APER_20_G	16.2	24.4
MAG_APER_30_G	15.8	24.6
MAG_GAAP_G	16.0	24.5
MAG_APER_20_R	15.3	23.2
MAG_APER_30_R	15.0	23.3
MAG_GAAP_R	15.1	23.3
MAG_APER_20_I	14.9	22.8
MAG_APER_30_I	14.6	23.0
MAG_GAAP_I	14.8	23.0

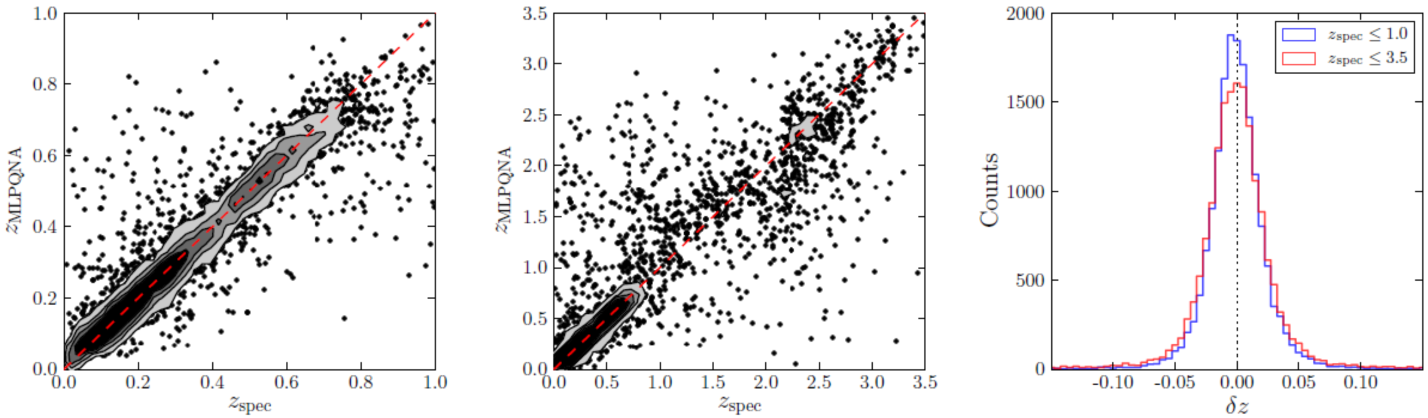
The final KBs consisted in:

i) 66,731 train and 16,742 test samples;

ii) 70,688 train and 17,559 test samples.

METAPHOR for KiDS DR3: Results

Statistics	$i)0.01 \leqslant z_{spec} \geqslant 1$	$ii)0.01 \leqslant z_{spec} \geqslant 3.5$
δz	0.0014	0.0063
σ	0.035	0.101
$NMAD$	0.018	0.022
$outliers$	0.93%	3.4%



de Jong et al. 2017

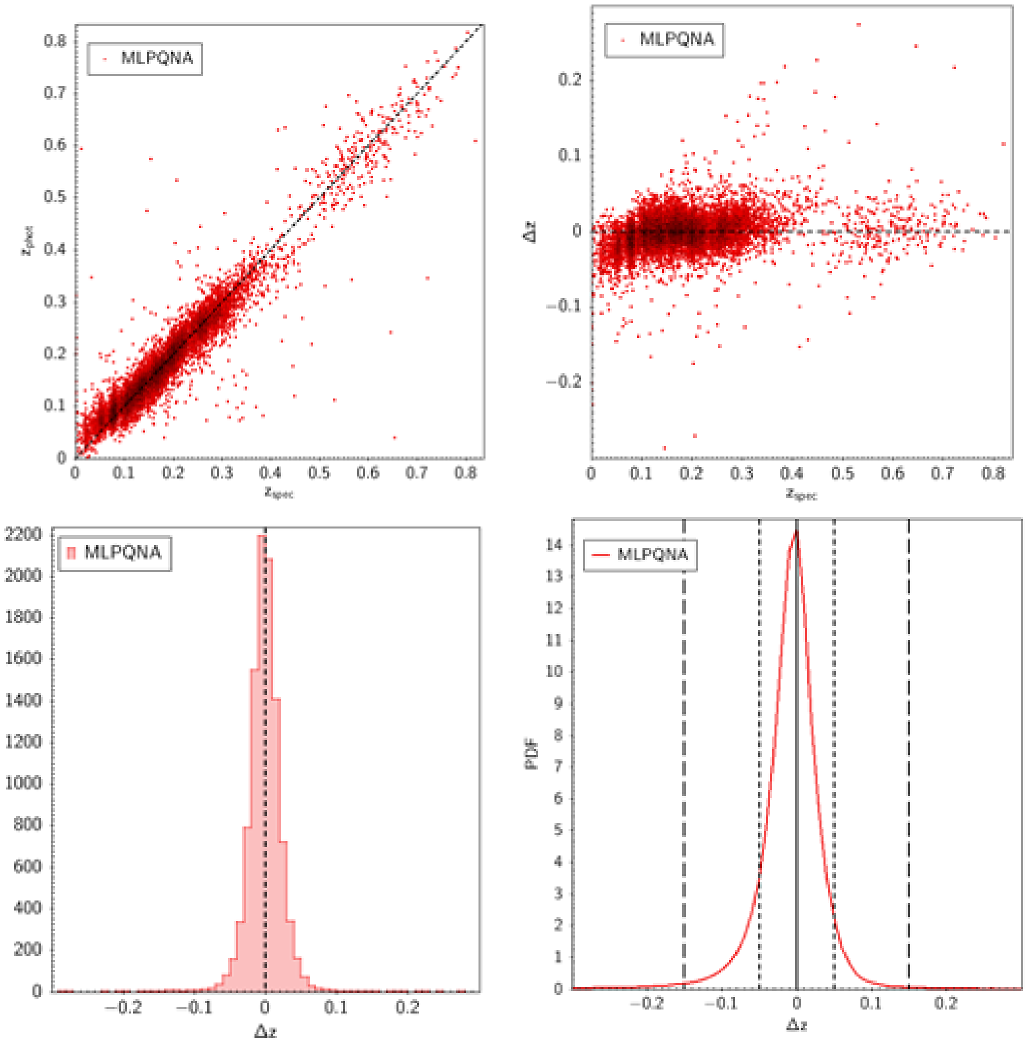
KiDS DR2 results with METAPHOR

Estimator	MLPQNA
mean	−0.0007
sigma	0.026
sigma68	0.018
NMAD	0.018
outliers>0.15	0.31%

Estimator	MLPQNA
$f_{0.05}$	81.3%
$f_{0.15}$	98.4%
$\langle \Delta z \rangle$	−0.0084

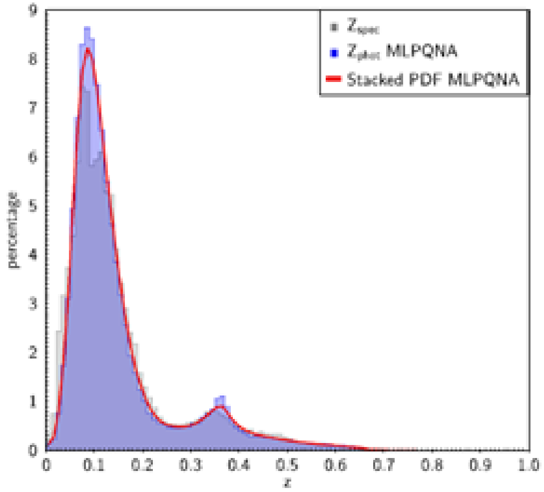
KB consisted of 15,180 training and 10,067 blind test objects

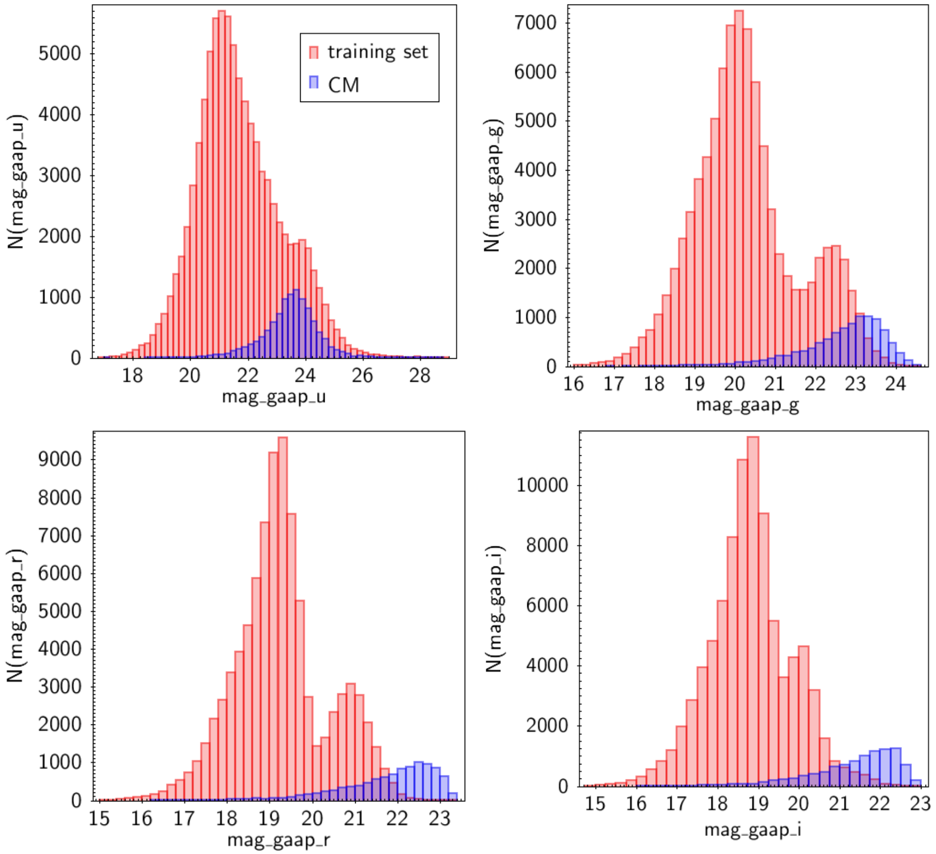
Cavuoti et al. 2015, MNRAS, 452



Ongoing analysis on KiDS DR3

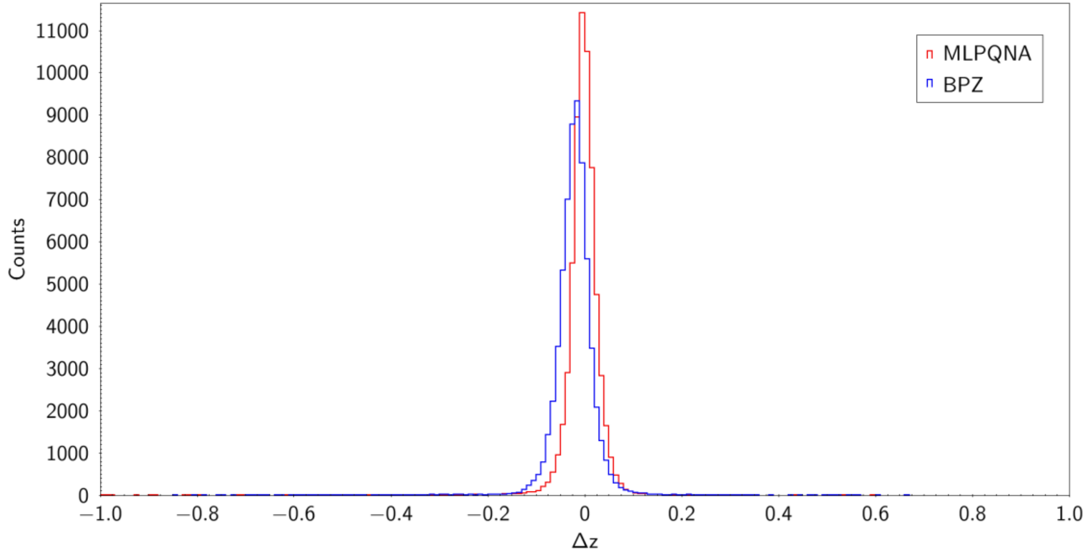
- Comparison of the overall photo-z statistics and of the stacked PDF performance of METAPHOR with respect to BPZ in the COSMOS and GAMA spectroscopic fields
- Further comparison among methods (*Bilicki et al, 2017, in prep*.)





CM is the cross-match between zCosmosBright and KiDS DR3 training set (SDSS + GAMA)

Ongoing analysis on KiDS DR3: preliminary results



Residuals distribution for the cross-match KiDS DR3-GAMA, comparison between MLPQNA and BPZ

On the stacked PDFs

KiDS CM GAMA	MLPQNA
$f_{0.05}$	63.2%
$f_{0.15}$	96.6%
$<\Delta z>$	-0,027

Conclusions

- **General applicability** : METAPHOR can be applied with any arbitrary empirical photo-z estimation model. It is able to take into account photometric errors due to both measurements and ***method*** itself;

- **Perspectives:** Besides the ongoing comparison between METAPHOR and BPZ KiDS DR3 PDFs, METAPHOR is going to be used for cosmology through weak lensing;

- Under preliminary testing in Euclid PHZ pipeline;

- Available for other surveys on request.