Deep Learning Based Photometric Redshifts of Galaxies in Kilo-Degree Survey

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How to measure Redshift?

Spectroscopic way

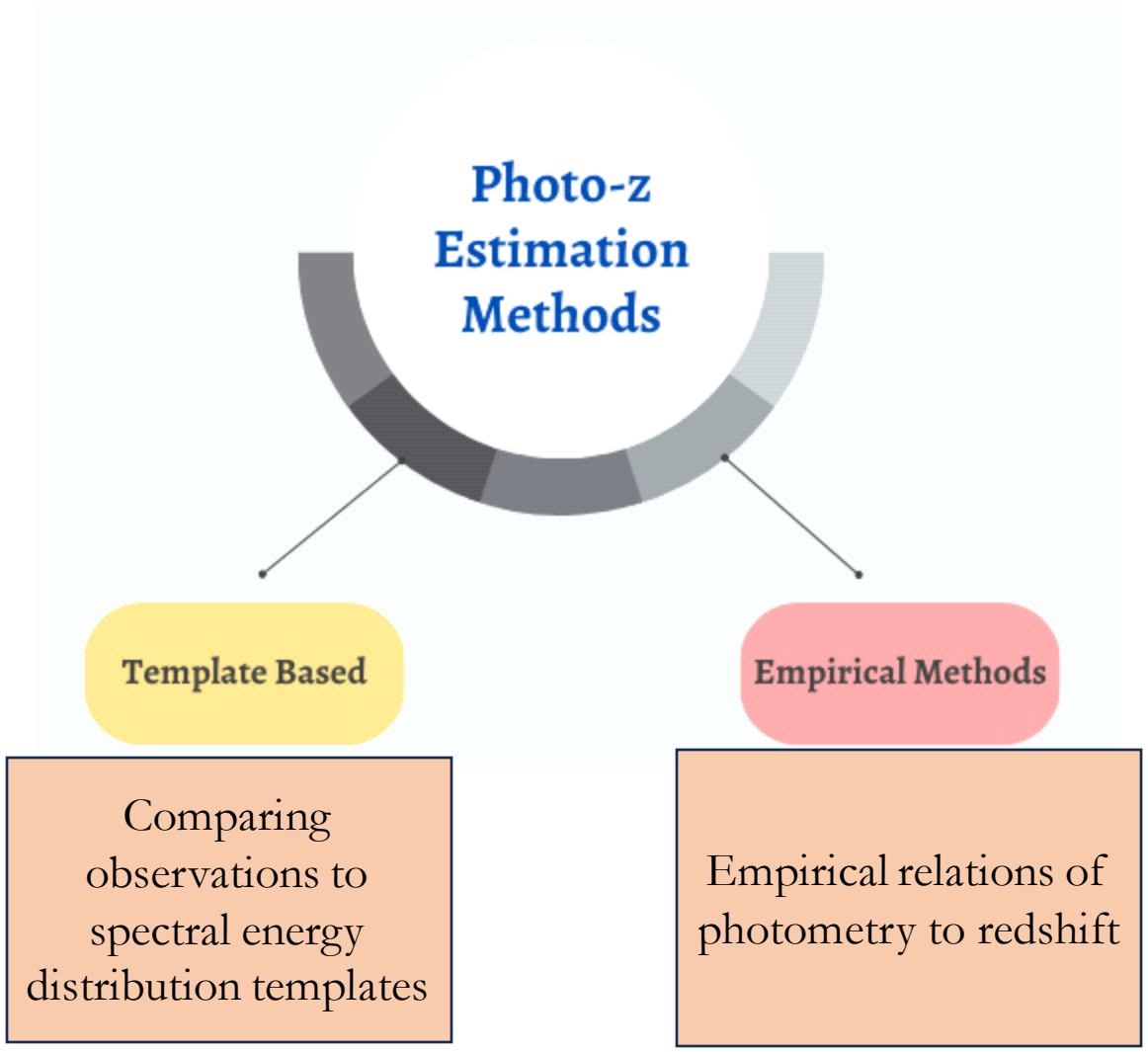
- Measuring the shift in spectral lines
- Spec-z

Photometric way

- Based on observed **photometric quantities**
- Mapping of photometric space into redshift space.
- Photo-z

- The measurable quantities or characteristics of an object's light.
- Derived from the object's intensity or flux measurements.

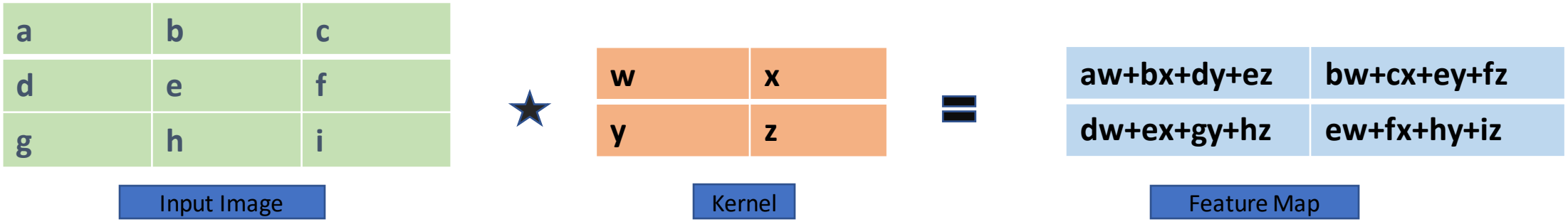
Photo-z estimation methods



- Deep learning based estimation is an empirical method.
- Convolutional Neural Network (CNN) is used for photo-z estimation of galaxies in Kilo-Degree Survey (KiDS).
- KiDS is a wide-angle image campaign using broad band optical filters (u,g, r and i).

Convolution

- Small matrix of weights – Kernel/Filter
- Convolved with input data to extract features such as edges, corners etc. of input data.



- Activation function is applied in feature map to introduce non-linearity into the network.

Feature Extraction

- Dense layer performs high-level feature extraction based on low-level features learned by the convolutional layers and pooling layers.

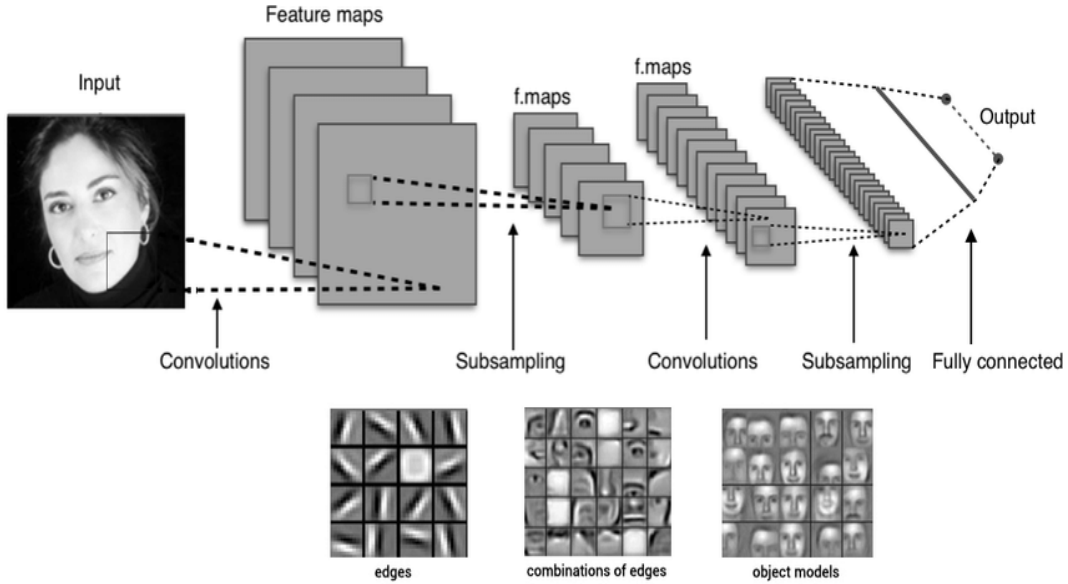
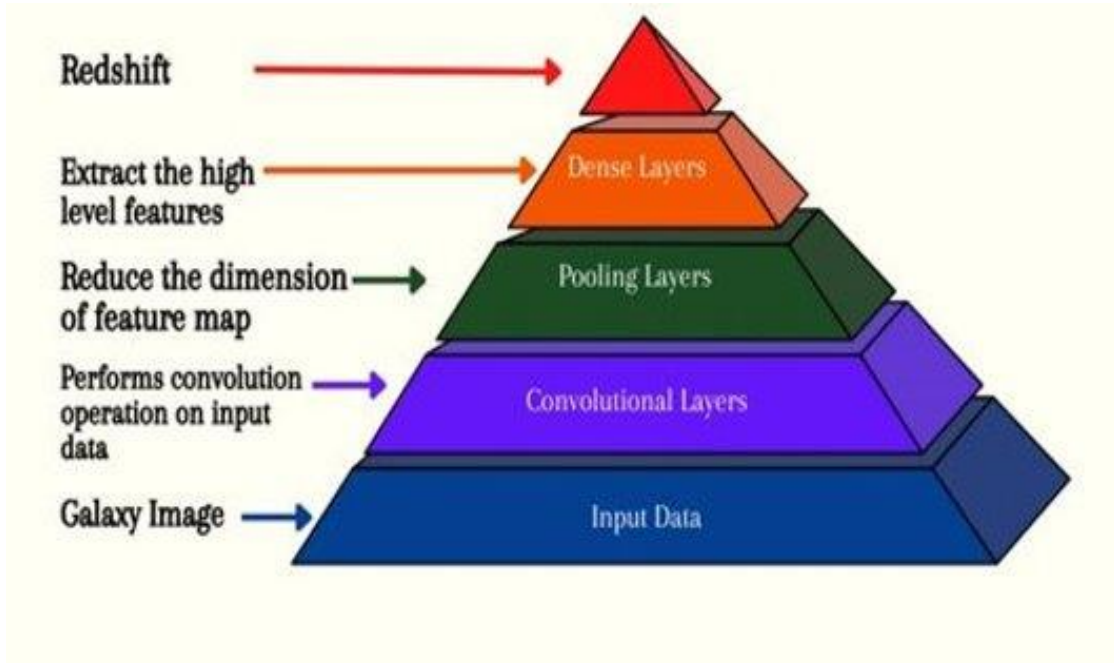
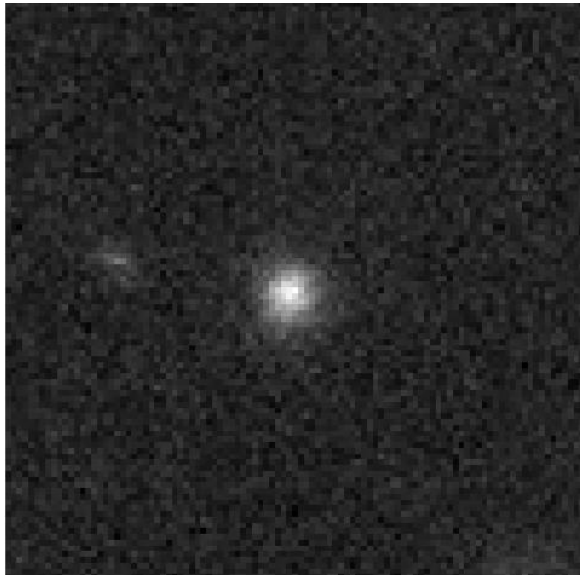


Image credit: Deep Feature Extraction for Sample-Efficient Reinforcement Learning
[Daniele Grattarola]


Redshift
Extract the high level features
Reduce the dimension of feature map
Performs convolution operation on input data
Galaxy Image
Dense Layers
Pooling Layers
Convolutional Layers
Input Data

Input Data

- Input images are galaxy cutouts from KiDS DR4 bright sample.
- Network is trained by **galaxy 4- band images** and their corresponding spectroscopic redshifts (spec-zs).
- **Spec-zs** are obtained from Galaxy And Mass Assembly (GAMA) survey.
- Images are supplement with **9-band magnitudes** (u, g, r, i, Z,Y,J,H and, Ks)
- Cutout size = (36,36,4)
  - Height = 36 pixels
  - Width = 36 pixels
  - Number of bands = 4; (u, g, r and, i)



36x36 cutout of Galaxy image in i-band and its rmag=19.37

Inception

- Inception is a CNN architecture for image recognition.
- Parallel convolution operation

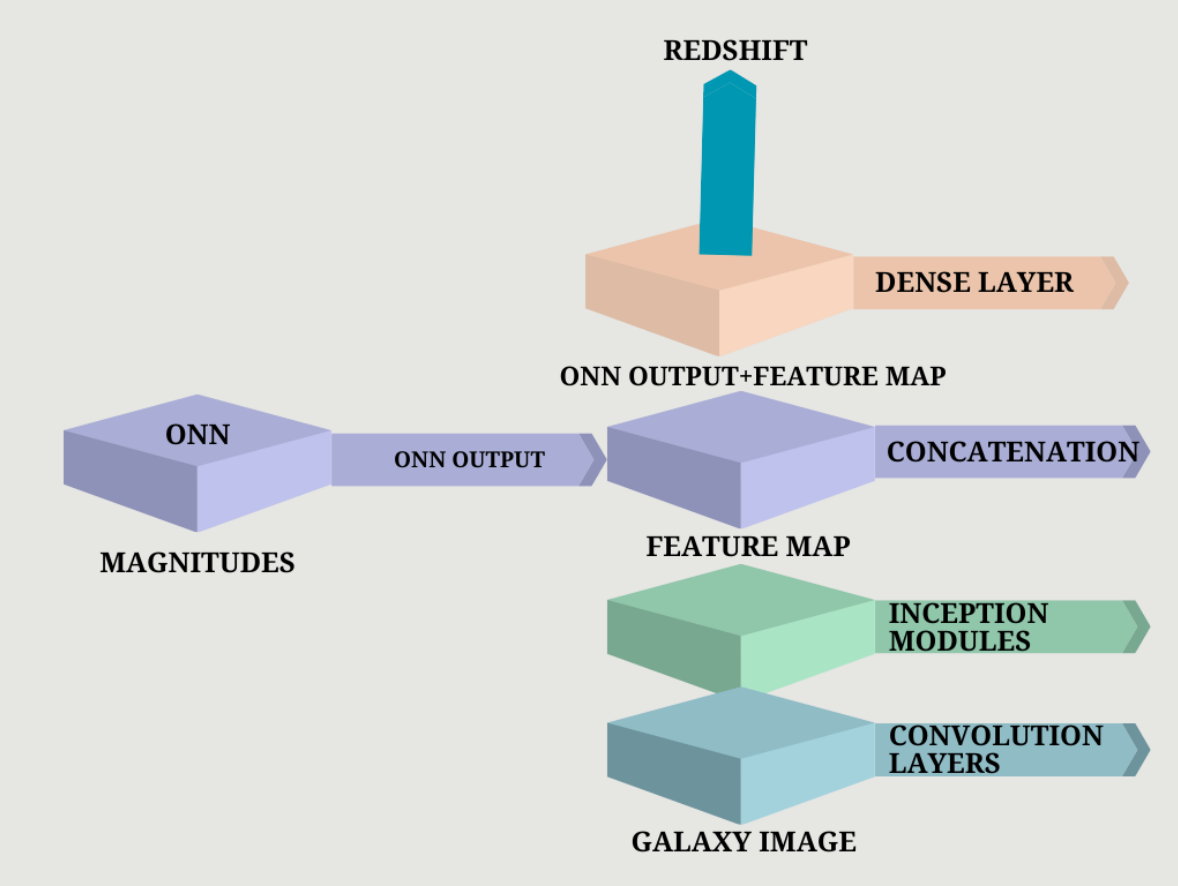
Inception Module

- Input layer
- 1x1 convolution layer
- 3x3 convolution layer
- 5x5 convolution layer
- Max pooling layer
- Concatenation layer

Inception based photo-z

- Developed a deep learning model based on Inception.
- Treated as a regression problem.

- This model uses two inputs:
  - Galaxy images
  - Magnitudes of galaxies



- ONN – Ordinary Neural Network
- Concatenation – Combines two outputs

Training

- Network predicts redshift.
- This predicted redshift is compared with the true redshift by loss function.
- Huber loss function is used.
- It is the combination of Mean Squared Error (MSE) and Mean Absolute Error (MAE).

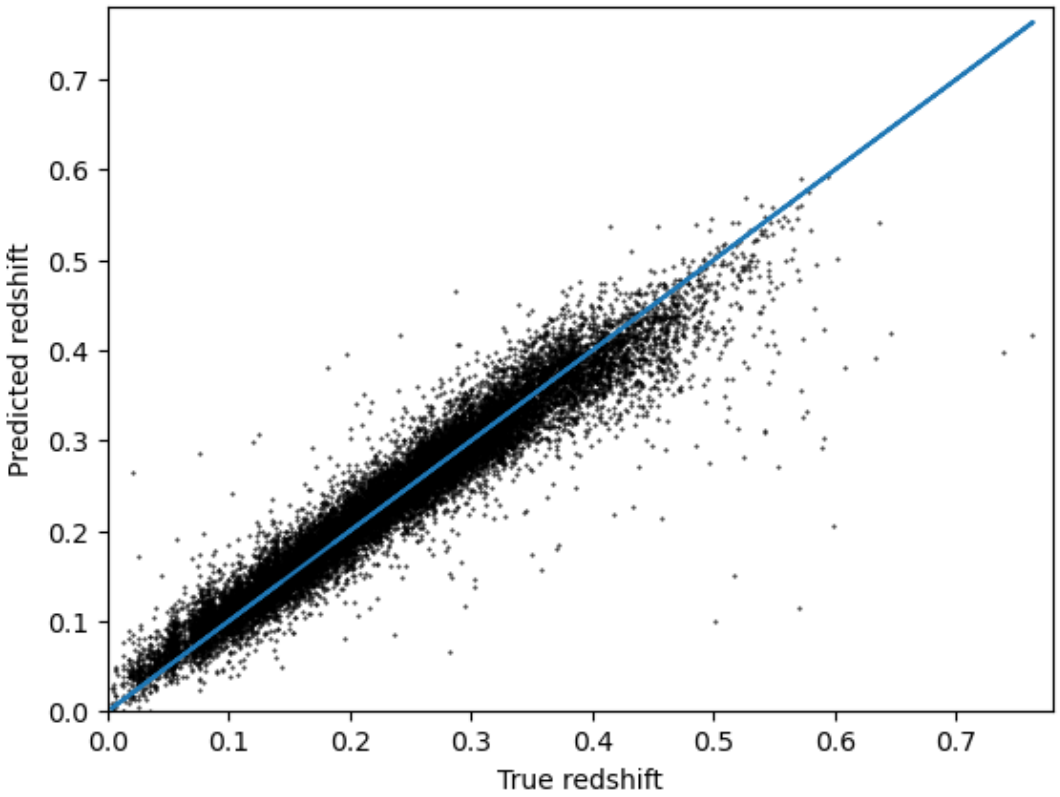
$$L_h = \begin{cases} \frac{1}{2}(e)^2, & |e| \leq \alpha \\ \alpha(|e| - \frac{1}{2}\alpha), & \text{otherwise} \end{cases}$$

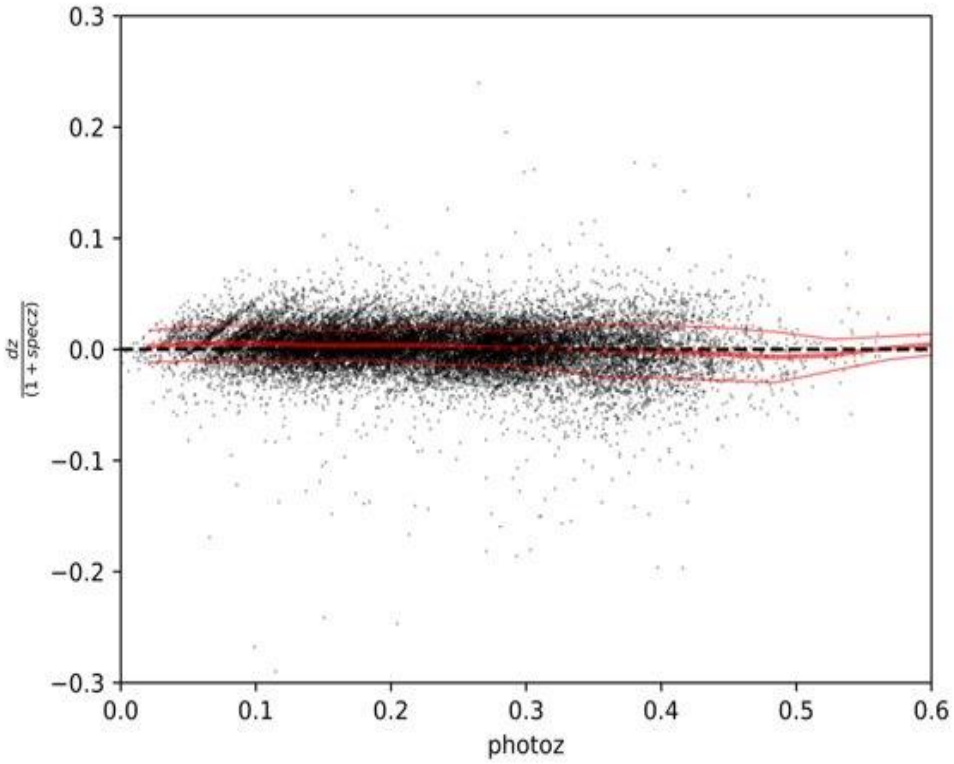
  - E= true redshift – predicted redshift
  - α is a hyperparameter that determines the transition between MSE and MAE
- During training, the network tries to minimize this loss function by adjusting the weights in kernel.
- Training : Validation: Testing = 70:15:15

Statistics

- Bias
  - **dz = Photoz – Specz**
- Normalized bias
  - **normdz = dz / (1+specz)**
- Standard Deviation of normdz, **SD(normdz)**
- **Median (normdz)**
- Scale Median Absolute Deviation of normdz, SMAD(normdz)
  - Where, **SMAD(x) = 1.4826*median(|x-median(x)|)**

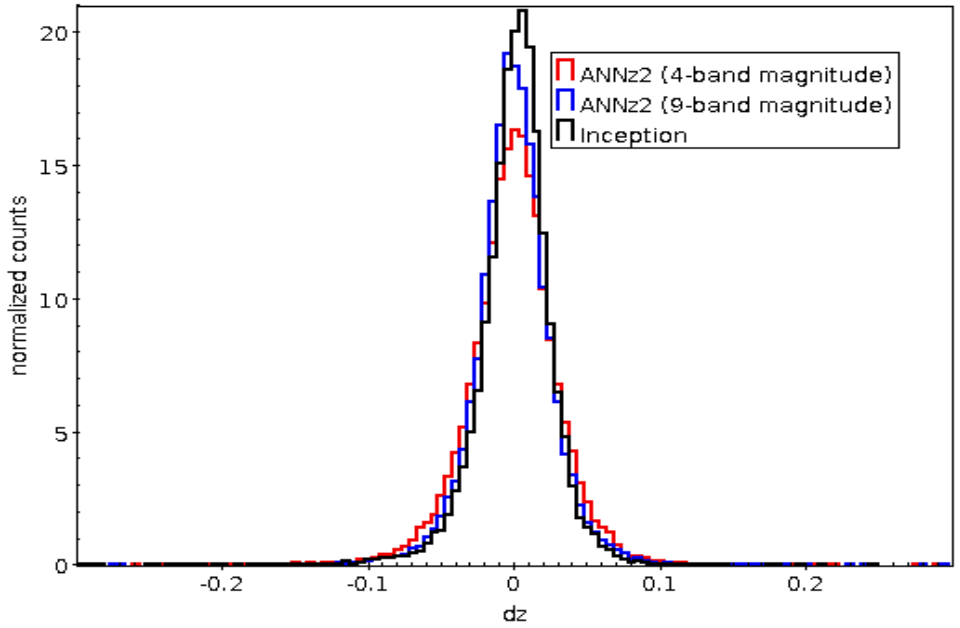
Result


Predicted redshift
True redshift
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7


$\frac{dz}{(1+specz)}$
photoz
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
0.0
0.1
0.2
0.3
0.4
0.5
0.6

Comparison with ANNz2 Result

- ANNz2 is a photo-z estimation method based on ordinary neural network. (*Bilicki et al. 2018, A&A 616, A69).*



Method	SMAD(normdz)
ANNz2 (4-band magnitude)	0.021
ANNz2 (9-band magnitude)	0.018
Inception	0.016

Future Work

- Apply to KiDS-DR5 bright sample. KiDS-DR5 is the final data release.

Thank you