Probabilistic photometric redshifts in the era of Petascale Astronomy

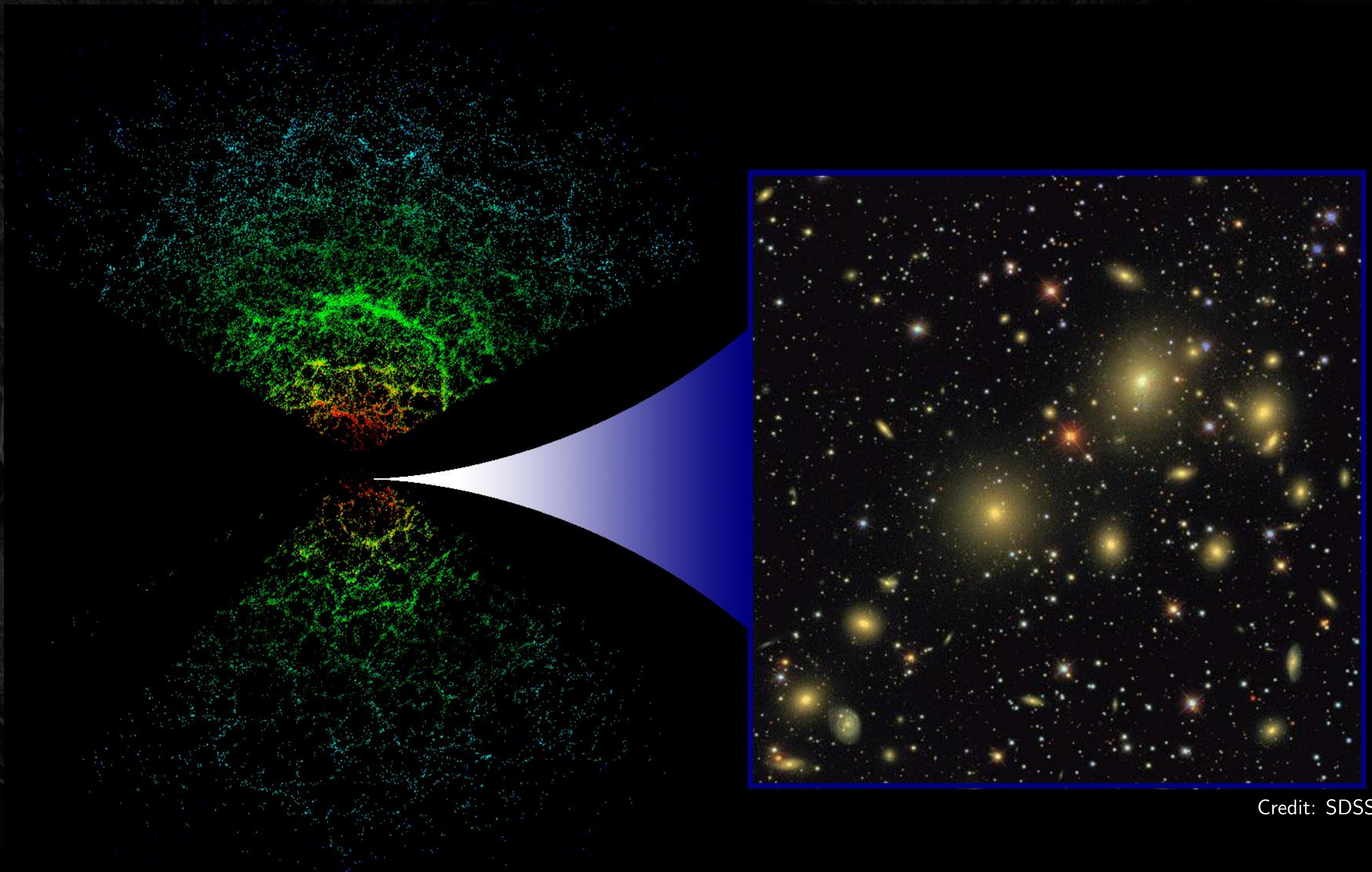
Matías Carrasco Kind

NCSA/Department of Astronomy

University of Illinois at Urbana-Champaign

Tools for Astronomical Big Data March 9th - 11th, 2015

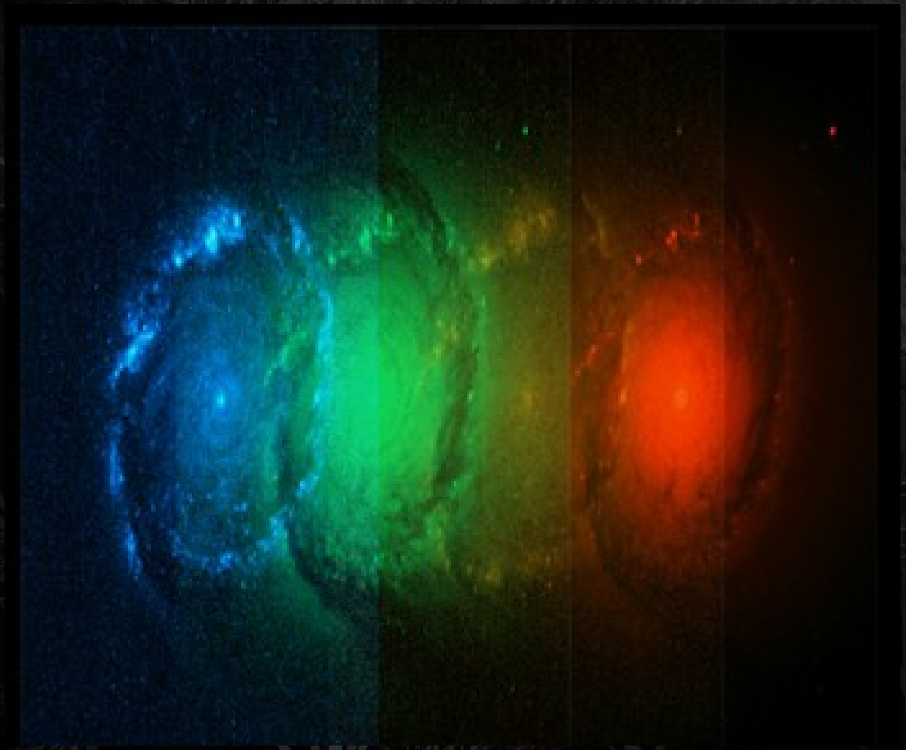
The need of distances in cosmology



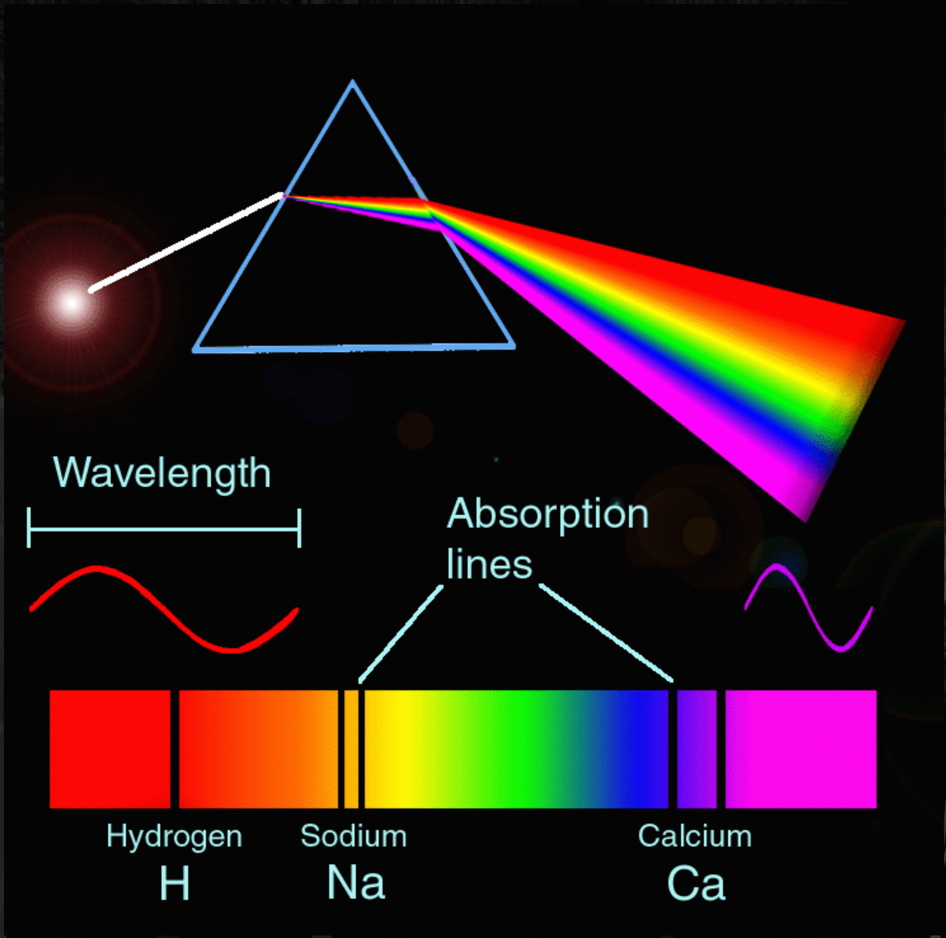
Credit: SDSS Collaboration

3D Clustering of galaxies as a probe in cosmology, e.g., 2 point correlation function, power spectrum of the galaxy distribution, etc.

Photometry vs. Spectroscopy



VS.



Big data problem

THE DARK ENERGY SURVEY

- It's happening! ☺
- $\sim$ 300 millions galaxies up to z =1.5
- 5,000 squares degrees (1/8 sky)
- Data managment at NCSA
- DES specially designed to probe the origin of dark energy
- S/G class and photo-z needed
- 1 TB of data per day
- 2 years completed, 3 more to go

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Large Synoptic Survey Telescope

$\sim$ 2020 first light

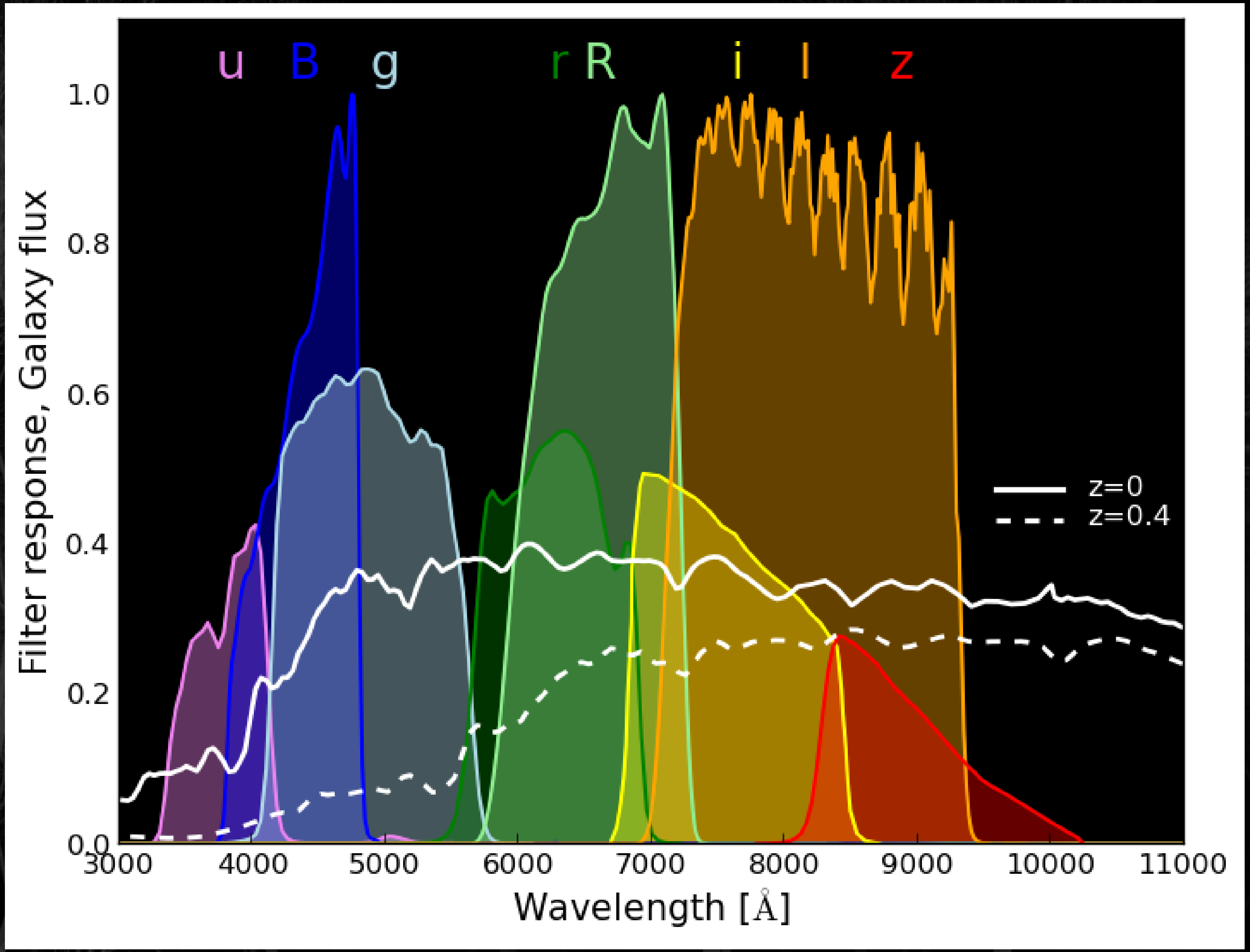
Half of sky

30 TB of data nightly for 10 years!!

NCSA involved in data analysis

Big Data Challenge, $\sim$1B galaxies

Data science challenge



Determine redshift using limited information.
8 points instead of thousands!

Motivation

- Photo-z Probability Density Functions needed
- Several methods/codes to compute photo-z
- Need for a meta-algorithm that combines multiple techniques
- PDF are good **but** for large datasets, storage and I/O will be an issue
- Machine Learning and statistical tools

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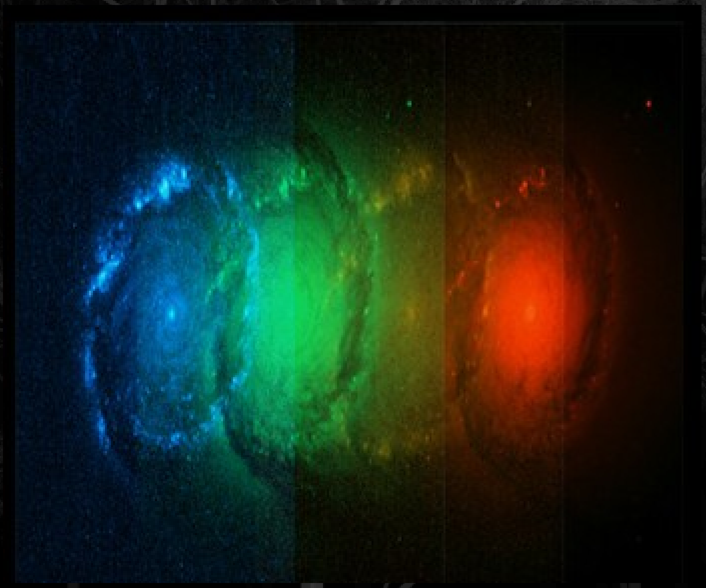
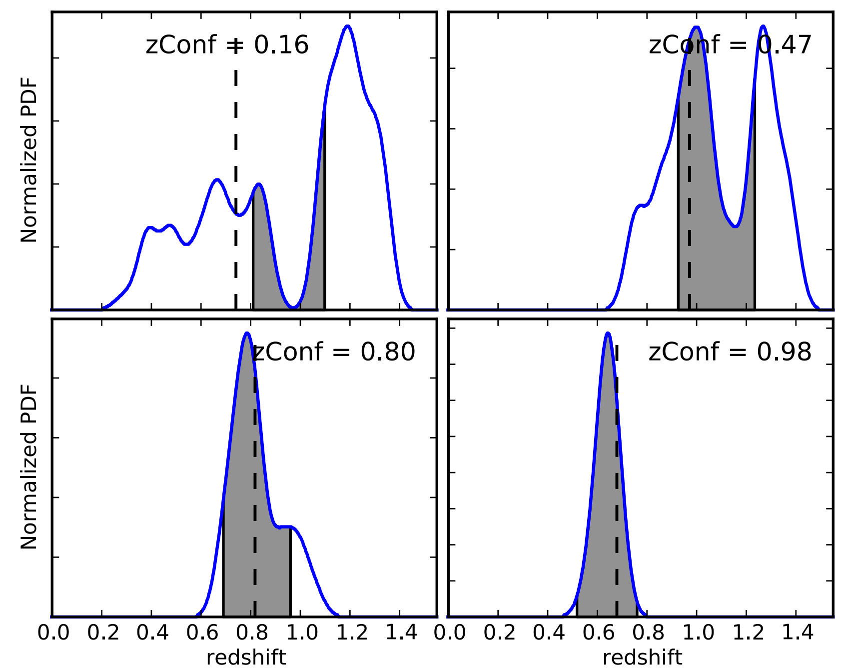
Photo-z PDF estimation (in 5 min.)

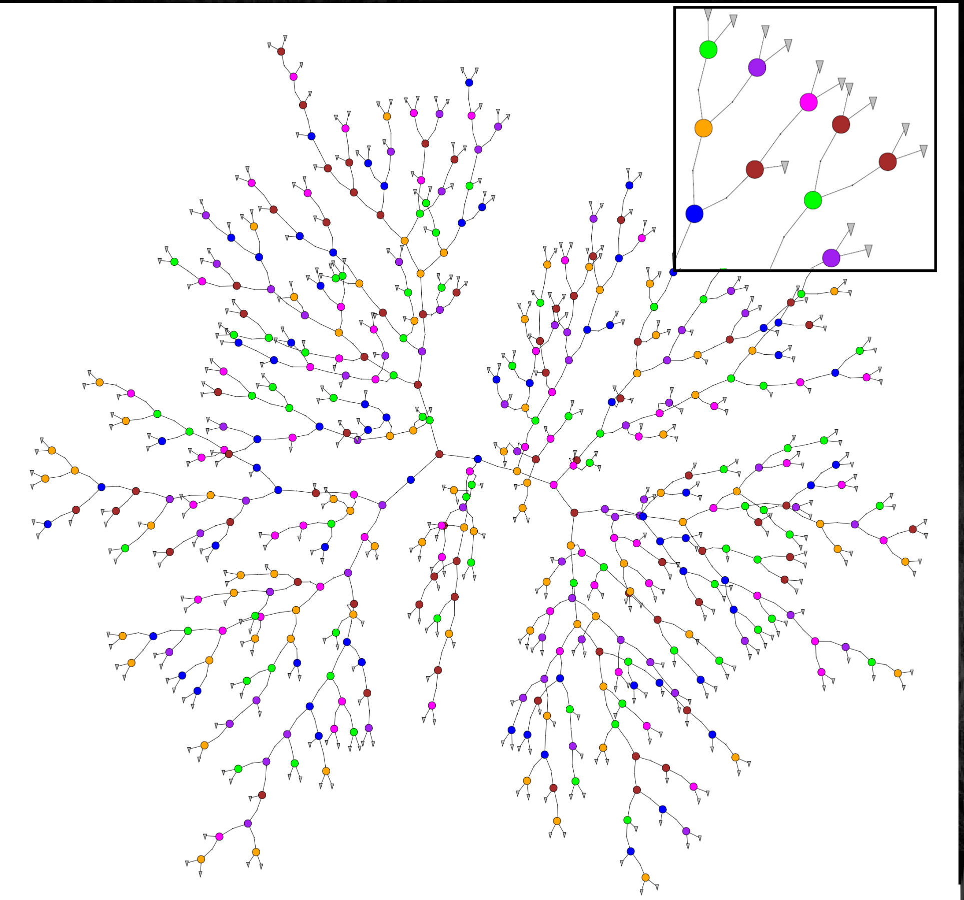




Carrasco Kind & Brunner 2013a (MNRAS, 432, 1483)

Photo-z PDF estimation: TPZ

- TPZ (Trees for Photo-Z) is a supervised machine learning code
- Prediction trees and random forest
- Incorporate measurements errors and deals with missing values
- Ancillary information: expected errors, attribute ranking and others
- Application to the S/G



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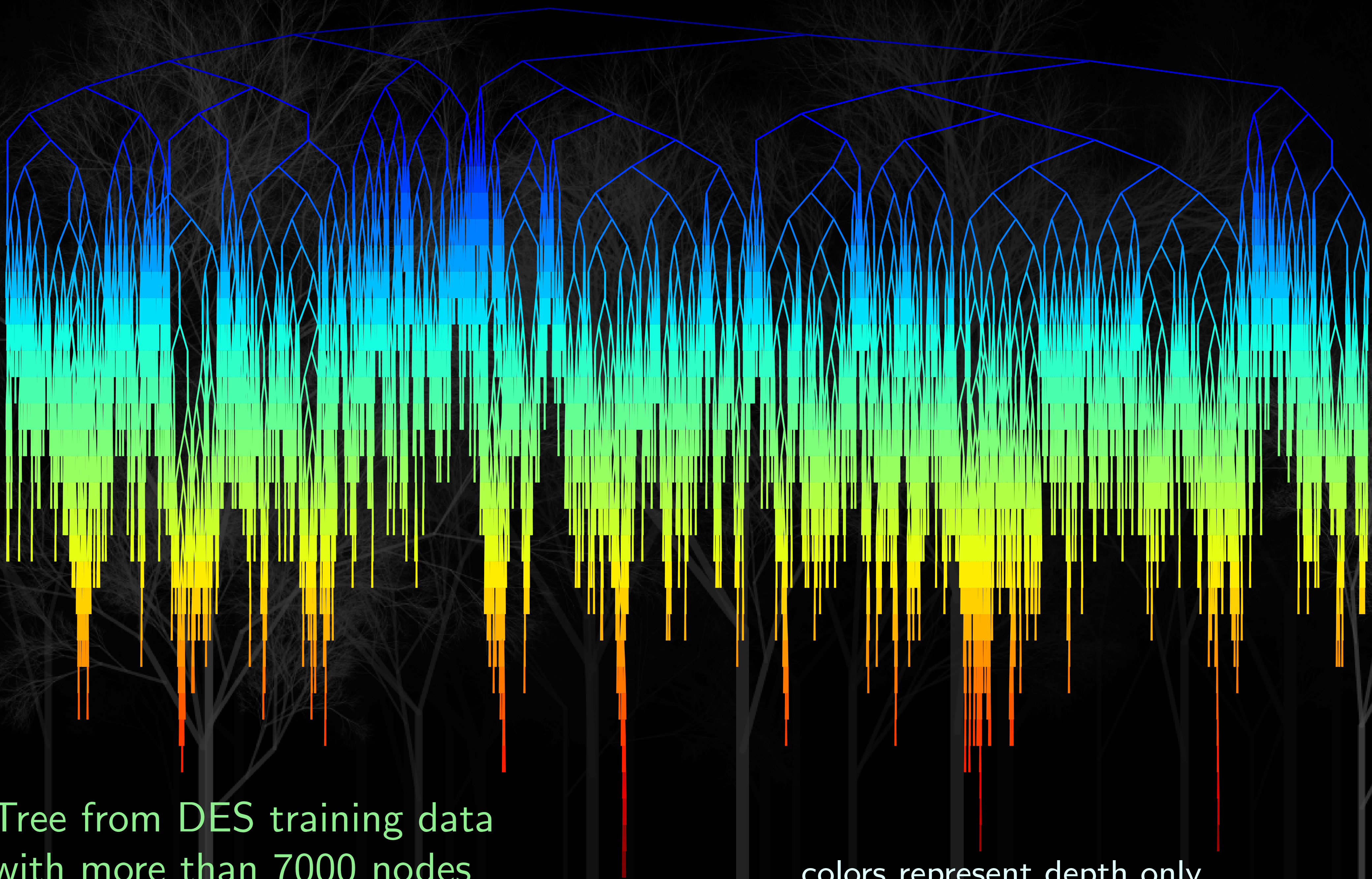
http://lcdm.astro.illinois.edu/code/mlz.html

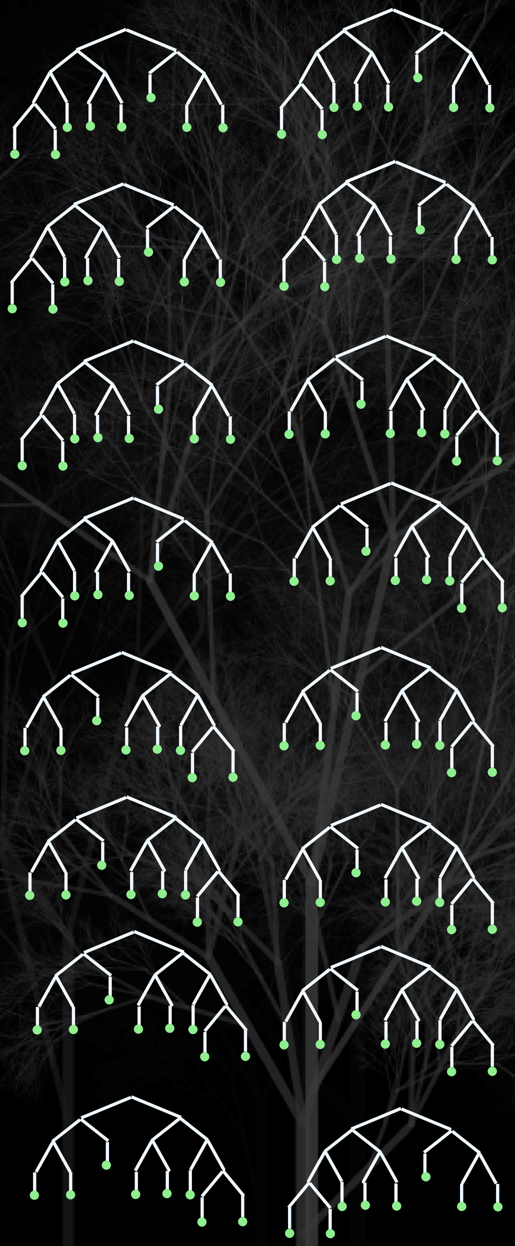
Photo-z PDF estimation: TPZ example



Tree from DES training data with more than 7000 nodes

colors represent depth only

Photo-z PDF estimation: Random forest



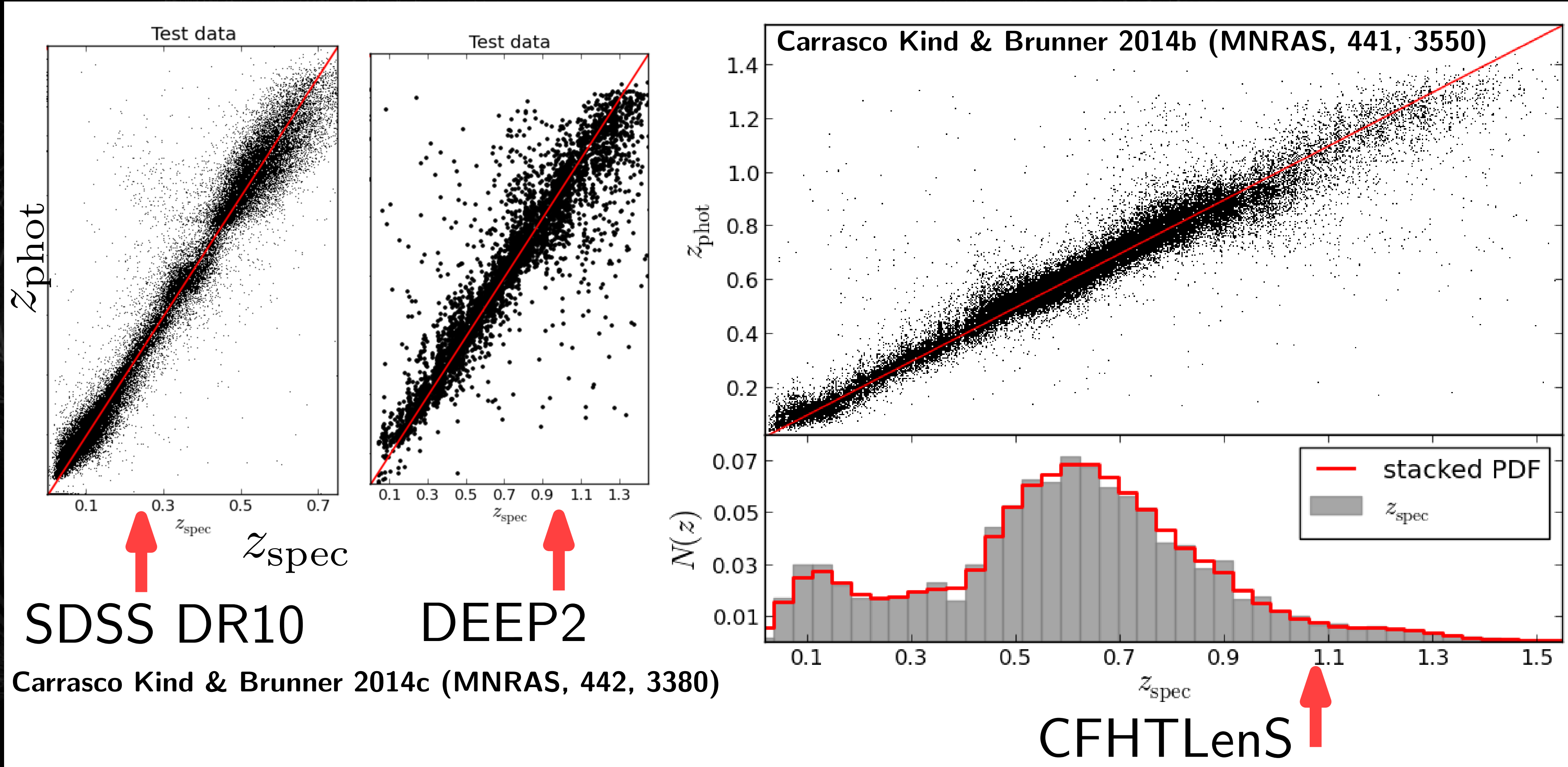
Combine predictions from trees

Trees are ideally uncorrelated and strong

Bootstrapping and error sampling

Random features at each node

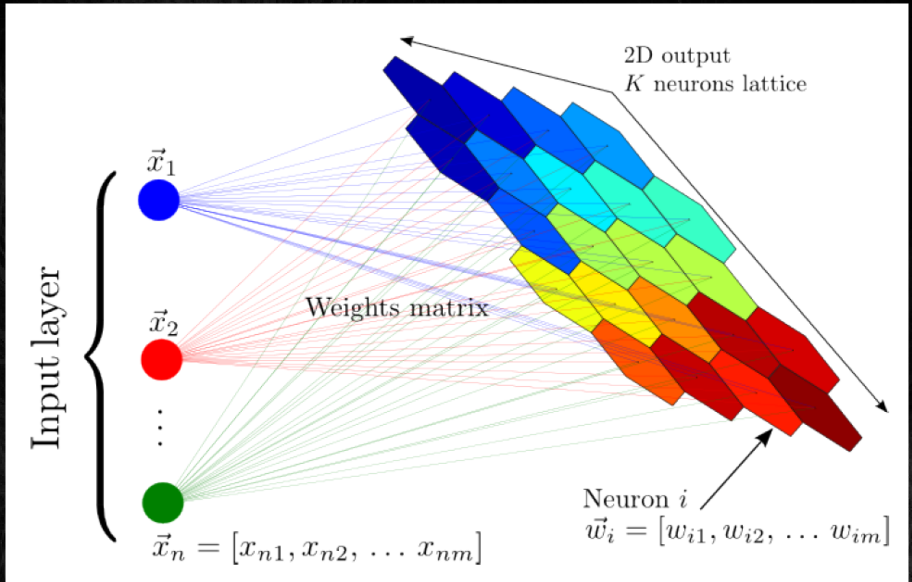
Photo-z PDF estimation: TPZ applications



TPZ has been tested in several databases with remarkable results

Photo-z PDF estimation: SOM

- SOM(Self Organized Map) is a unsupervised machine learning algorithm
- Competitive learning to represent data conserving topology
- 2D maps and *Random Atlas*
- Framework inherited from TPZ
- Application to the S/G



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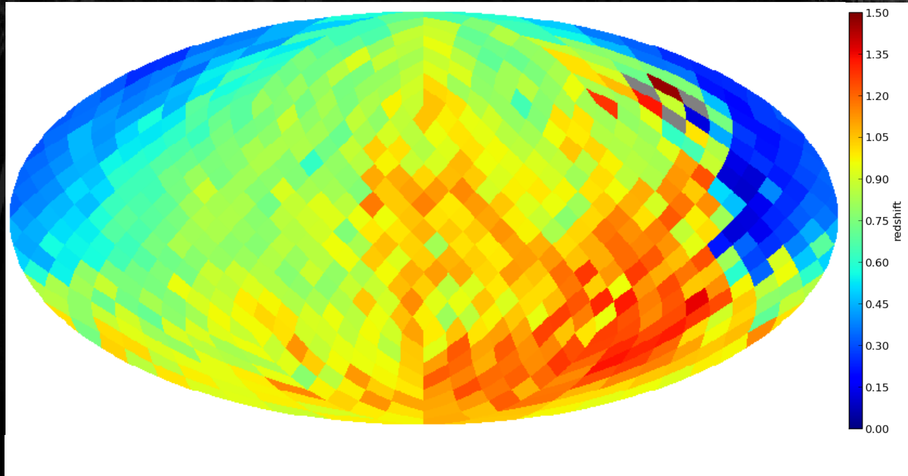

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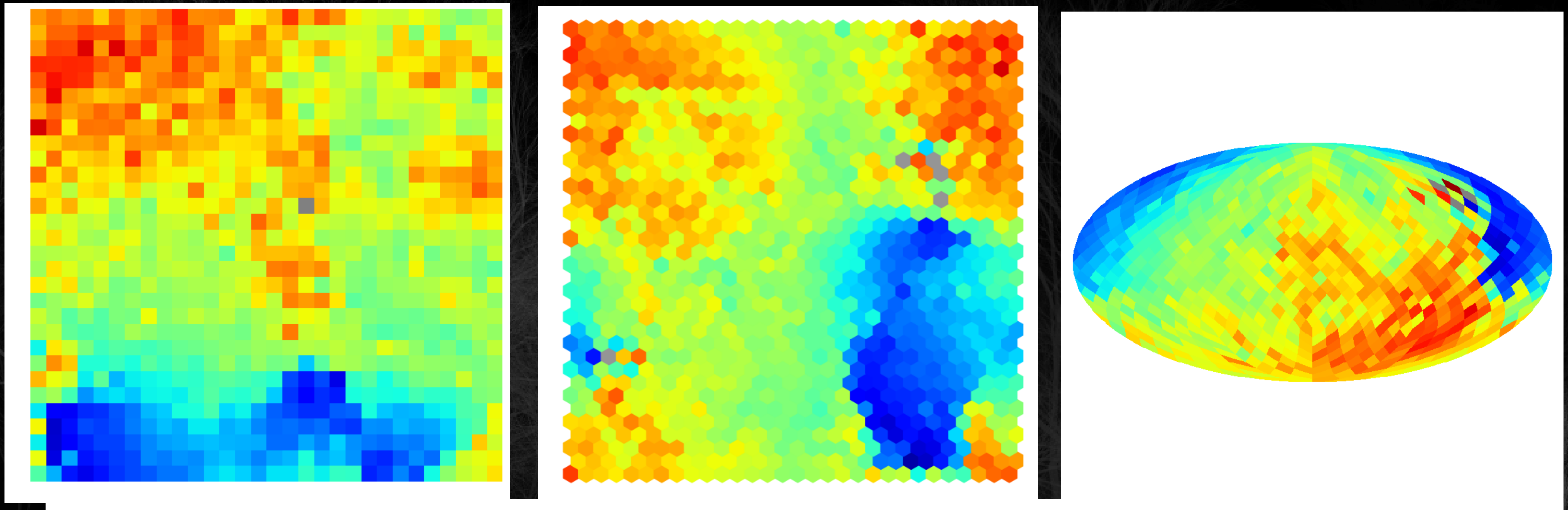
SOM topologies



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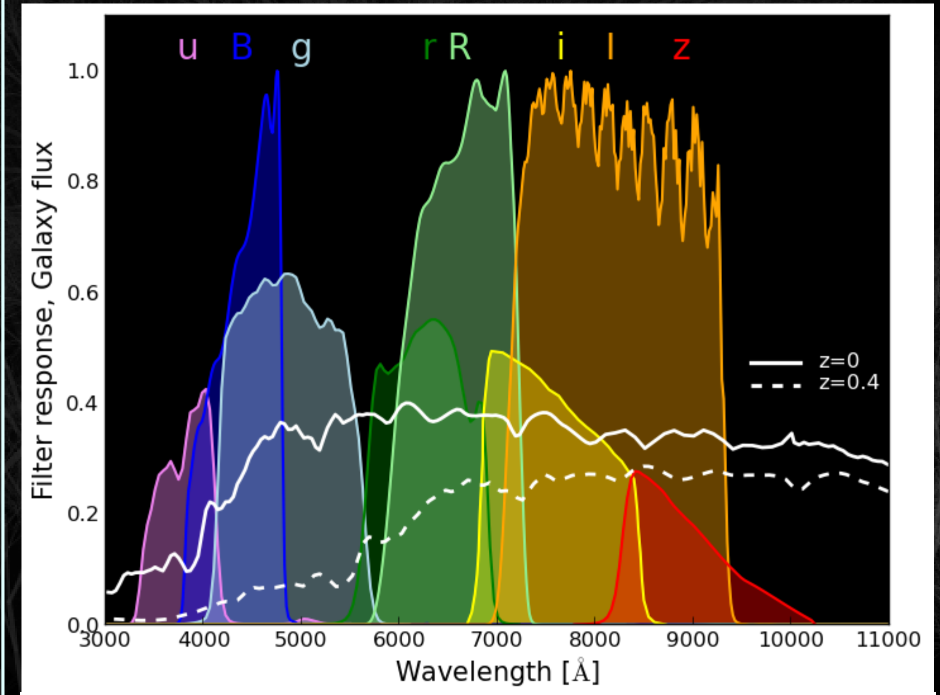
Different topologies can be used with or without periodic boundary conditions

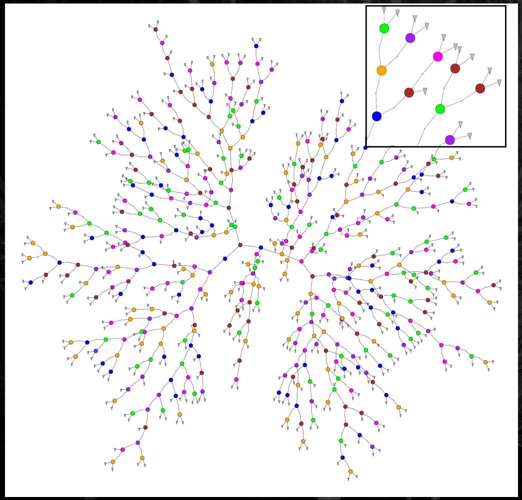
Photo-z PDF estimation: BPZ

- BPZ (Benitez, 2000) is a Bayesian template fitting method to obtain PDFs
- Set of calibrated SED and filters
- Doesn't need training data
- Priors can be included



Carrasco Kind & Brunner 2014c (MNRAS, 442, 3380)

Photo-z PDF combination



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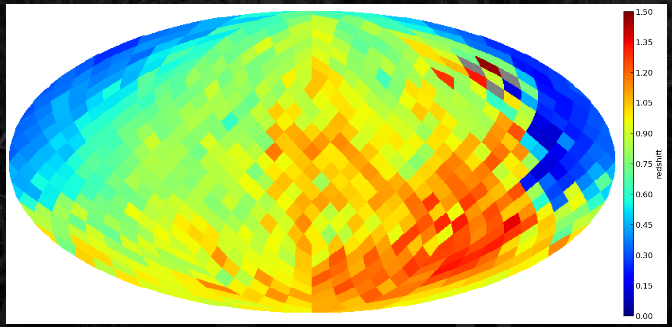

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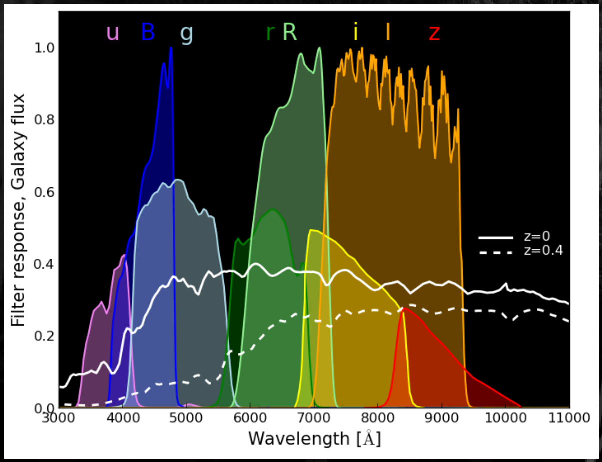
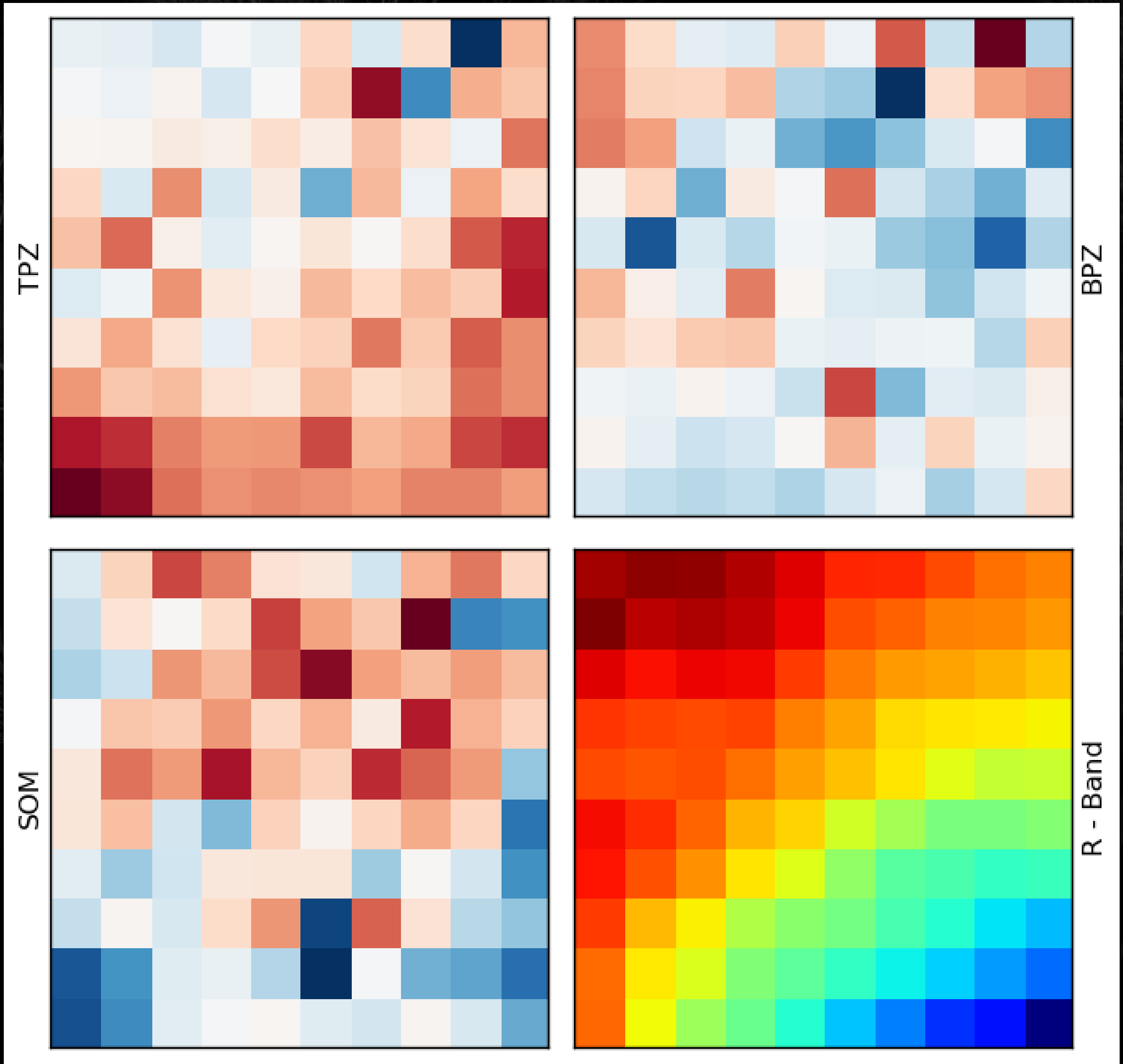


Bayesian framework



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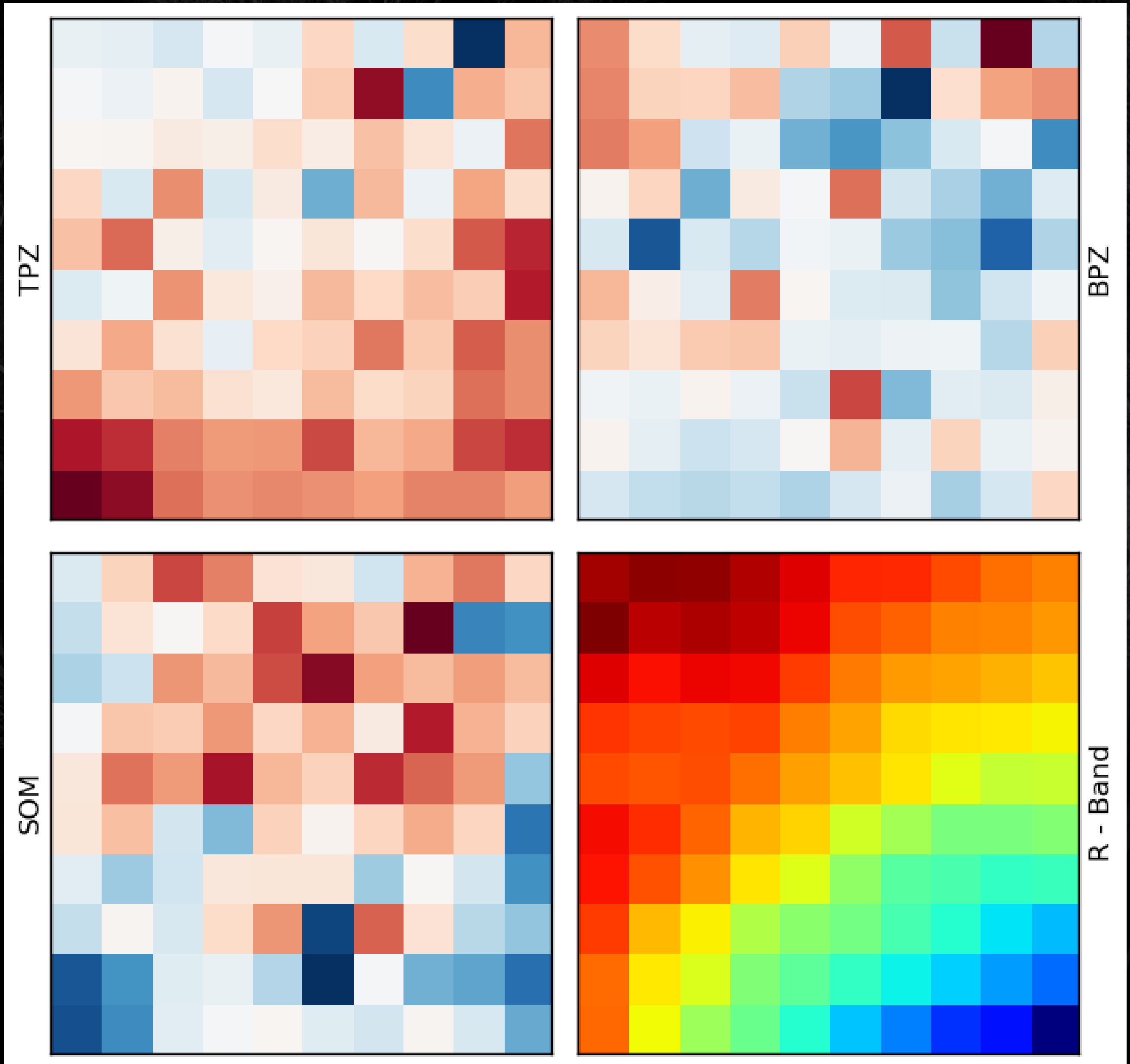


Carrasco Kind & Brunner 2014c (MNRAS, 442, 3380)

Our approach

Supervised method

+

Unsupervised method

+

Template fitting

+

Weighting scheme

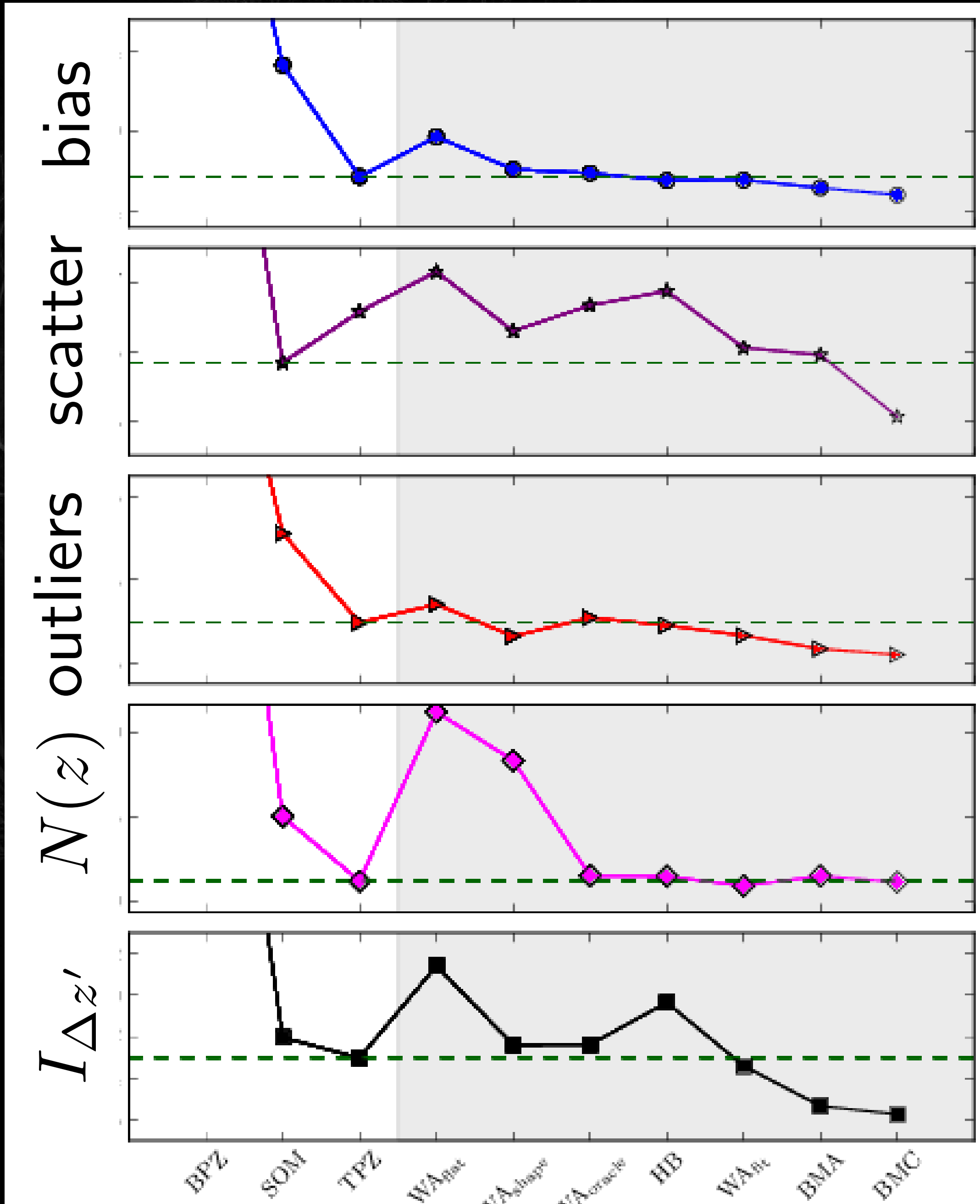
$\Downarrow$

photo-z PDF

+

Outliers

Photo-z PDF combination: Results



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- Several combination methods
- Bayesian model averaging (BMA) and combination (BMC) are the best
- Same applies to S/G (Kim, Brunner & CK in prep.)

Photo-z PDF combination: Outliers

Naïve Bayes Classifier (same used for spam emails) to identify "spam" galaxies using information from multiple techniques

Each feature provides information about these two classes, and can be combined to make a stronger classifier

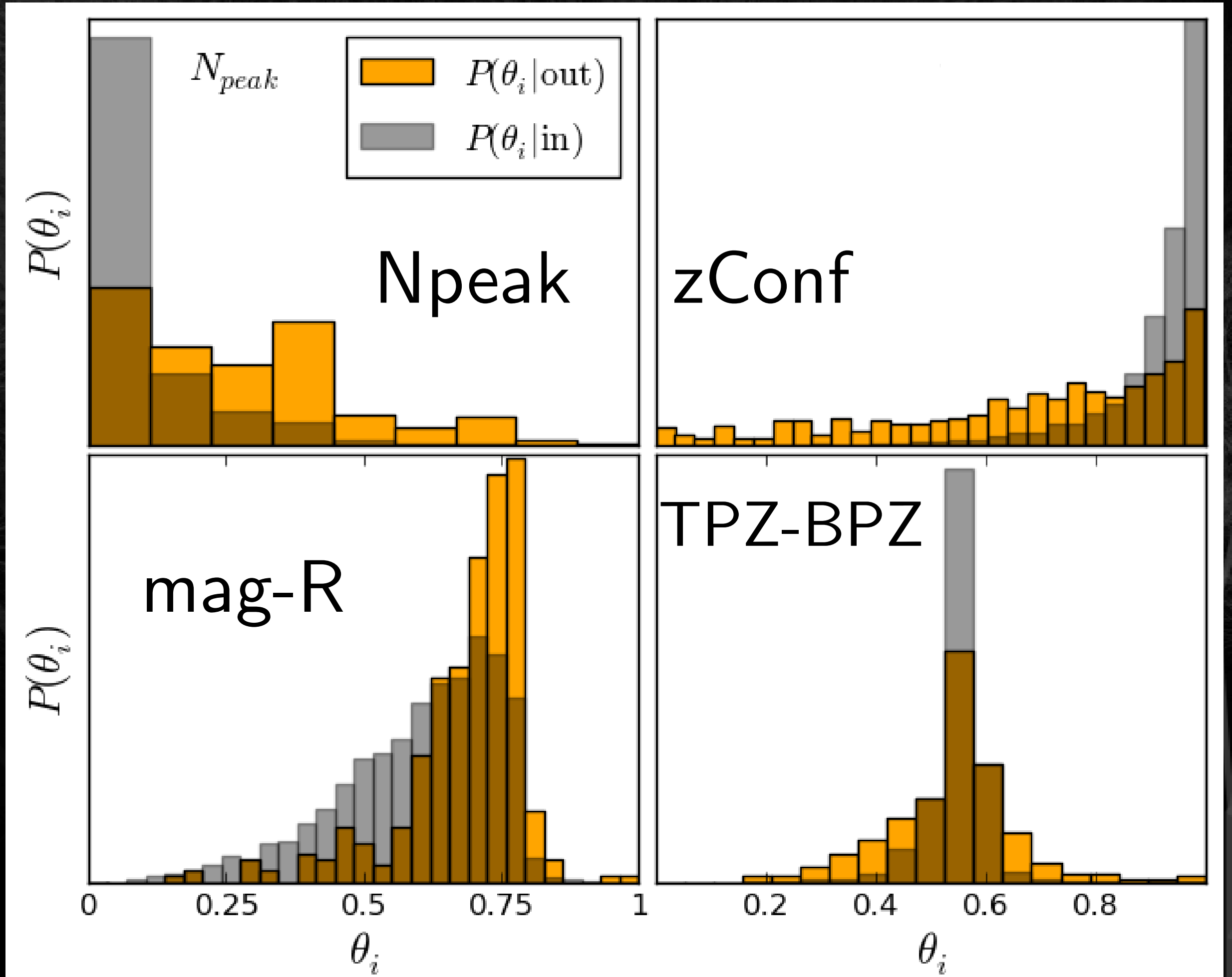

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Photo-z PDF representation and storage

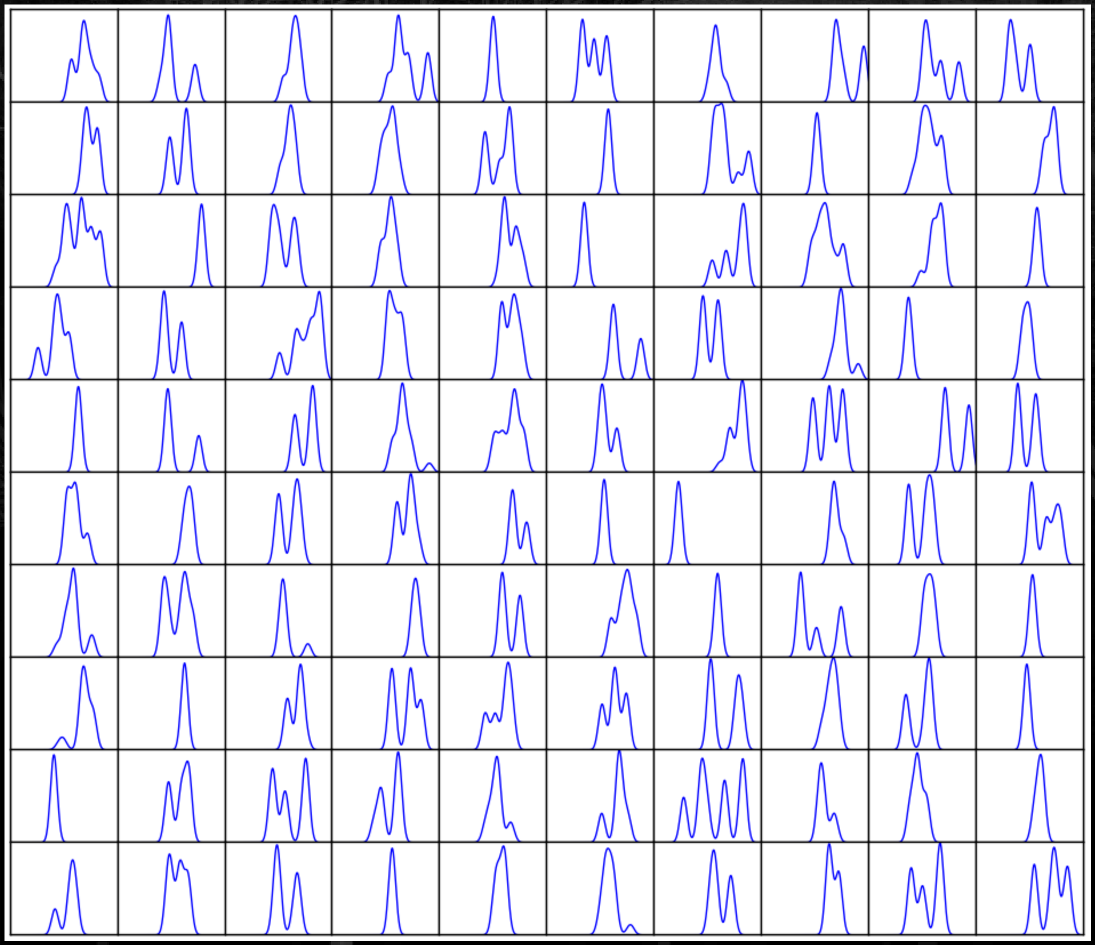

Photo-z PDF storage: Strategies

Single Gaussian fit

Multi-Gaussan fit

Monte Carlo sampling

Sparse representation techniques

Reduce number of points while increasing accuracy

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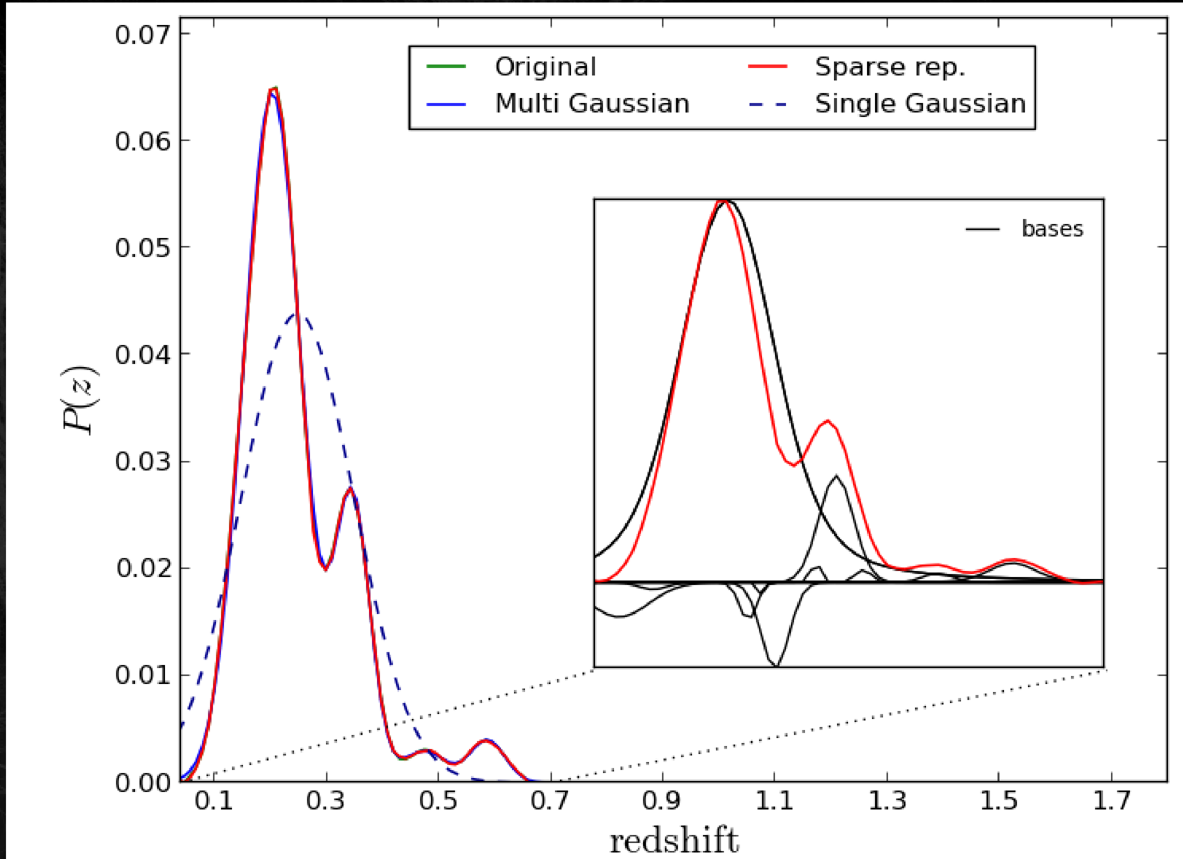

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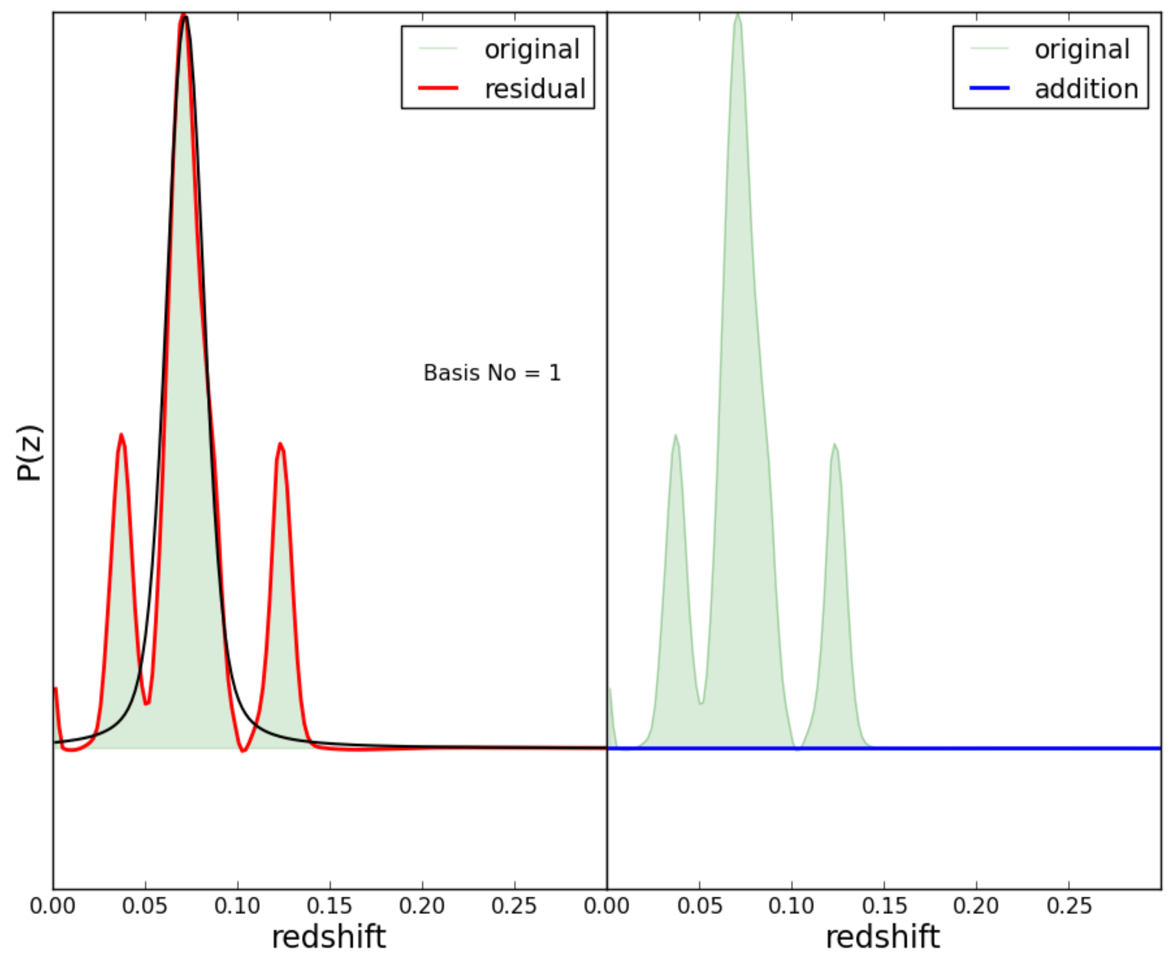
Photo-z PDF storage: Sparse representation

Use Gaussian and Voigt profiles as bases, need N^2_{original} bases

With only 10-20 bases achieve 99.9 % accuracy

Use 32-bits integer per basis, compression

Store Multiple PDFs



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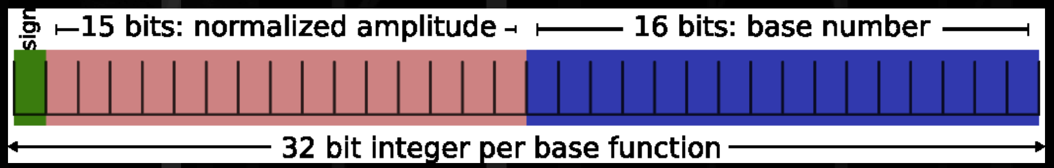

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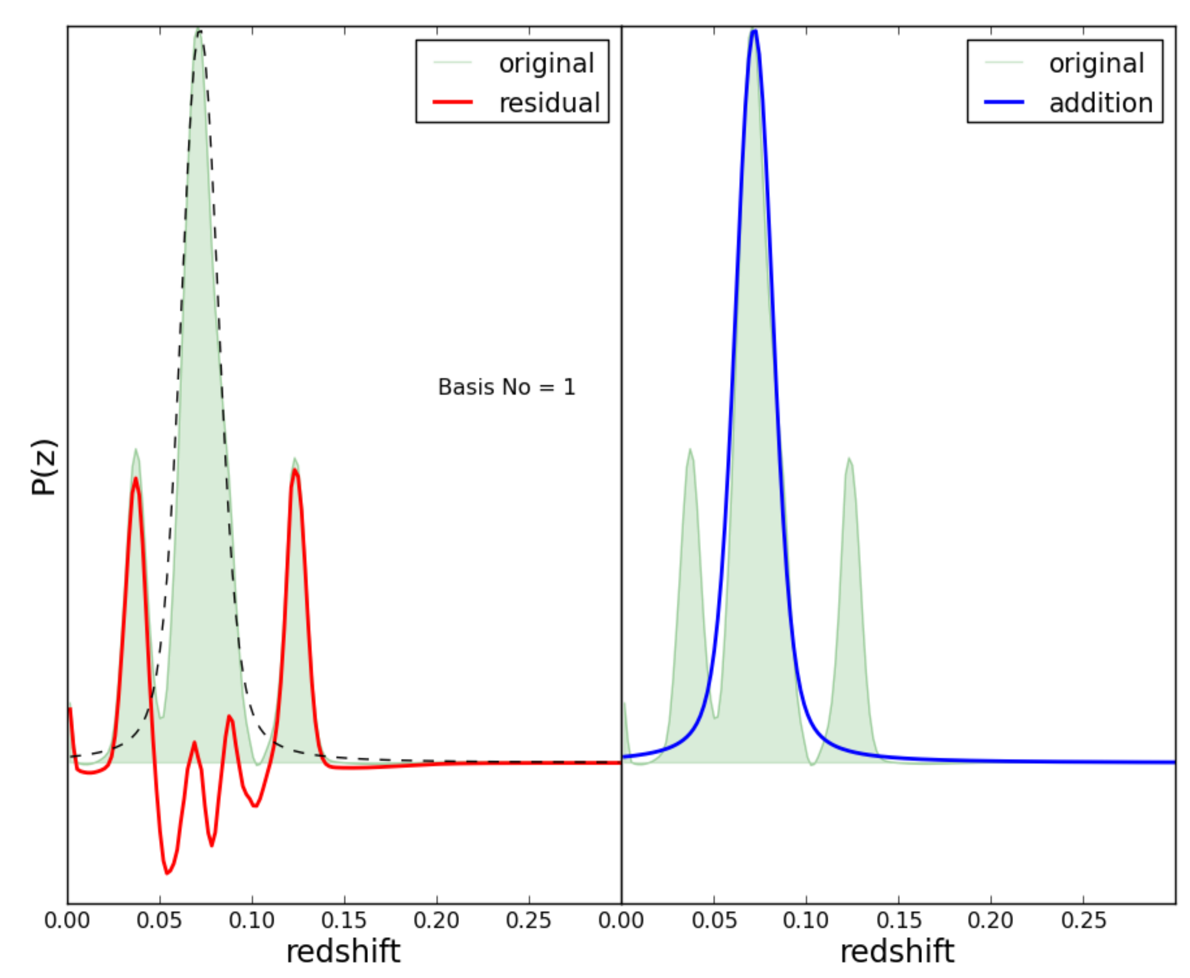

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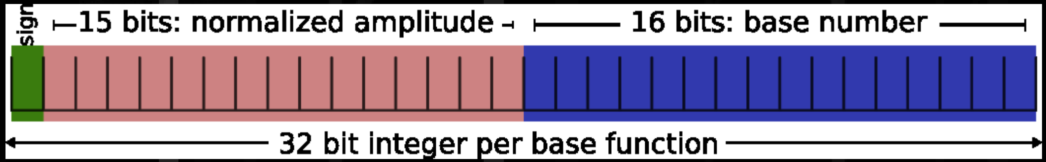

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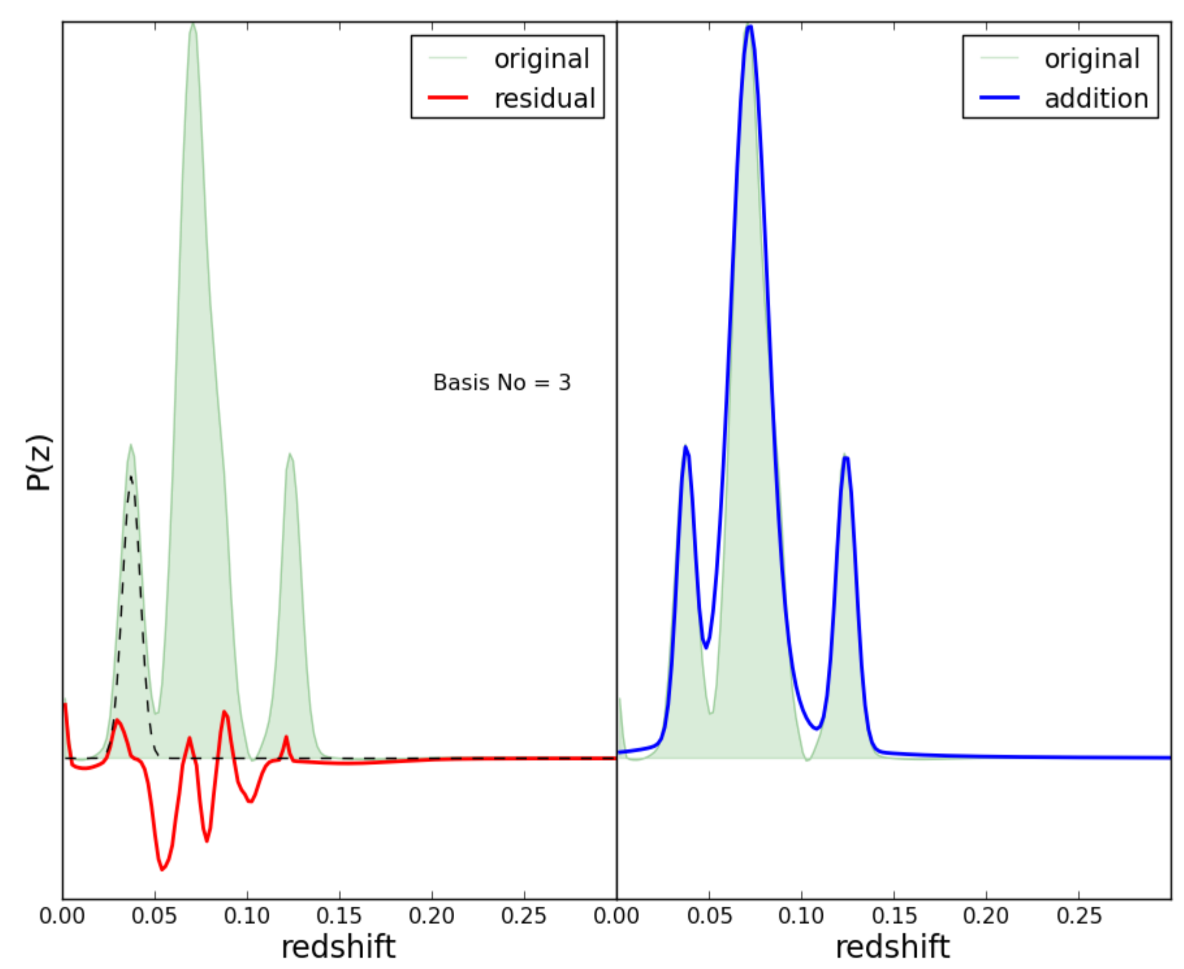

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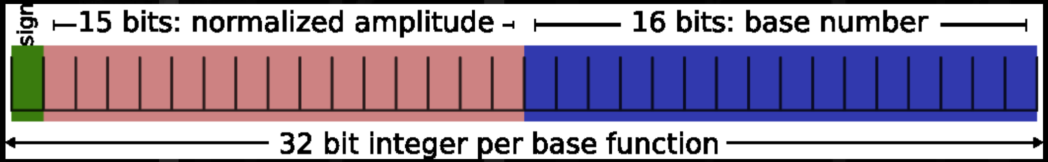

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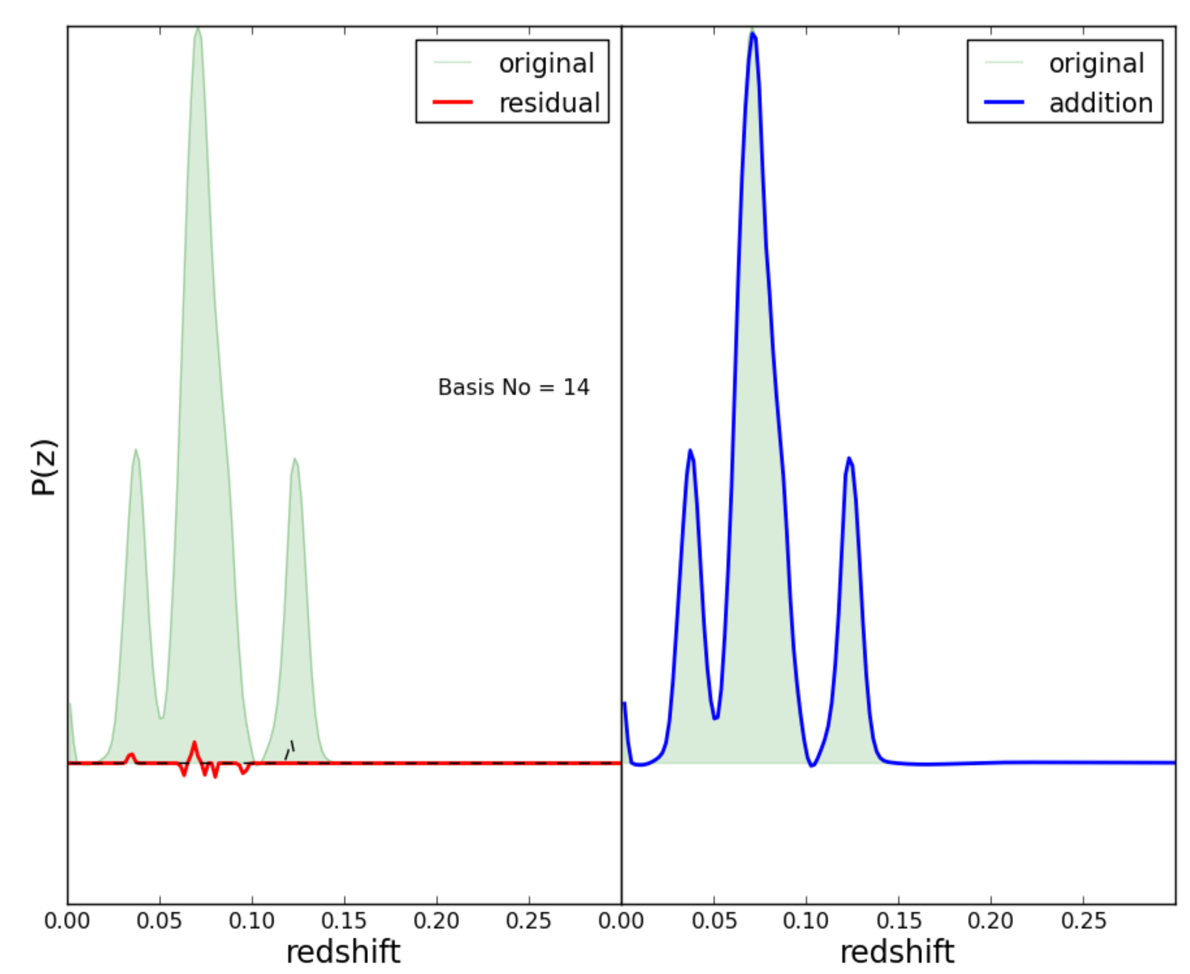

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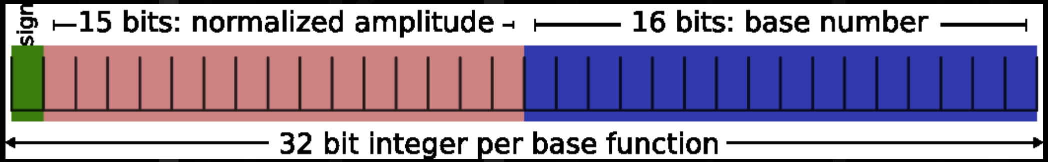

$N(z)$ and sparse representation

By definition:

$$\boxed{N(z) = \sum_{k=1}^{N} \int_{z-\Delta z/2}^{z+\Delta z/2} P_k(z) dz}$$

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Using sparse representation, we represent each PDF pz_k as:

$\mathbf{pz}_k \approx \mathbf{D} \cdot \boldsymbol{\delta}_k$ $\mathbf{D}$ is the dictionary, $\boldsymbol{\delta}_k$ is the sparse vector, then

$$N(z) = \sum_{k=1}^{N} \boldsymbol{\delta}_k \cdot \int_{z-\Delta z/2}^{z+\Delta z/2} \mathbf{D} dz$$

Only bases are integrated

by precomputing:

$$\boldsymbol{\delta}_N = \sum_{k=1}^{N} \boldsymbol{\delta}_k \qquad \mathbf{I_D}(z) = \int_{z-\Delta z/2}^{z+\Delta z/2} \mathbf{d}_j dz \qquad j = 1, 2, \ldots, m$$

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$N(z)$ is reduce to a simple dot product

$$\boxed{N(z) = \mathbf{I_D}(z) \cdot \boldsymbol{\delta}_N}$$

Talk on Friday (ad)

- Machine Learning in DES
- Photo-z in DES early data
- Photo-z PDF in DESDM
- New tools to access these from DB

Conclusions

✓ Compute photo-z PDF

Individual techniques (MLZ; arXiv:1303.7269, arXiv:1312.5753)

✓ Combine PDFs efficiently

Better than individual, outliers identification (arXiv:1403.0044)

✓ PDF Sparse Representation

99.9% accuracy in P(z) and N(z) with 15 points (arXiv:1404.6442)

✓ Uses of these tools!

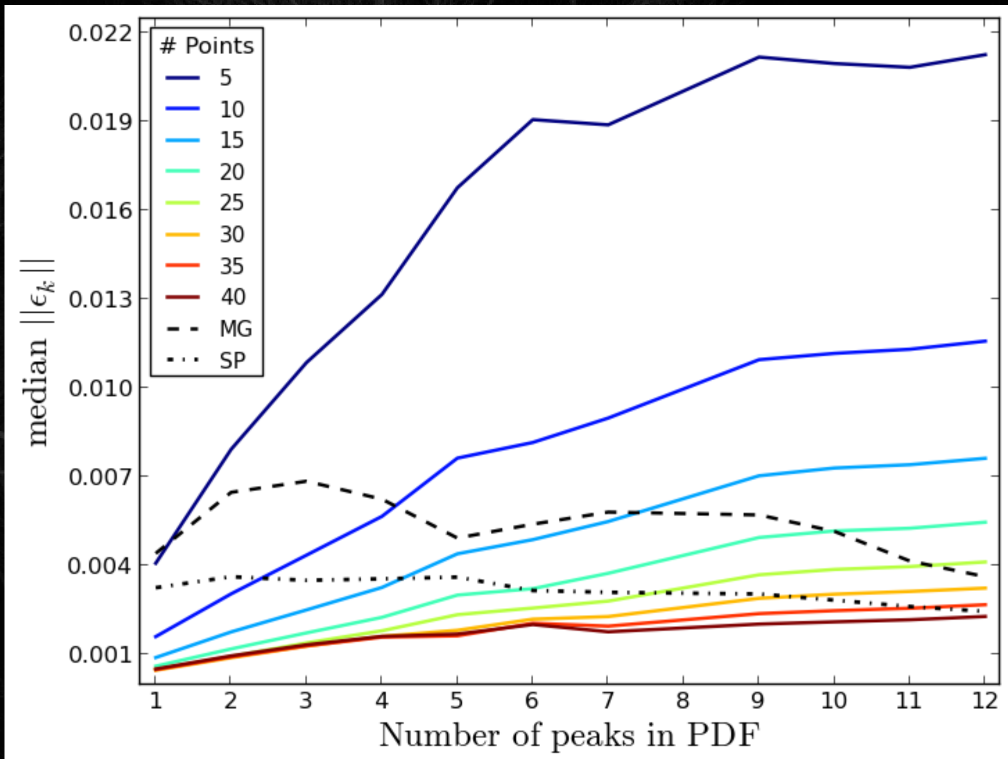
Clustering, weak lensing, DES, DESDM, etc...

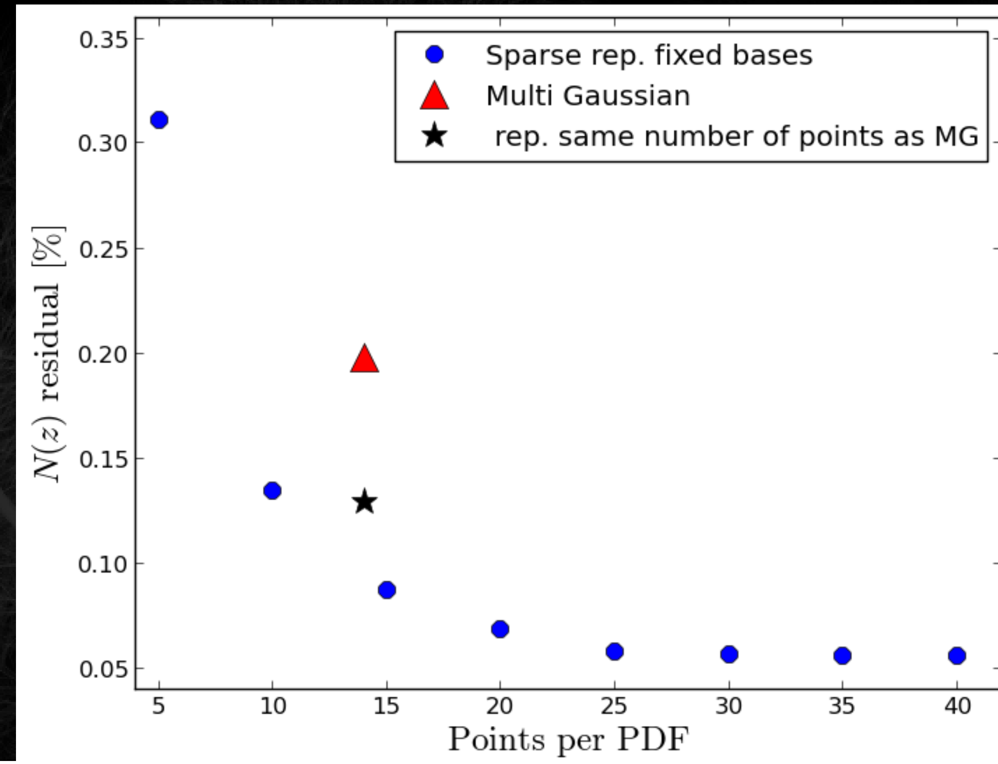
Questions?

Matias Carrasco Kind
NCSA/UIUC
mcarras2@ncsa.illinois.edu
http://matias-ck.com/
https://github.com/mgckind

EXTRA SLIDES

Photo-z PDF storage: Results



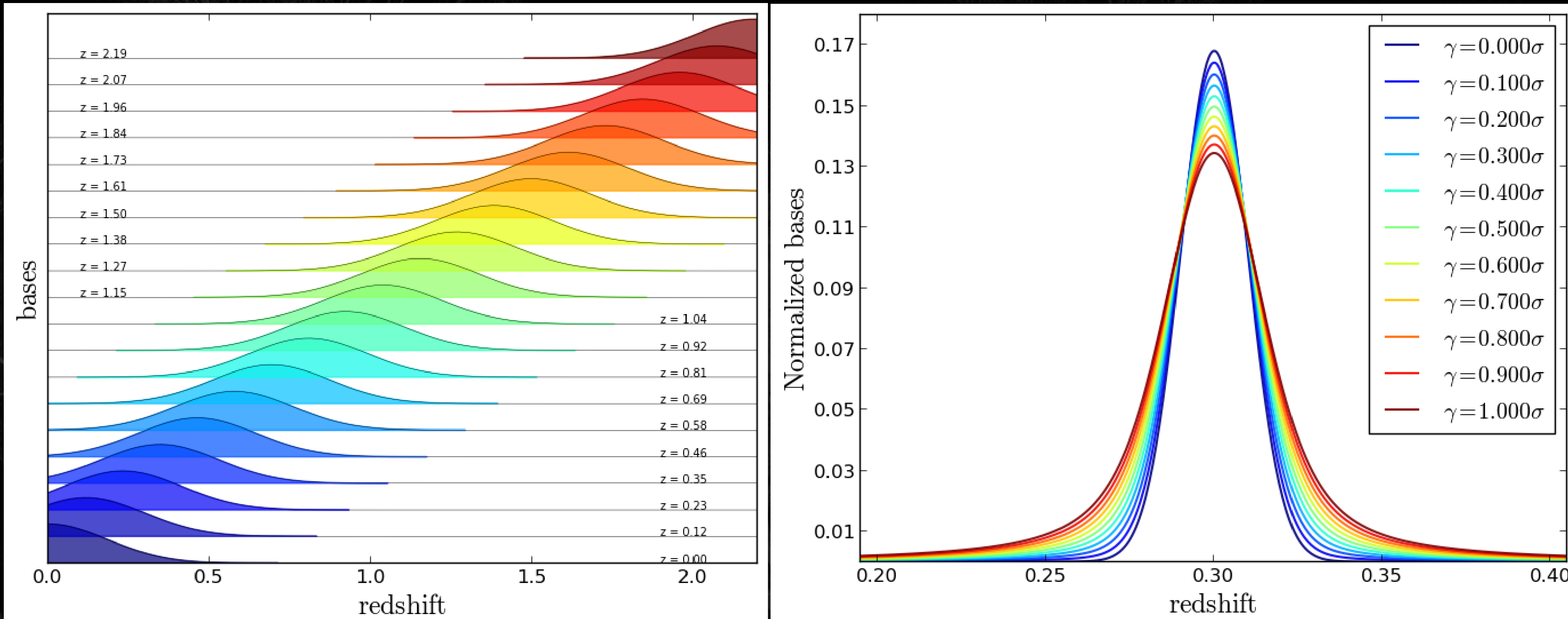


Carrasco Kind & Brunner 2014b (MNRAS, 441, 3550)

For PDFs with less than 4 peaks 5-10 points should be sufficient

Sparse representation gives more accurate and more compressed representation for N(z), 99.9% accuracy with 15 points (200 points originally)

Photo-z PDF storage: Dictionary



Carrasco Kind & Brunner 2014b (MNRAS, 441, 3550)

Combination of Gaussian and Voigt profiles

Covering the whole redshift space, at each location we have several bases

Photo-z PDF estimation: Error and validation

Out of Bag (cross-validation) data used to validate trees/maps

Changes for every tree/map and is not used during training

We can learn from the cross-validation data!

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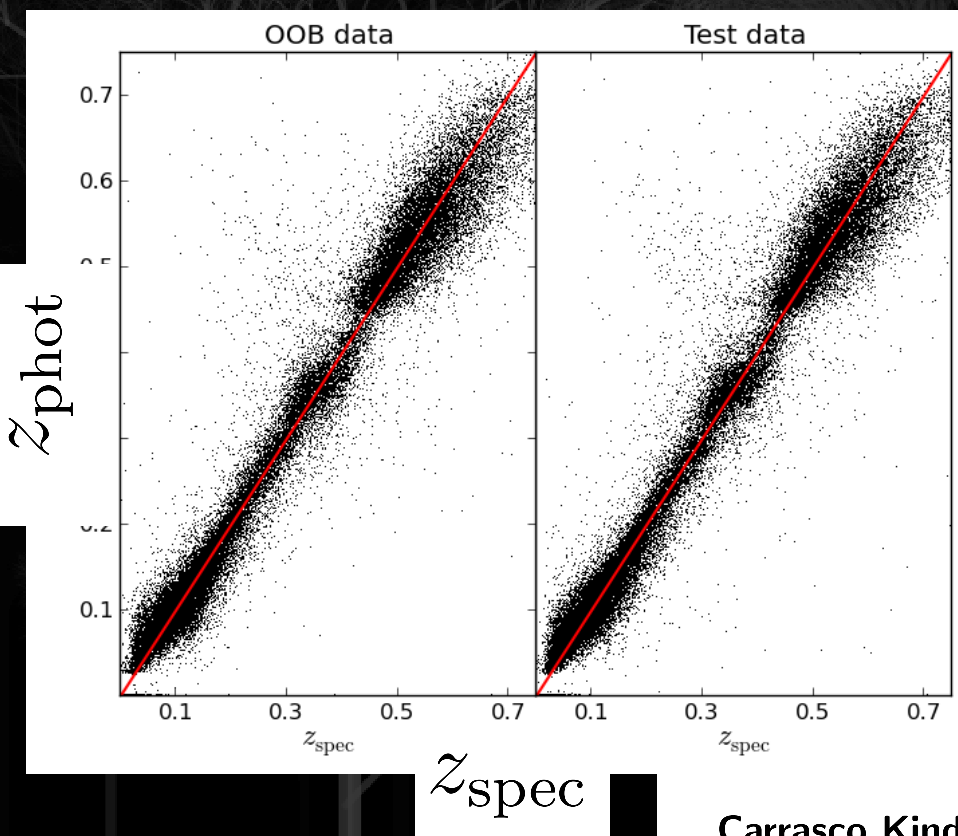

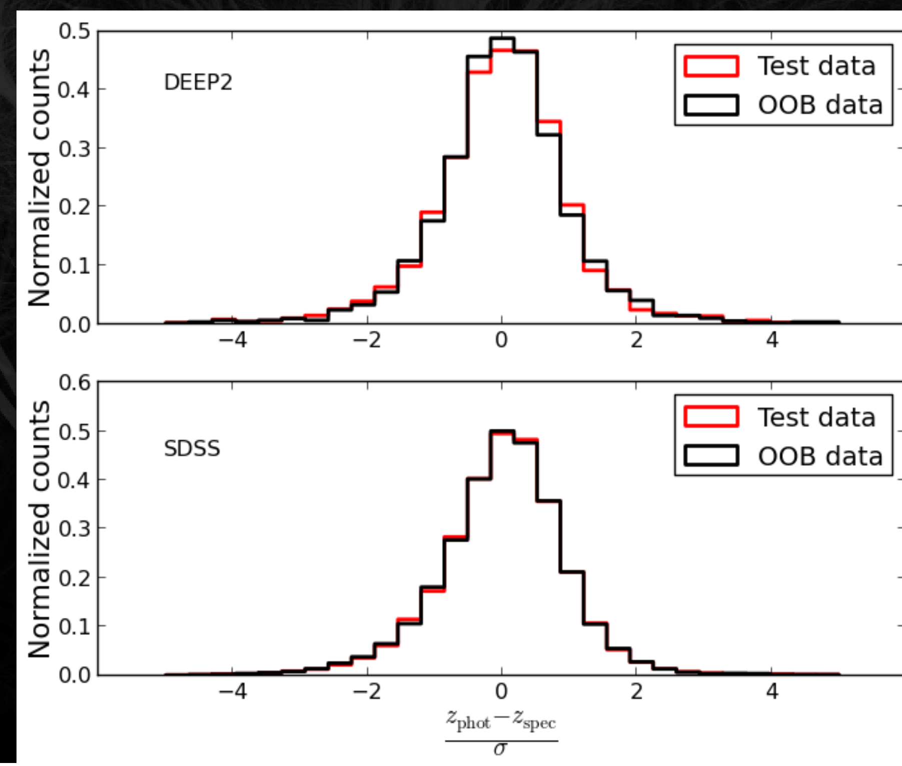

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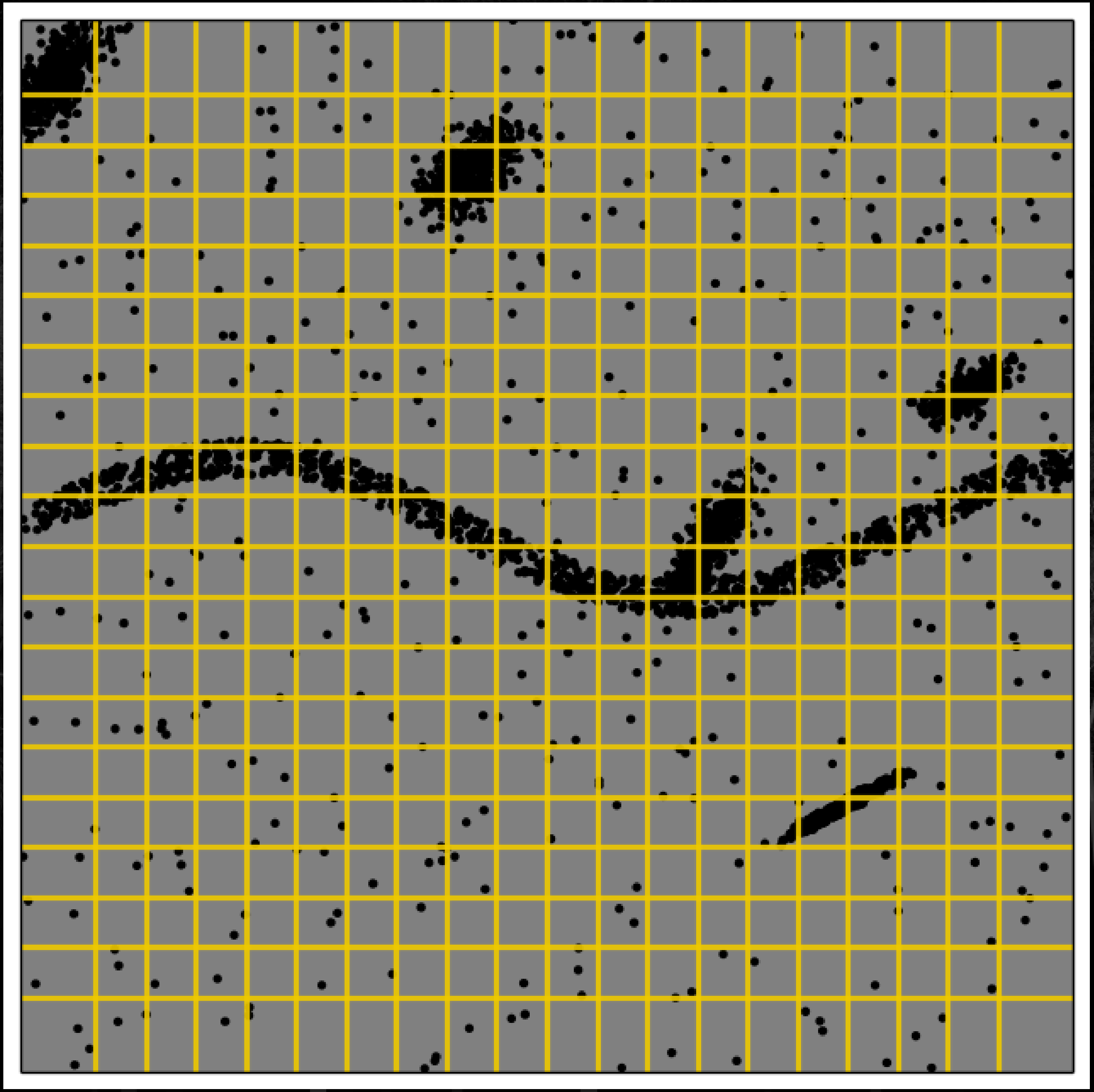
Photo-z PDF estimation: SOM 2D toy example



Suppose 2D data distributed in a given space

De-project the data in a 2D map

Each cell will contain objects with similar properties

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