Title: Clustering Redshifts: A New Era of Distance Measurement

Date: Aug 11, 2015 11:20 AM

URL: http://pirsa.org/15080008

Abstract: The measurement of distance has long been a fundamental challenge in astrophysics. We have developed a method of inferring distances to astrophysical sources using spatial cross-correlations with galaxies of known redshift. These â€œclustering redshiftsâ€• are robust to problems plaguing other distance estimates and require only knowledge of the on-sky position of the sources. We have verified the method with sources with spectroscopic redshifts, demonstrating accuracies exceeding those required for many cosmological probes. Using this technique, we have explored the SDSS photometric galaxies, characterizing their distances and discovering entirely unidentified populations within. Clustering redshifts are proving their potential in the era of large scale surveys, such as LSST and DES, and will be a new tool in unlocking the third dimension of astronomical observations from the radio to the X-ray.

Clustering Redshifts
A New Era of Distance Measurement

Mubdi Rahman

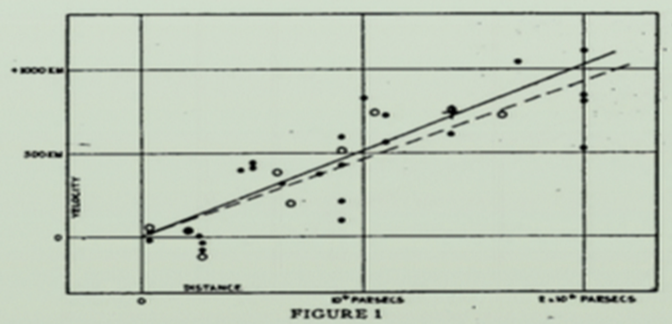
In collaboration with:
Brice Ménard, Alexander Mendez (JHU), Ryan Scranton, Sam Schmidt (UC Davis), & Christopher Morrison (AIfA)

Cosmic Flow (and Other Novelties on Large Scales)
Perimeter Institute
August 11, 2015

JOHNS HOPKINS
UNIVERSITY

The Landscape of Distance Inference Techniques

TRADITIONAL REDSHIFTS



Spectroscopic: Hubble (1929)

Precision Velocity Measurement

REQUIRES:

- Identifiable Spectral Feature
- Spectroscopic Observation

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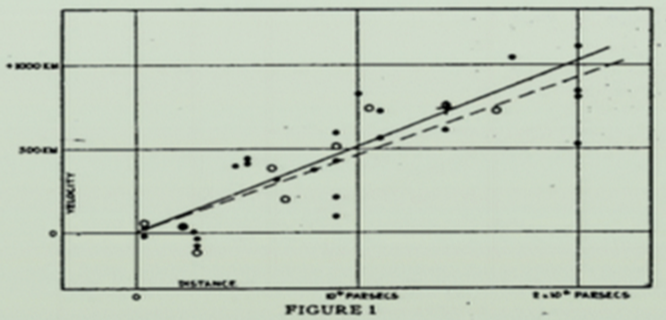

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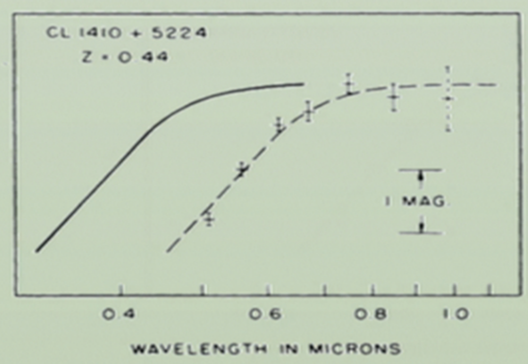

Photometric: Baum (1962)

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Coarse characterization of SED

REQUIRES:

- Precise Photometry
- Training Set and/or Spectral Templates

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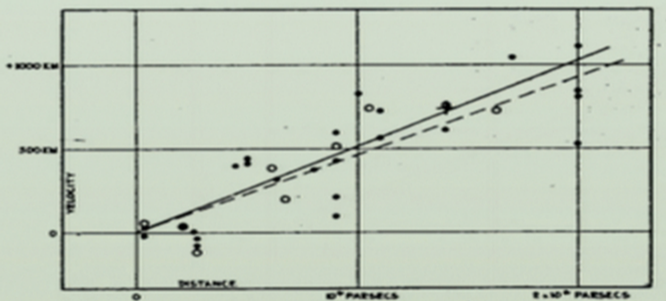

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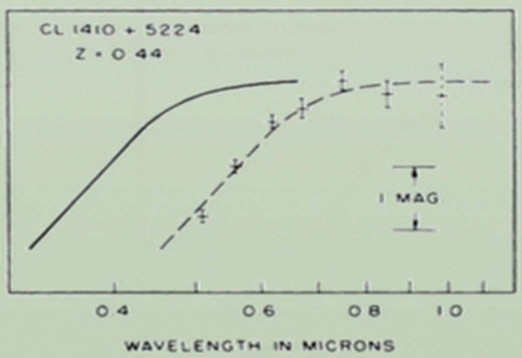

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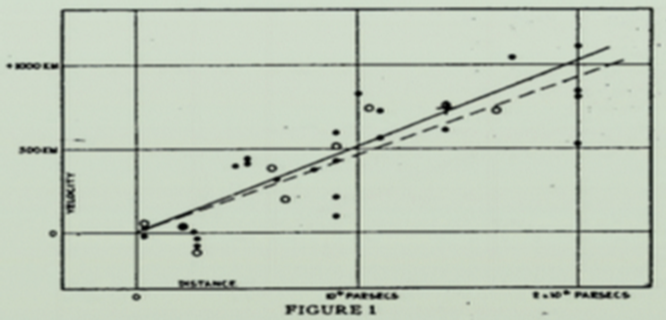

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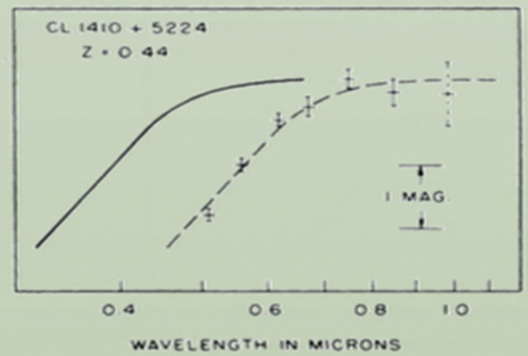

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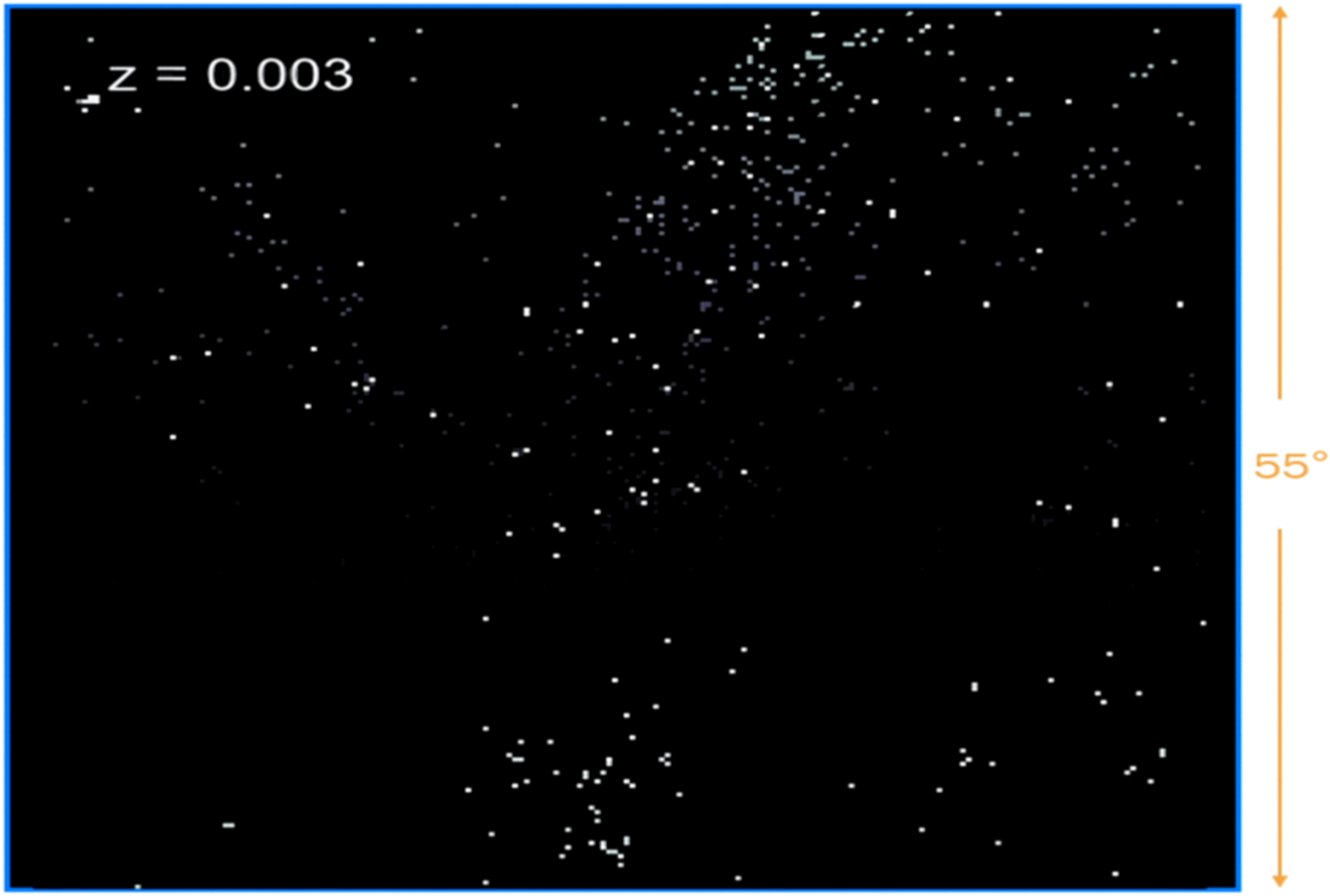
Clustering of Matter in the Universe



SDSS Spectroscopic Galaxies

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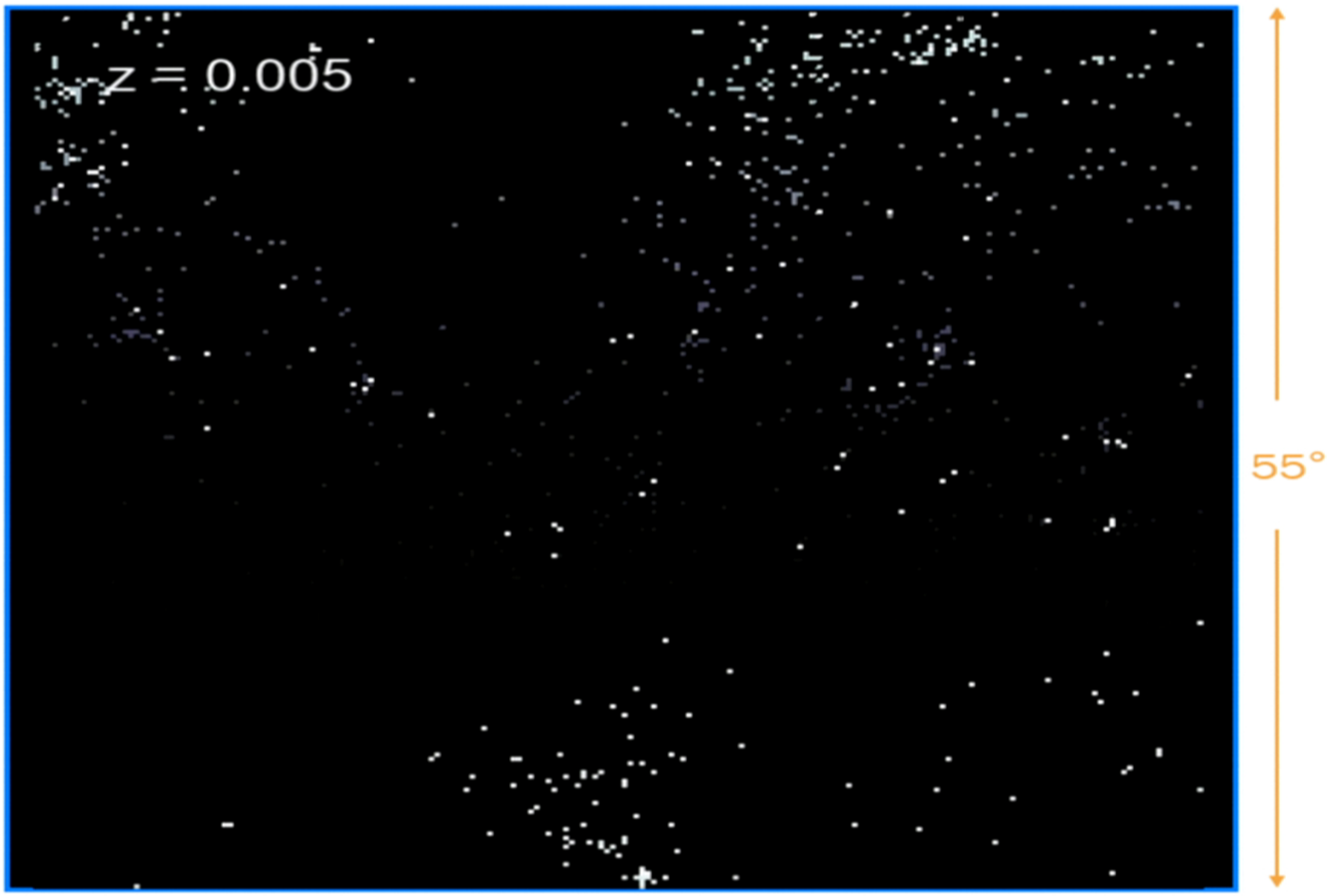

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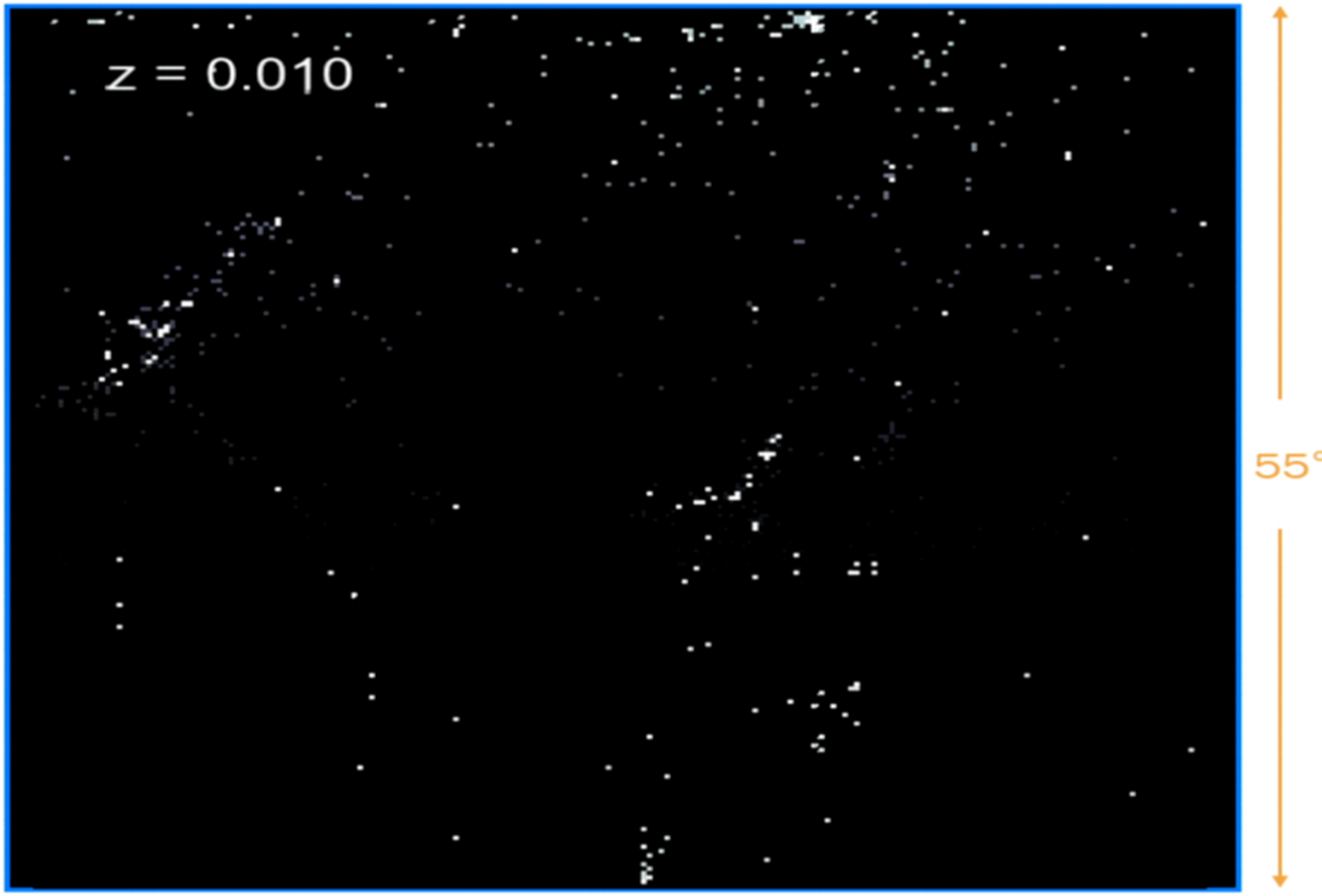

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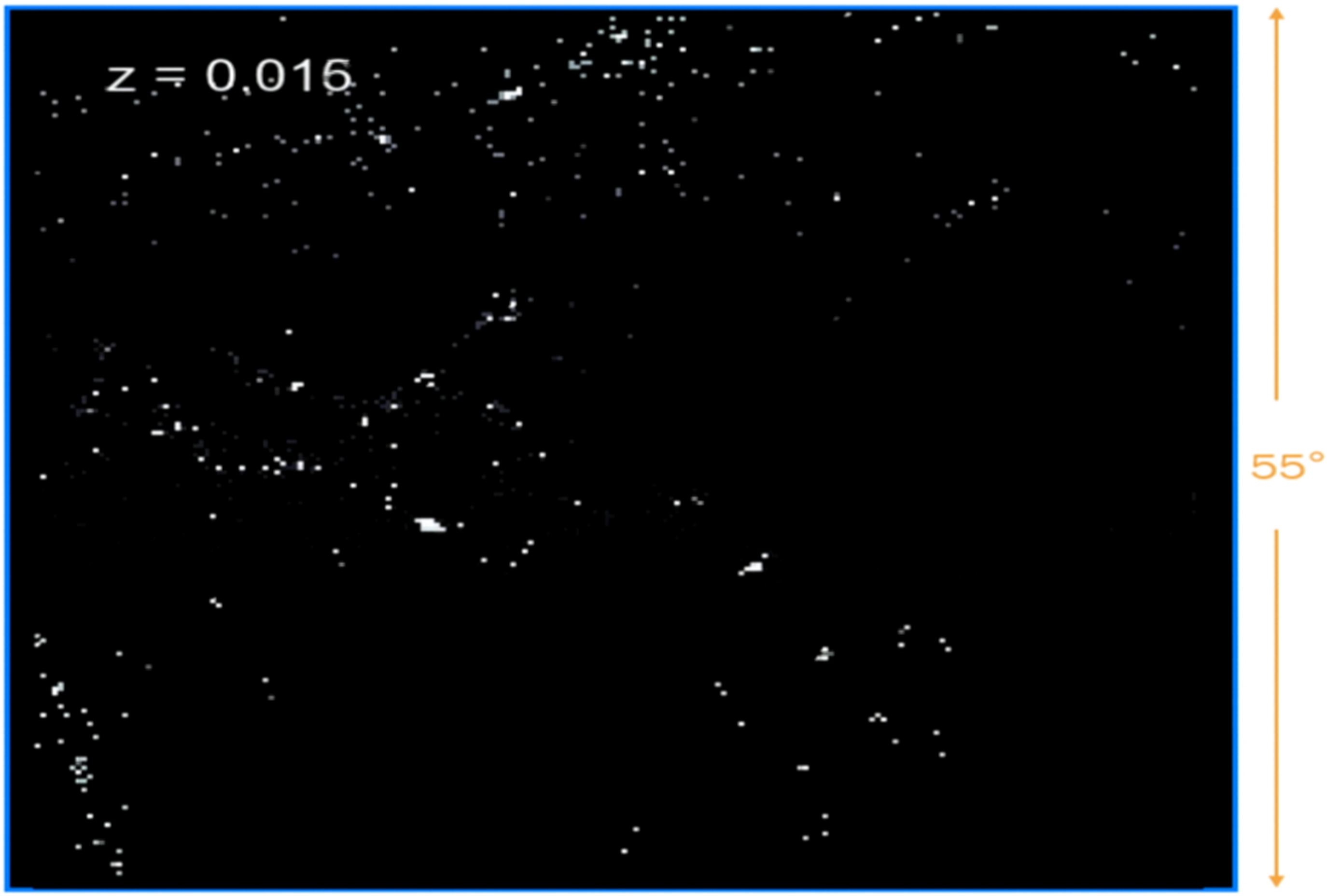

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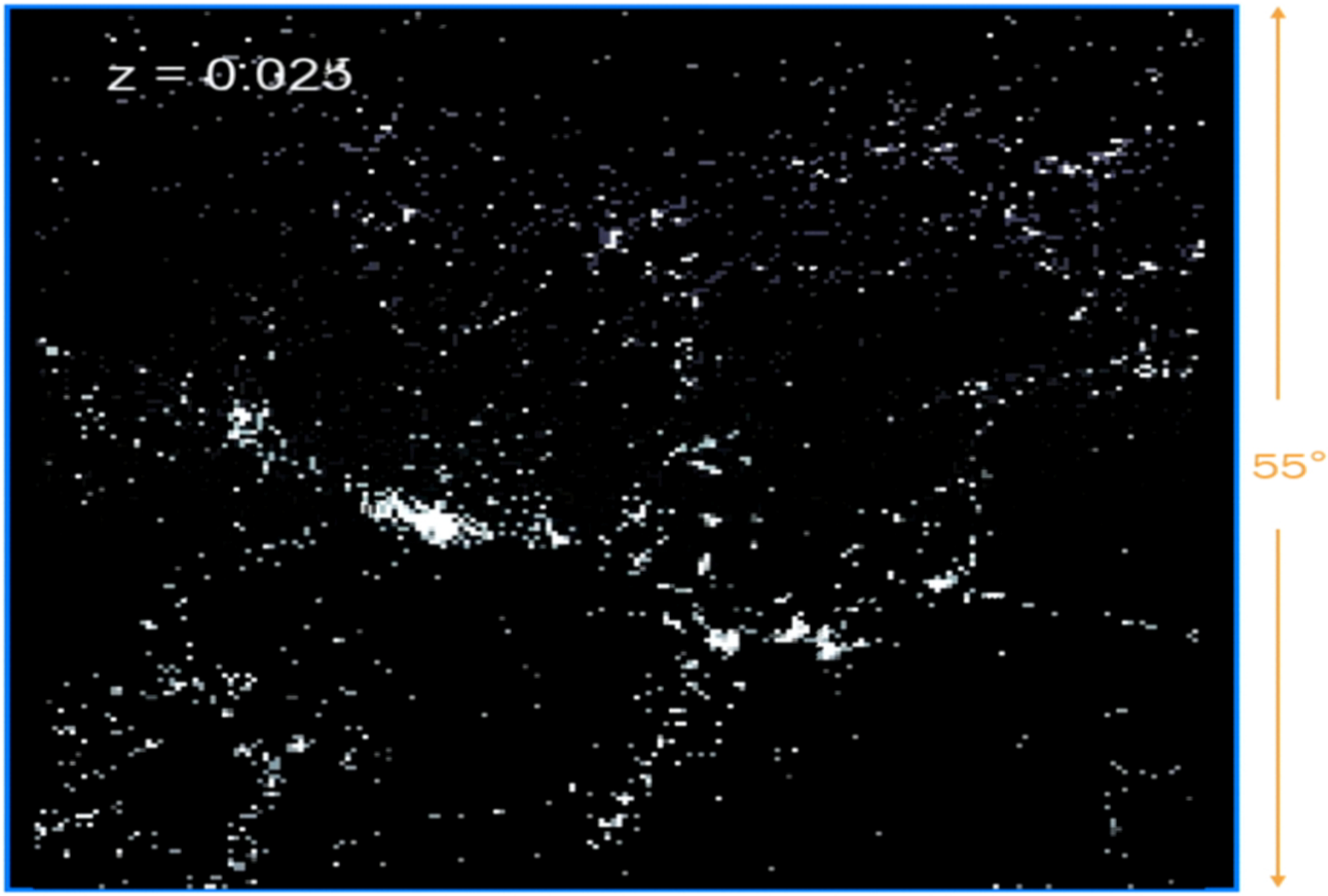

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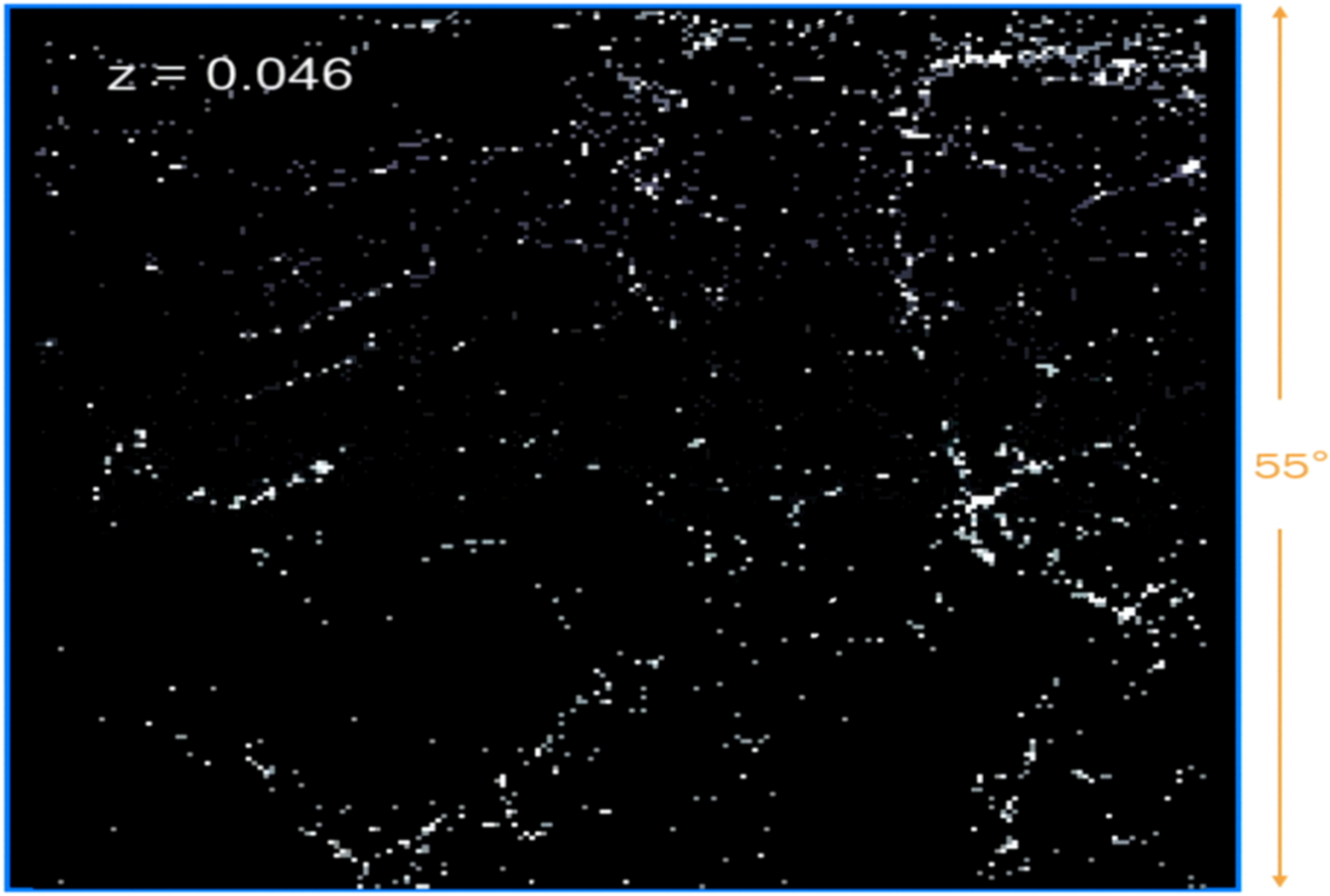

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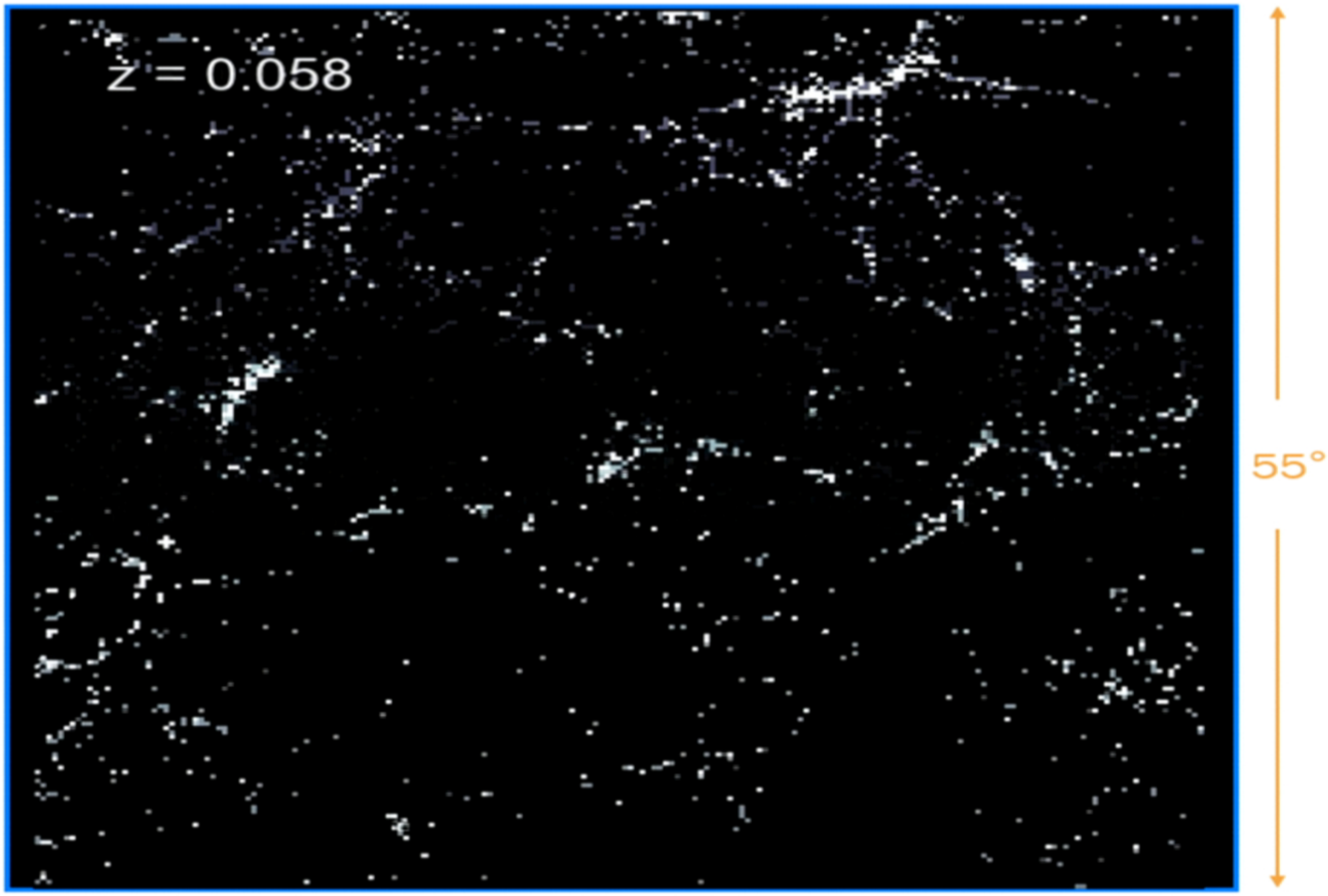

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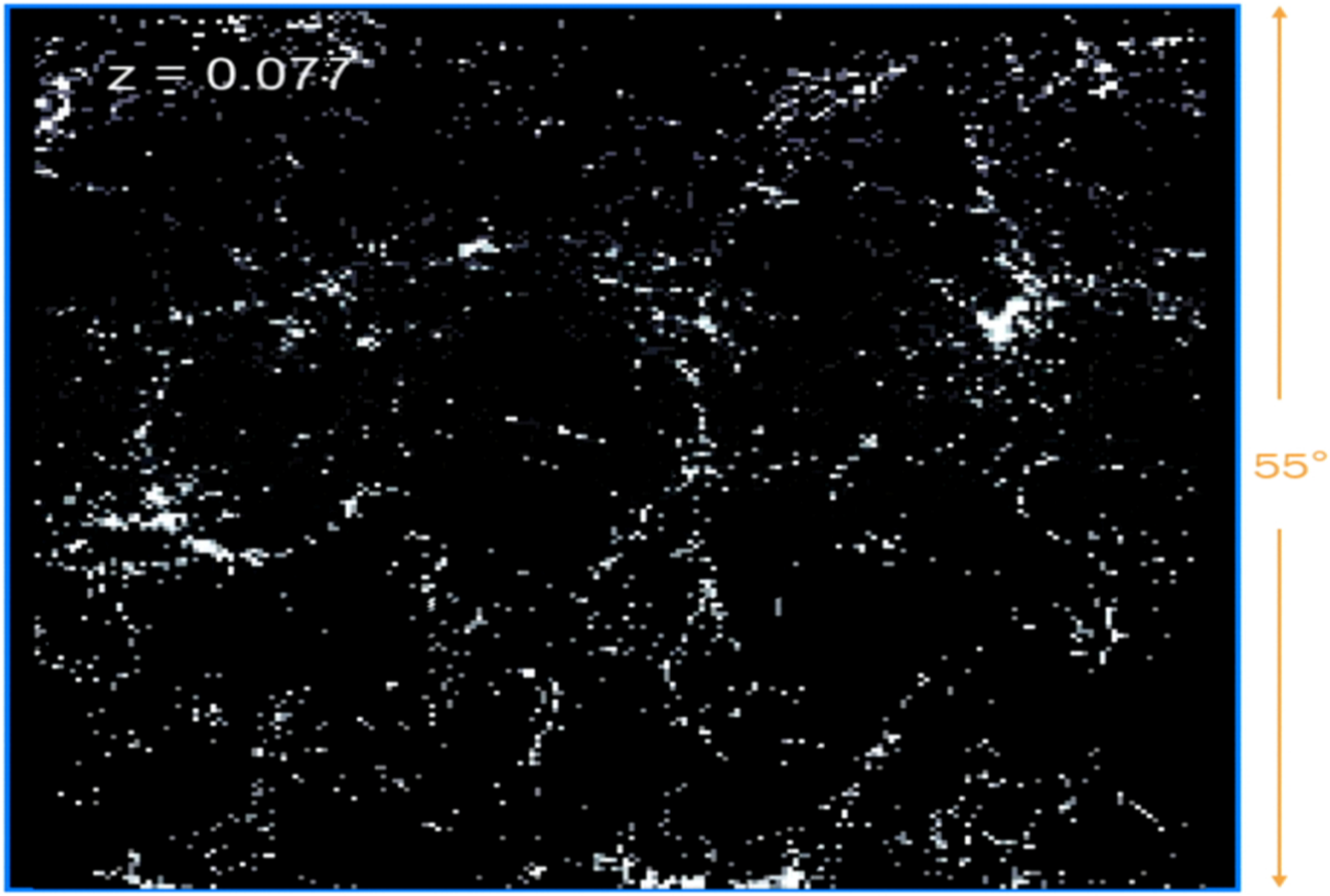
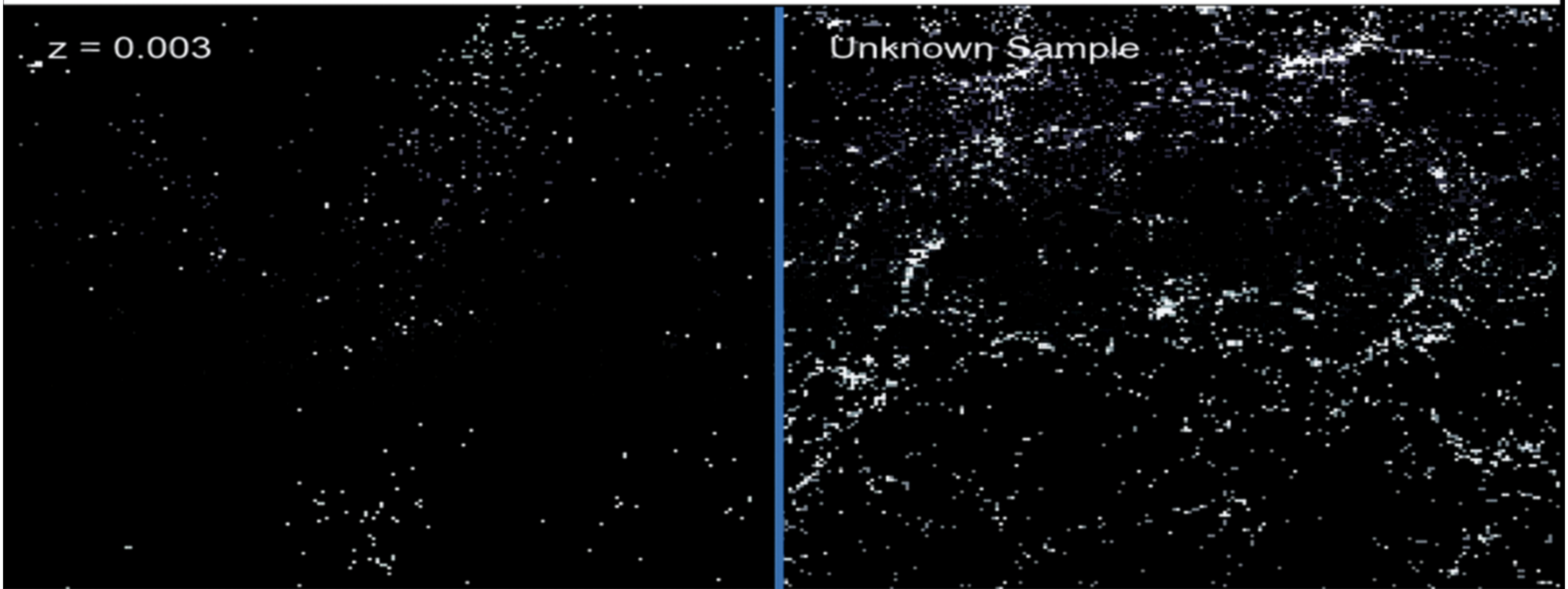


SDSS Spectroscopic Galaxies

Inferring Redshift through Spatial Cross-Correlation



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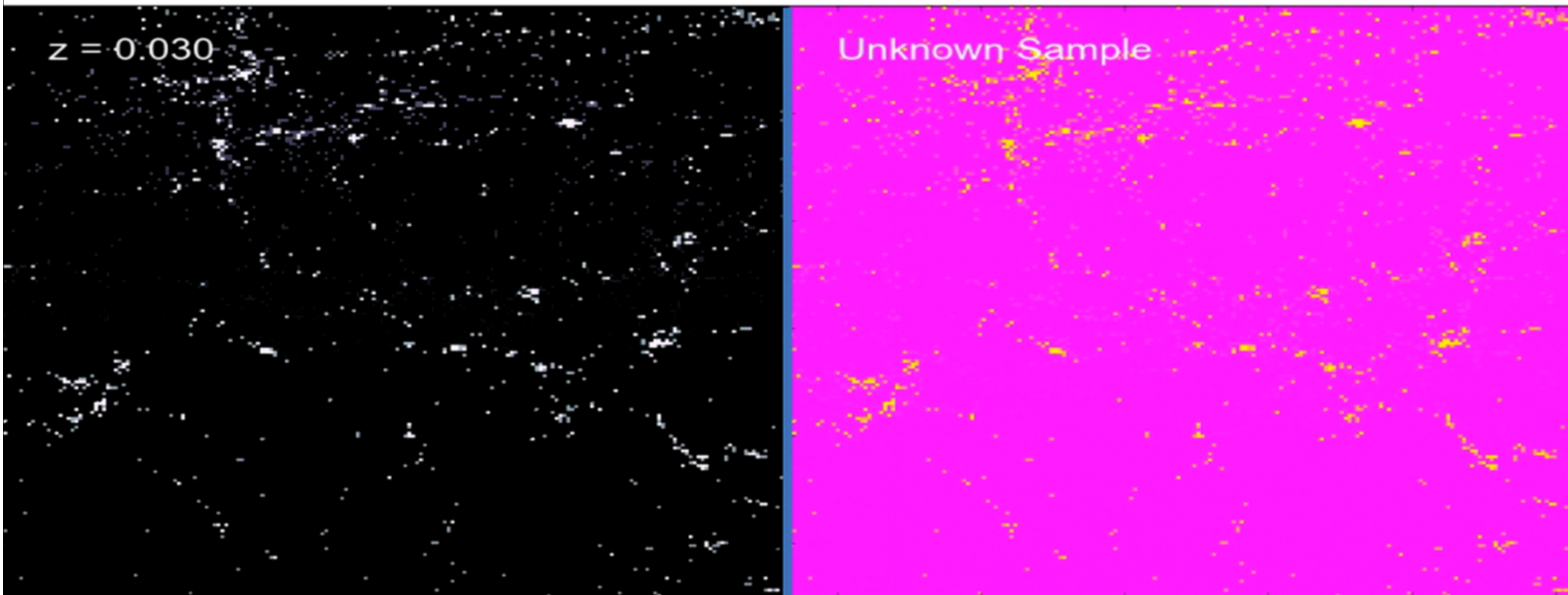

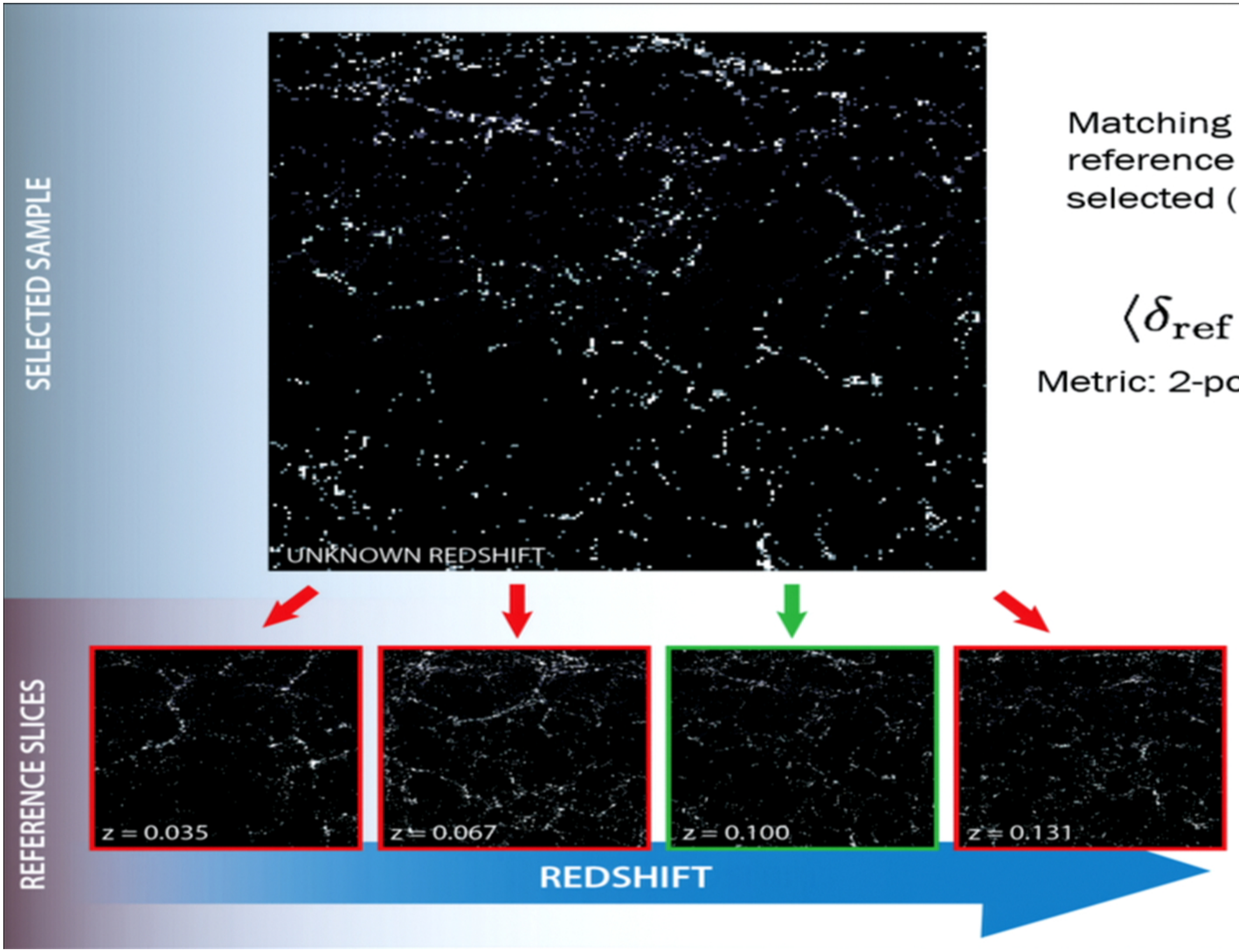

Matching on-sky structure in reference redshift slice with selected (unknown) sample

$$\langle \delta_{\mathrm{ref}} \cdot \delta_{\mathrm{unknown}} \rangle$$

Metric: 2-point correlation function

Fundamental Observable:

$$\overline{w(z)} = \int_{\theta_{min}}^{\theta_{max}} \frac{\Sigma_u(\theta')W(\theta') - \overline{\Sigma_u}}{\overline{\Sigma_u}} \, d\theta'$$

(u refers to unknown sample, r to the reference sample)

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$$\overline{w(z)} = \int_{z_{min}}^{z_{max}} \frac{dN_u}{dz'} \frac{dN_r}{dz'} \, \overline{b_u(z')} \, \overline{b_r(z')} dz'$$

$\bar{b}$ is the bias-related **integrated clustering amplitude**

As long as redshift bins span the entire redshift range of objects, we can normalize:

$$N_{tot} = \int_0^{\infty} \frac{dN_u}{dz'} \, dz'$$

For Delta function distributions, this recovers **exact** solution

The Landscape of Distance Inference Techniques

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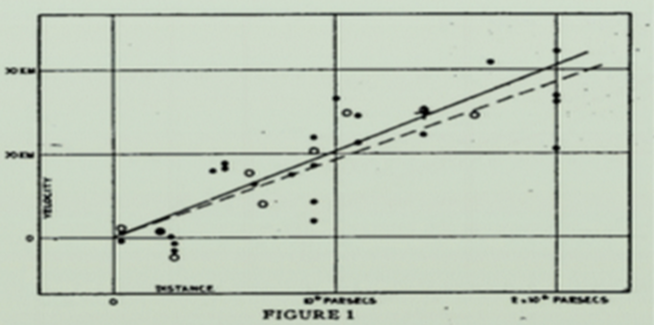

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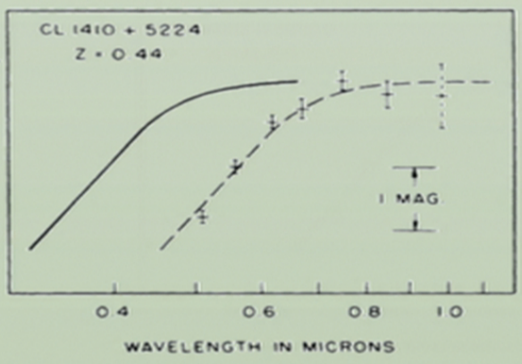
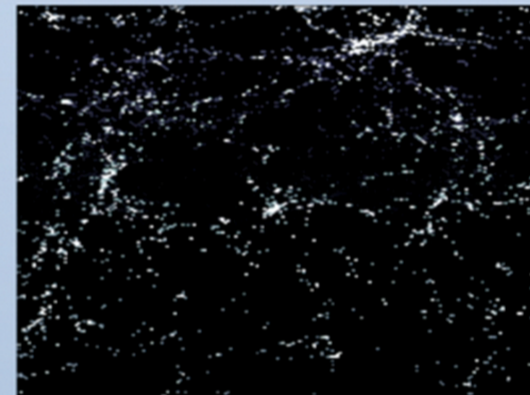


Photometric: Baum (1962)

CLUSTERING REDSHIFTS



Inferring distances based on the aggregation of matter

REQUIRES:

- Redshift spanning Catalog of Galaxies with known Redshift

The Landscape of Distance Inference Techniques

Peebles 1969
First mention of the idea

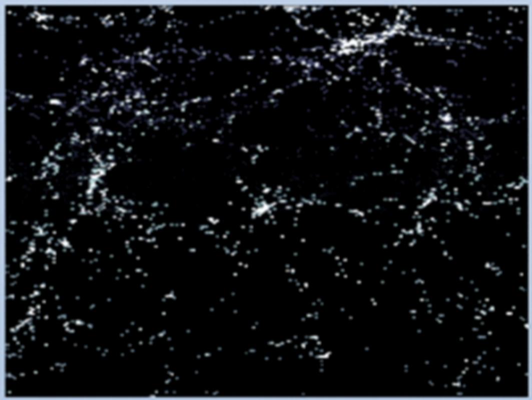
Landy, Szalay, & Koo 1996
First use of clustering in data

Newman 2008, Matthews & Newman 2010, Matthews & Newman 2012
Development of the technique on *linear-biasing scales*, for *precision measurements*

de Putter et al. 2013, McQuinn & White 2013
Forecasting & optimizing the linear-scale method

Ménard et al. 2013, Schmidt et al. 2013, Rahman et al. 2015a,b
Developing the technique on *all spatial scales*, development of the tools, and application to data

CLUSTERING REDSHIFTS



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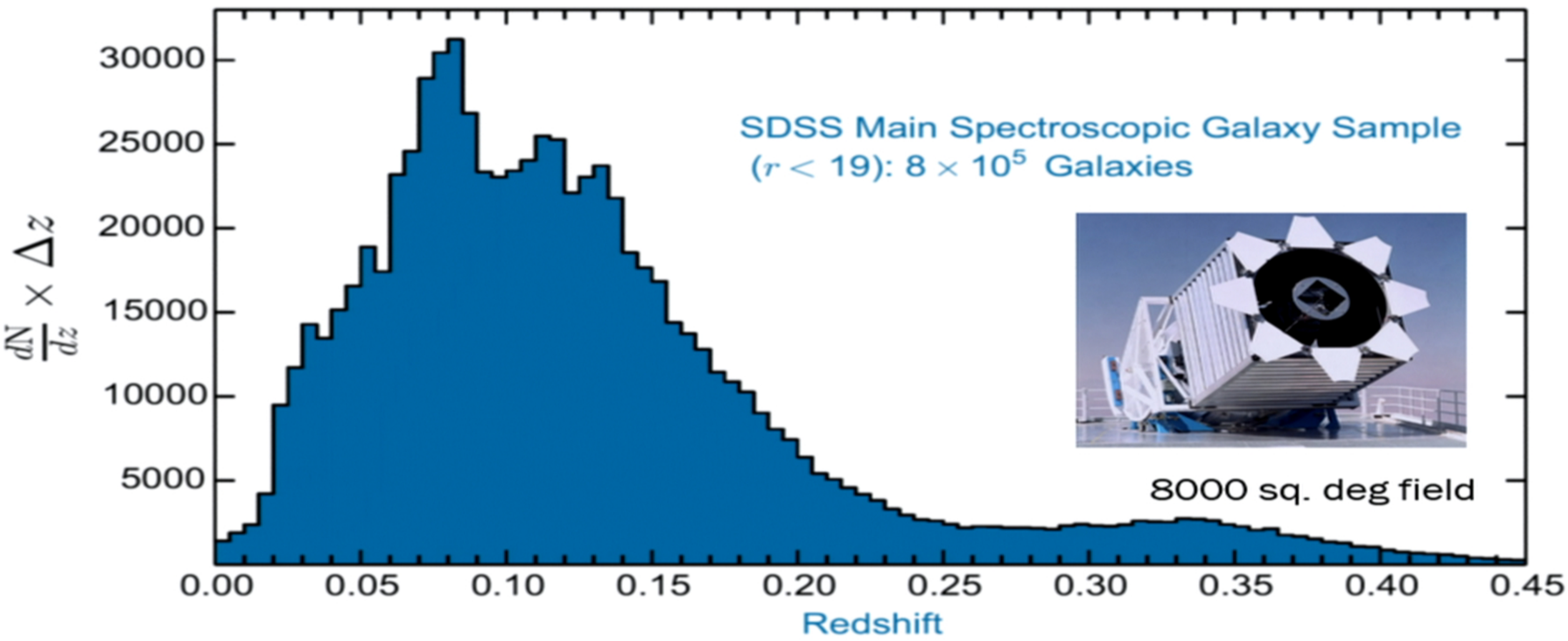
Actual Data: The Sloan Digital Sky Survey

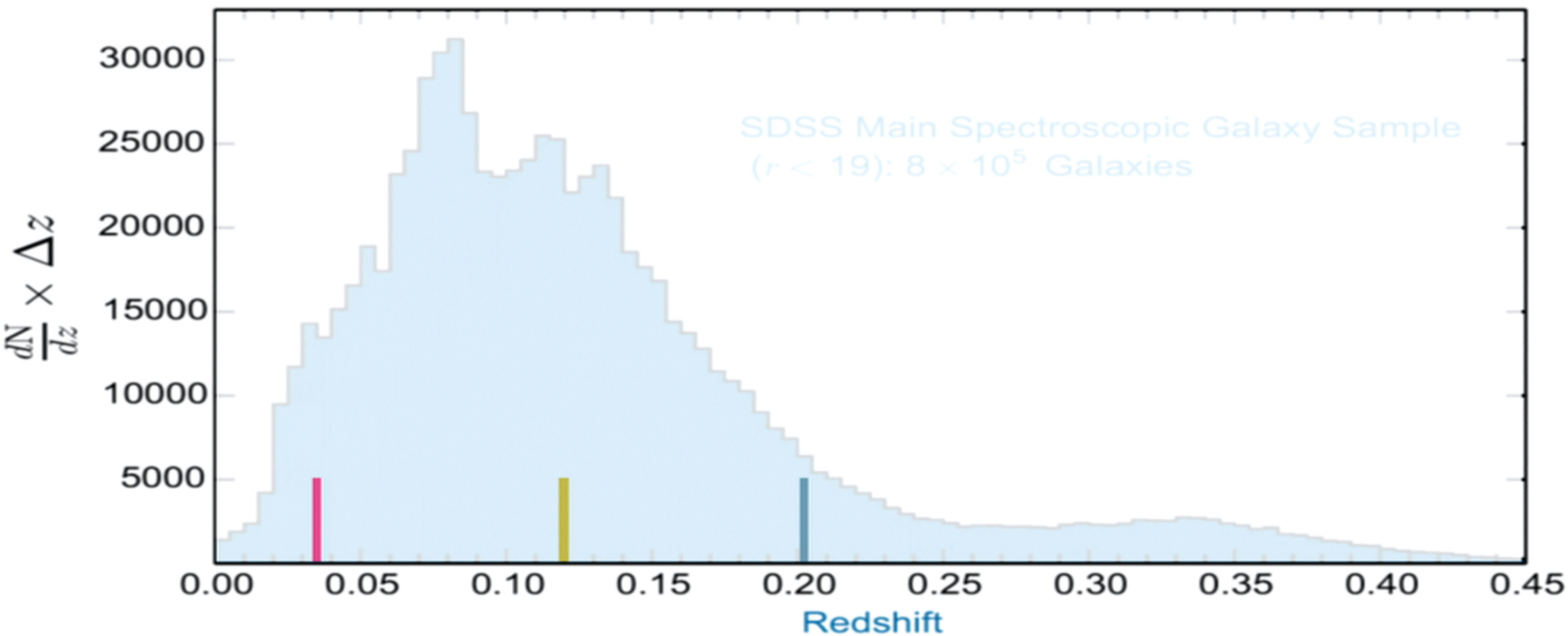


Large catalogs of spectroscopic redshifts exist!

Have Spectroscopic LRGs and Quasars spanning redshifts to z~5

Rahman et al. 2015a

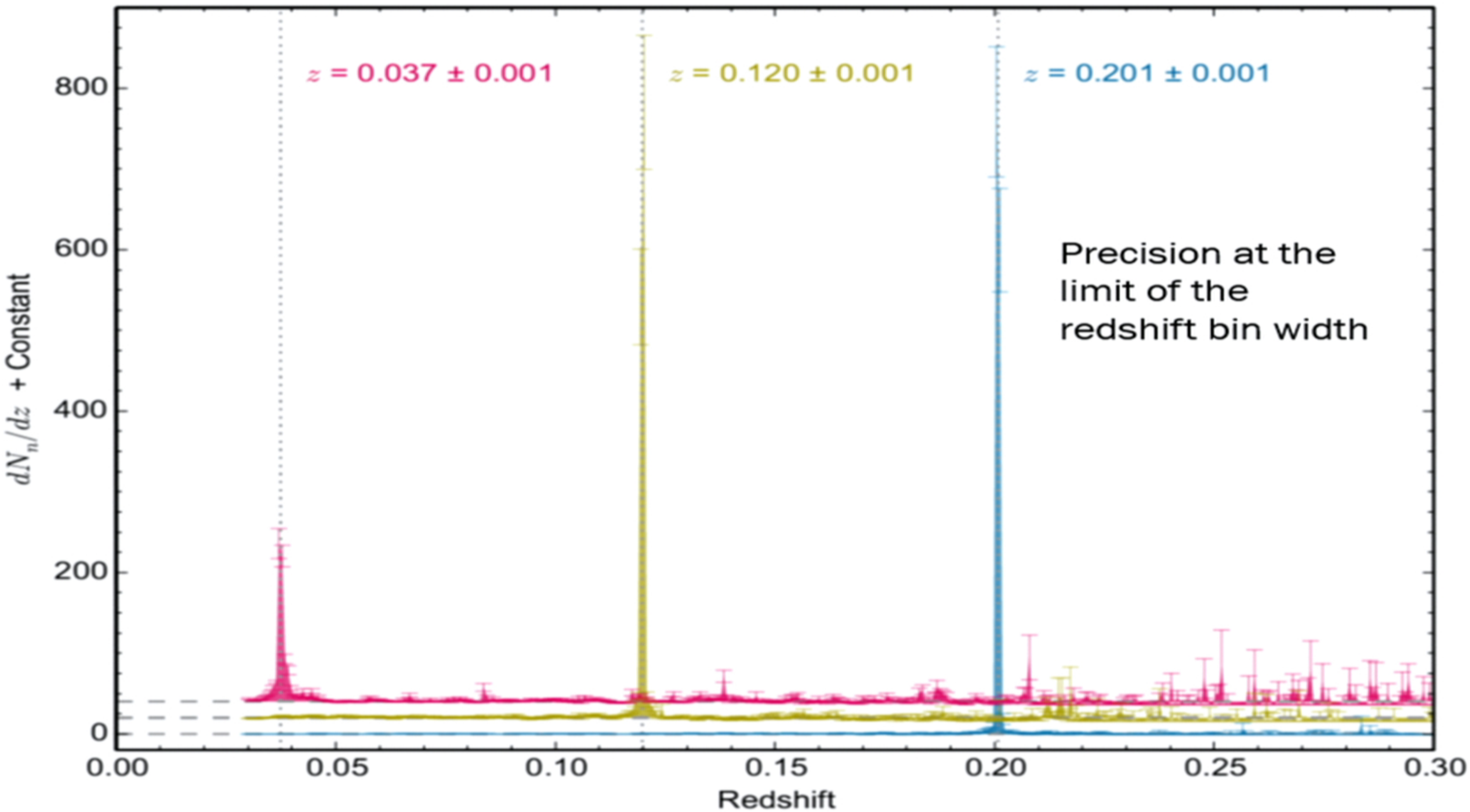
Actual Data: The Sloan Digital Sky Survey



Isolating narrow bins in redshift ($\Delta z \sim 10^{-3}$)
Recovering through Clustering Redshifts

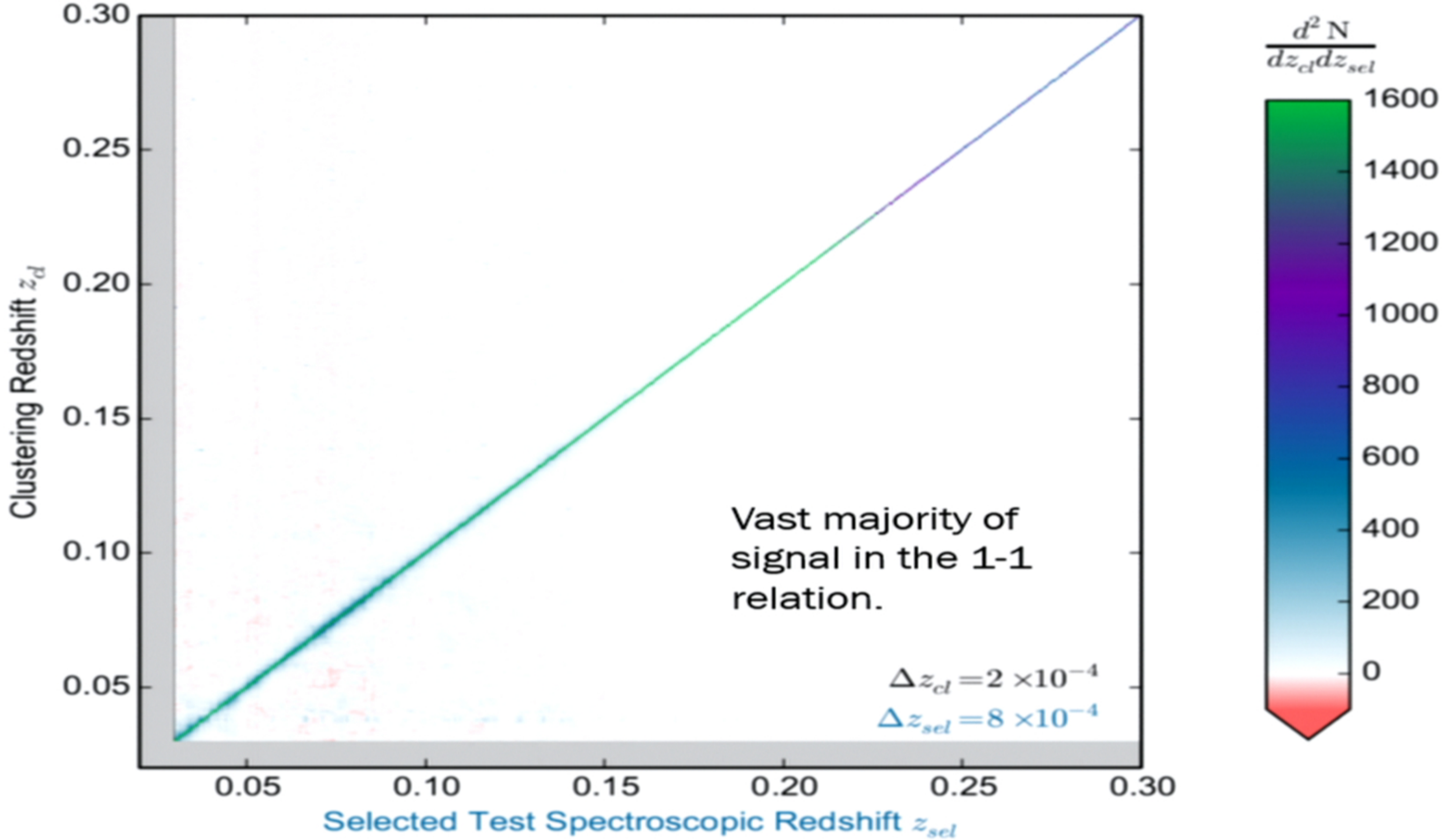
Rahman et al. 2015a

Clustering Redshift of Narrow z-bins



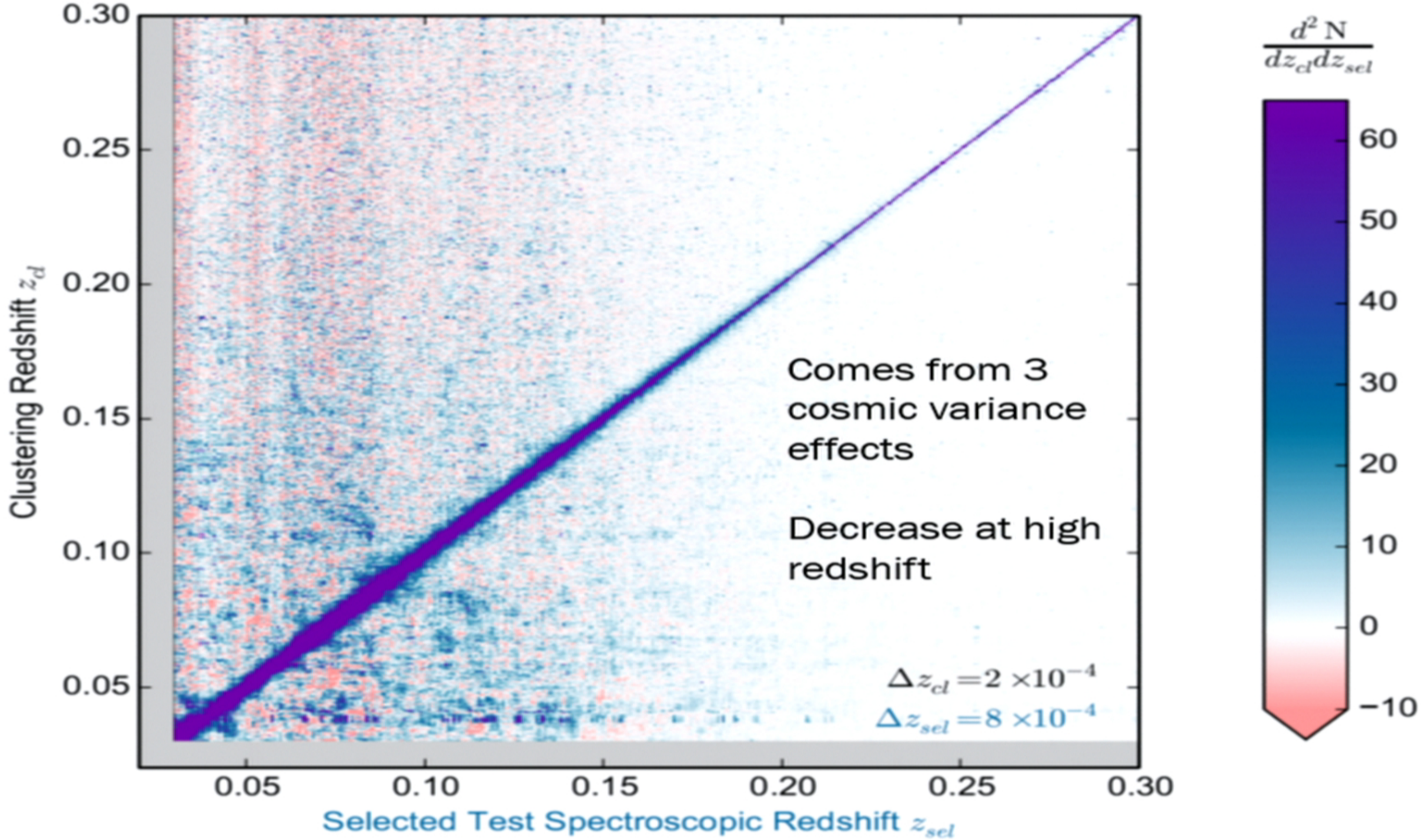
Rahman et al. 2015a

Clustering Redshift Density Plot



Rahman et al. 2015a

Coherent Noise



Rahman et al. 2015a

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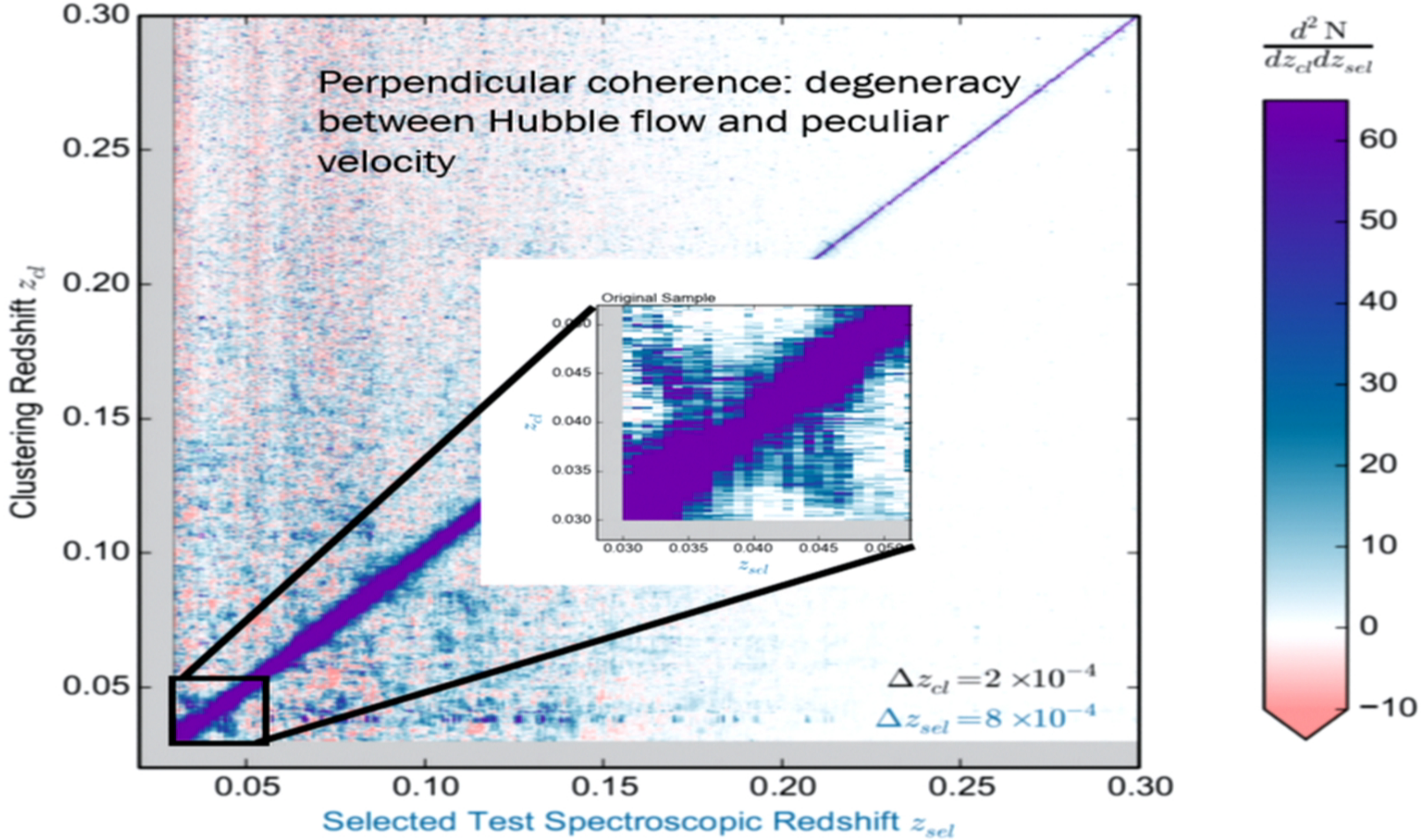

Rahman et al. 2015a

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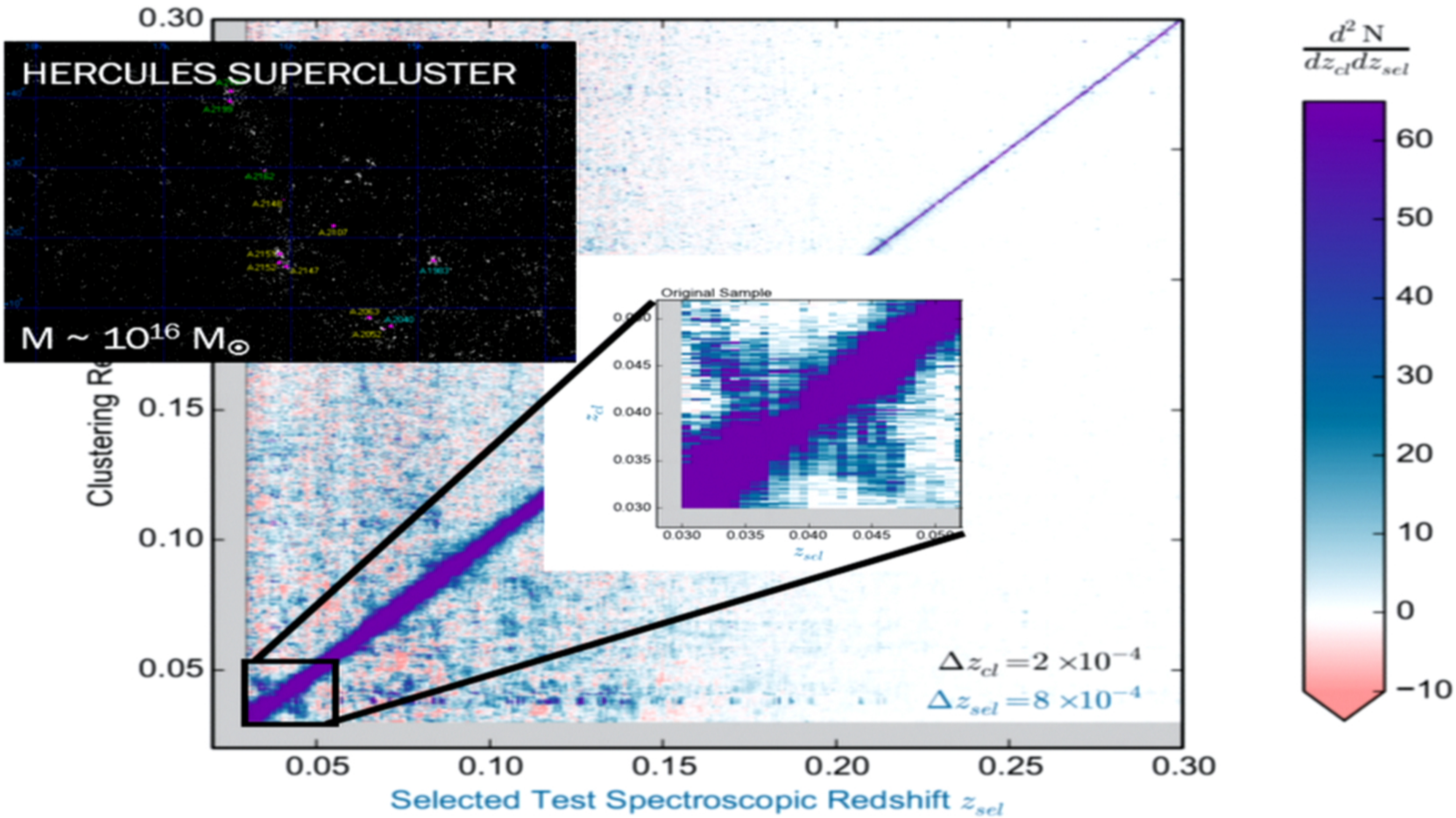


Rahman et al. 2015a

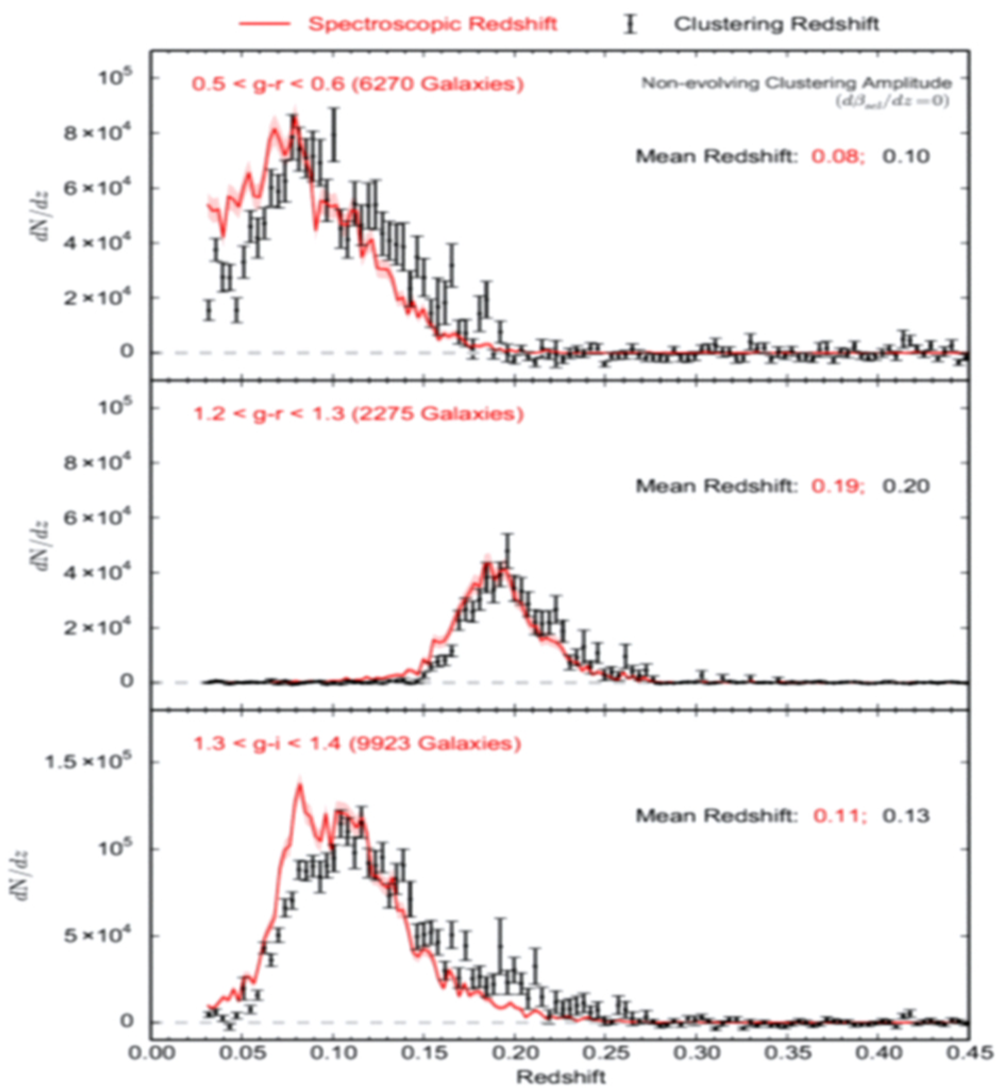
Measuring Redshift Distributions of Photometric Selections

Unknown samples selected from SDSS with r < 17.77

Colour selections:

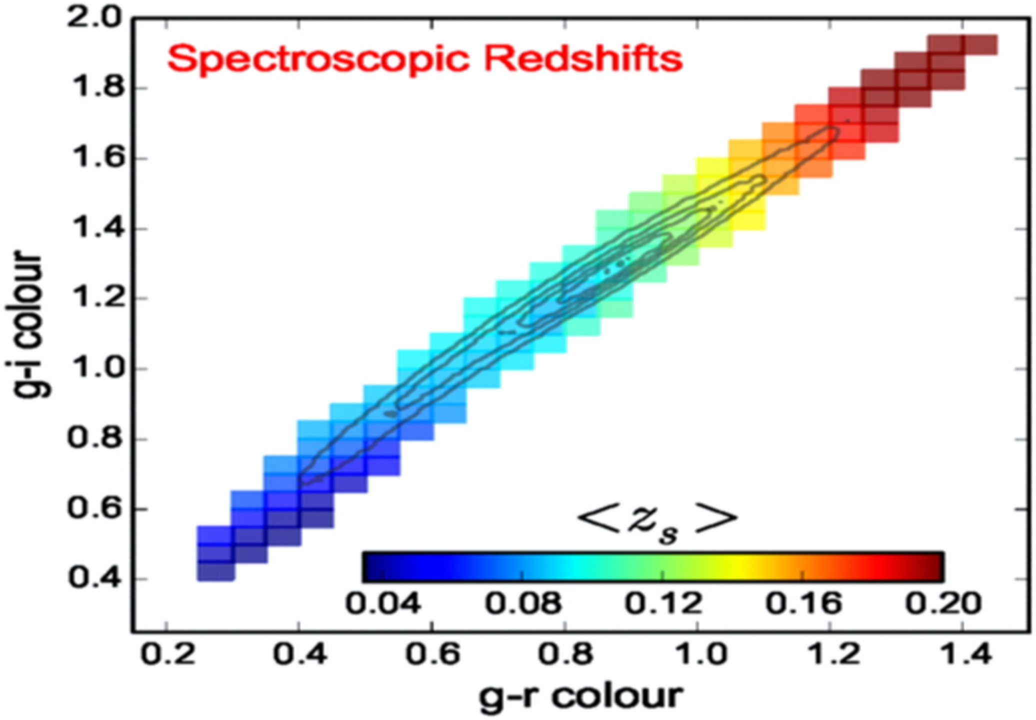
- 0.5 < g-r < 0.6
- 1.2 < g-r < 1.3
- 1.3 < g-i < 1.4

Without any further information, the clustering redshift is able to determine mean redshift to within Δz~0.01



Rahman et al. 2015a

Exploring the z-evolution of a colour-space



Using ~1M sources from the SDSS spectroscopic galaxies

Black contours represent the density of galaxies in colour-space

Can span an entire colour-colour space, determining the mean redshift of each colour voxel

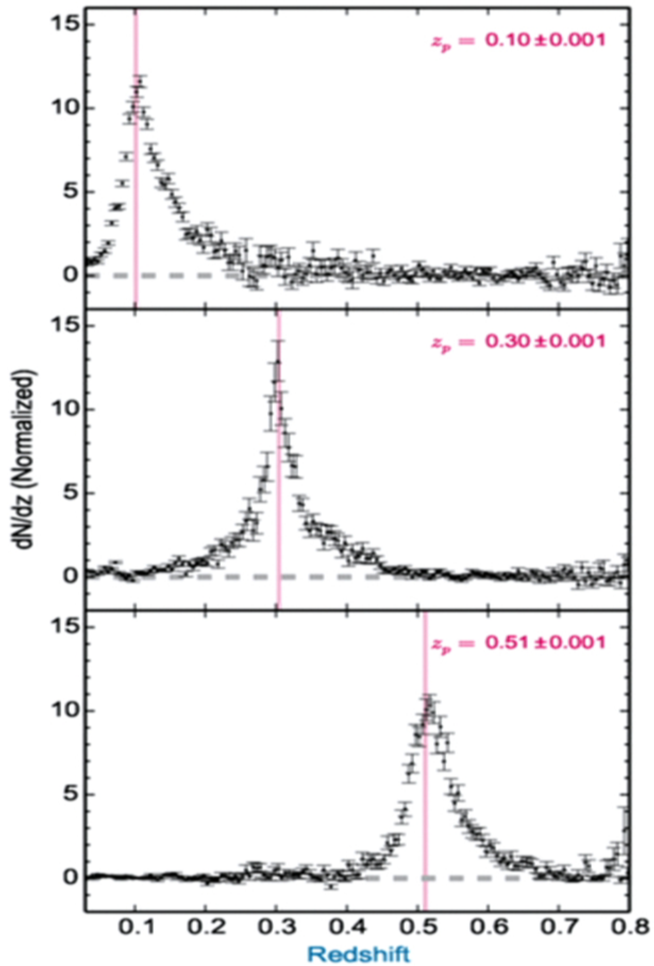
Rahman et al. 2015a

SDSS Photometric Galaxies

Using photo-z as a separating parameter.

Could use colour, size, or other observable

Demonstrates issue of using just colour-based information to determine redshift



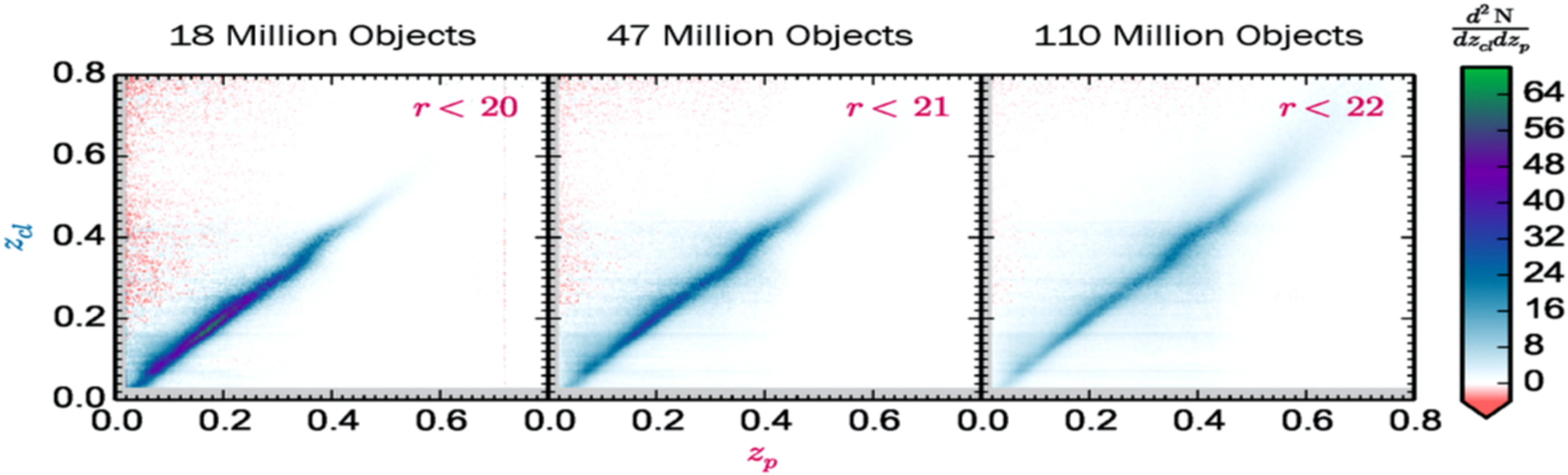
Pink line: input photo-z selection

Black points: Clustering Redshift

Demonstrates intrinsic uncertainty in the photo-zs

Rahman et al. 2015b

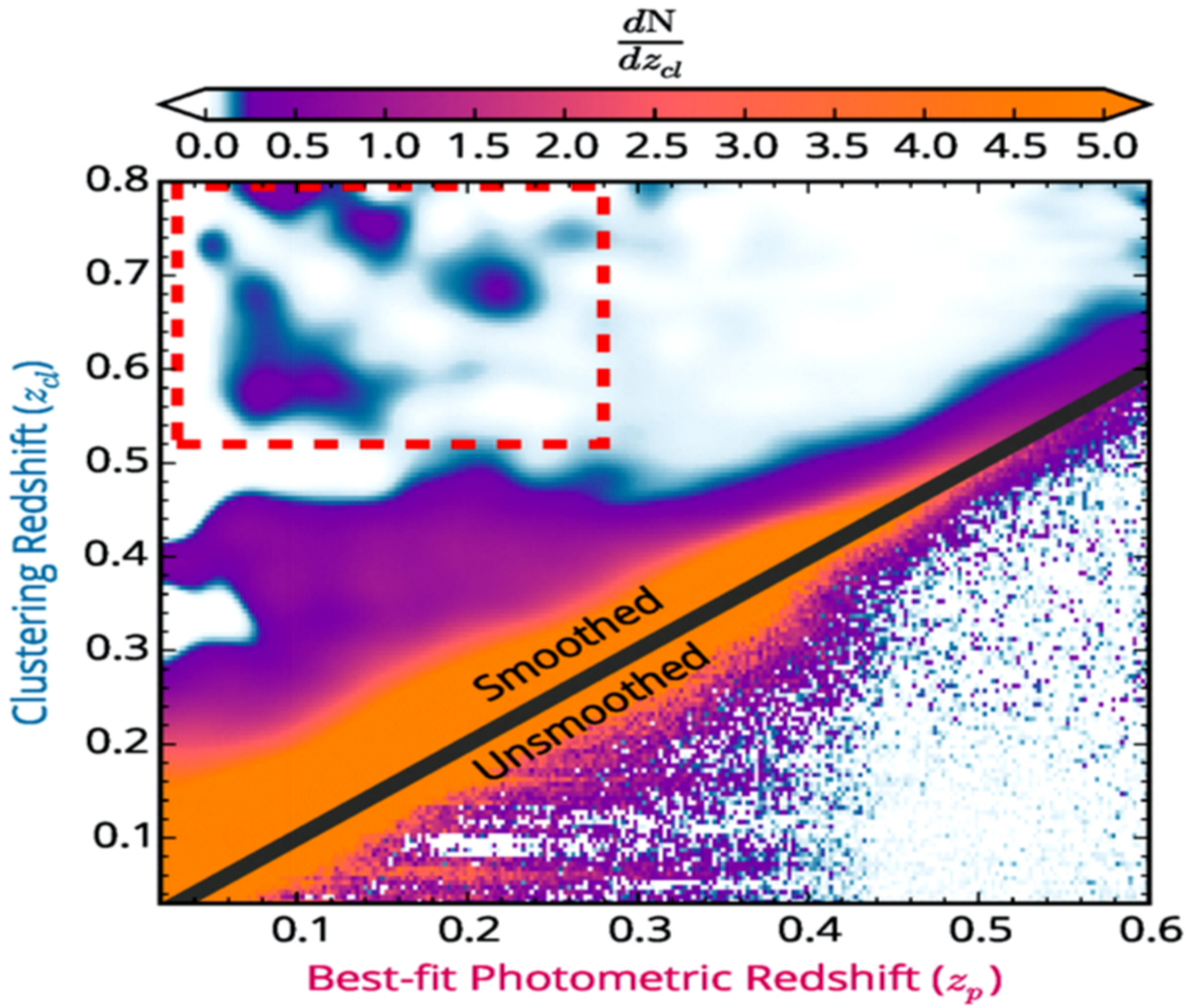
SDSS Photometric Galaxies



Can determine redshifts regardless of source brightness and/or SNR

Rahman et al. 2015b

SDSS Photometric Galaxies



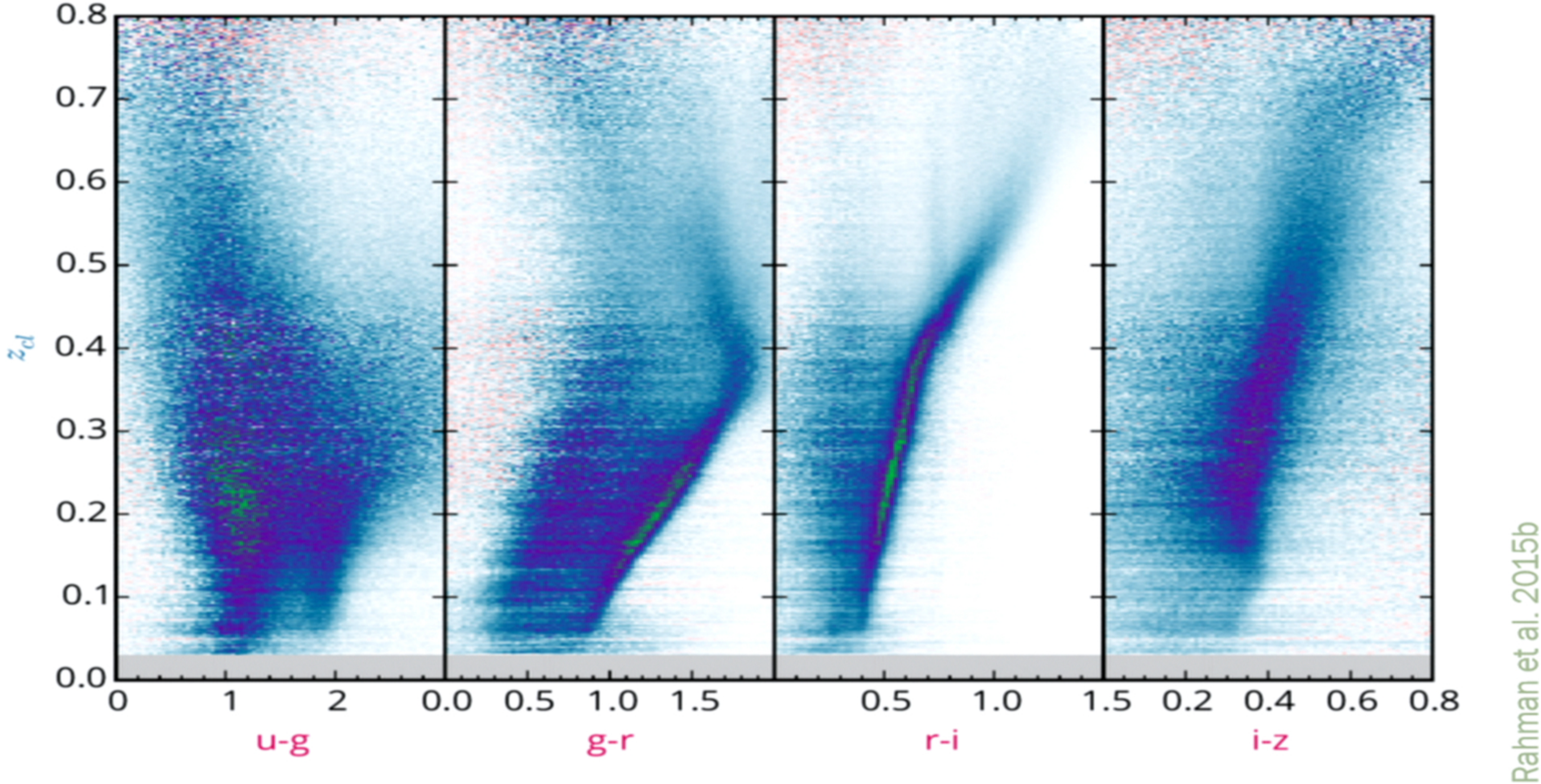
Can identify Emission Line Galaxies (ELGs) directly in the sample.

High redshift galaxies classified as low redshift in photo-zs.

Using this technique to find optimal colour cut for this population for upcoming eBOSS survey.

Rahman et al. 2015b

Full Colour Separation of SDSS Photometric Galaxies



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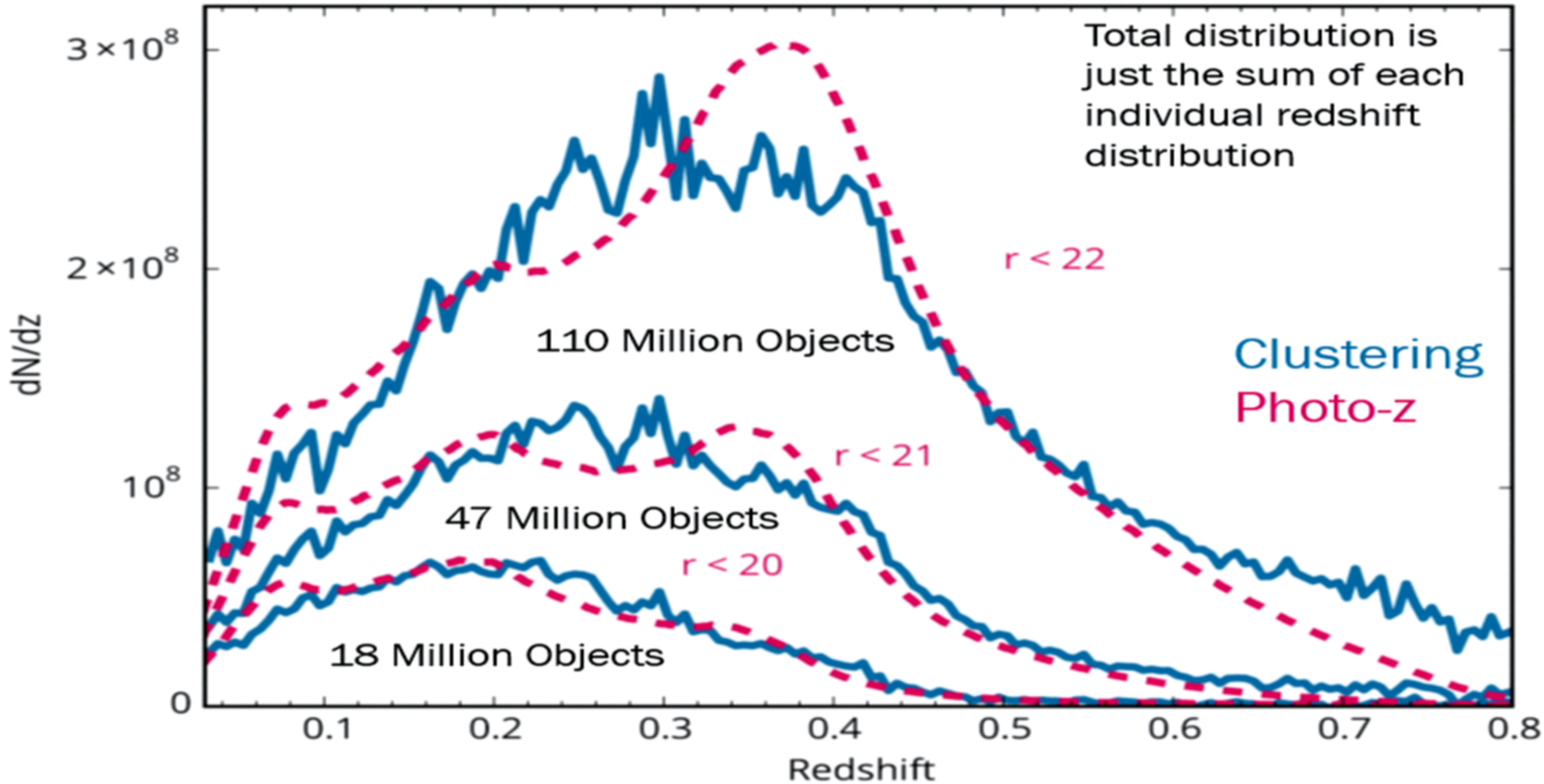
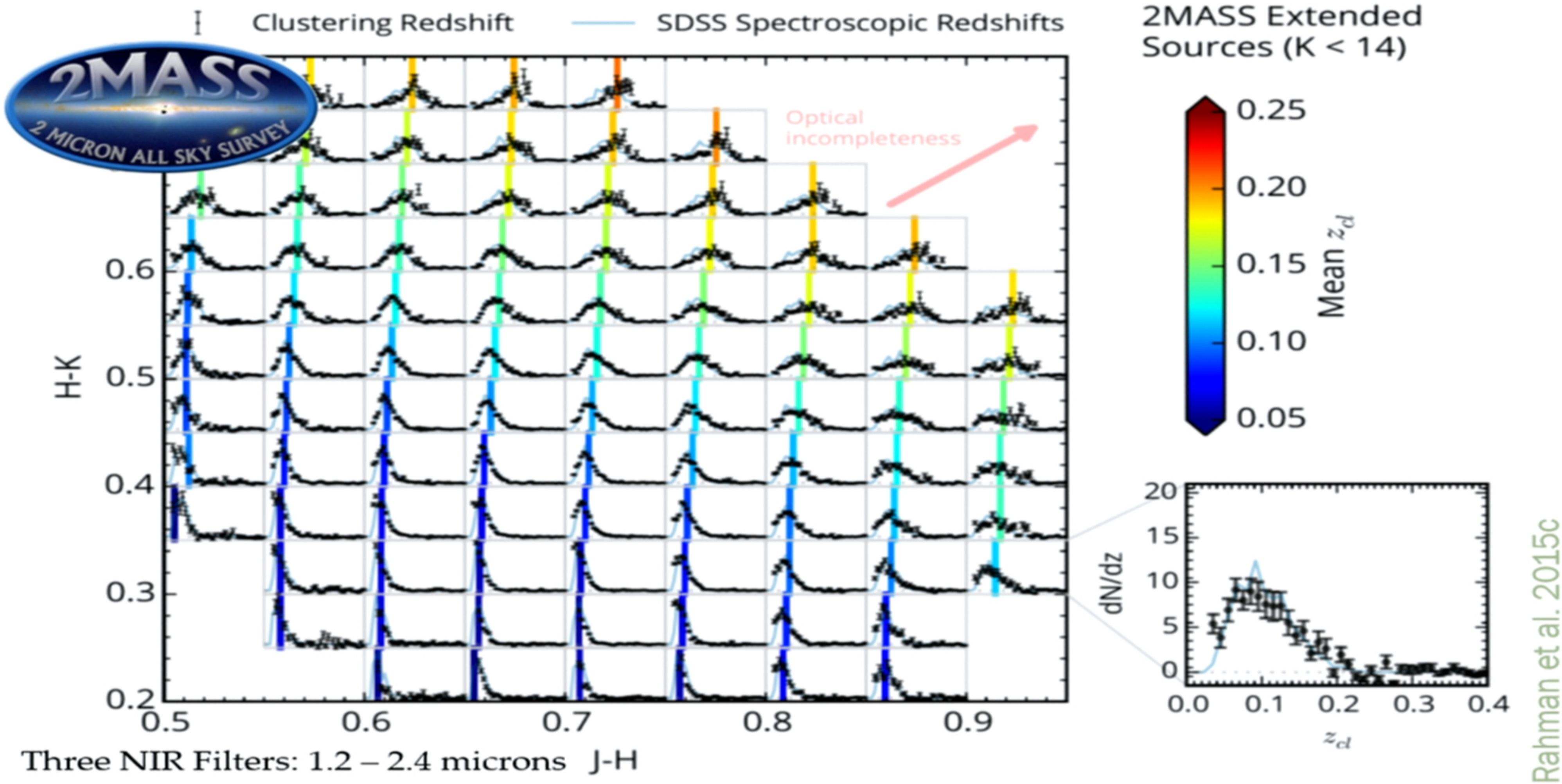


First determination of the full redshift distribution of SDSS

Rahman et al. 2015b

2MASS Clustering Redshift Distribution



Three NIR Filters: 1.2 – 2.4 microns J-H

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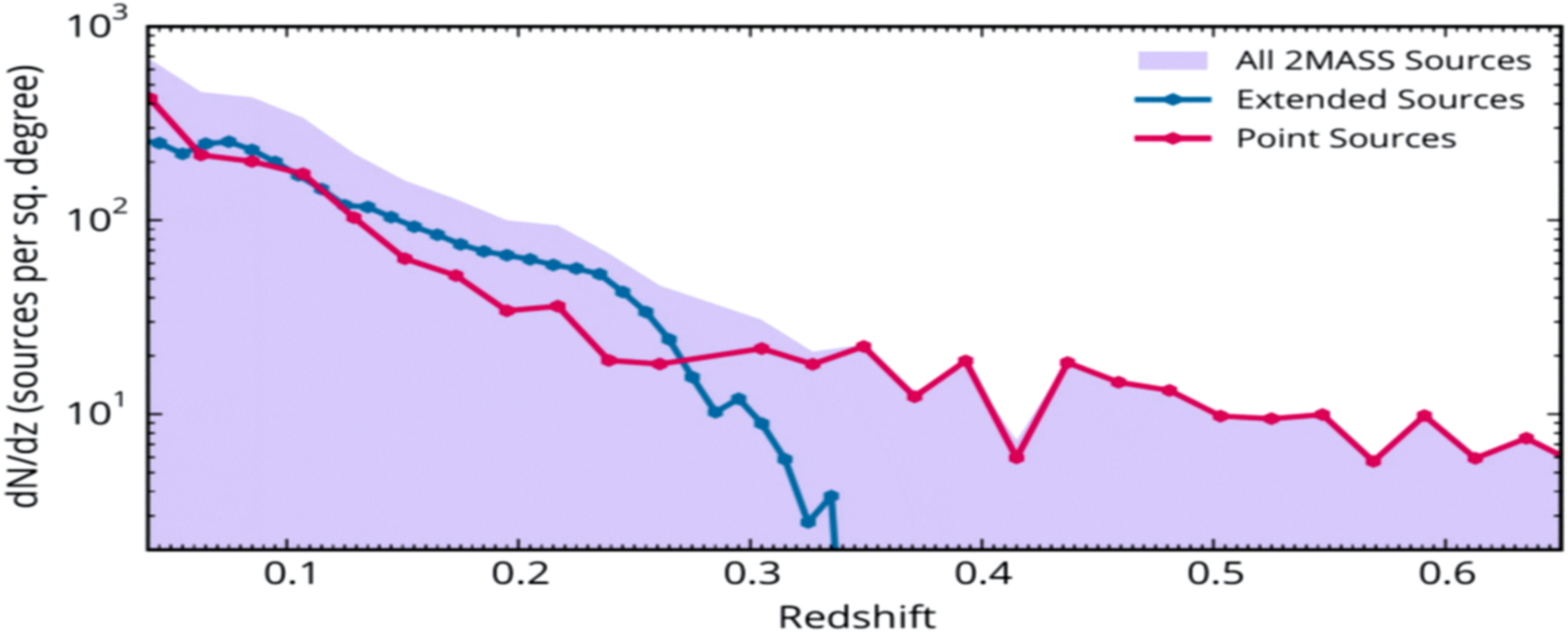

As many extragalactic sources in the point source catalog as in the extended source catalog

Rahman et al. 2015c

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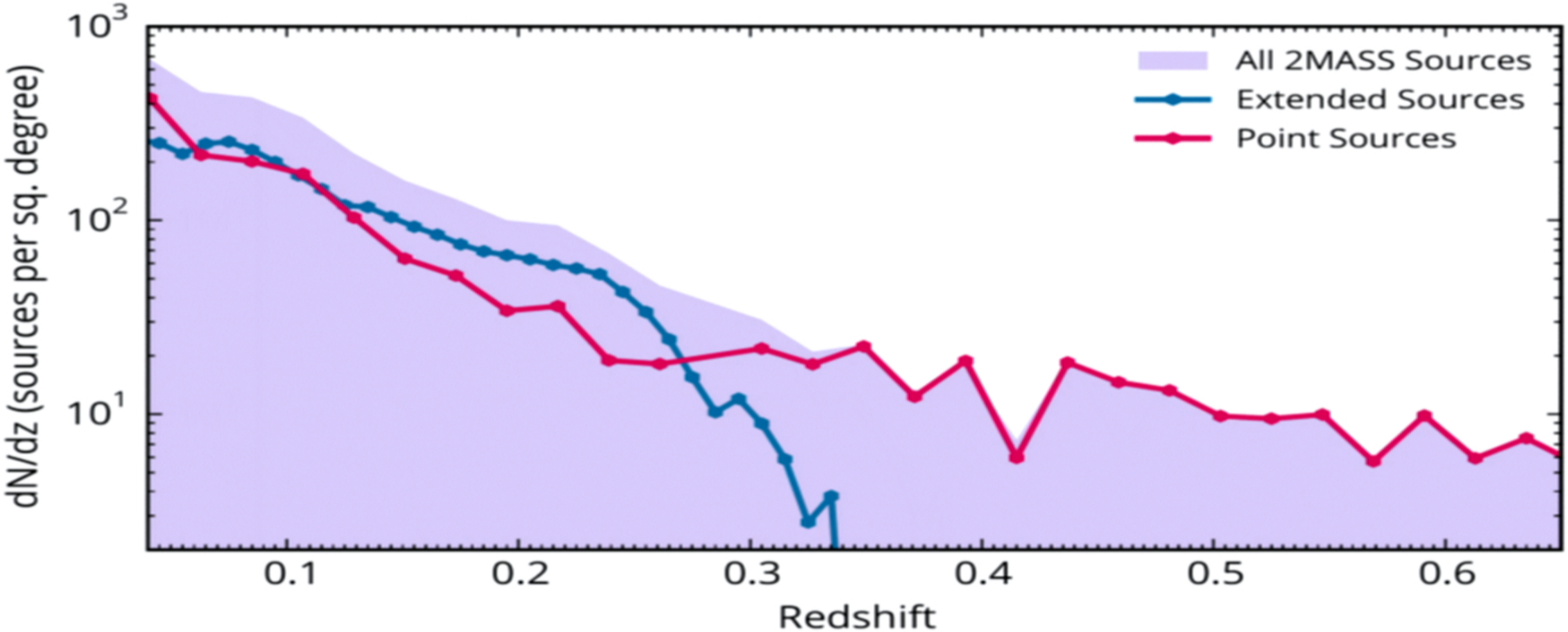

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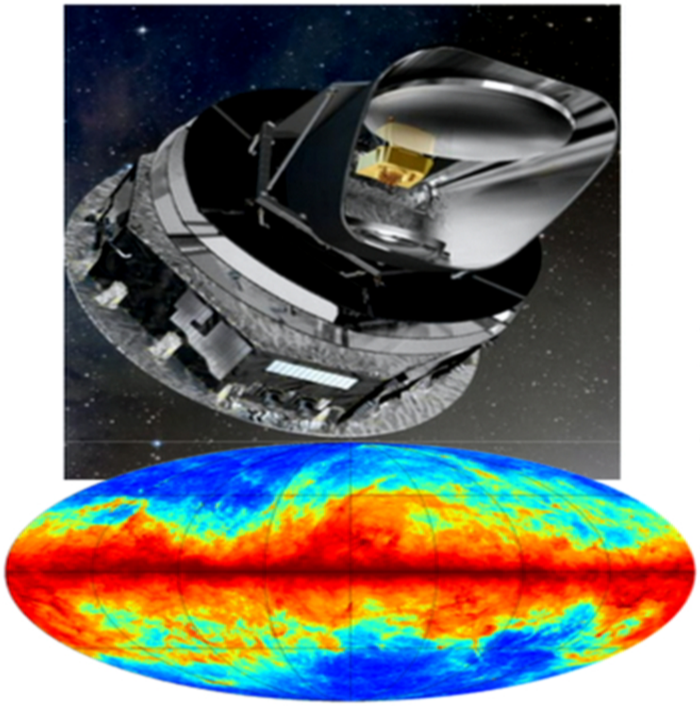
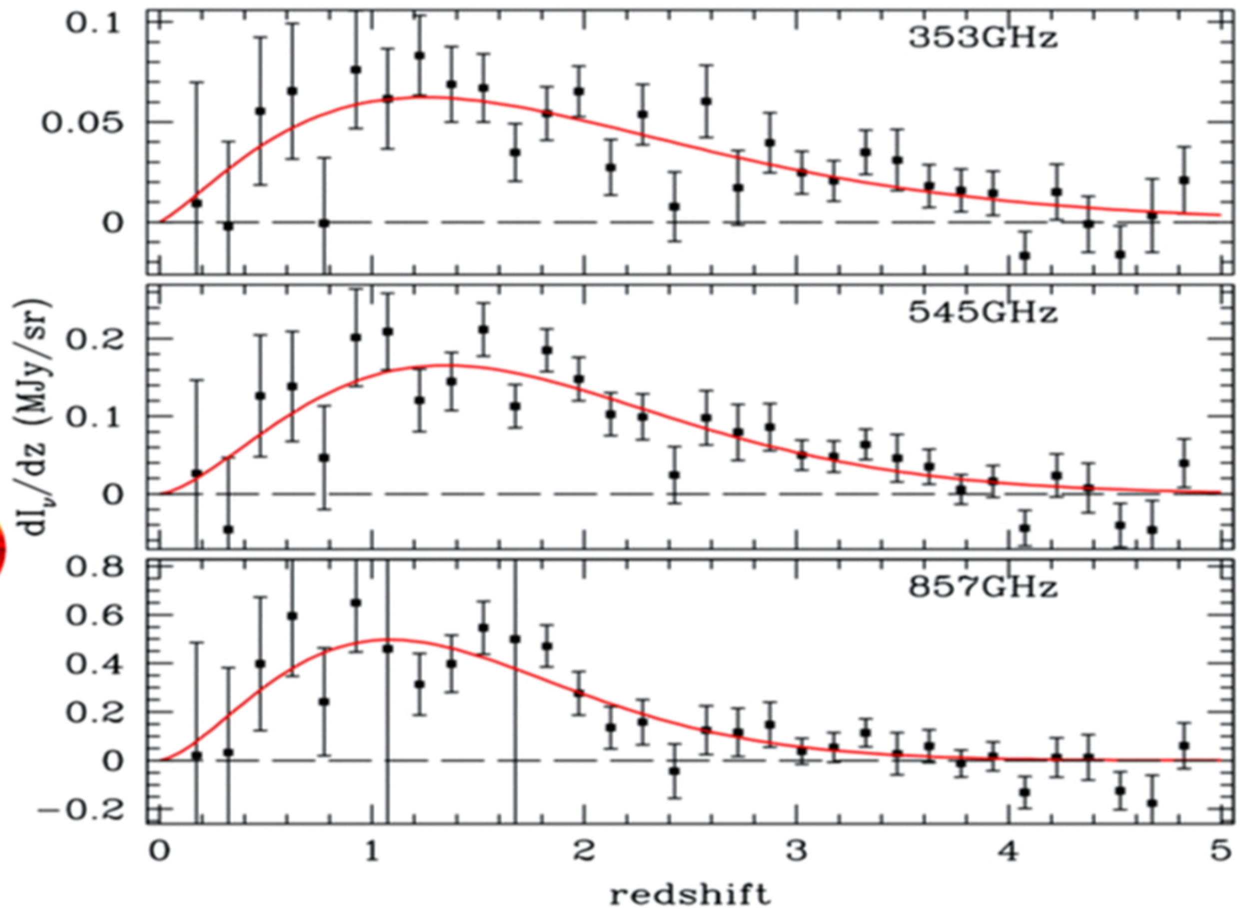
Rahman et al. 2015c

Cosmic Infrared Background with Planck



Recovery of Redshift dependent component from the Raw Planck maps



(Schmidt et al. 2015)

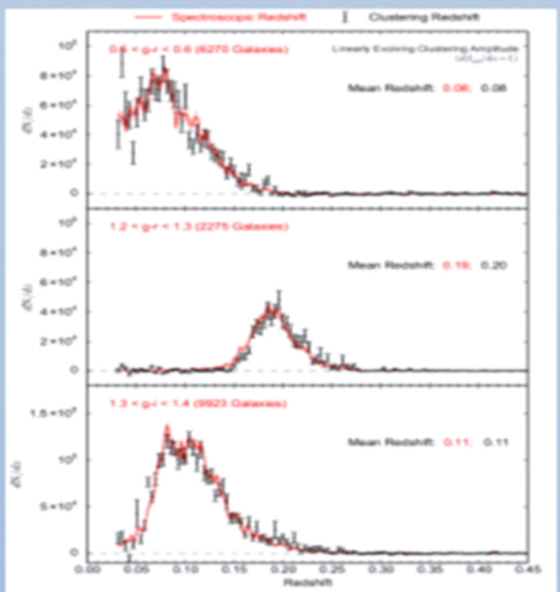
Conclusions

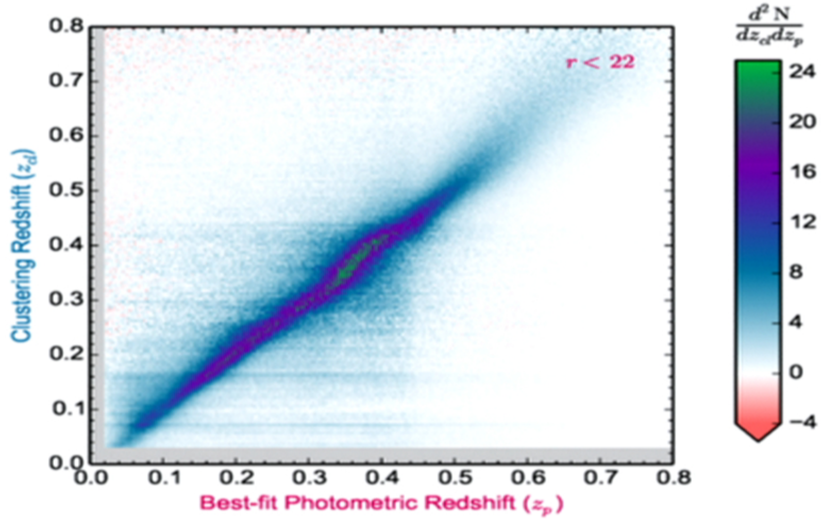
CLUSTERING REDSHIFTS

Inferring distances based on the aggregation of matter

- Requires only RA-Dec positions
- Robust to catastrophic failure

Rahman et al. 2015a





- Redshift sensitivity is only limited by the clustering scale
- Already sufficient numbers of catalogs to apply this technique
- Produces distance inference without need of training sets and/or models
- Opens redshift information to regimes beyond the optical

A new realm of distance estimation

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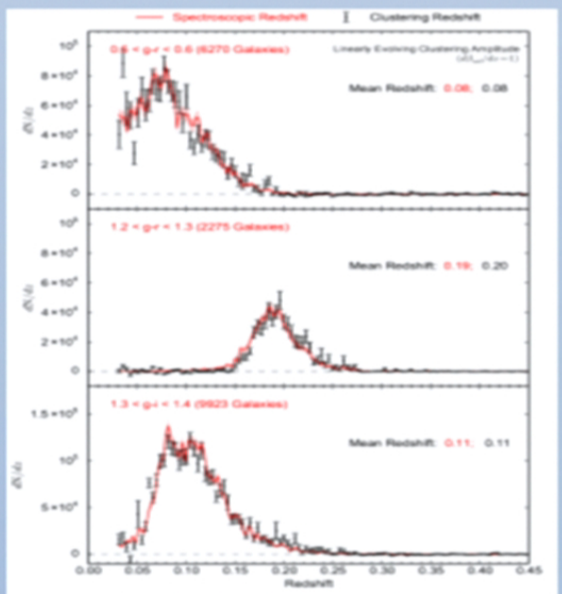

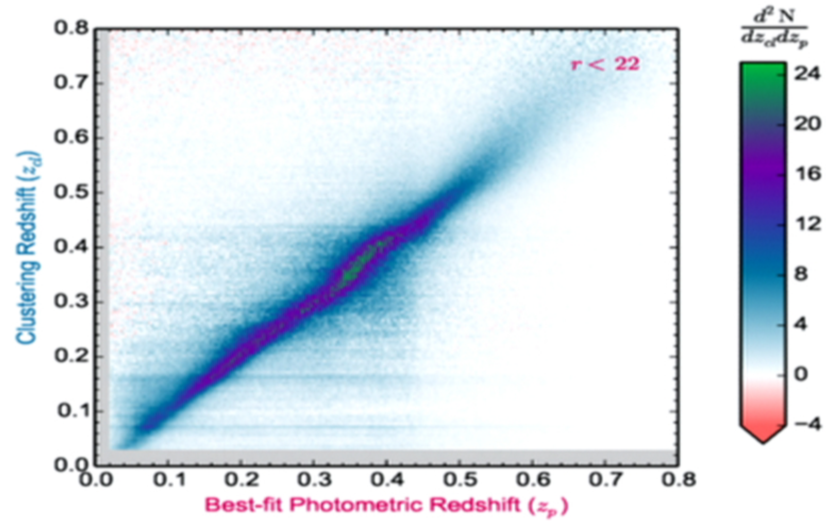

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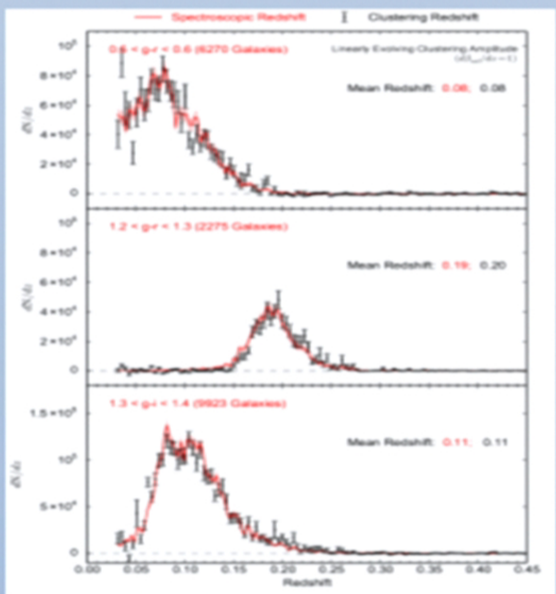

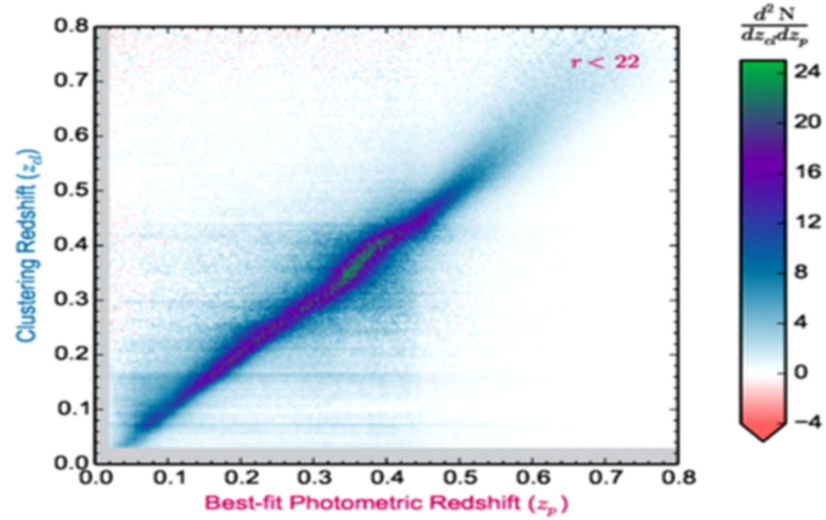

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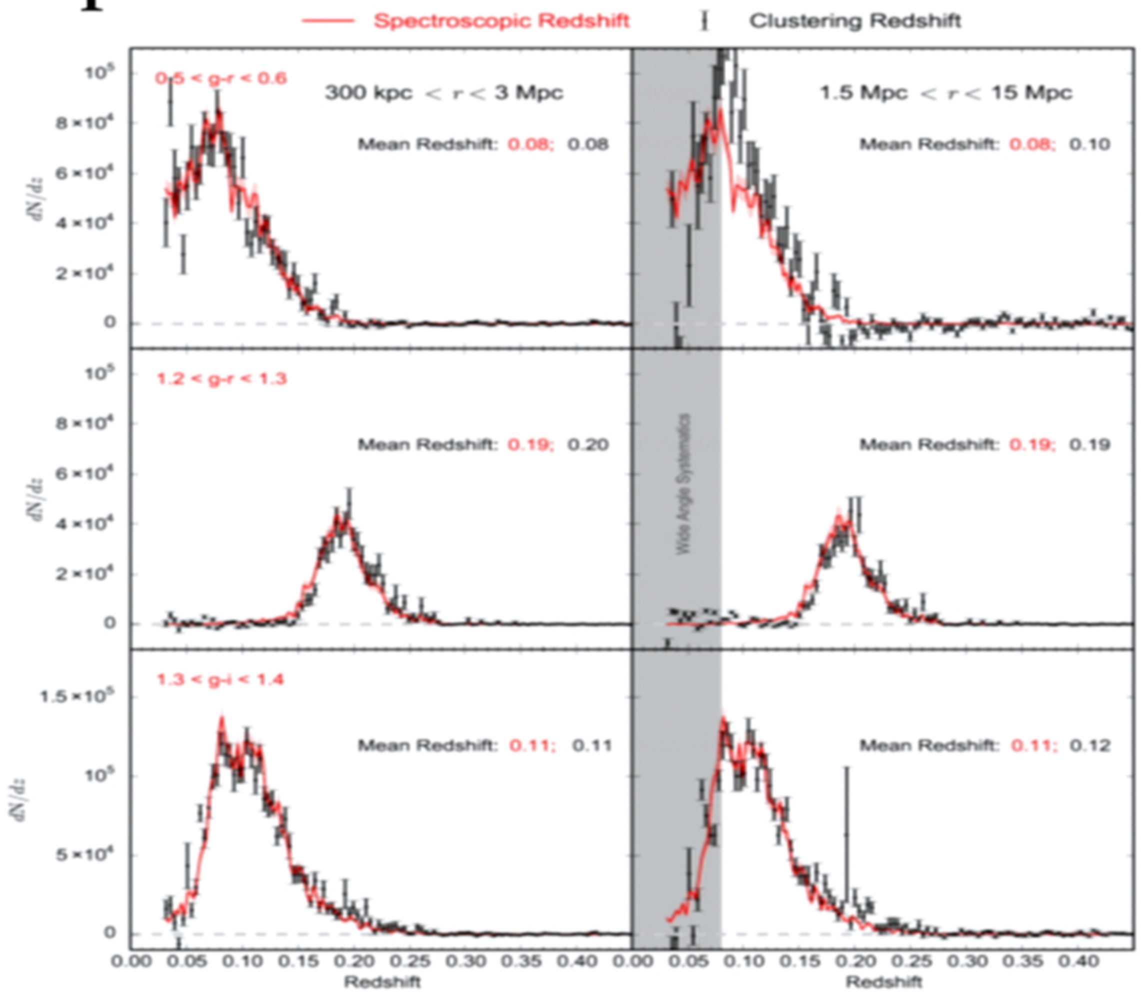
Scale Dependence



Rahman et al. 2014a