redmapper and redmagic: Enabling Precision Cosmology with Photometric Surveys

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Femilab
April 20, 2014

Summary

Ongoing and future photometric surveys are poised to become a critical tool for understanding dark energy.

Can study dark energy via:

- clusters
- cosmic shear
- distance—redshift relations (BAO, SN)

We are working in constructing the redmapper/ redmagic catalogs to enable this science.

Summary

redmapper = cluster finder

- Sufficiently clean sample for cluster cosmology
- Excellent photometric redshifts allow one to calibrate source photozs for cosmic shear.

SN, BAO need good *individual* photozs.

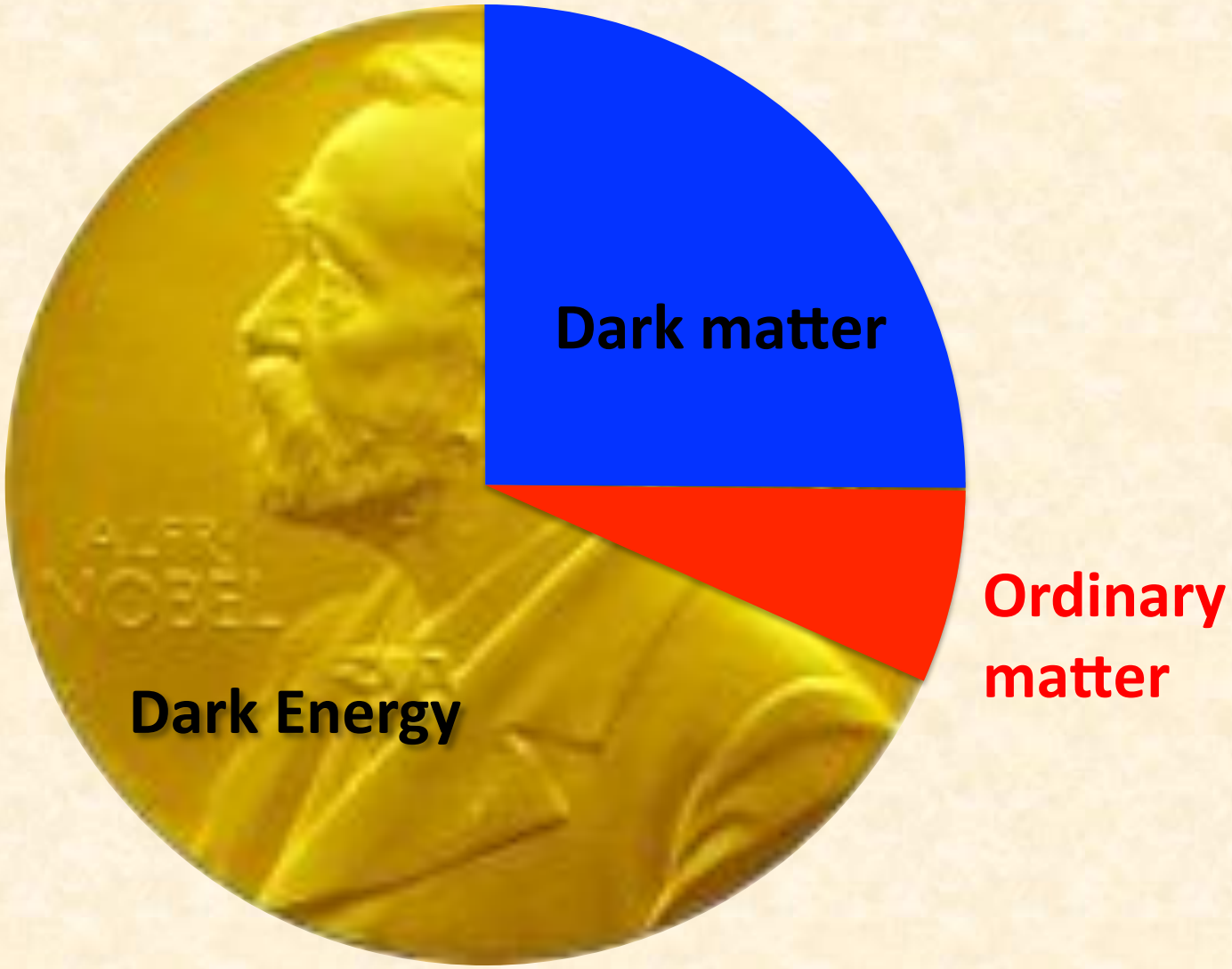
Very difficult to do in general, but we can make great progress by cherry-picking galaxies.

redmagic = gold sample for photozs

- Early indications suggest will enable BAO/SN cosmology with photometric survey data.

A Whirlwind Review of Cosmology

Most of the Universe is Dark Energy



Focus Here on Photometric Surveys (DES, LSST)

In the past, we had to choose between shallow/wide surveys and deep/narrow surveys:

- SDSS: 14,000 deg^2 (35% of sky) , $r \approx 22$
- CFHT Legacy Survey: 155 deg^2 (0.4% of sky), $r \approx 25.0$

Now entering era of **deep and wide** surveys.

- DES: 5,000 deg^2 (12%), $r \approx 25.5$ (HSC, KIDS)
- LSST: 20,000 deg^2 (50%), $r \approx 27.7$

These new surveys are poised to become a critical tool for understanding dark energy.

5 Main Dark Energy Probes

Geometric: distance—redshift relations.

- Supernovae (SN)
- Baryon Acoustic Oscillations (BAO)

Dynamical:

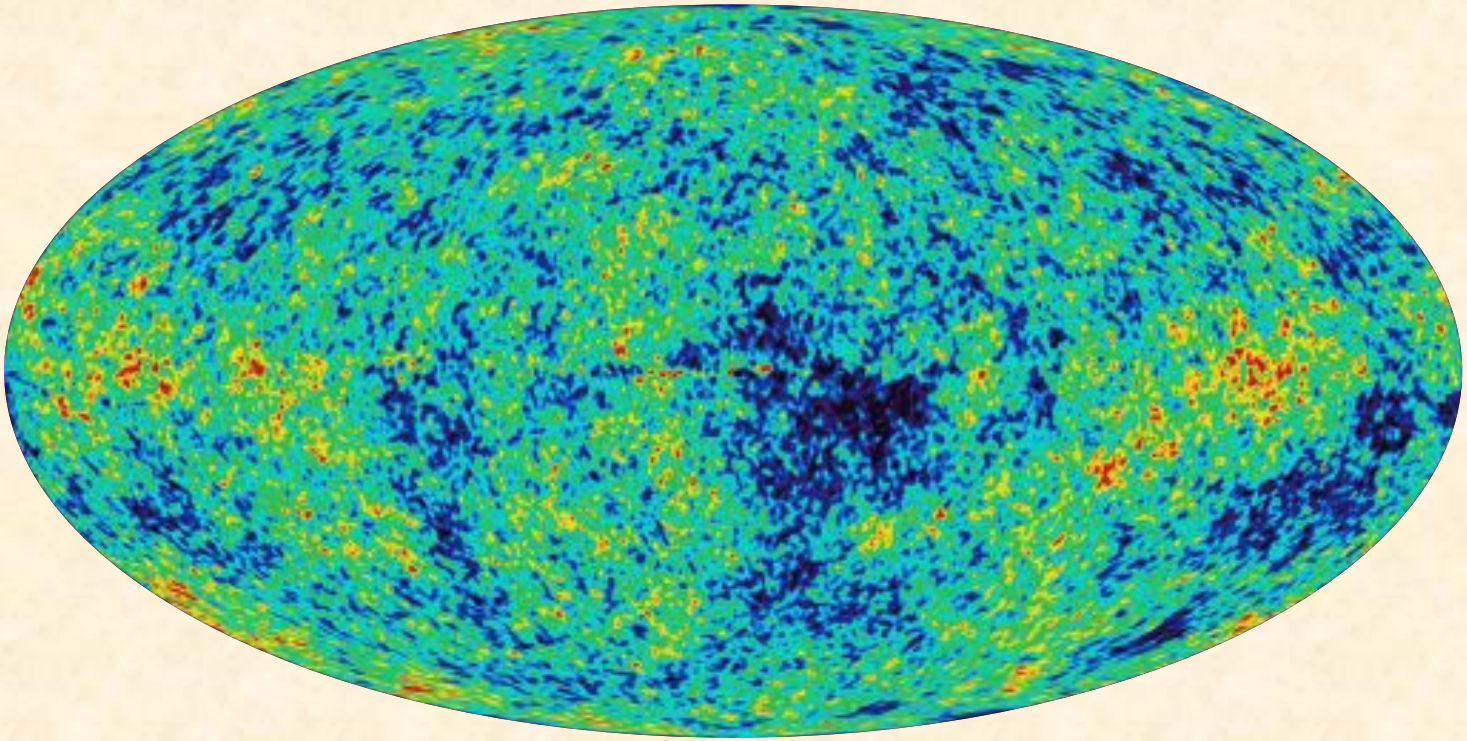
- Galaxy Clusters
- Cosmic Shear
- Redshift Space Distortions (RSD)

Dynamical Probes of Dark Energy

The Big Bang Theory in a Nutshell

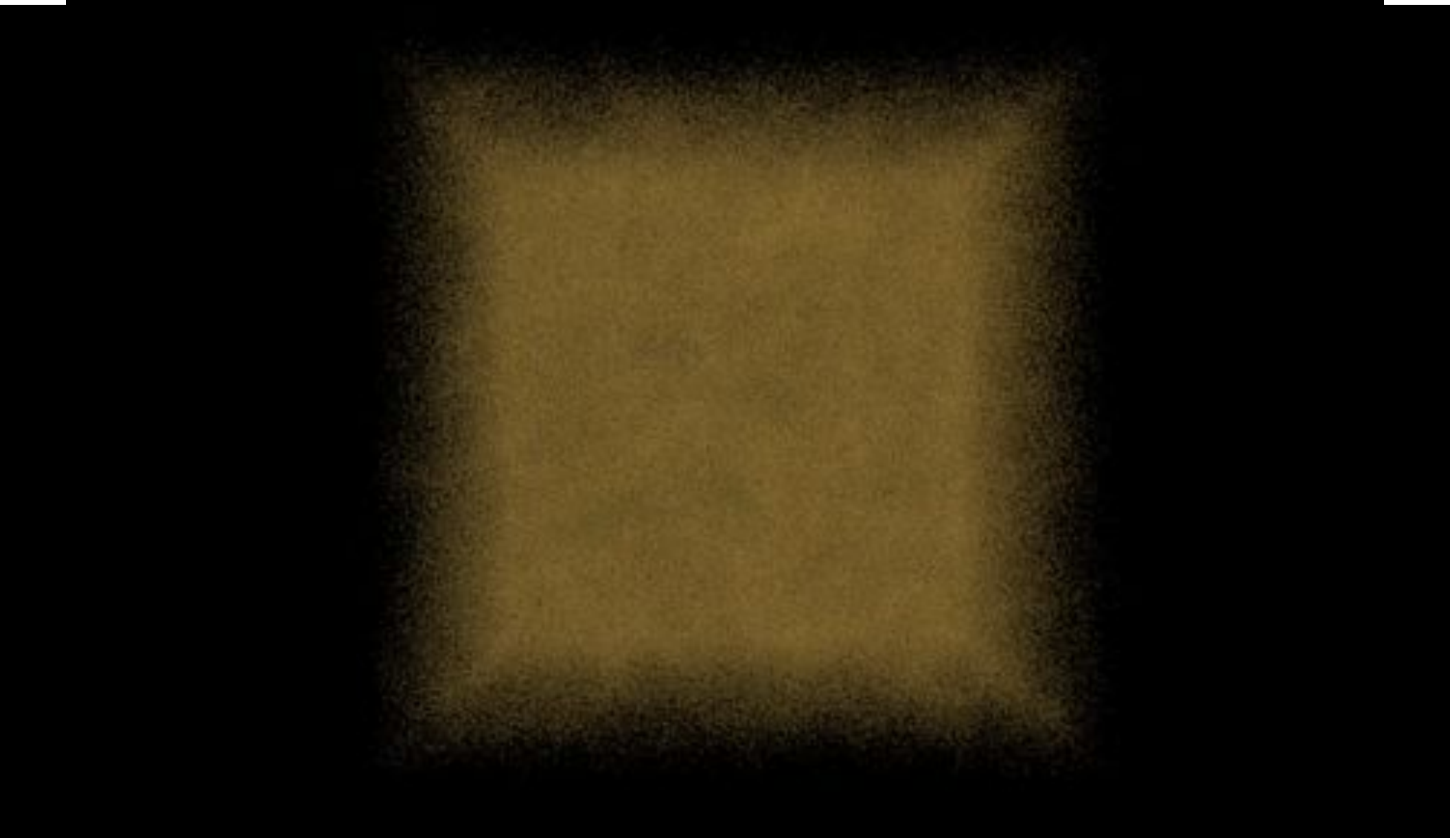
Using Large Scale Structure to Test GR/Dark Energy

Early universe was almost perfectly smooth.

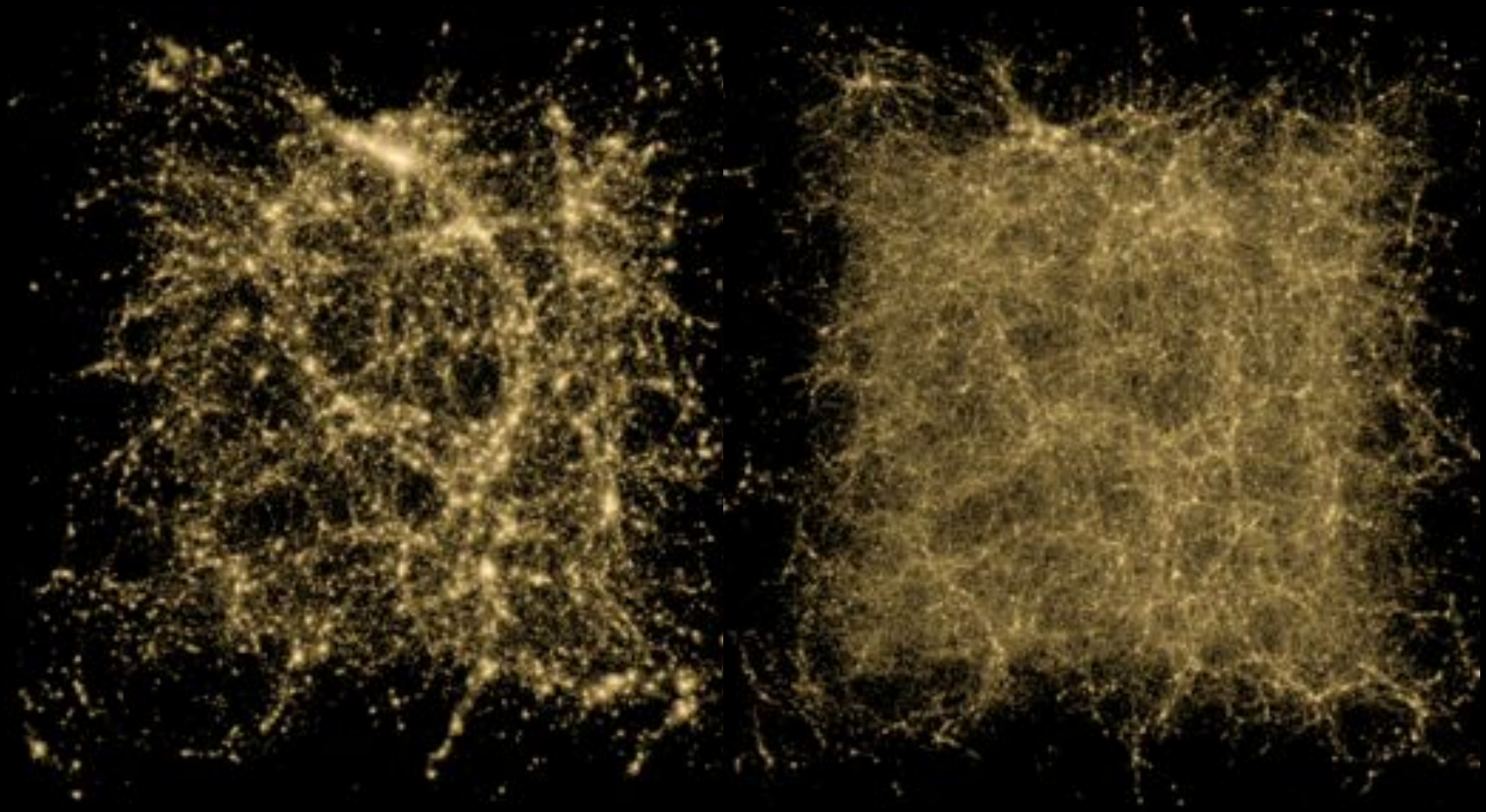


But we do see *tiny* (0.001%) perturbations.

Growth of Structure



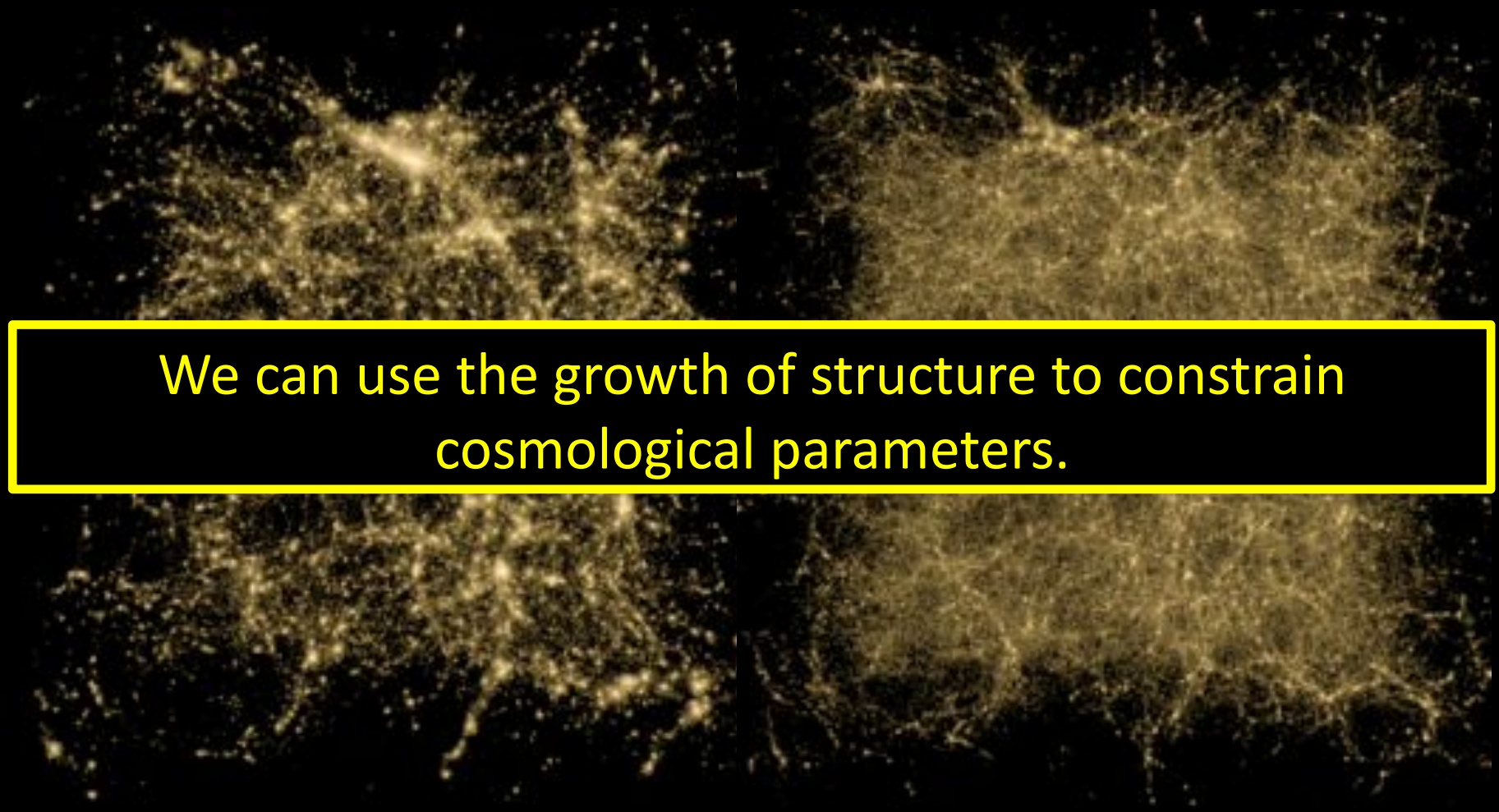
Structure Probes Cosmology!



High matter density

Low matter density

Structure Probes Cosmology!



We can use the growth of structure to constrain cosmological parameters.

High matter density

Low matter density

Why Measuring Structure is Hard

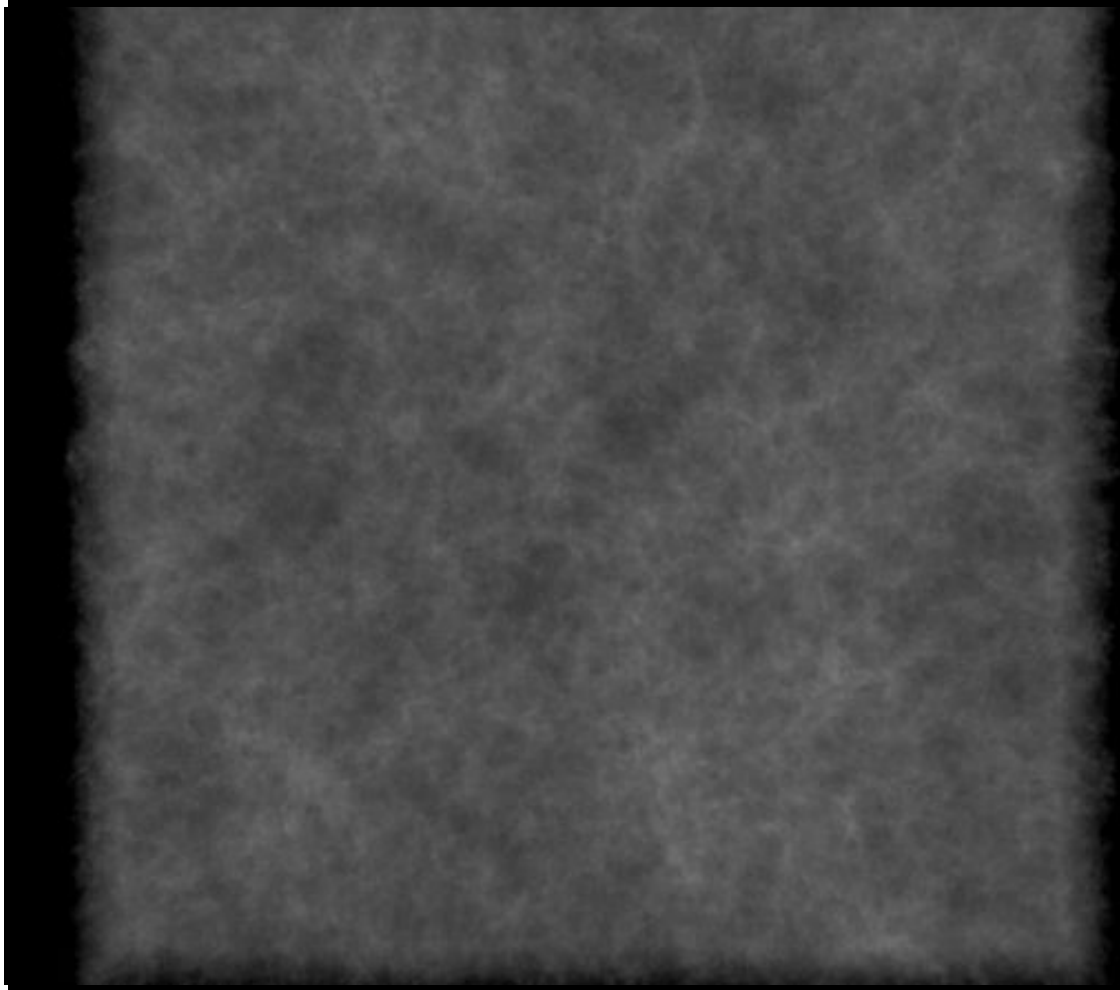
We're trying to tell that the mass distribution looks like this…

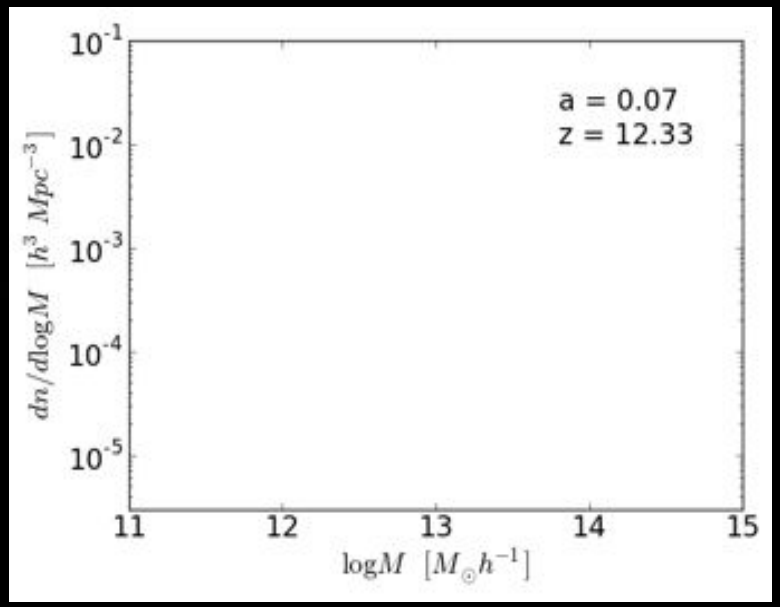
But this is all we can see!
Need some other method for probing *mass*.

Galaxy Clusters

Why Clusters Help

More structure = more massive halos





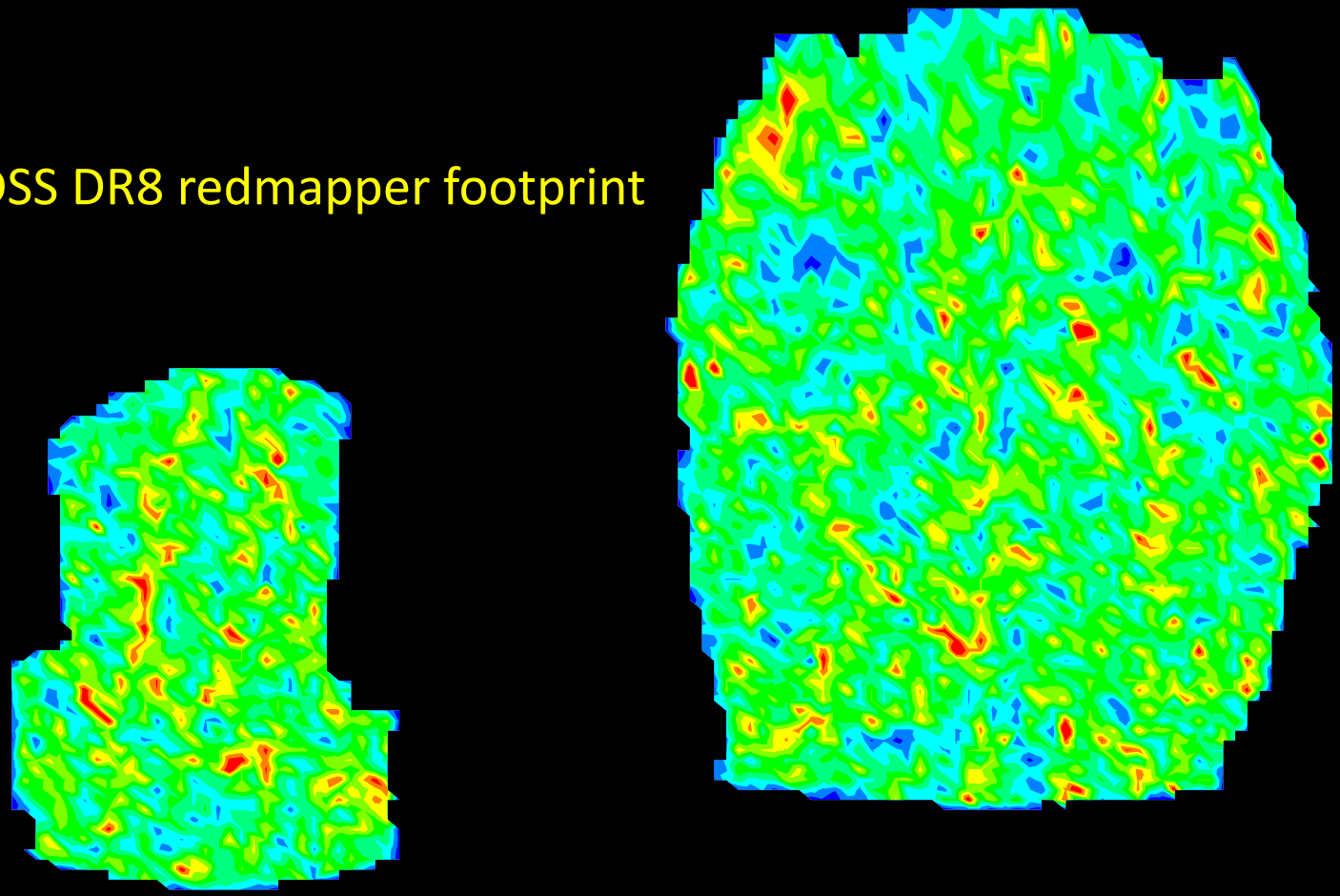
Count halos ***as a function of mass*** to infer σ_8.

Cluster Cosmology in 3 Easy Steps

1. **Find all galaxy clusters.**
2. Measure cluster masses.
3. Compare to theory!

redmapper

SDSS DR8 redmapper footprint



Rykoff, Rozo, et al. 2014, Rozo & Rykoff 2014.

What is redmapper?

redmapper is a photometric cluster finding algorithm.

Rogue's Gallery

Rogue's Gallery

Judging redmapper

The key outputs of a cluster finder:

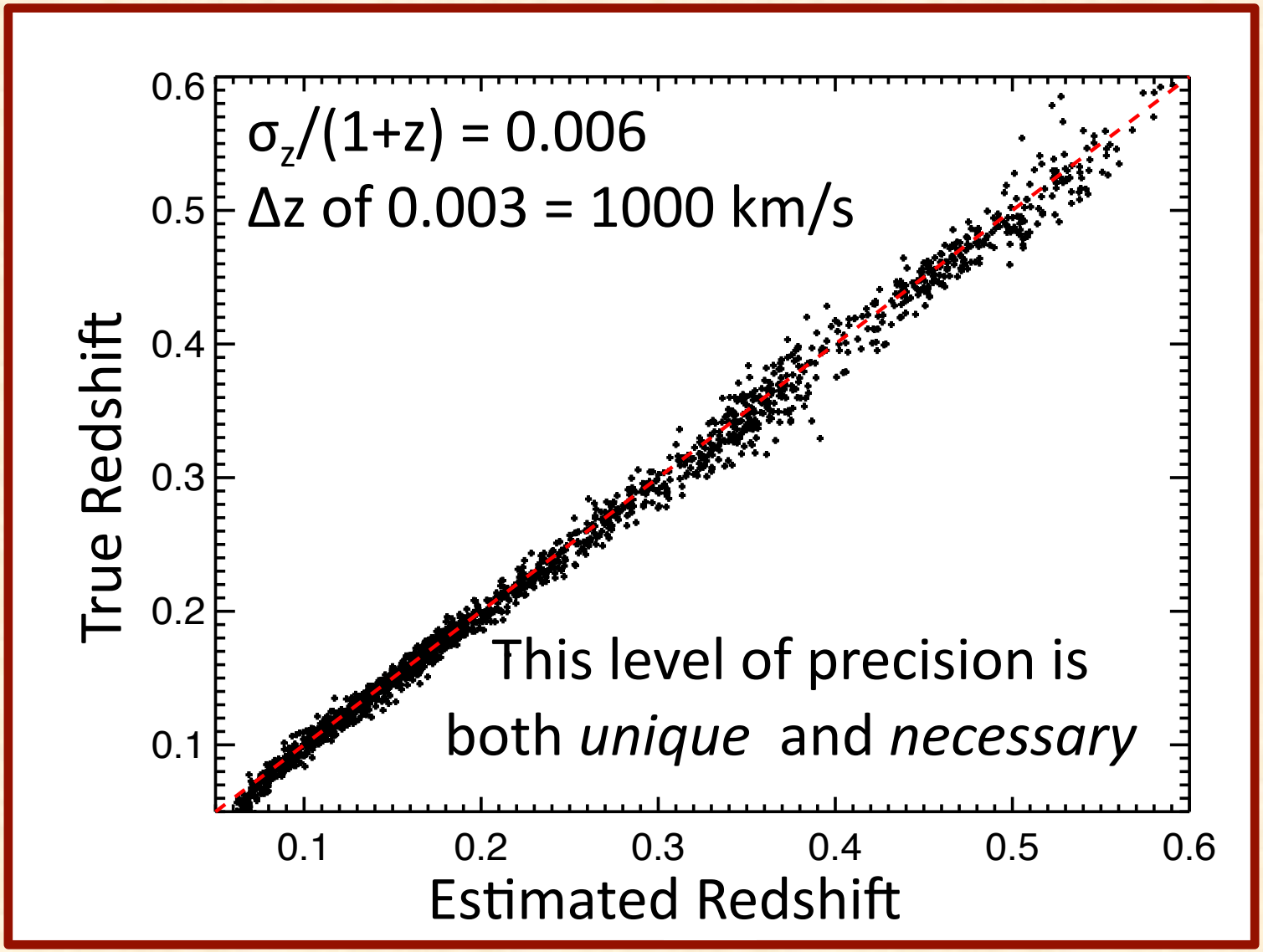
- Location of the cluster: redshift
- Some estimate of size: richness = # of galaxies.

  (Relation between size and mass is calibrated with WL)

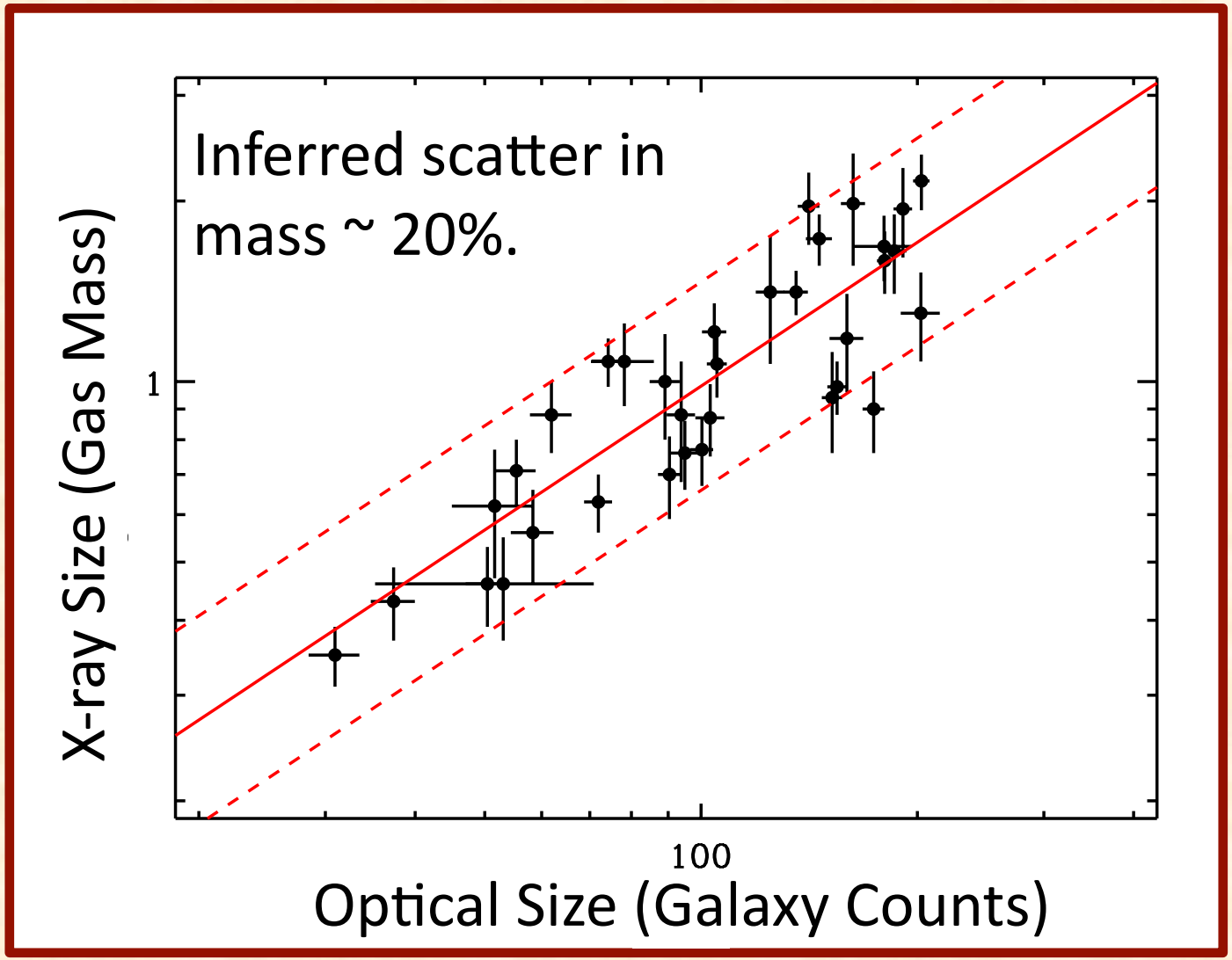
So how does redmapper do at these things?

AWESOME

Photometric Redshifts



Size Estimates



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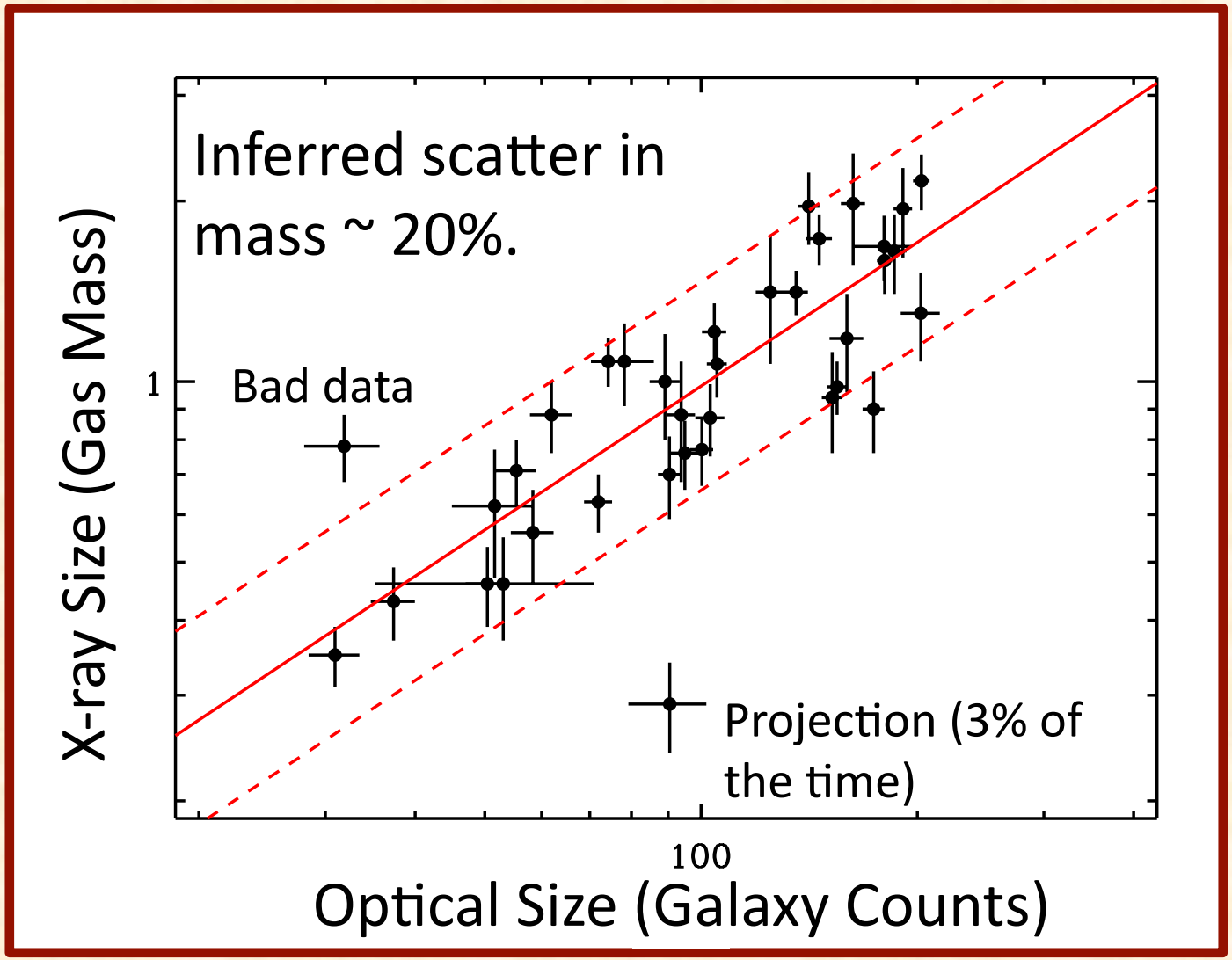
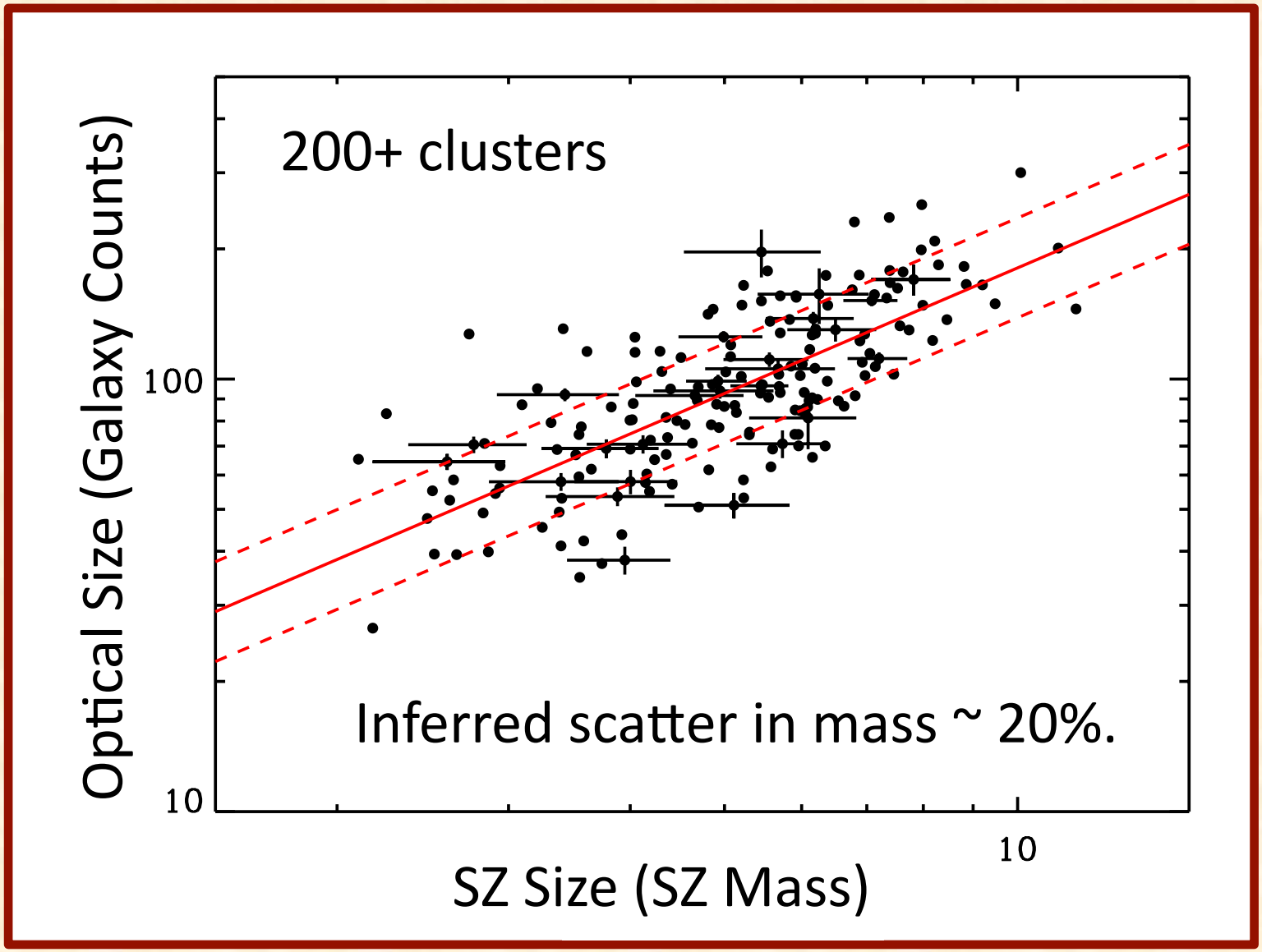
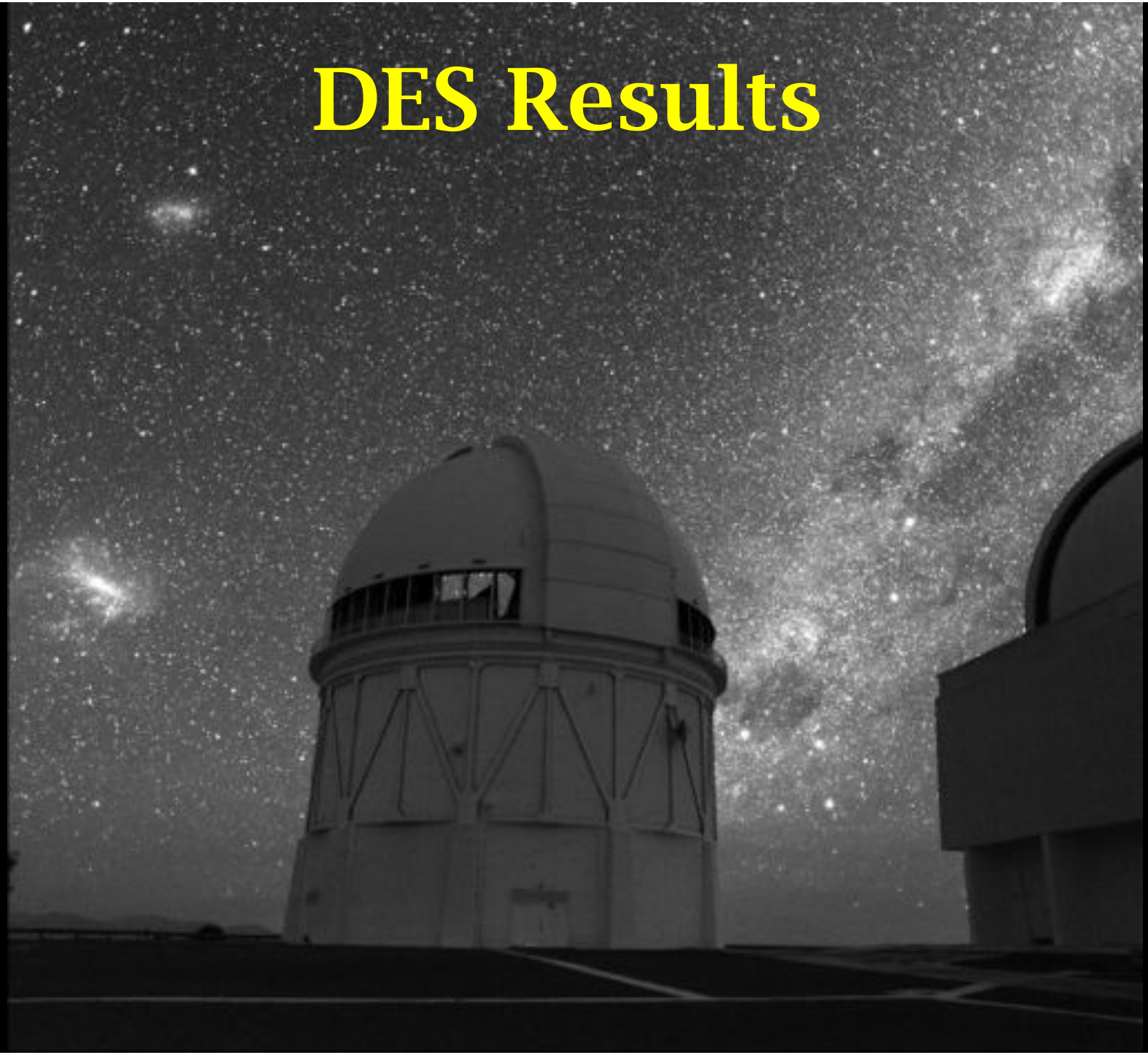


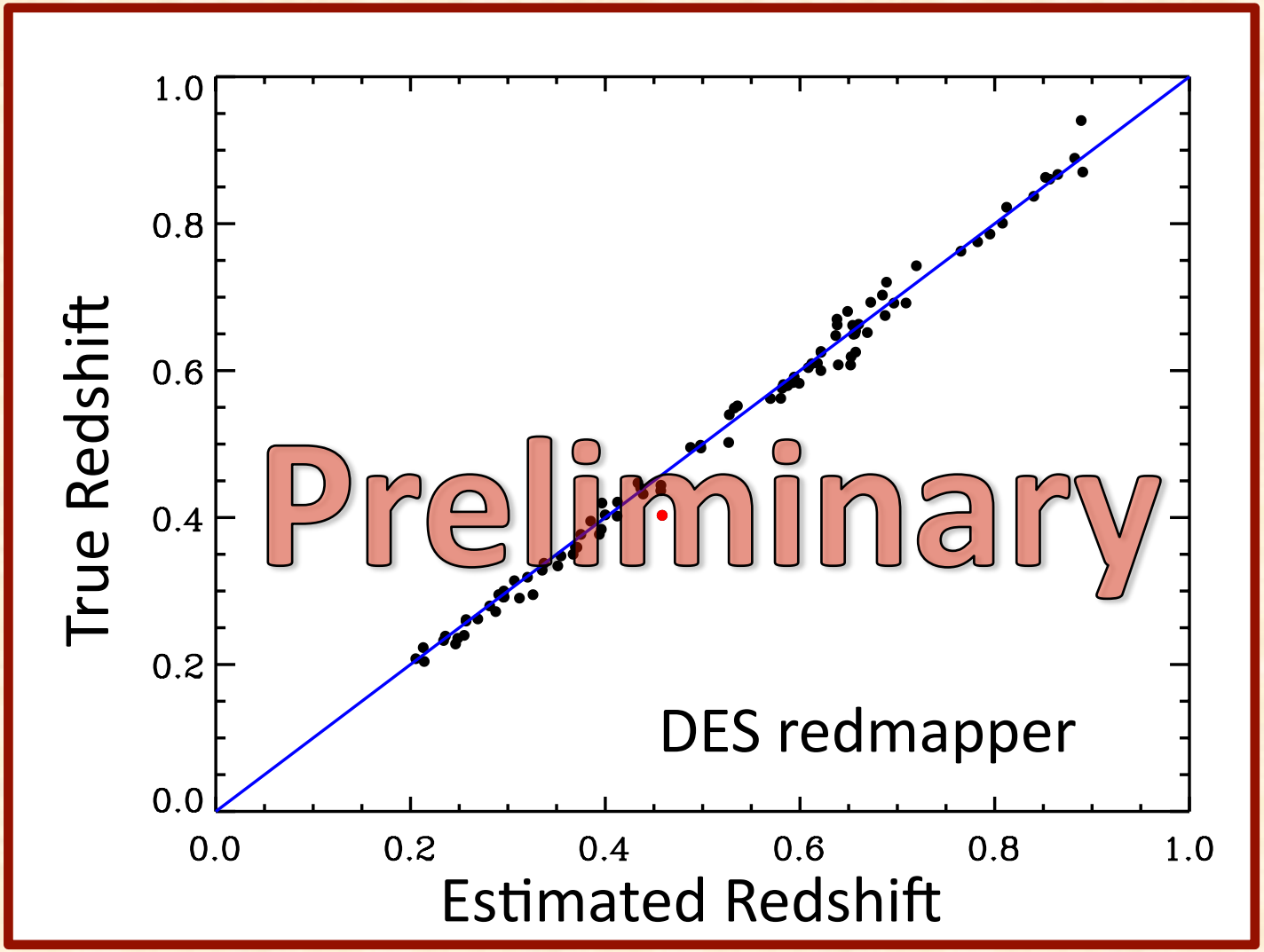
Size Estimates



DES Results

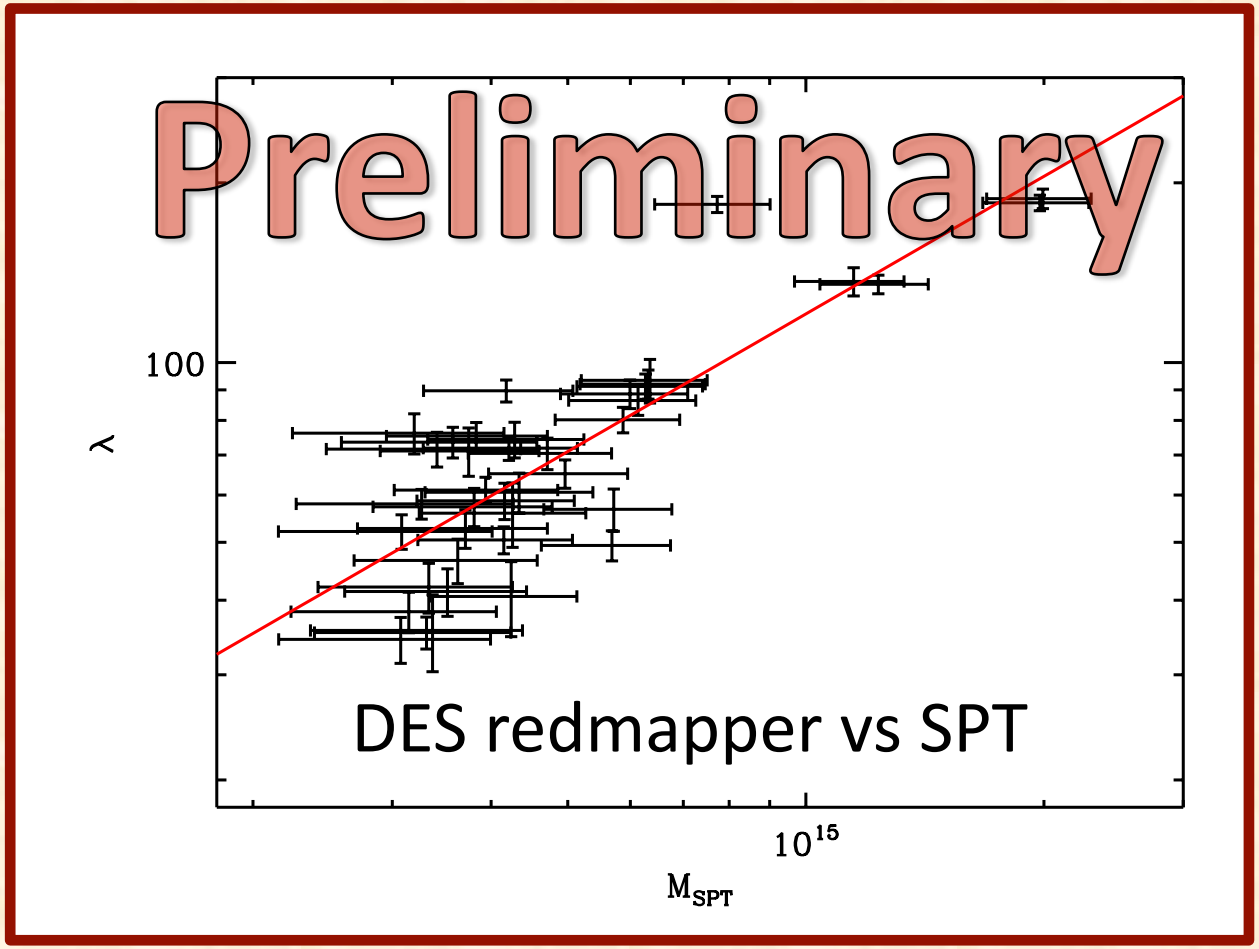


Redshift Accuracy: DES SV



DES Collaboration

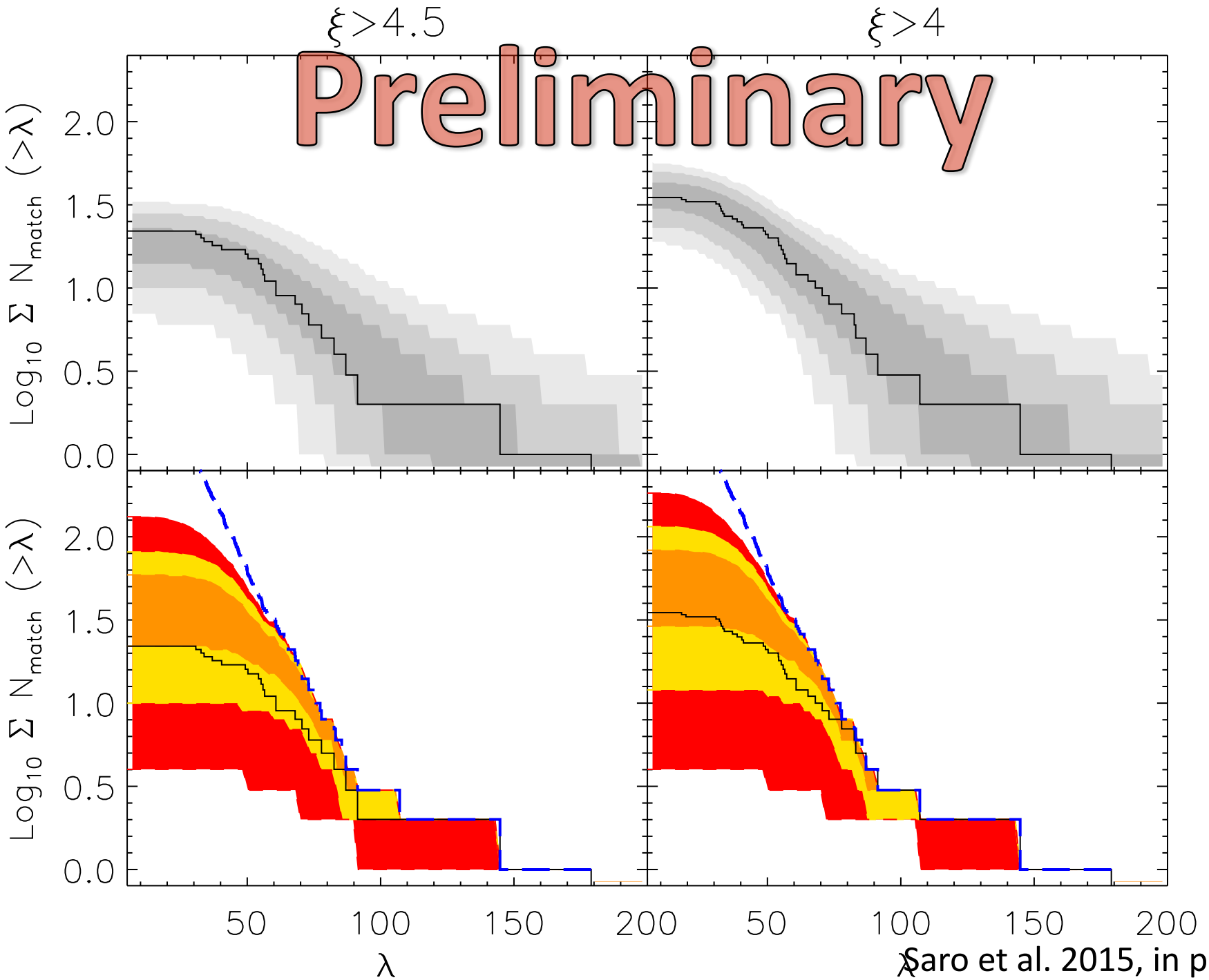
Scatter of Optical Mass Proxies



Inferred scatter in mass: 18%

Two outliers removed.

DES and SPT collaborations



Saro et al. 2015, in prep

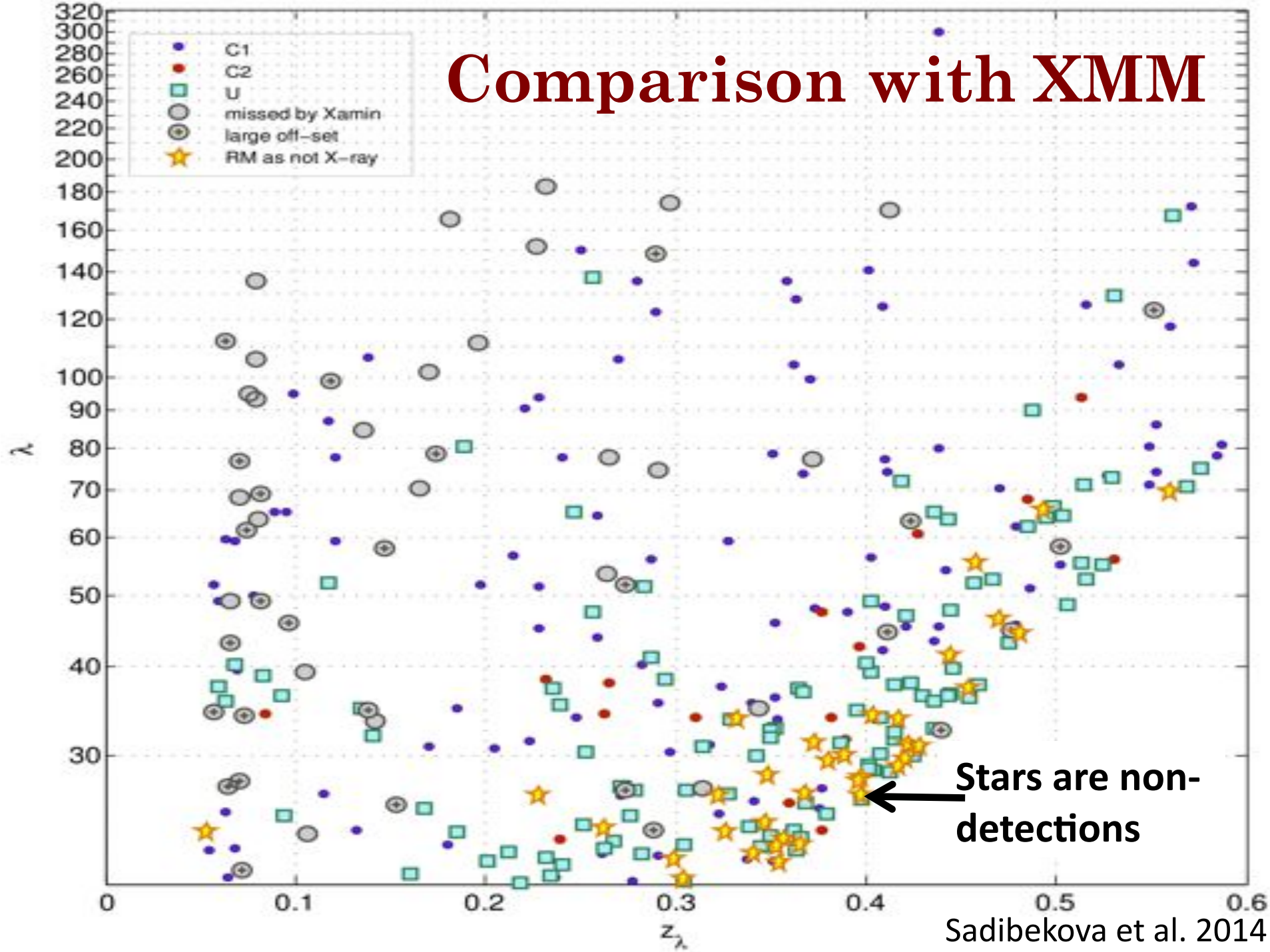
However…

Comparisons so far:

Take X-ray/SZ clusters, check they show up as optical clusters.

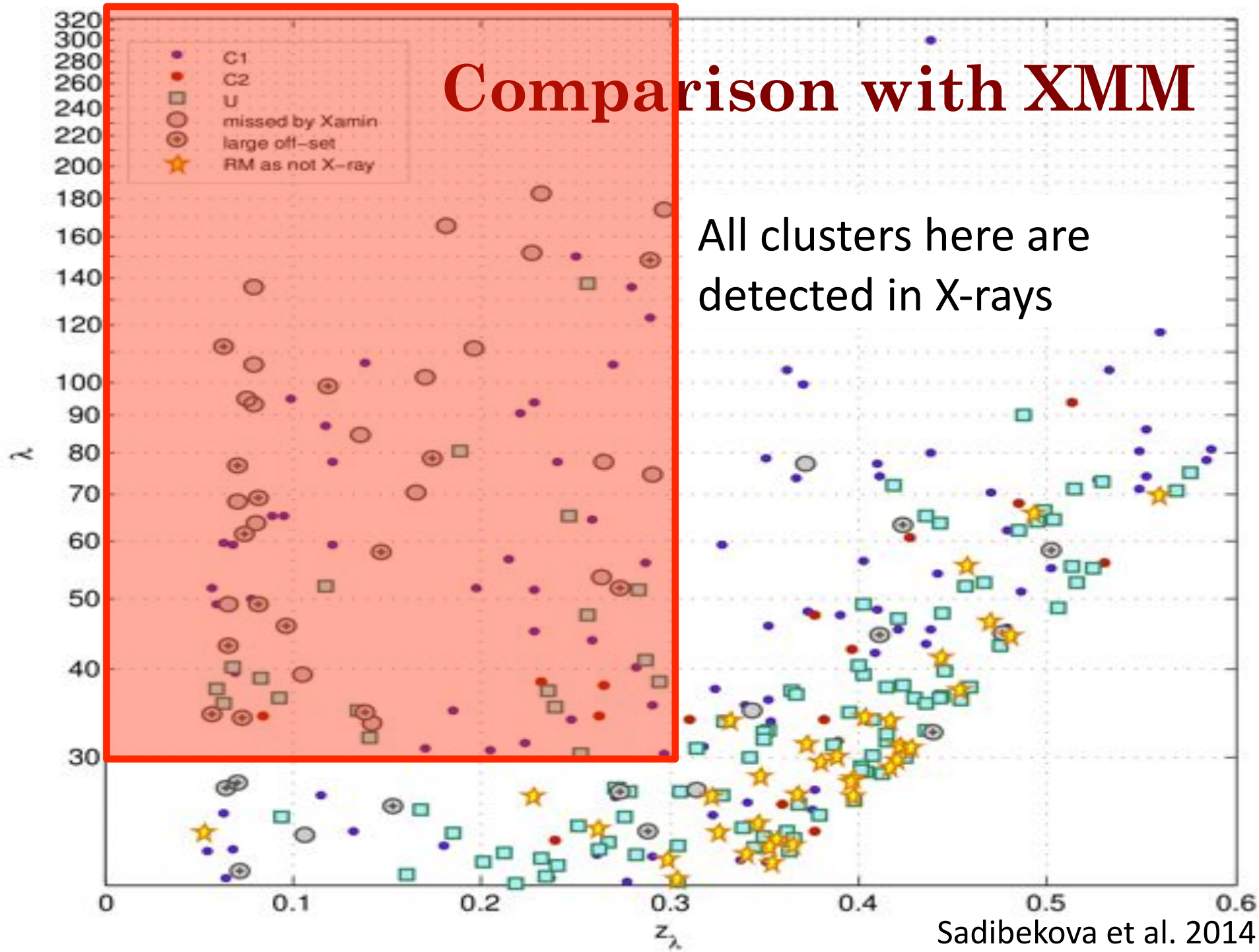
Does the converse hold?

Comparison with XMM



Sadibekova et al. 2014

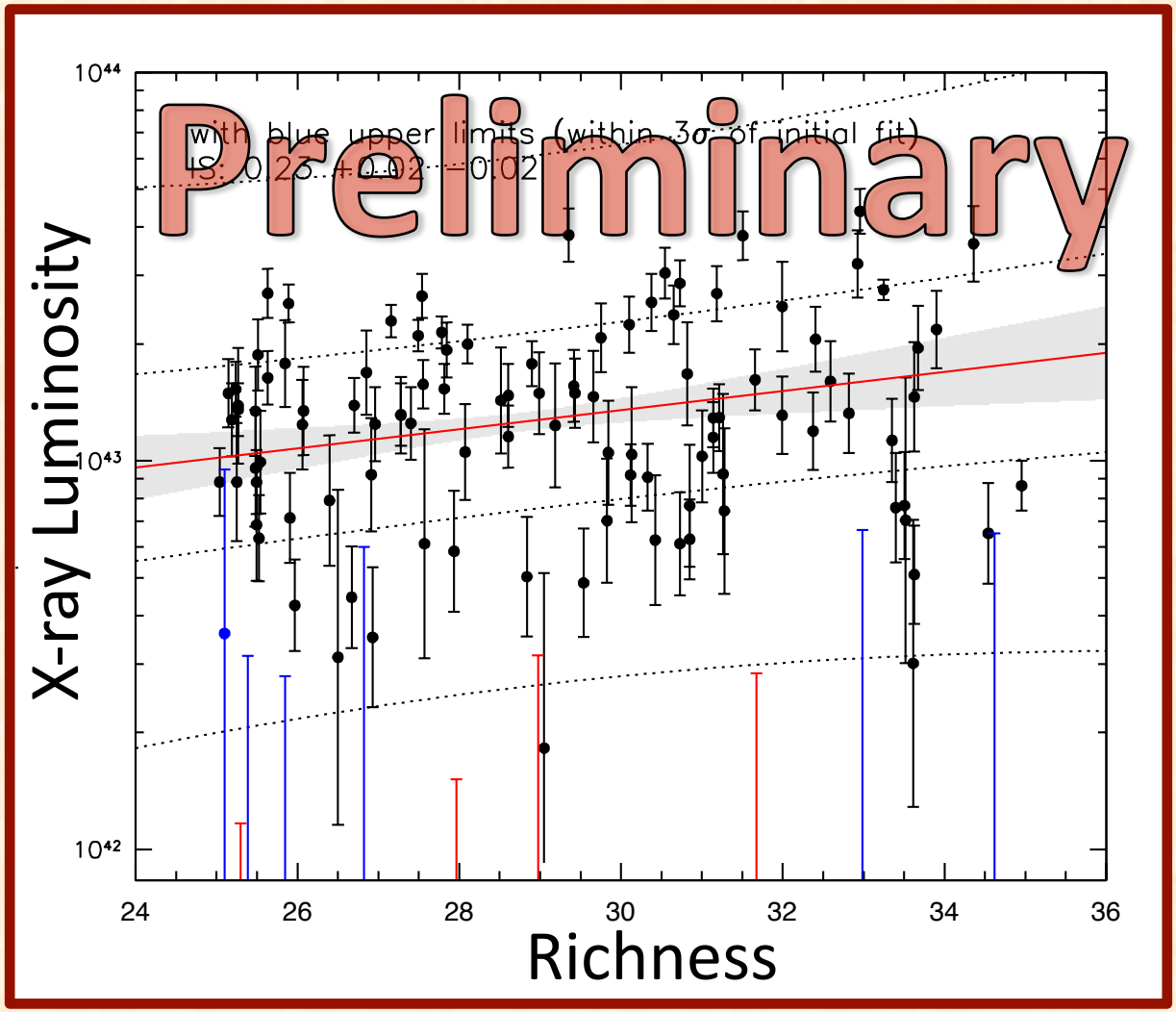
Comparison with XMM



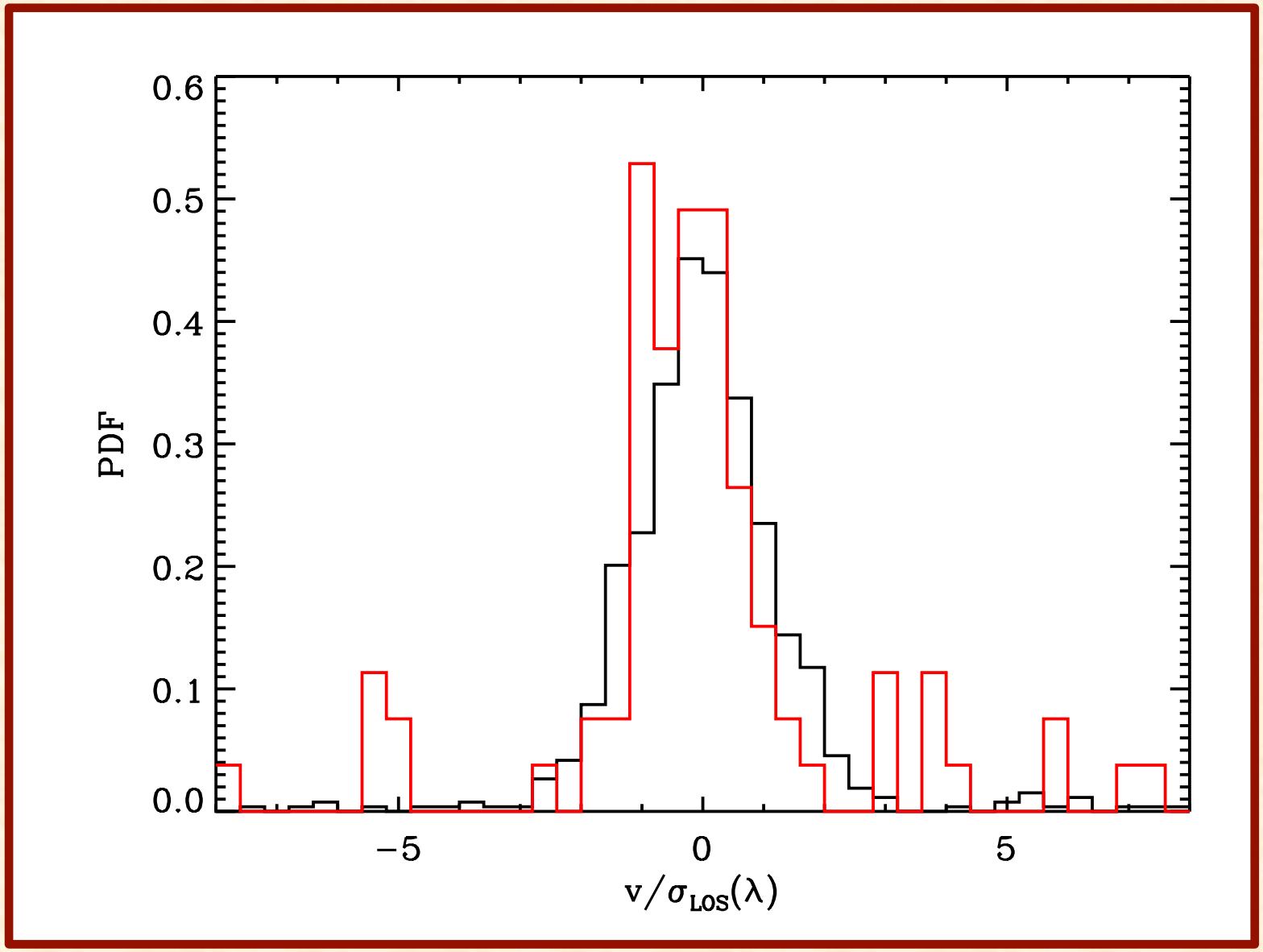
All clusters here are detected in X-rays

Sadibekova et al. 2014

Swift Data for a **Complete** sample of redmapper Clusters



Plot courtesy of Anja von der Linden. See also Andreon & Moretti 2011.


0.6
0.5
0.4
0.3
0.2
0.1
0.0
PDF
−5
0
5
v/σLOS(λ)

Some Outstanding Issues Remain

Are the effects of projections/triaxiality sufficiently well understood?

Masking-induced errors need to be reduced.

Cluster centering needs to be better tested.

Bottom Line

We are confident that redmapper is capable of creating a sufficiently clean cluster sample for enabling cluster cosmology with the DES.

LSST-quality catalogs will require additional work.

Next: how redmapper helps with cosmic shear…

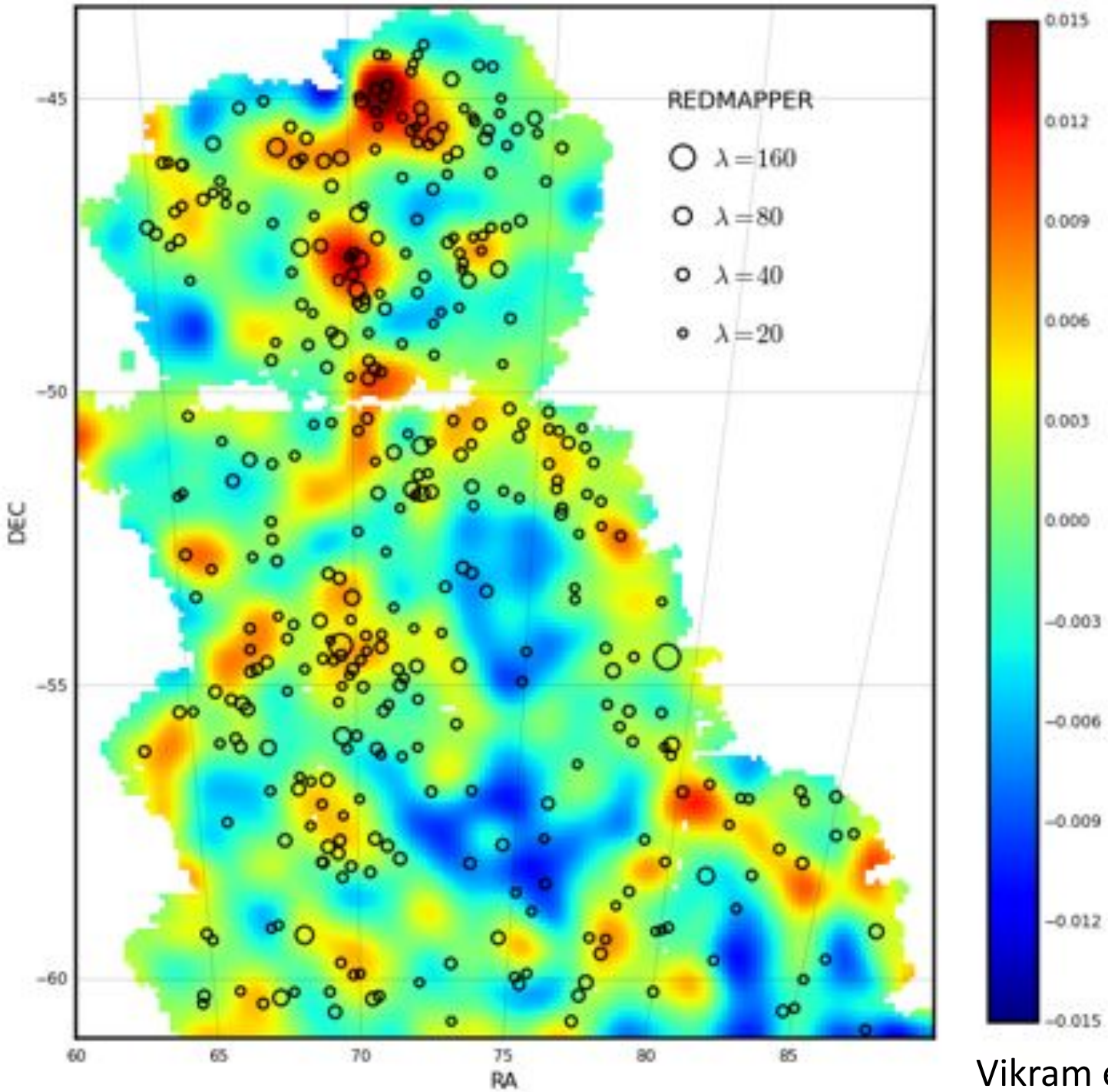
Cosmic Shear

Why Measuring Structure is Hard

We're trying to tell that the mass distribution looks like this…

But this is all we can see!
Need some other method for probing *mass*.

Gravitational Lensing Sees All Mass!



Vikram et al. 2015

Cosmic Shear and Photozs

Key difficulty for weak lensing experiments:

The amount of shearing a galaxy experiences depends on its redshift.

More distant galaxies are more strongly distorted.

Need to know the redshift distribution of sources, but we don't have spectroscopy!

Must rely on photozs. **How do we know if they are good enough?**

Cross-Correlation Method

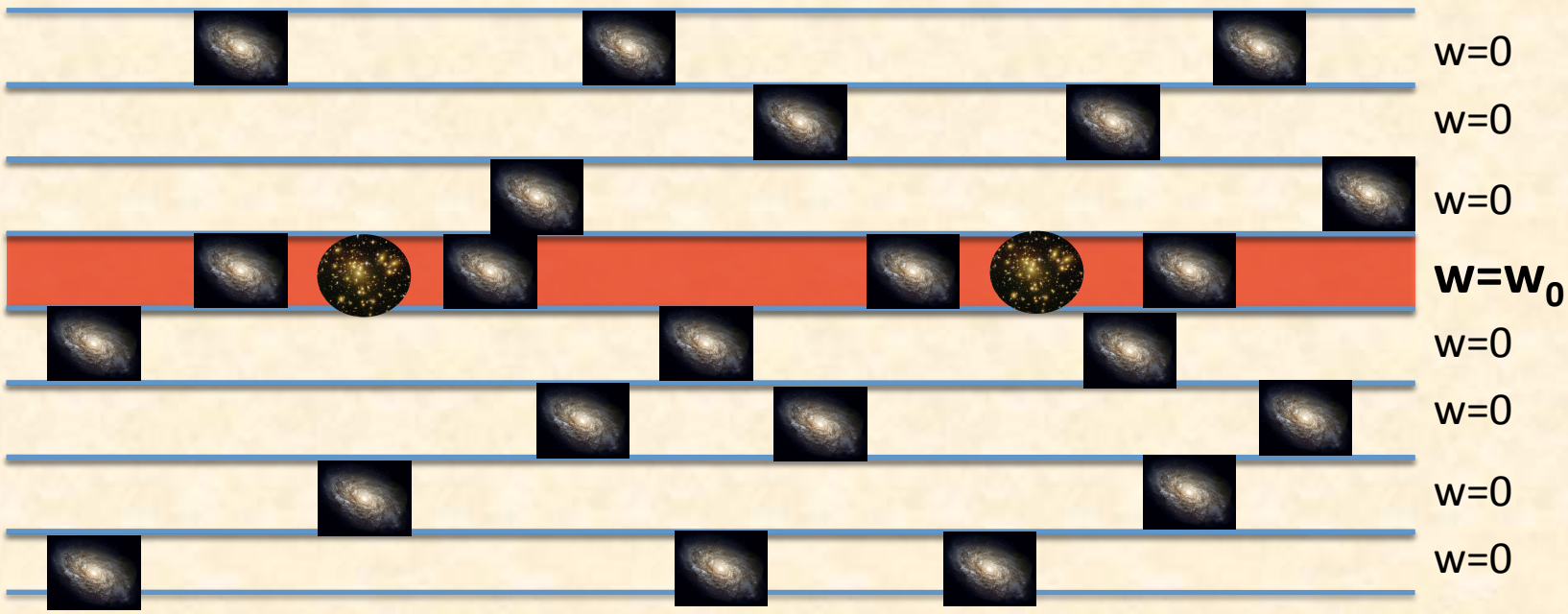
How to test photometric redshifts.

Weak lensing is statistical: we don't need the redshift of any individual galaxy, we need dN/dz

Cross-correlate lensing sources with samples of known redshift!

Cross-Correlation Method

Consider cross-correlation with a single redshift bin.



$$w_{obs} = \frac{\sum N_i w_i}{\sum N_i} = \frac{N_k}{\sum N_i} w_k = P(z_k) w_k \longrightarrow w_{obs} \propto P(z_k)$$

Newmann (2008), Rahman et al. (2014)

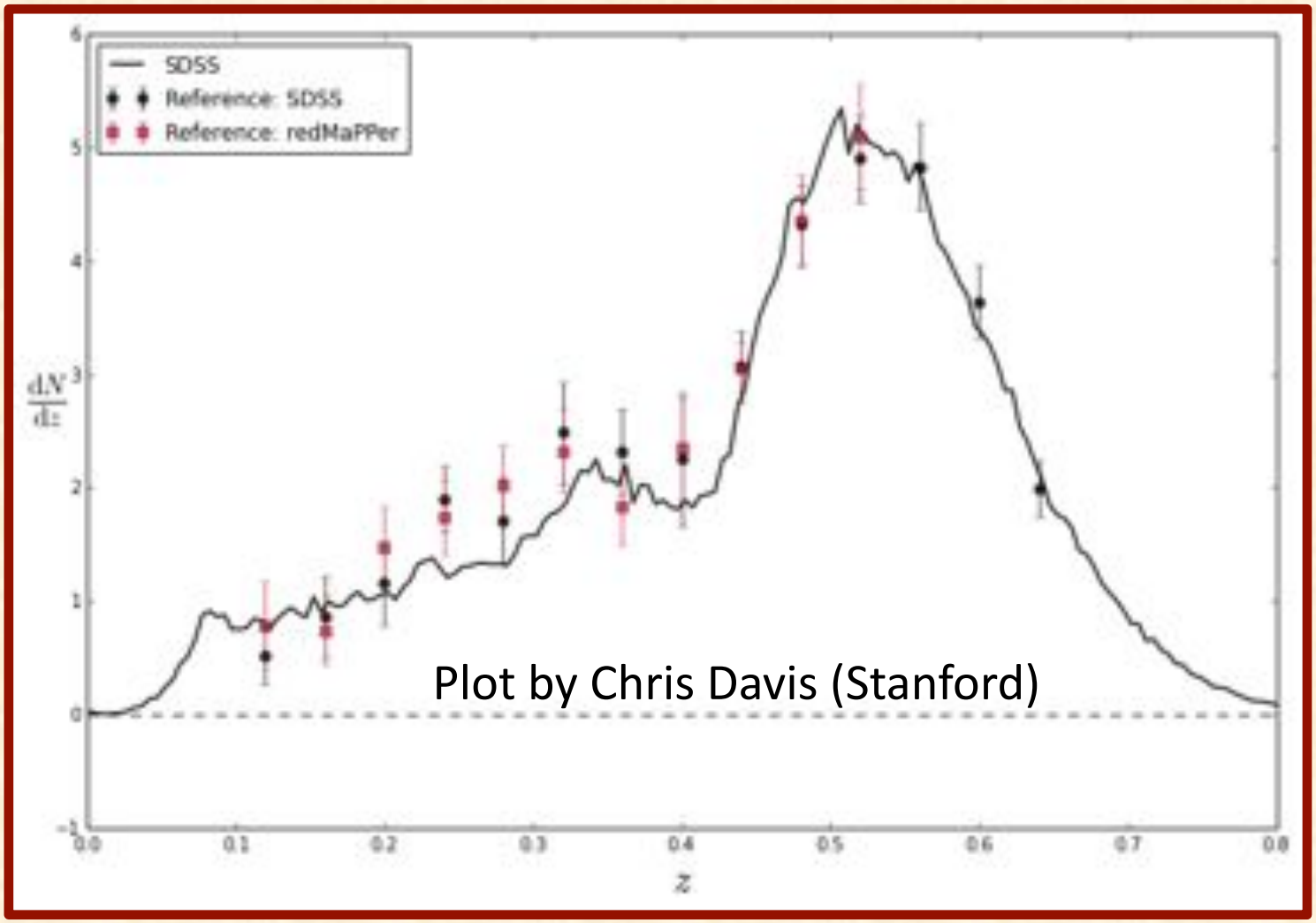
Cross-Correlation Method

Ideally want full overlap between lensing sources and calibration sources (i.e. sources of known redshift).

Problem: overlap between current spectroscopic surveys and photometric surveys is limited.

Solution: use redmapper clusters as the calibration sources!

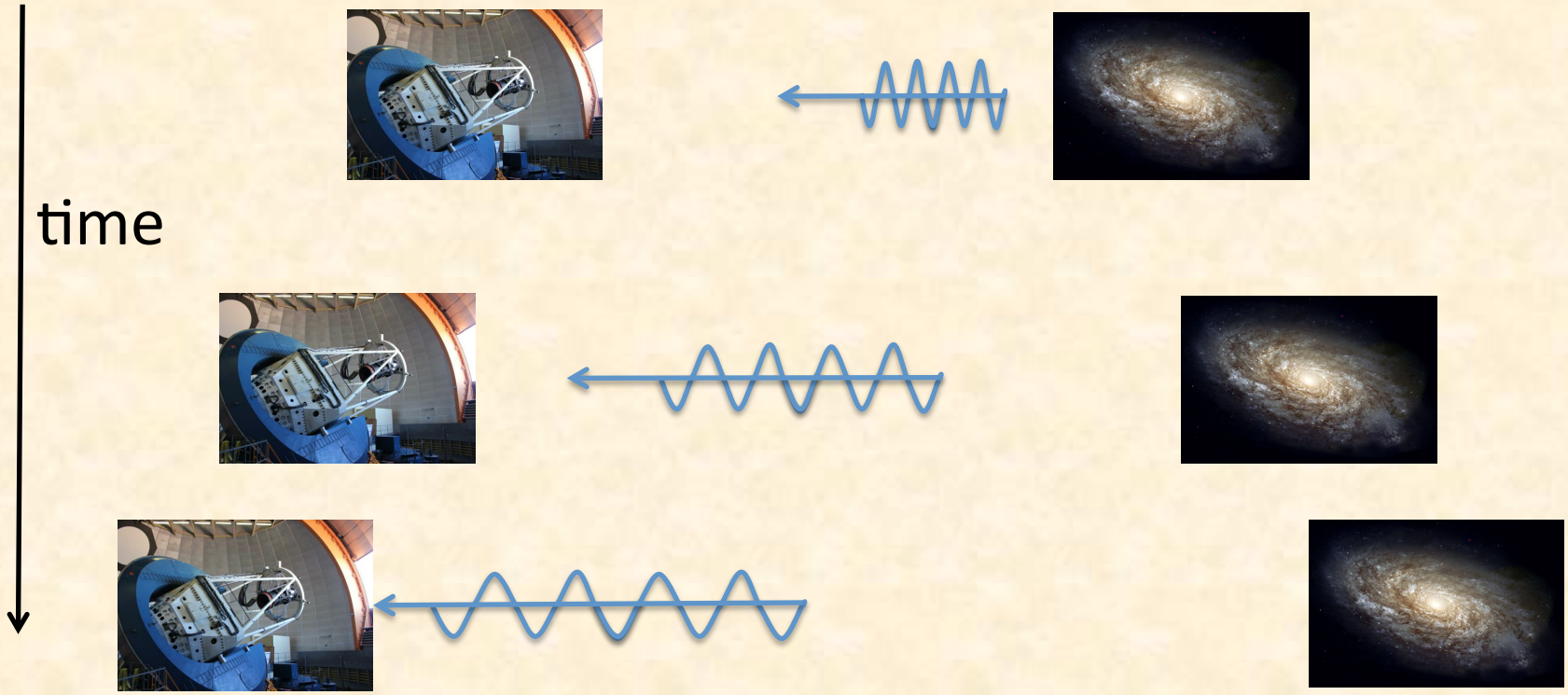
Photoz Calibration with redmapper



Expected precision appears to be close to DES requirement.

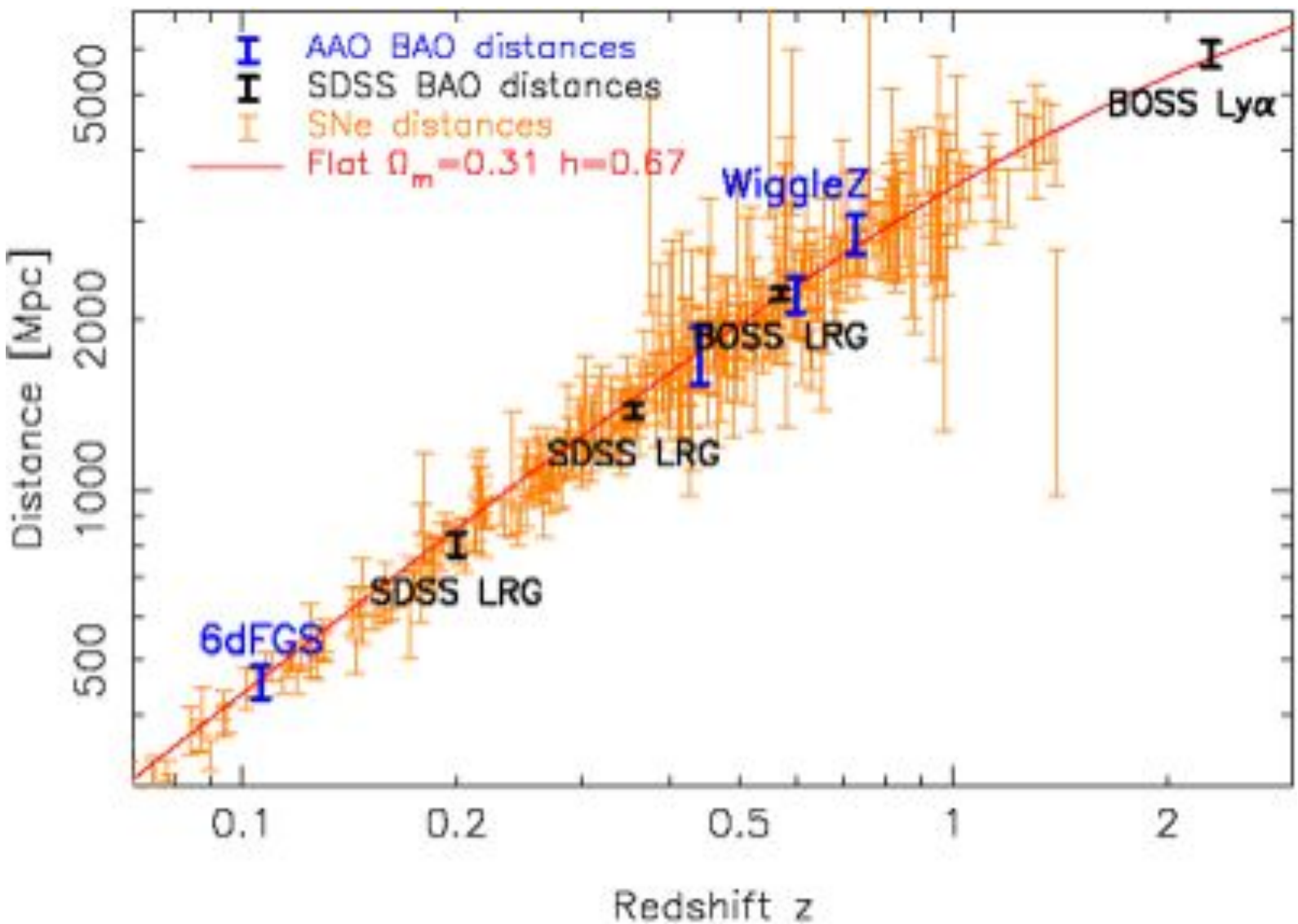
Geometric Dark Energy Probes

Cosmological Expansion and Redshifting



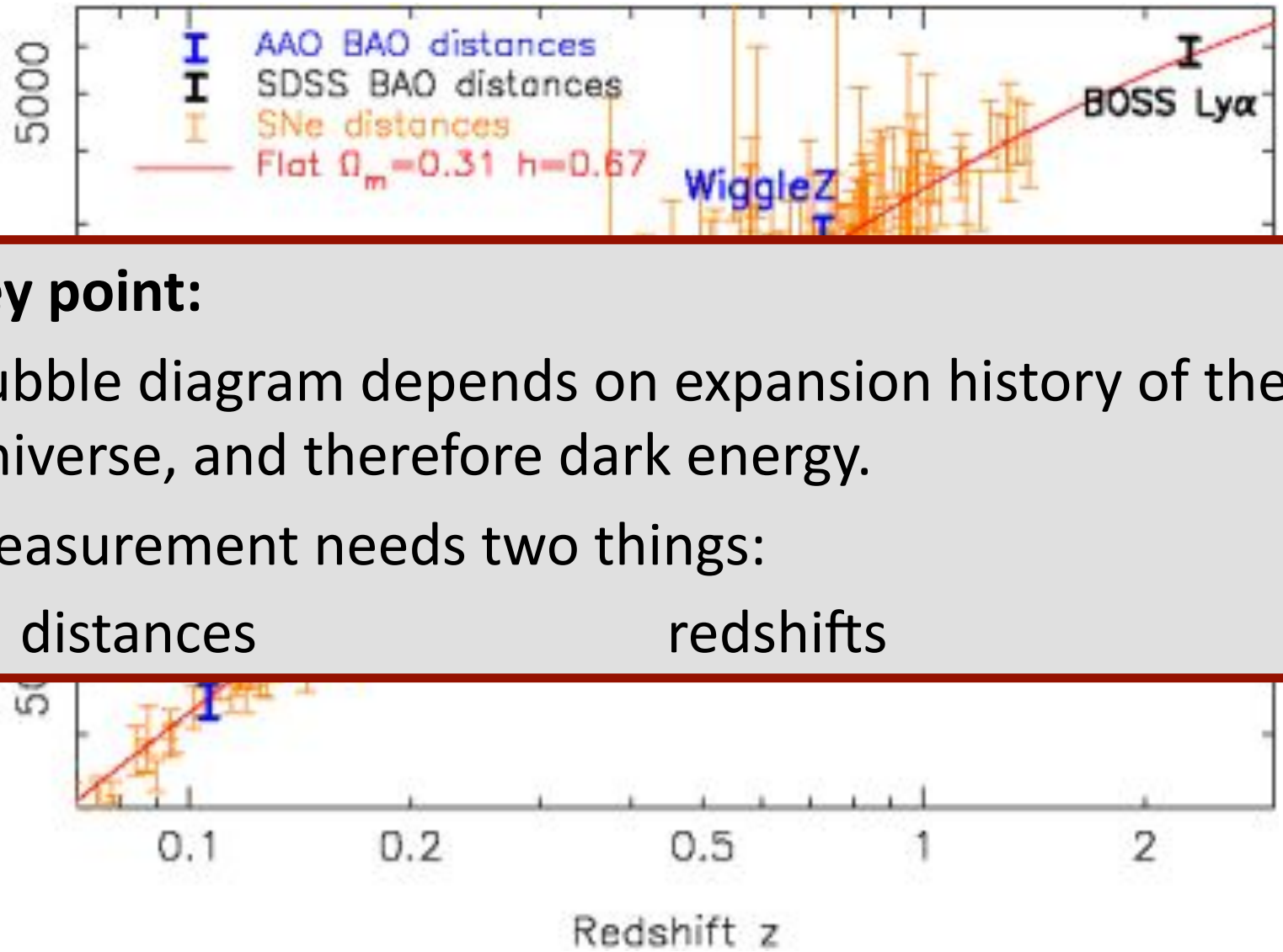
Further Galaxy → Longer time to reach observer → Light subject to more stretching

Hubble Expansion



Kowalski et al. 2008

Hubble Expansion



Key point:

Hubble diagram depends on expansion history of the Universe, and therefore dark energy.

Measurement needs two things:

distances redshifts

Kowalski et al. 2008

Distances: Standard Candles

Imagine you know the intrinsic brightness *B* of a lightbulb (aka supernova).

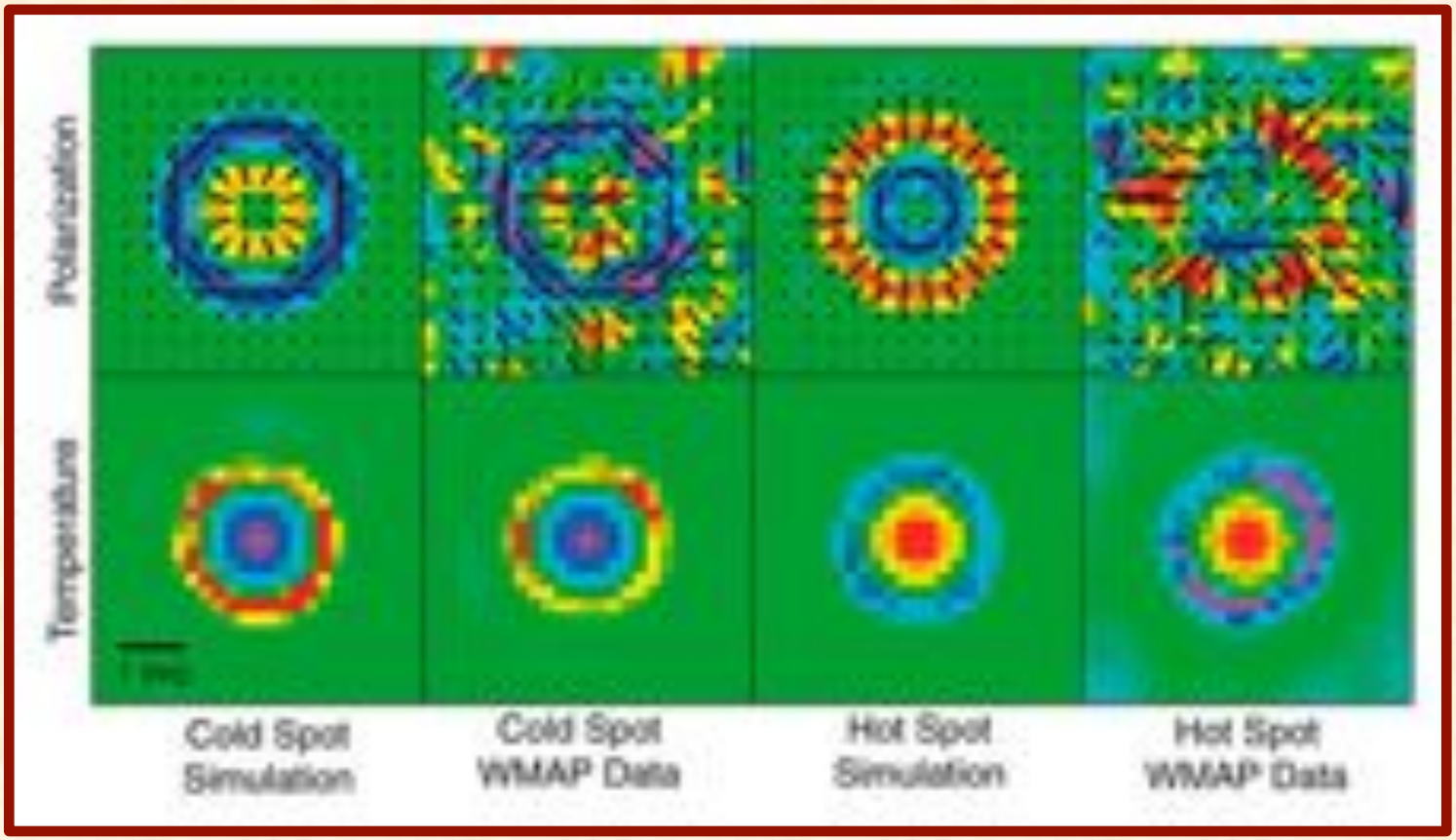
Apparent brightness: $b = B/d^2$.

If we know *B*, and measure *b*, we can deduce *d*.

Main difficulty with measuring distances with SN is calibrating the value of *B*.

BAO's Standard Ruler

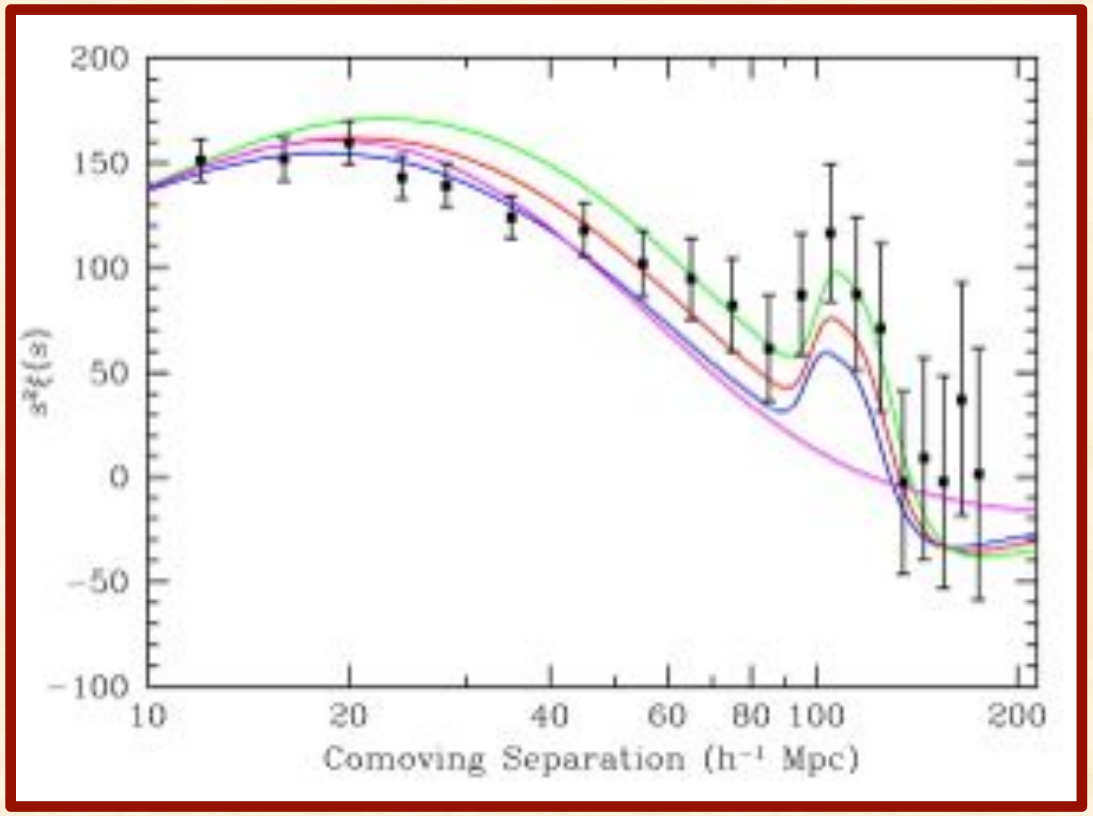
Initial density perturbations form rings of over-densities.



Measured very accurately from CMB

WMAP data (Komatsu et al.)

Overdense Ring Shows Up in the Galaxy Correlation Function



Measure **angular** radius of the ring.

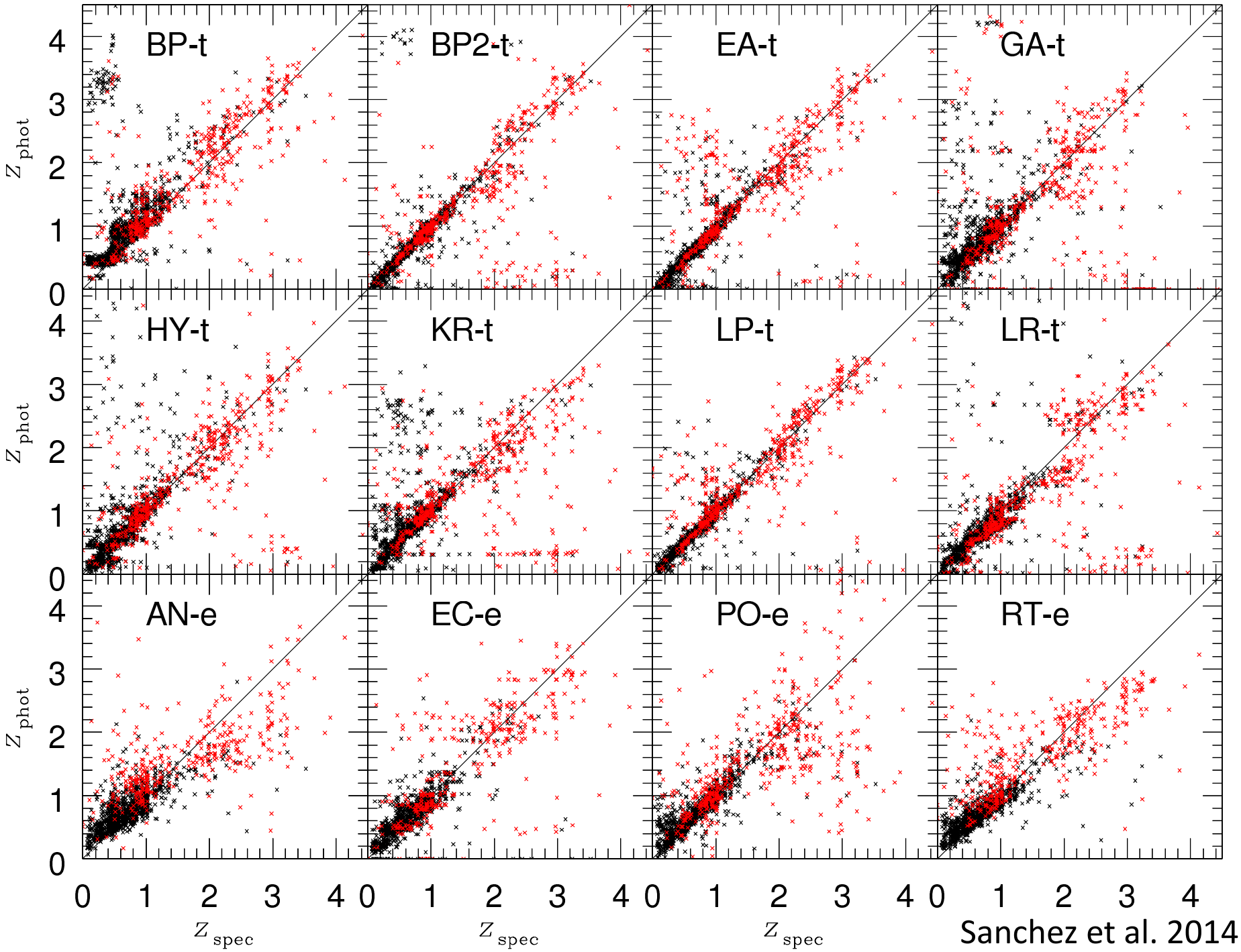
Know actual radius, so we can infer distance.

Eisenstein et al. 2005

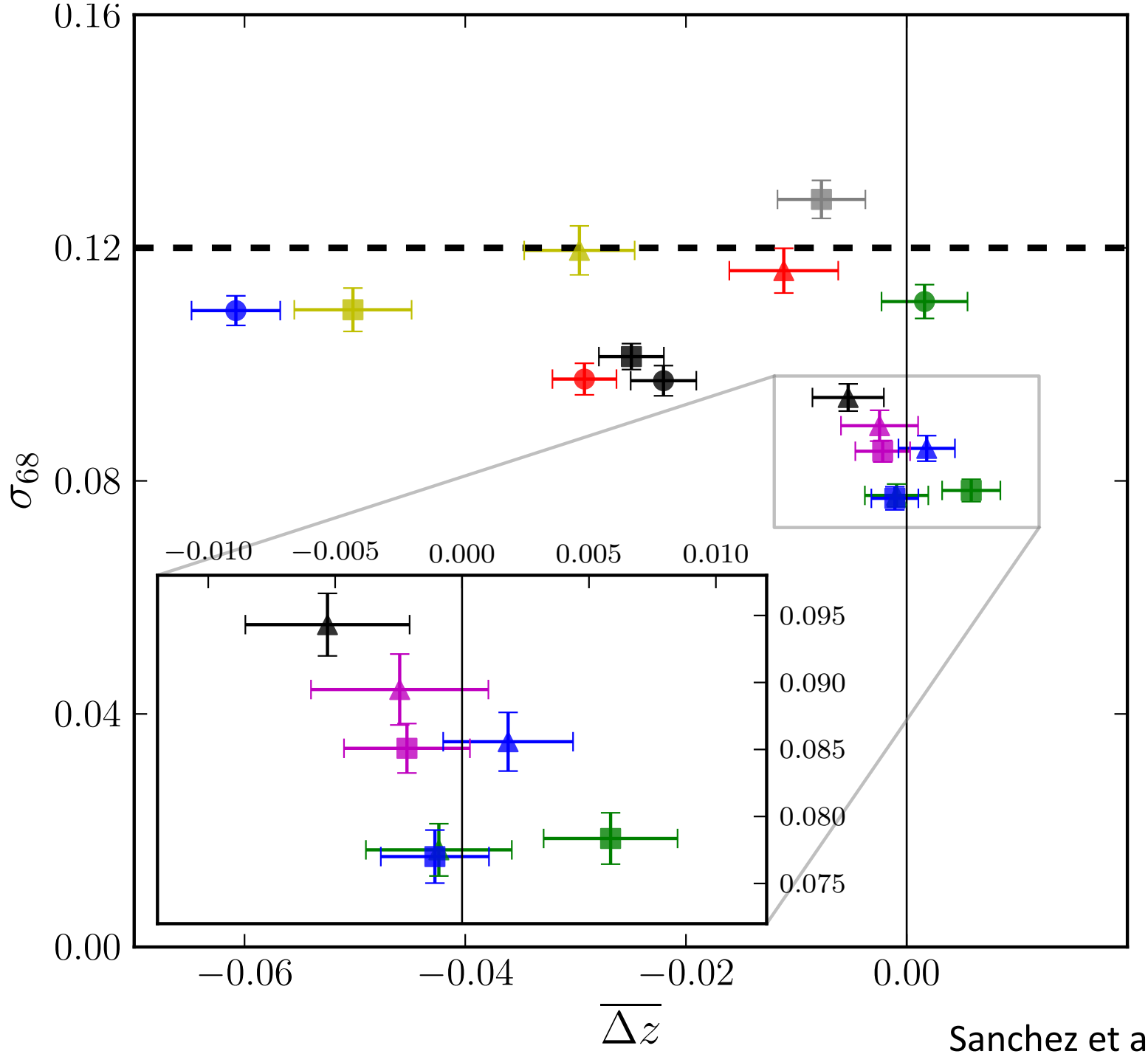
But…

Need to measure two things:

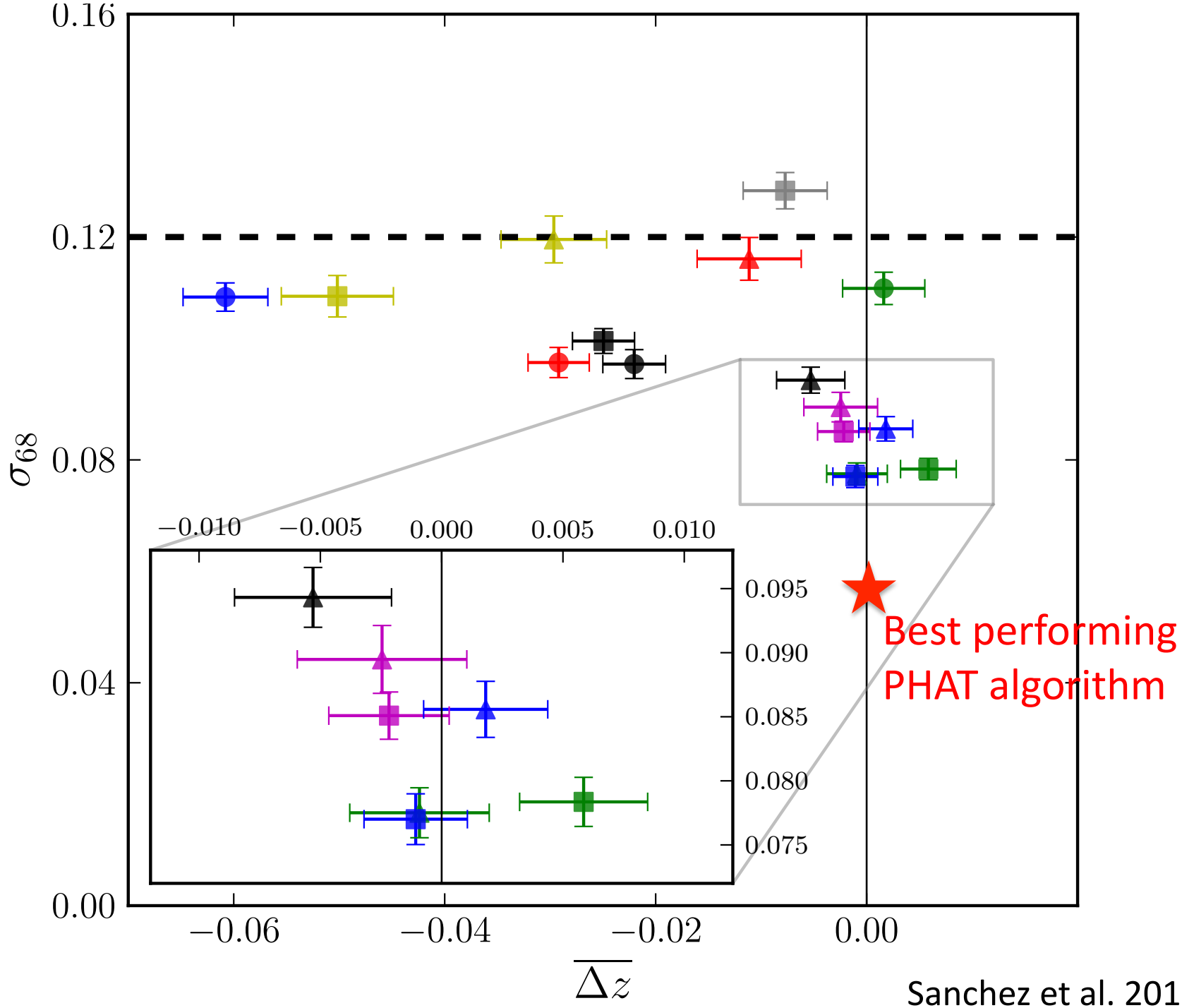
- distance to objects
- **redshifts: this is hard for photometric samples!**



Sanchez et al. 2014

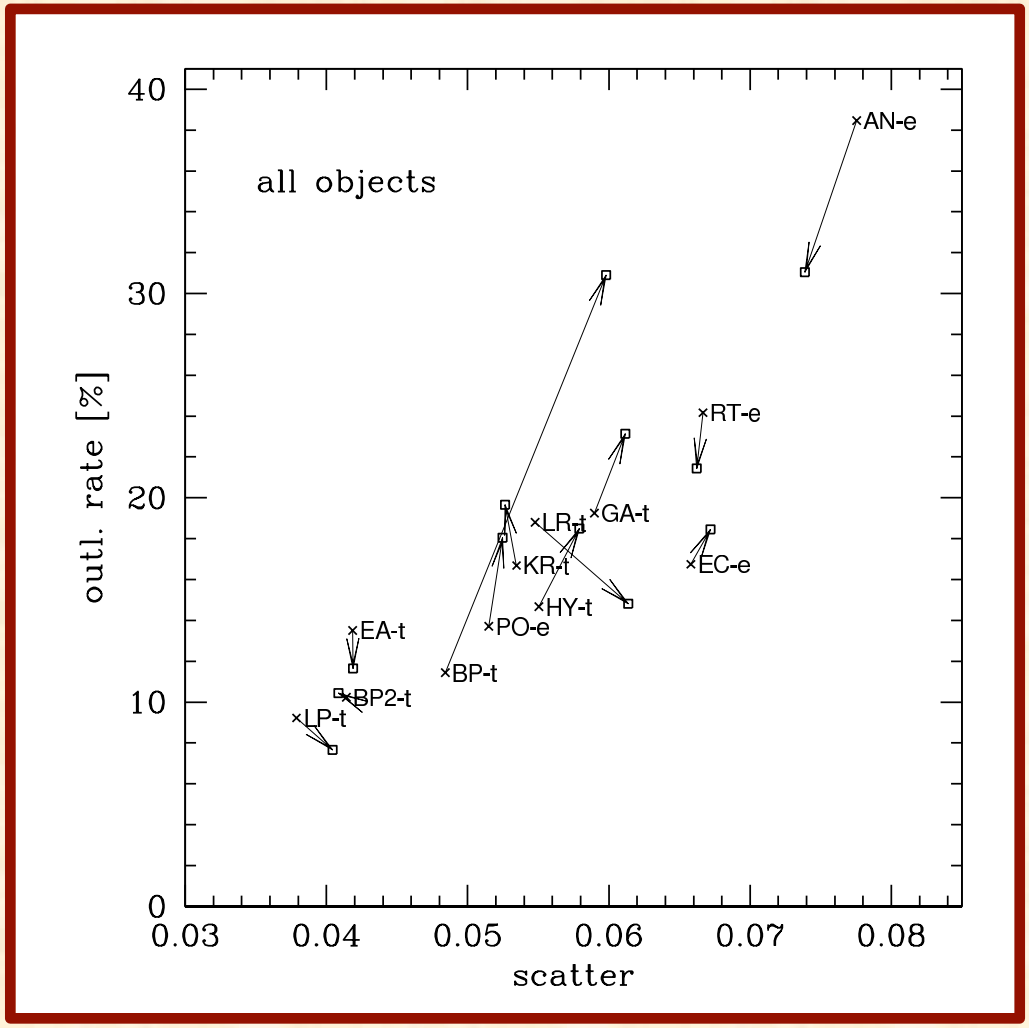


Sanchez et al. 2014



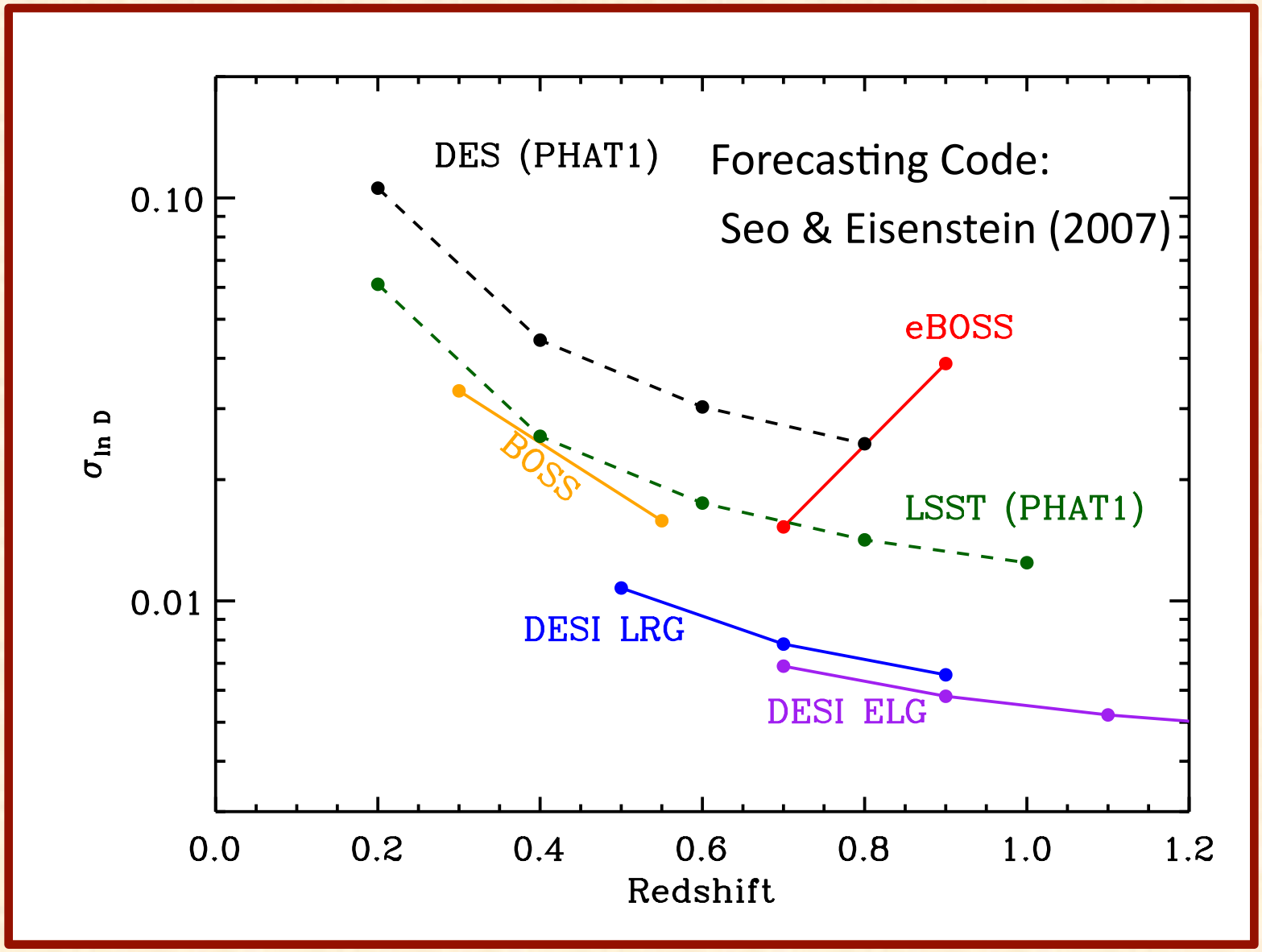
Sanchez et al. 2014

Photometric-redshift Accuracy Tests (PHAT)



Hildebrandt et al. 2010

BAO with Photoz



Can We Improve Things?

Key idea: we don’t need to use all galaxies.

Can we throw away junk to create a gold sample?

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Key idea: we don't need to use all galaxies.

Can we throw away junk to create a gold sample?

redmapper calibrates color(redshift) for red-sequence galaxies.

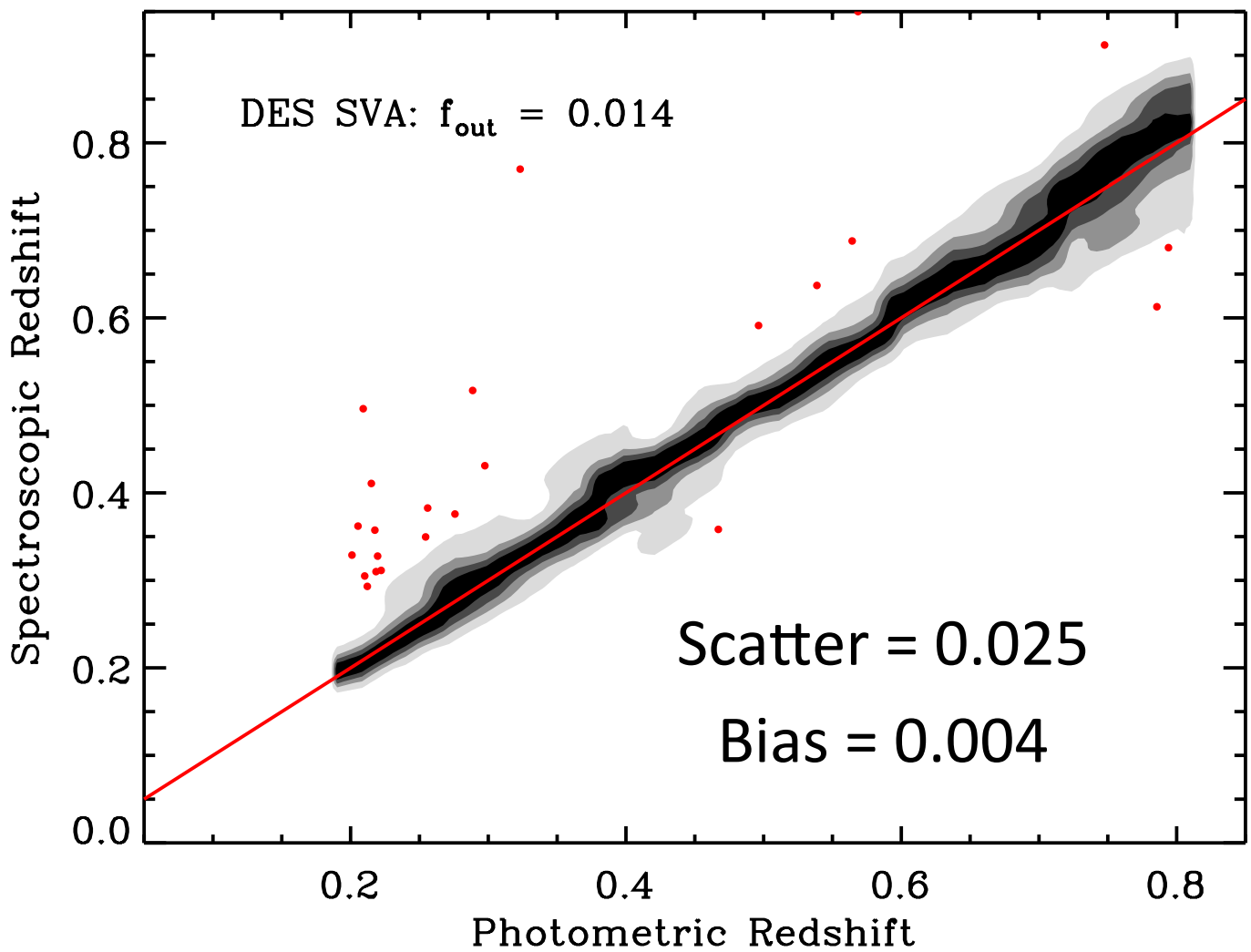
Fit this model to *all* galaxies, and throw away anything with a bad χ^2.

Resulting sample will be only red-sequence galaxies, and will have very good photozs!

Call this catalog **redmagic.**

There is some additional cleverness in the selection, but no time. Ask me privately interested.

redmagic DES SVA Catalog



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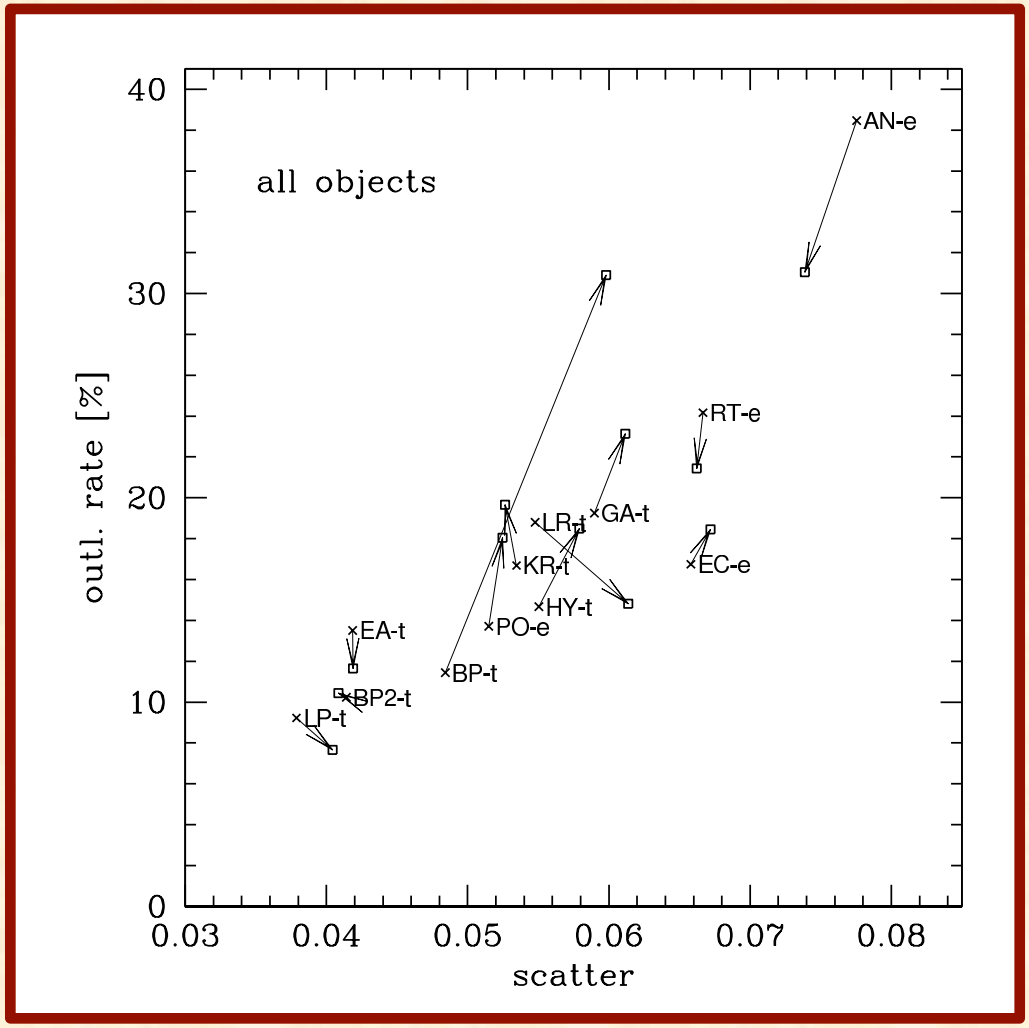

Hildebrandt et al. 2010

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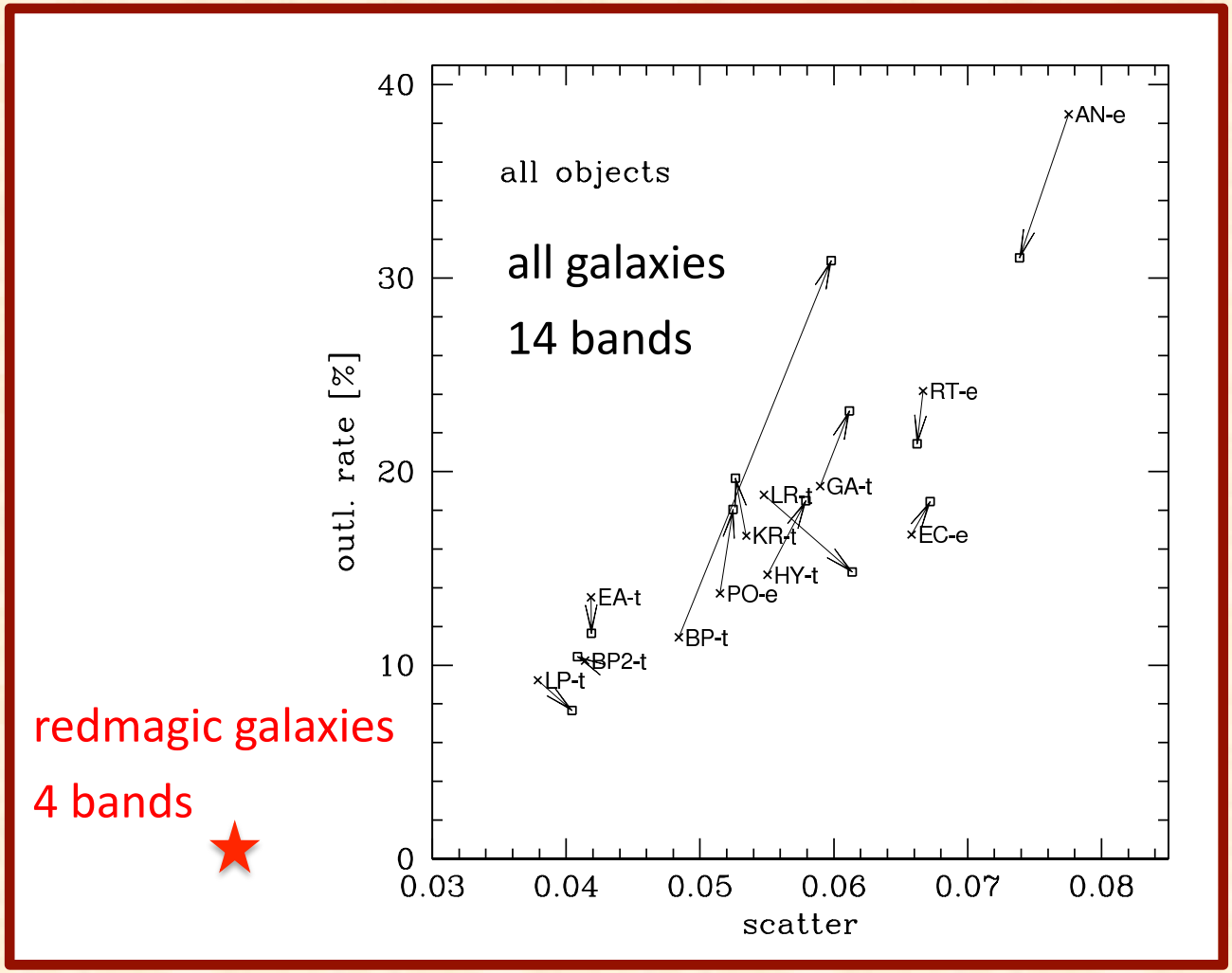

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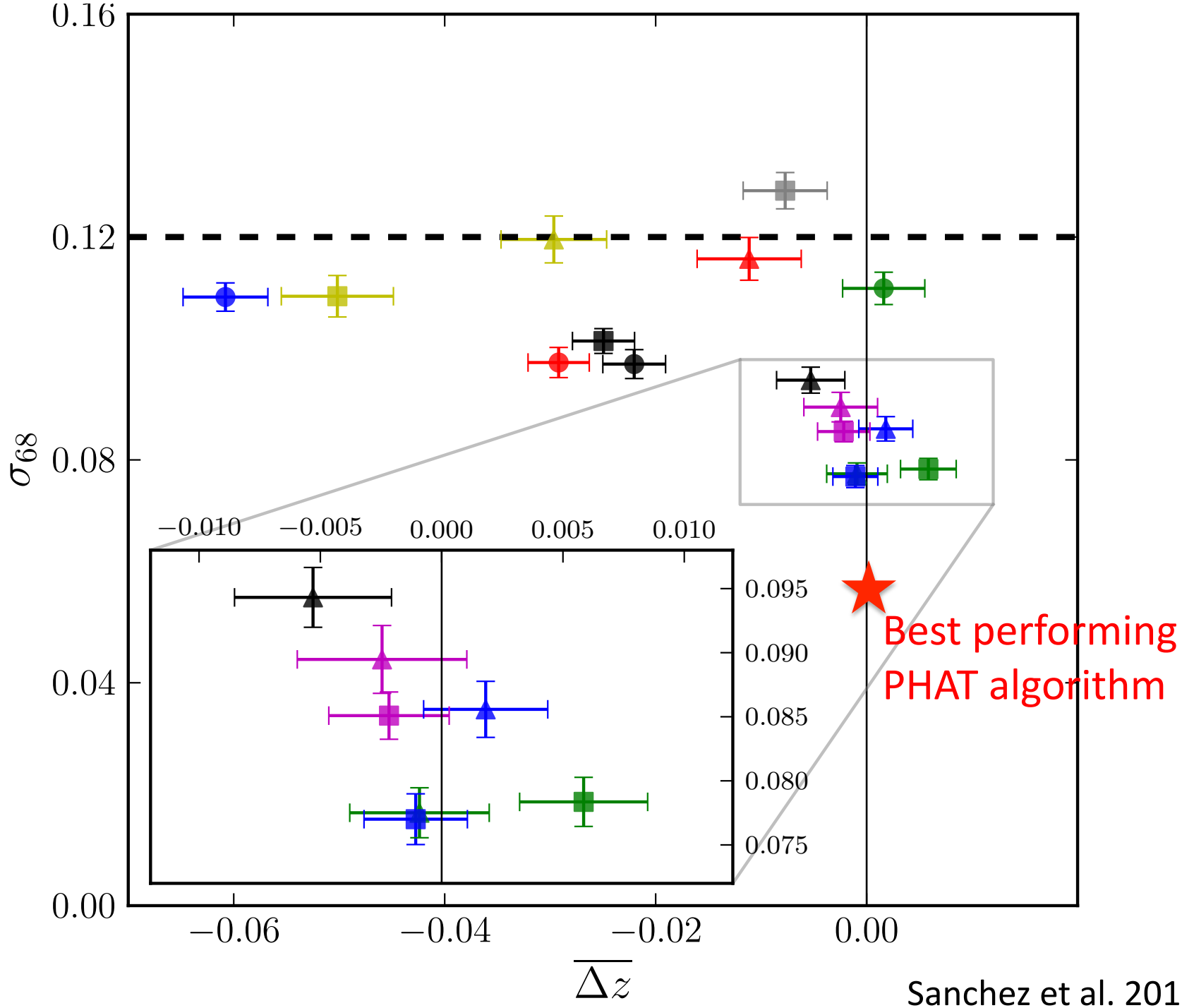
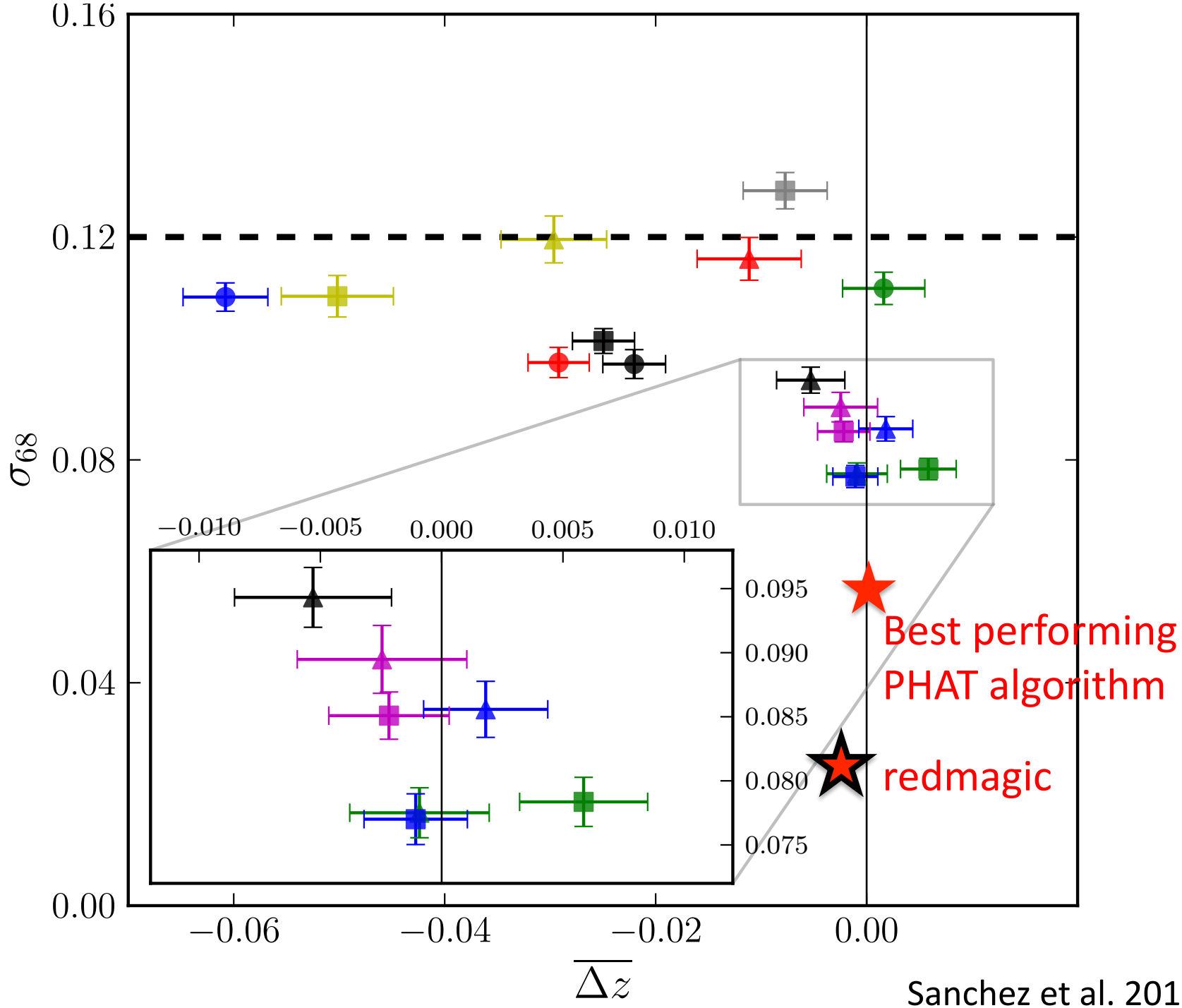
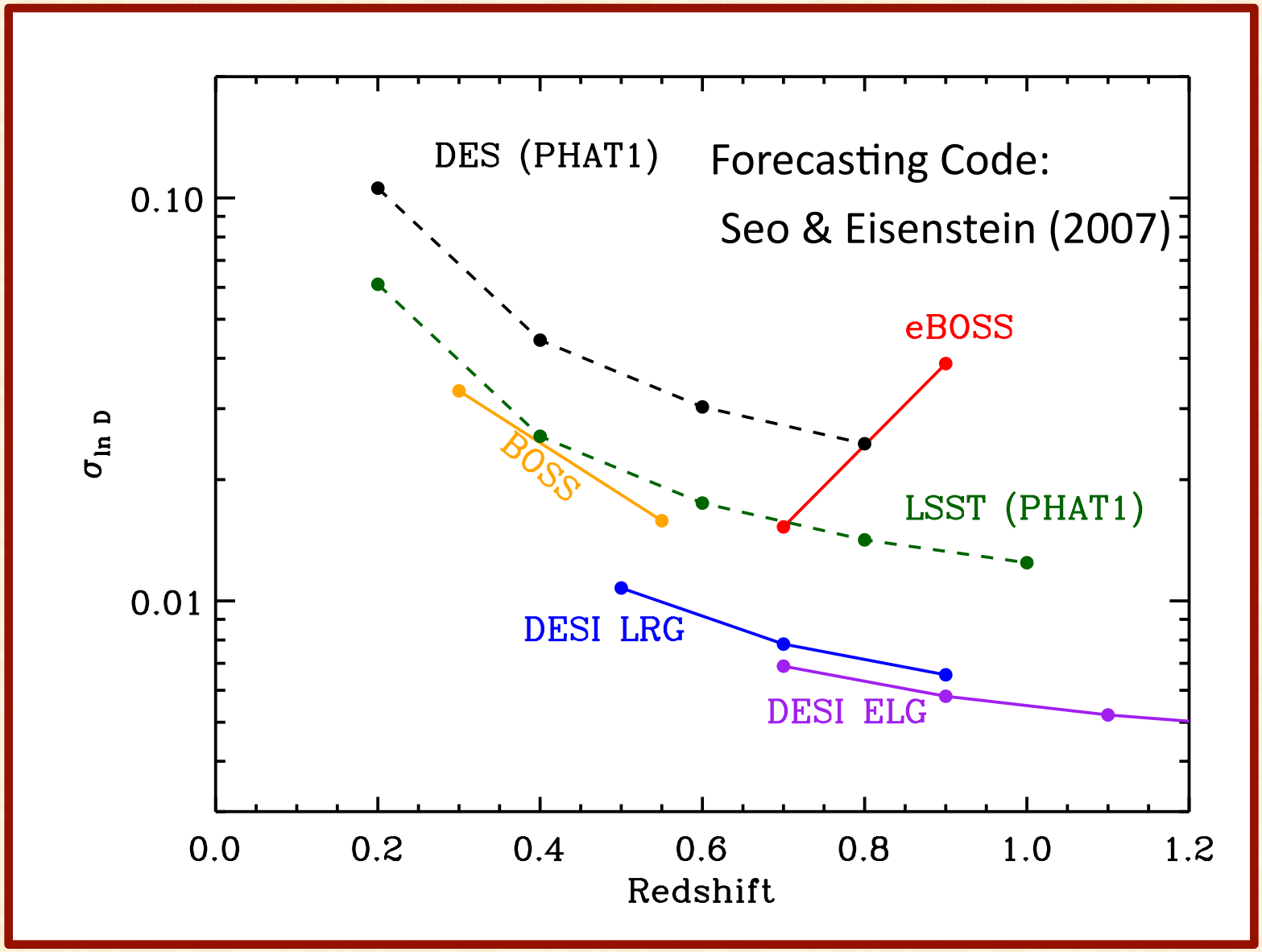


Sanchez et al. 2014

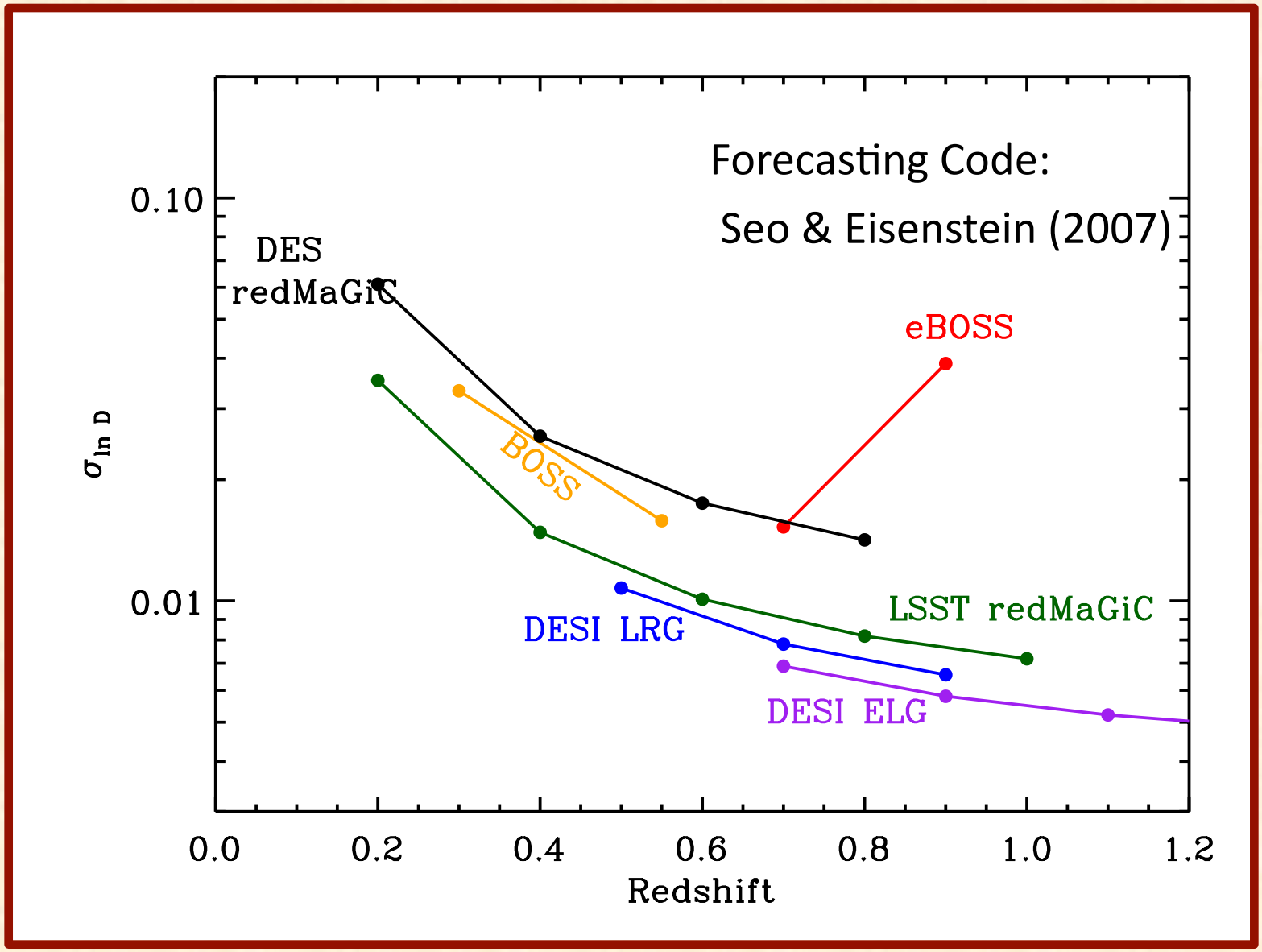


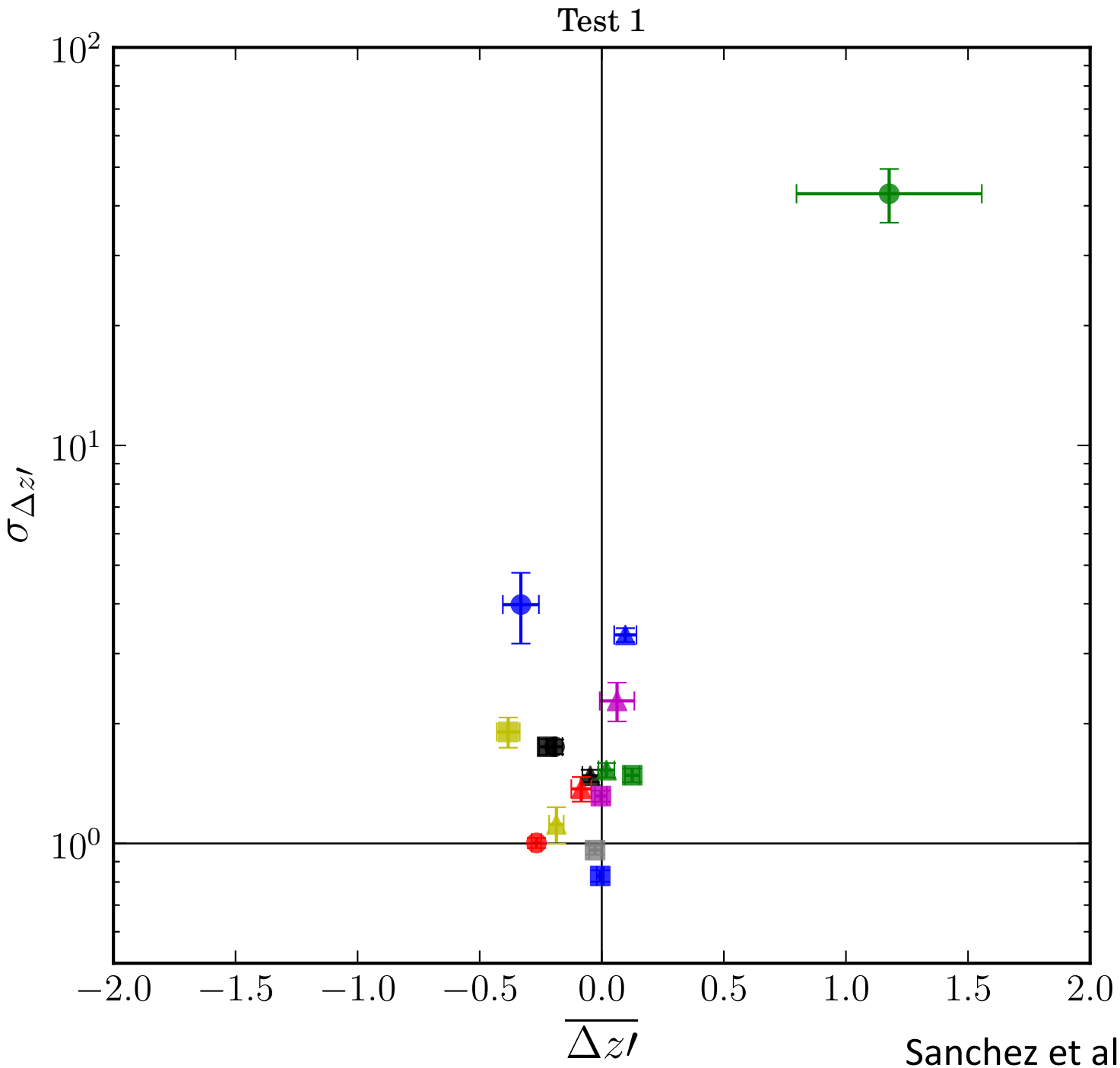
Sanchez et al. 2014

BAO with Photoz

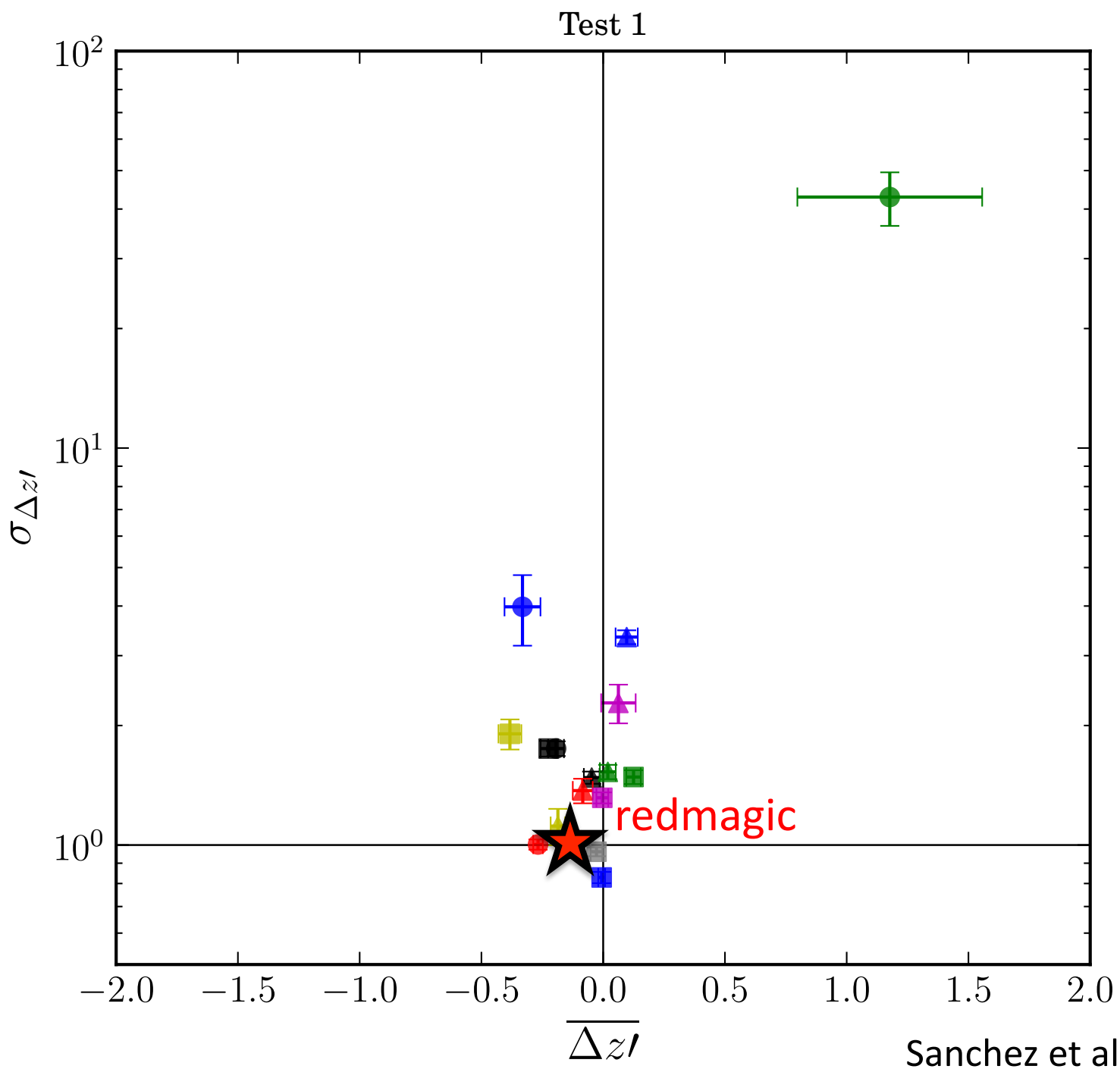


BAO with redmagic





Sanchez et al. 2014



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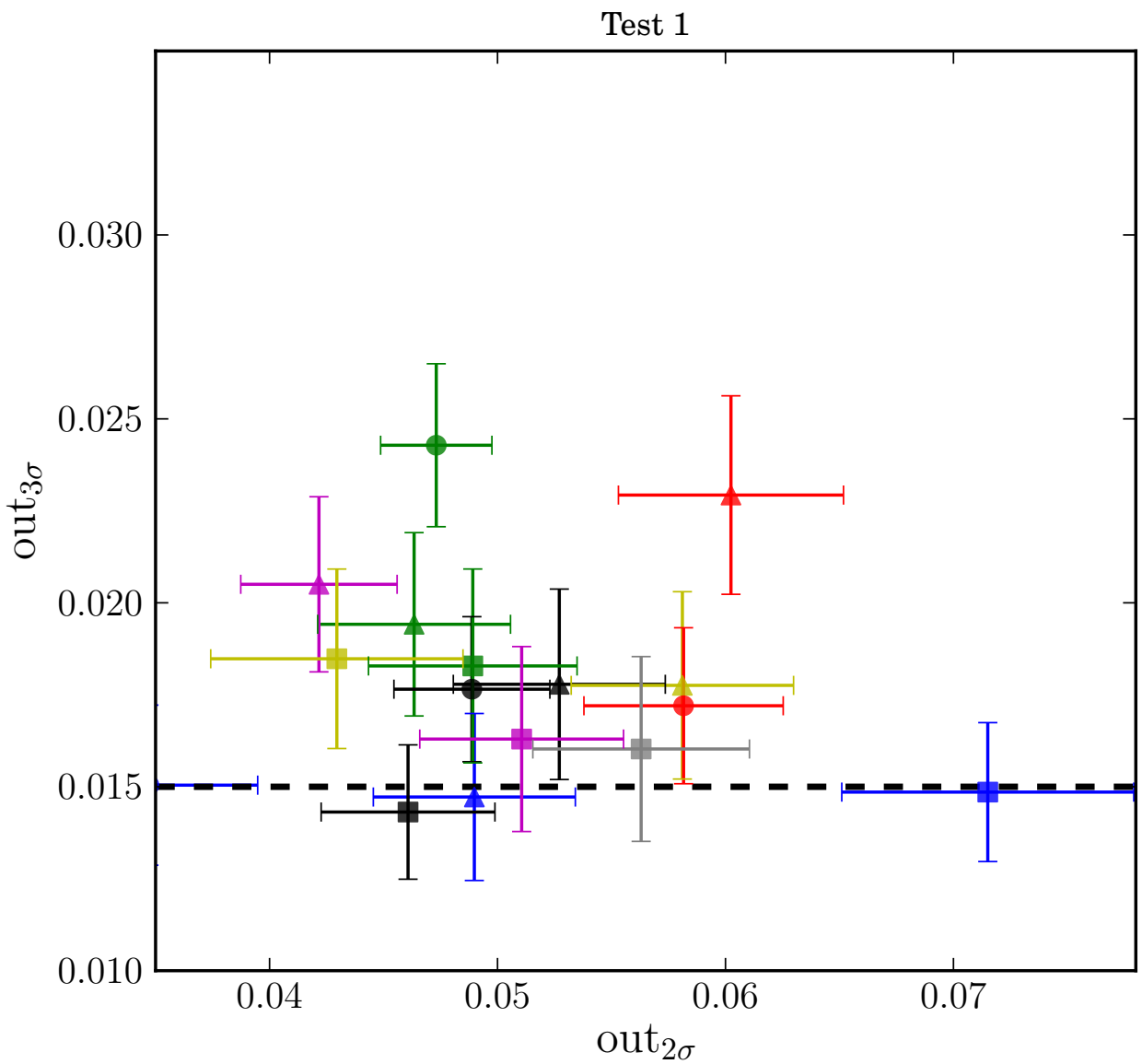
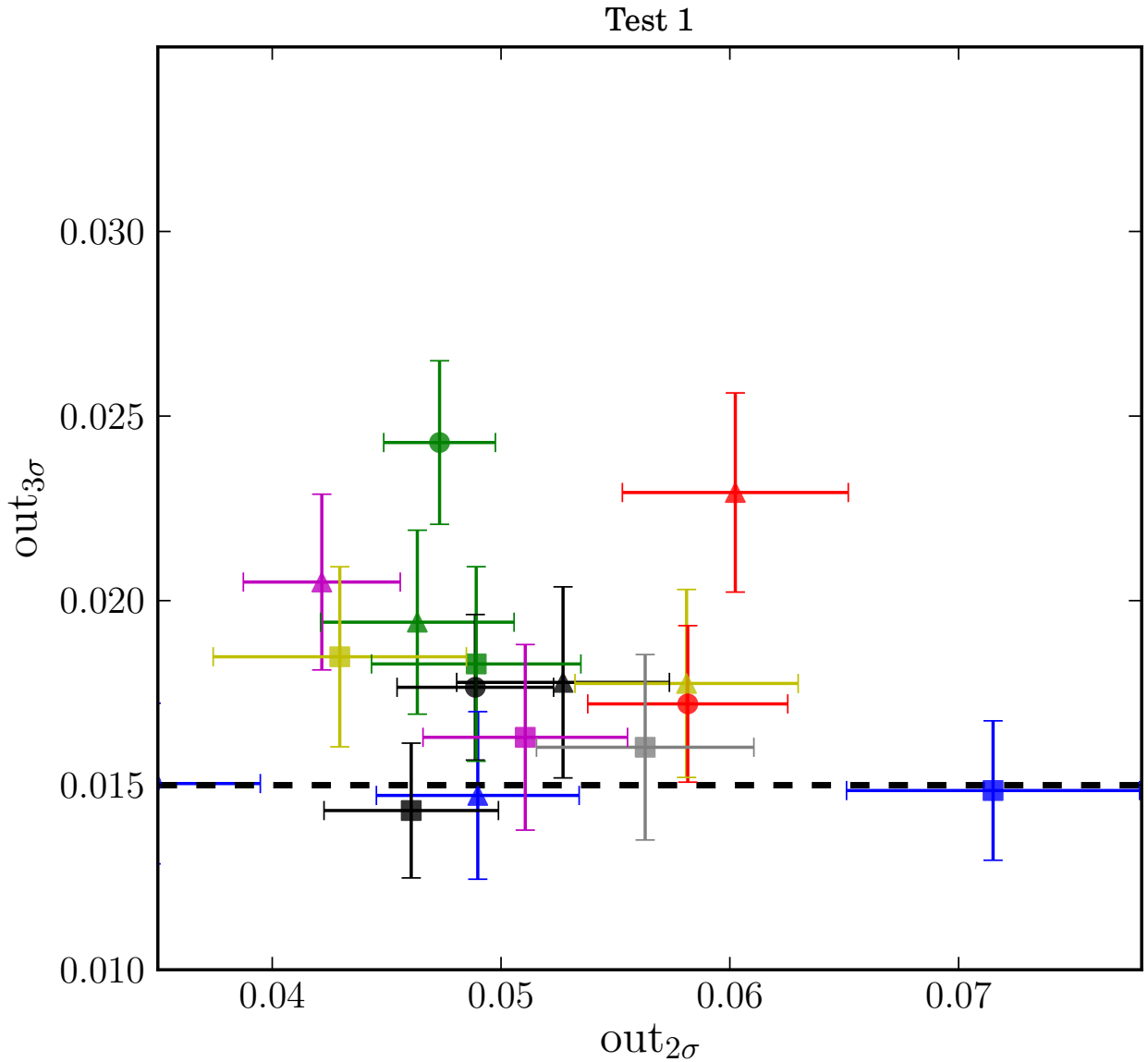


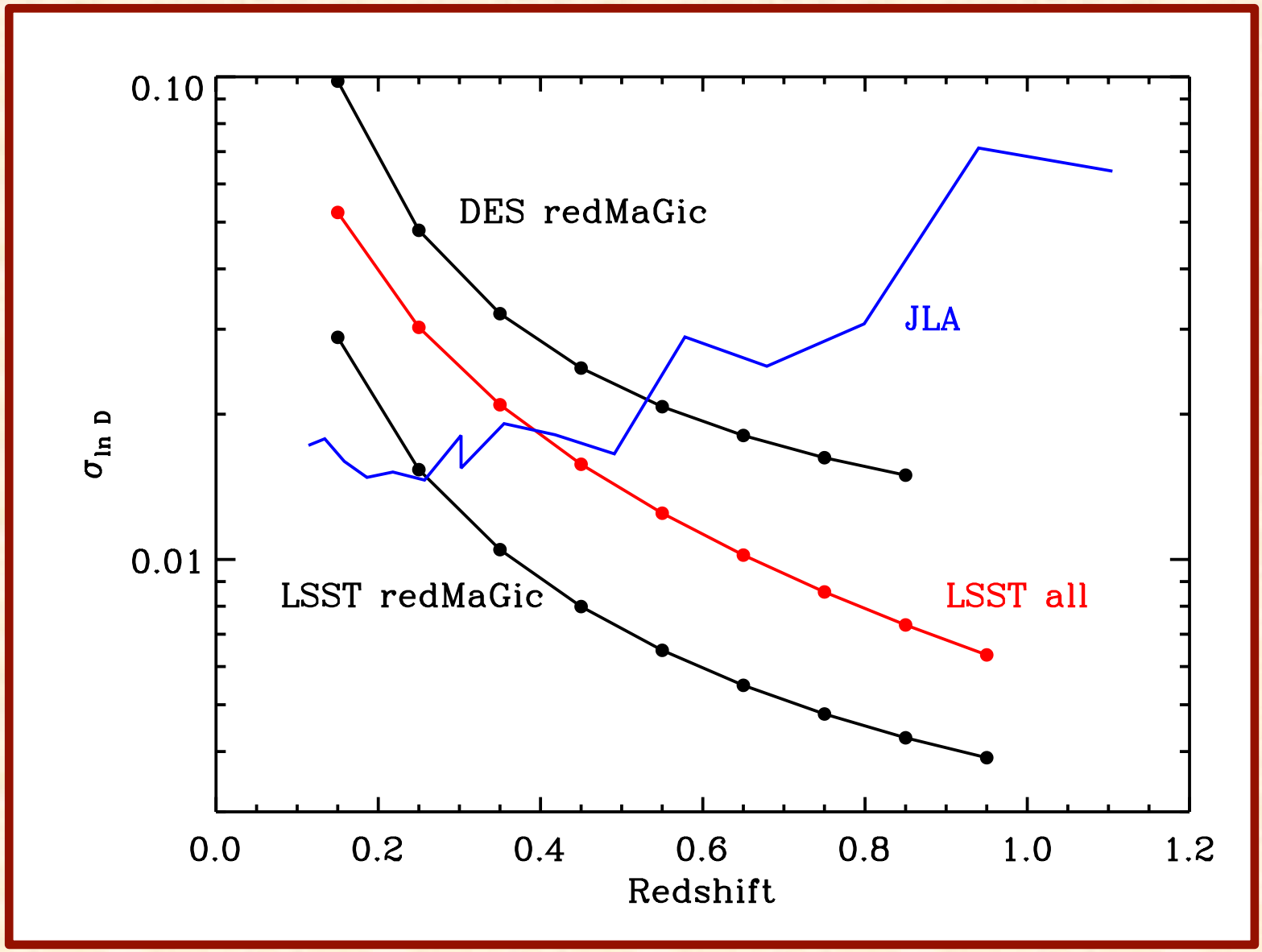
Sanchez et al. 2014



redmagic

Sanchez et al. 2014

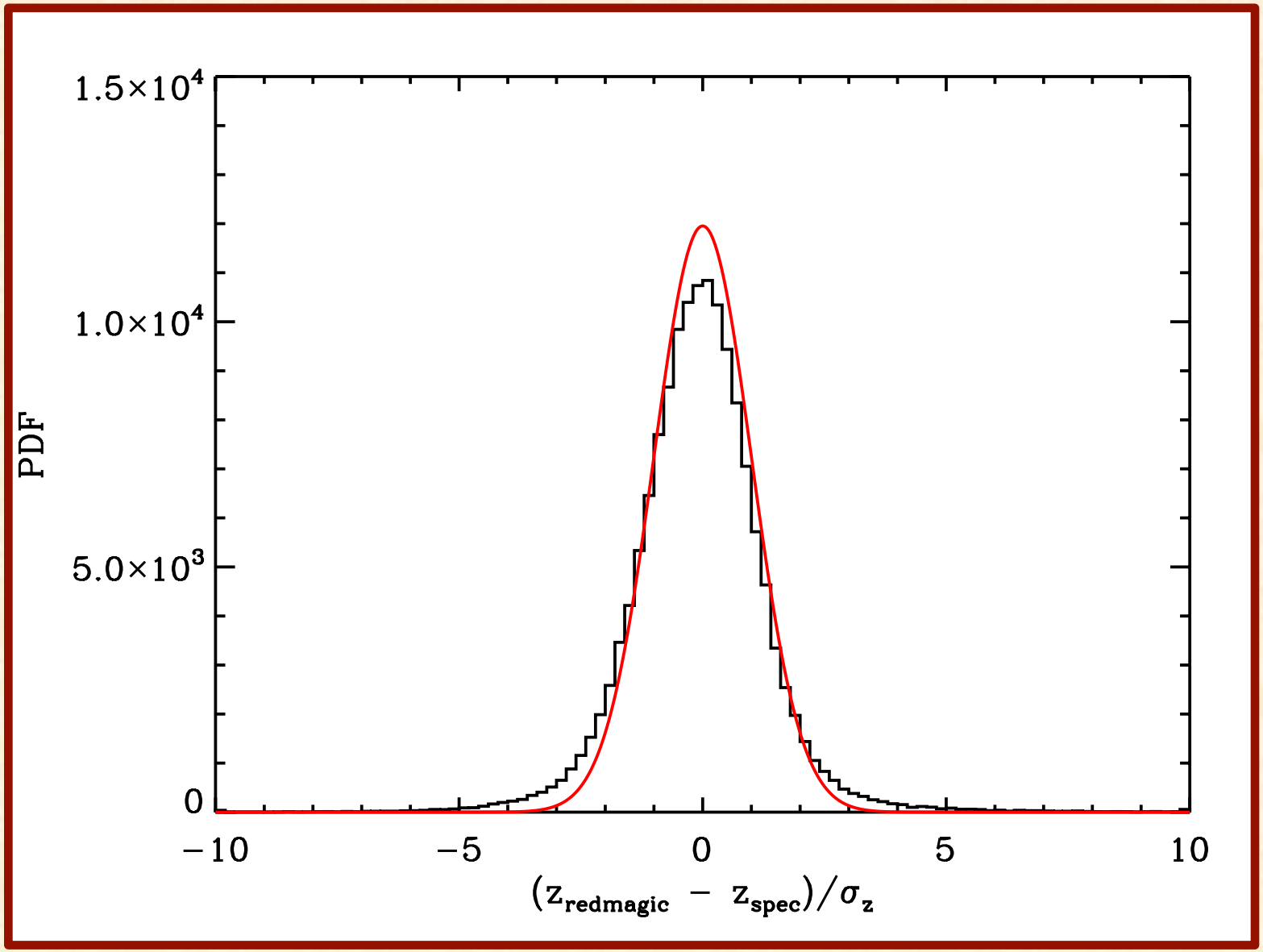
Similar Results with SN



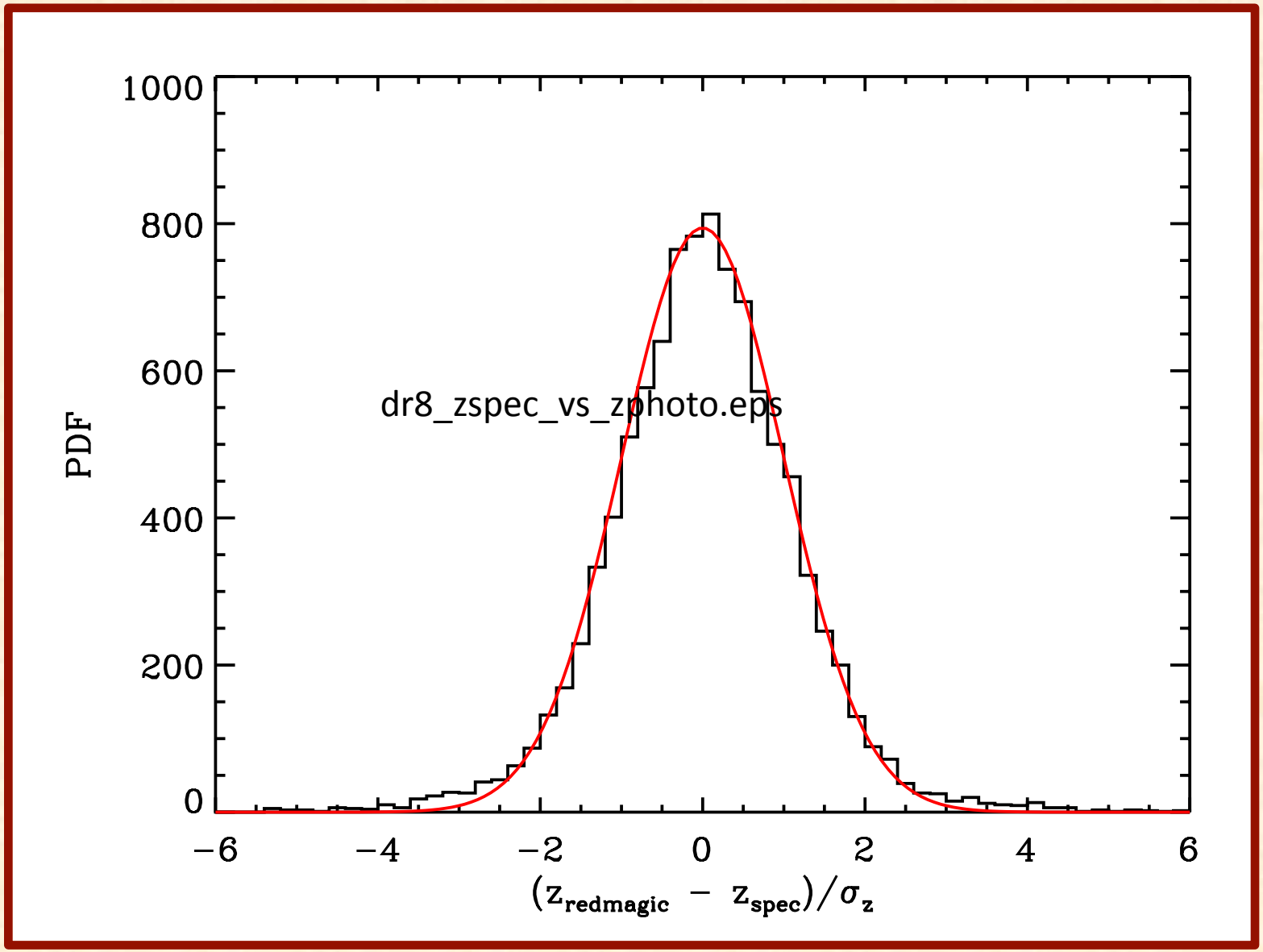
JLA = Betoule et al. 2014

Tests with SDSS

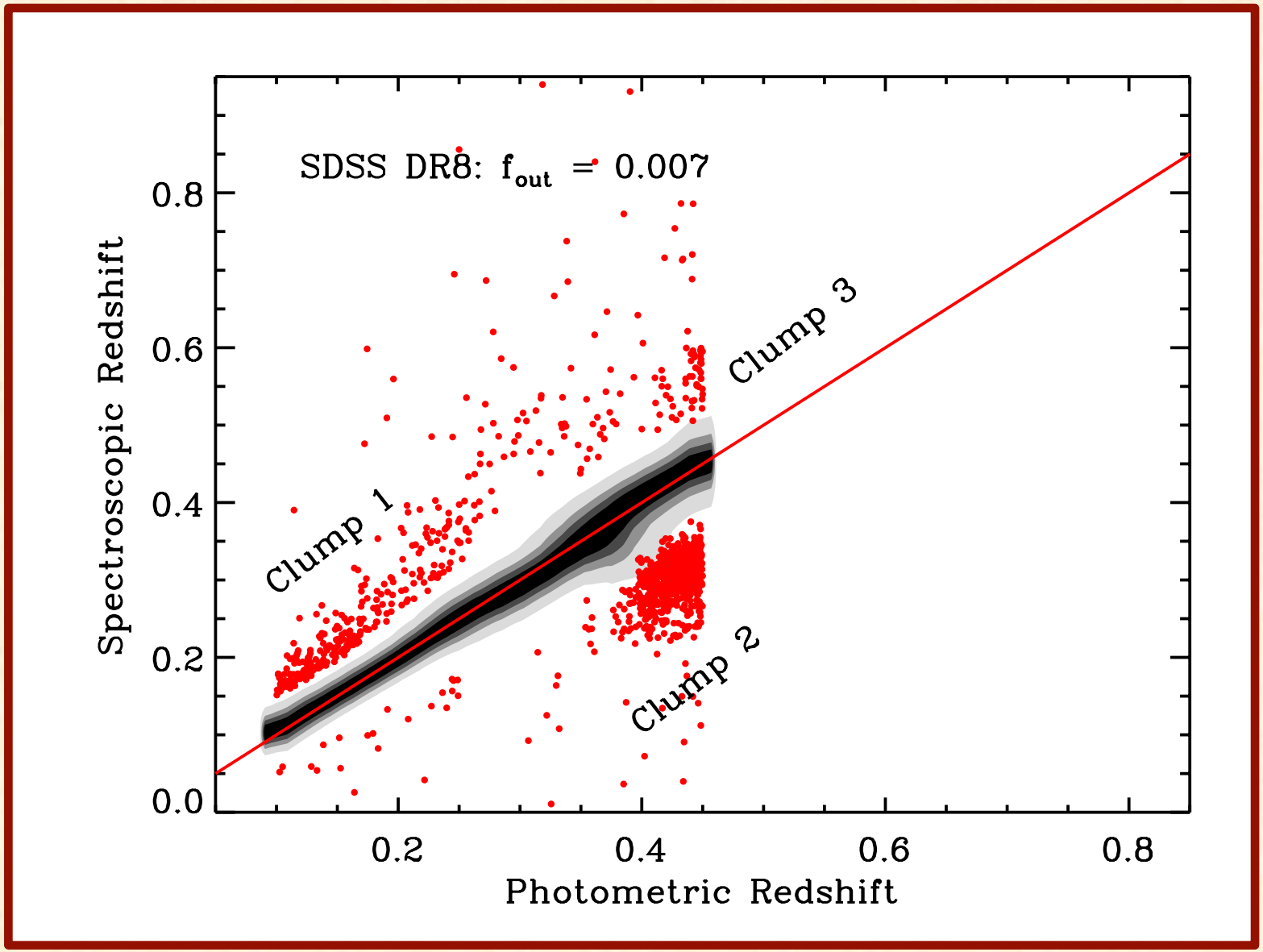
Out of the Box Performance



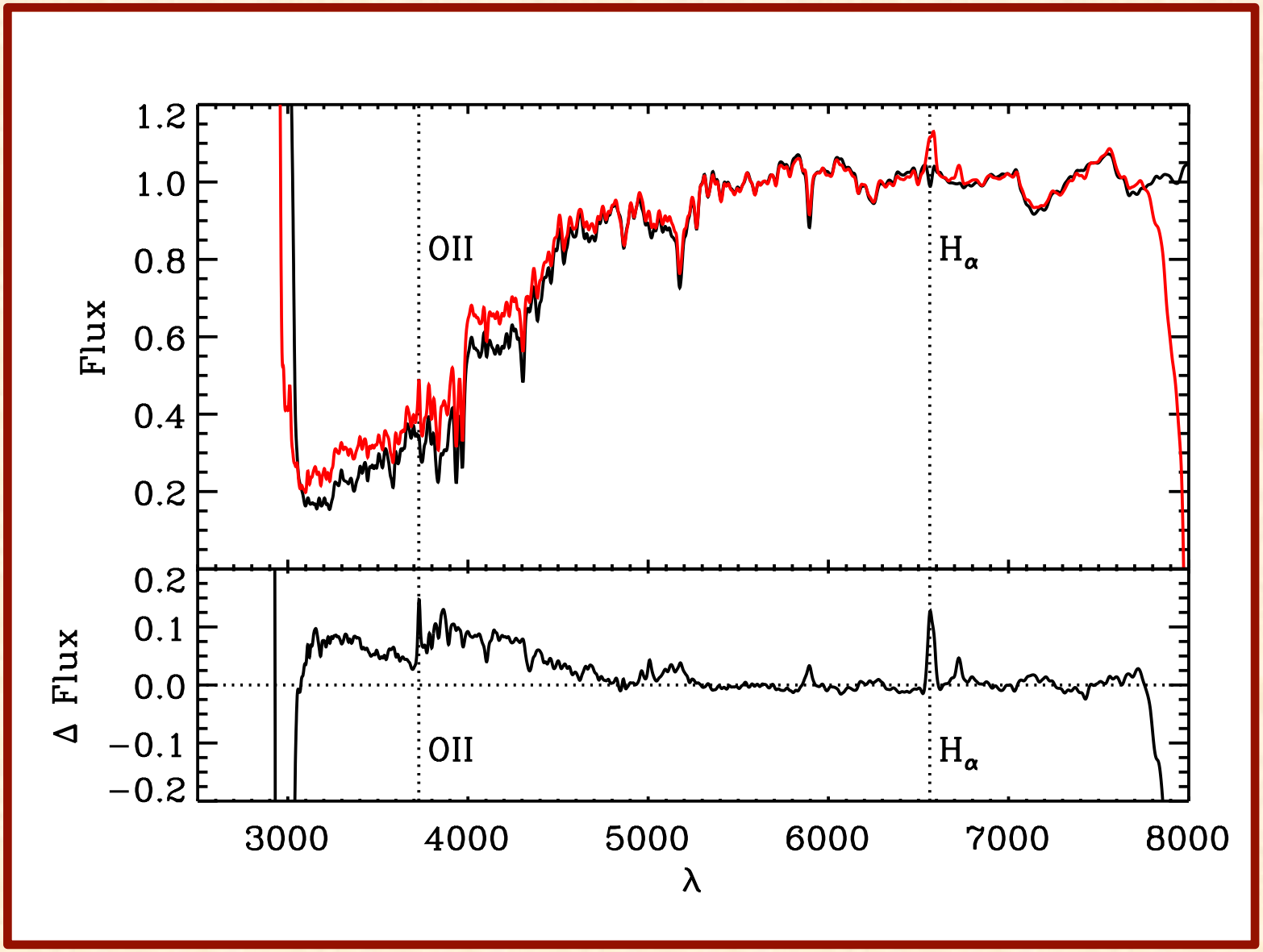
With Spectroscopic "Training"



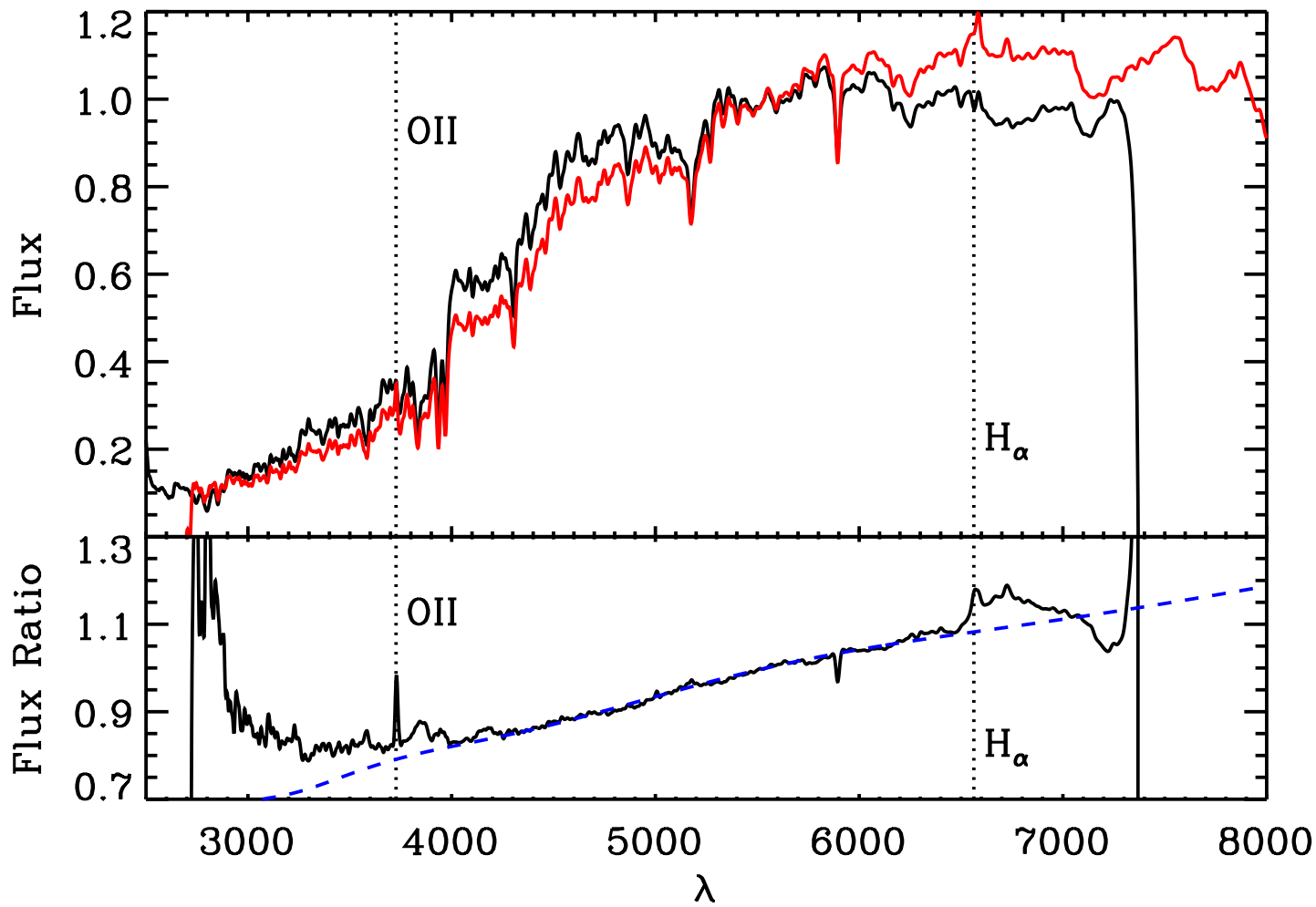
Interesting Outlier Populations



Clump 1 Spectra



Clump 2 Spectra



redmagic Bottom Line

redmagic successfully selects galaxies with extremely clean photozs

Density and precision appear to be good enough to enable competitive dark energy experiments with photometric survey data.

SN forecasts are particularly promising!

Summary

Ongoing and future photometric surveys are poised to become a critical tool for understanding dark energy.

Can study dark energy via:

- clusters
- cosmic shear
- distance—redshift relations (BAO, SN)

We are working in constructing the redmapper/ redmagic catalogs to enable this science.

Summary

redmapper = cluster finder

- Sufficiently clean sample for cluster cosmology
- Excellent photometric redshifts allow one to calibrate source photozs for cosmic shear.

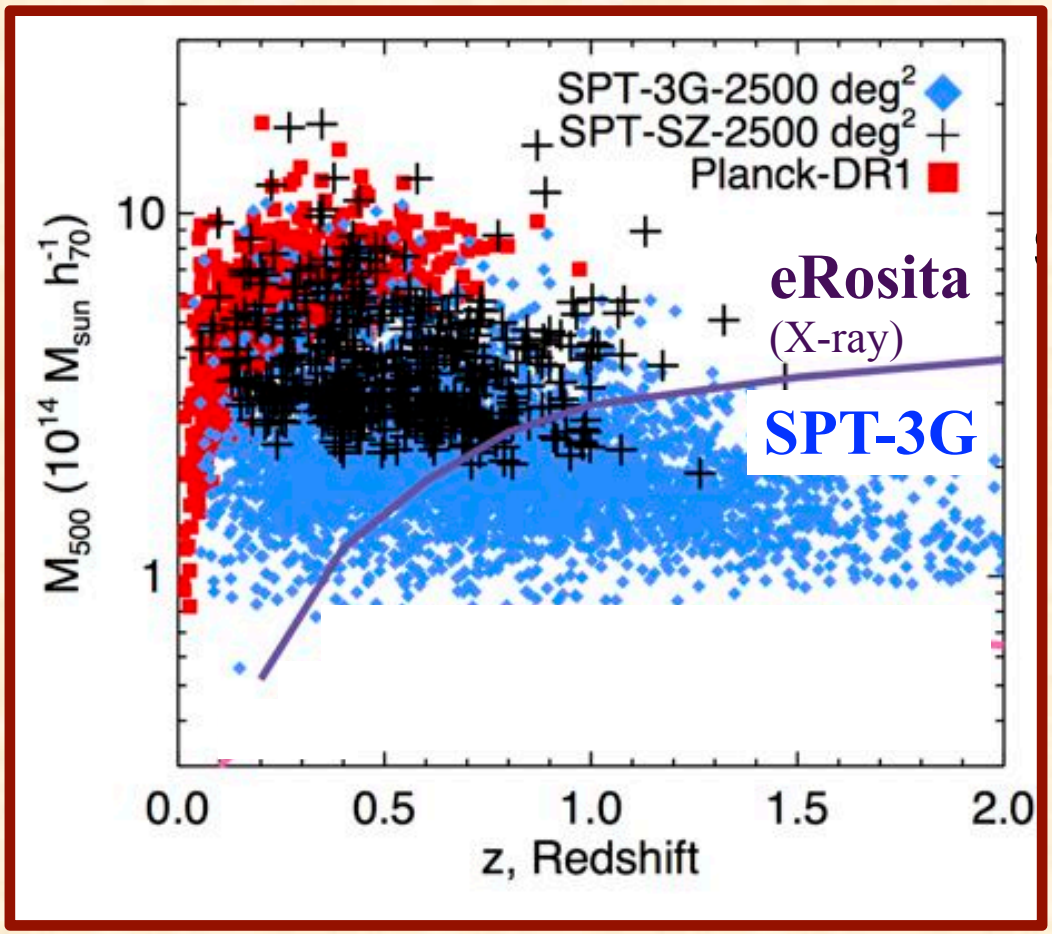
SN, BAO need good *individual* photozs.

Very difficult to do in general, but we can make great progress by cherry-picking galaxies.

redmagic = gold sample for photozs

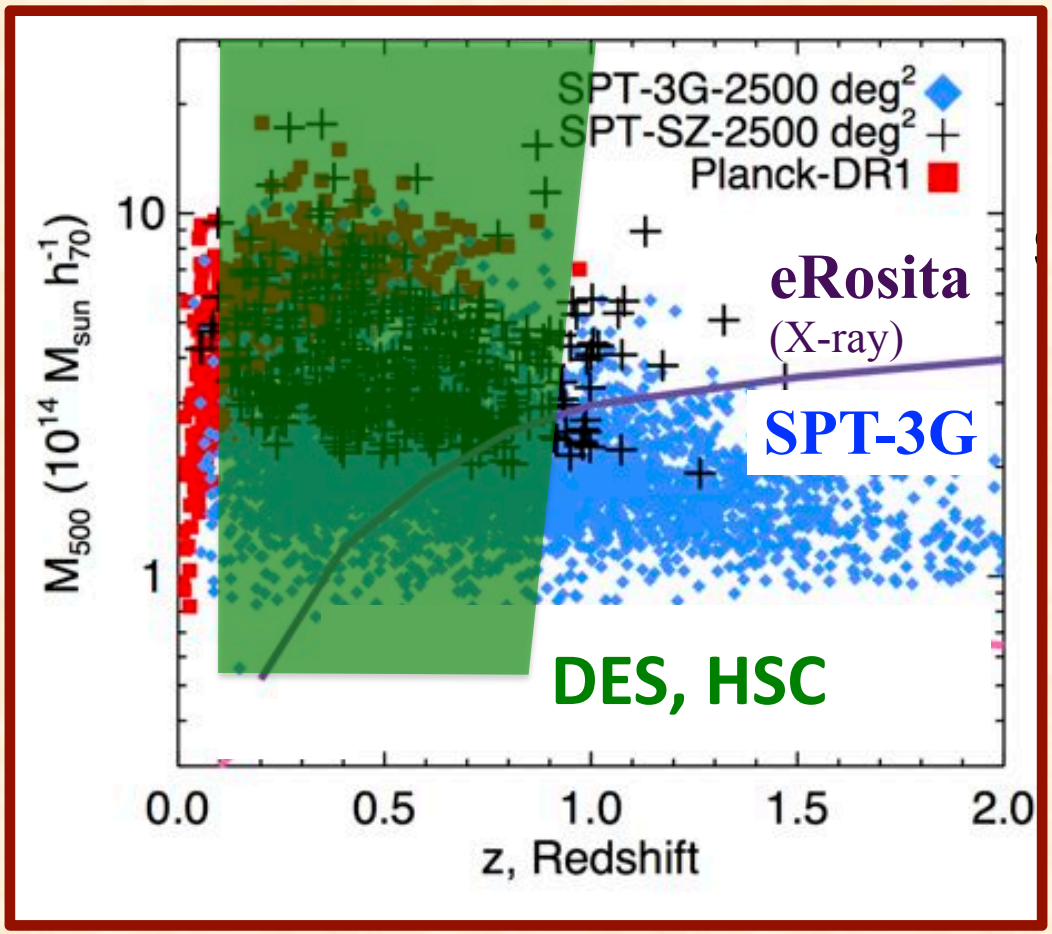
- Early indications suggest will enable BAO/SN cosmology with photometric survey data.

Cluster Selection in Different Wavelengths



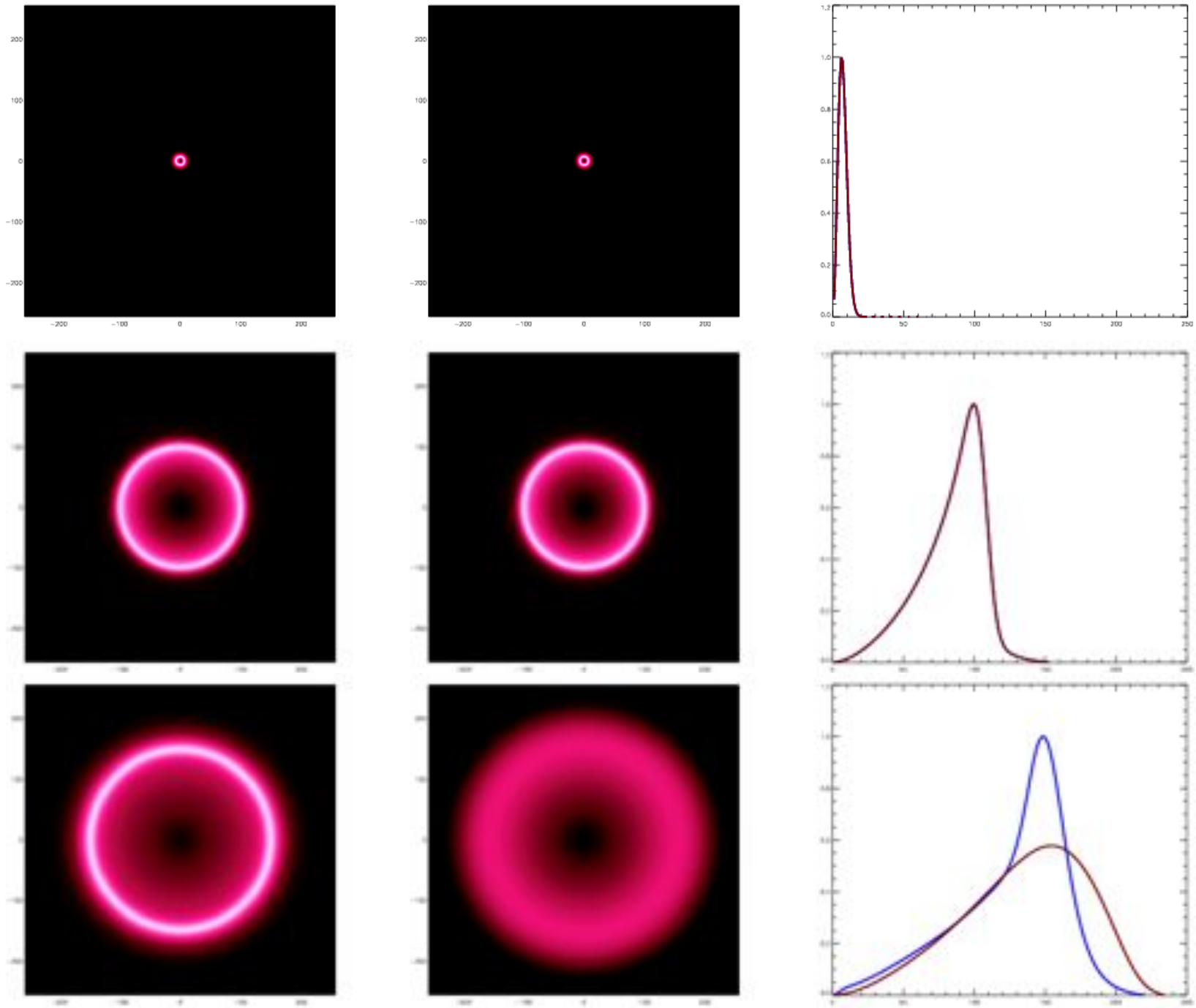
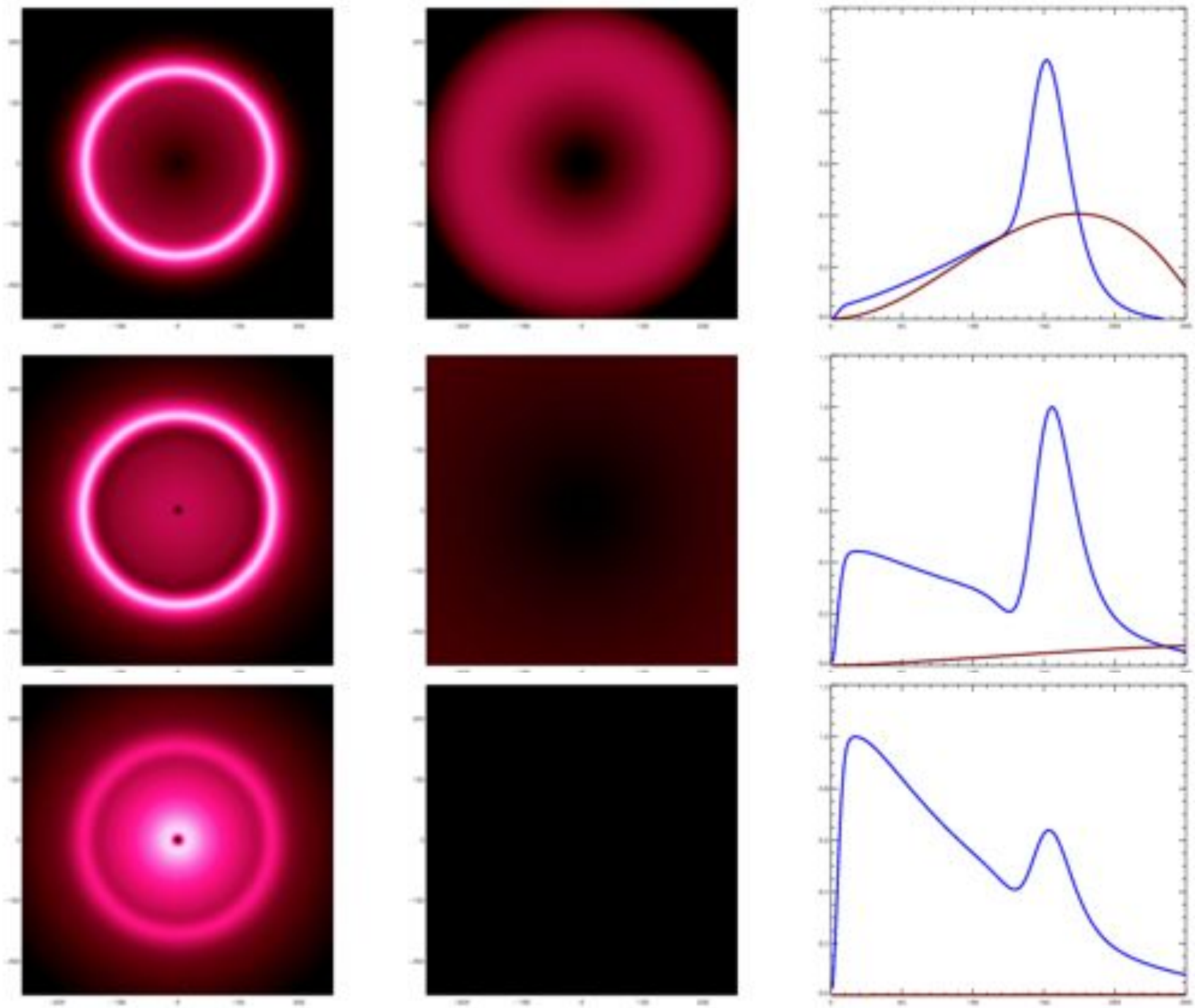
Plot courtesy of L. Bleem

Cluster Selection in Different Wavelengths



Plot courtesy of L. Bleem

Where Does the BAO Feature Come From?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