Planck Cosmology, Galaxy Clusters, and Neutrino Masses

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So What's The Fuzz All About?

Planck allows us to constrain cosmological parameters in several ways:

- CMB primaries
- Galaxy clusters

The problem: *if we assume vanilla LCDM,*

The cosmology from CMB primaries (pXVI) are in tension with the cosmology from clusters (pXX).

Tension can be eased if neutrinos are massive.

How Seriously Should You Take this Tension?

My answer: **not very**.

Why?

The cluster cosmology results are ***very*** sensitive to our ability to calibrate cluster masses.

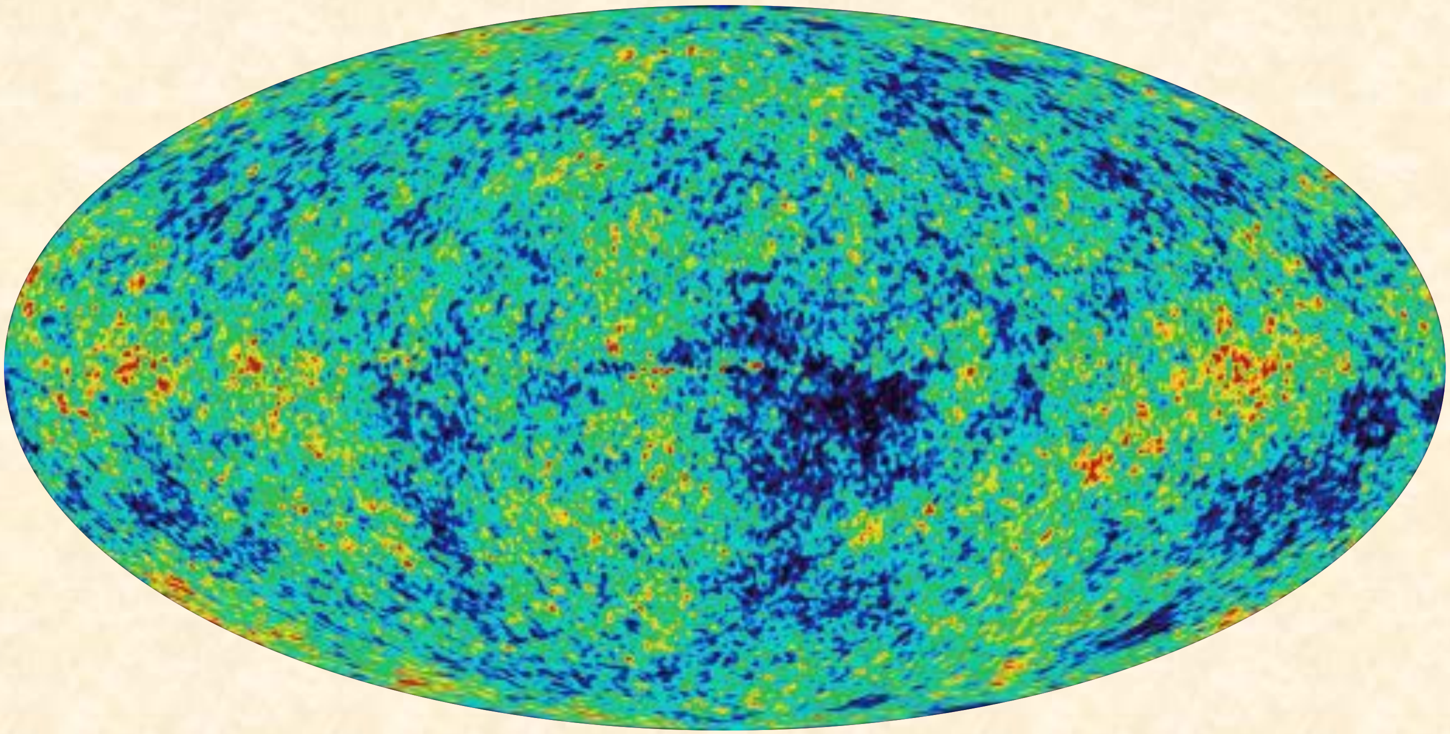
There is strong evidence of systematics in the mass calibration used by Planck.

In fact, this was all known a priori.

Cluster Cosmology

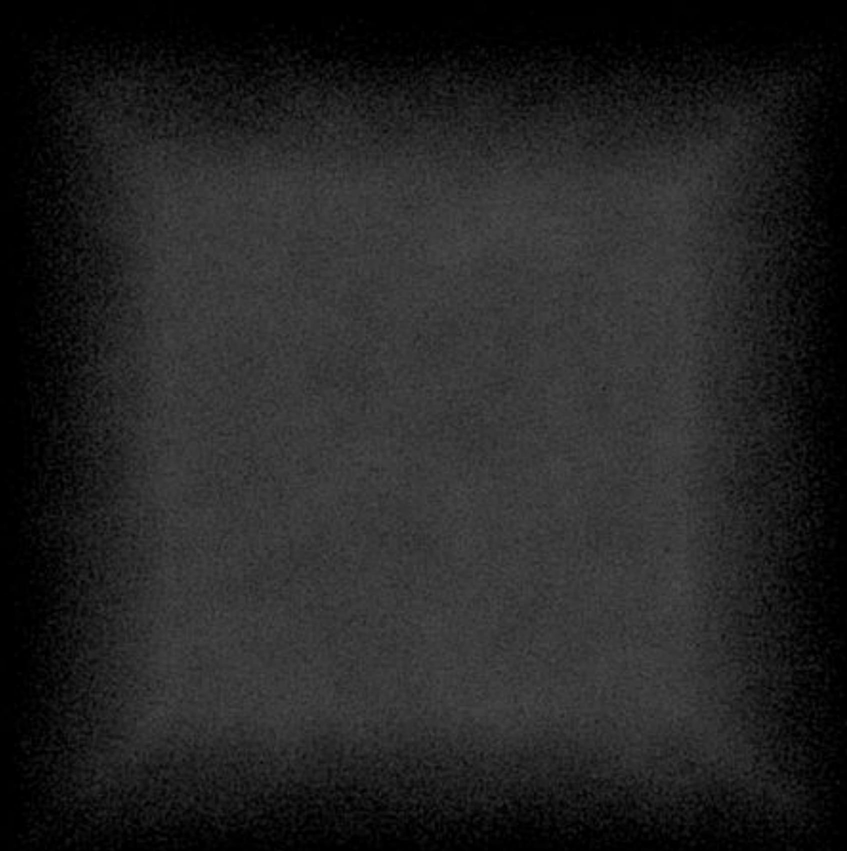
Using Large Scale Structure to Test GR/Dark Energy

Early universe was almost perfectly smooth.

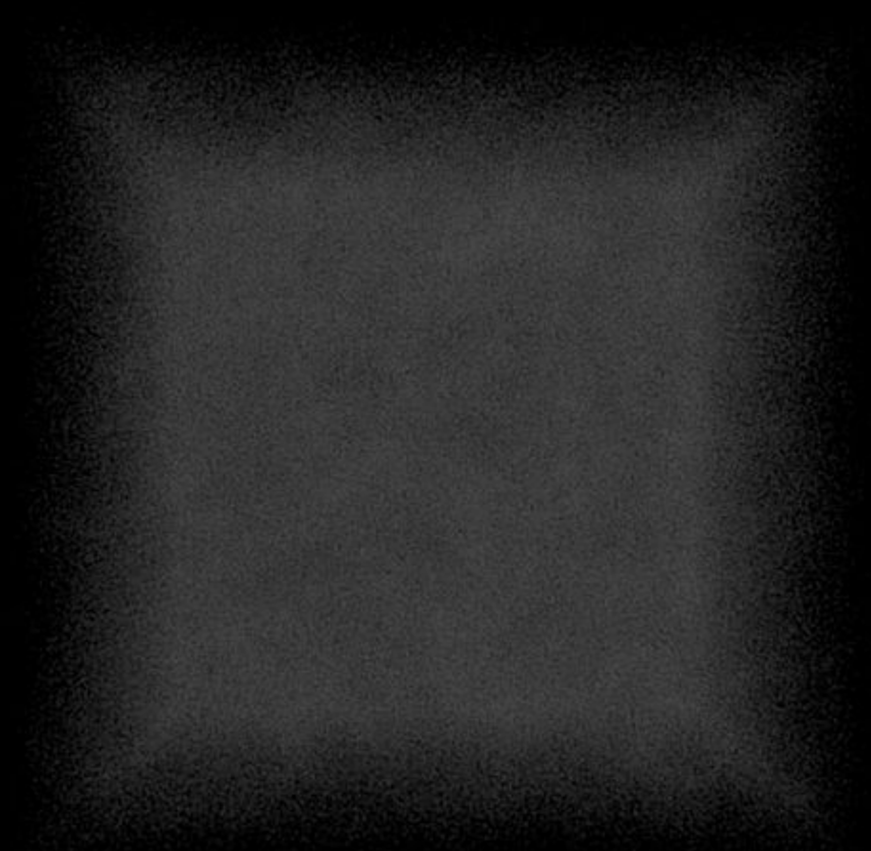


But we do see *tiny* (0.001%) perturbations.

Structure Growth is Sensitive to Cosmological Parameters



Low matter density



High matter density

Basic Plan of Attack

- Measure initial conditions (CMB).
- Measure expansion history (e.g. SN and/or BAO).
- Predict amount of structure today (σ_8).
- Measure structure today (σ_8), and compare to prediction. ← **This is where clusters come in.**

σ_8 = rms of the density field, smoothed over a sphere of radius 11 Mpc

i.e. σ_8 measures "clumpiness".

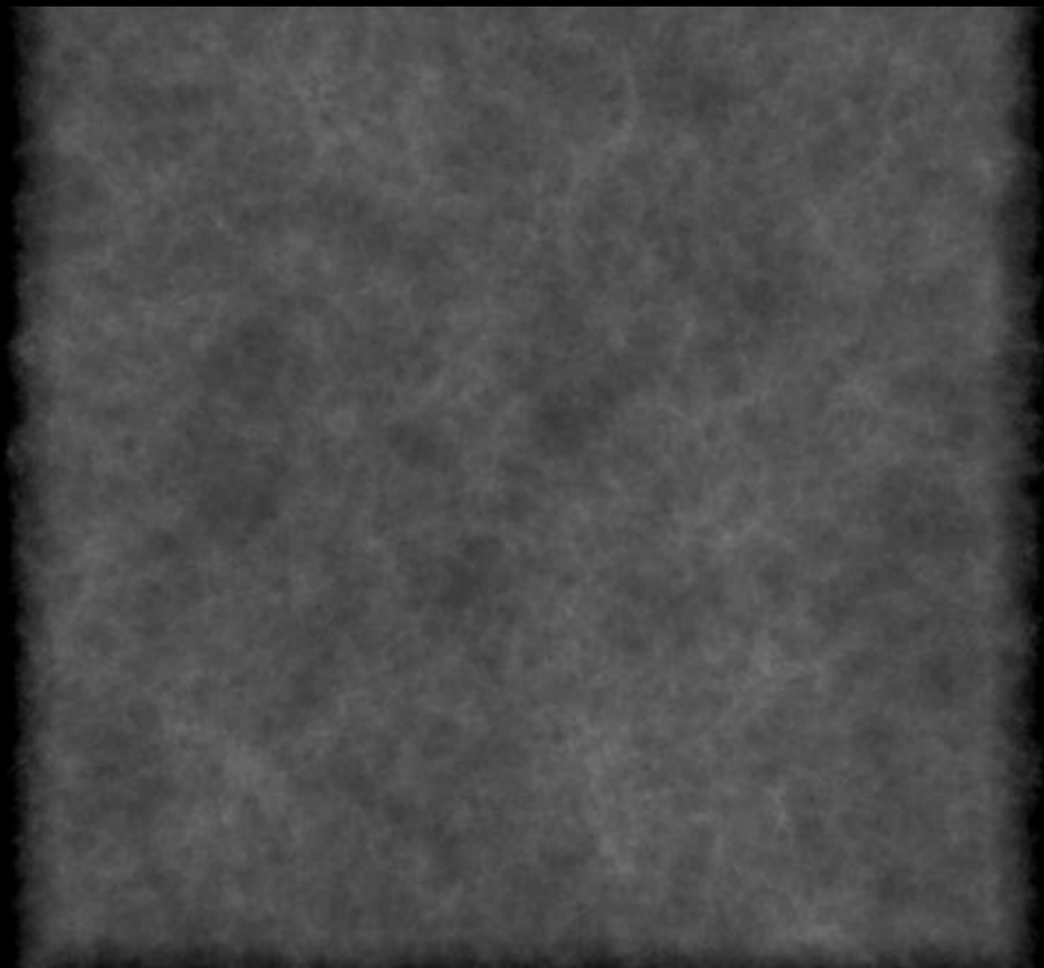
Why Measuring σ_8 is Hard

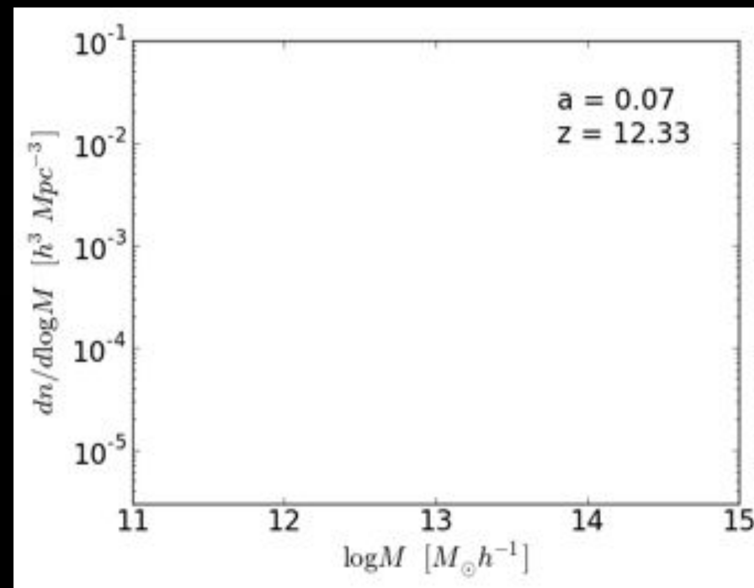
We're trying to tell the mass distribution looks like this…


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

Why Clusters Help

More structure = more massive halos





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

The Key Point

More massive clusters = more structure = higher σ_8

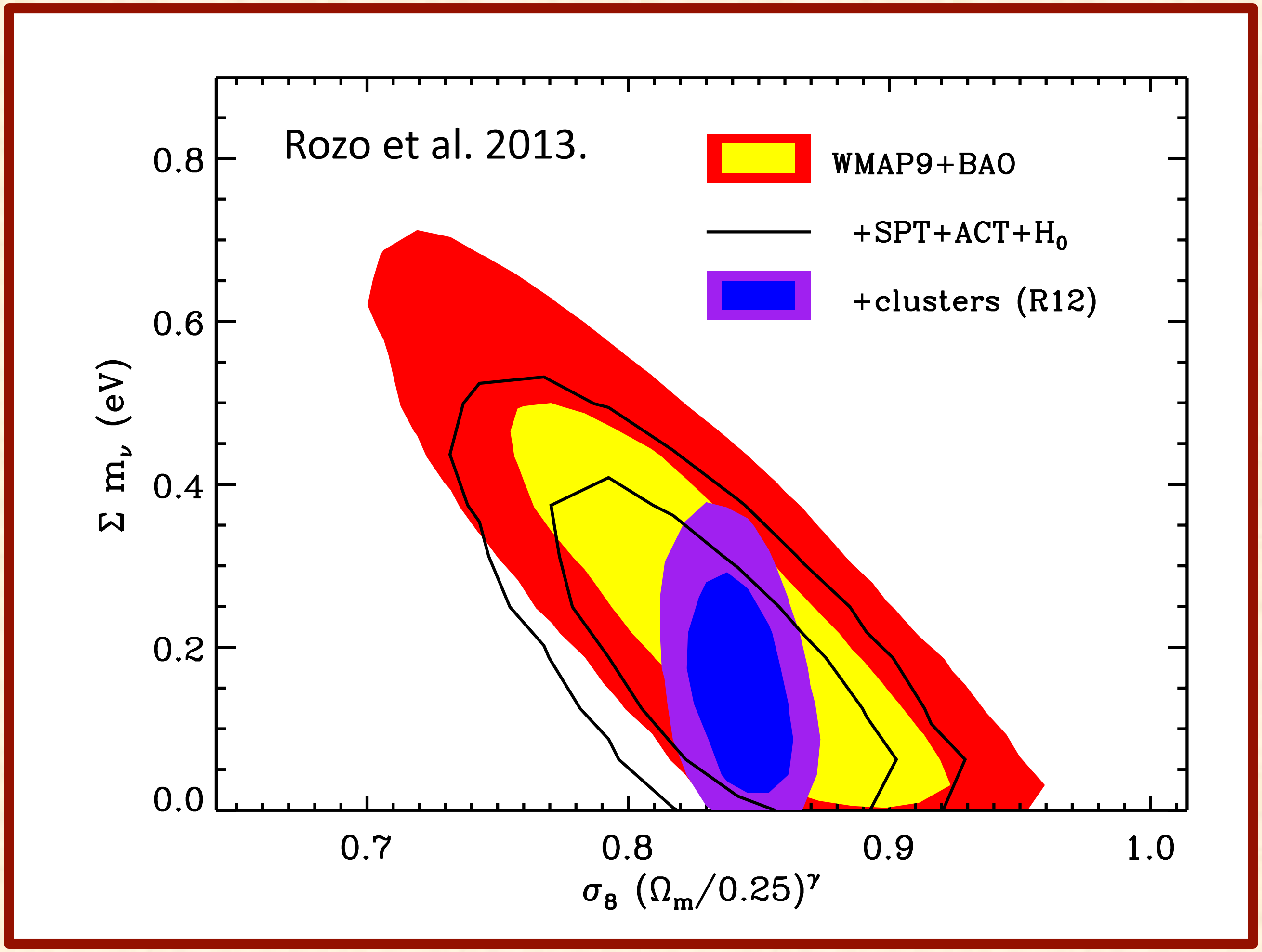
The abundance we observe is fixed;

The key moving part is the cluster mass.

Cluster mass goes up, σ_8 goes up.

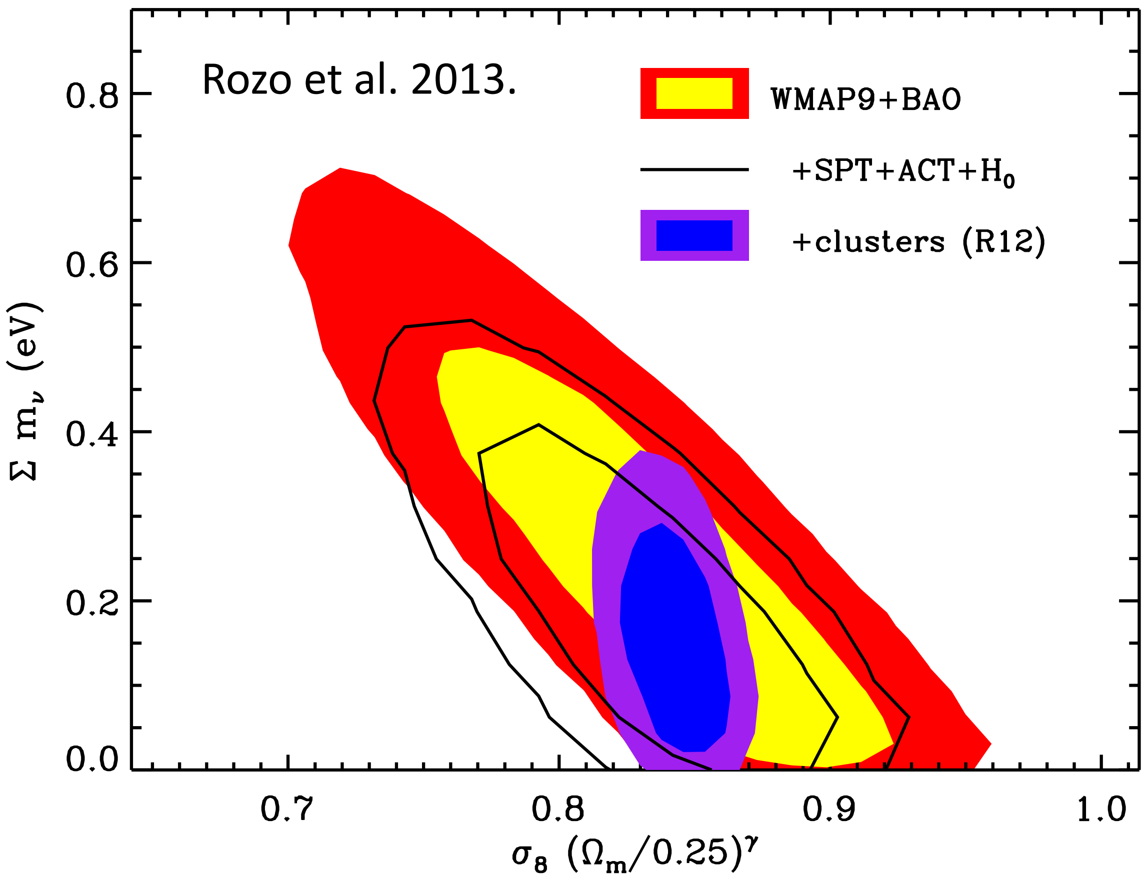
It's all about the masses!

Neutrinos and σ_8



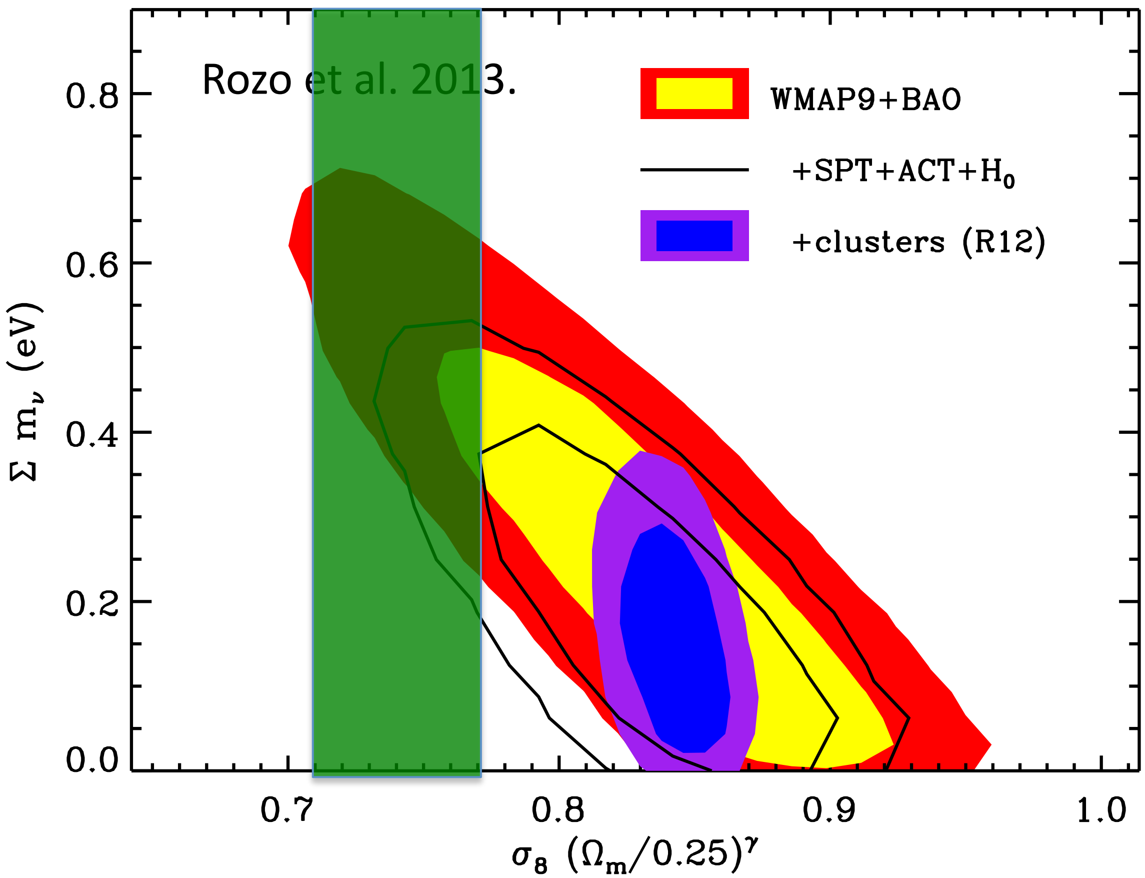
Given initial conditions from the CMB, massive neutrinos result in reduced structure

Neutrinos and Clusters



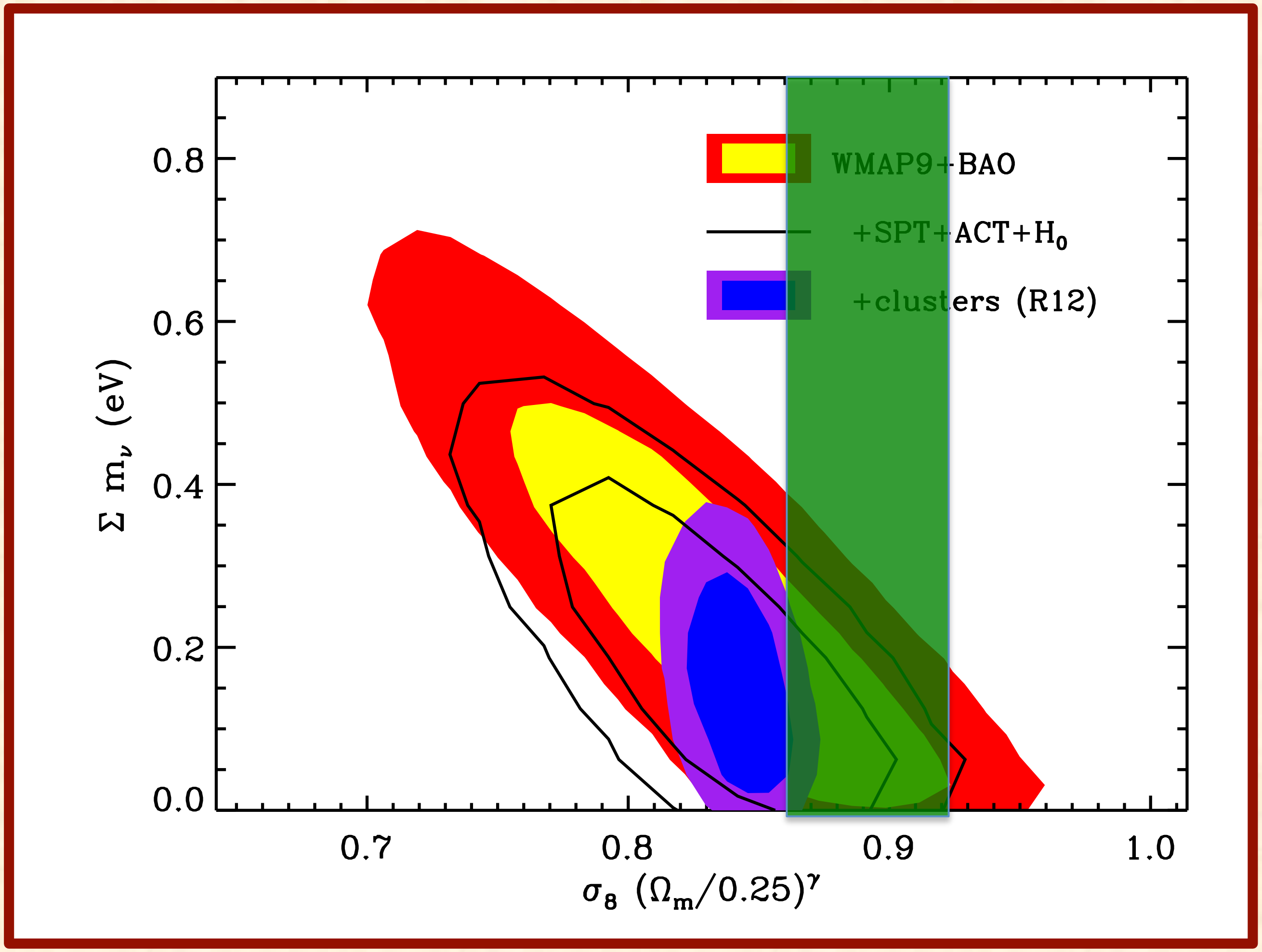
Clusters measure the x-axis - **but remember the key point!**

Neutrinos and Clusters



Low mass clusters.

Neutrinos and Clusters



High mass clusters.

Cluster Cosmology in 3 Easy Steps

1. Find all galaxy clusters.
   This part is comparatively "easy."

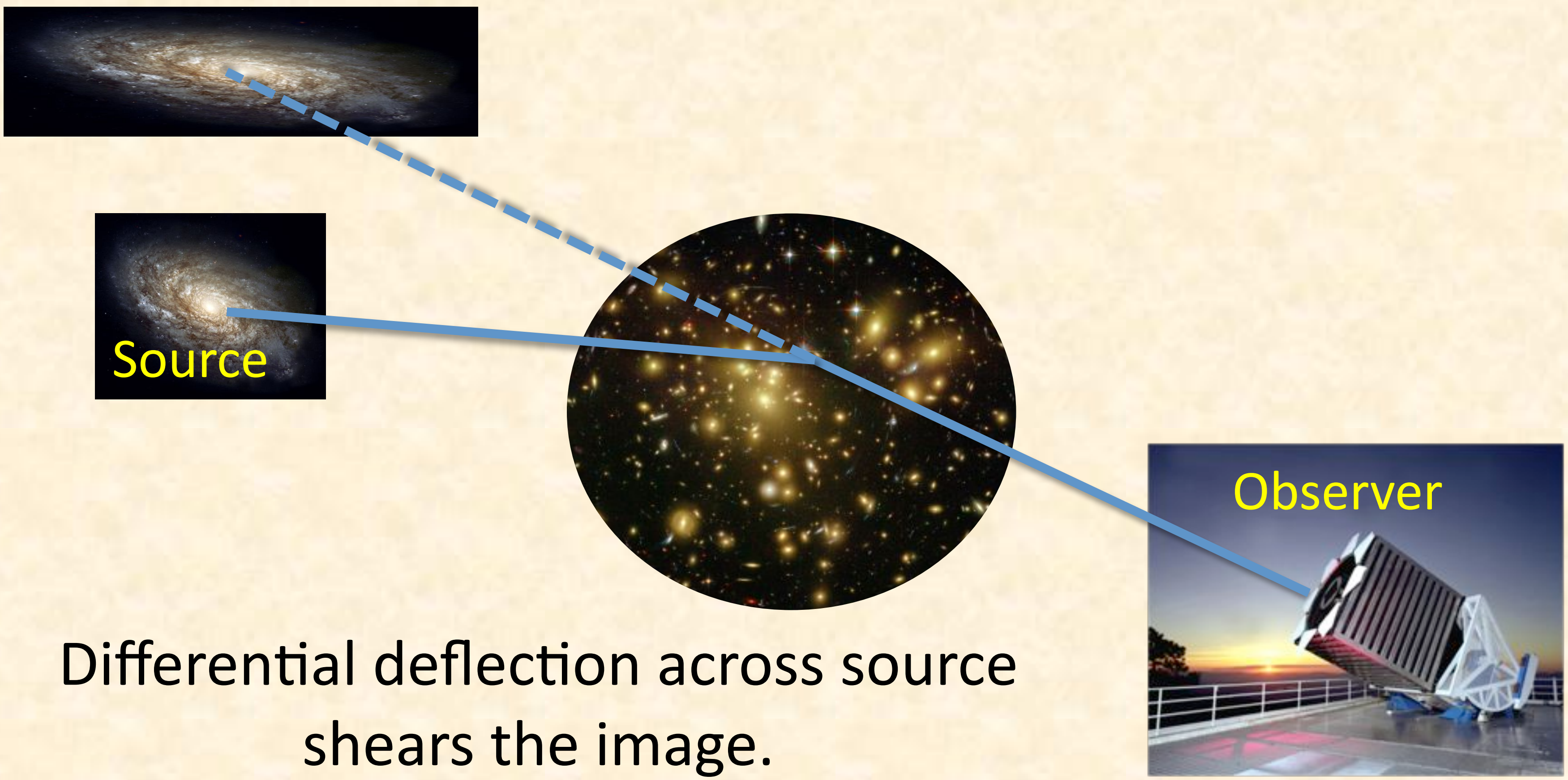
2. Measure cluster masses
   This part is hard.

Two Ways of Measuring Masses

- X-rays (this is what Planck used).
  - flux ~ ρ^2 : measure gas density
  - spectrum measures temperature.
  - **Assume hydrostatic equilibrium**, get masses.
- Weak gravitational lensing.

Weak Lensing

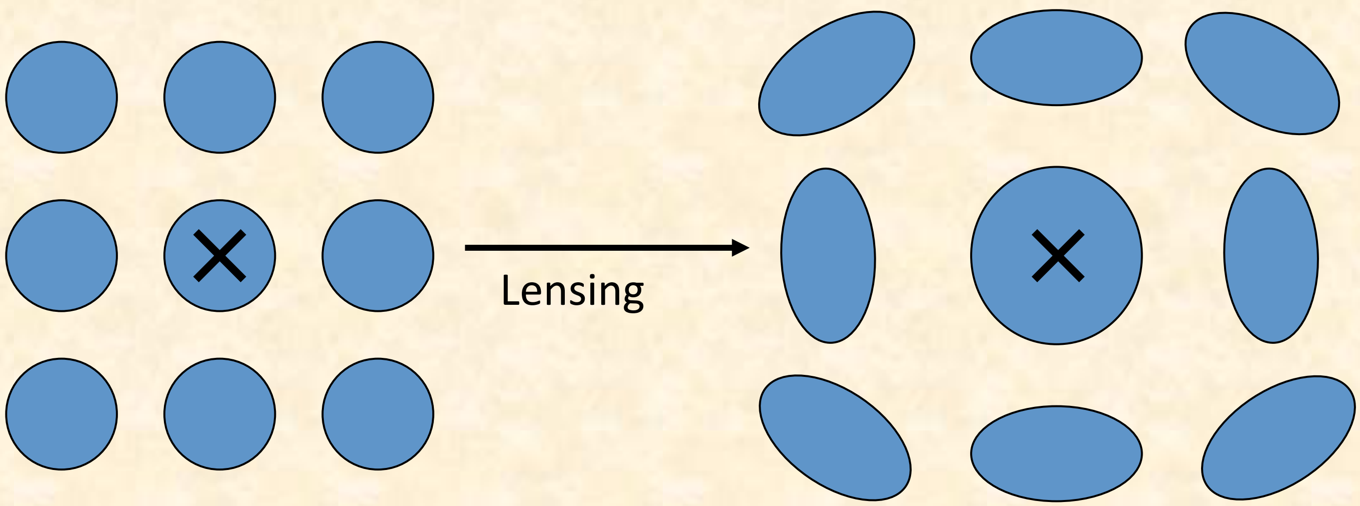
The gravity of a galaxy cluster bends the light of galaxies behind it.



Differential deflection across source shears the image.

Weak Lensing

We can detect *shear* statistically:

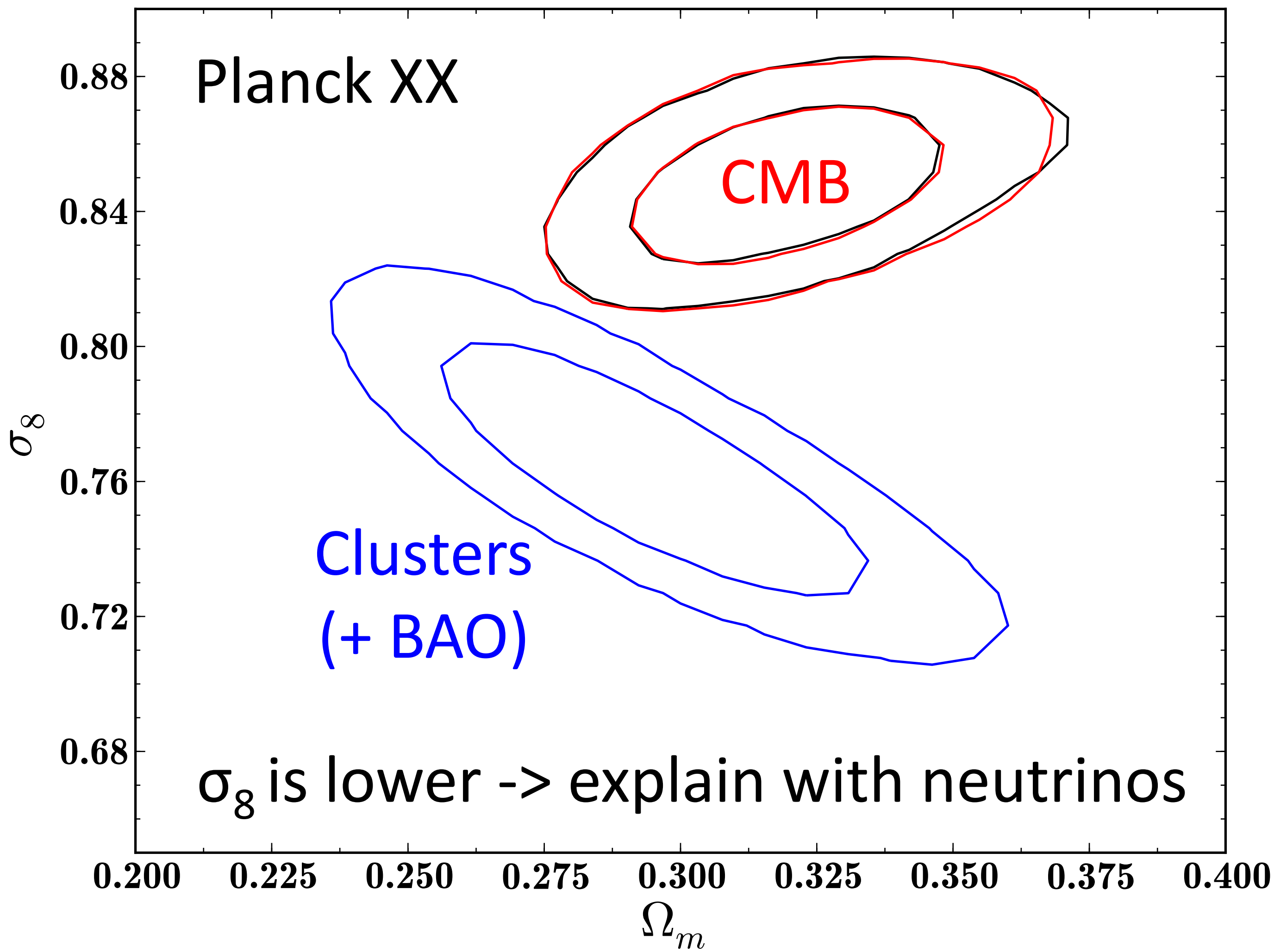


The mean tangential ellipticity of *background* galaxies around galaxy clusters depends on the cluster mass.

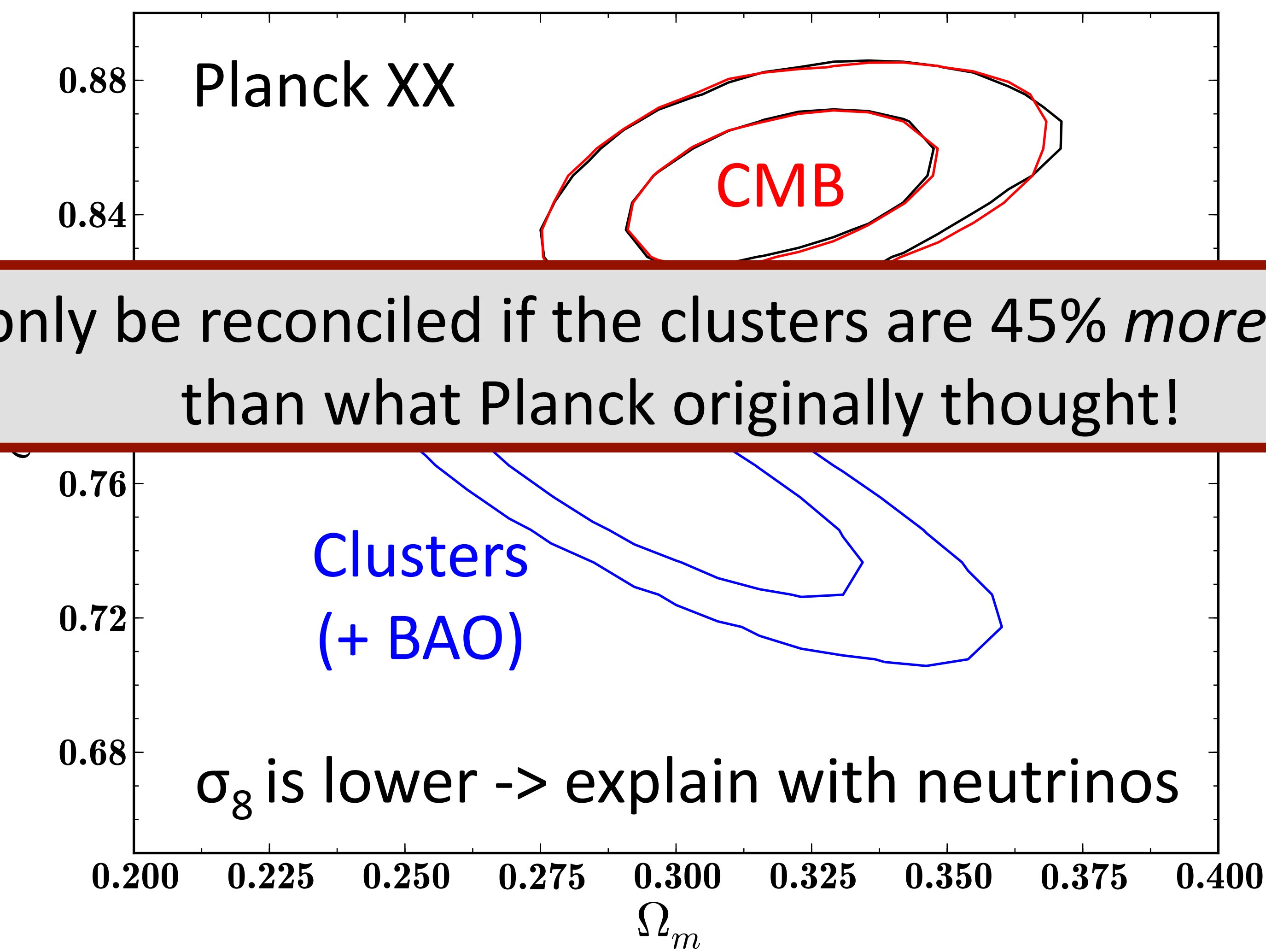
Cluster Cosmology in 3 Easy Steps

1. Find all galaxy clusters.
   This part is comparatively "easy."
2. Measure cluster masses.
   This part is *very* hard.
3. Infer σ_8 from cluster counts and learn about neutrinos!

Planck Results



Planck Results



Can only be reconciled if the clusters are 45% *more massive* than what Planck originally thought!

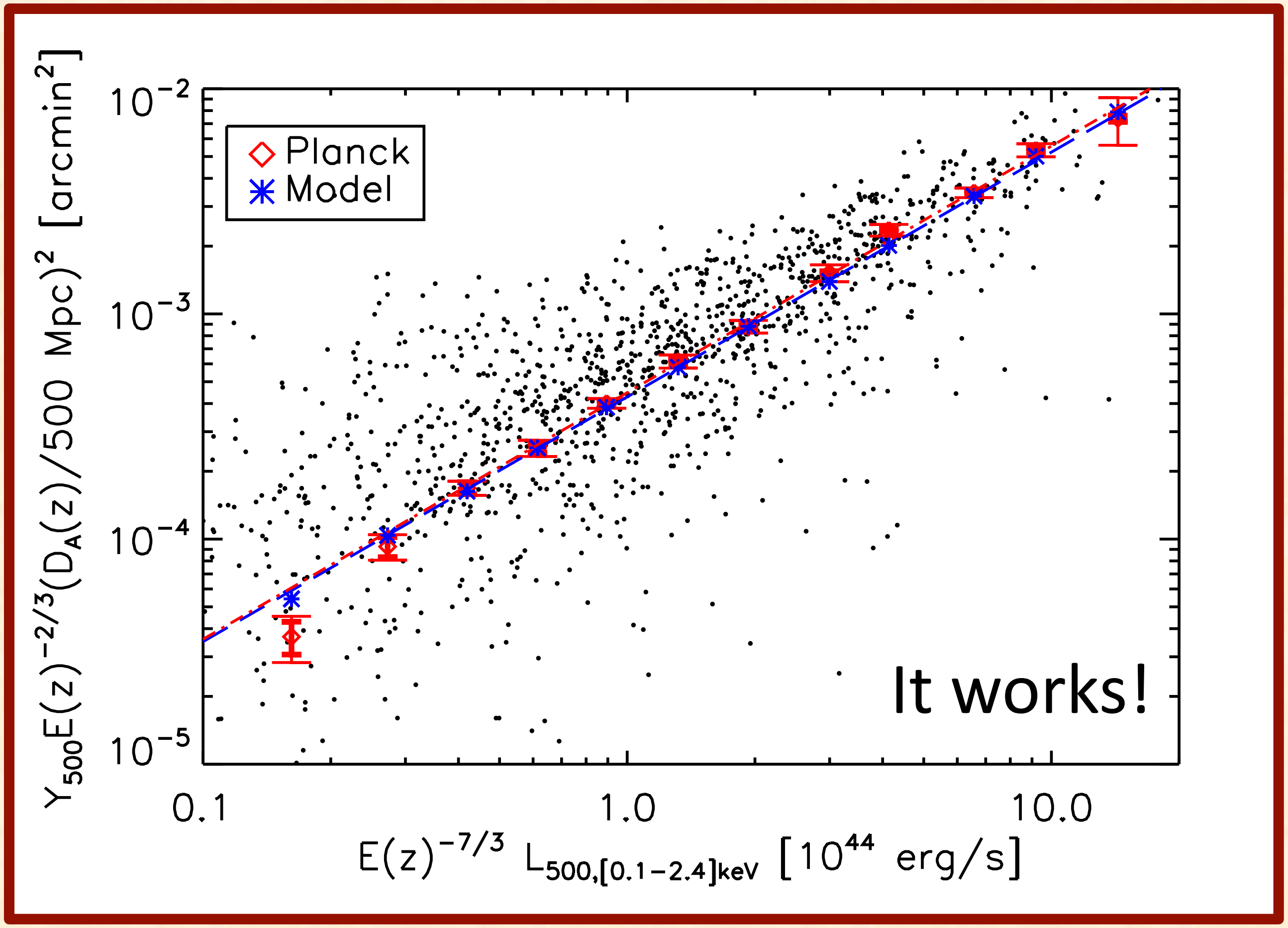
But are Planck cluster masses trustworthy?

A Brief History of Planck Masses

Is There Good Evidence in Favor of the Planck Masses?

Evidence *for* Planck Masses

Measure L_X-M relation
Measure Y_{SZ}-M relation → Predict Y_{SZ}-L_X relation



Evidence *for* Planck Masses

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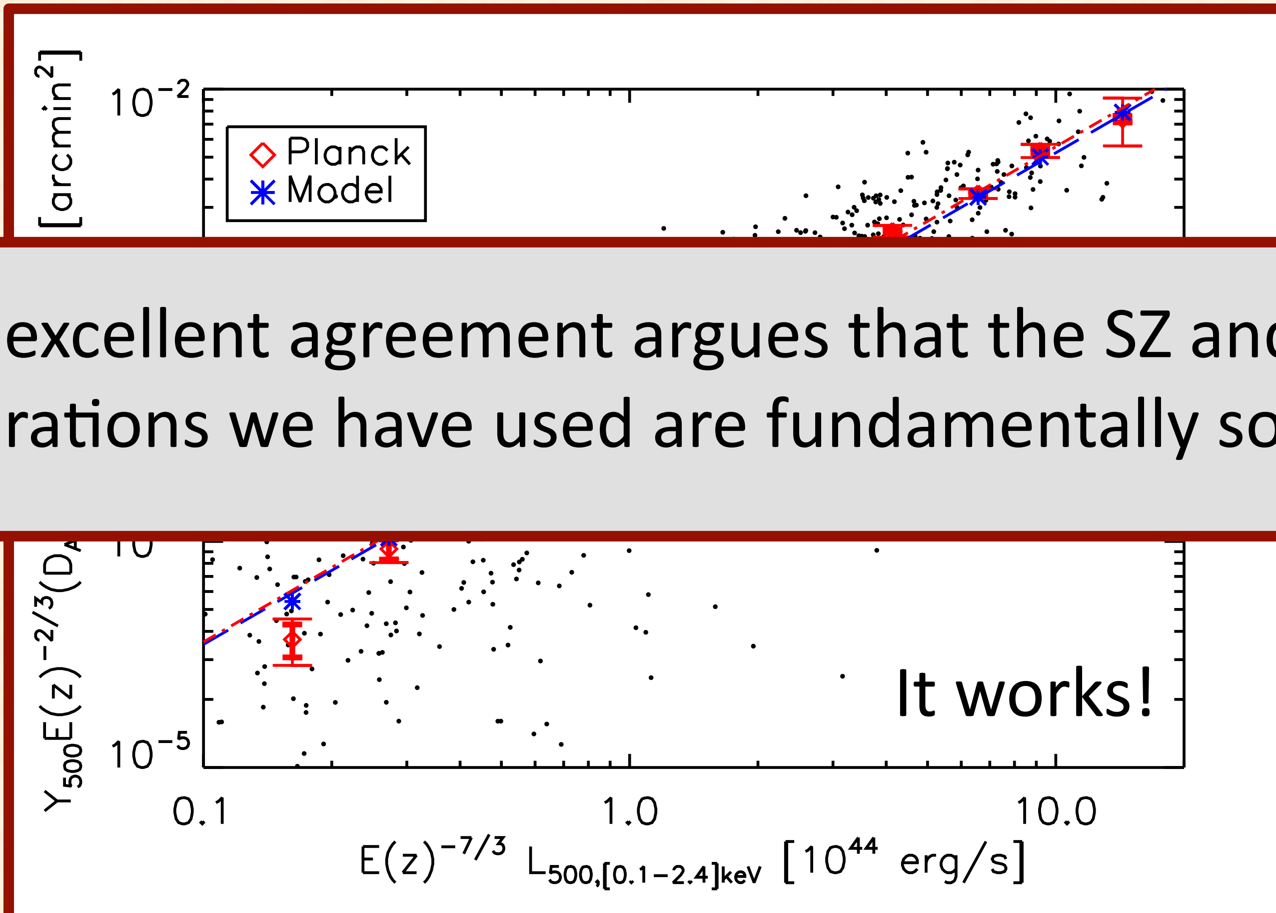
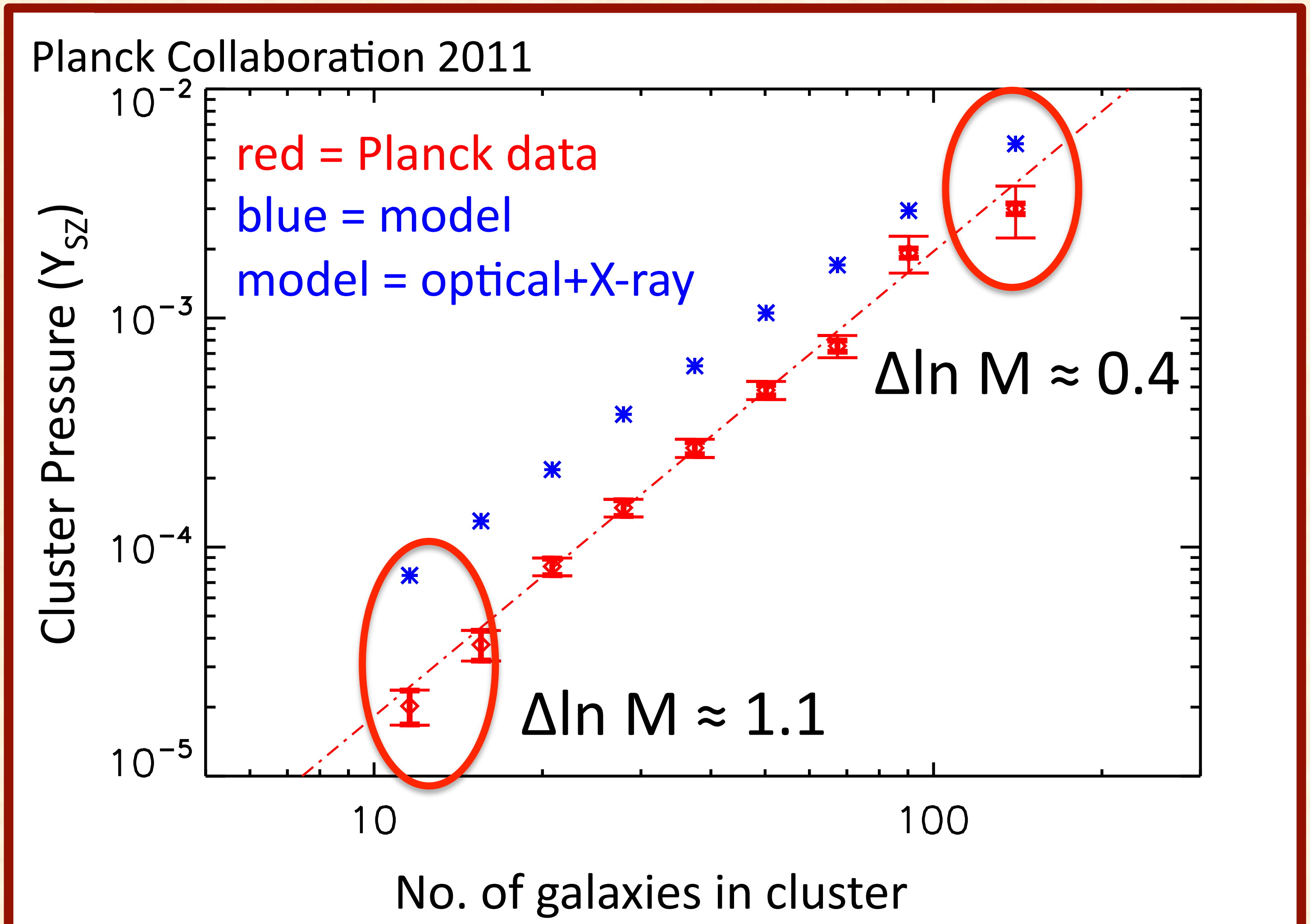


"The excellent agreement argues that the SZ and X-ray calibrations we have used are fundamentally sound."

But-

A Puzzle: Optical Doesn't Fit!



Optical requires X-ray masses to be biased low by 40%.

How to Reconcile?

Possibilities:

- Optical masses/predictions could be wrong.
- X-ray masses/predictions could be wrong.

Answer: both! (Rozo et al. 2012 a,b,c,d).

Where Do Planck Masses Come From?

Calibration of Y_{SZ}-M in 3 steps:

1- Calibrate Y_X-M using **hydrostatic masses.**

2- Calibrate Y_{SZ}-Y_X (ask me after)

3- Combine to get Y_{SZ}-M (ask me after)

There is evidence of problems in all 3 steps!

X-Ray Masses

2 key systematics:

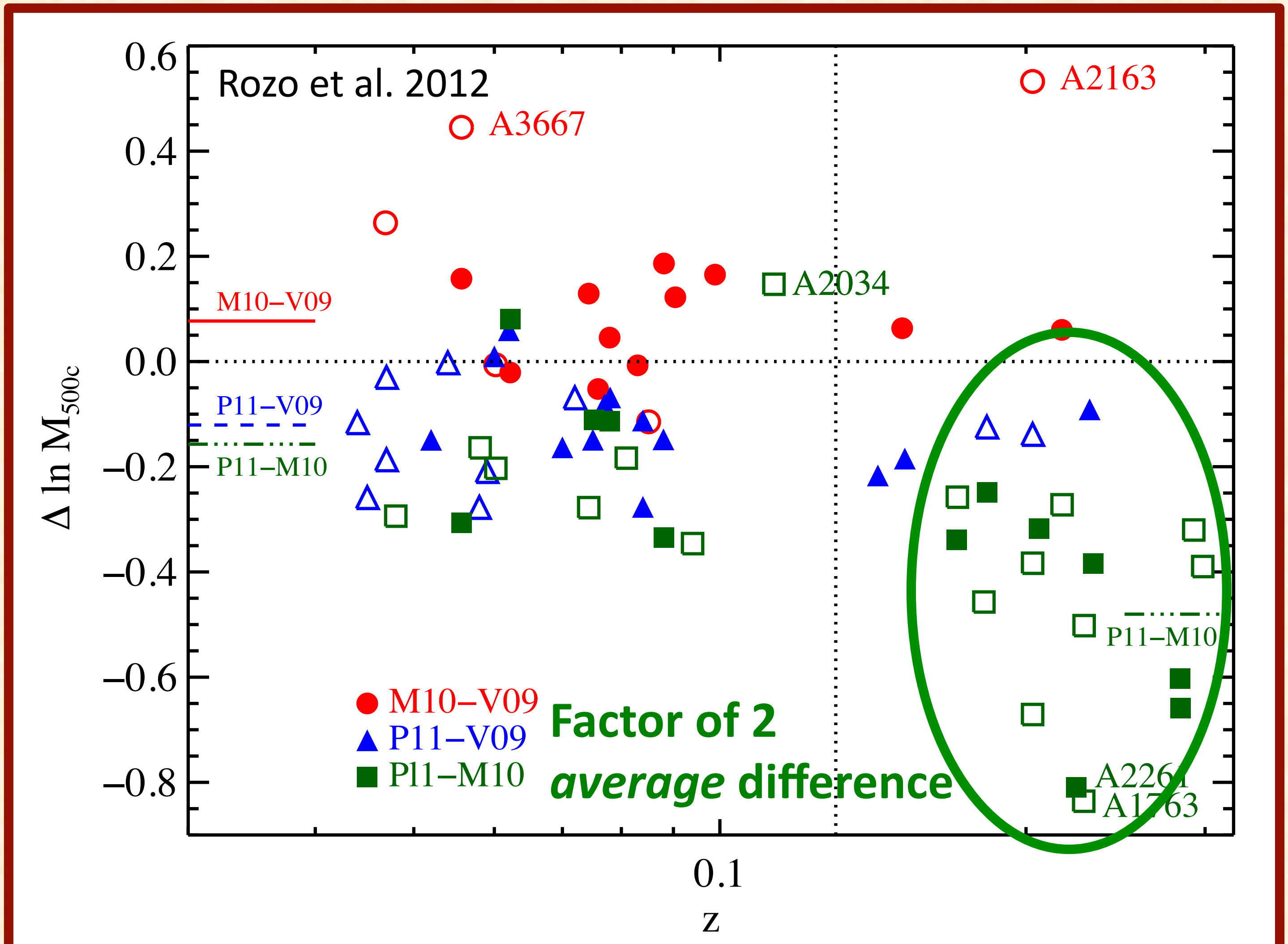
- hydrostatic bias
- measurement systematics (e.g. detector calibration)

Hydrostatic bias:

- Simulation values are range from 10%-30%.
- Cosmology analysis assumes 20% ± 0% (!)
- Inconsistent with treatment in Planck 2011.

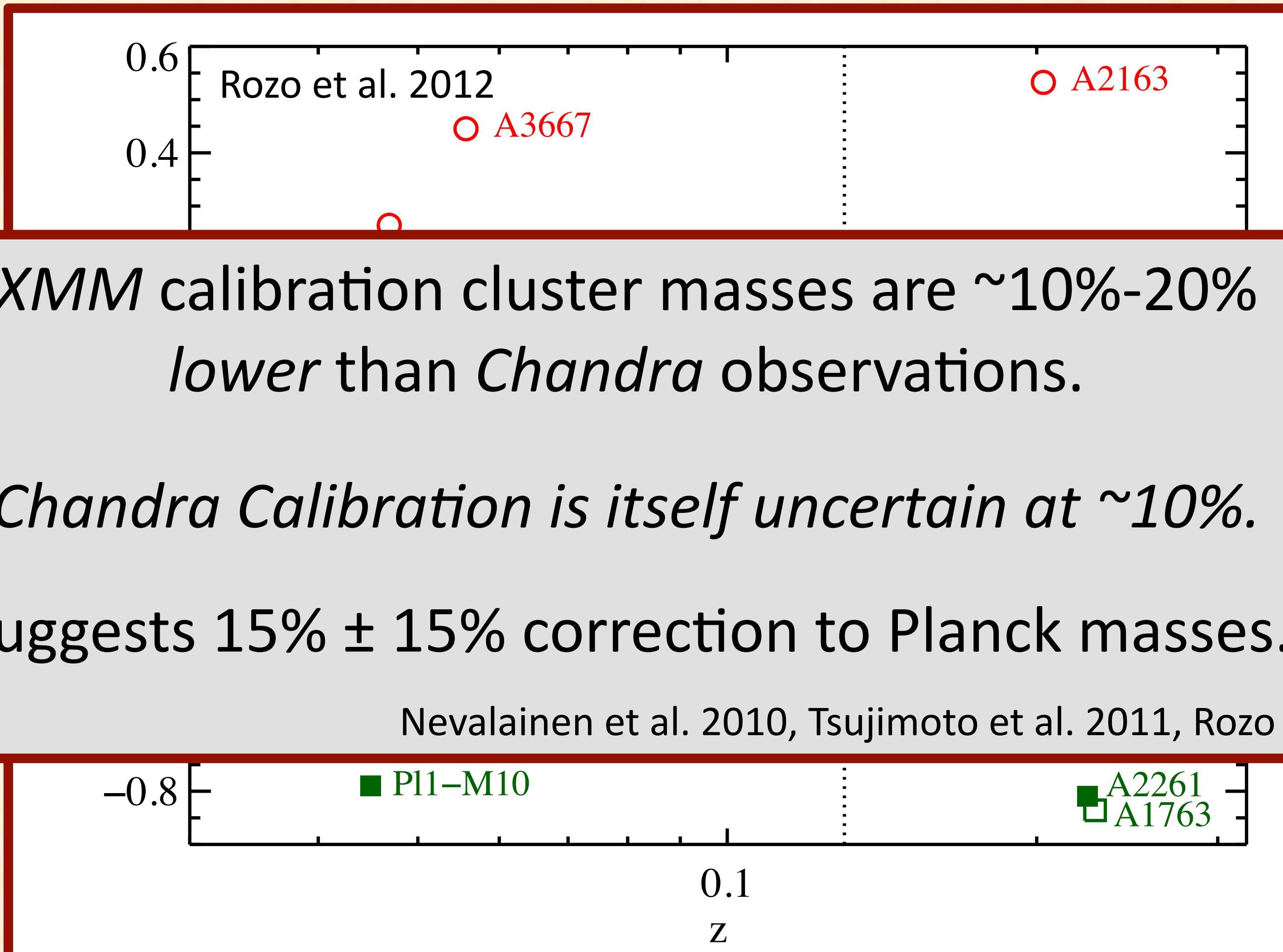
Bottom line: need ~20% ± 10% correction

Comparing X-rays to X-rays



10%-15% systematic differences seen in T_X, Y_X.

Comparing X-rays to X-rays



XMM calibration cluster masses are ~10%-20% *lower* than *Chandra* observations.

Chandra Calibration is itself uncertain at ~10%.

Suggests 15% ± 15% correction to Planck masses.

Nevalainen et al. 2010, Tsujimoto et al. 2011, Rozo et al. 2012

10%-15% systematic differences seen in T_X, Y_X.

Optical Masses

- Raw measurements seem very robust:
  - 3 independent shear measurements
  - 1 quasar magnification
  - 1 galaxy magnification measurement
  - 1 CMB lensing measurement

  These are *all* consistent with each other.

- Interpretation is subtle!
  - Mass and optical richness are *correlated.*
  - Introduces a ~10% bias.

Johnston et al. 2007, Mandelbaum et al. 2008, Simet et al. 2012, Bauer et al. 2012, Coupon et al. 2013, Planck XVII

Angulo et al. 2012, Noh et al. 2012, Rozo et al. 2012, Dietrich et al. in preparation.

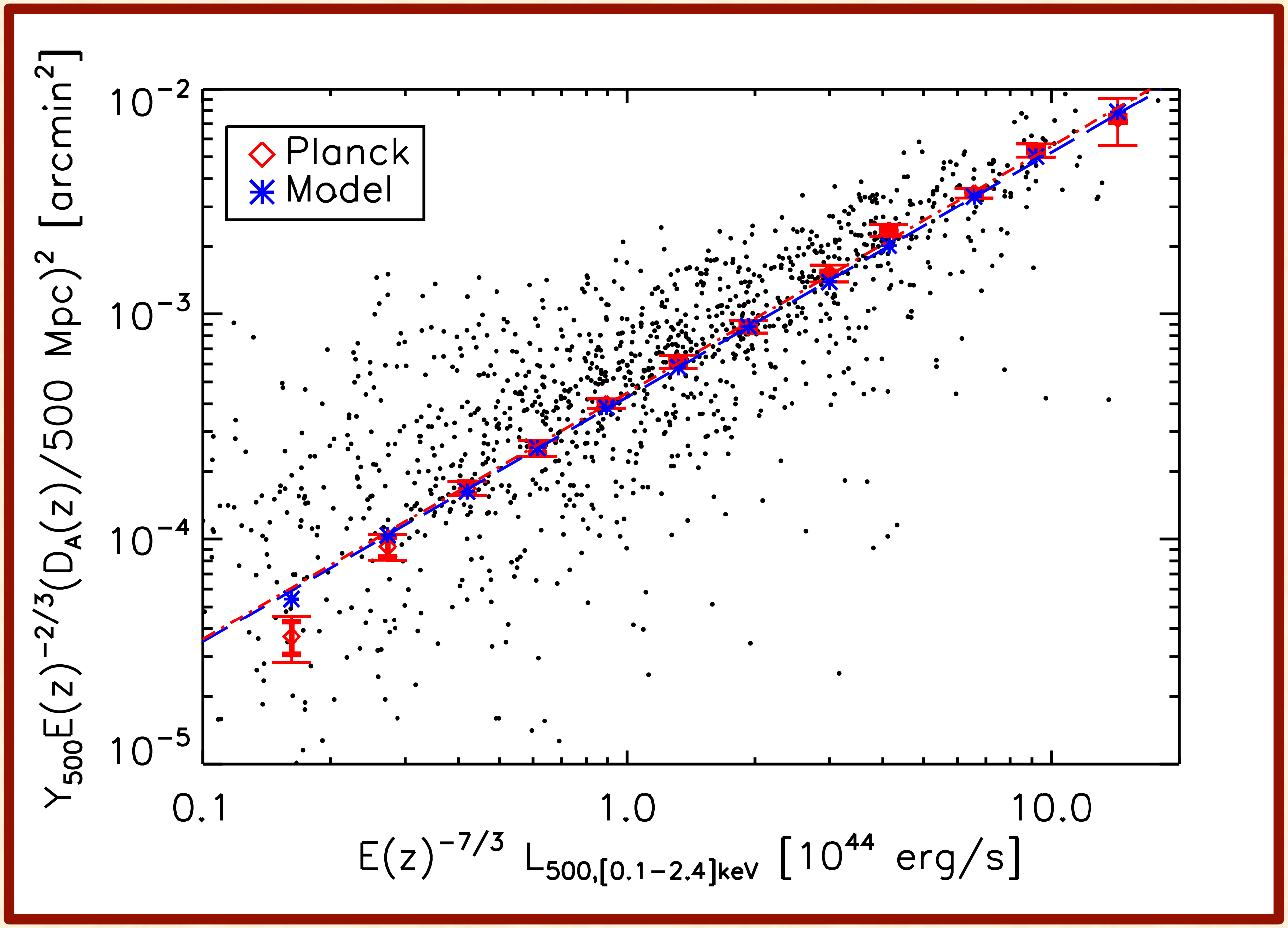
Net Result

Planck mass calibration should be increased by 35%±20%.

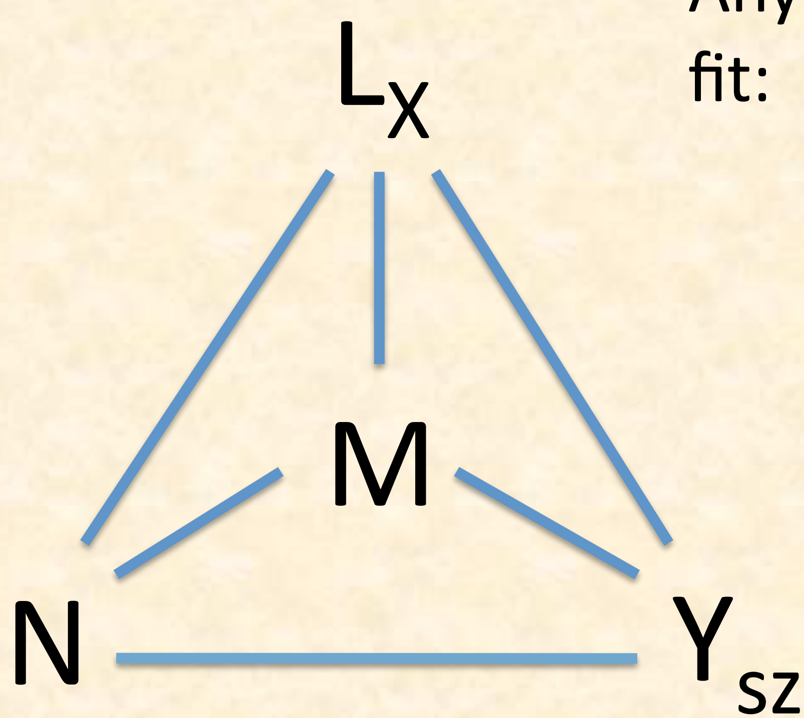
Optical calibration should be reduced by 10%±10%.

These 2 effects reconcile optical+X-ray+SZ data!

But What About This?



Important Point: Solution Must be Consistent with ***All*** Data.



Any solution must simultaneously fit:

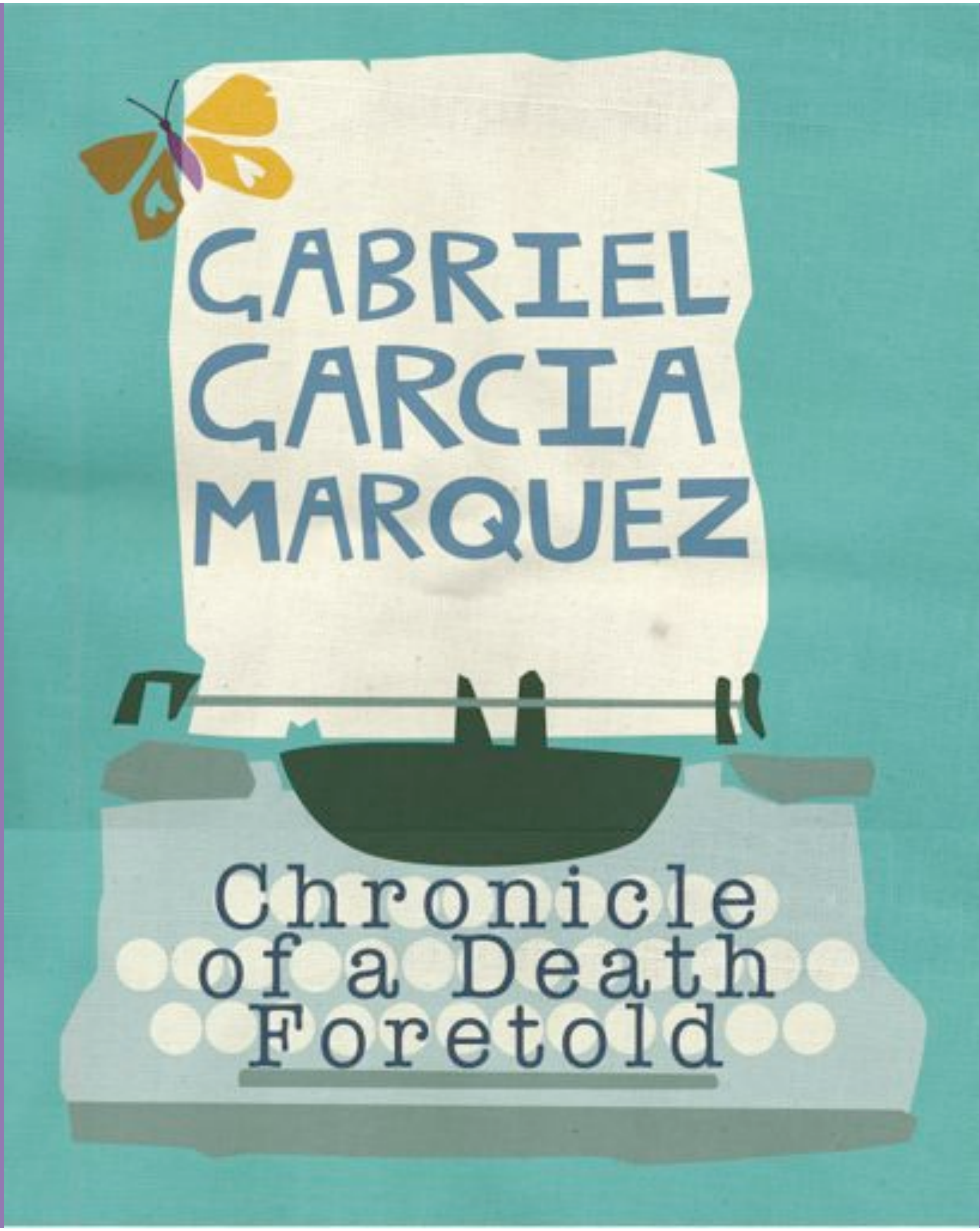
- ✔ • Abundance data (Optical *and* X-ray)
- ✔ • WL data
- ✔ • L_X data
- ✔ • Y_{SZ} data (Integrated pressure)

In R12, we show **our scaling relations fit all available data.**

Bottom Line

This is *strong evidence* that Planck masses are biased.

In fact- we predicted the tension between Planck and CMB primaries! (Rozo et al. 2013).


GABRIEL
GARCIA
MARQUEZ
Chronicle
of a Death
Foretold

Are Our Masses Consistent with Planck?

We don’t have the Planck selection functions.

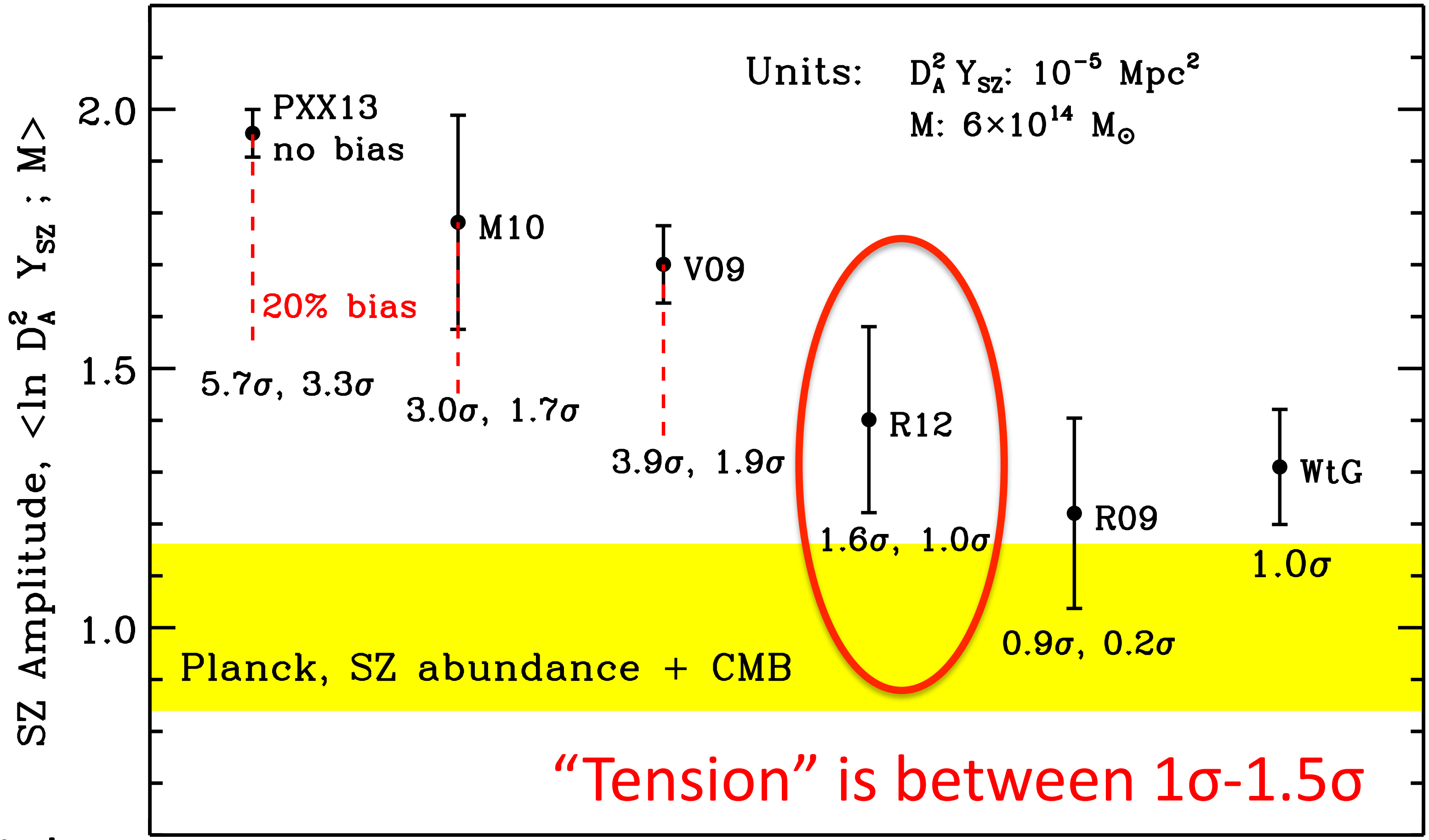
But-

We can assume Planck cosmology, and infer cluster masses from abundance.

How do these CMB-inferred masses compare to our?

Mass Comparison

Low masses



High masses

68% Error Bars

Lessons and Conclusions

1. There is significant constraining power in multi-wavelength observations of galaxy cluster.
2. Planck (+BAO) clearly favors a *high* – but plausible - cluster mass calibration.

At this time, there is **no tension** between clusters and CMB for a flat LCDM cosmology.

i.e. **no evidence for massive neutrinos.**

But?

There are other lines of evidence that prefer a lower matter density and/or $\sigma_{8,}$ e.g.:

- Cosmic shear from CFHTLens
- Growth measurements from RSD
- gg lensing+clustering.

How solid are these lines of evidence?

I don't know.


One more thing...

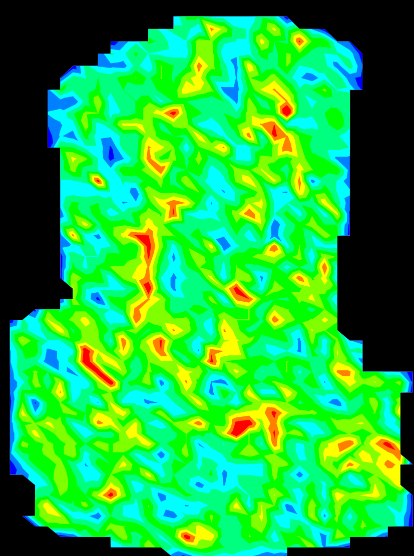
Cluster Cosmology in 3 Easy Steps

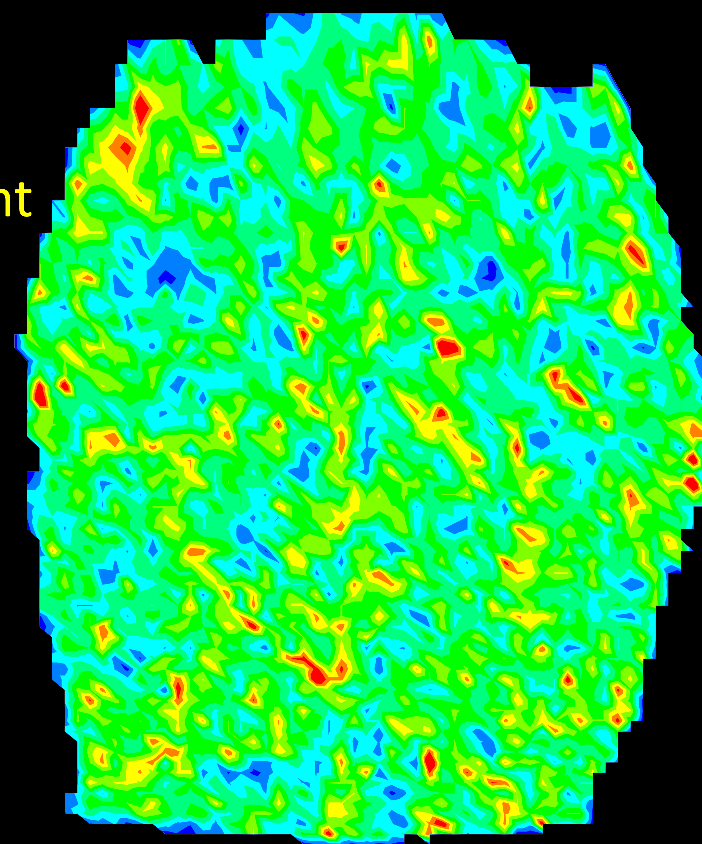
1. Find all galaxy clusters.

   This part is comparatively "easy."

redMaPPer

SDSS DR8 redMaPPer footprint





Rykoff, Rozo, et al. 2013, Rozo & Rykoff 2013.

What is redMaPPer?

redmapper is a photometric cluster finding algorithm.

The key outputs of a cluster finder:

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

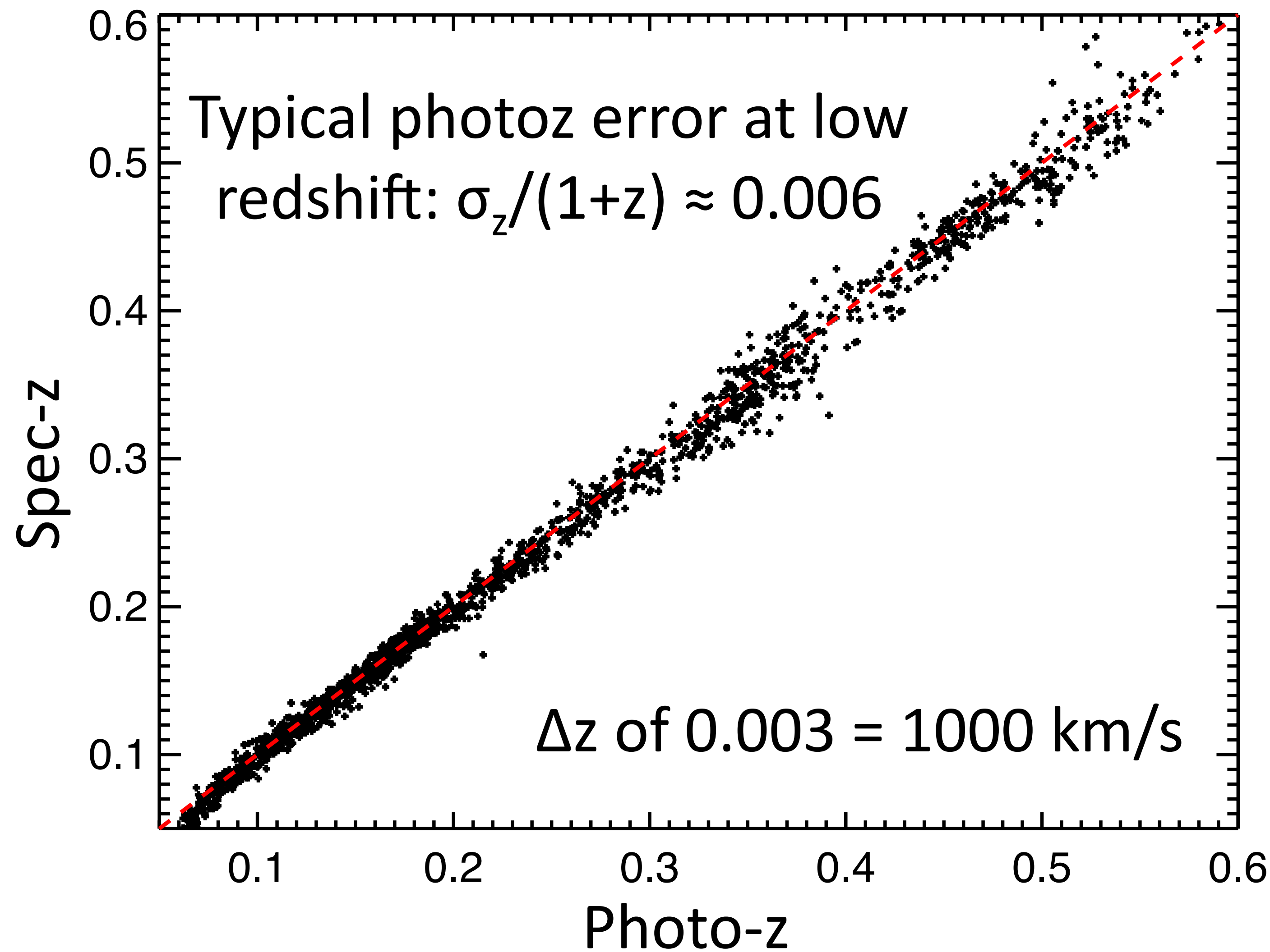
  (Relating between size and mass is calibrated with WL)

So how does redmapper do at these things?

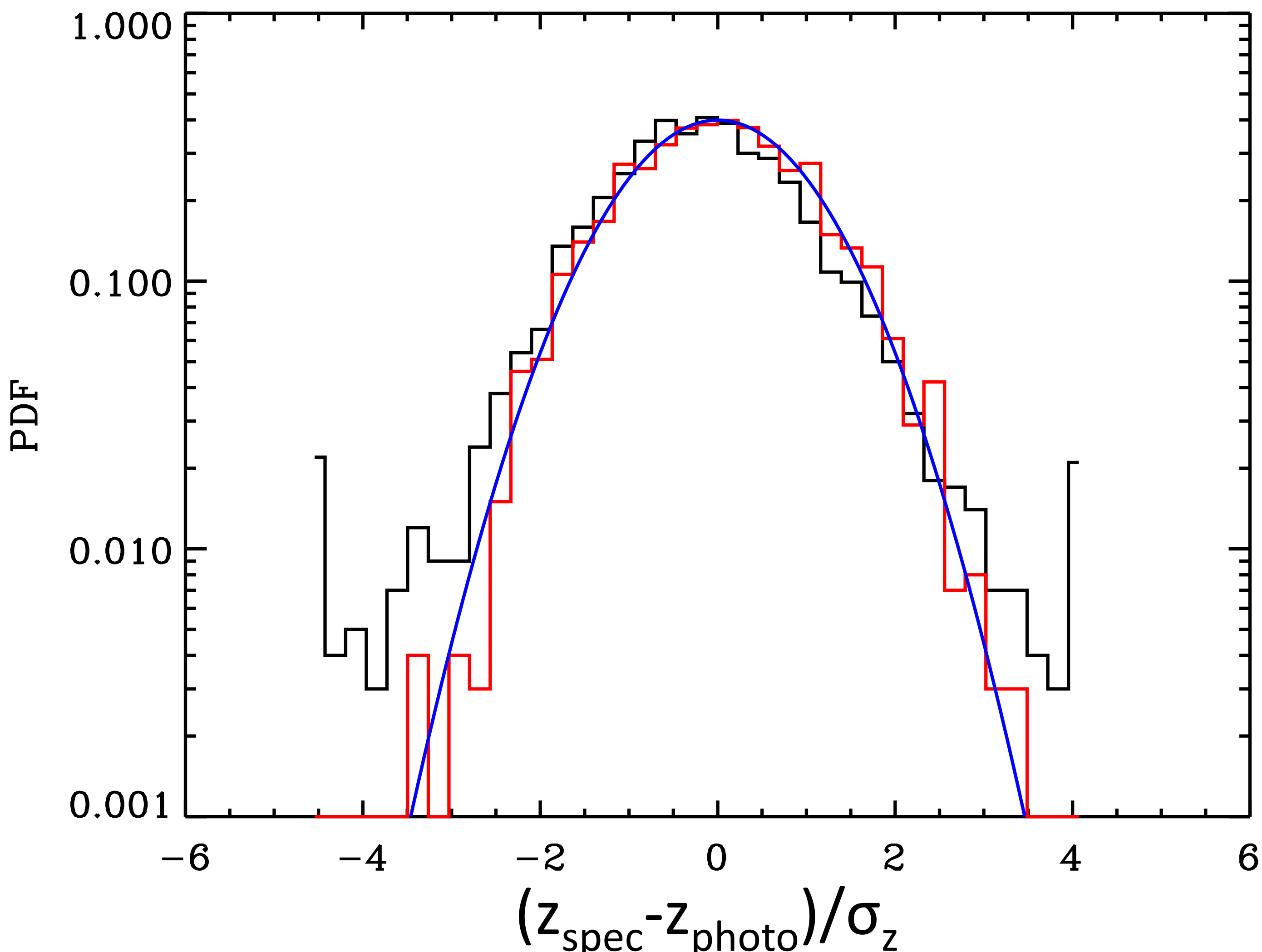

AWESOME

Performance Tests in DR8

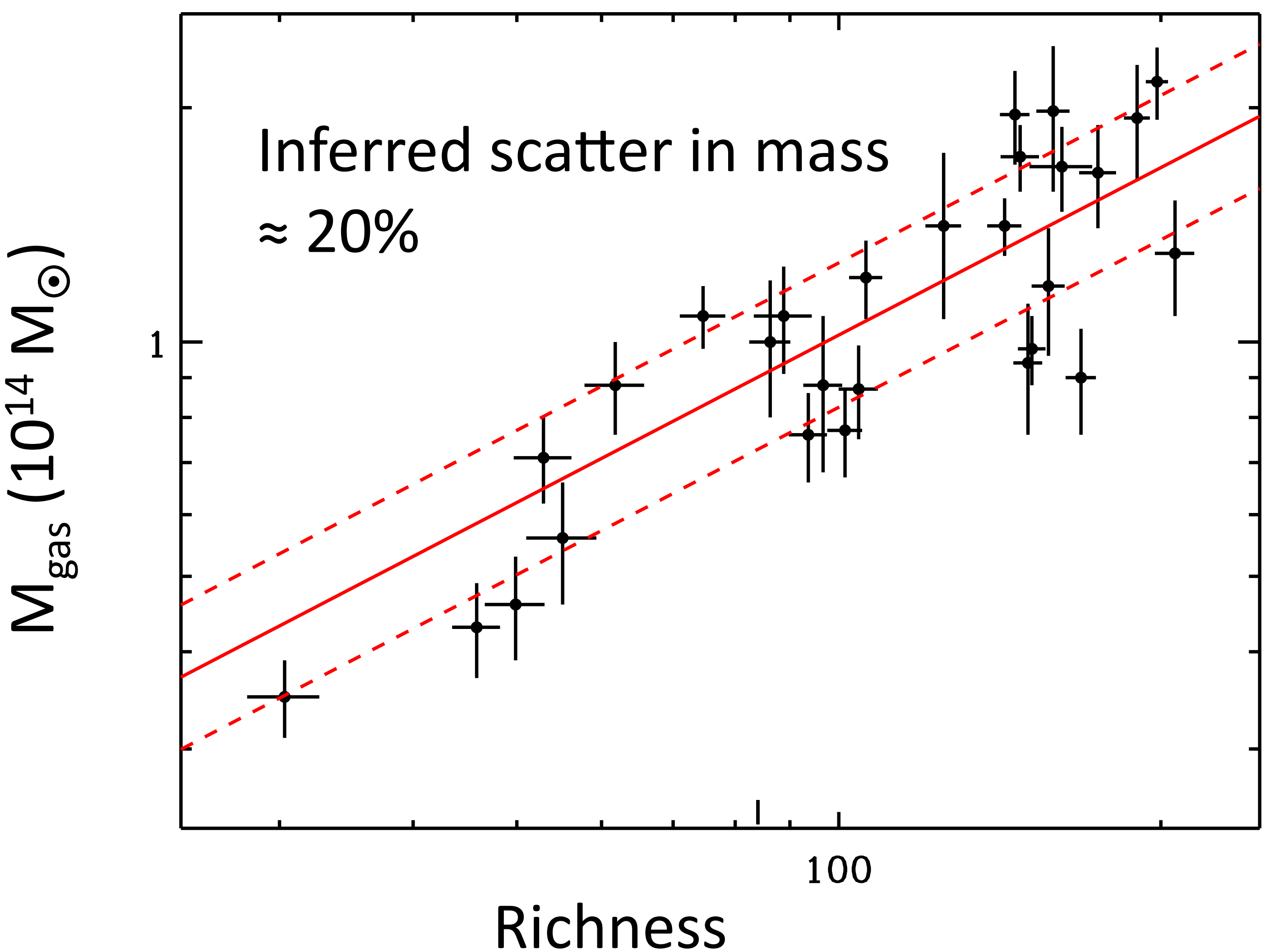
Excellent Photozs



Well Understood Photozs



Low Scatter Mass Proxy



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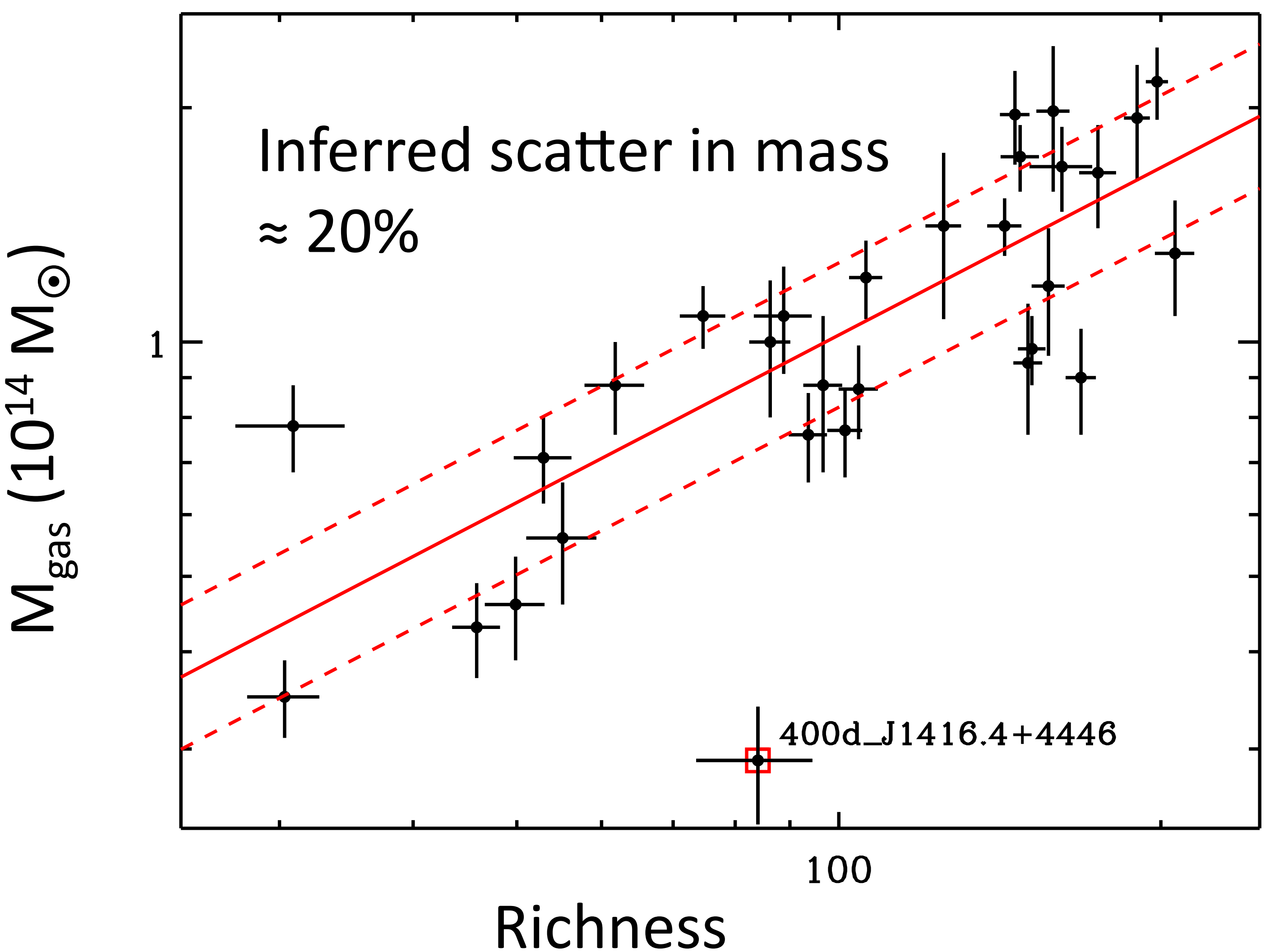

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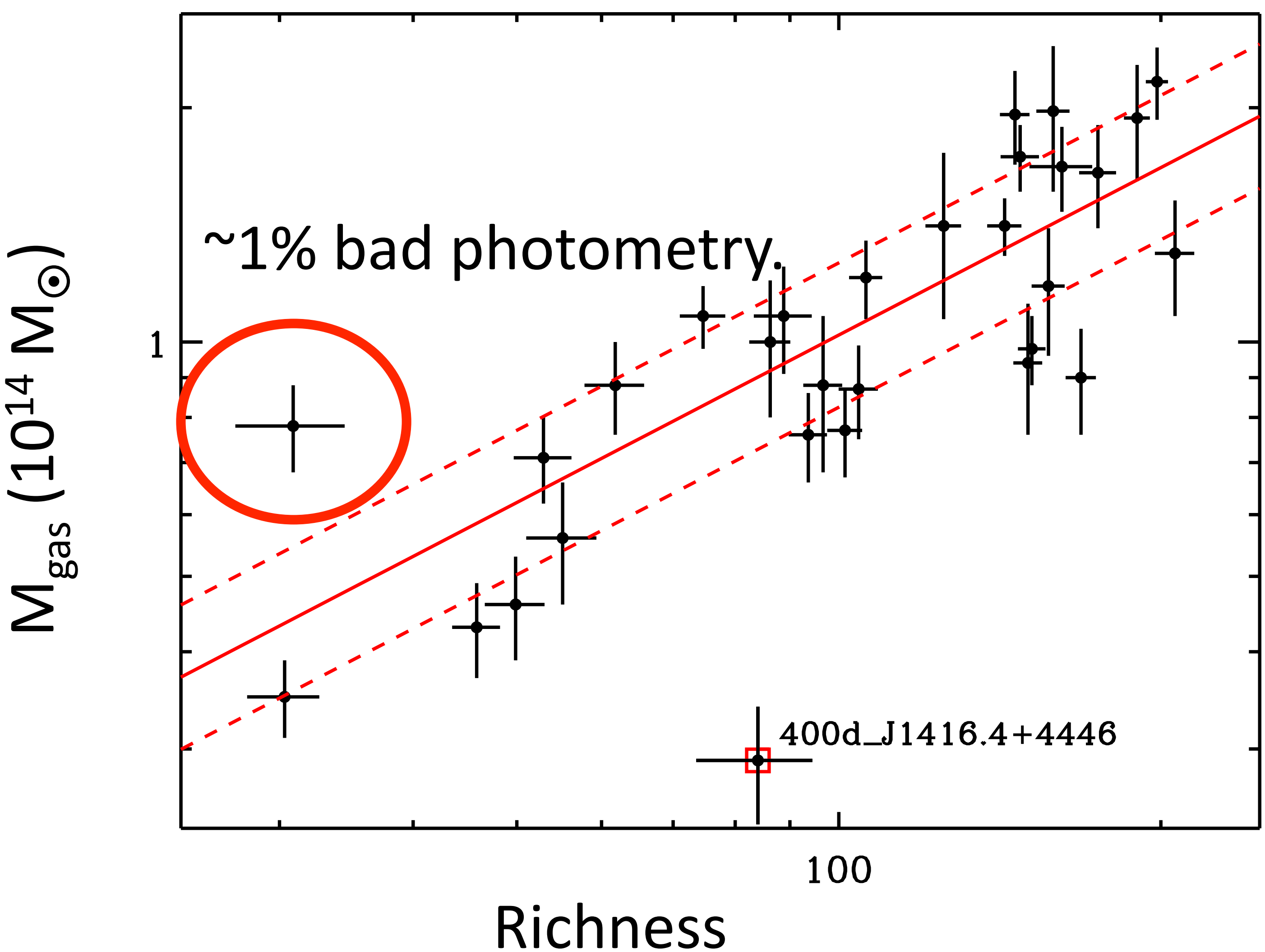

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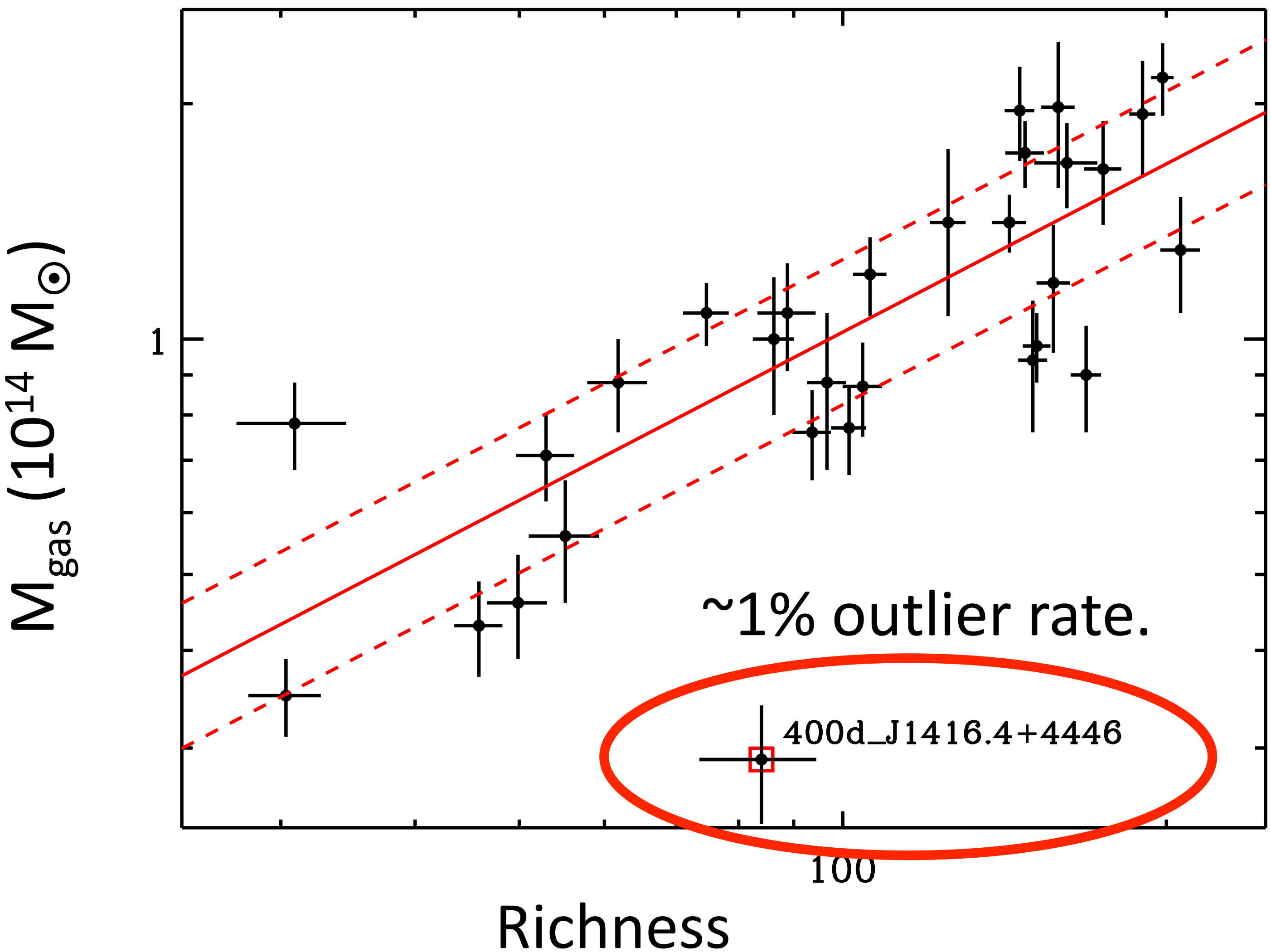
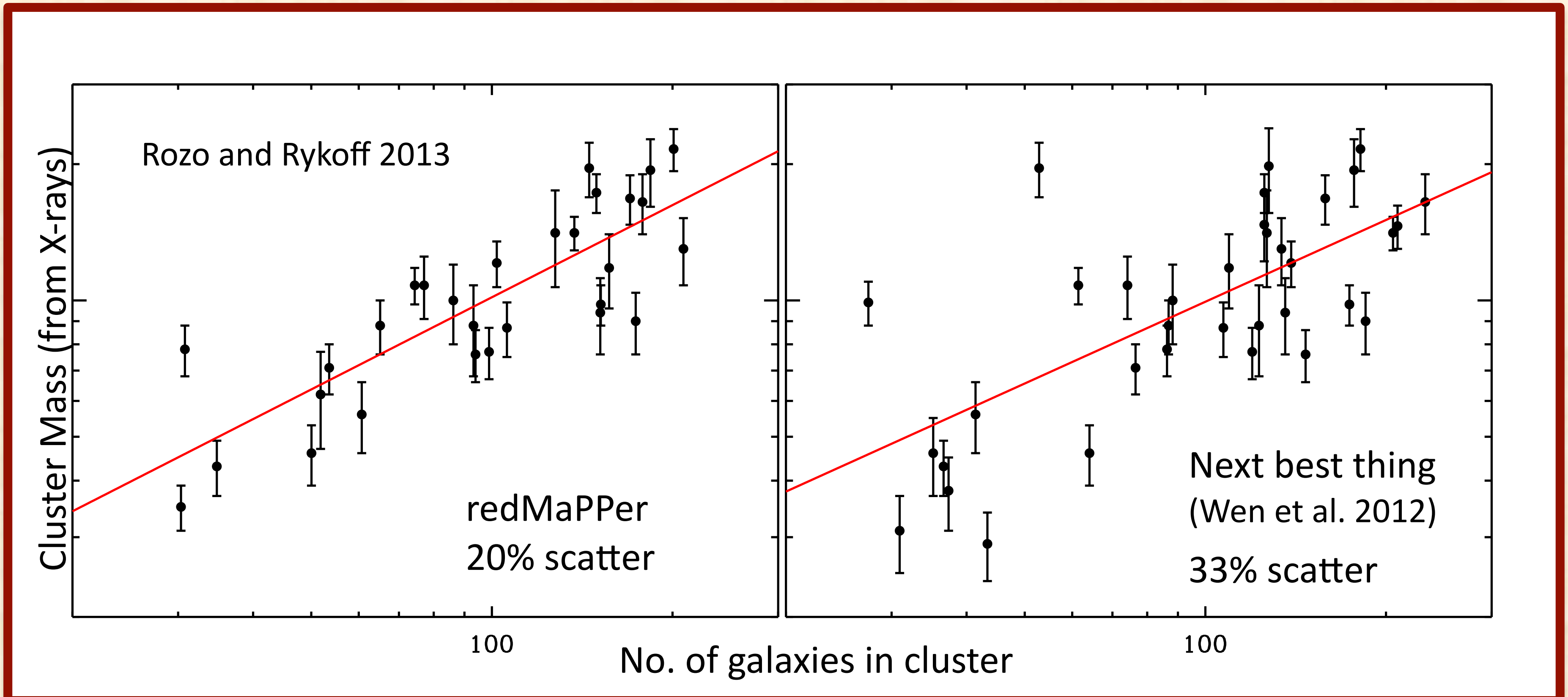


Low Scatter is Unique to redMaPPer



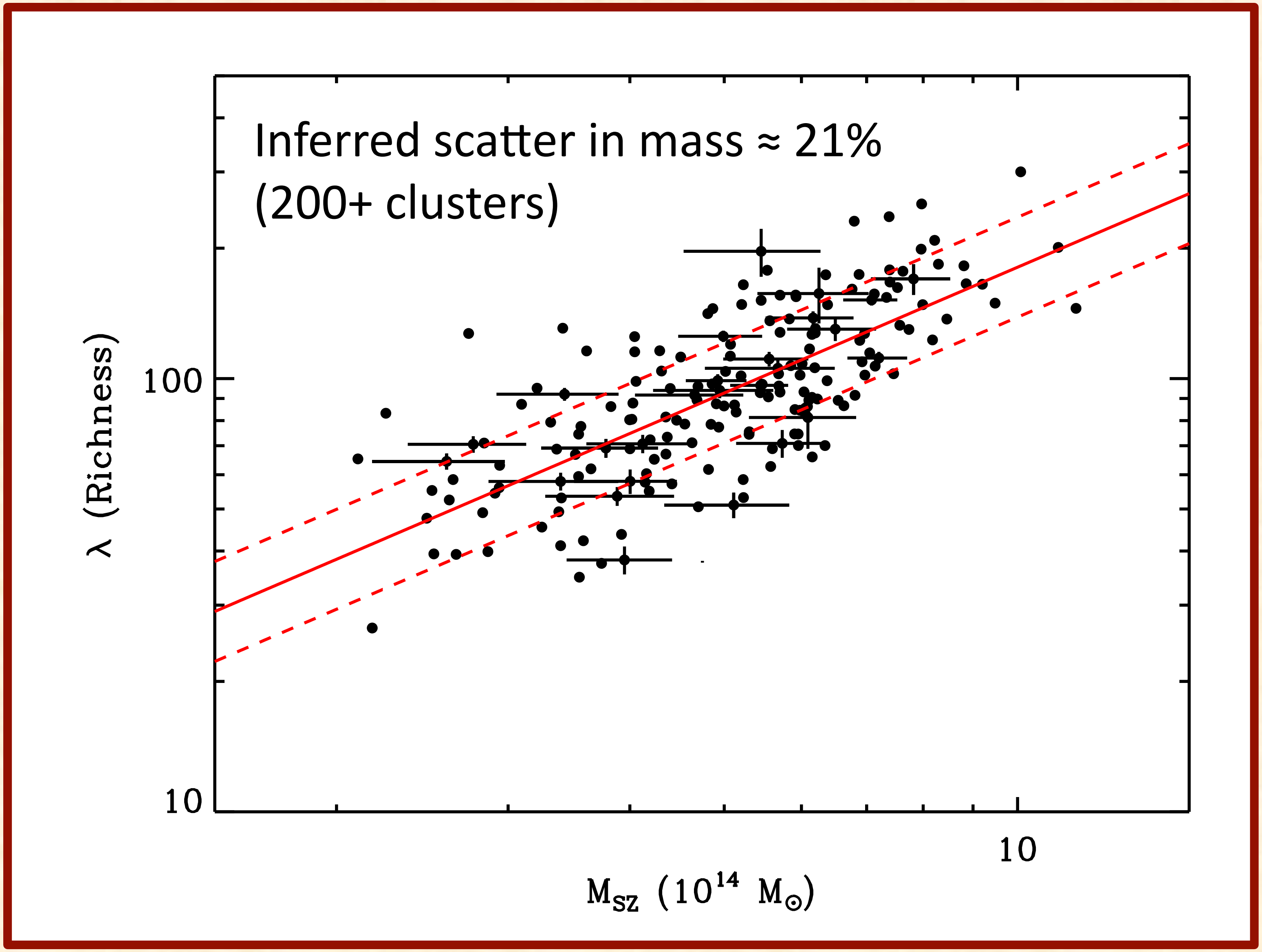
We Can Test redMaPPer with Planck and Vice Versa

245 clusters in common between Planck and SDSS RM.

100% of Planck cluster clusters in SDSS region, z<0.6.

Rozo et al. 2014

Comparison to Planck Clusters



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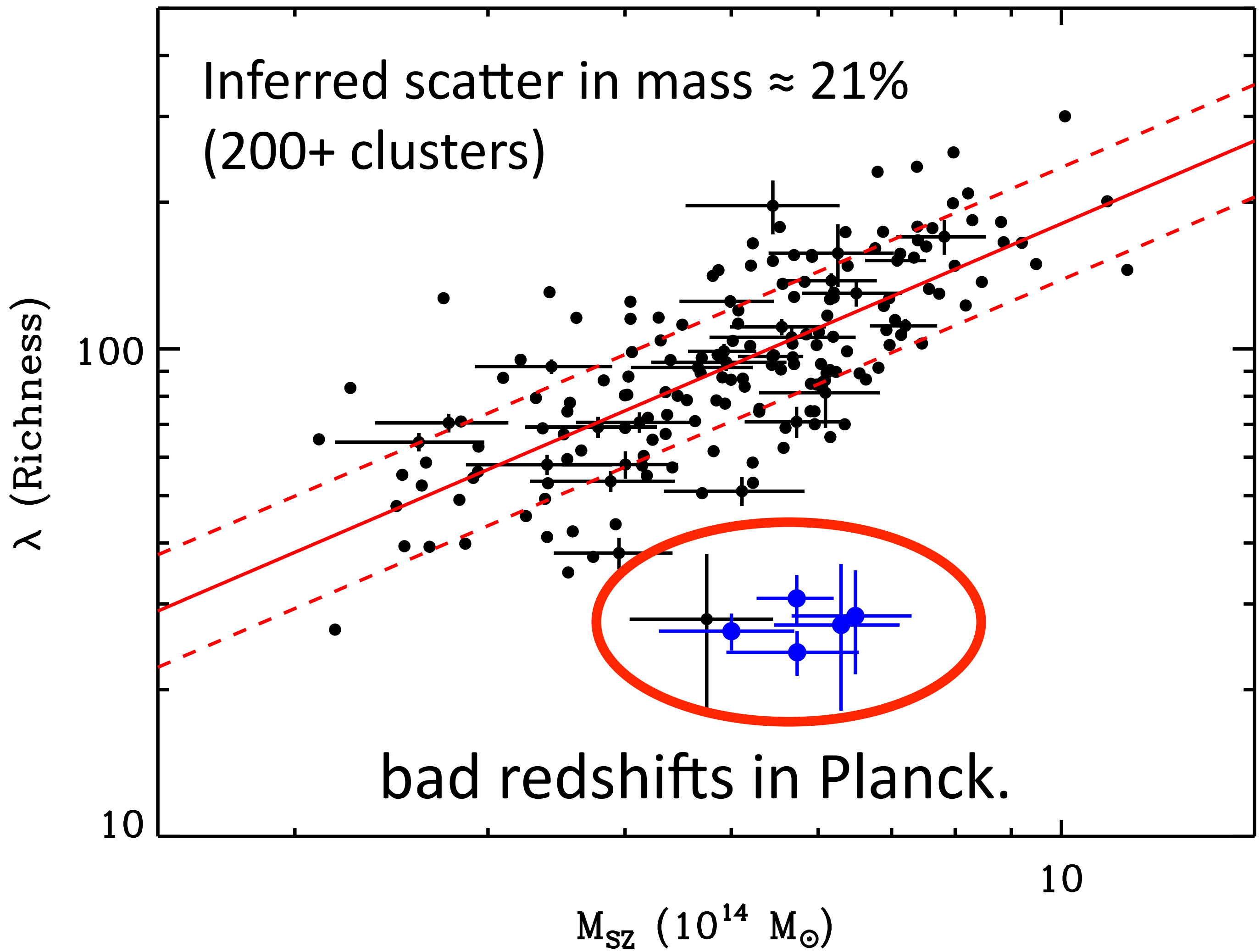


We Can Test redMaPPer with Planck and Vice Versa

245 clusters in common between Planck and SDSS RM.
    100% of Planck cluster clusters in SDSS region, z<0.6.

Clusters establish a tight scaling relation.

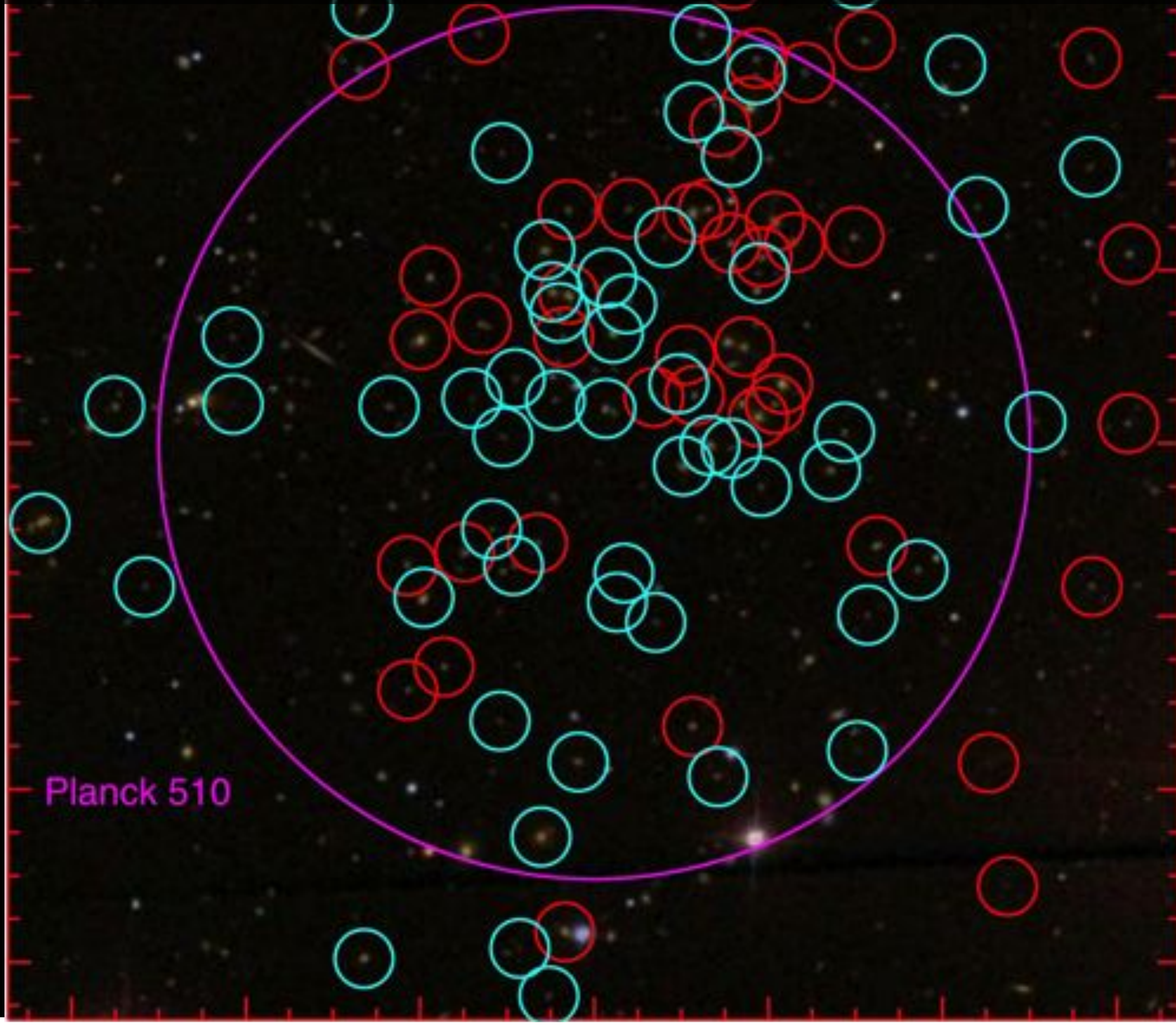
Identified 3 failures in redMaPPer (1.2% failure rate).

Identified 36 redshift failures in Planck (14.7% rate).

Also: 5 projection effects
    17 new high z candidates (z>0.6)

Rozo et al. 2014

Cool Projection!



Completeness and Purity

Completeness:

100% of all Planck and ACT clusters in SDSS found.

100% (90%) of all $L_X > 10^{44}$ ergs/s (10^{43} ergs/s) clusters found.

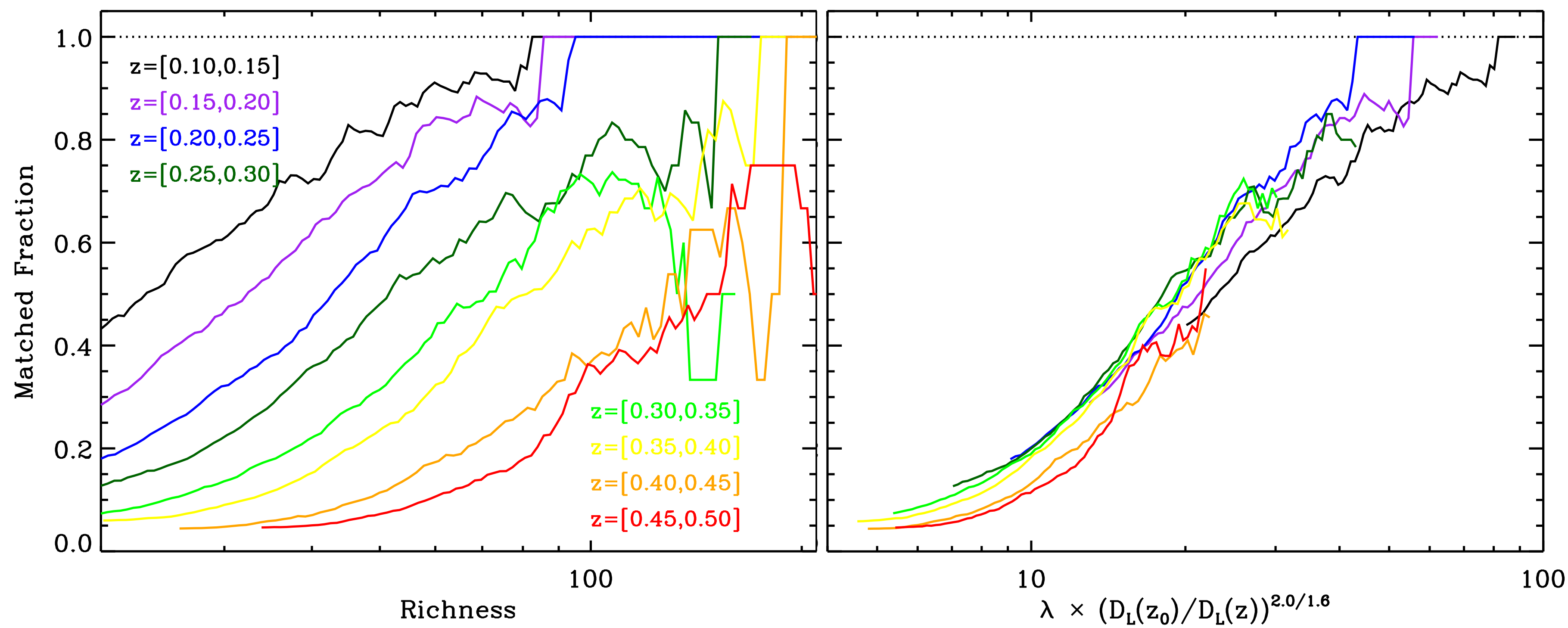
Purity:

100% of all rich, low redshift clusters detected in X-rays.

(X-ray detection is only limited by depth in RASS).

Purity

Non X-ray detection rate consistent with RASS flux limit.



Matching to ROSAT Bright and Faint Source Catalogs.

Summary

At this time, there is **no tension** between clusters and CMB for a flat LCDM cosmology.