Calibrating Cluster Masses

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Cluster Cosmology in 3 Easy Steps

1. Find all galaxy clusters.
2. Measure cluster masses.
3. Learn about gravity and dark energy!

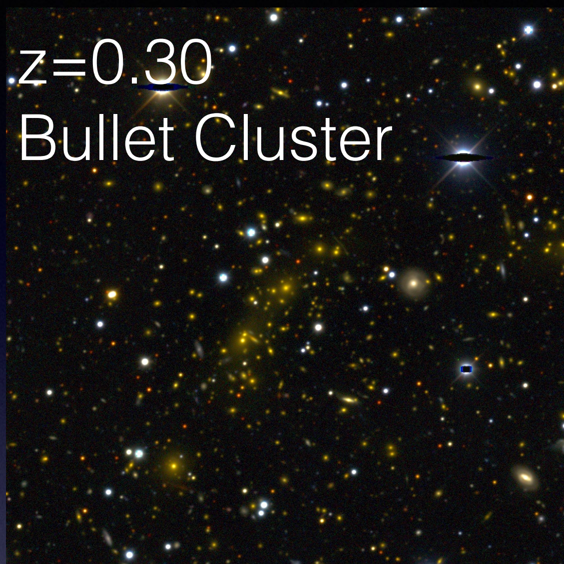
Cluster Cosmology in 3 Easy Steps

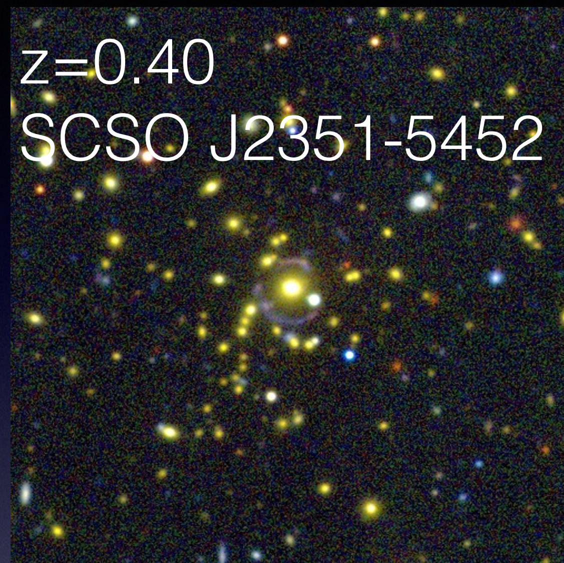
1. Find all galaxy clusters.

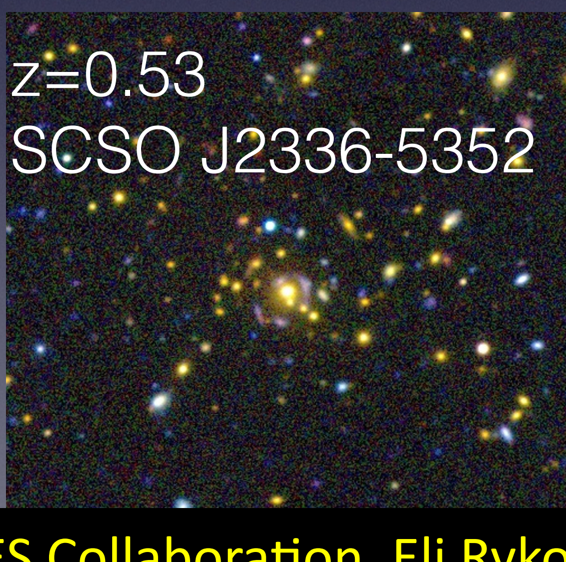
   - rely on photometrically identified galaxy clusters (redMaPPer)

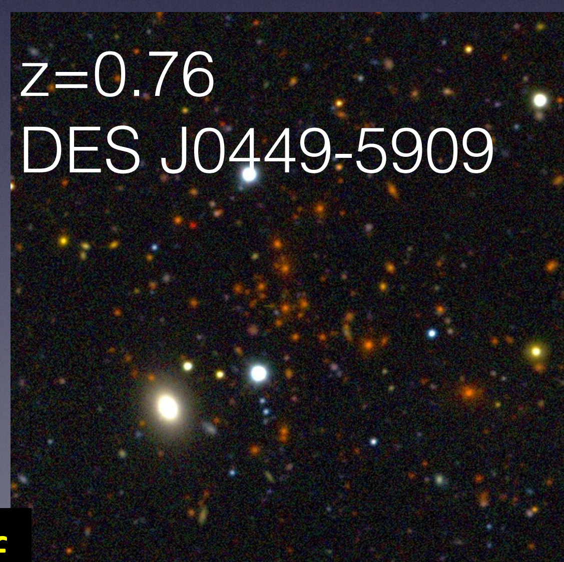
   - two distinct data sets: SDSS and DES.

Rogue’s Gallery



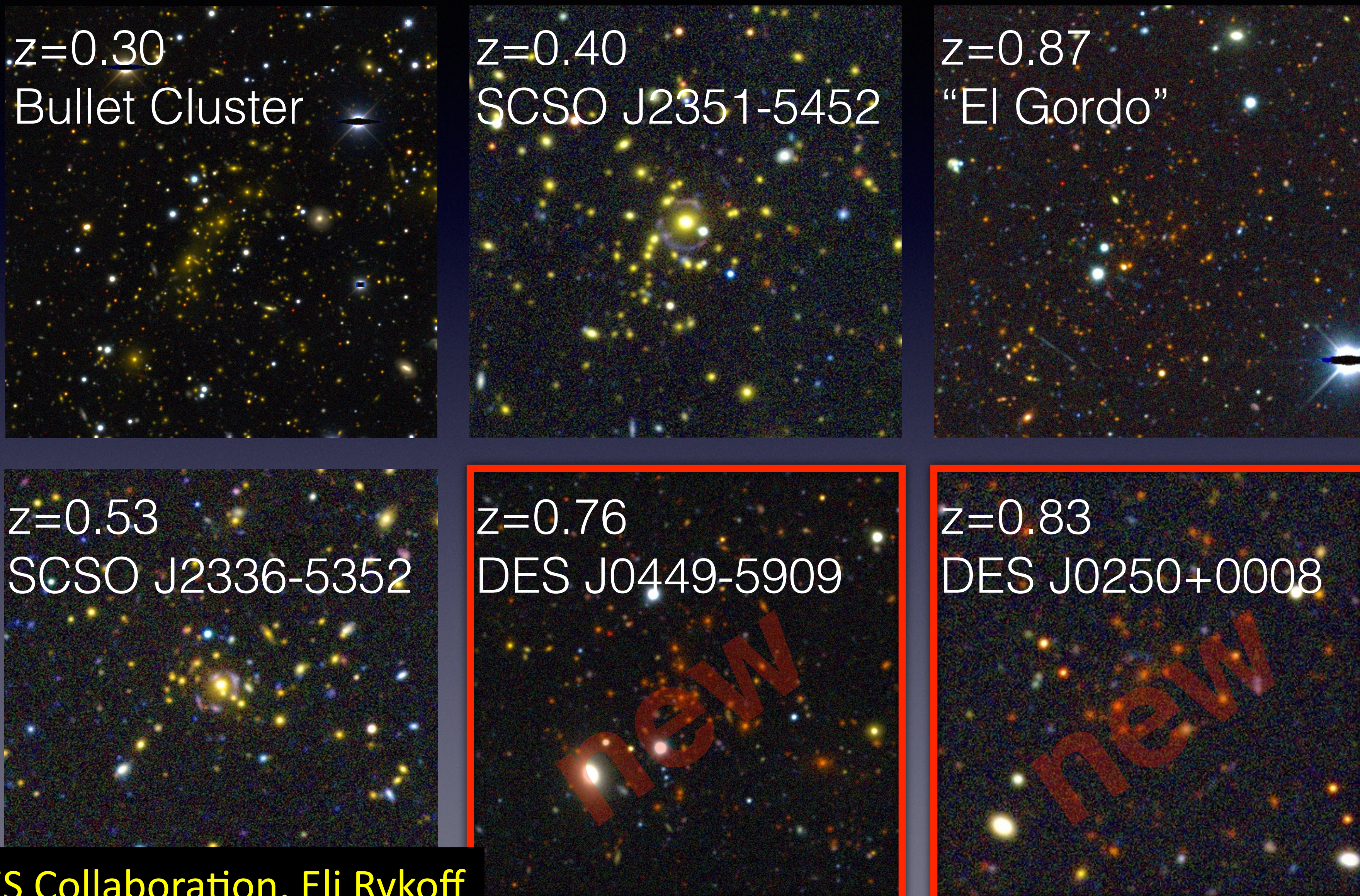






DES Collaboration, Eli Rykoff

Rogue's Gallery



DES Collaboration, Eli Rykoff

Cluster Cosmology in 3 Easy Steps

1. Find all galaxy clusters.

2. **Measure cluster masses.**

   - This is the thing that limits the precision of cluster cosmology!

   - Want P(Mass|Observable)

   - Focus primarily on DES analysis.

(Brief Aside)

Relation between **mass** and **observable (X)** is *statistical.*

$$M(X) = AX^{\alpha}$$

This notation is ambiguous! Does it mean this?

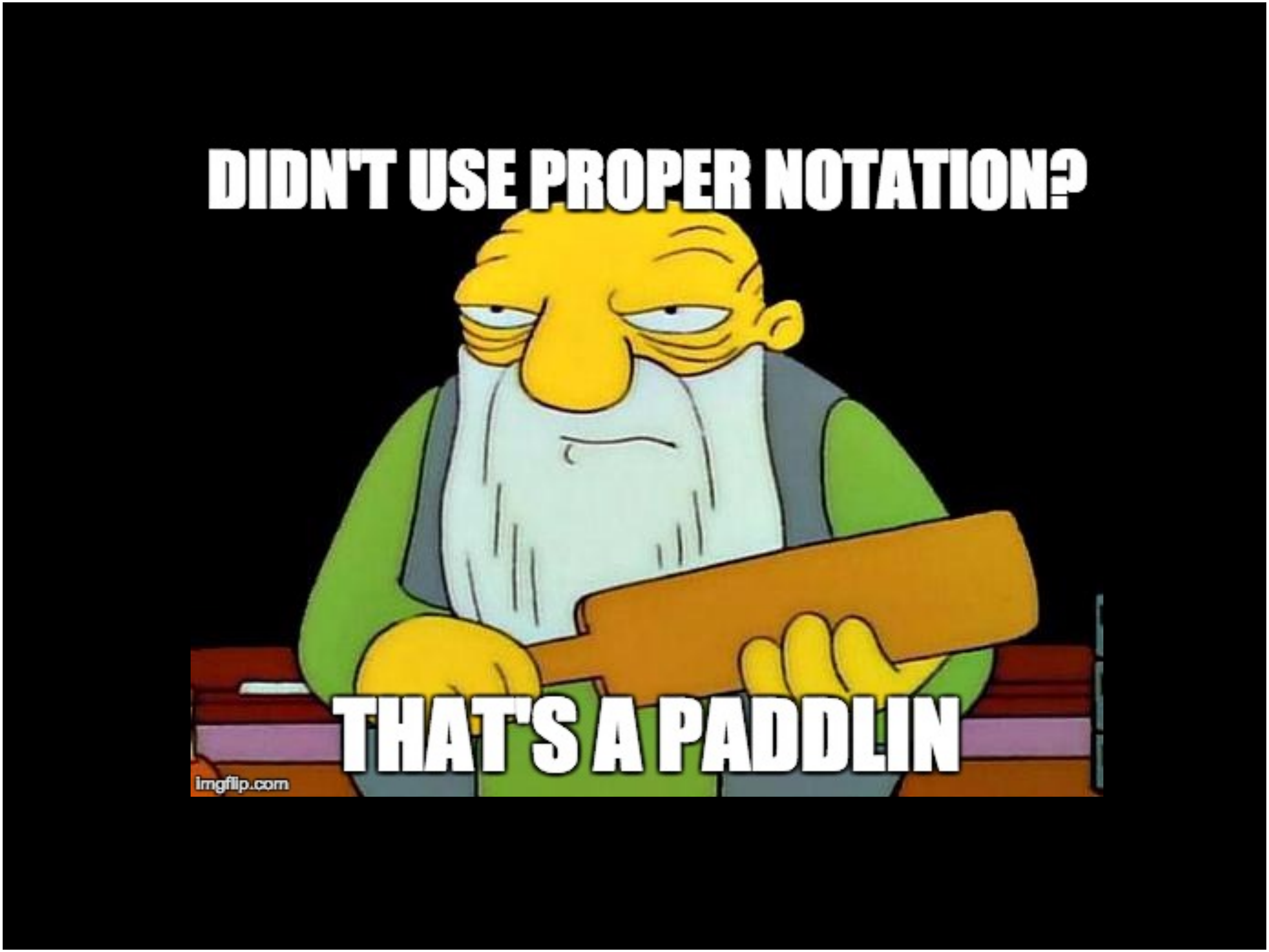
$$\langle M \mid X \rangle = AX^{\alpha}$$

Or this?

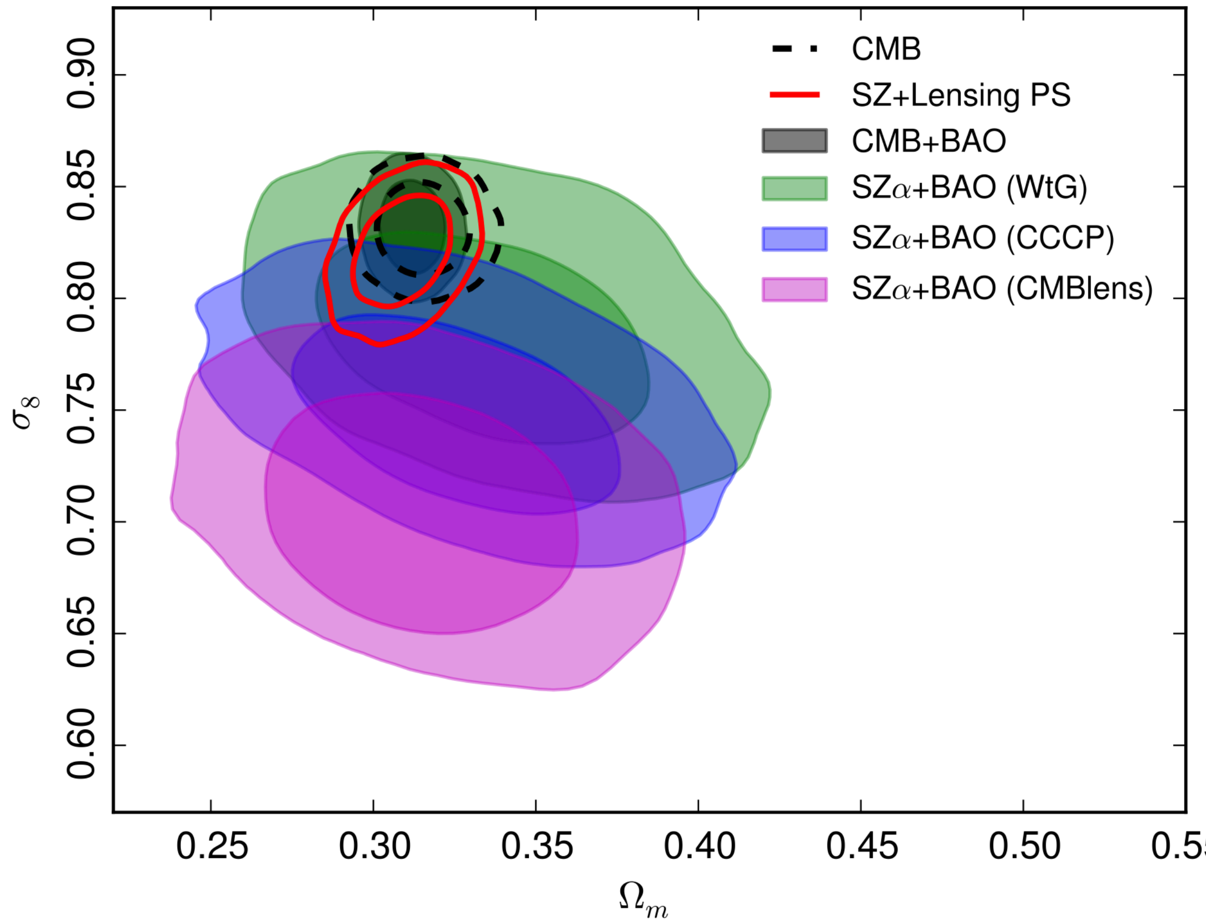
$$\langle \ln M \mid X \rangle = \ln A + \alpha \ln X$$

These two are not equivalent

Offsets relevant at ≈1σ.

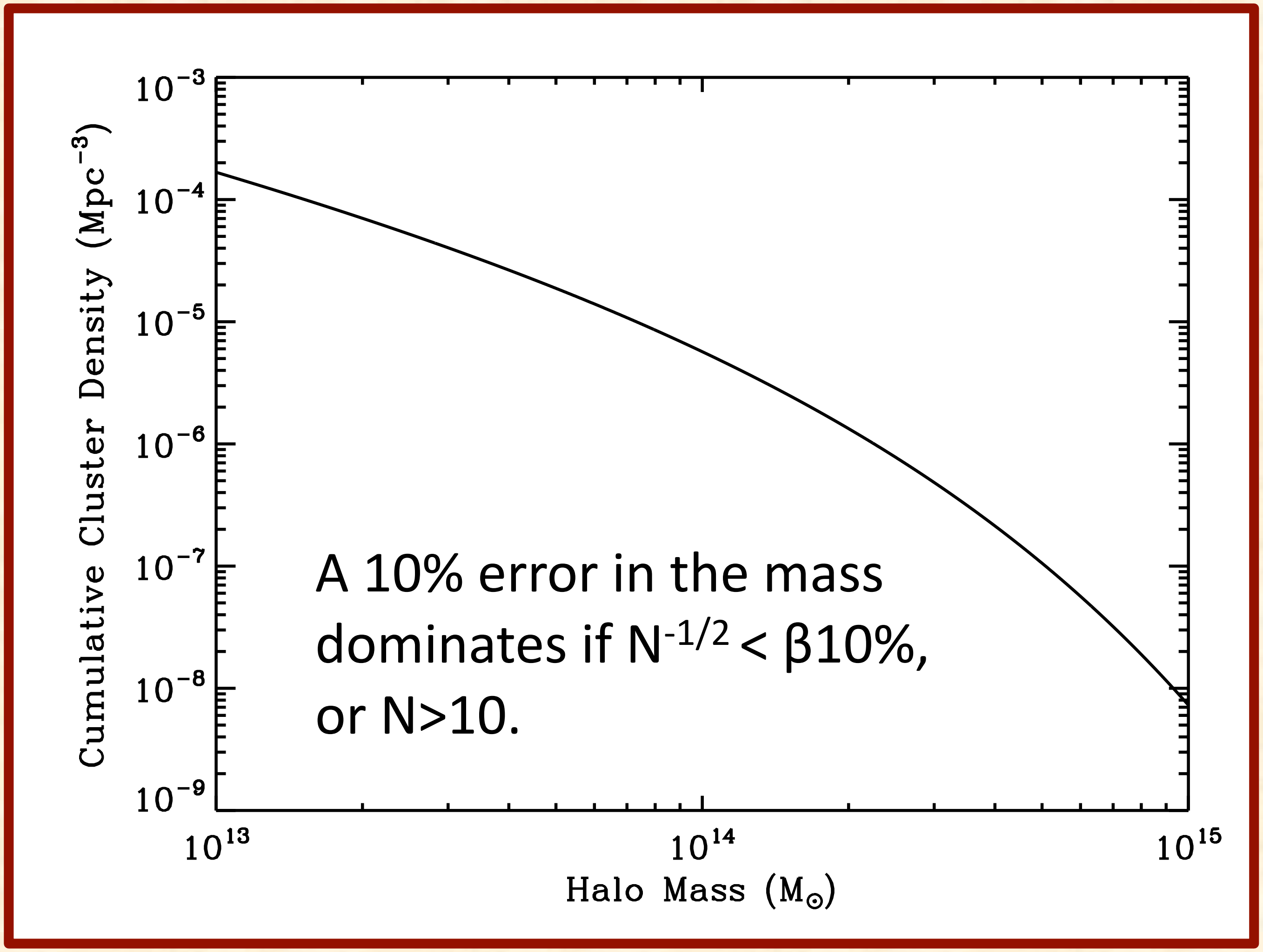

DIDN'T USE PROPER NOTATION?
THAT'S A PADDLIN
imgflip.com

The Impact of Mass Calibration



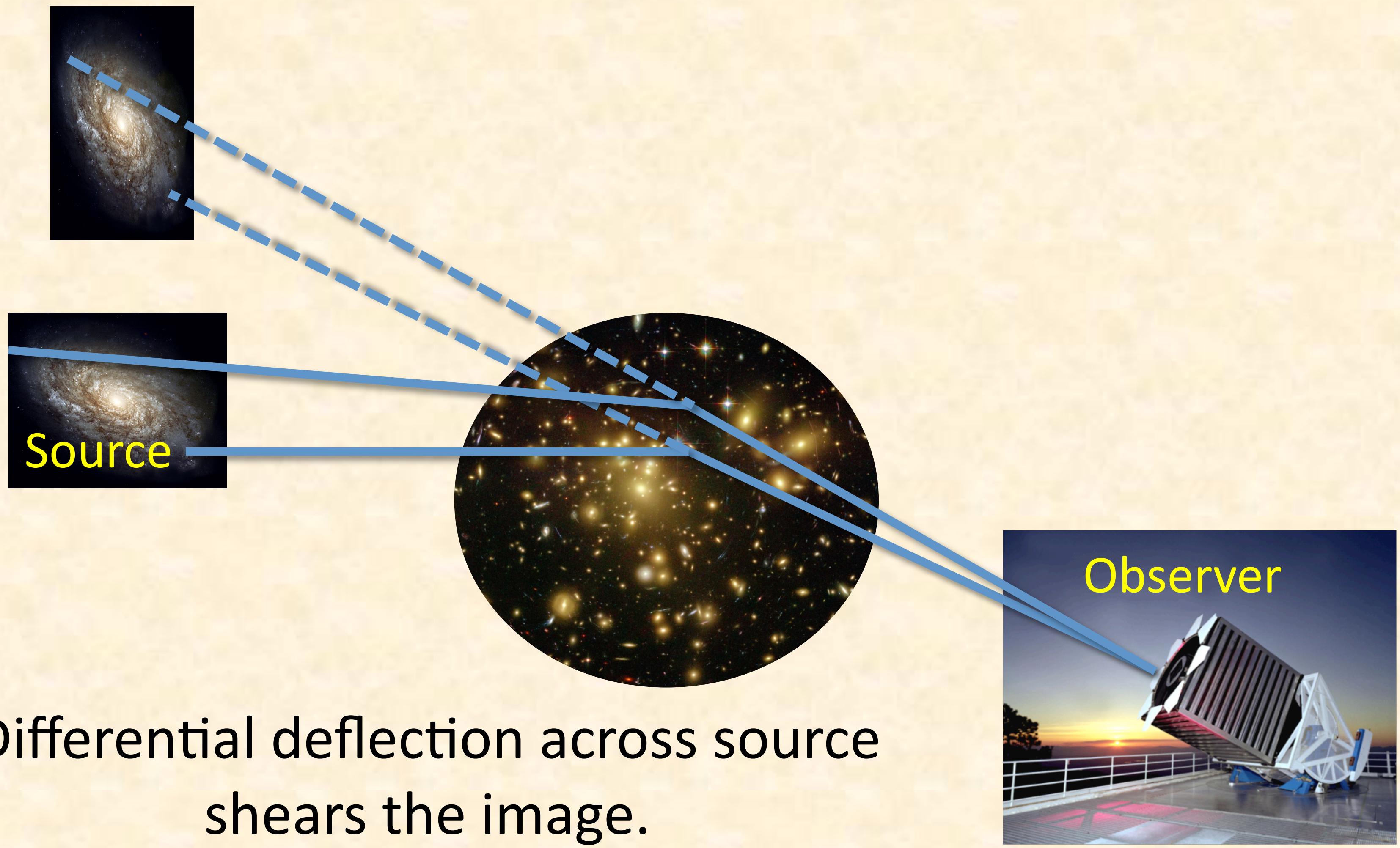
Planck 2015 XXIV

Why Mass Calibration Matters



Weak Lensing Mass Calibration

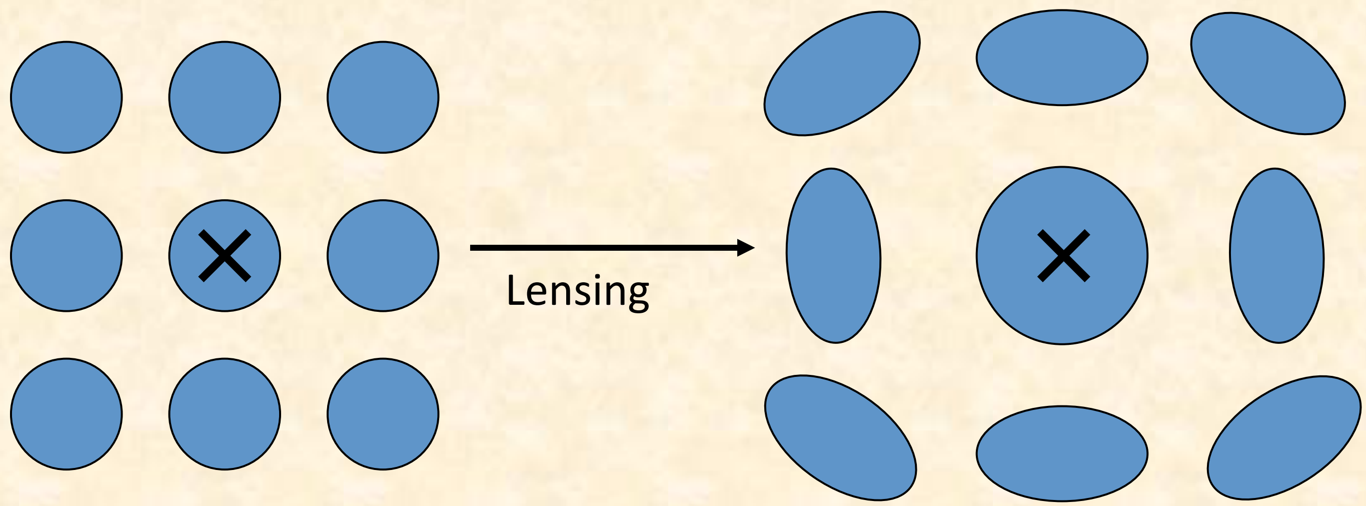
The gravity of a galaxy cluster bends the light of galaxies behind it.



Differential deflection across source shears the image.

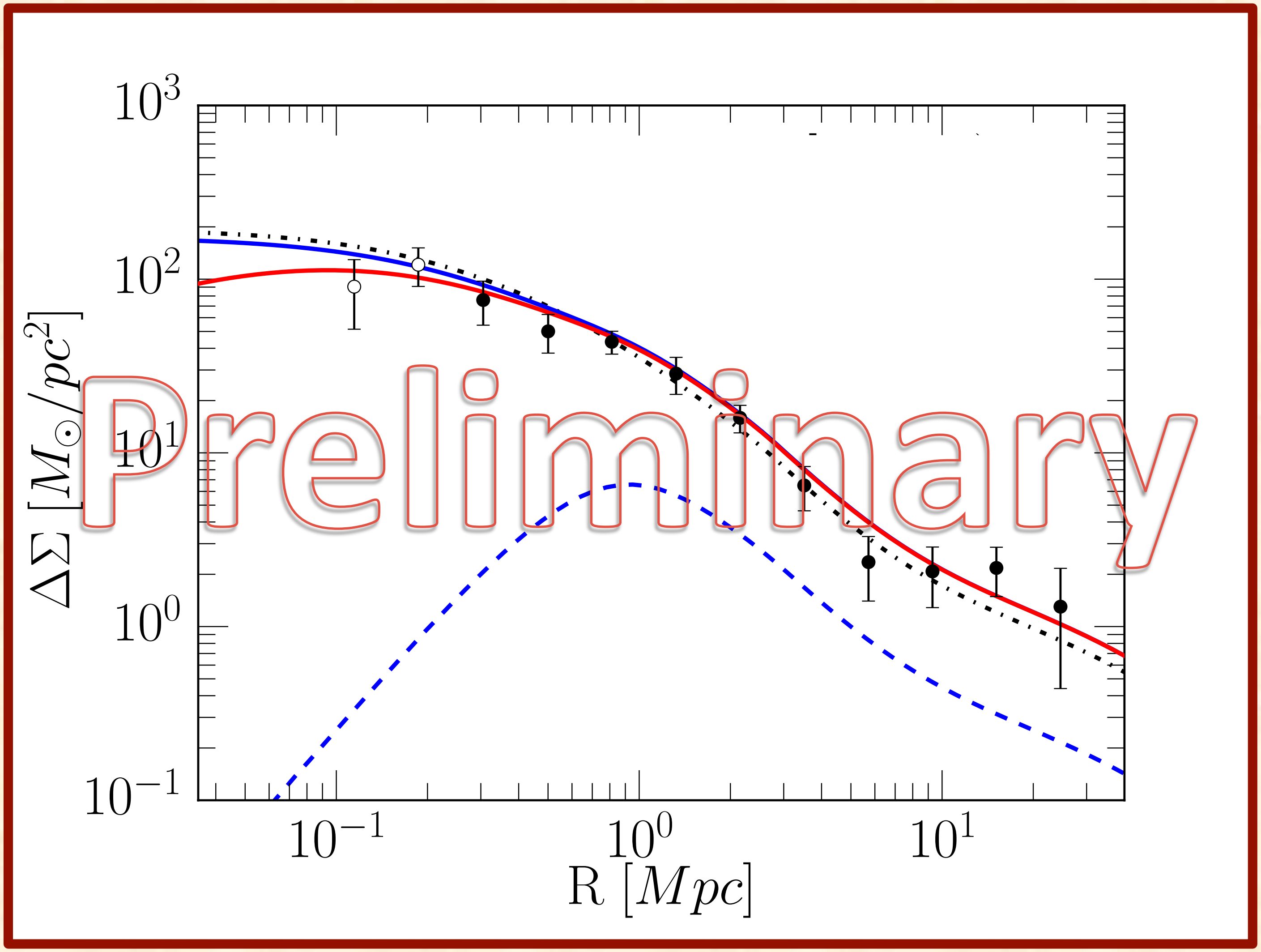
Weak Lensing Mass Calibration

We can detect *shear* statistically:



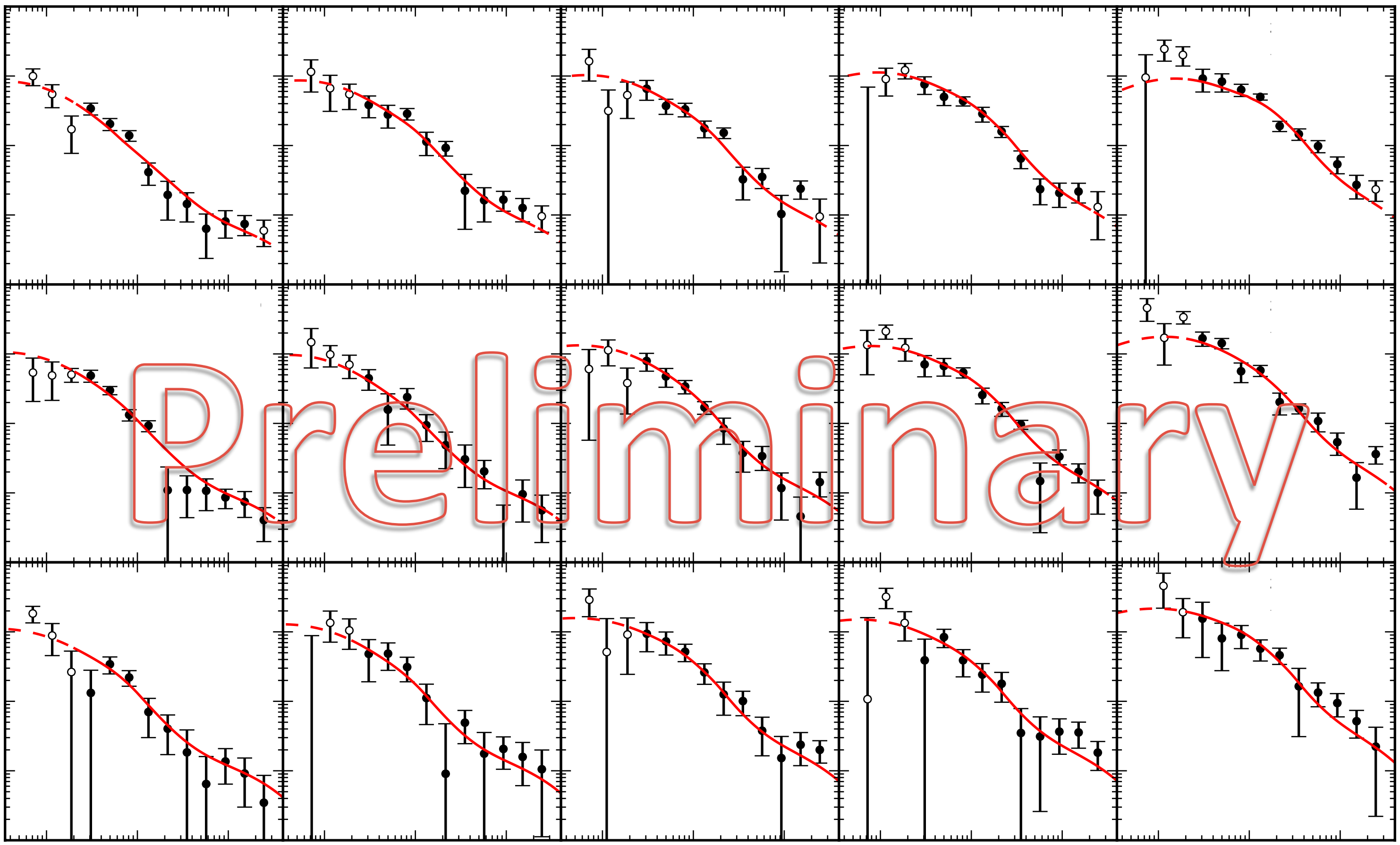
The mean tangential ellipticity of *background* galaxies around galaxy clusters depends on the cluster mass.

Mass Calibration of DES SV Clusters



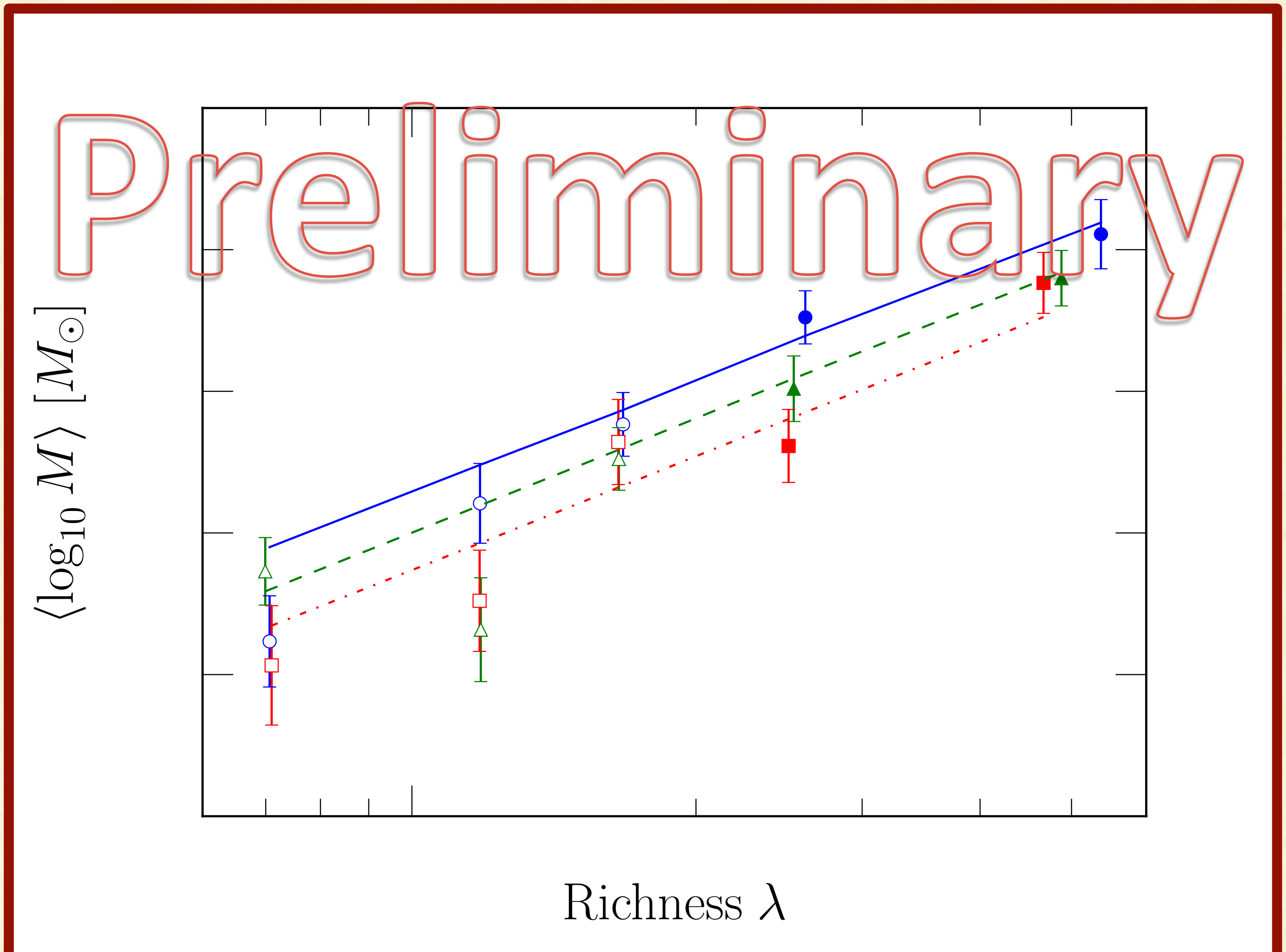
Melchior et al., in prep., plot by Tom McClintock

Mass Calibration of DES SV Clusters



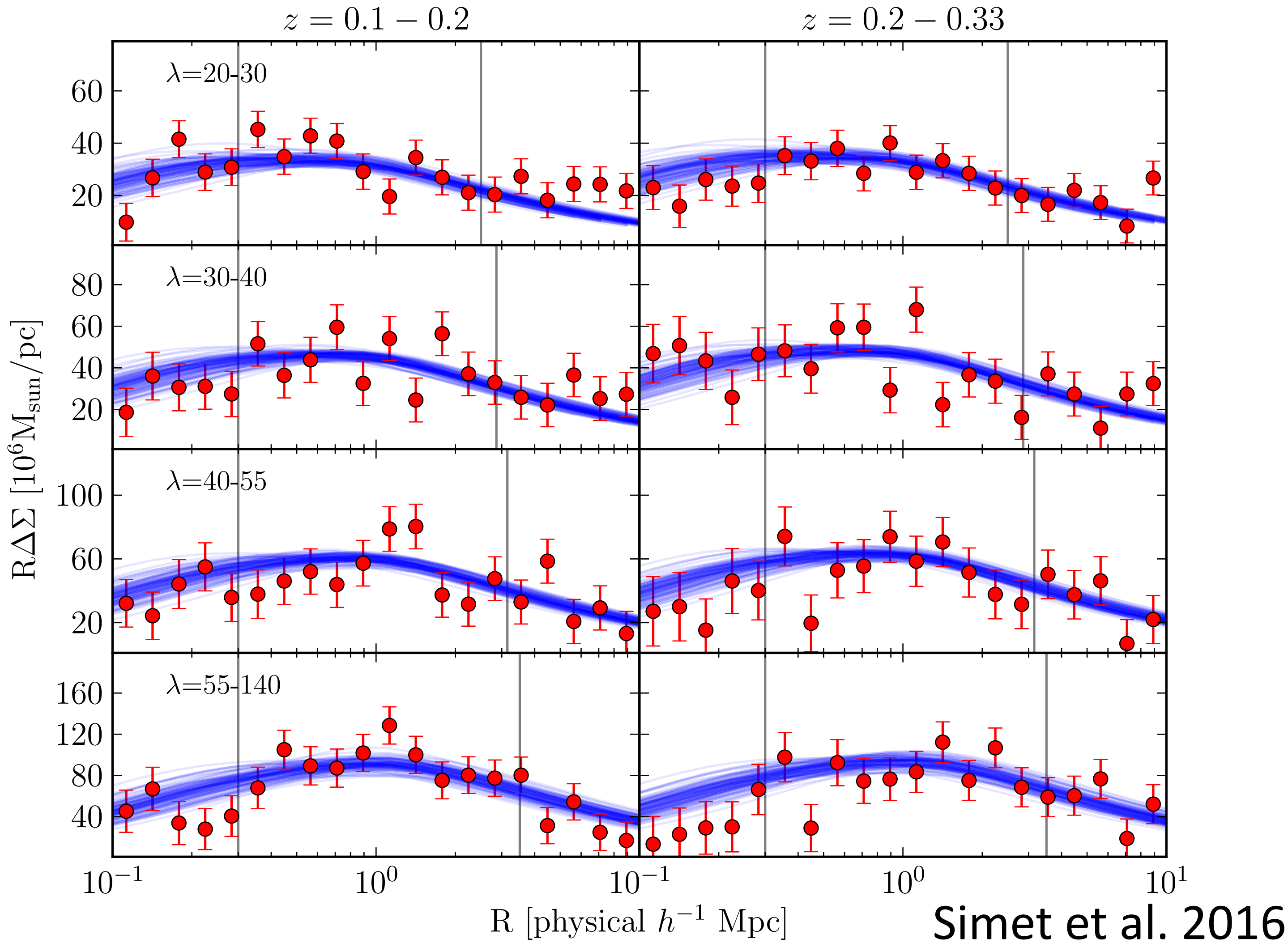
Melchior et al., in prep., plot by Tom McClintock

The Mass-Richness Relation in DES SV



Melchior et al., in prep., plot by Tom McClintock

Mass Calibration of SDSS Clusters



End Result

DES SV: (UPDATE AFTER UNBLINDING)

$$\log_{10}\langle M \mid \lambda \rangle = (14.X \pm X \pm X) + (1.X^{+X}_{-X})\log_{10}\left(\frac{\lambda}{30}\right)$$

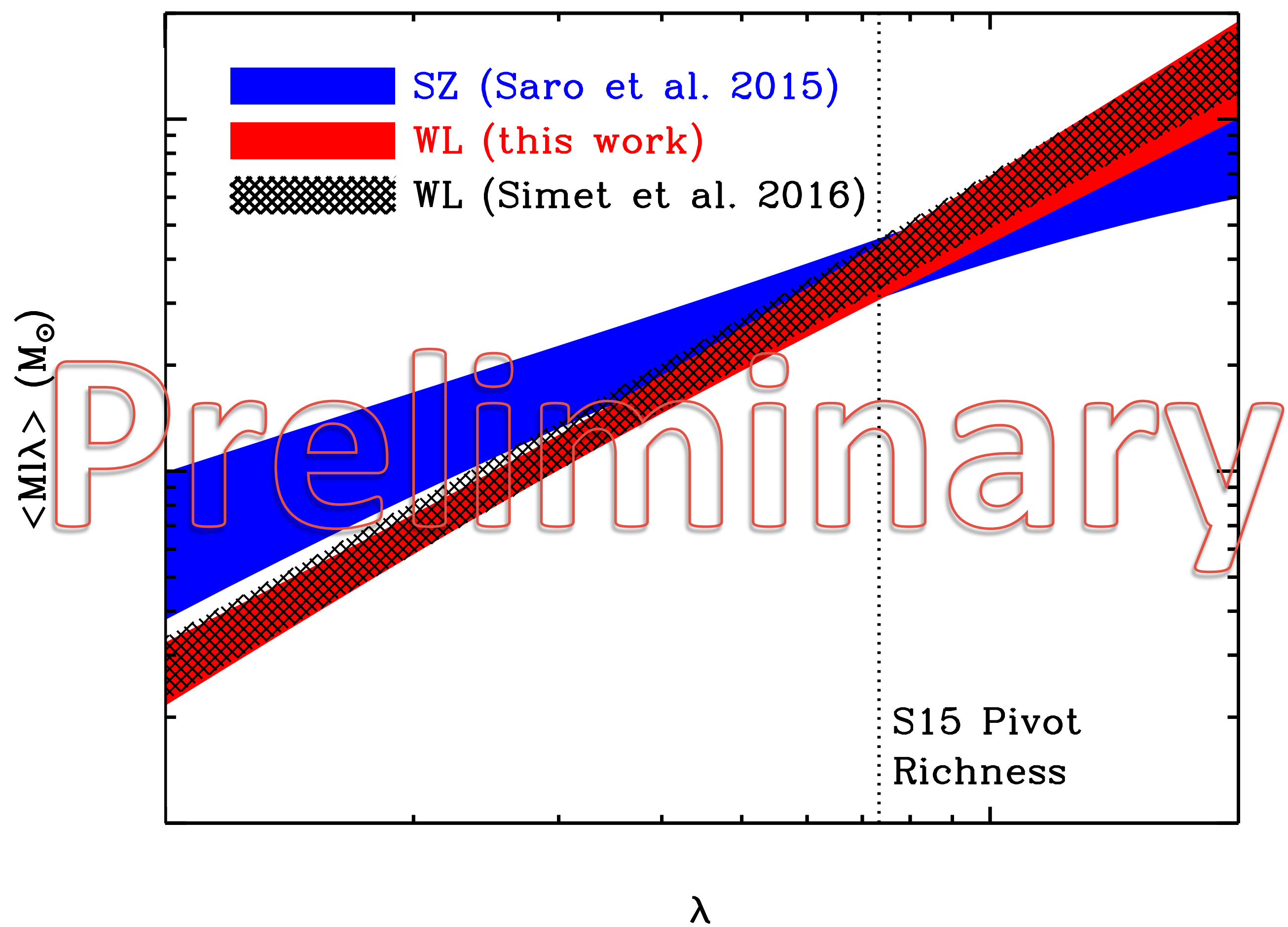
Note- units are $M_{\odot}$, z_{pivot}=0.6

SDSS:

$$\log_{10}\langle M \mid \lambda \rangle = (14.344 \pm 0.021 \pm 0.023) + (1.33^{+0.09}_{-0.10})\log_{10}\left(\frac{\lambda}{40}\right)$$

Note- units are h^{-1} $M_{\odot}$, z_{pivot}=0.25

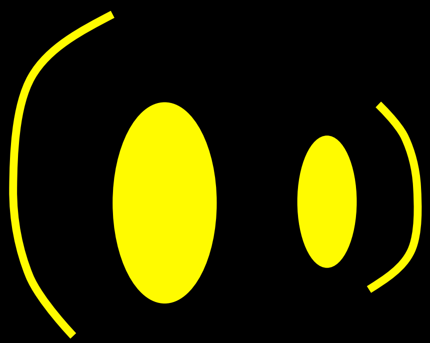
Comparison of DES and SDSS



Melchior et al., in prep.

Systematics

(The Monster in the Dark)



Our Approach to Systematics

End Result

DES SV: (UPDATE AFTER UNBLINDING)

$$\log_{10}\langle M \mid \lambda\rangle = \left(14.X \pm X \pm X\right) + \left(1.X^{+X}_{-X}\right)\log_{10}\left(\frac{\lambda}{30}\right)$$

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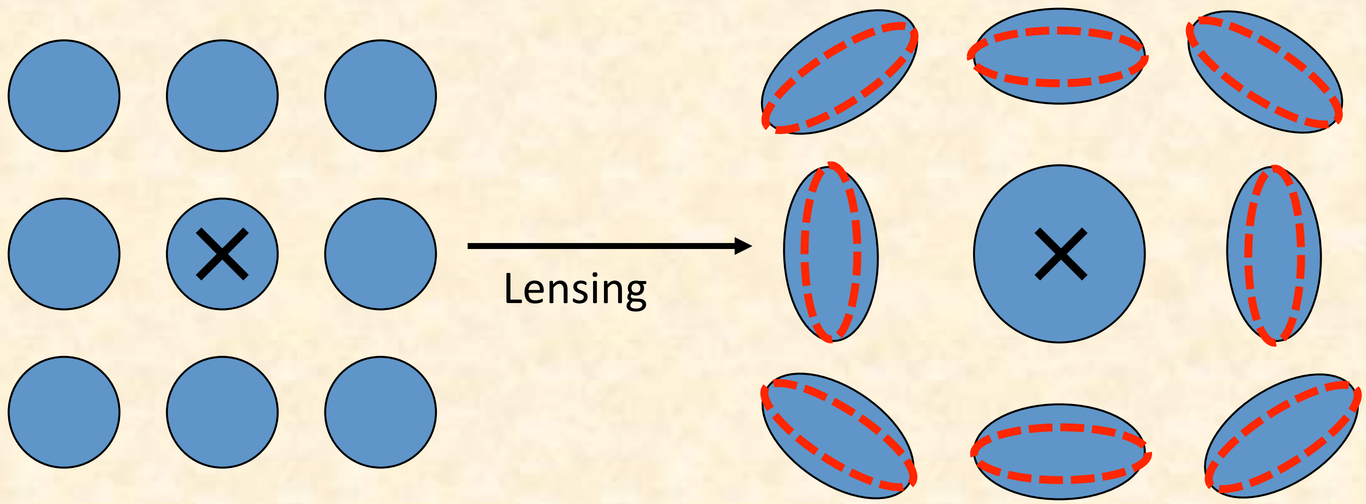
Current List of Systematics

- **Shape systematics (4%)**
- **Photoz systematics (3%)**
- Triaxiality (2.0%)
- Projections (2.0%)
- Modeling Systematics (2.0%)
- Membership dilution. (1% or less)
- Cluster centering. (1% or less)

Systematics are essentially identical
for DES and SDSS.

Why Shape Systematics Matter

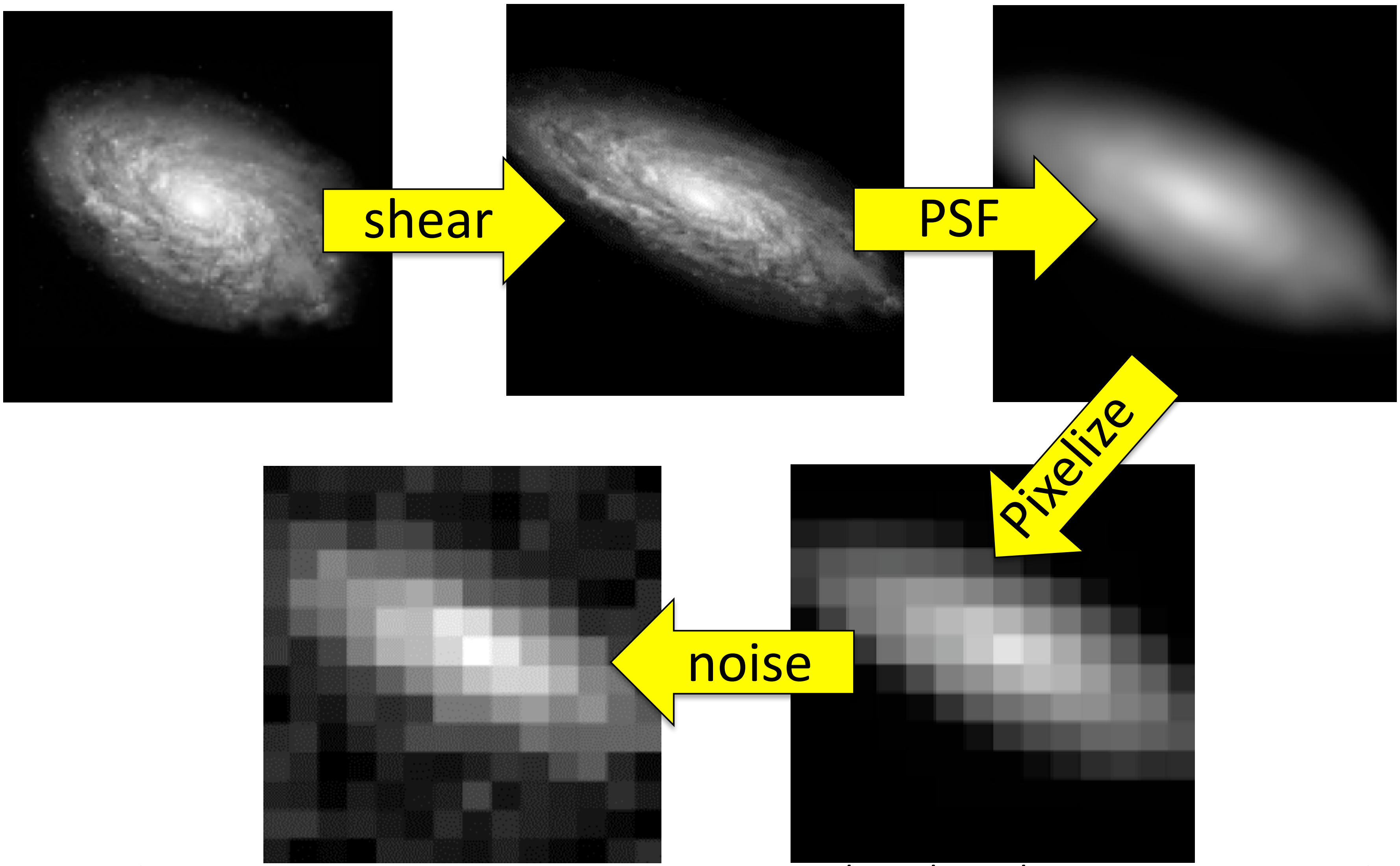
$$\gamma_{obs} = (1+m)\gamma_{true}$$



Biased shear = biased mass

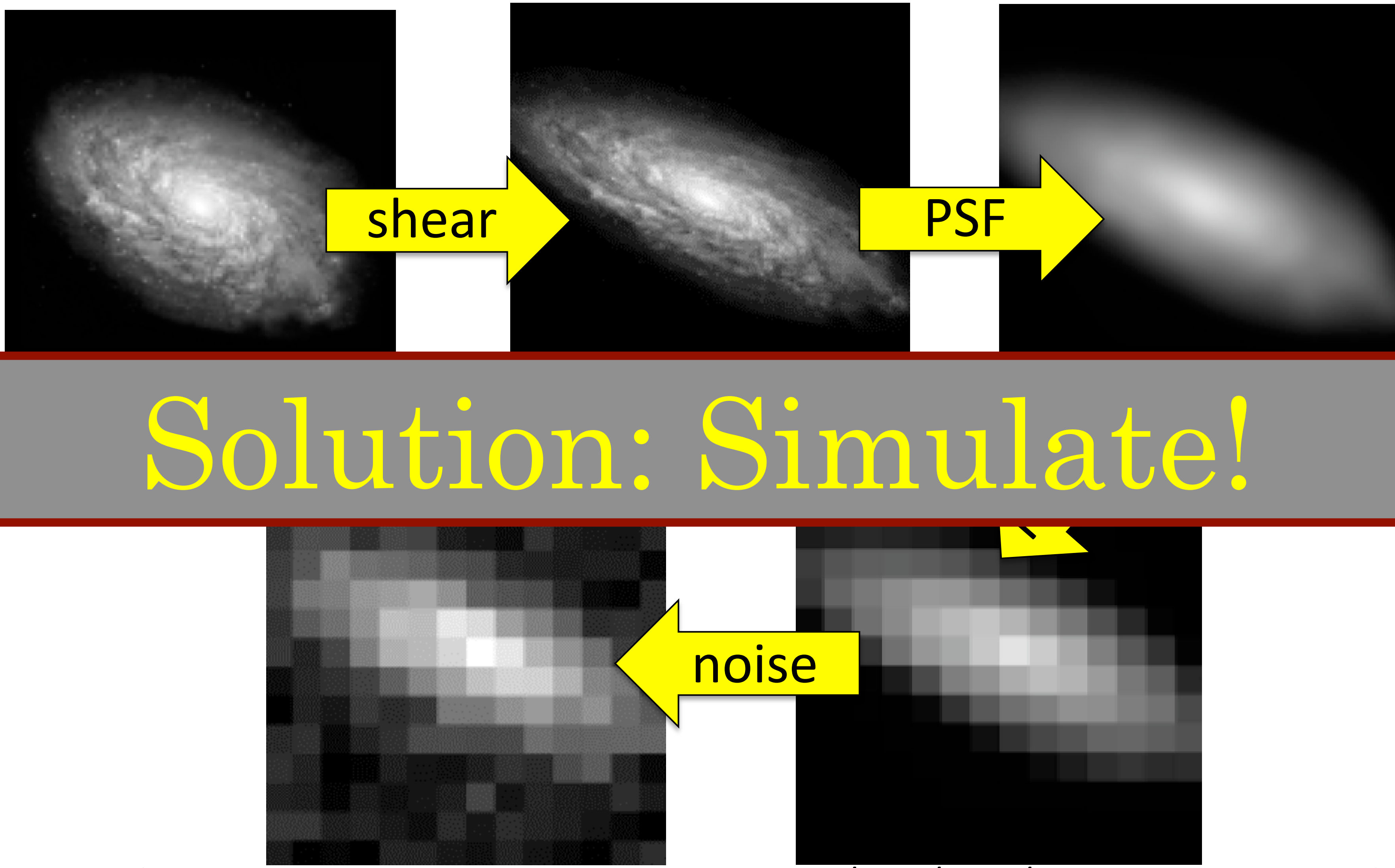
m = multiplicative shear bias

Why Shape Systematics Exist



Images from talk by Thomas Kitching: www.nesc.ac.uk/talks/1003/16Kitching_lensing.pdf

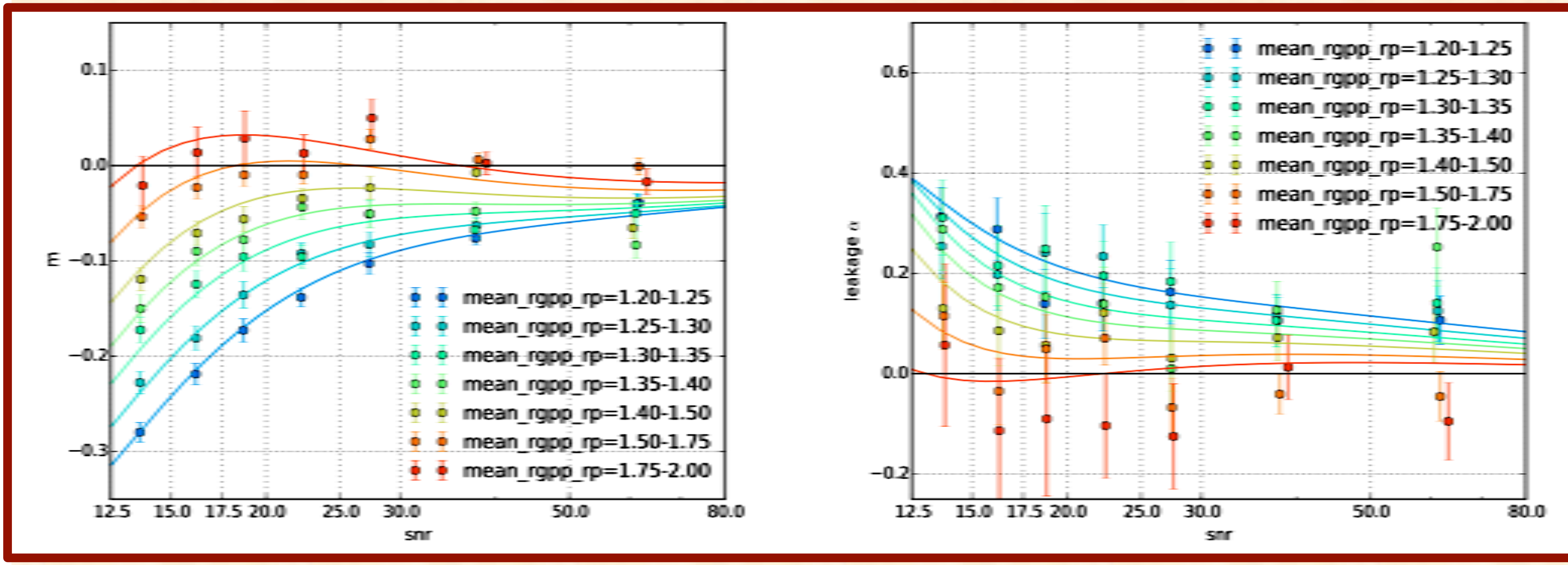
Why Shape Systematics Exist



Solution: Simulate!

Images from talk by Thomas Kitching: www.nesc.ac.uk/talks/1003/16Kitching_lensing.pdf

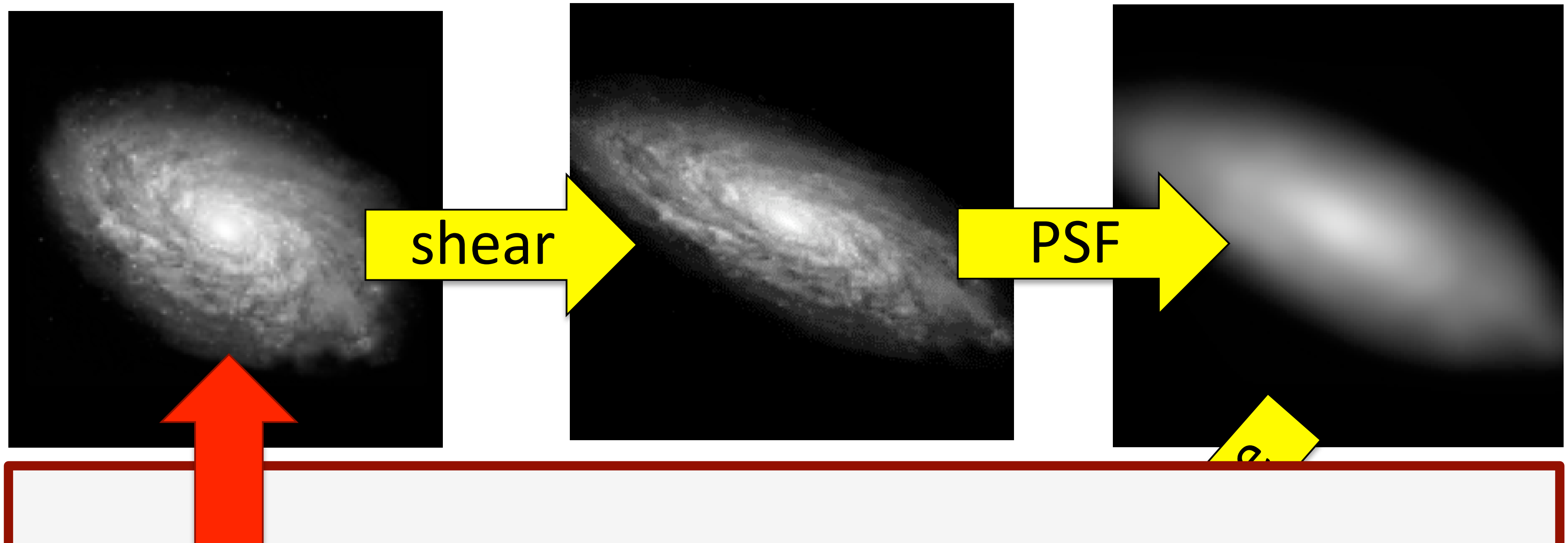
Shear Calibration



Residual systematics below 3% in simulations.

Jarvis et al. 2016.

Simulations are Not Perfect



Most important difficulty:

- Bias depends on detailed internal structure of galaxies.
- Differences between simulated and real galaxies results in shear biases.

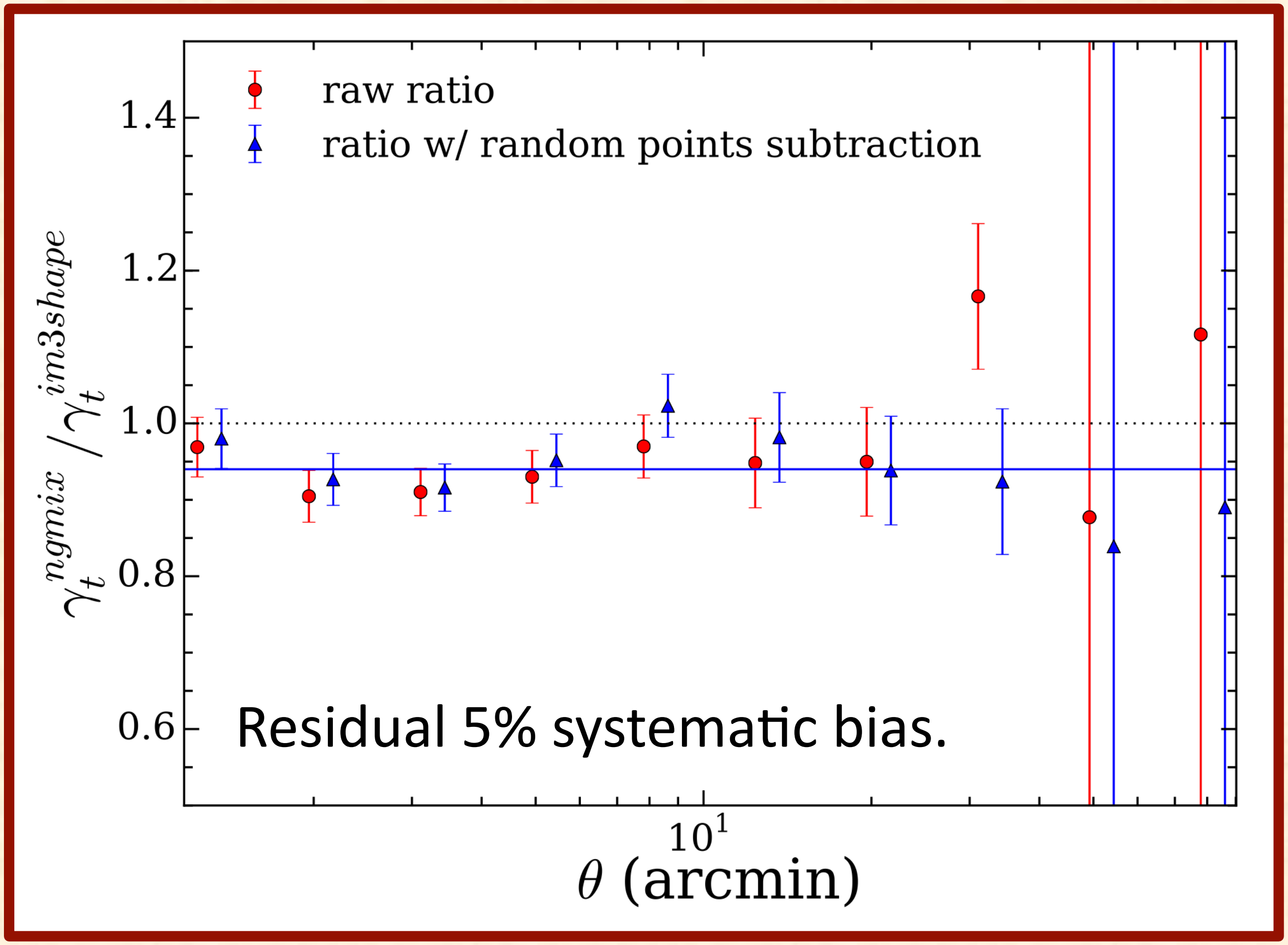
Images from talk by Thomas Kitching: www.nesc.ac.uk/talks/1003/16Kitching_lensing.pdf

How to Test if the Simulation Calibration is Good Enough?

Use two different calibrated methods for measuring shear.

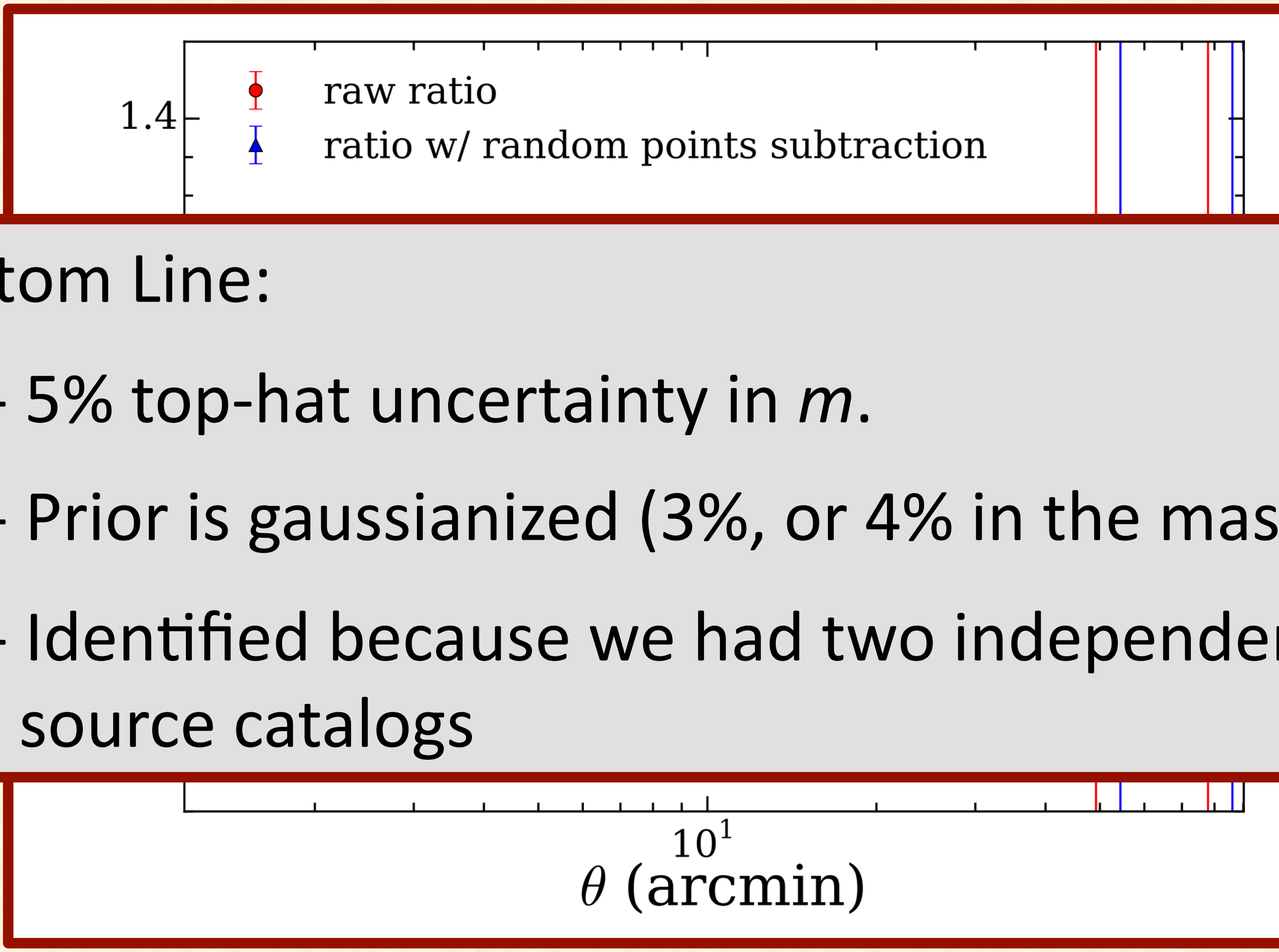
- Do they agree?

Residual Calibration Bias



This possible bias would was undetected by simulations!

Residual Calibration Bias



Bottom Line:

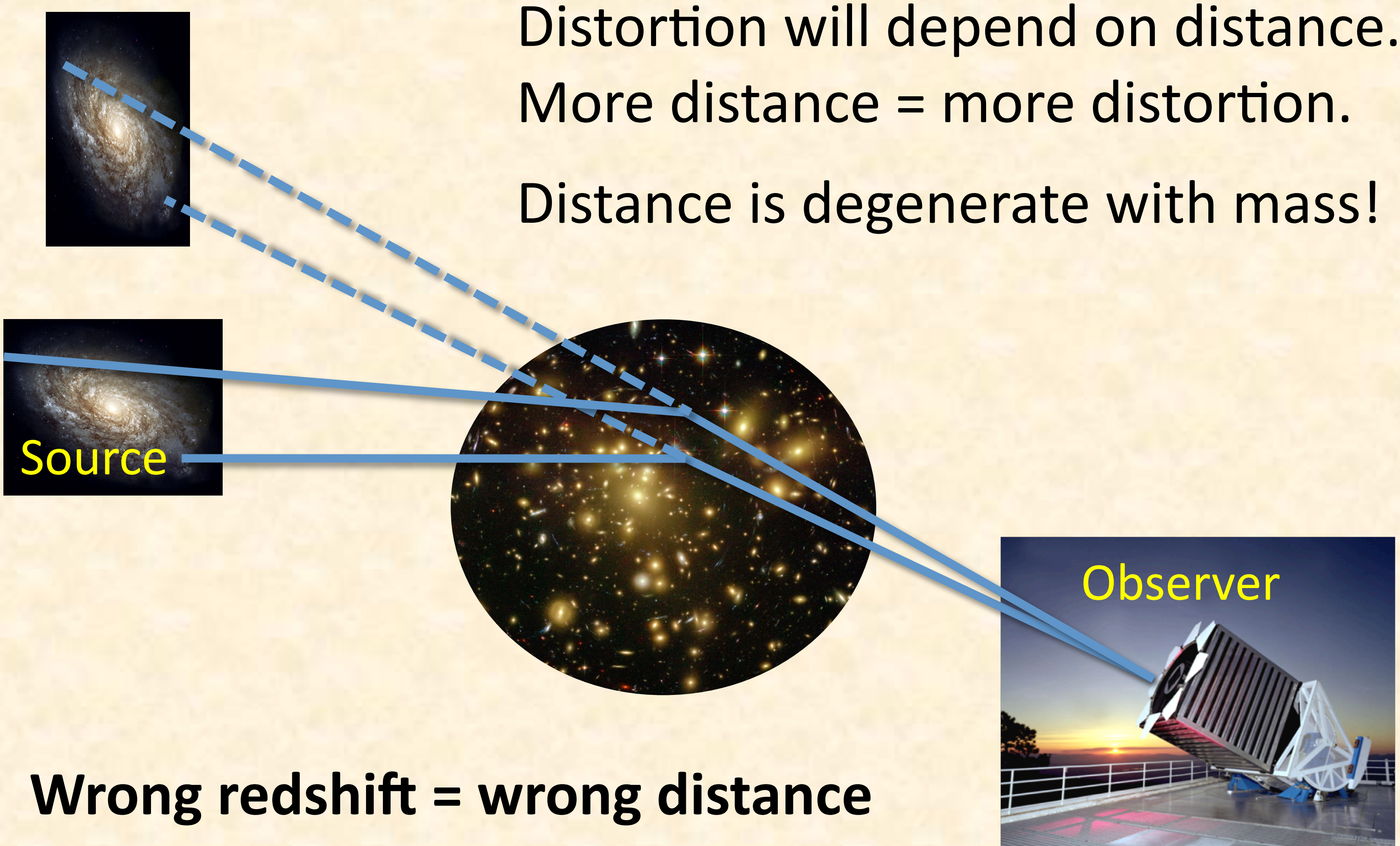
- 5% top-hat uncertainty in *m*.
- Prior is gaussianized (3%, or 4% in the mass)
- Identified because we had two independent source catalogs

This possible bias would was undetected by simulations!

Why Photoz Systematics Matter

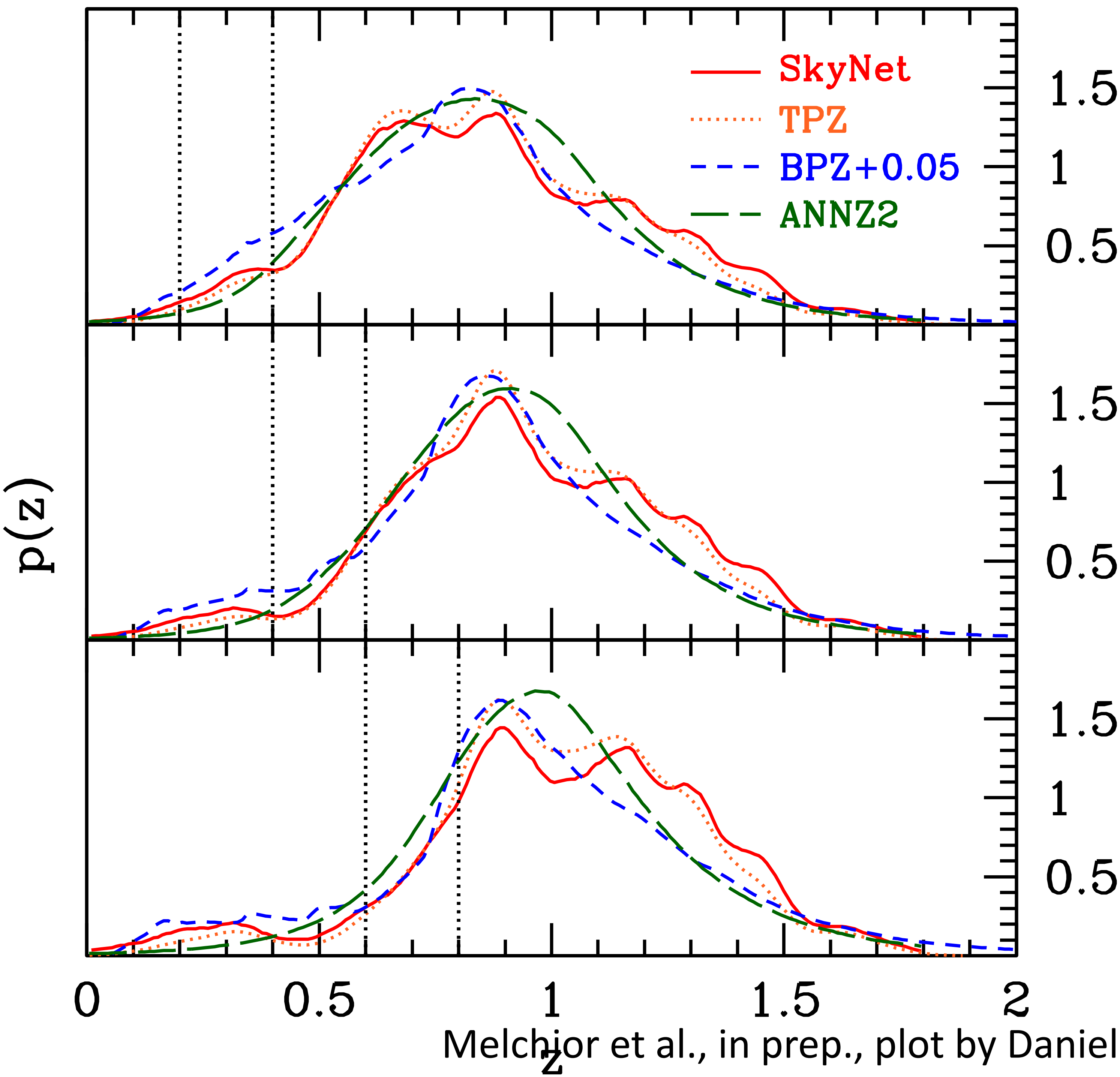
Distortion will depend on distance.
More distance = more distortion.

Distance is degenerate with mass!



Wrong redshift = wrong distance
= wrong cluster mass

Photoz Systematics



Melchior et al., in prep., plot by Daniel Gruen

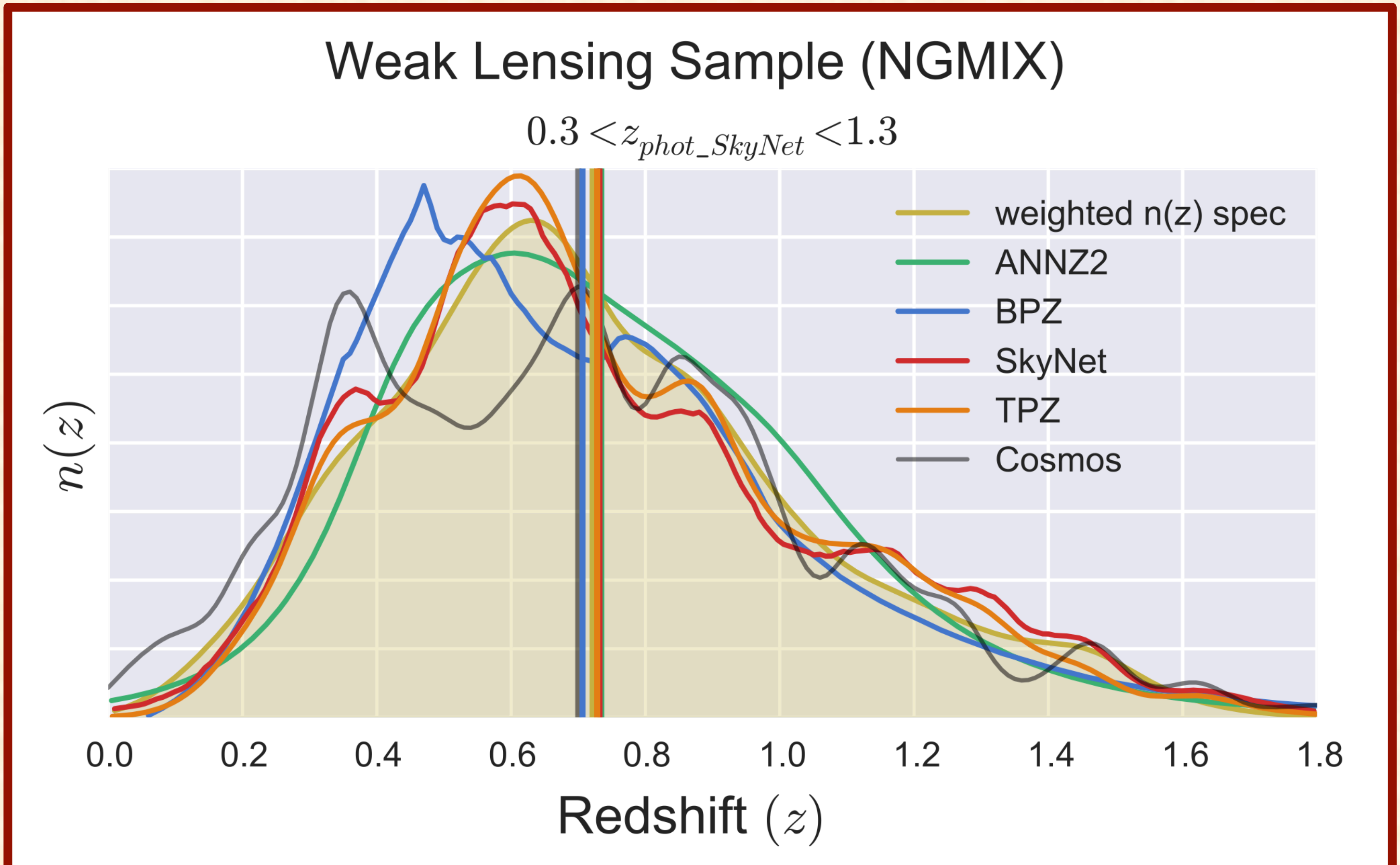
How to Test?

Compare predictions of photozs to spectroscopic redshift distribution.

Problem: spectra don't exist!

Solution: use COSMOS 30-band photozs to test.

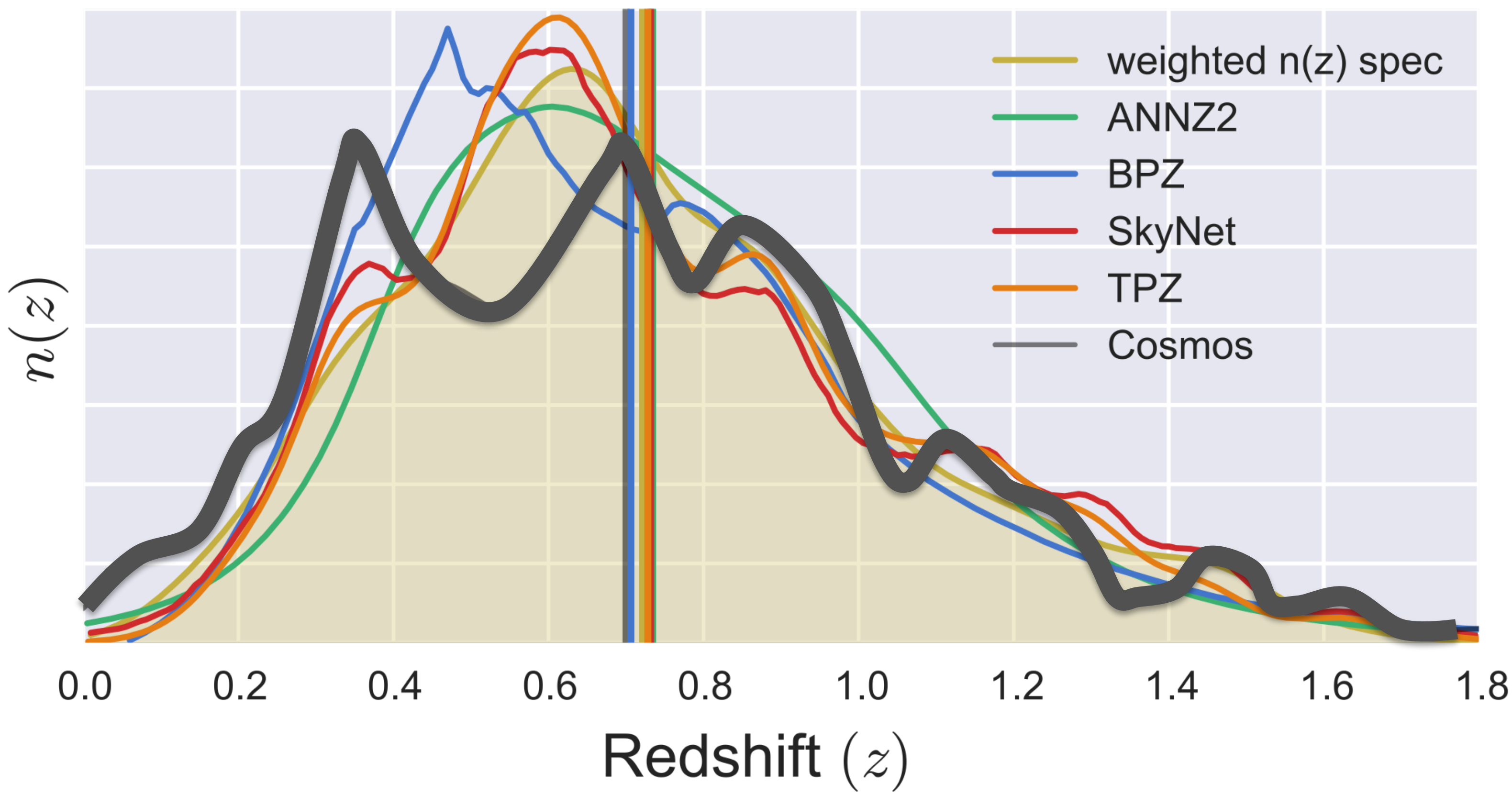
COSMOS Test



Bonnet et al. 2015

COSMOS Test

Radial structure and differences with other methods suggests COSMOS by itself is not a sufficient test.



Bonnet et al. 2015

How to Test?

Compare predictions of photozs to spectroscopic redshift distribution.

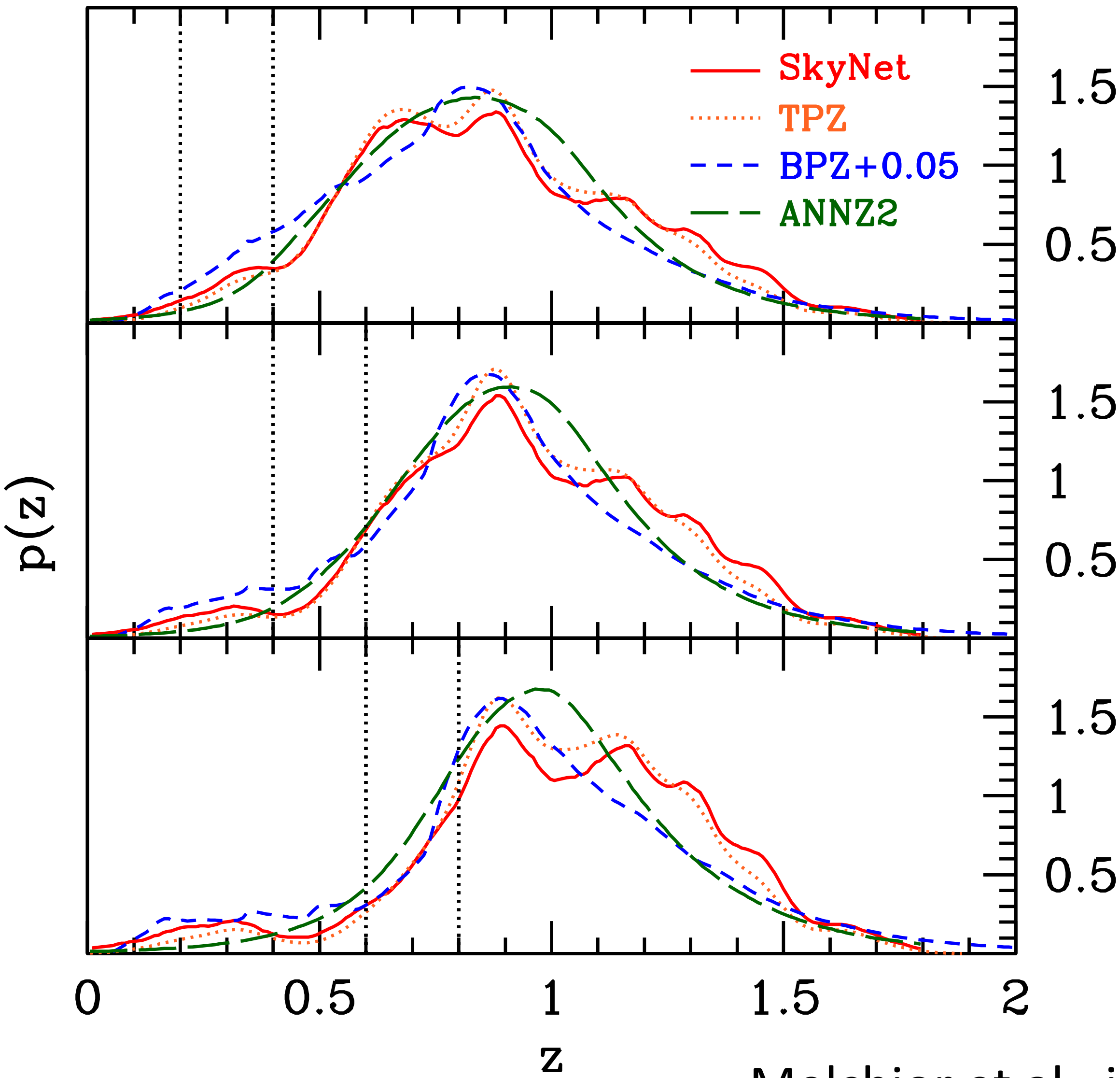
Problem: spectra don't exist!

~~**Solution**: use COSMOS 30-band photozs to test!~~

Solution:

- use multiple (a priori equally valid) methods.
- systematic error is mass range spanned by methods

Photoz Systematics



$\Delta M_{sys} = \pm\ 2.3\%$

$\Delta M_{sys} = \pm\ 3.2\%$

$\Delta M_{sys} = \pm\ 3.3\%$

Melchior et al., in prep., plot by Daniel Gruen

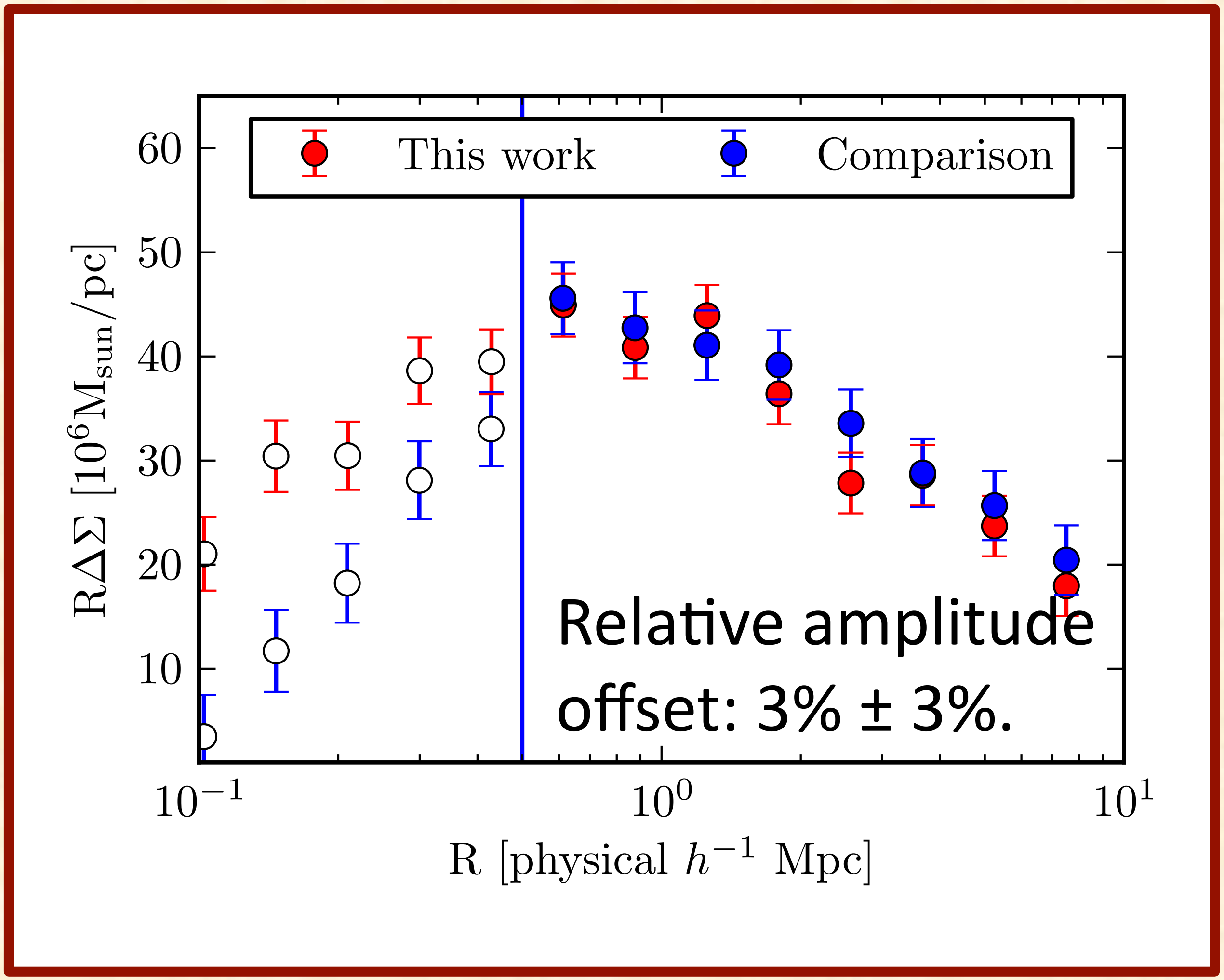
Systematics Require us to do Everything (at least) Twice

Two independent shape catalogs.

4 independent photoz catalogs.

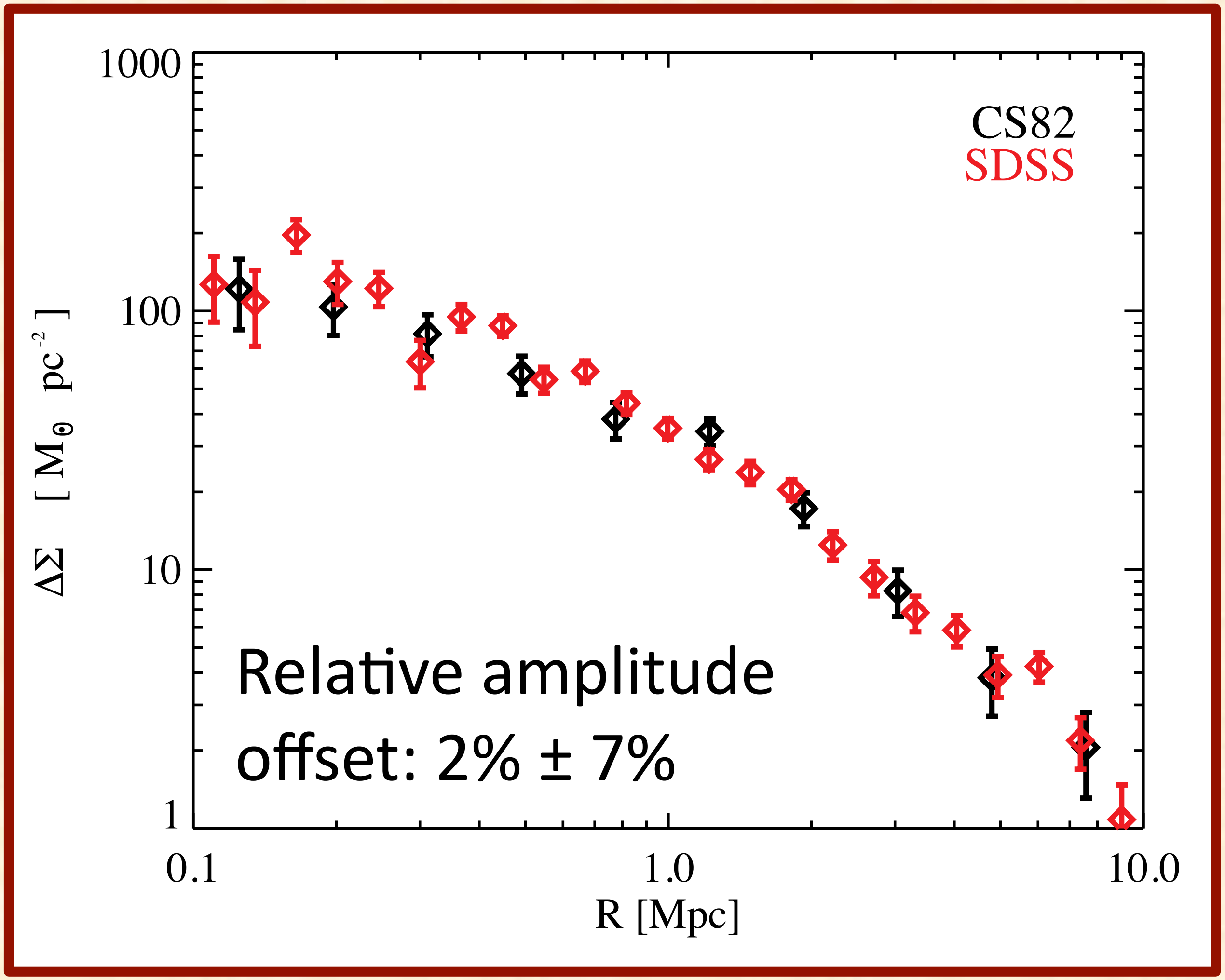
Significant efforts have gone into characterizing the relative performance of each.

Equivalent Tests for SDSS



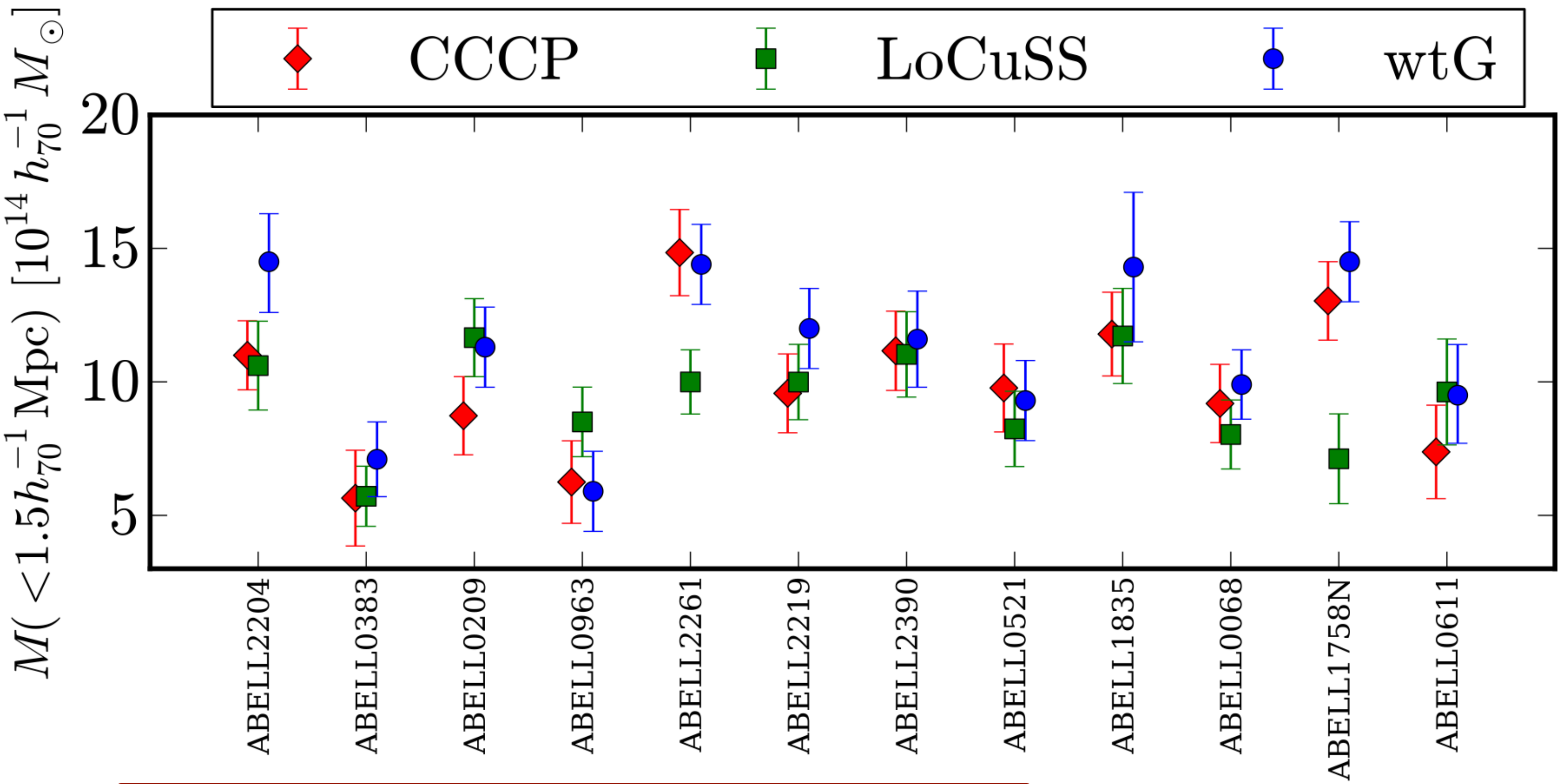
Simet et al. 2016

Equivalent Tests for SDSS



Plot by Alexie Leauthaud

Other Comparisons



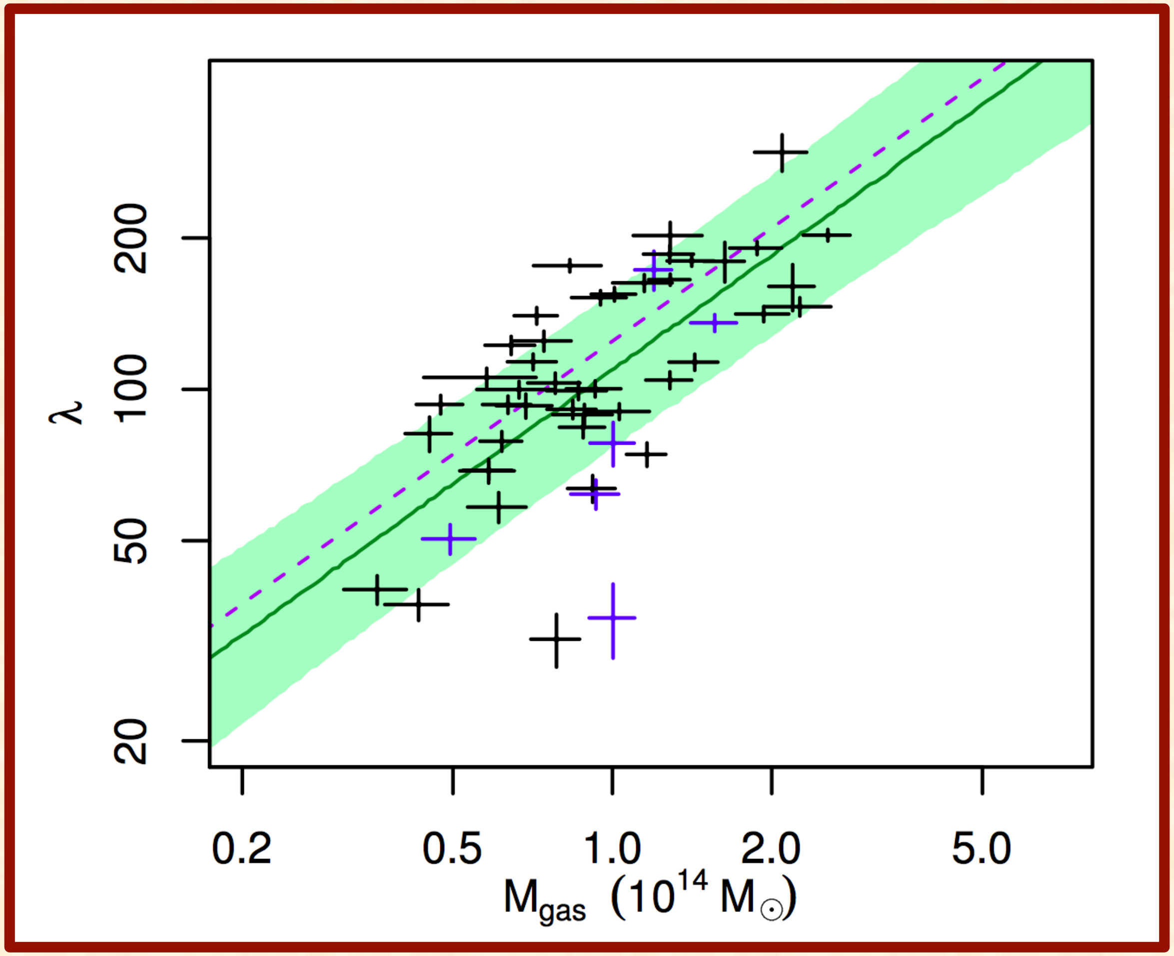
$M_{\mathrm{CCCP}}/M_{\mathrm{LoCuSS}} : 1.04 \pm 0.07$

$M_{\mathrm{wtG}}/M_{\mathrm{LoCuSS}} : 1.18 \pm 0.08$

$M_{\mathrm{wtG}}/M_{\mathrm{CCCP}} : 1.13 \pm 0.08$

Okabe and Smith 2015

redMaPPer—WtG



Mantz et al. 2016

Prospects for Improvement

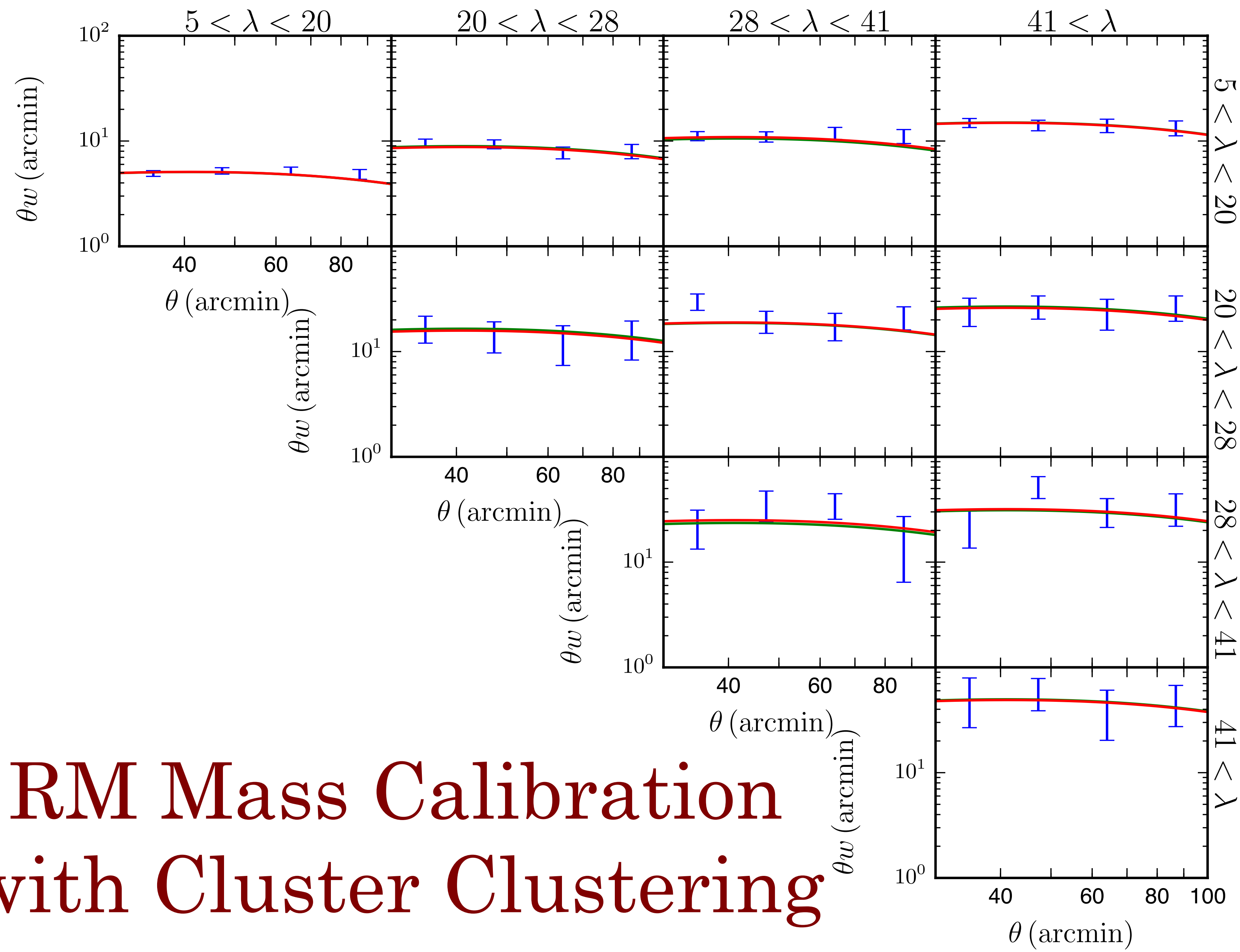
- Shape systematics:
  - New estimators (e.g. Bernstein & Armstrong 2014).
- Photoz systematics:
  - Spectroscopic campaigns.
  - cross-correlation methods.

Alternative mass calibration methods!

Alternatives

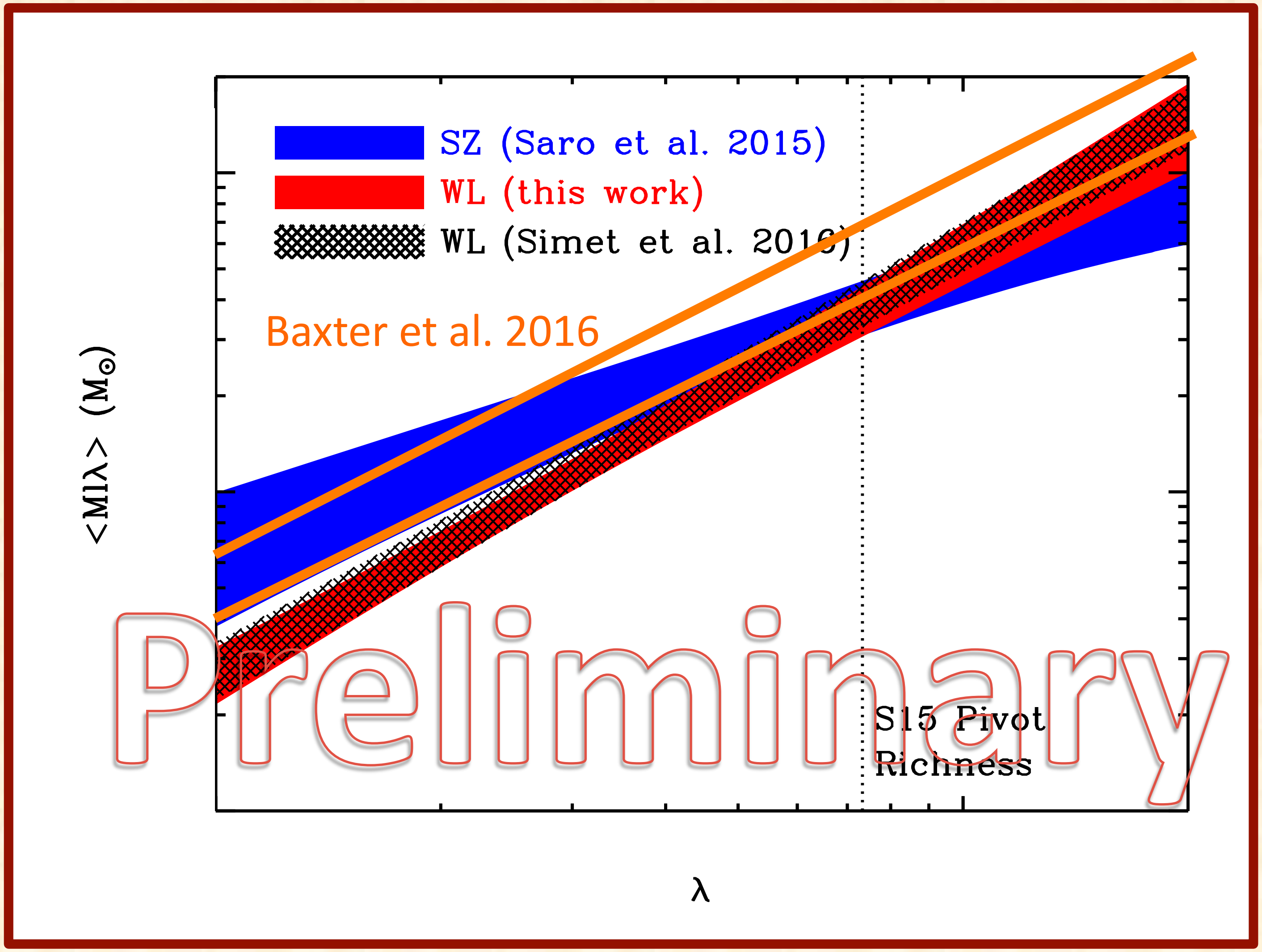
- X-ray/SZ
  - See following talk by Stefano Ettori.
- Cluster dynamics: (see talk by August Evrard)
  - Statistical precision is better than 2% (!).
  - Large systematic uncertainty: velocity bias.
- CMB lensing:
  - See talk be Jean Baptiste Melin.
- Cluster clustering

Baxter et al. 2016.



RM Mass Calibration with Cluster Clustering

Comparison of DES and SDSS



Melchior et al., in prep.

Alternatives

- Cluster clustering

  - Statistical precision = 7% in SDSS.

  - Systematics dominated: 18% uncertainty from the calibration of the bias—mass relation.

Expect we can reach statistical limit in
the not too distance future.

Summary

- Mass calibration is currently **systematics dominated.**

- WL is currently our best tool for mass calibration:
    - Shape systematics
    - Photoz systematics

- **Main take-away: we should estimate both shape and photozs in more than one way!**

- Multiple alternate methods are likely to become competitive in the near future.
    - CMB lensing
    - Cluster clustering