A Tale of Two Tensions

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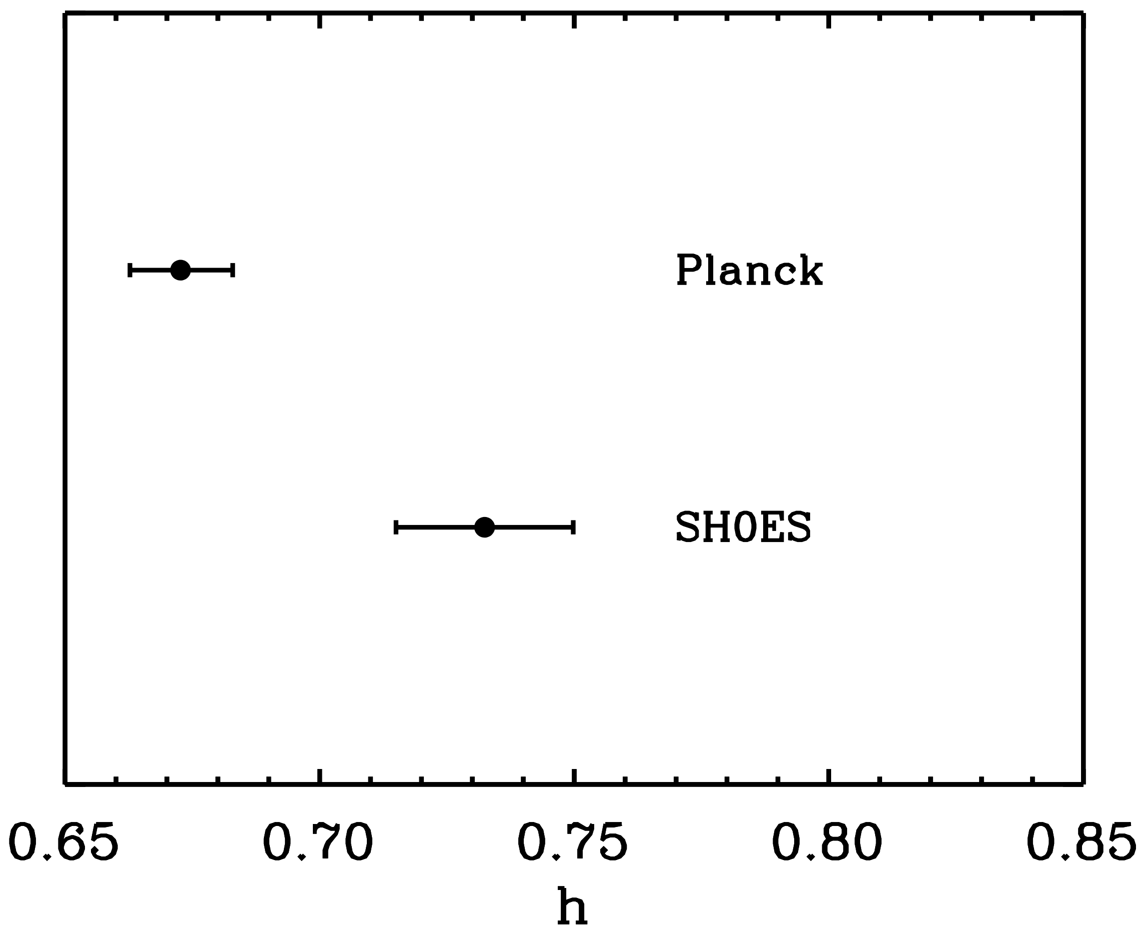
University of Arizona

Tensions in the LCDM Paradigm
Mainz, May 18, 2018

I assume a flat LCDM model throughout this whole talk.

Tension in H_0



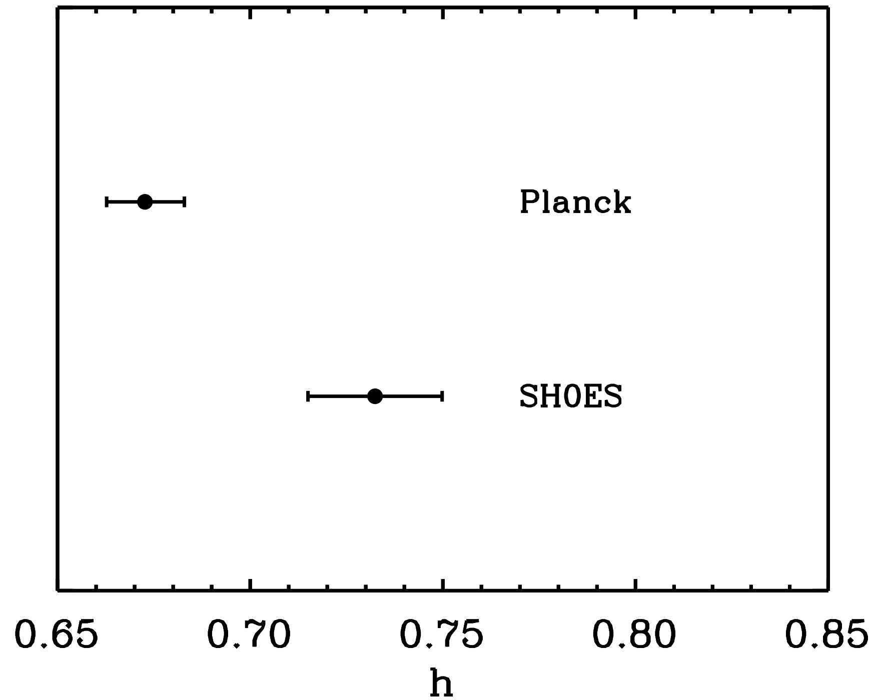
Difference is 3.3σ using Riess 2018 and Planck 2016 values.

Possibilities

A. Planck H_0 is basically right.

B. SH0ES H_0 is basically right.

C. Truth lives in between.



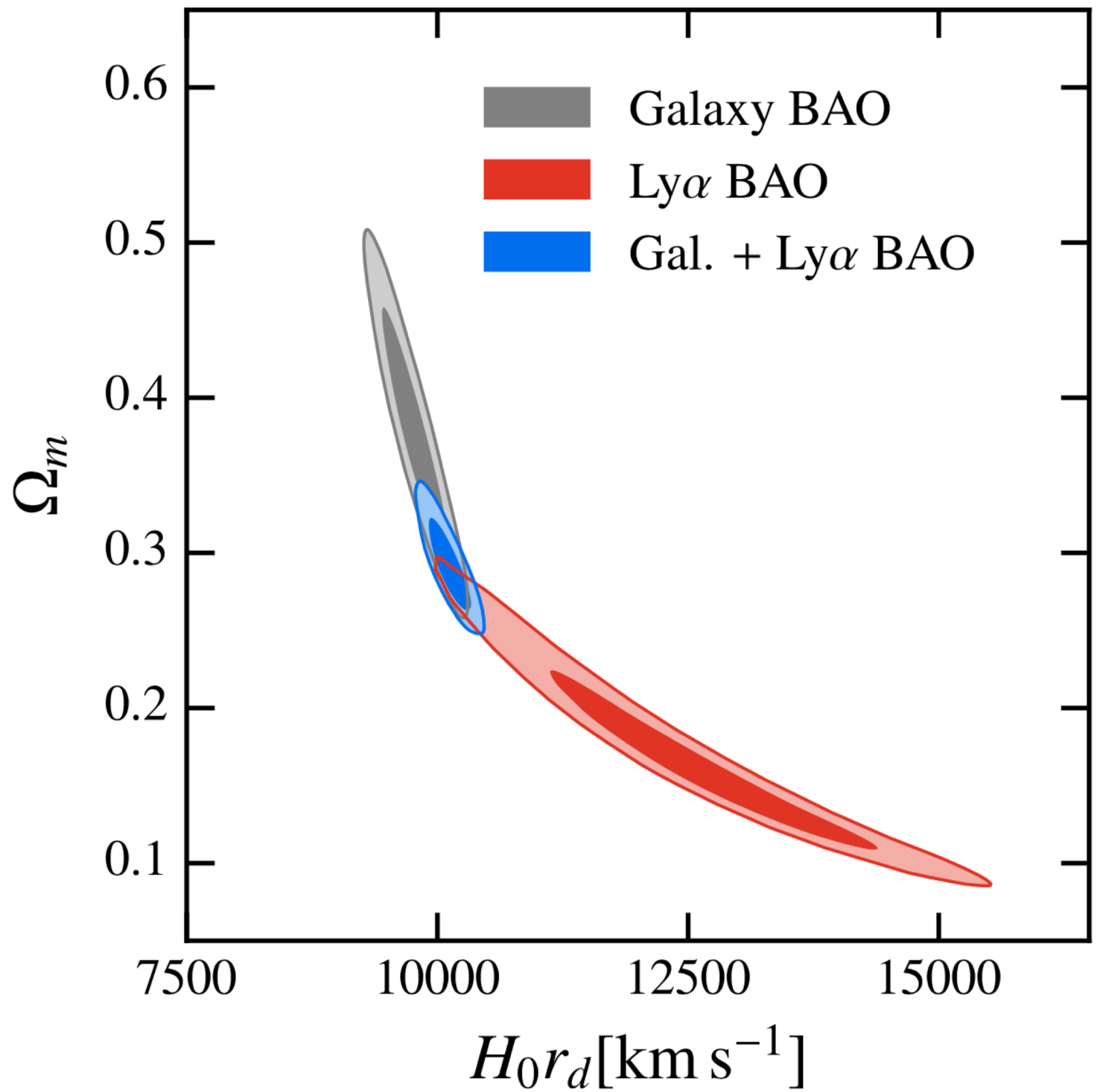
Suppose you were given new, 100% independent measurements of *h*.

What would the new data look like given each of the three options above?

An Astonishing Fact

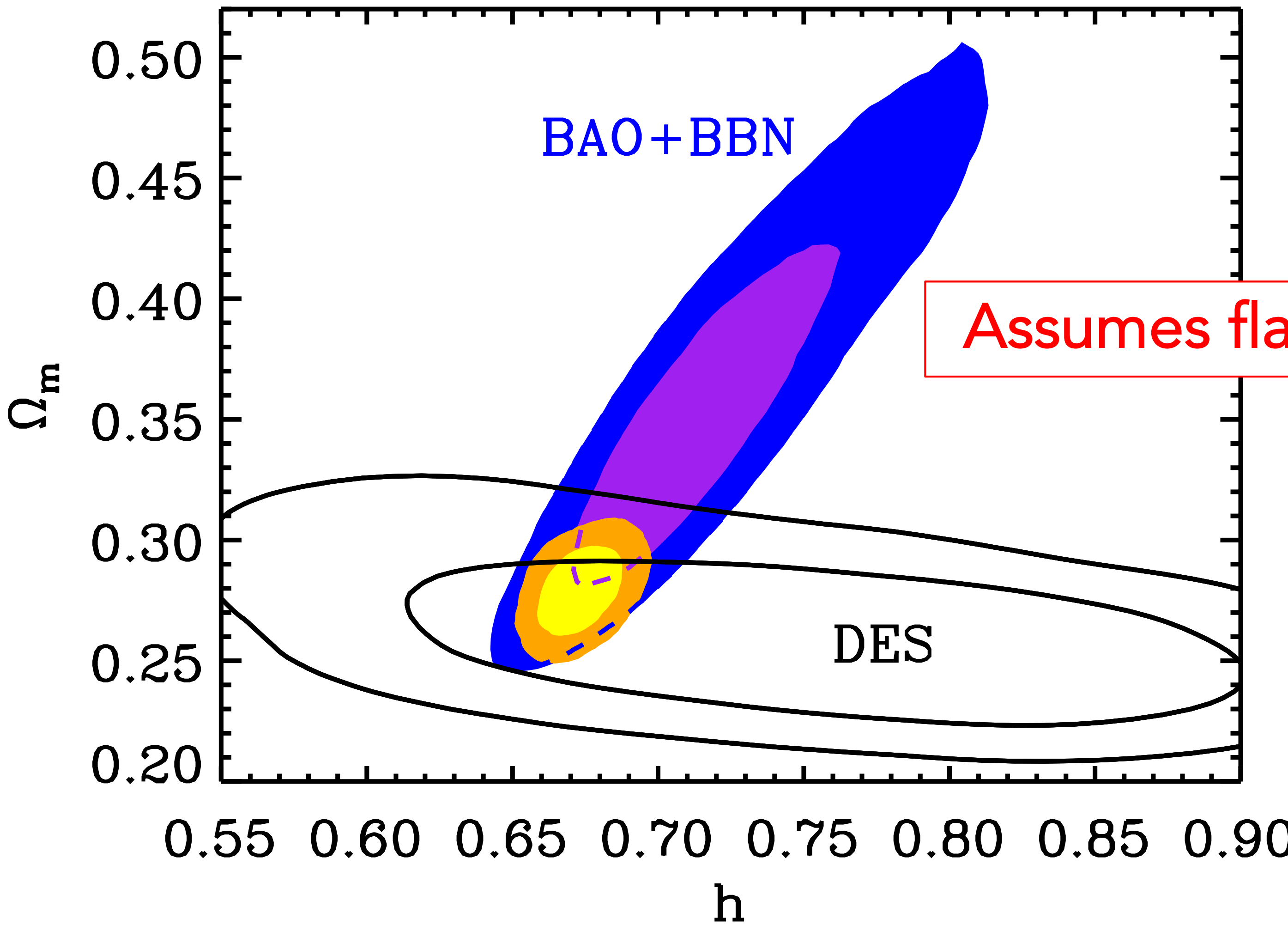
There are now ***FIVE*** *completely independent measurements of the Hubble constant with* ***comparable precision****!*

- Distance ladder
- Planck
- SPTPol (Henning et al. 2017)
- H0LiCOW
- **galaxy-BAO + BBN + (DES or Ly-α)**



Addison et al. 2018

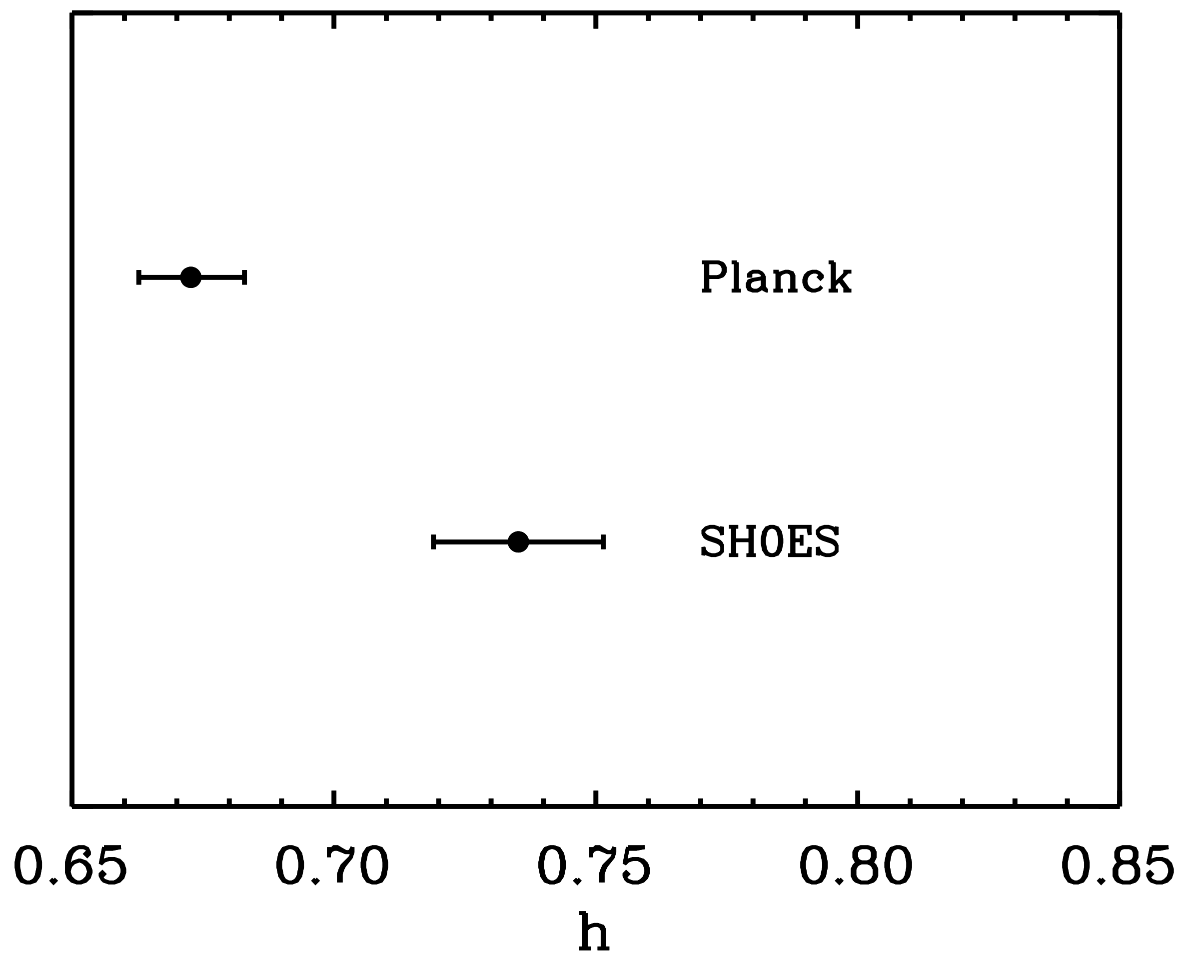
$$H_0 = 67.4^{+1.1}_{-1.2}\ \text{km/s/Mpc}$$



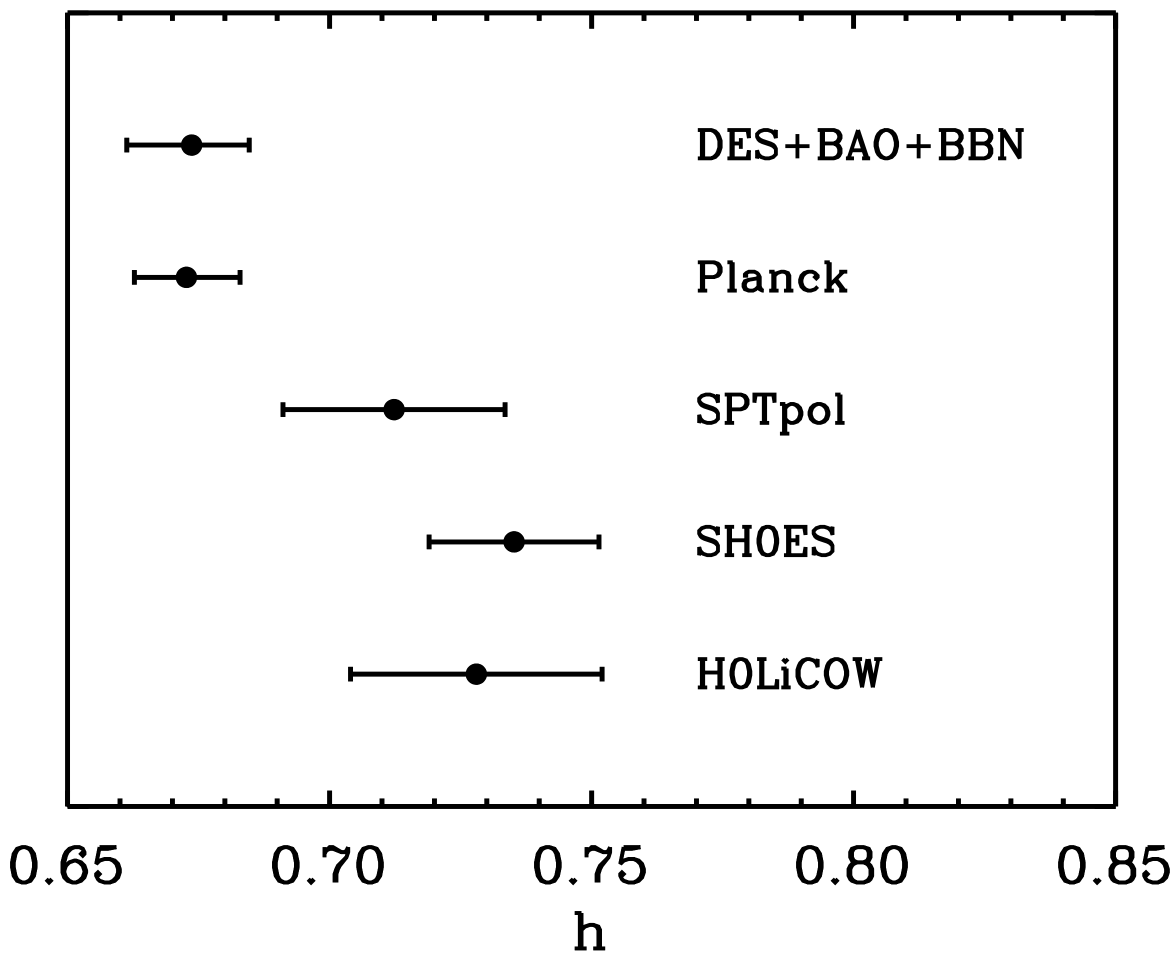
Assumes flat LCDM

Dark Energy Survey Year 1 Results: 1711.00403

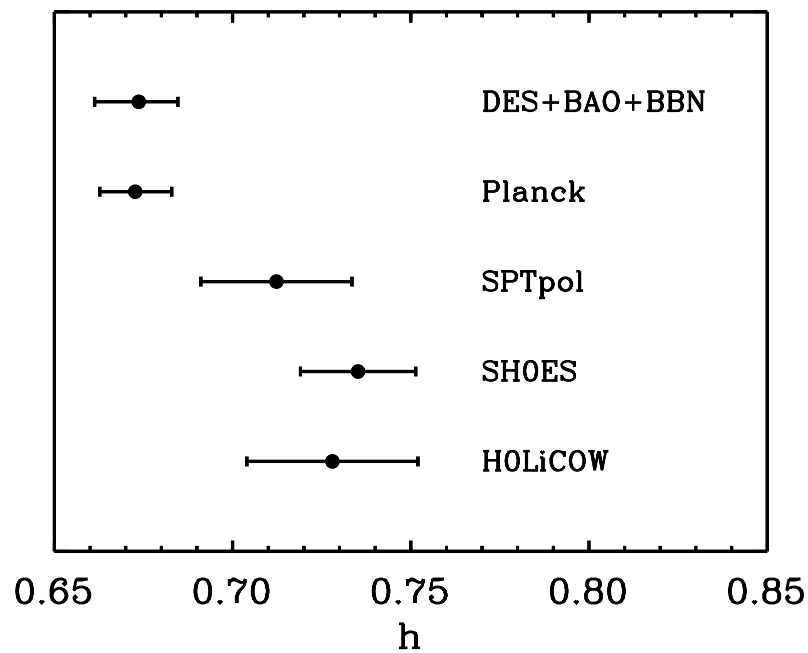
Let’s Fill Out This Plot



Is H_0 a Problem?



But Wait!

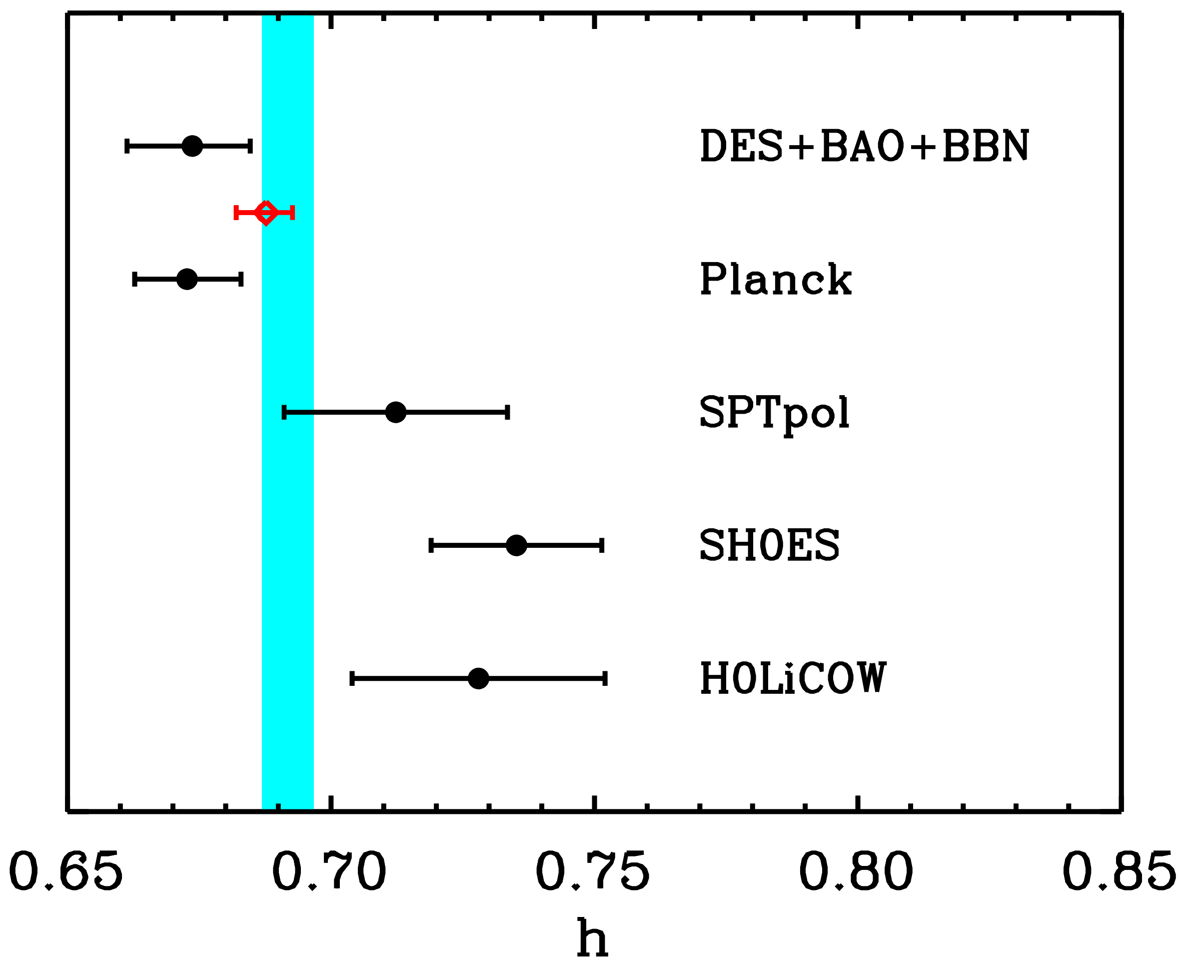


This is not the whole story.

Several of these data sets share more parameters than just *h*.

We need consistency across all data sets in the full N-dimensional parameters space!

Why Looking at the Full Space is **Necessary**



Everything: $H_0 = 69.3^{+0.4}_{-0.6}$ km/s/Mpc

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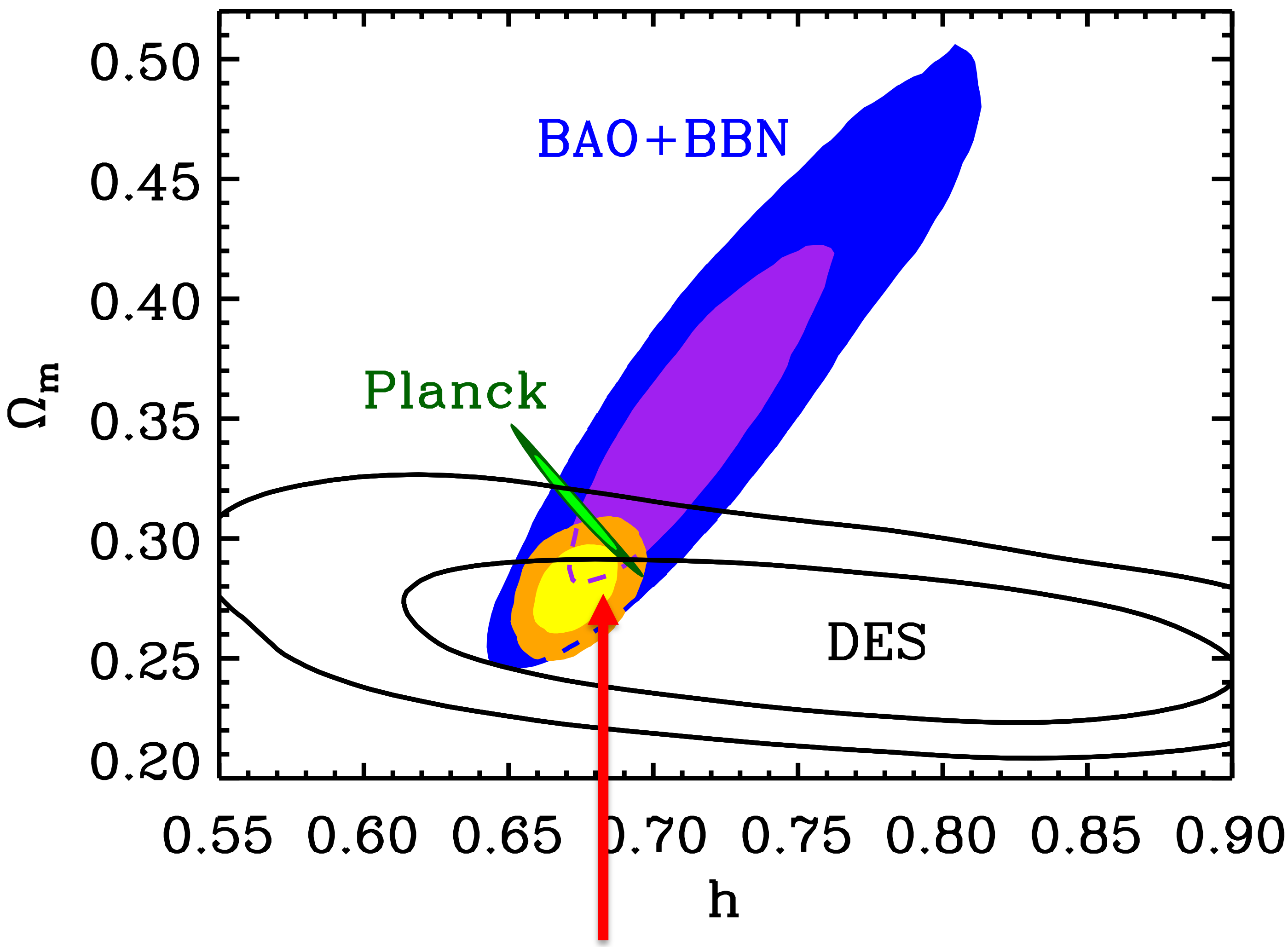


Intersection of *Planck* w/ DES+BAO+BBN is at high *h*

Consistency

There is more to life then *h*!

Planck:	Ω_m, Ω_b, h, σ_8, n_s
SPTpol:	Ω_m, Ω_b, h, σ_8, n_s
DES+BAO+BBN:	Ω_m, Ω_b, h, σ_8
SH0ES:	h
H0LiCOW:	h

Can't just look at *h*.

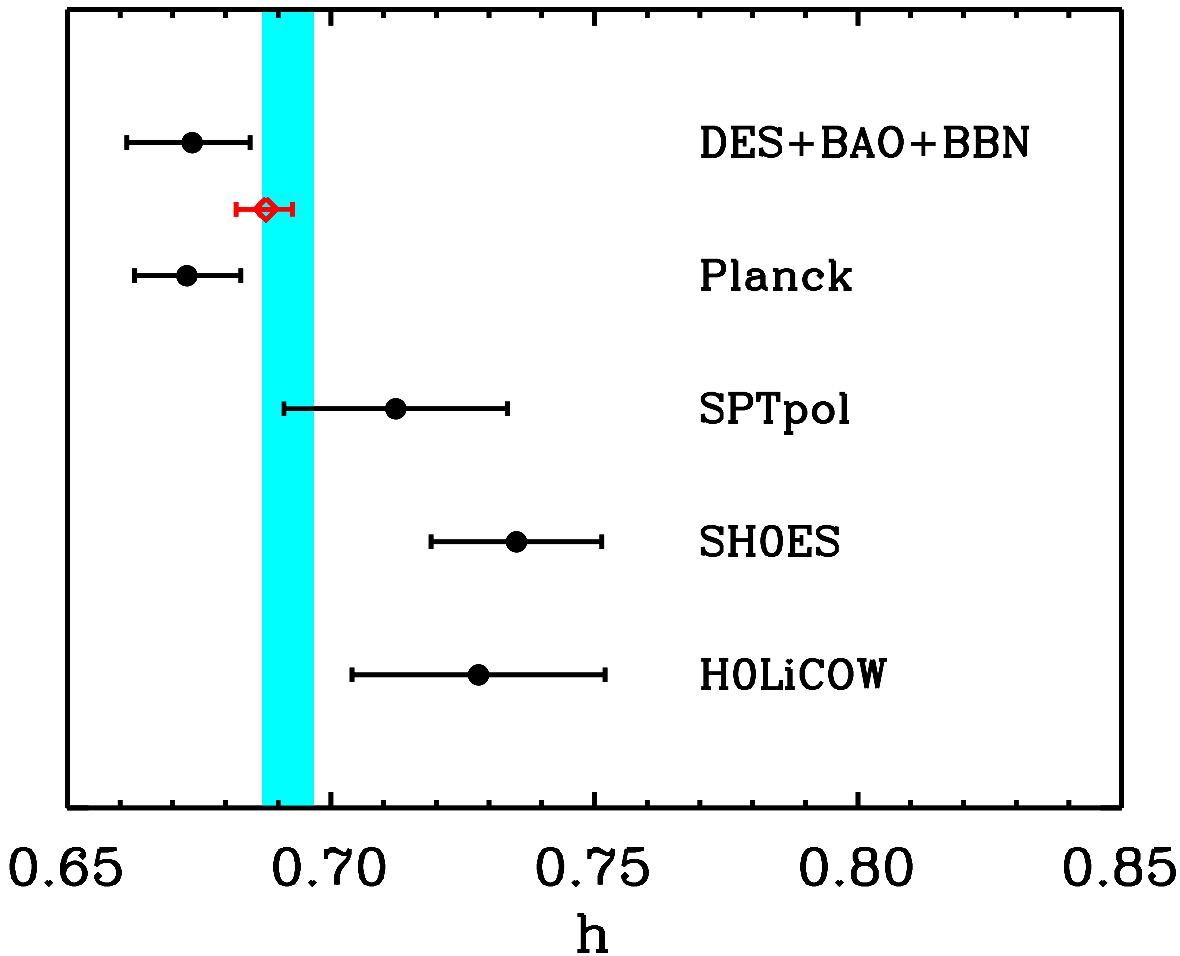
χ^2/DOF = 24.3/11

Significance: 2.5σ

Where is the Tension?

- Planck: $\chi^2/dof = 5.5/5$
- BAO+BBN+DES: $\chi^2/dof = 3.8/4$
- SPTPol: $\chi^2/dof = 5.6/5$
- SH0ES: $\chi^2/dof = 7.2/1$
- H0LiCOW: $\chi^2/dof = 2.3/1$

Is It Just High-z vs Low-z?



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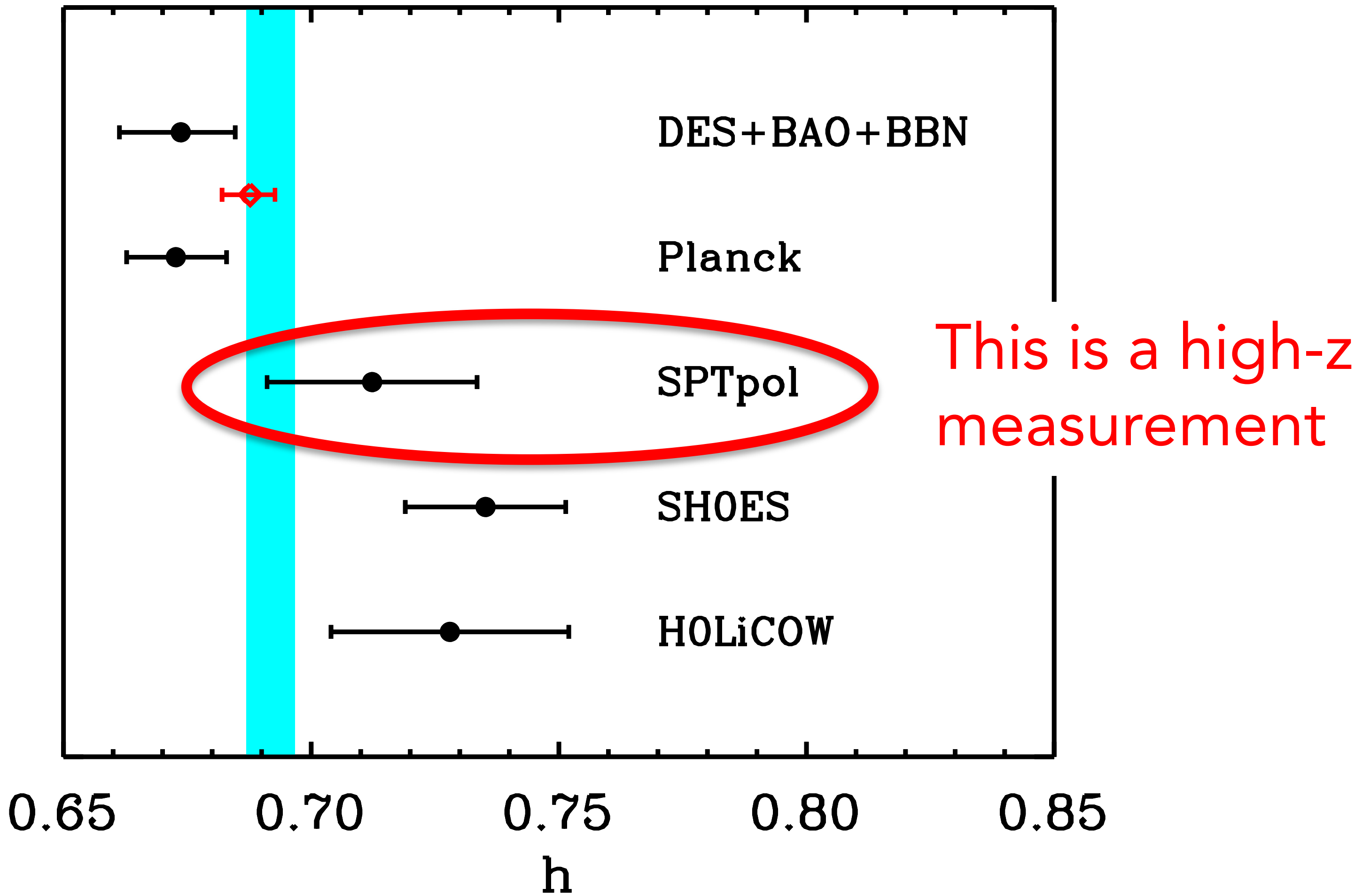

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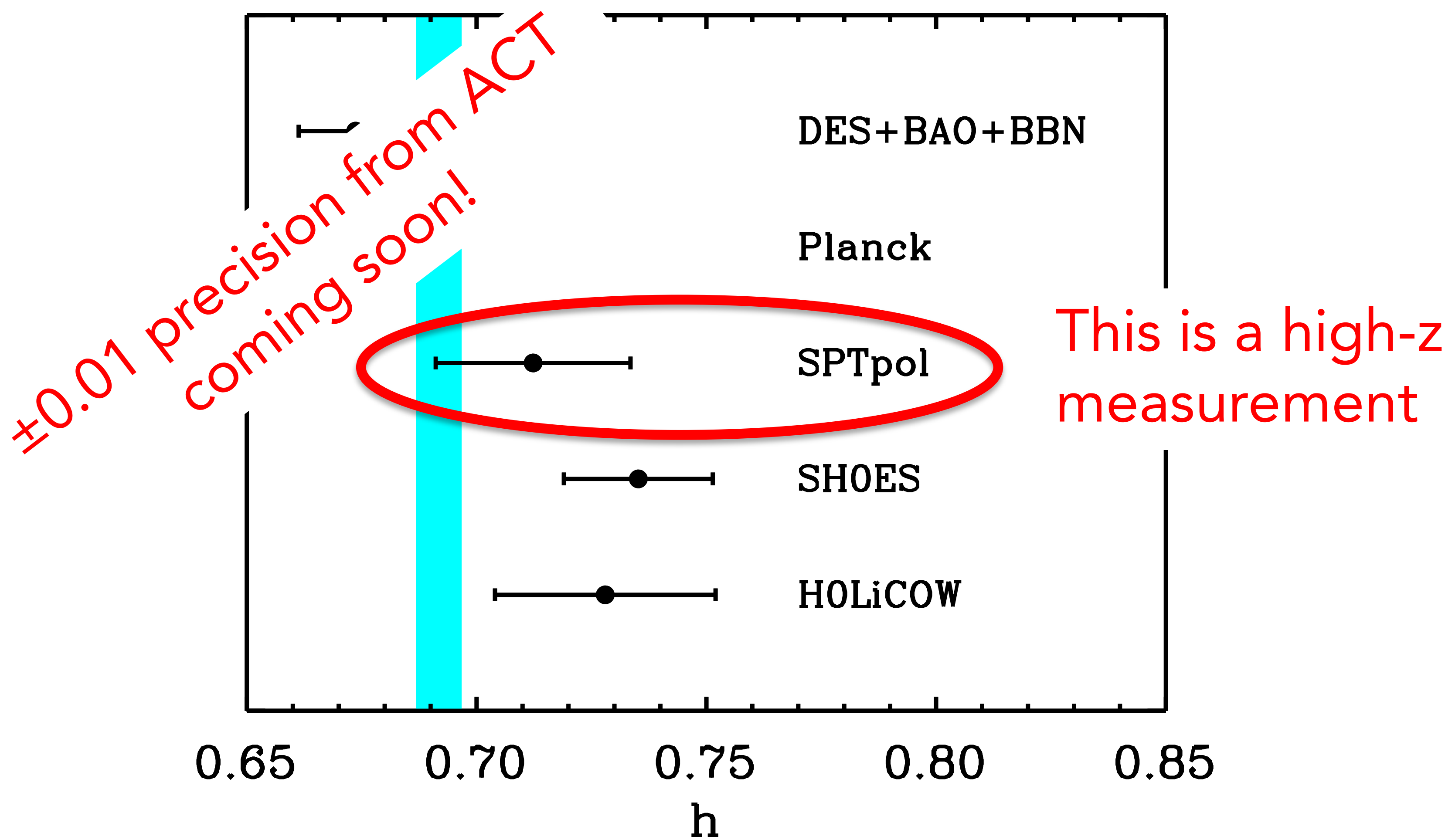

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Can We Relax Tension in SH0ES?

Table 6
Best Estimates of H_0 Including Systematics

Anchor(s)	Value ($\mathrm{km\ s^{-1}\ Mpc^{-1}}$)
One Anchor	
NGC 4258: Masers	72.25 ± 2.51
MW: 15 Cepheid Parallaxes	76.18 ± 2.37
LMC: 8 Late-type DEBs	72.04 ± 2.67
M31: 2 Early-type DEBs	74.50 ± 3.27
Two Anchors	
NGC 4258 + MW	74.04 ± 1.93
NGC 4258 + LMC	71.62 ± 1.78

Correlated errors!

- Two anchor value is consistent with everything else: 1.9σ.
- Tension seems to be driven by the addition of MW cepheids.

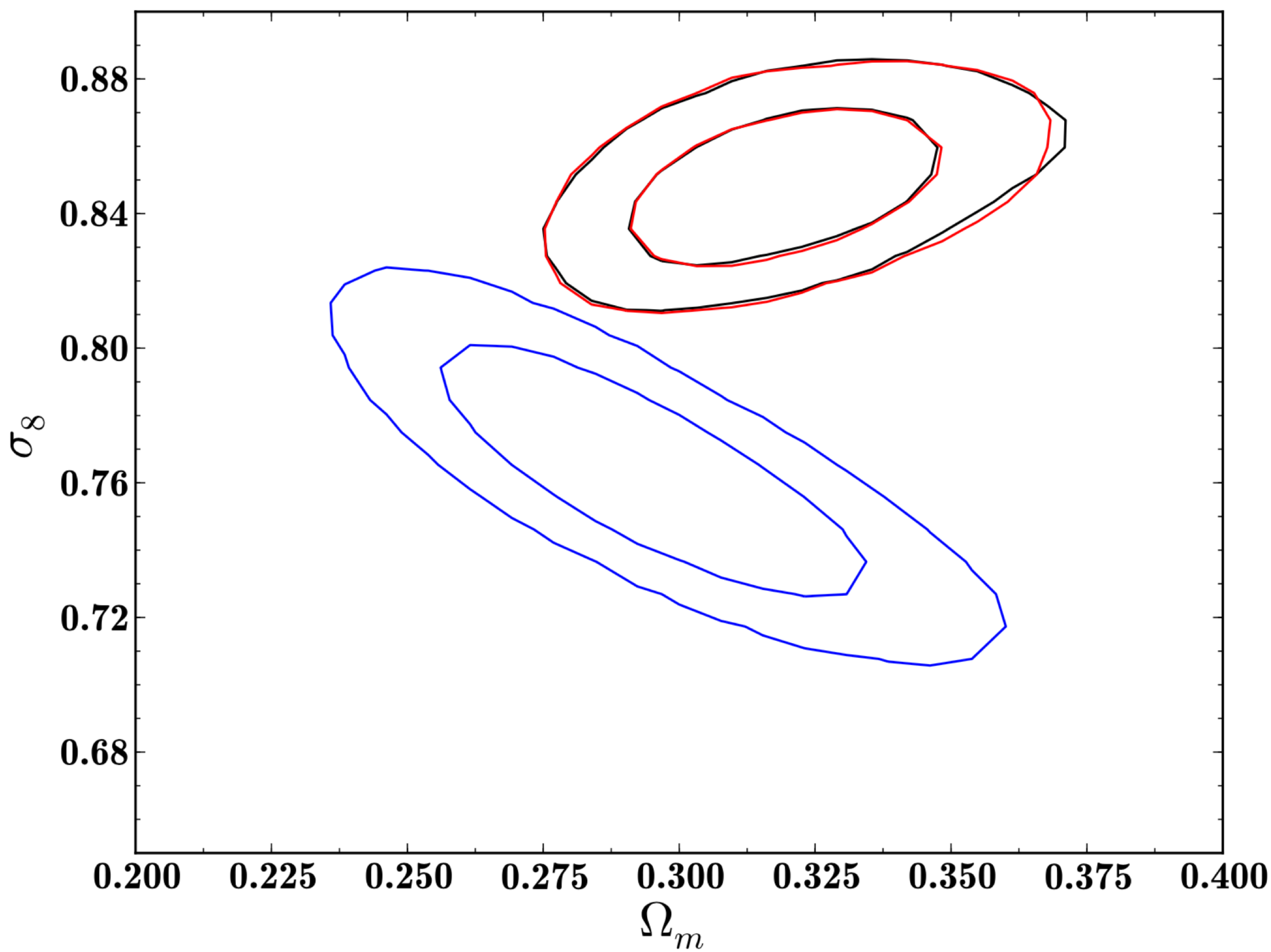
Can We Relax Tension in SH0ES?

- Is there tension in the P-L relation between the calibrator cepheids/LMC cepheids and MW cepheids?
- Are the different anchors consistent with one another?
  - Testing H_0 posterior w/ each individual calibrator is not enough.
  - Need to verify consistency prior to combining.

Summary

- There are now five fully independent, high-precision measurements of the Hubble constant.
- To me eye, "things scattering around a central value" looks plausible.
- Quantitatively, tension is 2.5σ. Are MW parallax/cepheids consistent with LMC/calibrator cepheids?
- $H_0 = 69.3^{+0.4}_{-0.6}$ km/s/Mpc
- ACT result coming soon: **what do you expect under each scenario?**

Are Clusters in Tension w/ Planck?



Strong tension reported in the original 2013 analysis.

The Problem

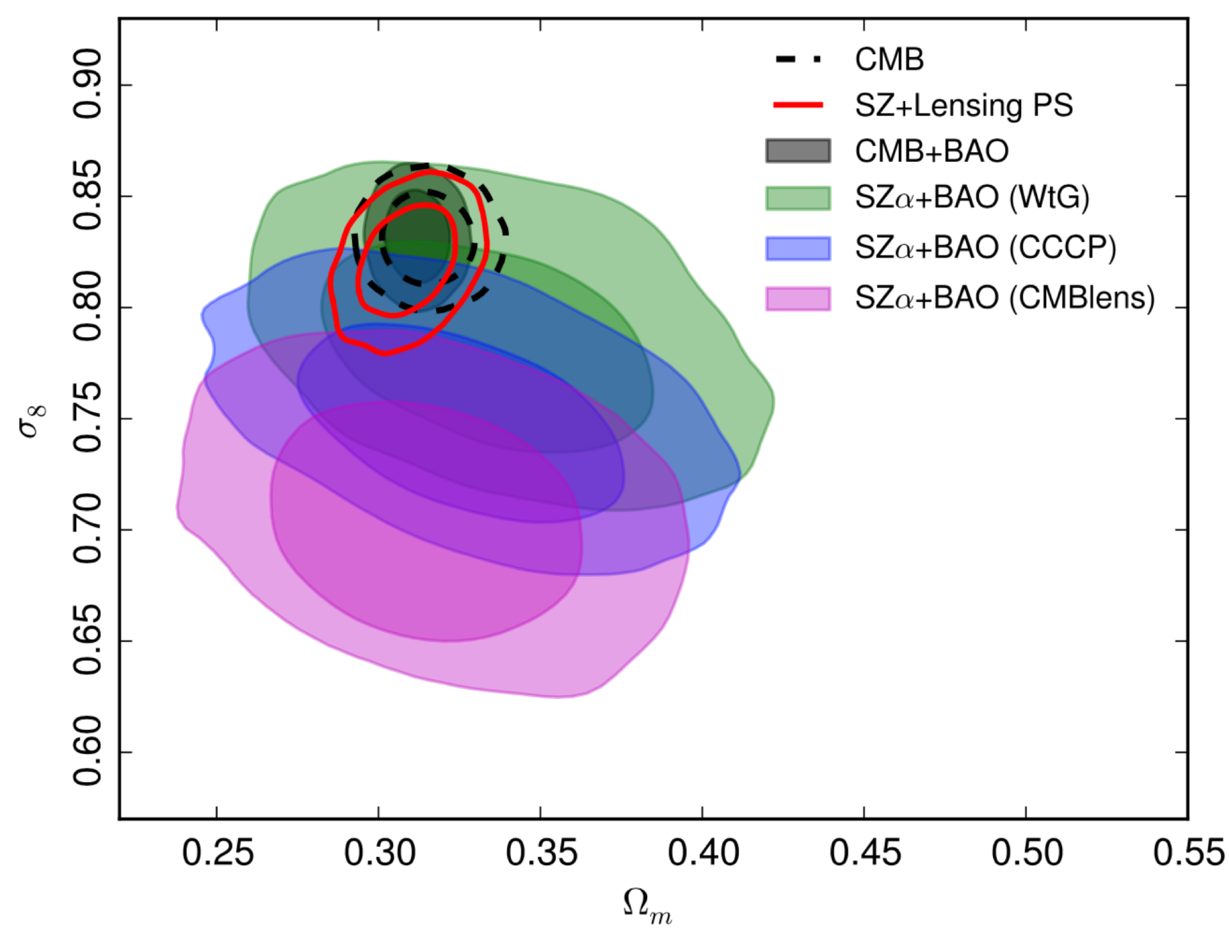
Basic idea behind cluster abundance as a cosmology probe is very simple:

More mass
More clustering ⟷ More *massive* clusters!

Key difficulty: we *must* have well-measured cluster masses.

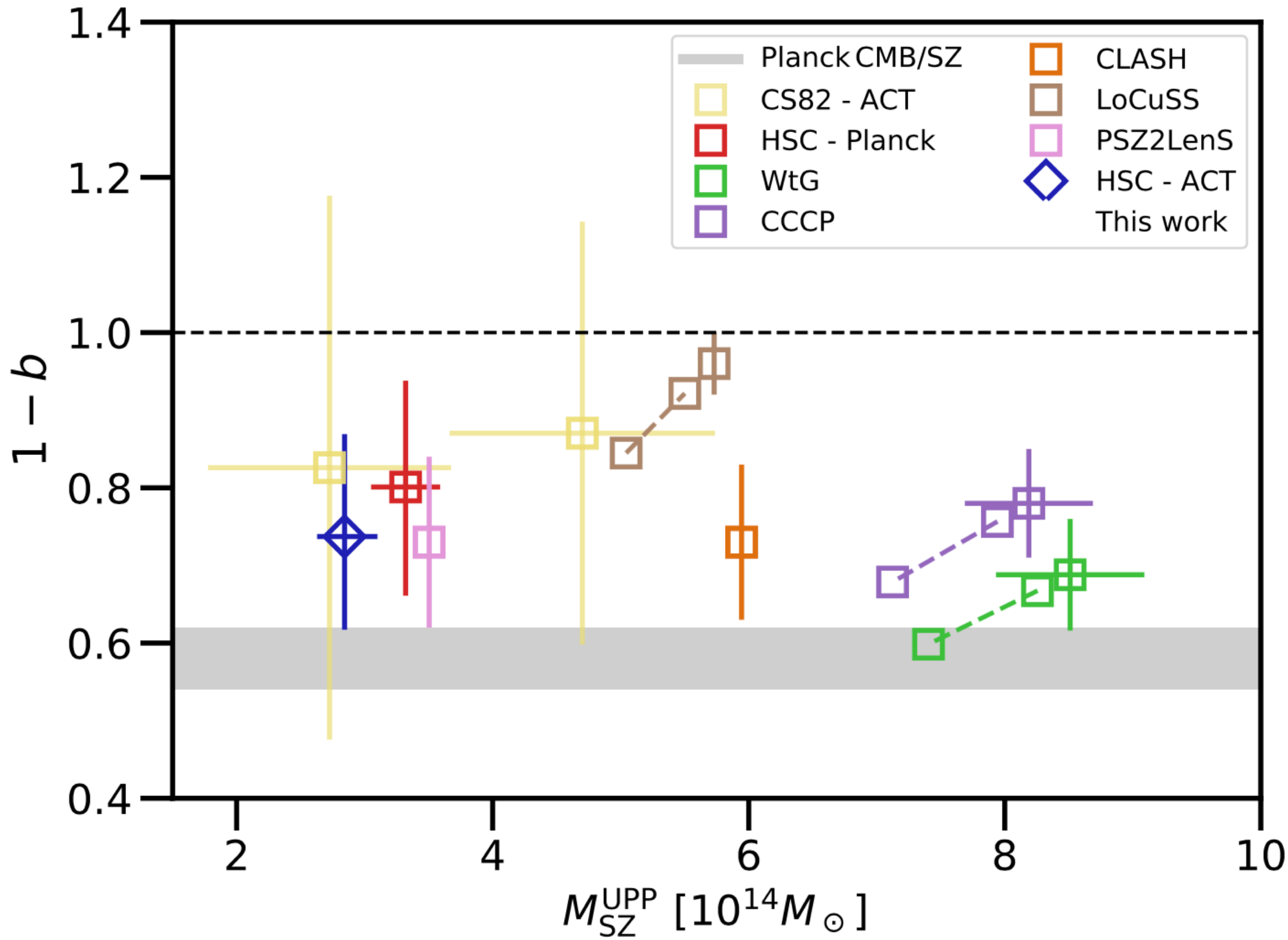
To zeroth order, that's the only thing that matters.
If you get the masses wrong, you get the cosmology wrong.

The Problem



Consistency rests entirely in our ability to measure cluster masses.

Where are We Now?



Miyatake et al. 2018

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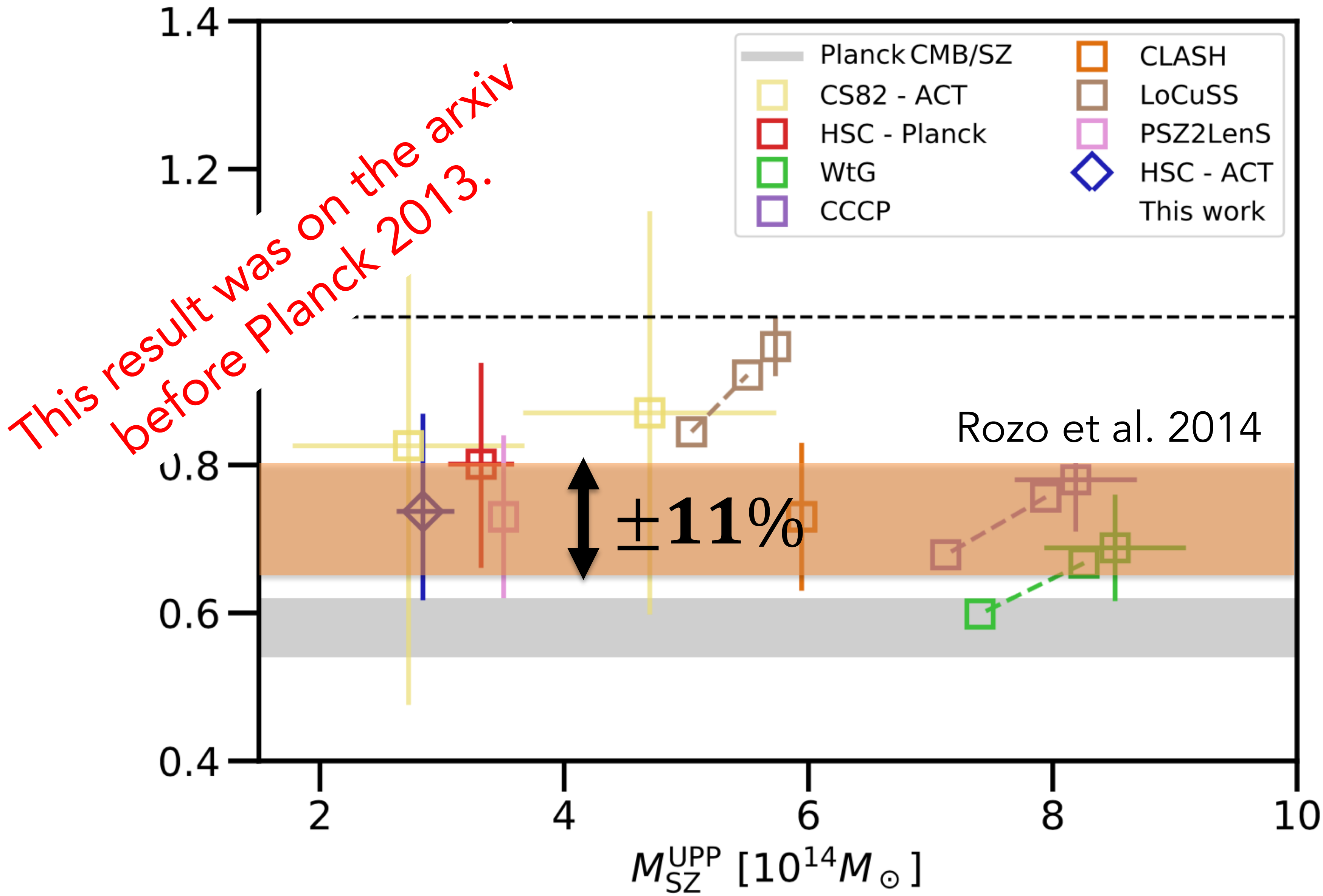

Miyatake et al. 2018

Long Story Short

- I don't think the SZ cluster abundance is in tension with Planck.
- Mass calibration clearly points towards lower $S_8 = \sigma_8 \Omega_\mathrm{m}^{1/2}$.

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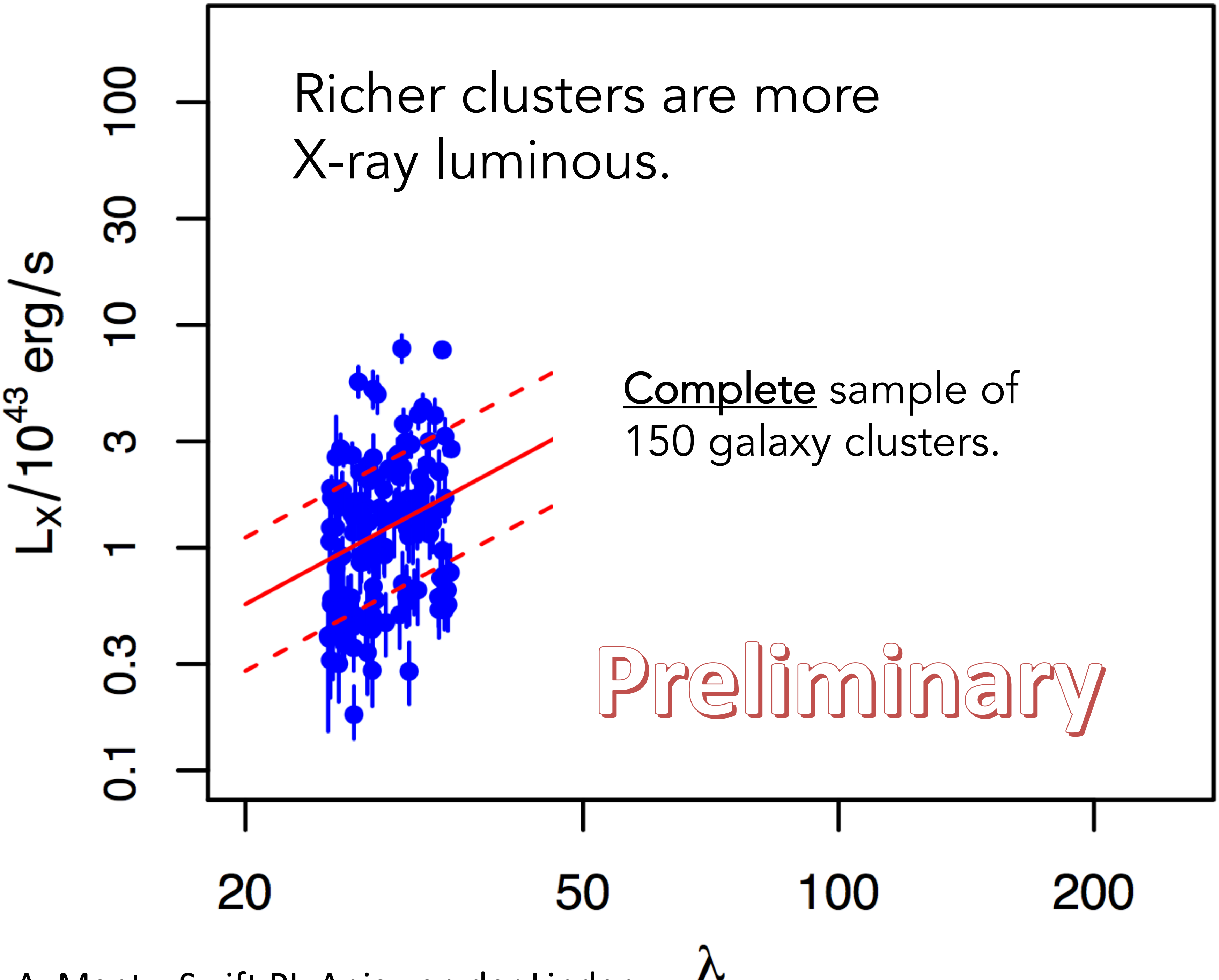
Hmmmmm…

You know- what I <u>**really**</u> want is an independent, <u>**blind analysis**</u> of another cluster sample with kick-ass WL mass calibration.

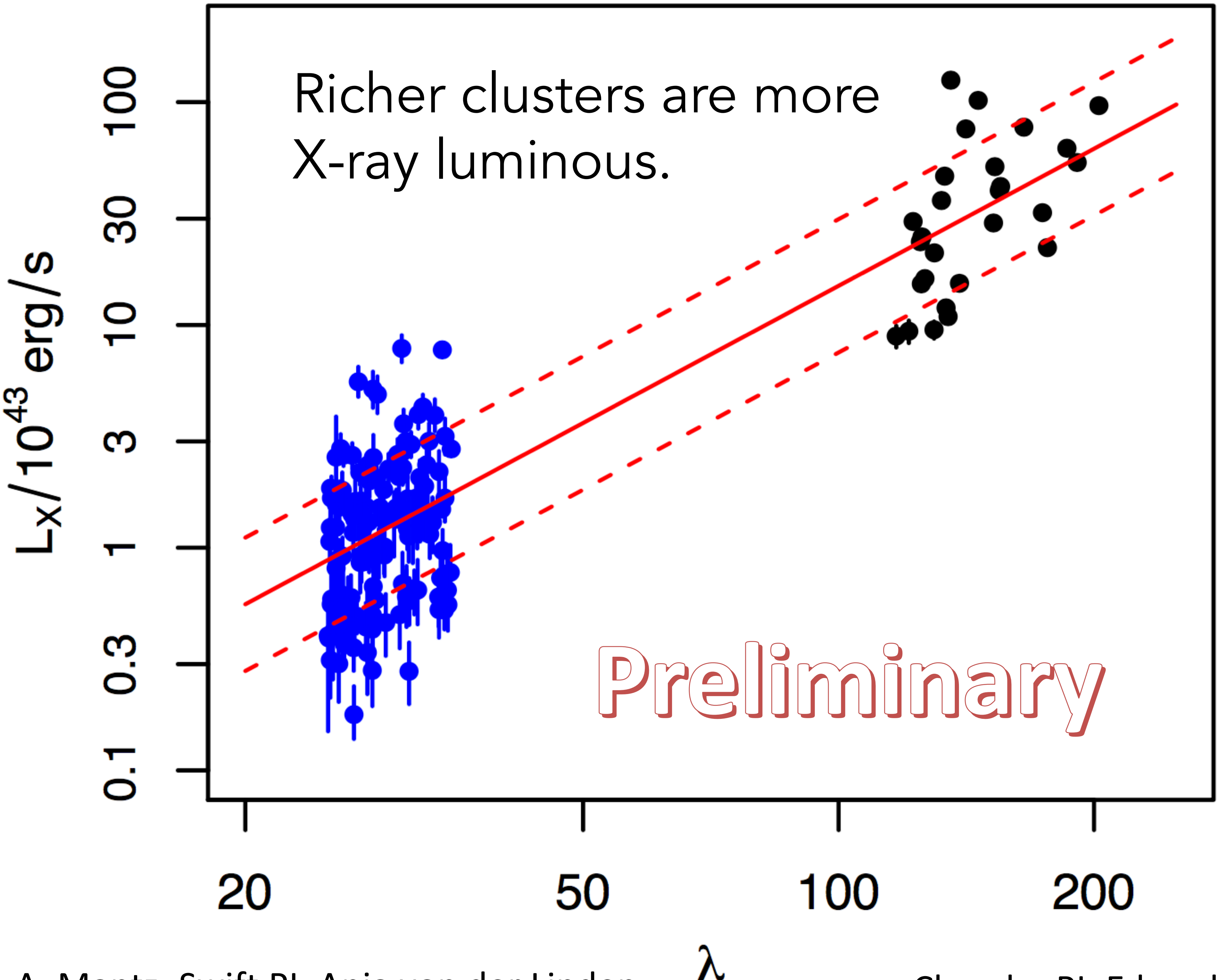
Cosmology with redMaPPer Clusters

redMaPPer is a red-sequence cluster finding algorithm, applied to both SDSS and DES.

- Fantastic photozs: $\sigma_z/(1+z) \approx 0.006$.
- Richness correlates well with mass.



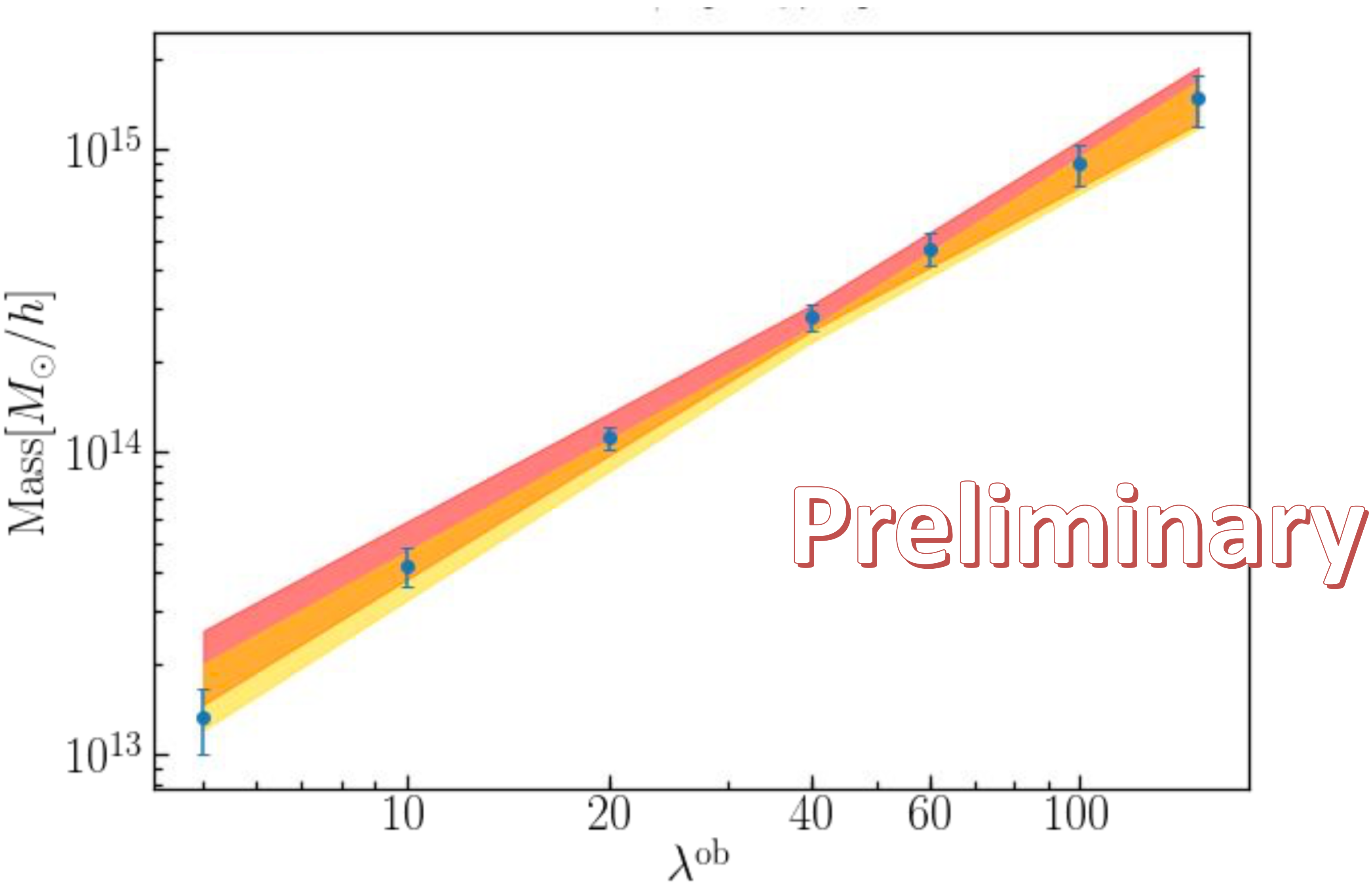
Plot: A. Mantz; Swift PI: Anja von der Linden



Plot: A. Mantz; Swift PI: Anja von der Linden

Chandra PI: Eduardo Rozo

Richness Correlates with Mass



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- Amazing weak lensing mass calibration

Tom McClintock

Tamas Varga

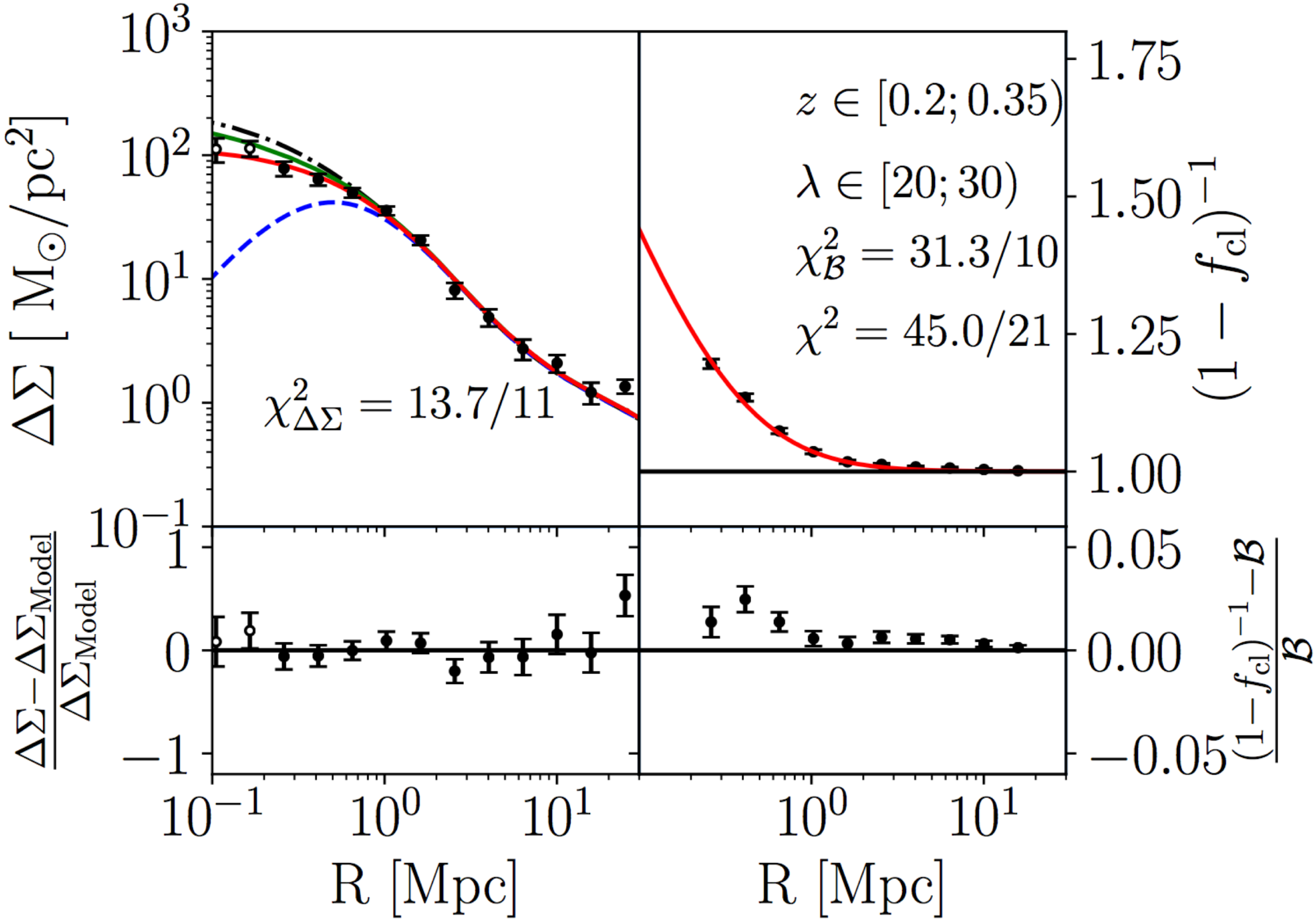
Mass calibration heroes!

WL Mass Calibration in the DES

- Measure tangential shear in redshift/richness bins.
- Blind analysis
- Fit using a halo model calibrated to simulations.
- Semi-analytic covariance matrix in excellent agreement with JK estimates.
- Accounts for:
  - Cluster miscentering
  - Projections and cluster triaxiality
  - Modeling systematics
  - Photoz/shape systematics
  - Membership dilution

McClintock et al. 2018

WL Mass Calibration in the DES



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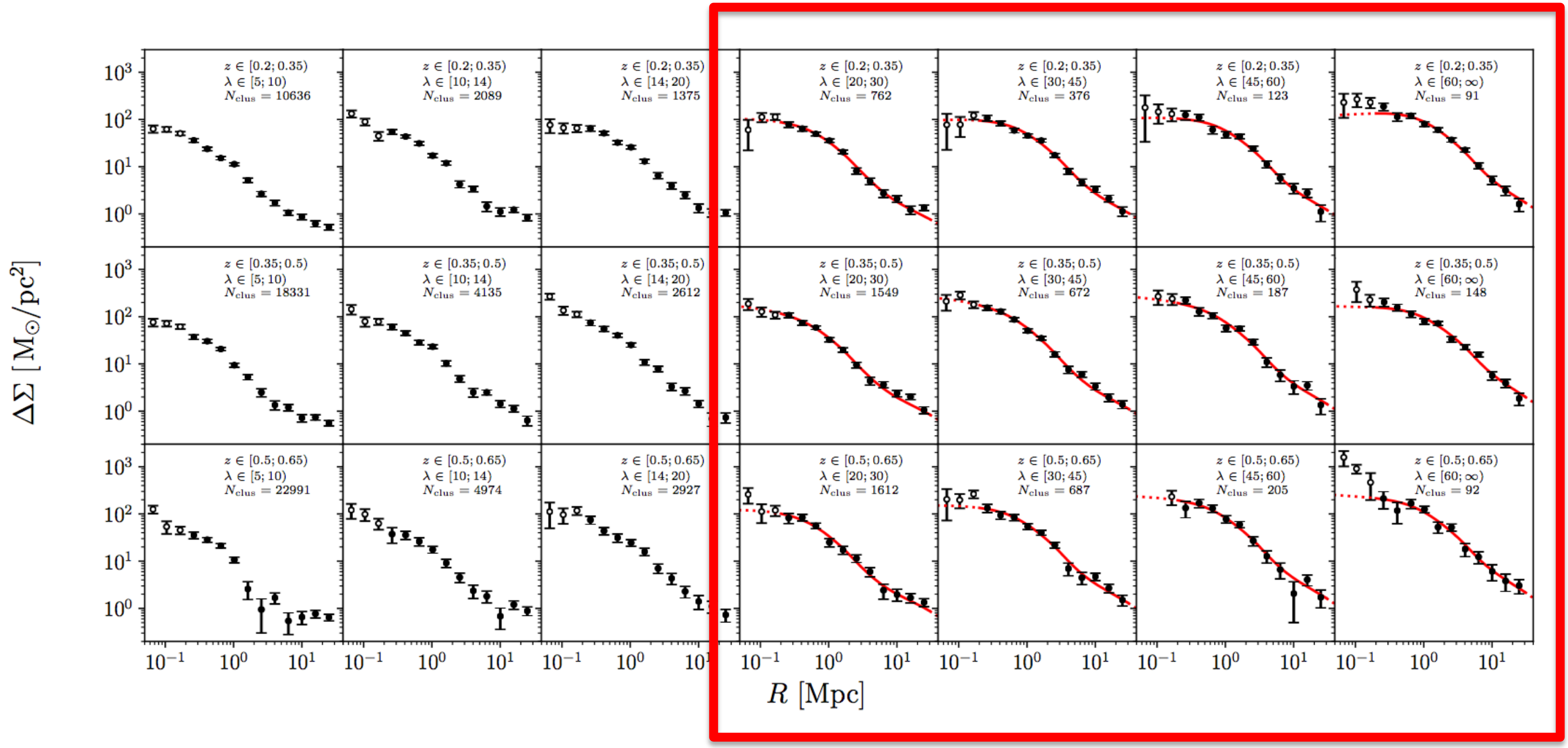
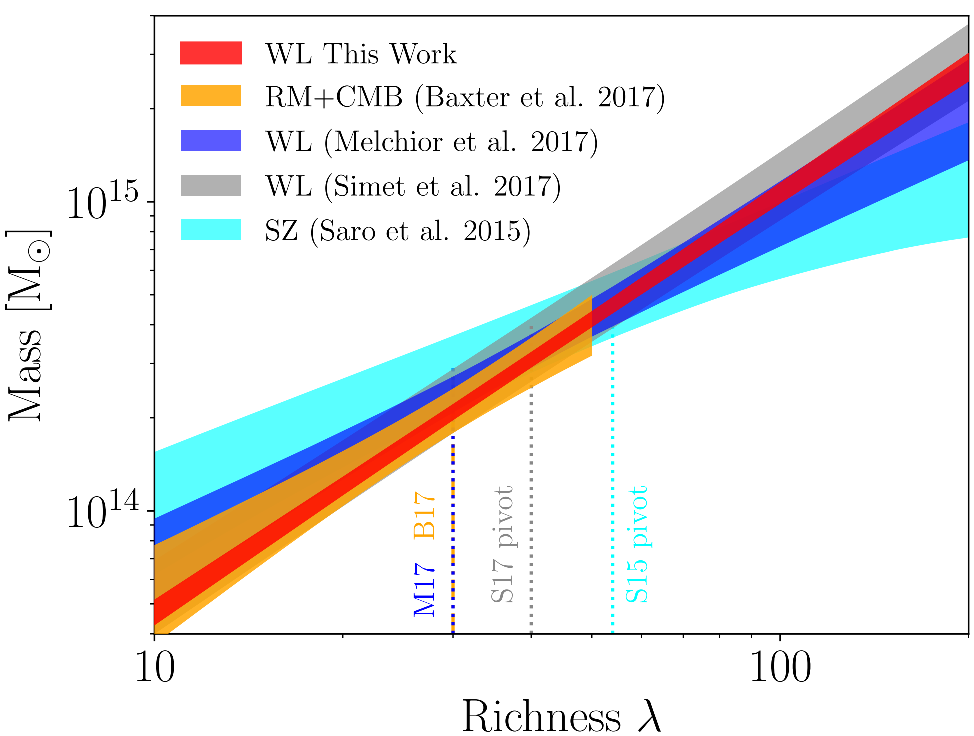


We fit 12 bins in richness/redshift.

McClintock et al. 2018

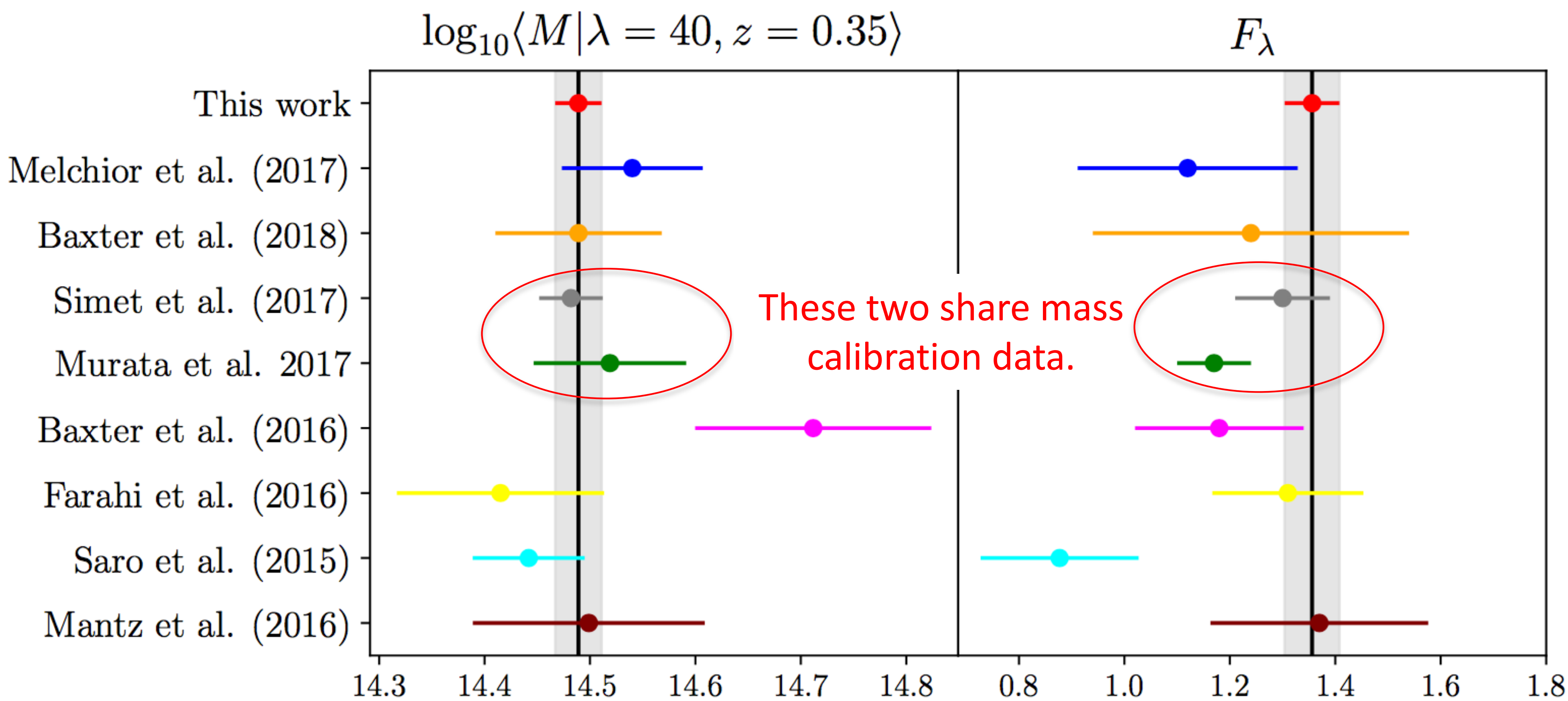
Source of systematic	SV Amplitude uncertainty	Y1 Amplitude Uncertainty
Shear measurement	4%	1.7%
Photometric redshifts	3%	2.6%
Modeling systematics	2%	0.73%
Cluster triaxiality	2%	2.0%
Line-of-sight projections	2%	2.0%
Membership dilution + miscentering	$\leqslant 1\%$	0.78%
Total Systematics	6.1%	4.3%
Total Statistical	9.4%	2.4%
Total	11.2%	5.0%



- Blind analysis
- Most accurate and precise mass calibration to date.

McClintock et al. 2018

Comparison to Previous Results



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I am sold. This is amazing! What did you find?

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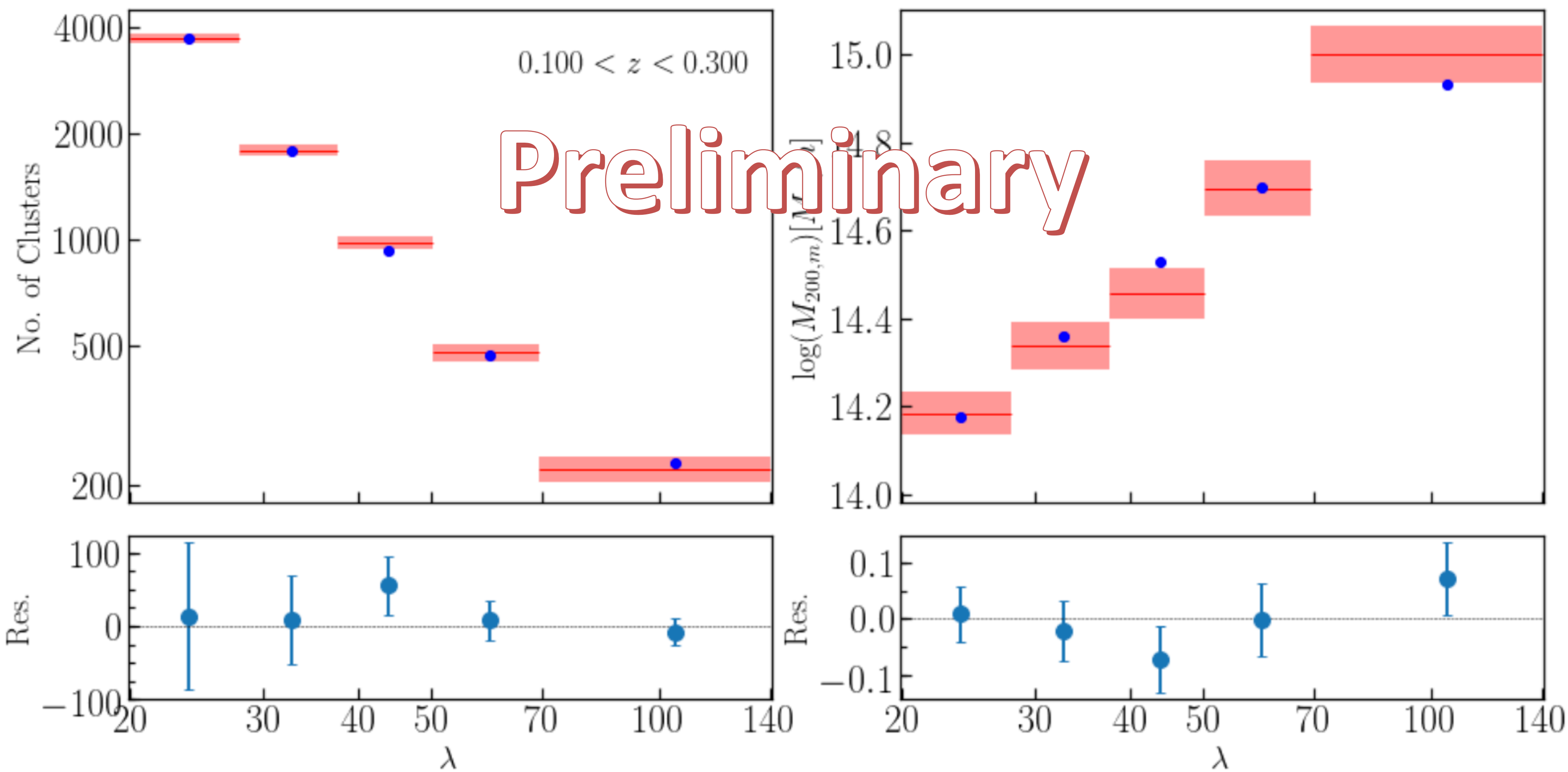
- DES analysis has a 2-stage blinding:
  - Run full analysis in SDSS (done).
  - Then run full analysis in DES (still blind).

SDSS Cluster Cosmology

Matteo Costanzi



Blinding

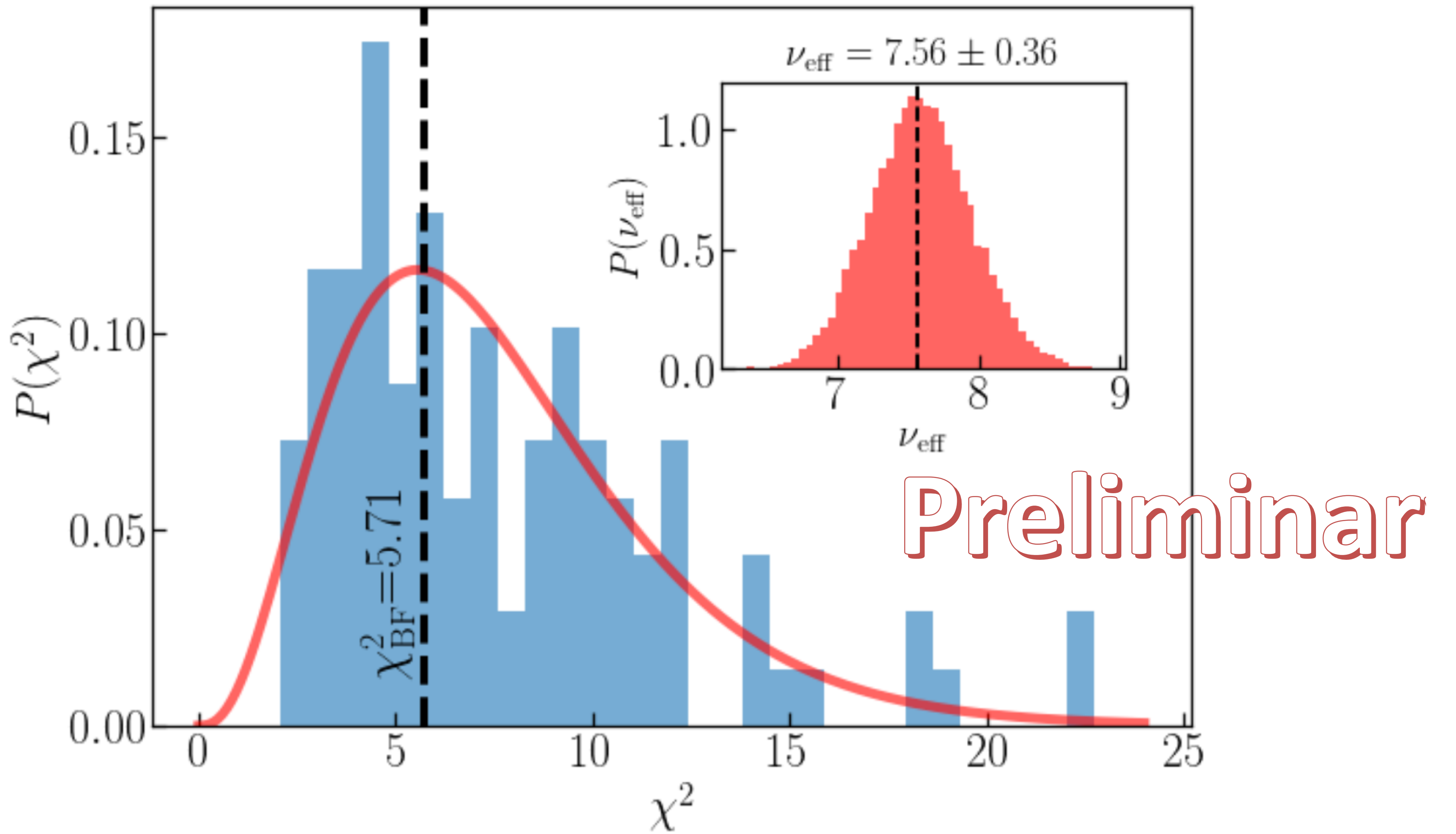
Before unblinding:

- Specify all modelling choices, including calibrating any necessary nuisance parameters.
- Select external data sets for comparison, consistency metric, and consistency threshold for combining analyses.
- Catalogs must have passed 3x2pt validation tests.
- Data vectors unblinded and frozen.

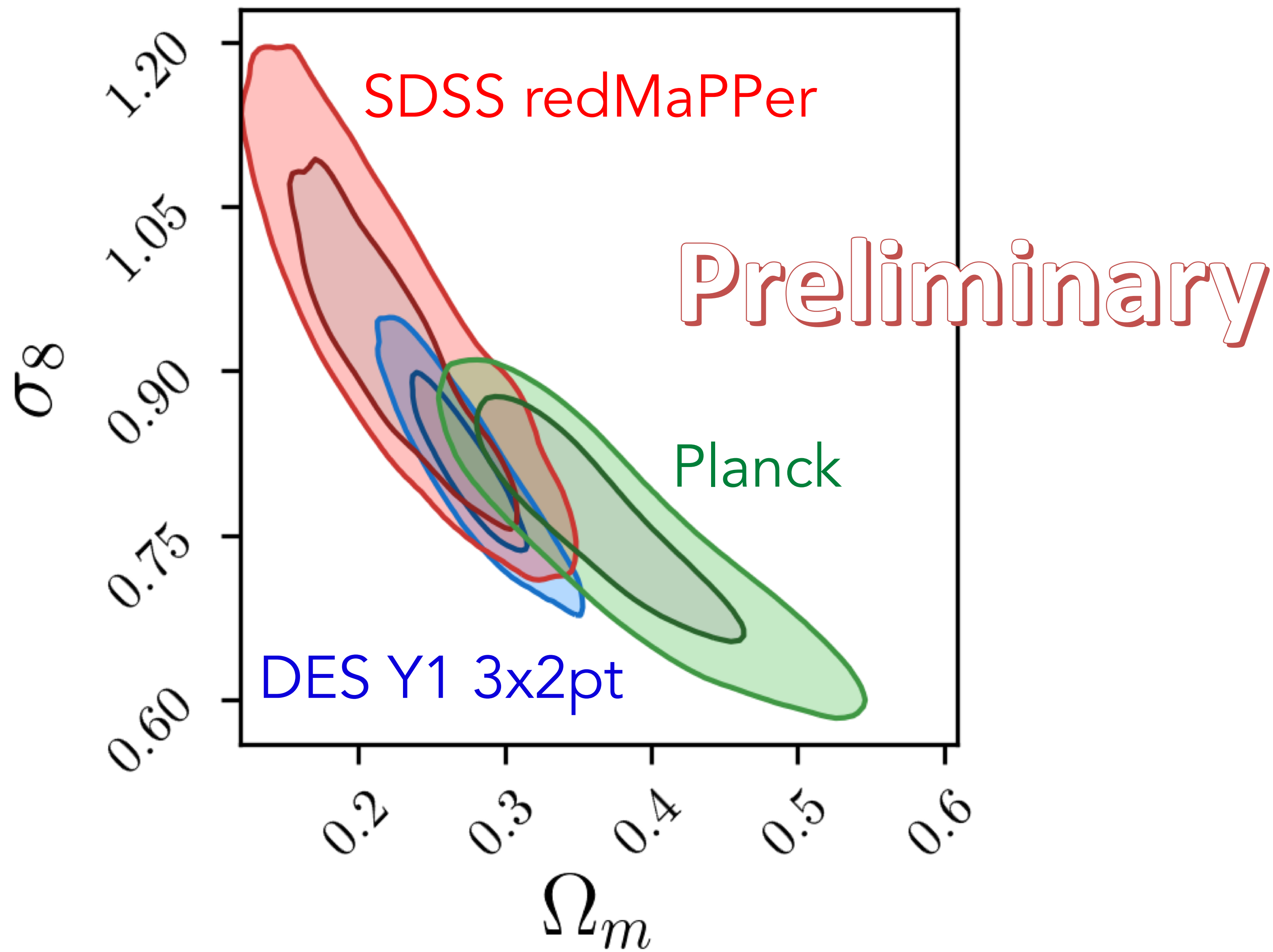
To unblind:

- Validate pipeline by analyzing synthetic data sets.
- Verify prior ranges are adequate, chains are converged.
- Verify best fit model has an acceptable χ^2.

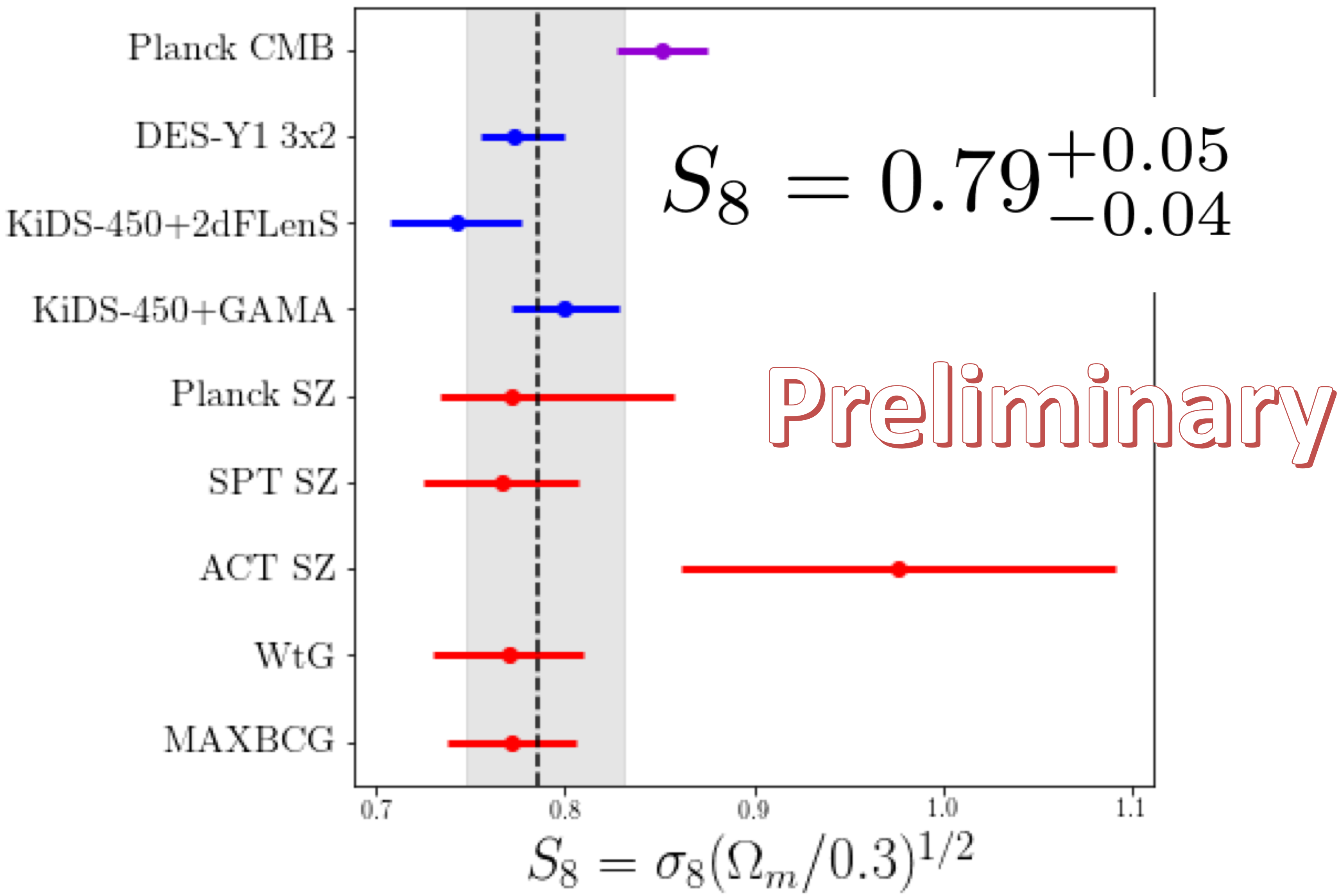
Model is a Good Fit



SDSS Cluster Cosmology

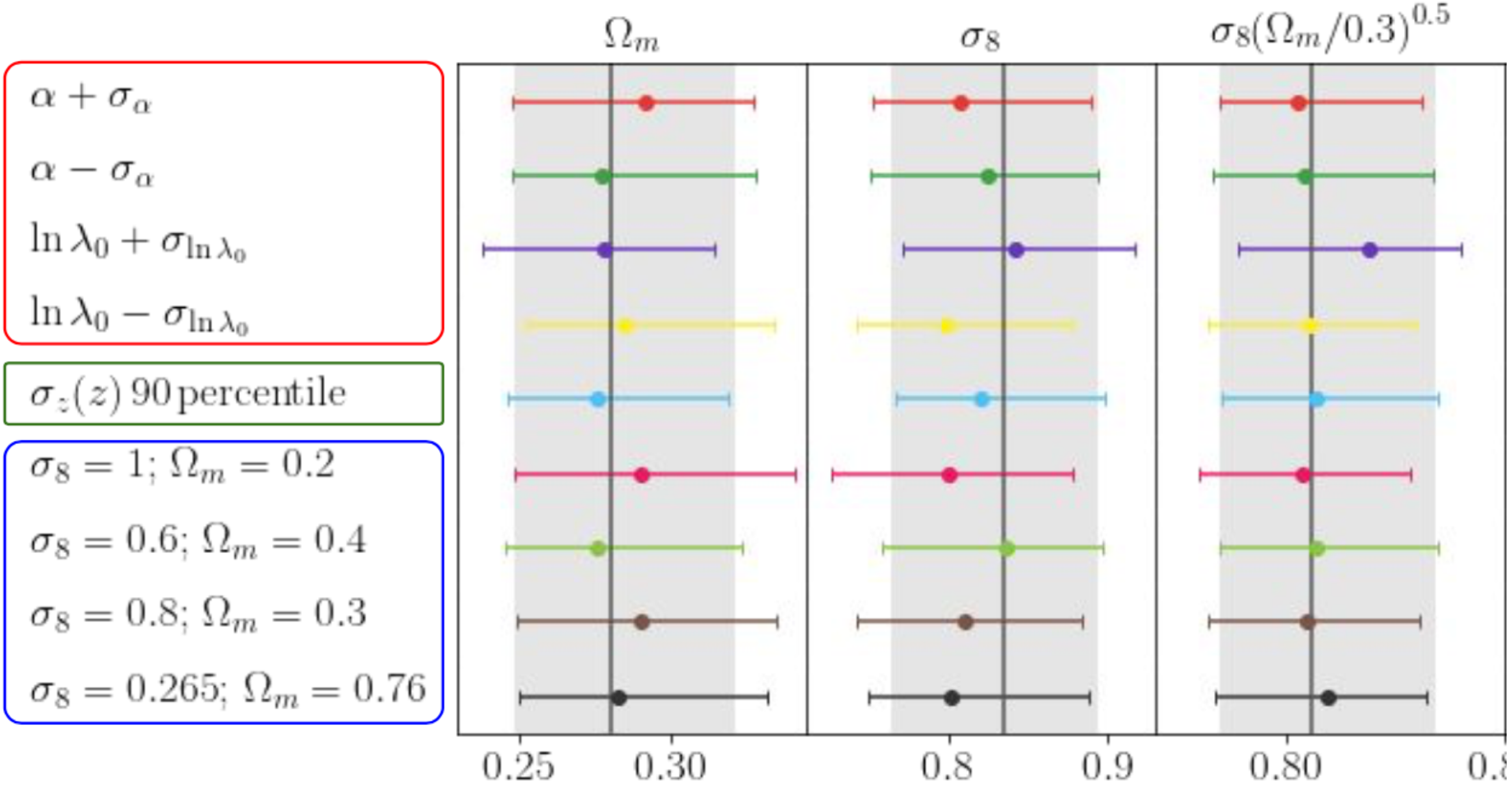


The Broader Picture

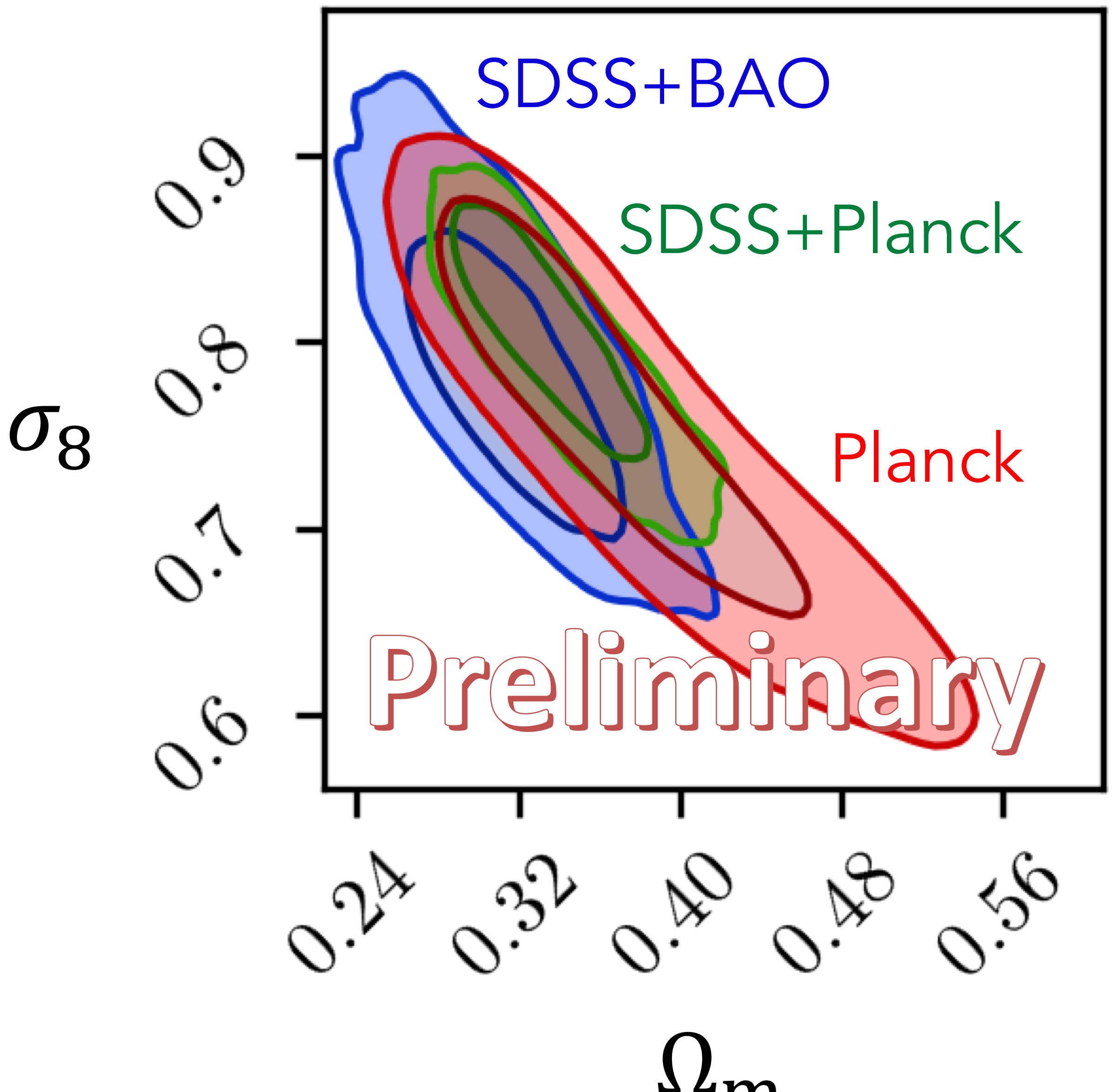


Robust to Modeling Details

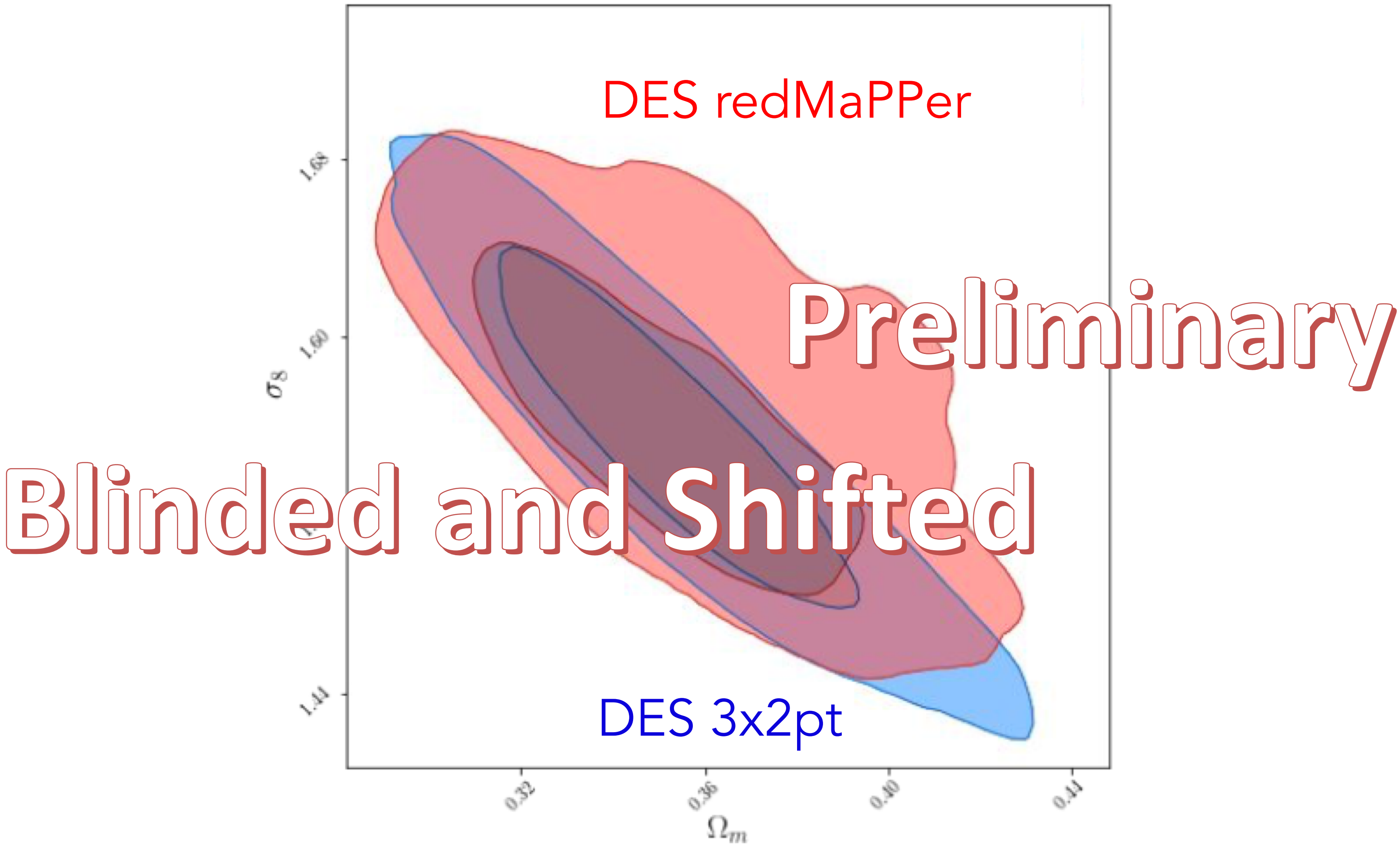
Preliminary



Combining w/ BAO



DES Cluster Cosmology



- Comparable precision to DES combined probes.
- Highly non-trivial consistency test!

Summary

- Cluster cosmology is all about mass calibration: that is **always** the weakest point.
- Weak lensing mass calibration produces results that are consistent with *Planck*.
- No compelling evidence of tension.
- Performed a new, blind, completely independent cluster abundance analysis.
- SDSS result is consistent with Planck: $S_8 = 0.79^{+0.05}_{-0.04}$.
- DES cosmology coming: clusters will achieve similar precision to the 3x2pt analysis.