DES Y1 CLUSTER COSMOLOGY

M. Costanzi (INAF - O.A. Trieste), DES Galaxy Clusters & Weak Lensing working groups

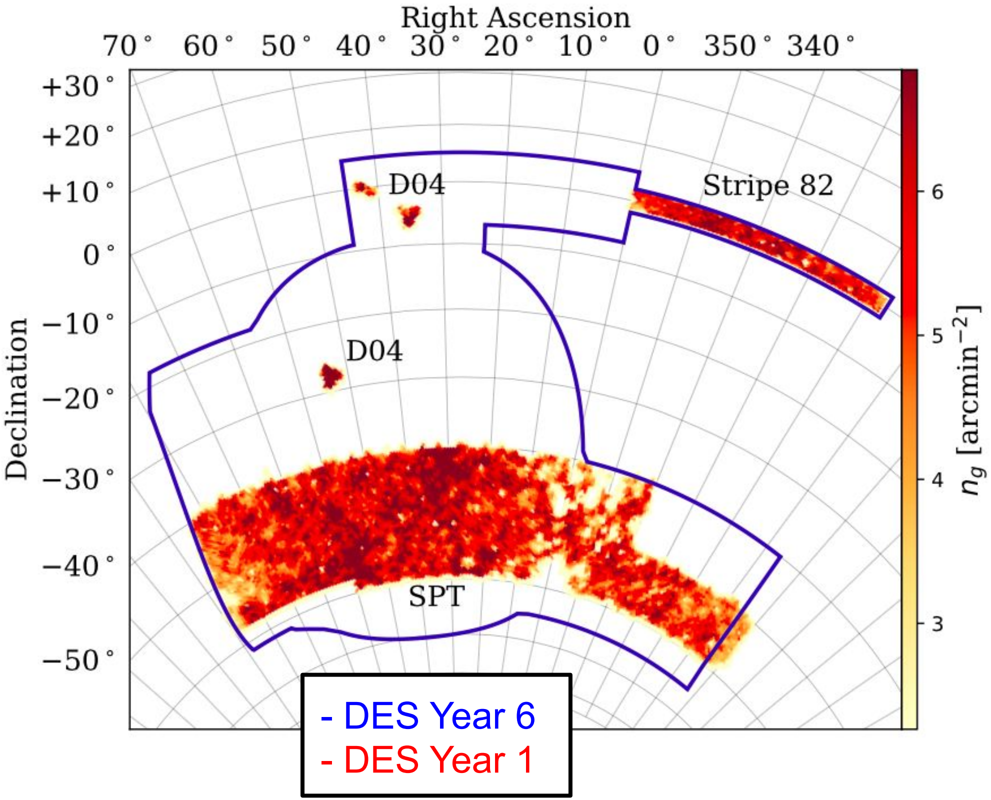
Modeling of the Selection Function: Costanzi+ 18a (arXiv:1807.07072)
Methodology paper - SDSS Cluster Cosmology: Costanzi+ 18b (arXiv:1810.09456)
DESY1 WL mass calibration: McClintock+ 18 (arXiv:1805.00039)
Modeling of Miscentering Effects: Zhang+ 19 (arXiv:1901.07119)
Modeling of Membership Dilution: Varga+ 18 (arXiv:1812.05116)
Prior on observable-mass relation scatter: Farahi+ 19 (arXiv:1903.08042)
DES Y1 Cluster Cosmology: DES Collaboration 20 (arXiv:2002.11124)

GCCL Seminar - April 2020 | Matteo Costanzi

THE DARK ENERGY SURVEY

- **DES Survey:**
  - ~5000 deg^2 of southern sky
  - g,r,i,z,(Y) bands
  - 10 visits per pointing to reach i~24

- **DES Year 1 clusters:**
  - ~1500 deg^2 with 10σ depth i~22.9
  - N_{eff}~6.3 arcmin^{-2} (34M source glxs)



From Zuntz+ 17

redMaPPer DES Year 1 CLUSTER CATALOG

- **red**-sequence **Ma**tched-filter **P**robabilistic **Per**colation cluster finding algorithm **(Rykoff+14):**

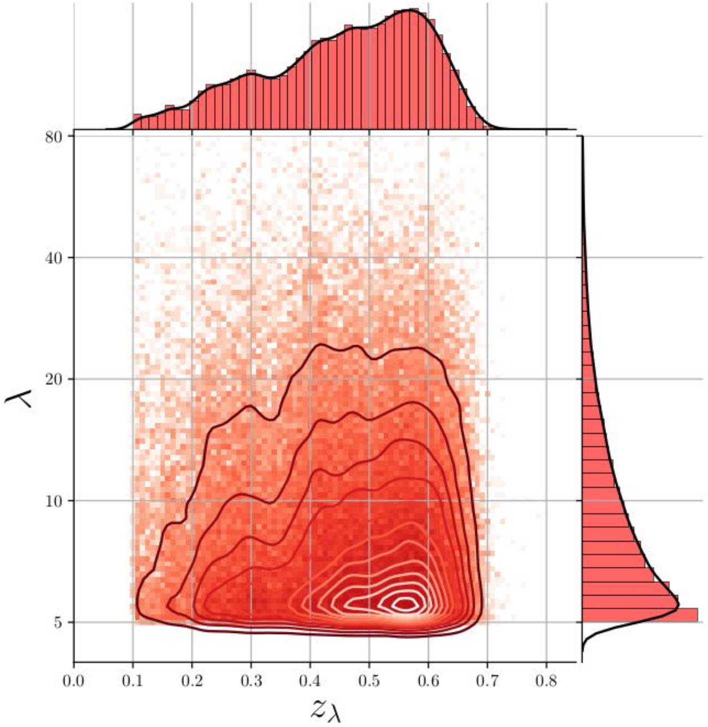
Detect overdensities of red-sequence galaxies and assign a membership probability, p_{mem}, to each cluster member candidate

$$\lambda^{\mathrm{ob}} = \sum_{R<R_\lambda} p_{mem}$$

$$z^{\mathrm{ob}}$$

Area [deg^2]	Redshift range	# of clusters (λ>20)	σ_z/(1+z)
1470	0.2<z<0.65	~6540	0.006

***z*-λ distribution of redMaPPer clusters in DES Y1**



From McClintock+18

COSMOLOGY WITH CLUSTER NUMBER COUNTS

The abundance of galaxy clusters is sensitive to the growth rate of cosmic structures and expansion history of the Universe

σ_8: Amplitude of the matter power spectrum

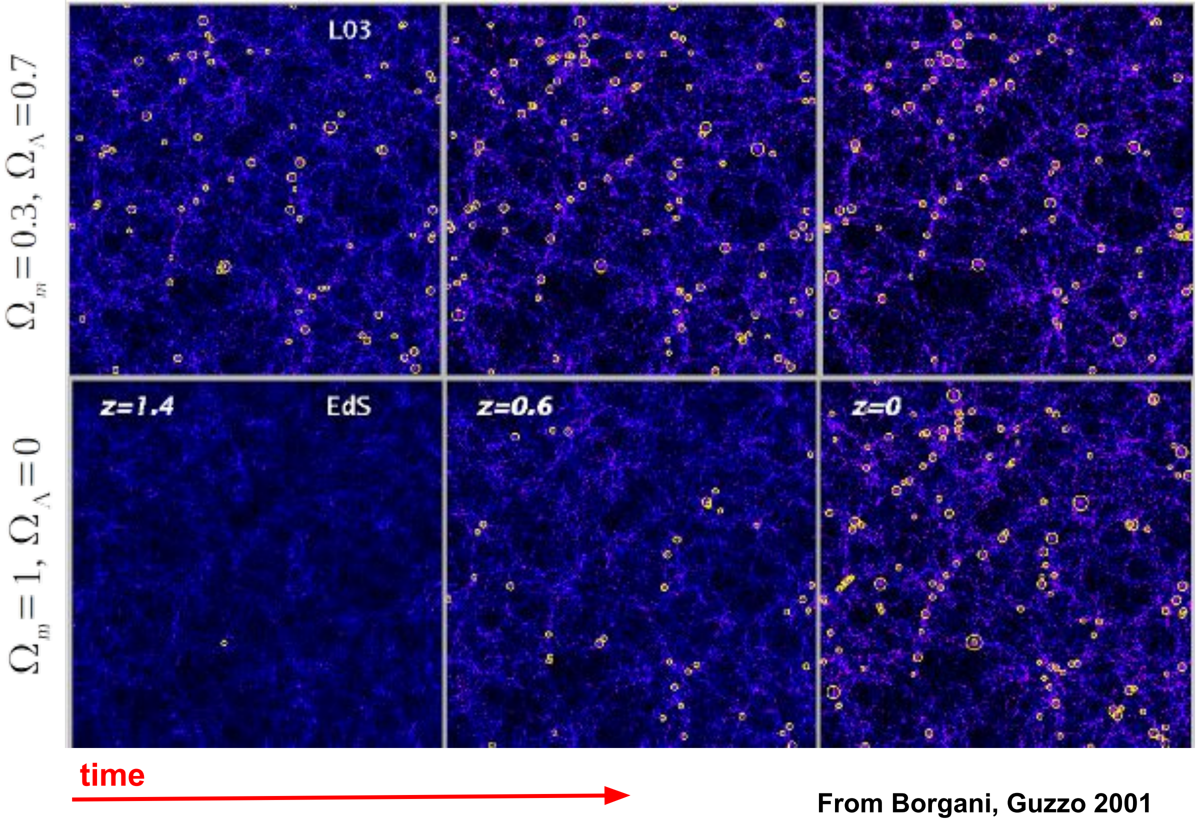
Ω_m: Present-day total matter density

$$\boxed{S_8 = \sigma_8 \, (\Omega_m / 0.3)^{0.5}}$$

Dark energy equation of state parameter
Total neutrino mass
Deviation from GR
….

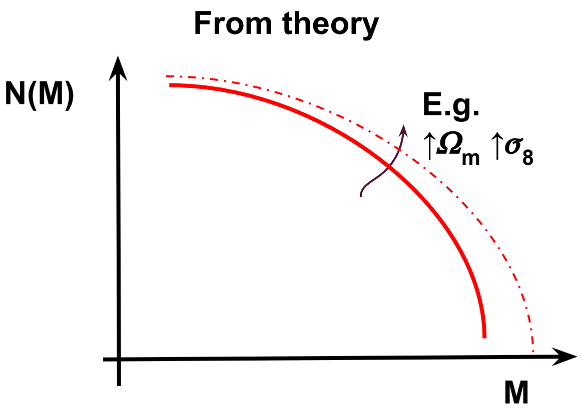
See e.g. Allen+2011 or Kravtsov+2012 for a review

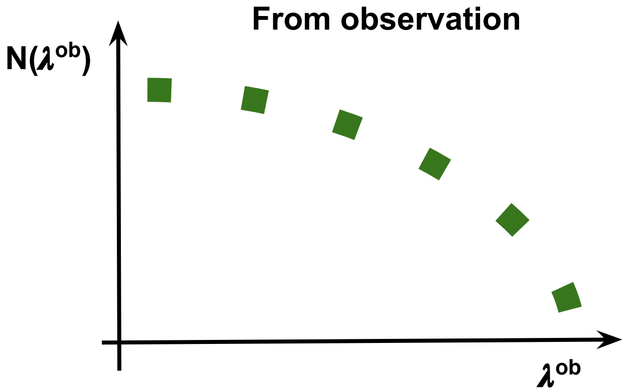
Evolution of the clusters population in 2 N-body simulations



From Borgani, Guzzo 2001

- **From theory to observation**



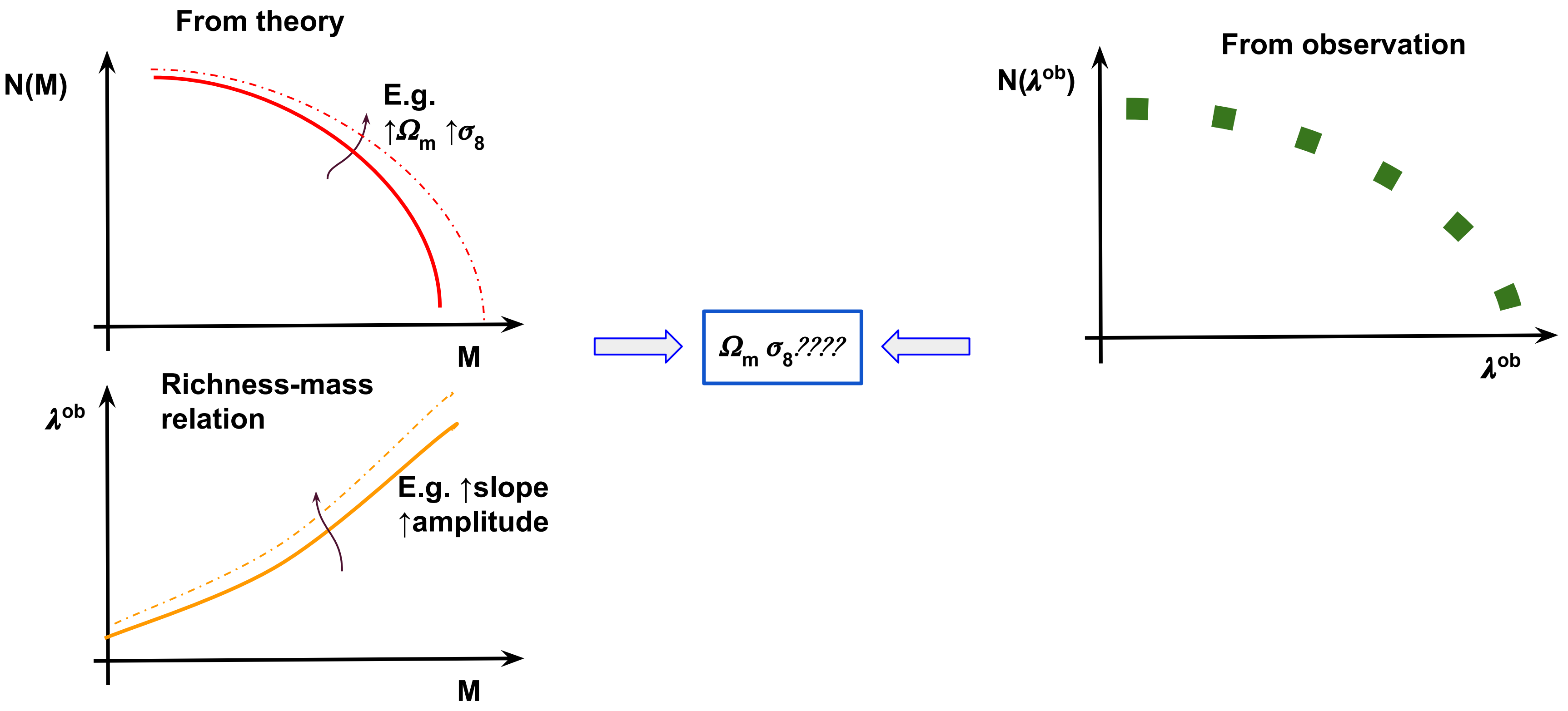


For optically-selected clusters:

λ=richness~ # member galaxies

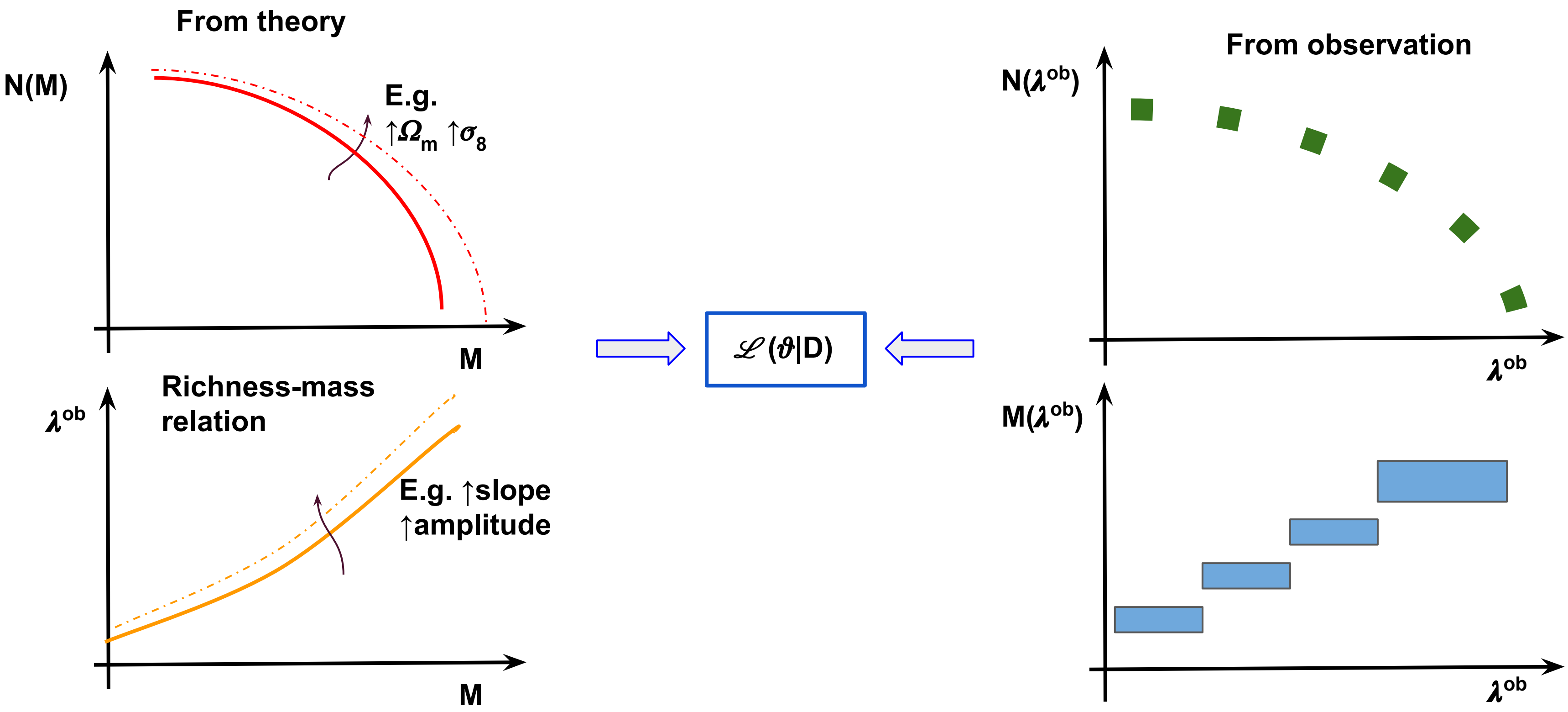
COSMOLOGY WITH CLUSTER NUMBER COUNTS

- **From theory to observation**



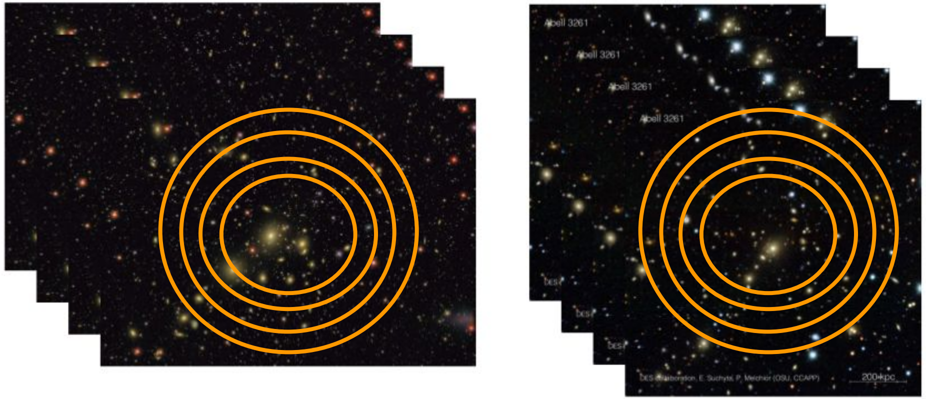
COSMOLOGY WITH CLUSTER NUMBER COUNTS

- **Combine cluster abundance and cluster mass estimates to simultaneously constrain cosmology and the richness-mass relation**

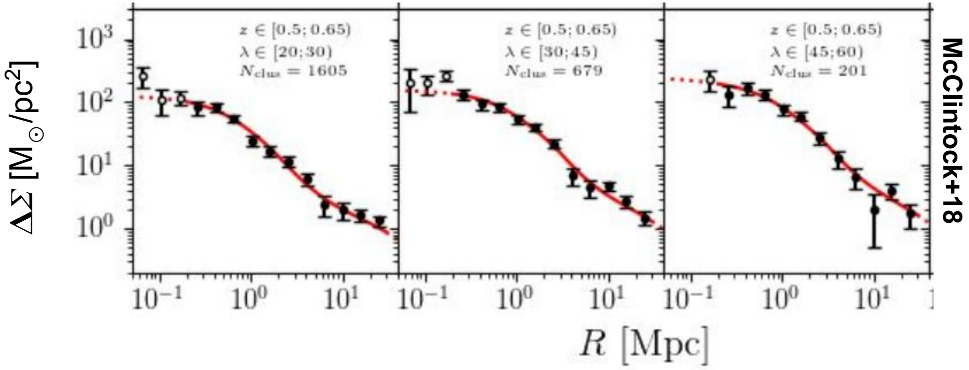


WEAK LENSING MASS ESTIMATES

- **Stack clusters in bin of richness and redshift**
- **Measure the mean tangential shear of background galaxies in radial bin around the cluster center**
- **Compute the surface mass density profile $\Delta\Sigma$**
- **Fit for the mean mass of the λ/z bin**



Surface mass density profile from stacked lensing analysis

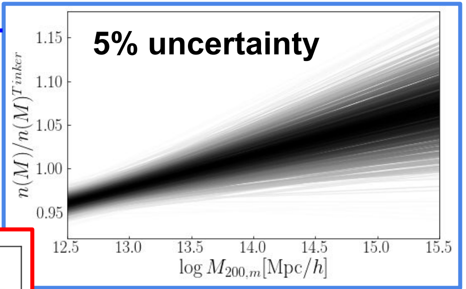


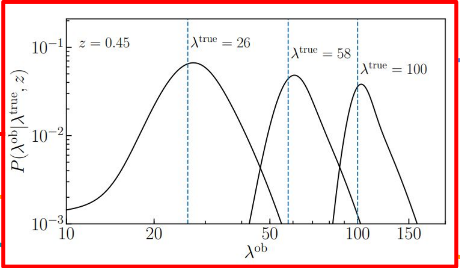
CLUSTER NUMBER COUNTS MODELING AND SYSTEMATICS

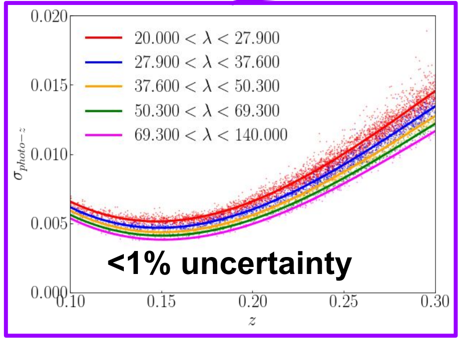
- **Halo mass function calibration**
- **Richness-mass relation**

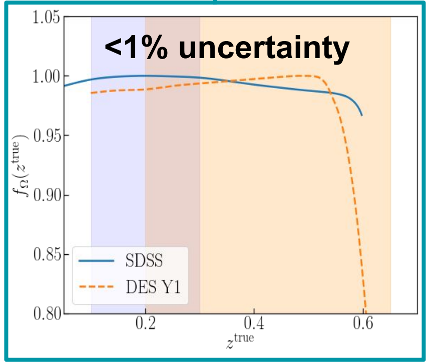
$$\langle \lambda^{\mathrm{sat}} | M, z \rangle = \left(\frac{M - M_{\mathrm{min}}}{M_1 - M_{\mathrm{min}}} \right)^{\alpha} \left(\frac{1+z}{1+z_*} \right)^{\epsilon} \quad + \sigma_{\mathrm{intr}}$$

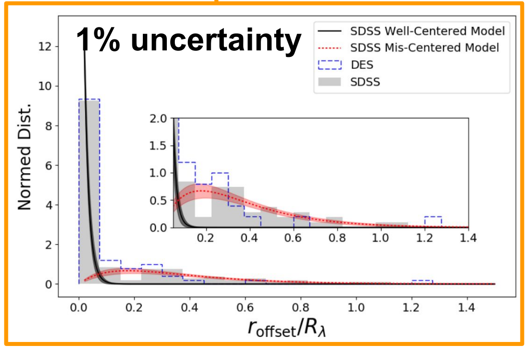
- **Selection function:**
  - **Observational noise on richness estimates**
  - **Miscentering**
  - **Variation of the survey depth/masking effects**
  - **Photometric redshift uncertainty**







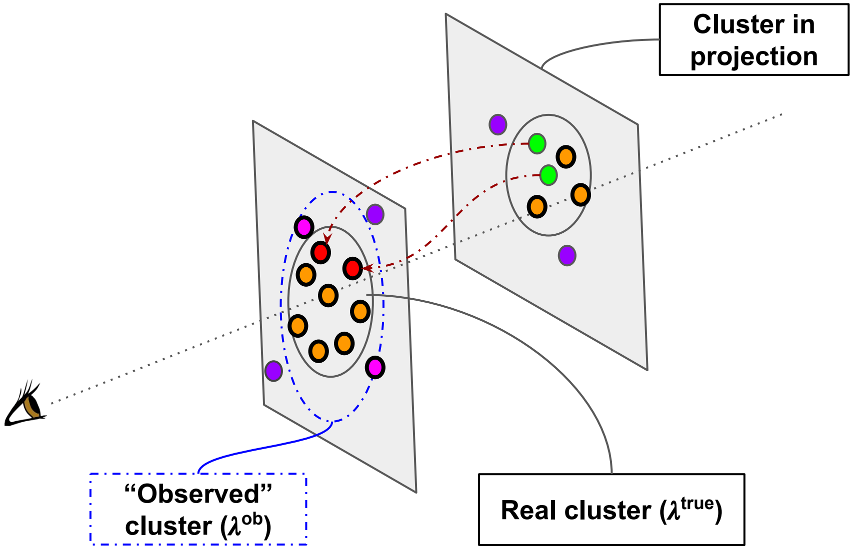




From Zhang+18

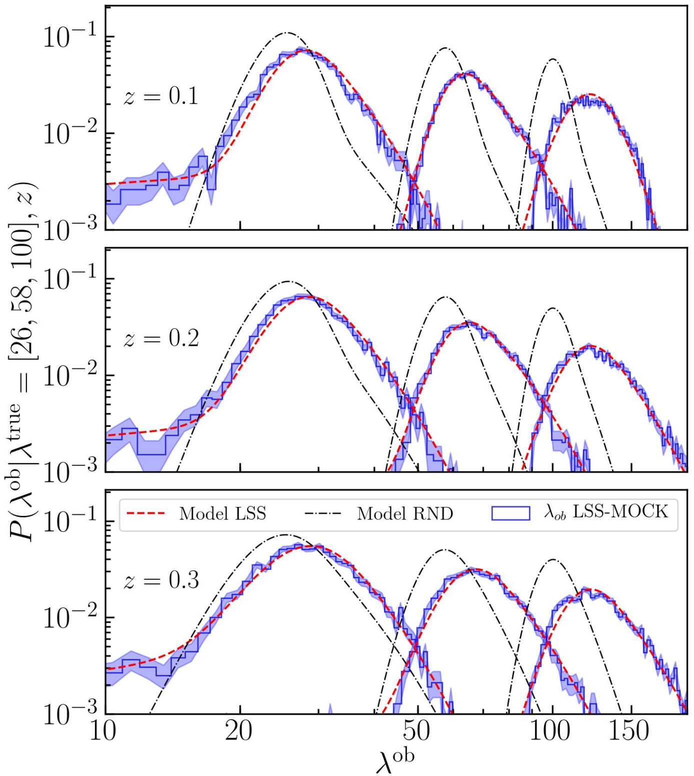
MODELING OBSERVATIONAL NOISE ON RICHNESS ESTIMATES

$$\lambda^{ob} = \lambda^{true}(M) + \Delta\lambda^{obs\text{-}noise}$$



- Main sources of scatter in richness estimates:
  - Uncertainties in the background subtraction
  - Projection effects
  - Masking effects (Percolation)

Scatter between true and observed richness



Costanzi+ 18a (arXiv:1807.07072)

Dash-dotted line: Neglecting the scatter due to correlated structures

WL MASS ESTIMATES MODELING AND SYSTEMATICS

- **WL mass calibration (McClintock, Varga+19):**

Source of systematic	Y1 Amplitude Uncertainty
Shear measurement	1.7%
Photometric redshifts	2.6%
Modeling systematics	0.73%
Membership dilution + miscentering	0.78% **(Varga+19, Zhang+19)**

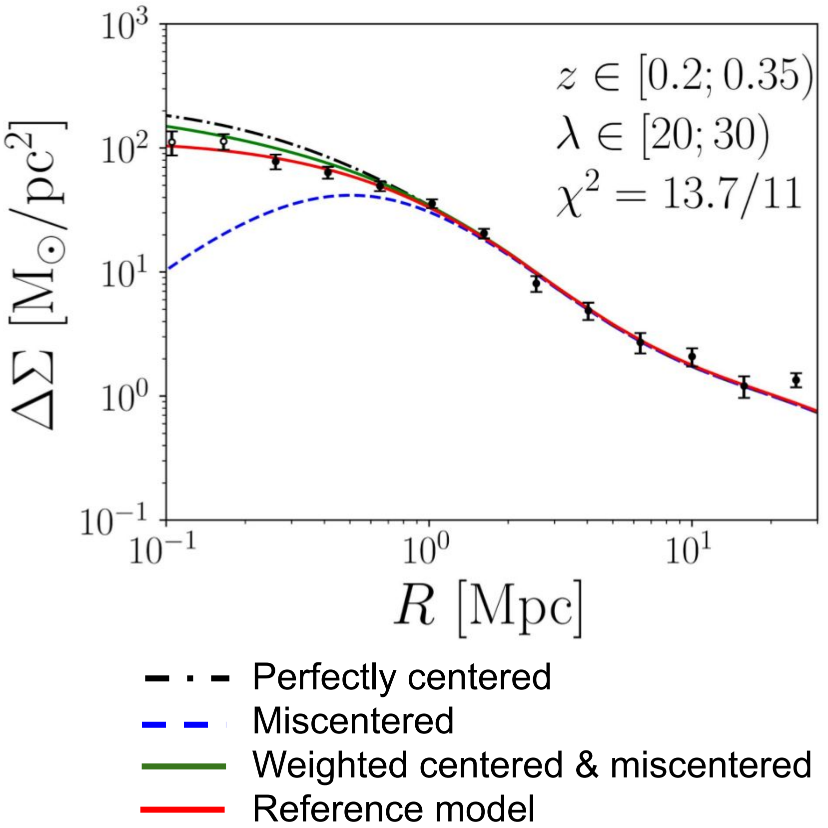
+

Modeling of the cosmological dependence of the WL mass estimates (<1% uncertainty)

+

Selection effect bias (~13% uncertainty on mass)

Effect of different systematics on the model prediction



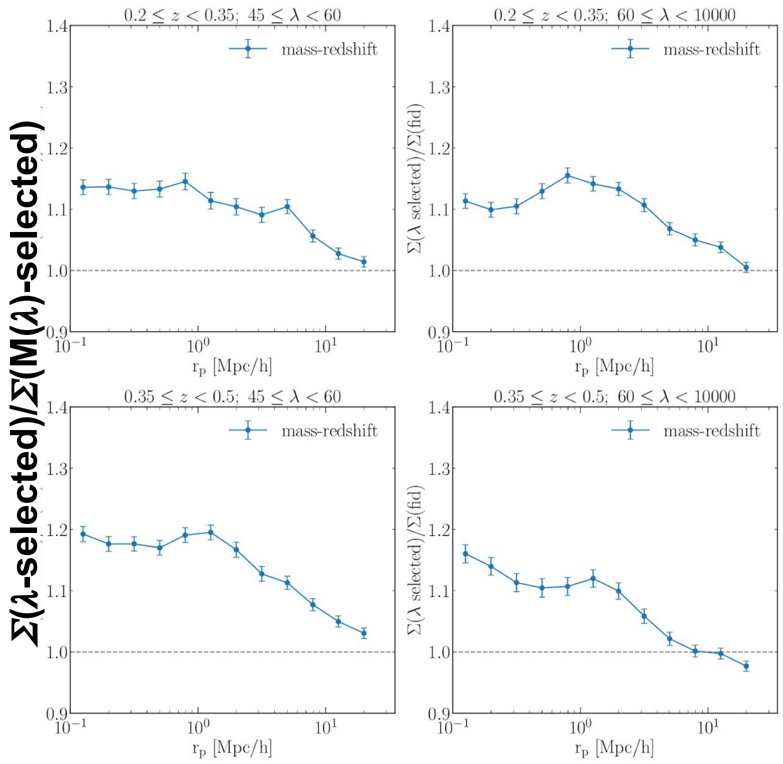
WL MASS ESTIMATES: SELECTION EFFECT SYSTEMATICS

Selection effect bias i.e. the bias introduced by the cluster finder for preferentially selecting clusters with properties that correlate with the WL signal at fixed mass (e.g. elongated along the l.o.s.).

Calibrate selection effects with simulations:

- **Run redMaPPer on simulations**
- **Select clusters in λ/z bins**
- **Select clusters with the same mass/z distribution as the λ/z selected sample**
- **Compare the stacked Σ(R) profiles of the two samples**

Selection effects systematics on WL profile

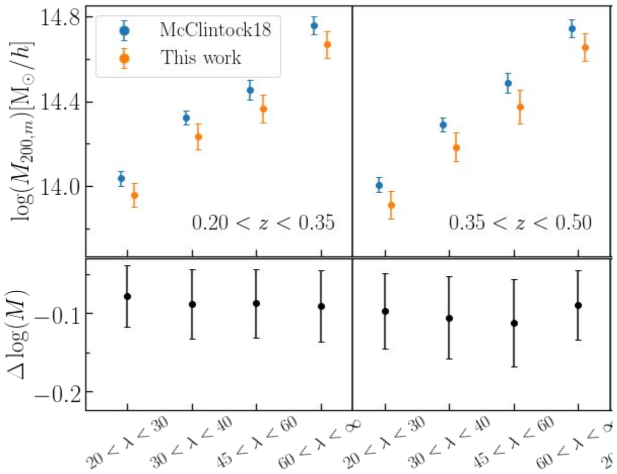


Wu et al. (in prep.)

WL MASS ESTIMATES: SELECTION EFFECT SYSTEMATICS

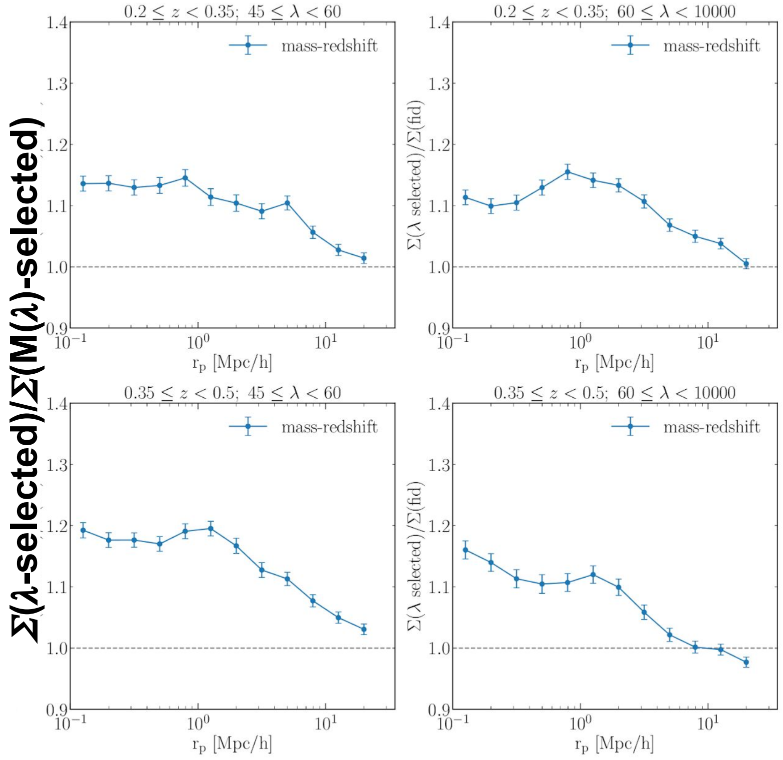
Selection effect bias:

- Mostly explained by projection and triaxility effects
- Lowers mass estimates by ~20%-30% in all richness and redshift bins
- Increases the error on WL mass estimates by a factor of 2 (main source of uncertainty for Y1!)



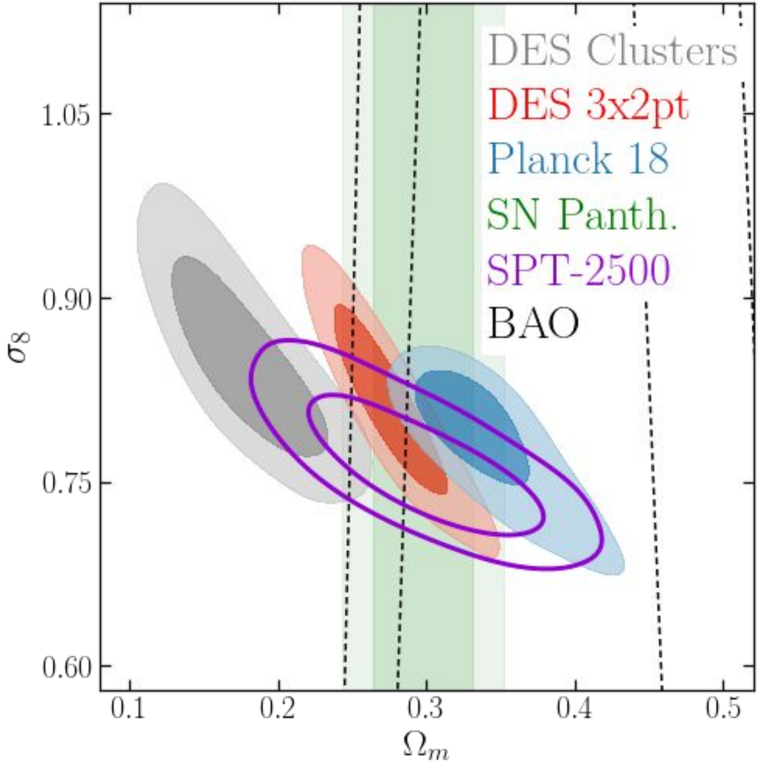
Mean % error budget	
σ^{tot}/ M	18%
σ^{stat}/ M	10%
σ^{syst}/ M	15%

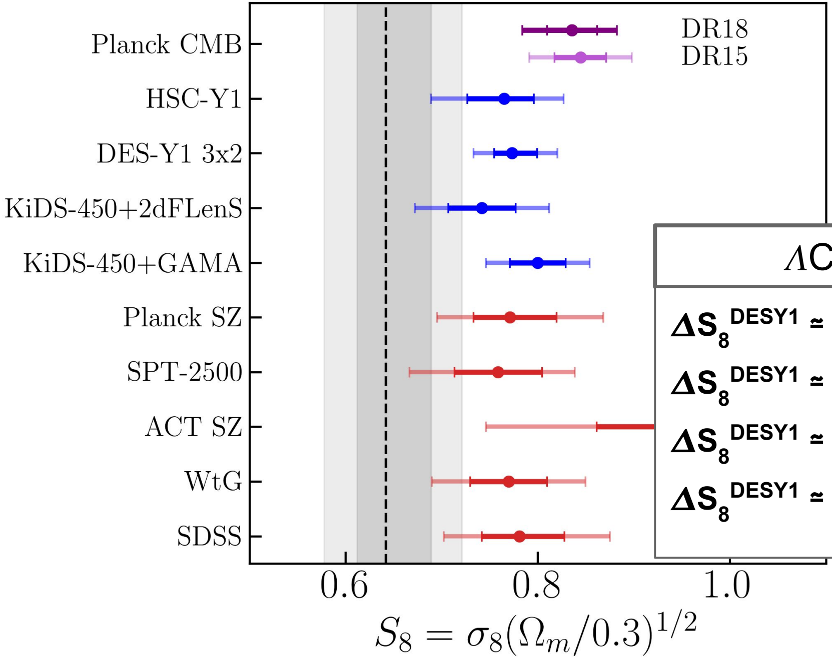
Selection effects systematics on WL profile



Wu et al. (in prep.)

COSMOLOGICAL CONSTRAINTS DESY1 ΛCDM+ν model





ΛCDM+ν

$\Delta S_8^{DESY1} \simeq 0.9\, \Delta S_8^{SDSS}$

$\Delta S_8^{DESY1} \simeq 0.8\, \Delta S_8^{SPT\text{-}SZ}$

$\Delta S_8^{DESY1} \simeq 1.7\, \Delta S_8^{DES3x2}$

$\Delta S_8^{DESY1} \simeq 1.8\, \Delta S_8^{Planck18}$

- **2.4σ tension with DES 3x2pt**
- **5.6σ tension with Planck 18**

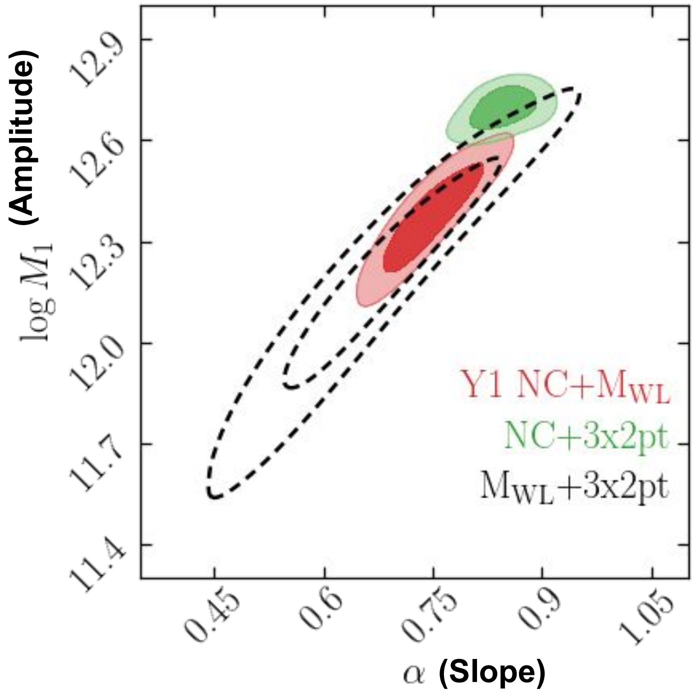
➔ **Selection effect uncertainty accounts for 16% of the total error budget on S_8**

WHAT DRIVES THE TENSION WITH OTHER PROBES?

The large tension with multiple cosmological probes implies that either:

- **The cosmological model is wrong (ΛCDM+ν)**
- **There are unmodeled systematics, either in the NC or M_{WL} data (or both)**

Assume DESY1 3x2pt cosmology fit for the λ-M relation using only NC or M_{WL} data



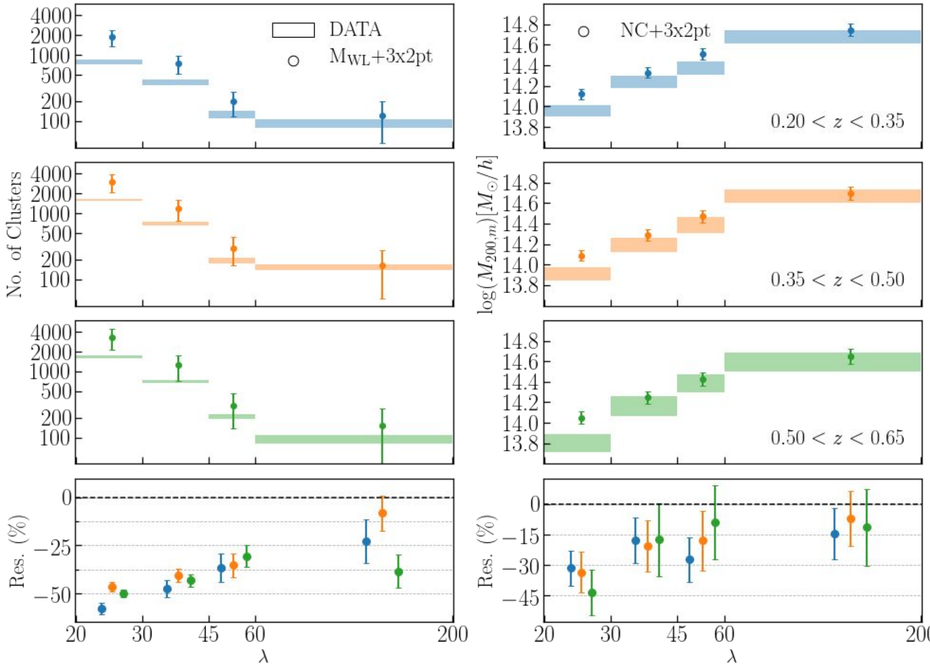
WHAT DRIVES THE TENSION WITH OTHER PROBES?

The large tension with multiple cosmological probes implies that either:

- **The cosmological model is wrong (ΛCDM+ν)**
- **There are unmodeled systematics, either in the NC or M_{WL} data (or both)**

- **If M_{WL} estimates are correct: redMaPPer should be incomplete at ~50% at low λ and ~25% at high λ**
- **If NC data are correct: M_{WL} should be biased low by ~30% at low λ and ~10% at high λ**

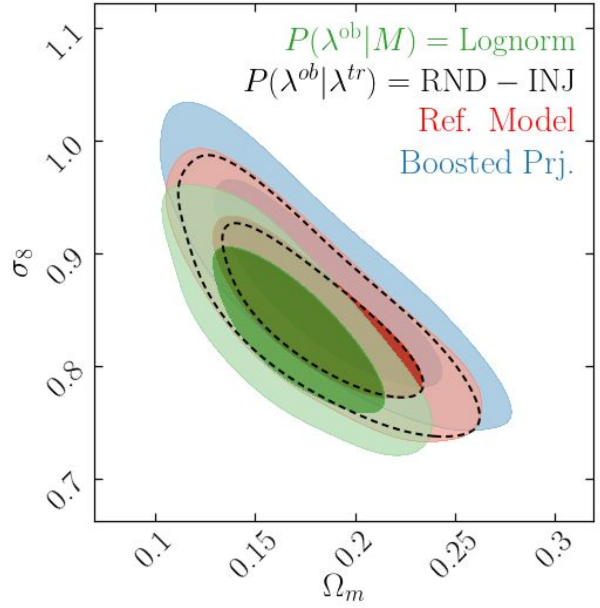
Prediction from NC or M_{WL} @3x2pt Cosmology Vs. Data



NOT VIABLE SOLUTIONS . . .

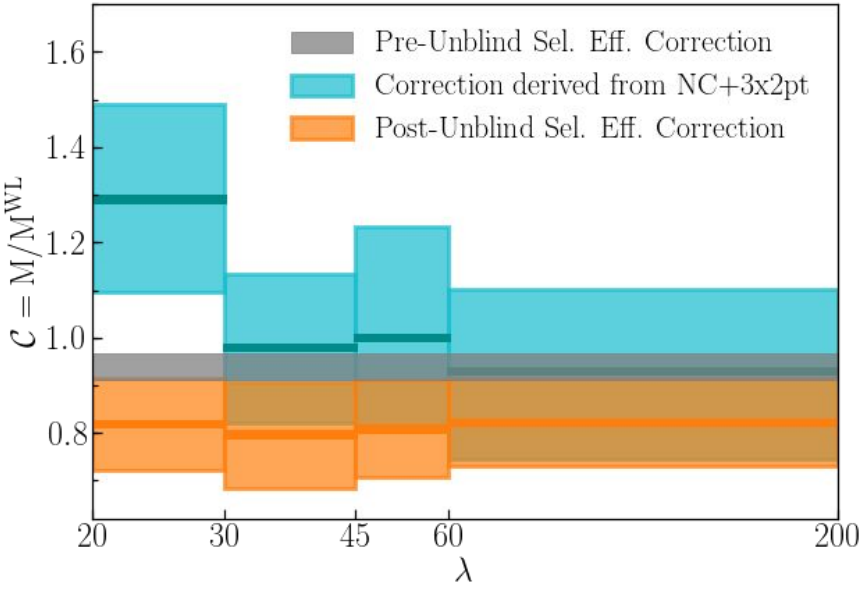
- Shear and photo-z systematics would affect the 3x2pt results even more strongly. They would not lead to a λ-dependent bias
- Miscentering model validated with 2 X-ray samples
- Cross-match with SZ (Planck, SPT) and X-ray (XCS) samples exclude large incompleteness at $\lambda \gtrsim 40$
- Cross-match with *Swift* X-ray sample exclude large contamination at $\lambda \approx 30$. Also, assuming large contamination, to accommodate the abundance data we need to introduce a large incompleteness.
- NC modeling/systematics does not have large impact on the posteriors
- Baryonic effects cannot account for 30% mass depletion in ~10^{14} $M_\odot$ halos (e.g. Cui+14, Velliscig+14,Henson+17,Springel+17,)
- Too aggressive percolation scheme: decreasing the redMaPPer percolation radius by 20% change the NC by less than 1%

Effect on σ_8 and Ω_m of different model assumptions

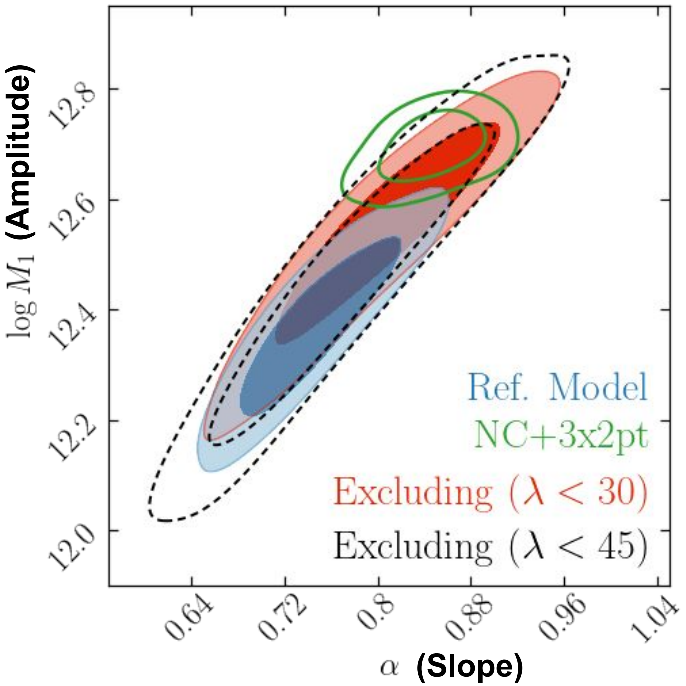


POSSIBLE SOLUTIONS . . .

- Selection effects bias might be overestimated at $\lambda \gtrsim 30$, but cannot explain correction needed at lowest λ-bin (i.e. no projection/triaxiality)

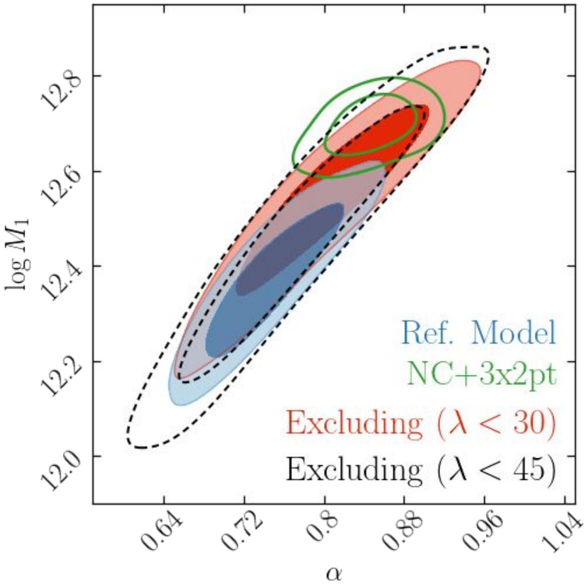


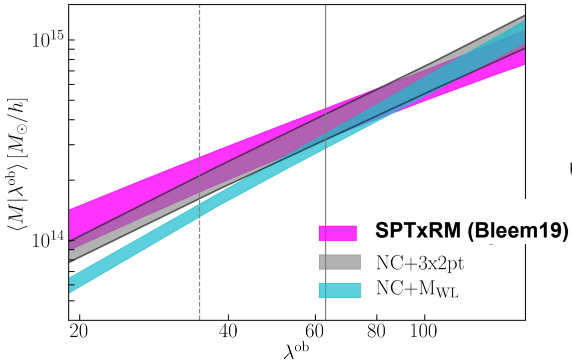
- Unmodeled systematic at λ<30

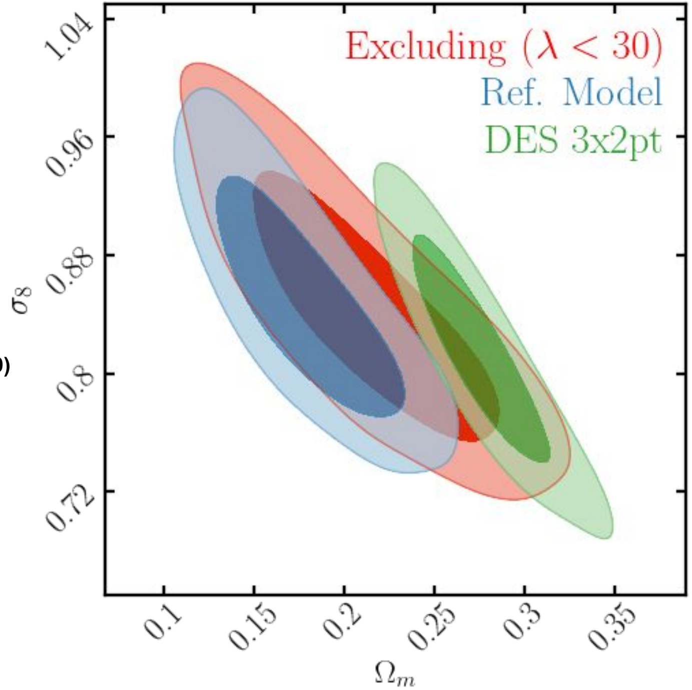


POSSIBLE SOLUTIONS . . .

➔ **Removing the lowest λ-bins: reduce the tension with 3x2pt cosmology steepening the λ-M relation, but the error on S_8 increase by 18%**







SUMMARY AND CONCLUSIONS

- **Our cosmological posteriors are in tension with multiple cosmological probes. This finding is robust to the adopted cosmological and richness--mass relation model.**
- **The internal inconsistency of the DES Y1 cluster data with other DES probes rule out the possibility that the tension is driven by an observational systematic affecting the DES data.**
- **Cross checks of the redMaPPer catalog with X-ray and SZ data suggest that the abundance data and related modeling are not driving the tension but it is likely a consequence of an incorrect interpretation of the stacked weak lensing signal of the DES redMaPPer clusters.**
- **Low richness data ($\lambda\in$ [20,30]) are the main driver of the tension with the DES 3x2pt cosmological results. In particular, the weak lensing mass estimates for λ<30 push the slope and amplitude posteriors of the richness--mass relation towards low values.**
- **Assuming our abundance data, modelling and DES 3x2pt results to be correct the mass bias we recover is richness dependent, corresponding to a steeper slope in the richness--mass relation compared to the one preferred by the weak lensing data.**
- **Our understanding of how photometric cluster selection impacts the stacked lensing profiles of clusters might have a major role in the observed tension. However, at low richness, the necessary selection effect bias requires the raw weak-lensing masses of photometrically selected clusters to be biased \it low \rm relative to a mass-selected sample. This is contrary to our *a priori* expectations, and we have not yet been able to identify a systematic that could give rise to such a selection effect.**

OUTLOOK FOR DES Y3 CLUSTER COSMOLOGY

- redMaPPer DES Y3: 4600 deg^2 up to z=0.7 → ~3 times more clusters than redMaPPer DES Y1

- Improved mock catalogs to calibrate selection effects and validate the modeling.
  Main limitations: galaxy color and clustering model, resolution limit for shear measurements.

- Validation of selection effects with external data (especially at low λ):
  - Complete samples of spectroscopic data to validate projection effects
  - X-ray follow-up of complete samples to model miscentering and contamination and constrain the λ-M relation scatter
  - Cross-match with SZ and X-ray data to assess completeness (@ medium/high λ; SPT-3G and eROSITA might help also at low λ), test selection effects on WL signal (e.g. comparing WL signal of SZ and X-ray selected samples to redMaPPer)

- "Full" forward modeling of NC and WL signal (rather than passing through the mass calibration) to ensure consistency between the likelihoods and correctly account for cross correlations between observables