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Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

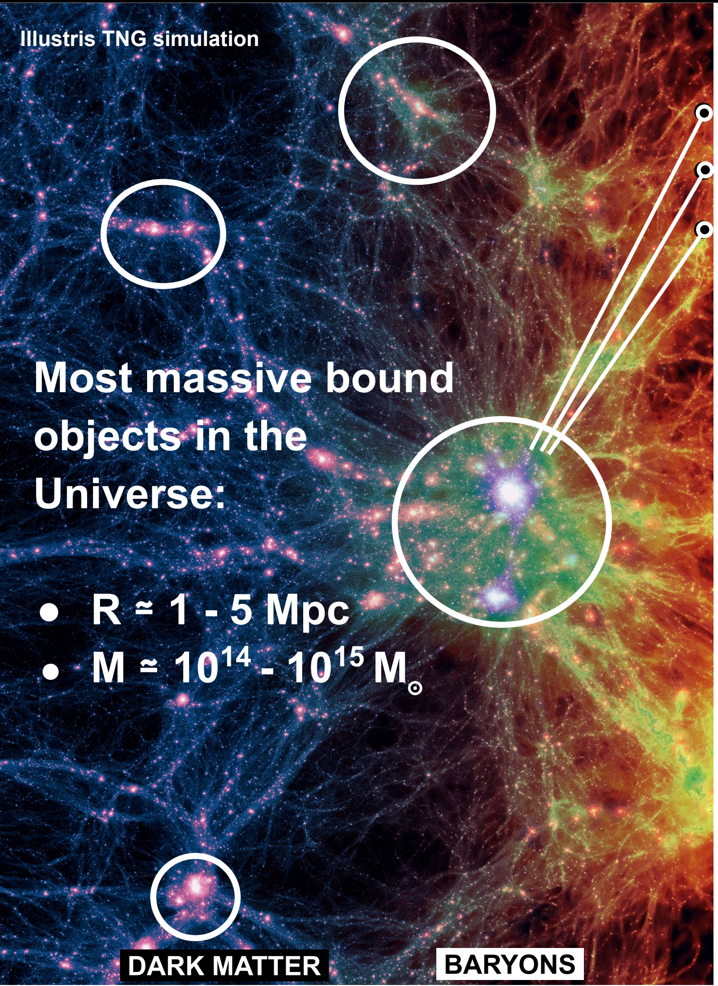
DARK ENERGY SURVEY

THE EMERGENCE OF THE COSMIC WEB:
LATEST RESULTS FROM THE DES CLUSTER SURVEY

Matteo Costanzi on behalf of the DES Cluster SWG

UNIVERSITÀ DEGLI STUDI DI TRIESTE

GALAXY CLUSTERS



Most massive bound objects in the Universe:

- $R \simeq 1 - 5$ Mpc
- $M \simeq 10^{14} - 10^{15}\ M_\odot$

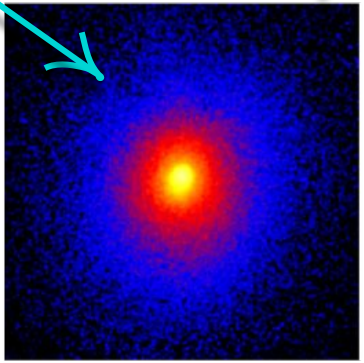
Multi-component systems:

- **Galaxies and stars (~5%)**
- **ICM (~15%)**
- **DM (~80%)**

OPTICAL

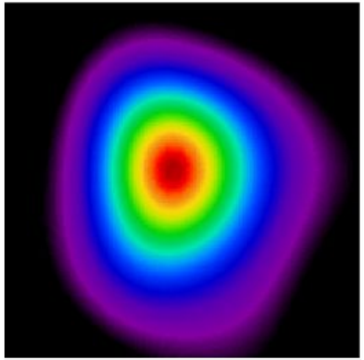
RICHNESS, LENSING EFFECTS

X-RAYS



LUMINOUS AND EXTENDED X-RAY SOURCES

MICROWAVES



SUNYAEV-ZEL'DOVICH EFFECT

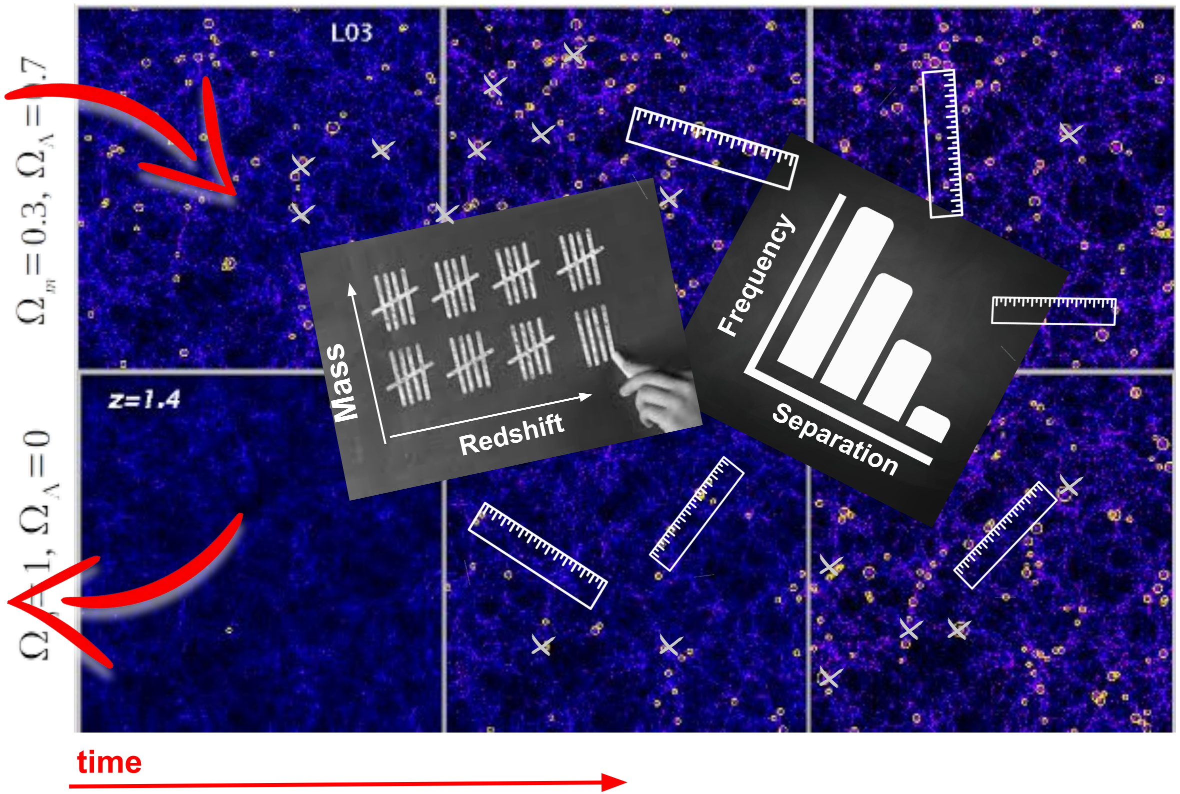
Credit: Allen+11

CLUSTER COSMOLOGY IN A NUTSHELL

The abundance and spatial distribution of galaxy clusters are sensitive to the **growth rate** of cosmic structures and **expansion history** of the Universe

- Amplitude of matter fluctuations, σ_8
- Total matter density, Ω_m
- Dark energy equation of state parameter w
- Total neutrino mass, Σm_ν
- Modified gravity models

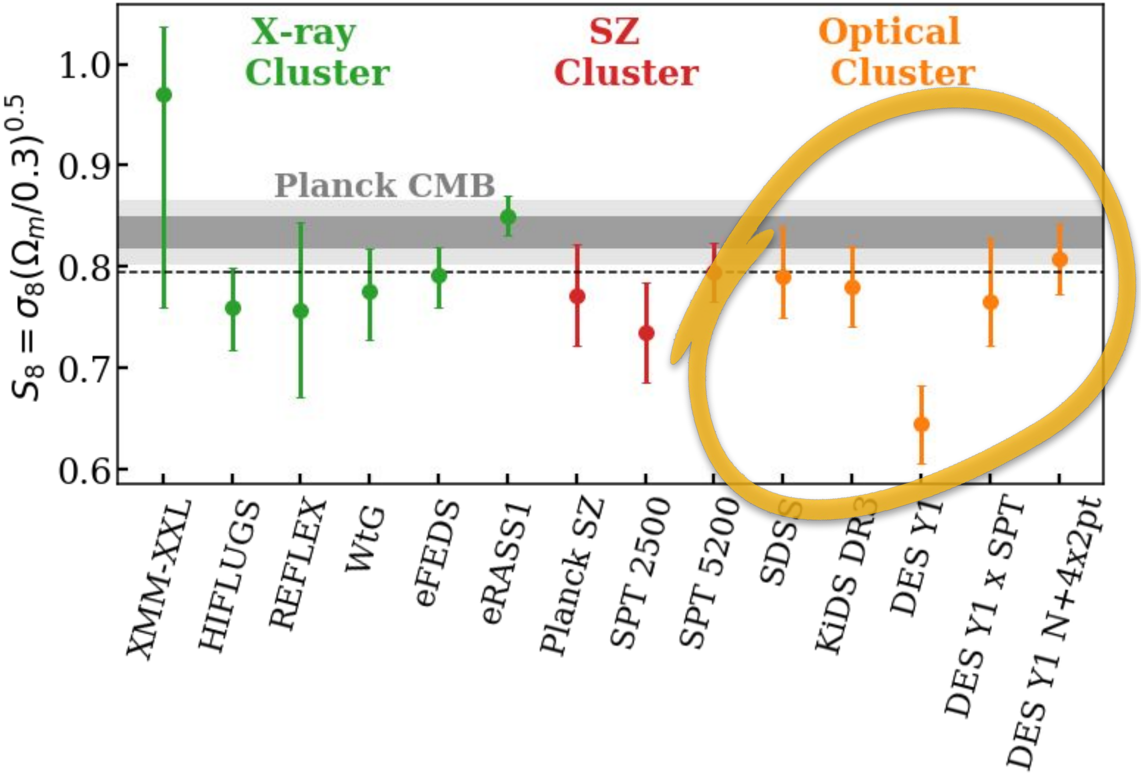
...



From Borgani, Guzzo 2001

CLUSTER COSMOLOGY IN A NUTSHELL

The abundance and spatial distribution of galaxy clusters are sensitive to the **growth rate** of cosmic structures and **expansion history** of the Universe



- Amplitude of matter fluctuations, σ_8
- Total matter density, Ω_m
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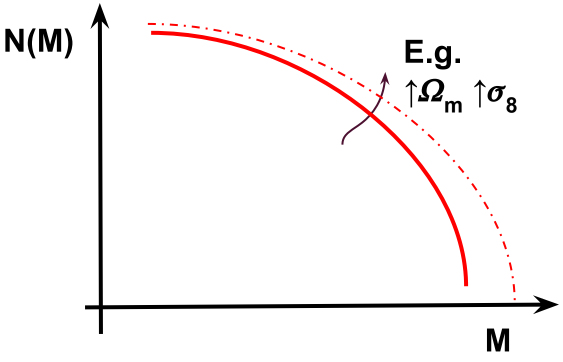
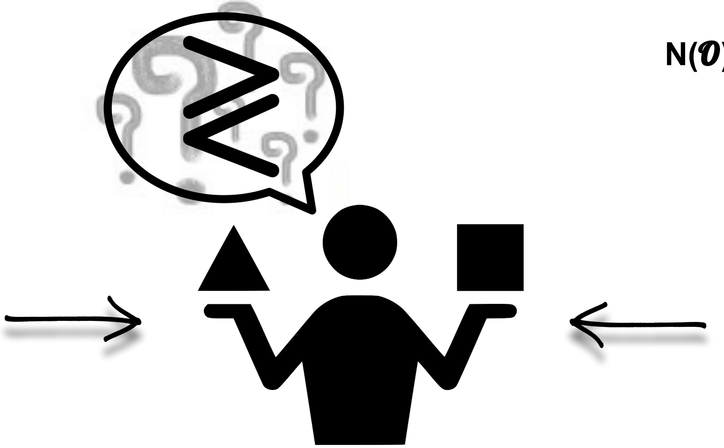
- Modified gravity models

...

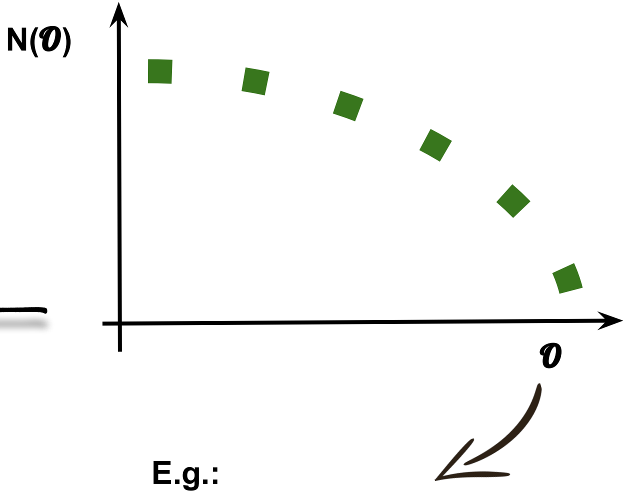
FROM OBSERVATION TO COSMOLOGICAL CONSTRAINTS

Theoretical prediction





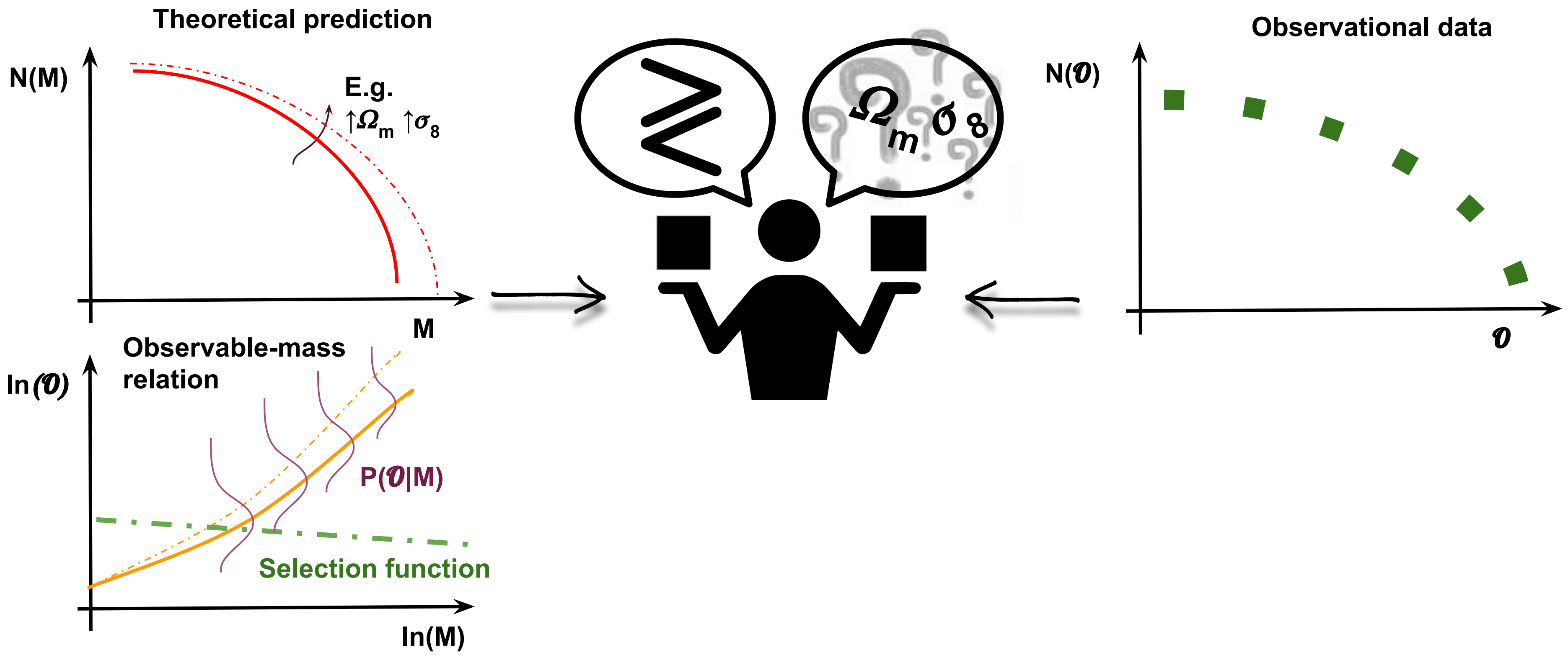
Observational data



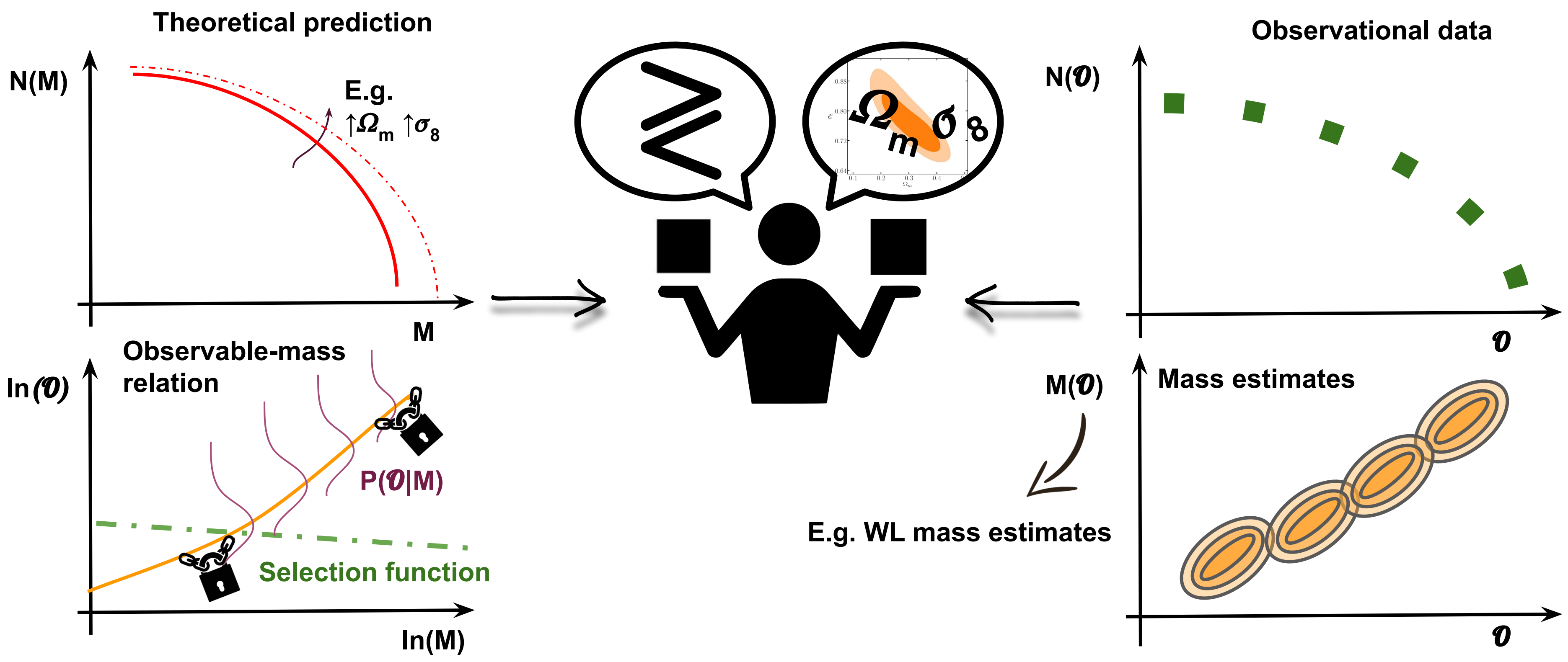
E.g.:

- Richness
- X-ray luminosity or photon counts
- SZ signal

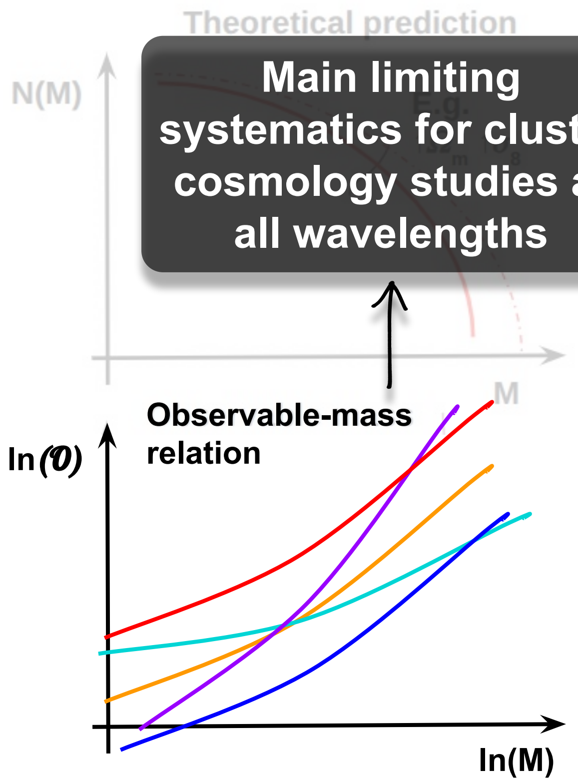
FROM OBSERVATION TO COSMOLOGICAL CONSTRAINTS



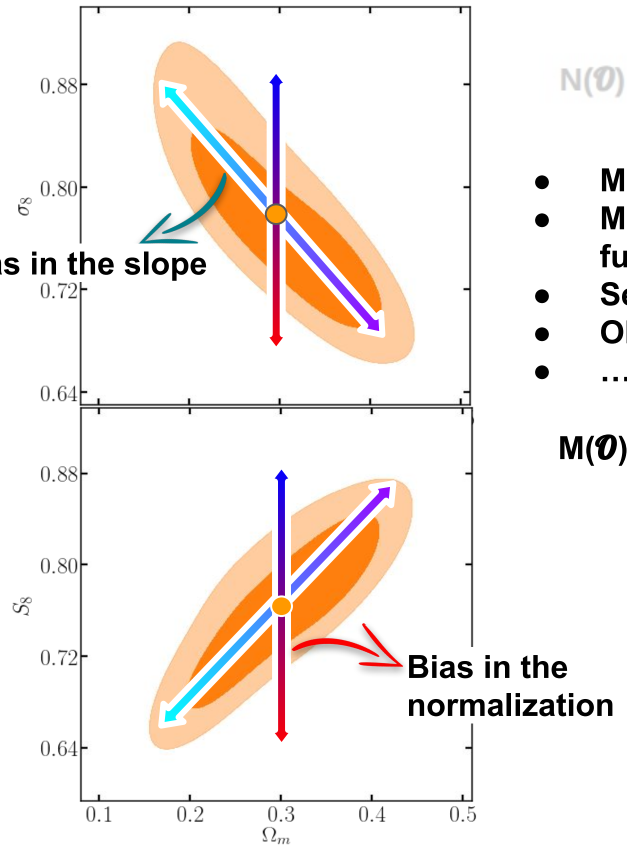
FROM OBSERVATION TO COSMOLOGICAL CONSTRAINTS



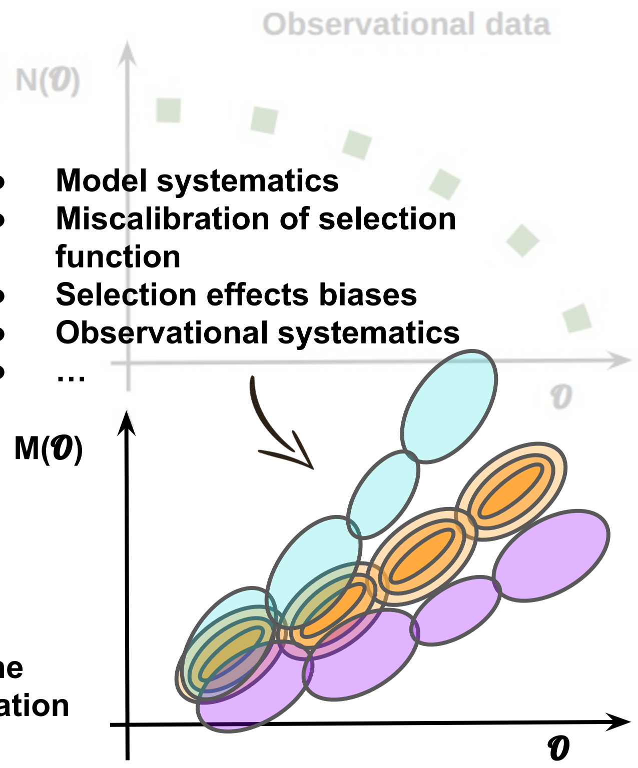
MASS CALIBRATION AND COSMOLOGICAL POSTERIORS



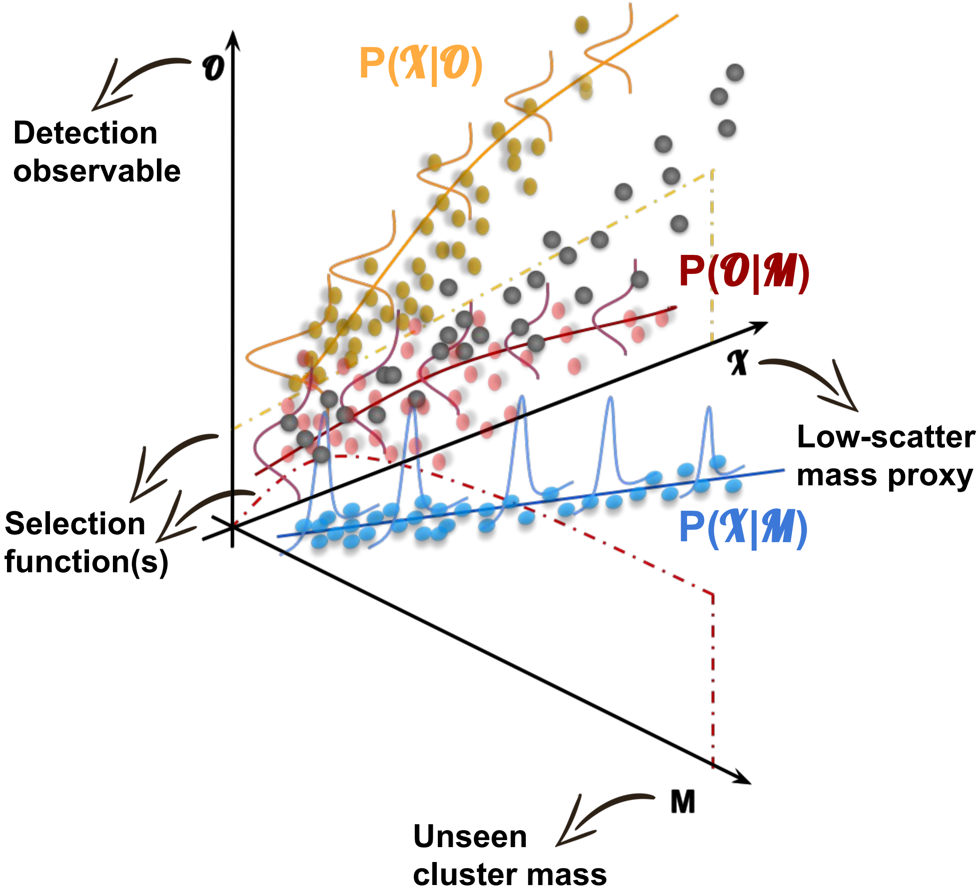
Main limiting systematics for cluster cosmology studies at all wavelengths



- Model systematics
- Miscalibration of selection function
- Selection effects biases
- Observational systematics
- …



SELECTION FUNCTION AND MASS CALIBRATION

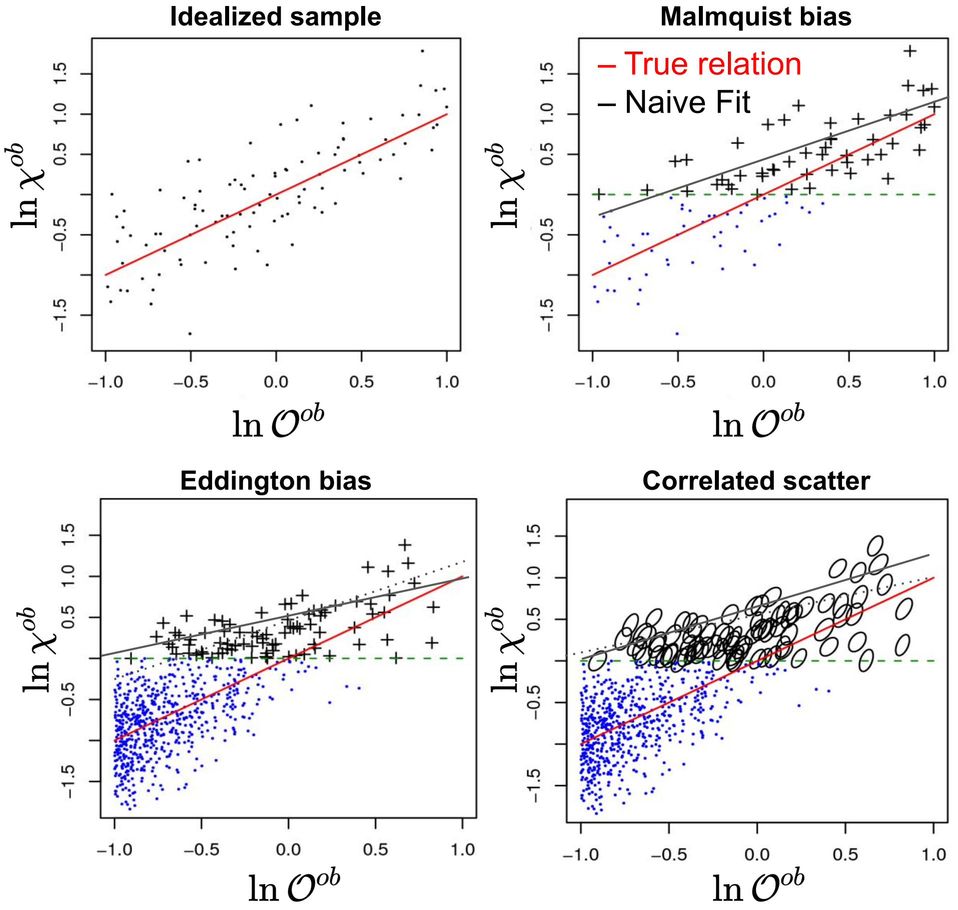


Different detection techniques imply different mass proxies, mass calibration data and systematics.

The calibration of the observable-mass relation(s) requires:

- **Well defined selection function(s)**
- **A model to describe the parent distribution as a function of mass (halo mass function)**
- **A model to describe the PDF of the multivariate observable space: $P(\mathcal{X},\mathcal{O}|\mathcal{M})$**

SELECTION FUNCTION AND MASS CALIBRATION



Credit A. Mantz

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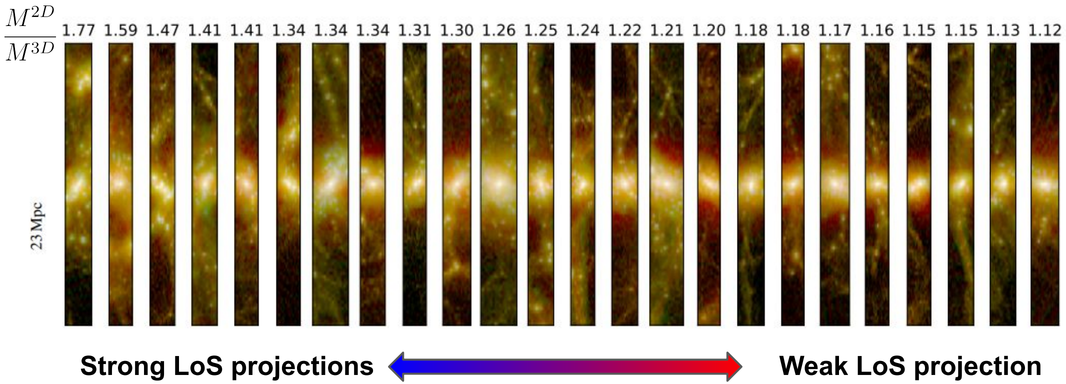
CORRELATION BETWEEN MULTI-λ OBSERVABLES

- **Observationally, we only have access to projected quantities.**

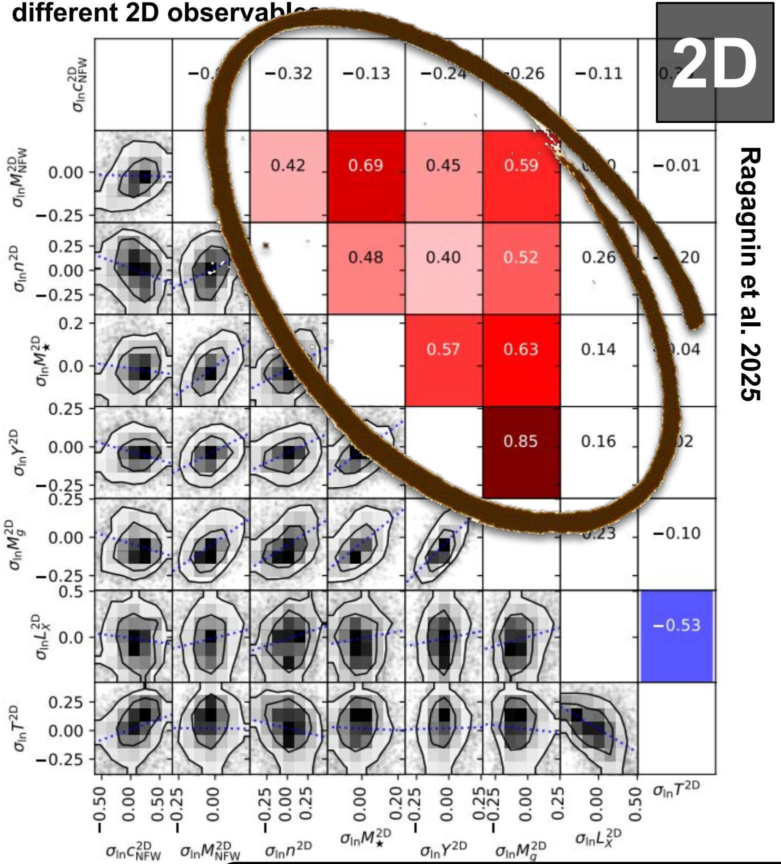
Projected cluster mass maps along a cylinder of length 23 Mpc



- **Line-of-sigh projections increase the scatter and skewness of the Obs-Mass relations and introduce correlations between observables measured at different wavelengths**

See also e.g. Farahi et al 2019

Correlation coefficients matrix (upper-right triangle) and scatter plot (bottom-left triangle) of log-residual for different 2D observables.



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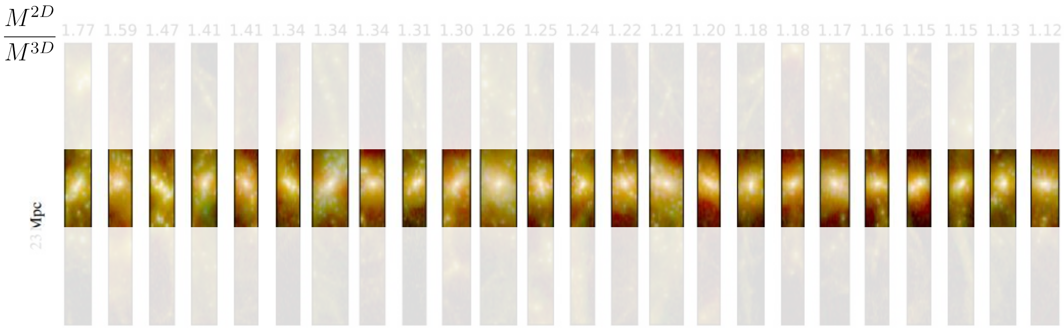
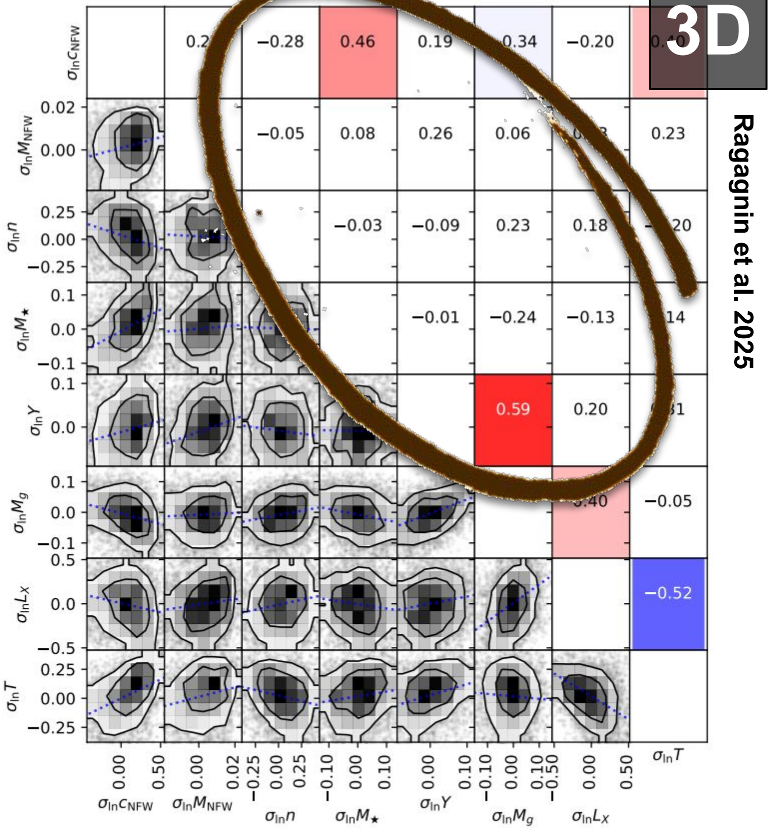


Strong LoS projections ⟷ **Weak LoS projection**

- **Line-of-sigh projections increase the scatter and skewness of the Obs-Mass relations and introduce correlations between observables measured at different wavelengths**

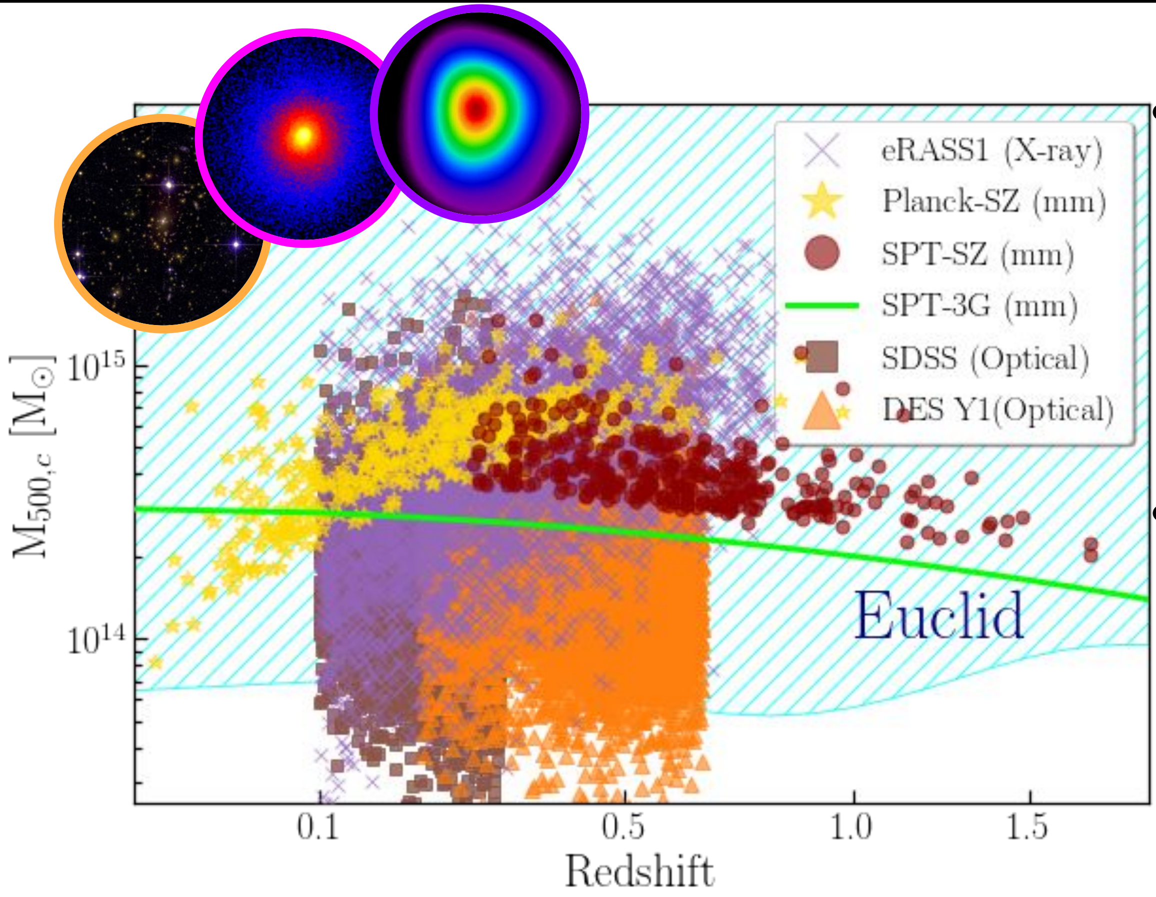
See also e.g. Farahi et al 2019

Correlation coefficients matrix (upper-right triangle) and scatter plot (bottom-left triangle) of log-residual for different 3D observables



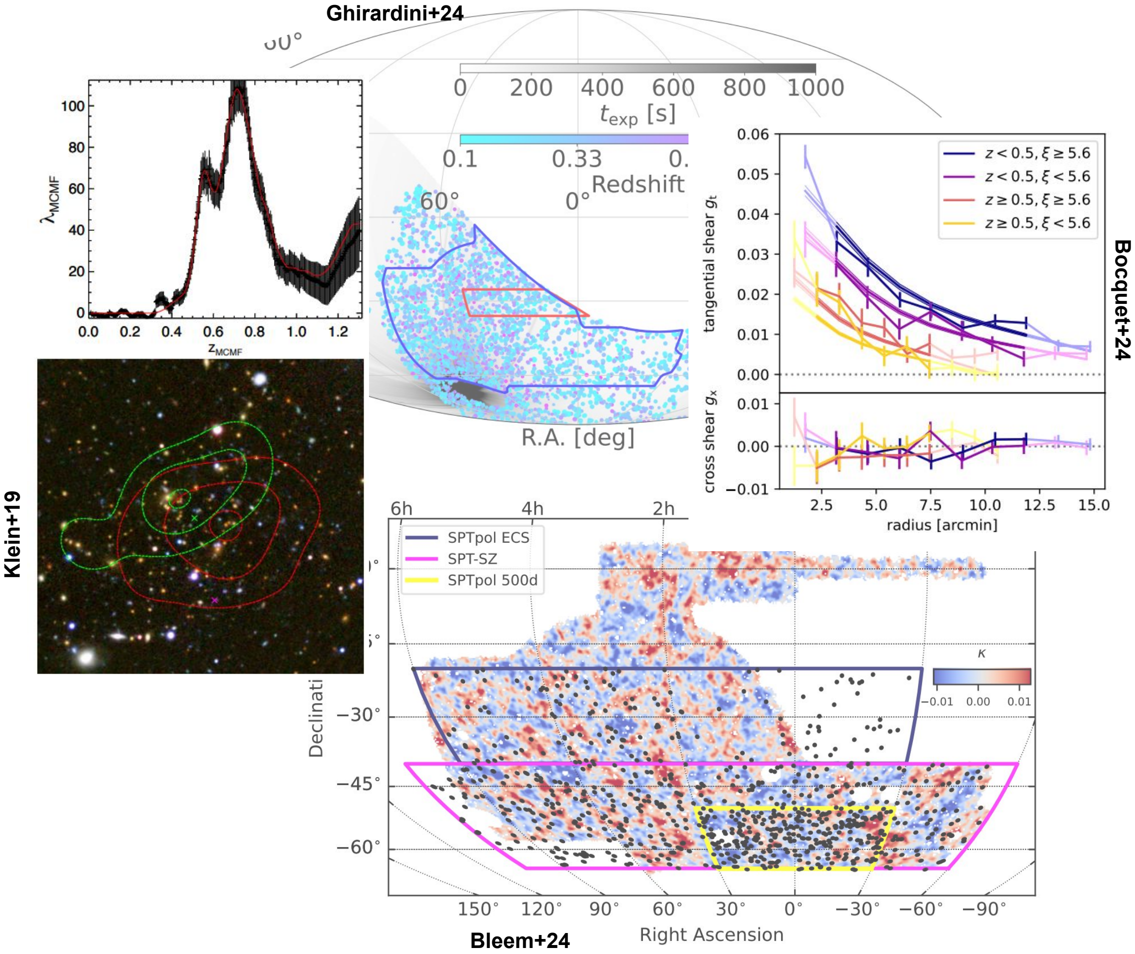
Ragagnin et al. 2025

CLUSTER CATALOGUES AT DIFFERENT λs



- **ICM-selected (X-ray, SZ)**:
  - Mass limit $M \sim 2 \cdot 10^{14} M_\odot$
  - 👍 Clean selection function (SZ signal independent of redshift!)
  - 👎 Need optical follow-up for confirmation, redshift and WL data
- **Optically-selected**:
  - 👍 Lower mass limit $M \sim 5 \cdot 10^{13} M_\odot$ (x10 sample size)
  - 👎 Selection function harder to model
  - 👍 WL and photo-z data readily available

CLUSTER CATALOGUES AT DIFFERENT λs



- ICM-selected (X-ray, SZ):
  - Mass limit M~2 · 10^{14} $M_\odot$
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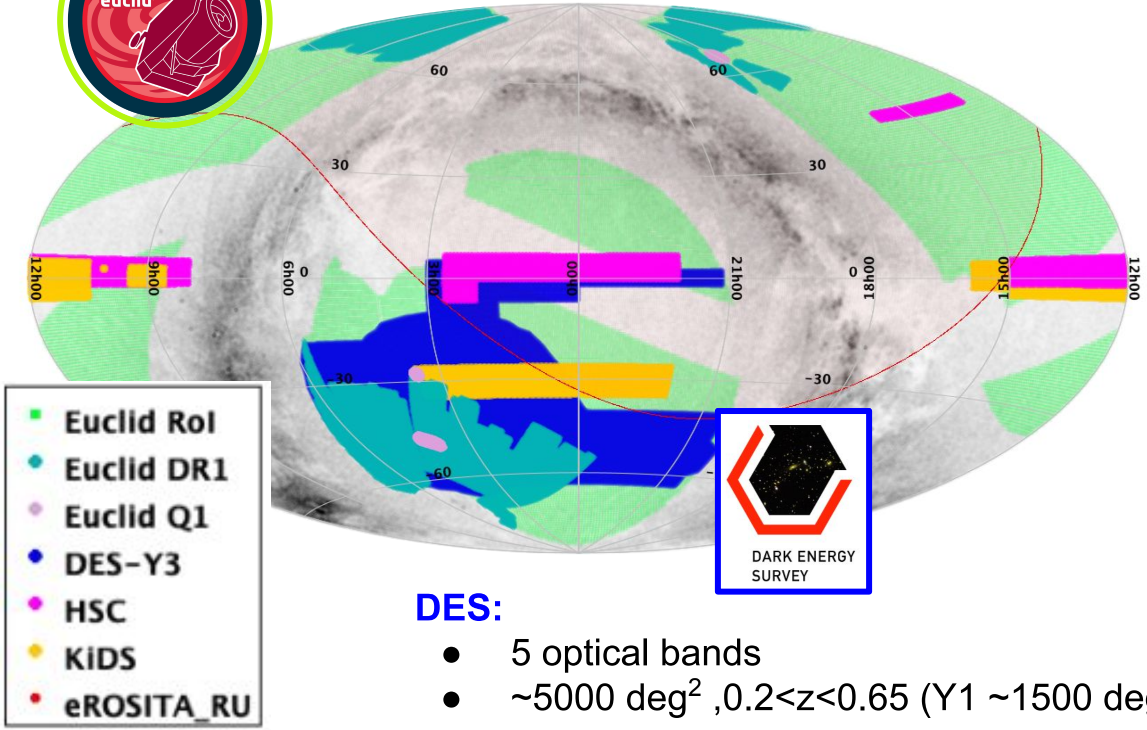
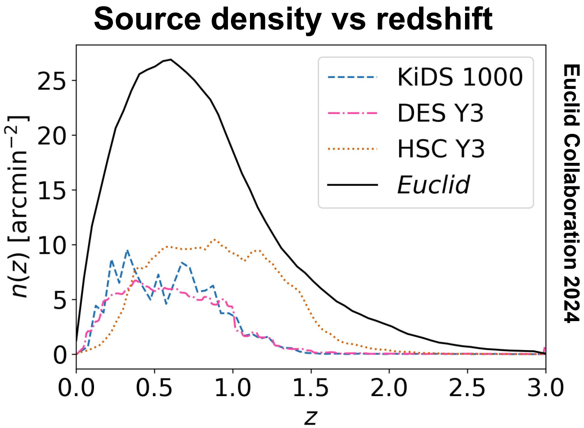
  - WL and photo-z data readily available

CLUSTER CATALOGUES AT DIFFERENT λs

Euclid:

- Optical and IR bands + slitless spectroscopy
- ~15000 deg^2 ,0.2<z<2.0 (DR1 ~1700 deg^2)



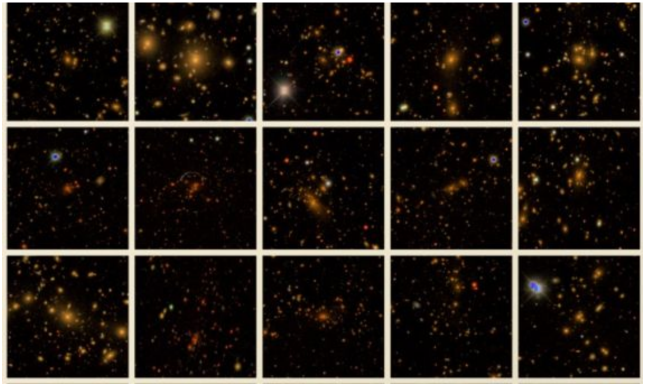


DES:

- 5 optical bands
- ~5000 deg^2 ,0.2<z<0.65 (Y1 ~1500 deg^2)

- **Optically-selected:**
  - **Lower mass limit M~5 · 10^{13} M$_\odot$ (x10 sample size)**
  - **Selection function harder to model**
  - **WL and photo-z data readily available**

THE DARK ENERGY SURVEY



- **DES Photometric Survey:**
  - ~5000 deg^2 of southern sky
  - *g*,*r*,*i*,*z*,(Y) bands (mag lim *i*~24)
- **DES Y3 catalog:**

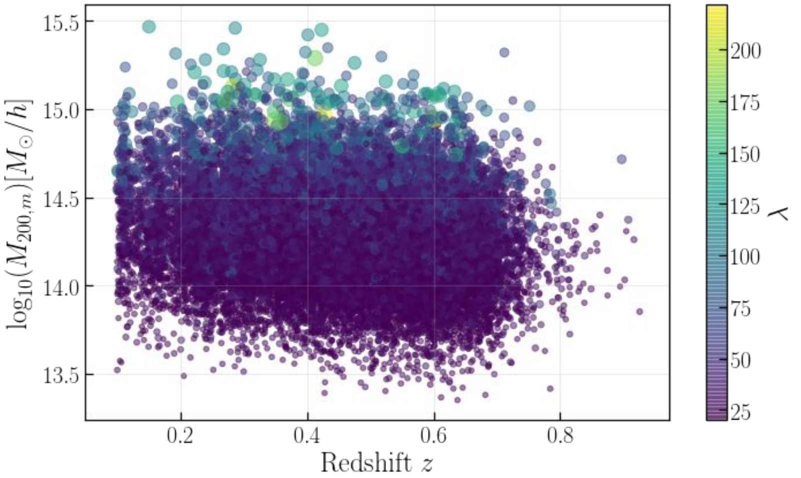
→ **red**-sequence **Ma**tched-filter **P**robabilistic **Per**colation cluster finding algorithm (Rykoff+14)

Mass Proxy: $\lambda^{\rm ob} = \sum_{R<R_\lambda} p_{mem}$

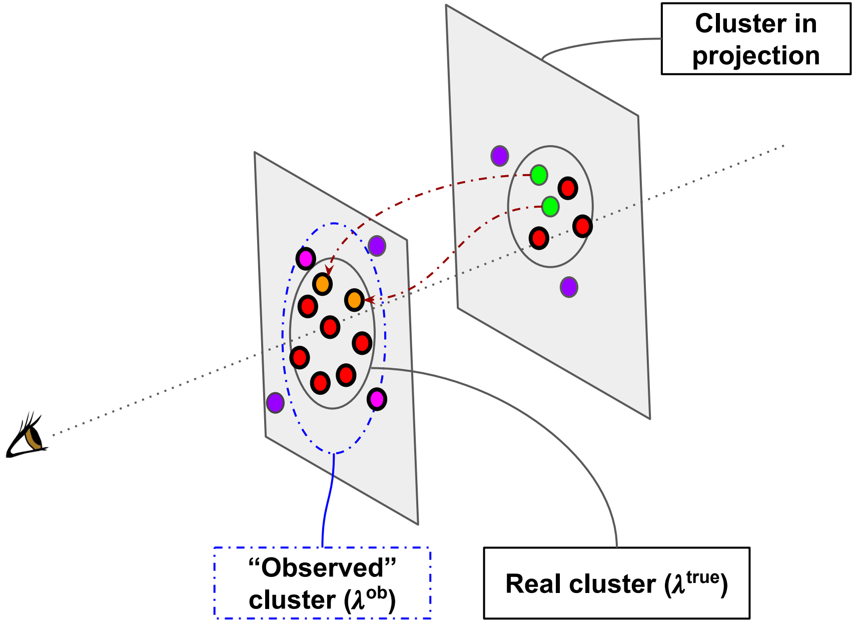
Sub-percent redshift accuracy: $\sigma(z_\lambda)/(1+z_\lambda) \simeq 0.006$

~18k cluster with λ > 20 and 0.2<z<0.65

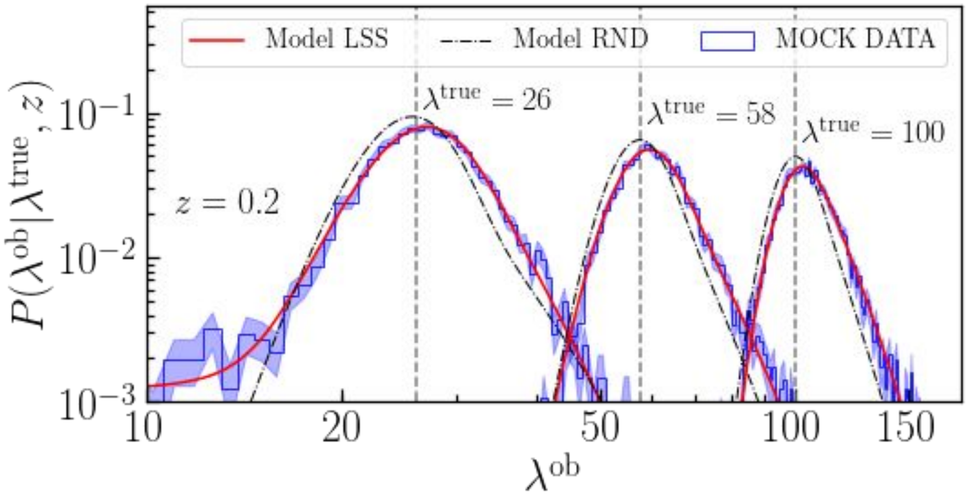
Selection function extensively tested in simulation (e.g. Zhang+23, Lee+25, Cao+25) **and vetted with multi-wavelength data** (e.g. Upsdell+23, Kelly+24, Grandis+25, Myles+25, Giles+in prep)



redMaPPer DES SIMULATION TESTS



Scatter between true and observed richness calibrated via mock/data analysis



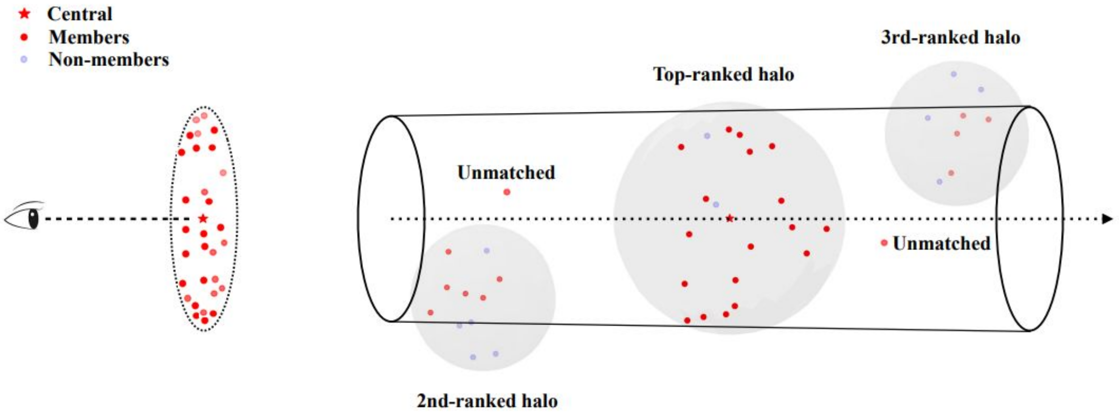
Costanzi et al. 2019

$$\lambda^{ob} = \lambda^{true}(M) + \delta\lambda(\lambda, \ldots)$$

$$\Delta^{bkg} + \Delta^{prj} + \Delta^{perc}$$

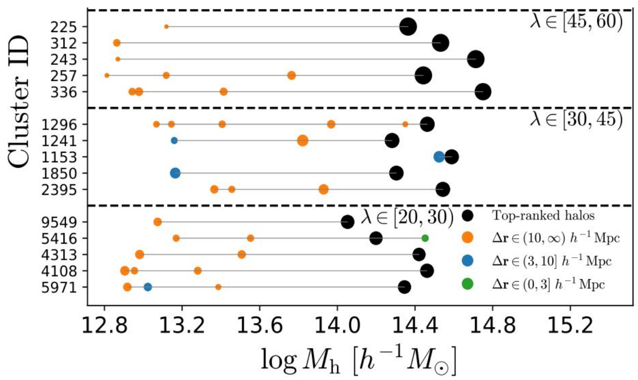
See also: Lee et al. 2025

redMaPPer DES SIMULATION TESTS

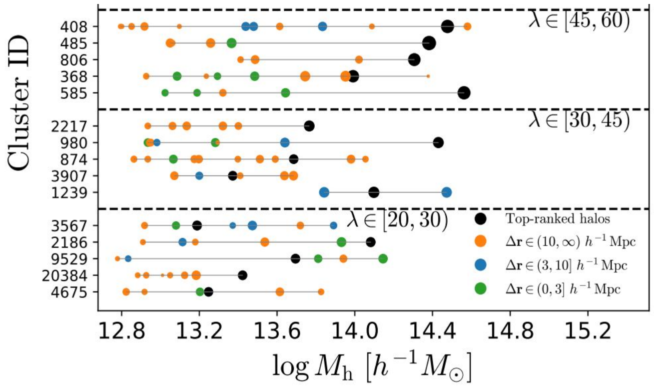


Examples of halos matched to a cluster:

Typical clusters

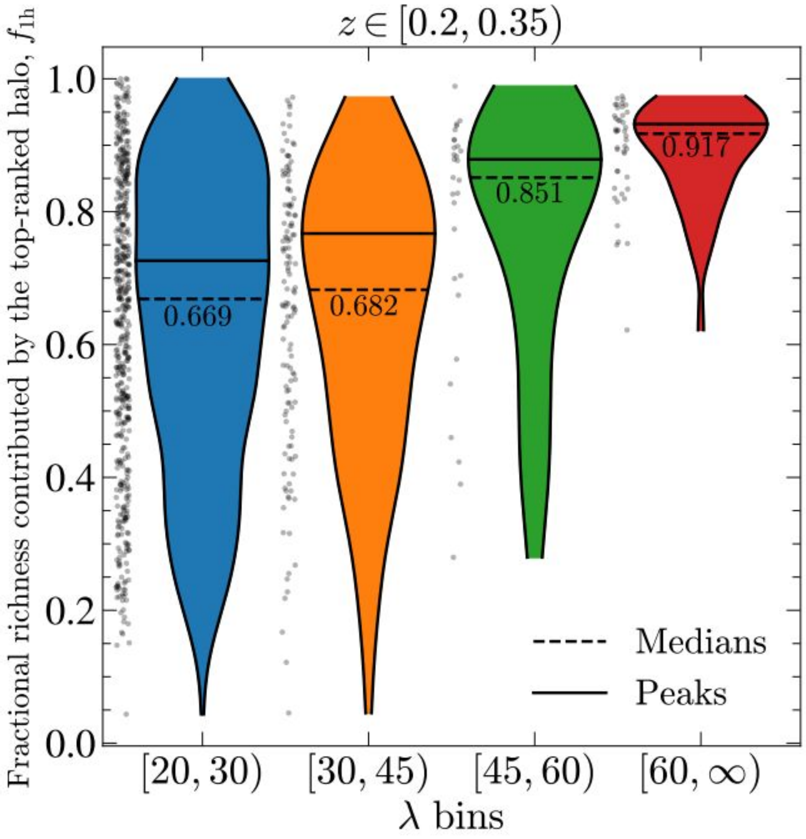


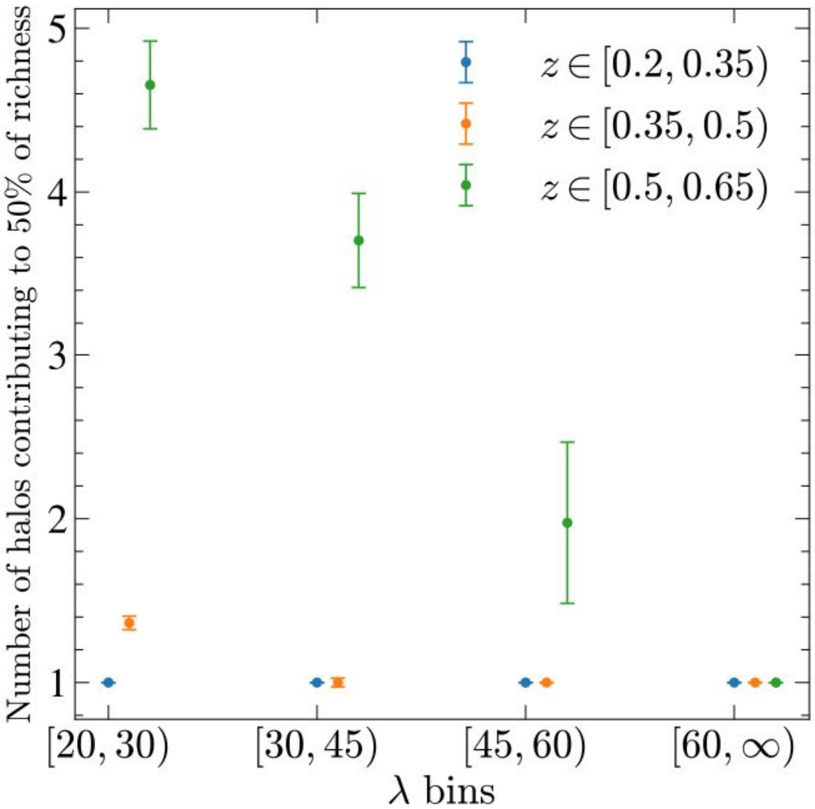
Heavily projected



redMaPPer DES SIMULATION TESTS

$\lambda_{MAIN} / \lambda_{TOT}$



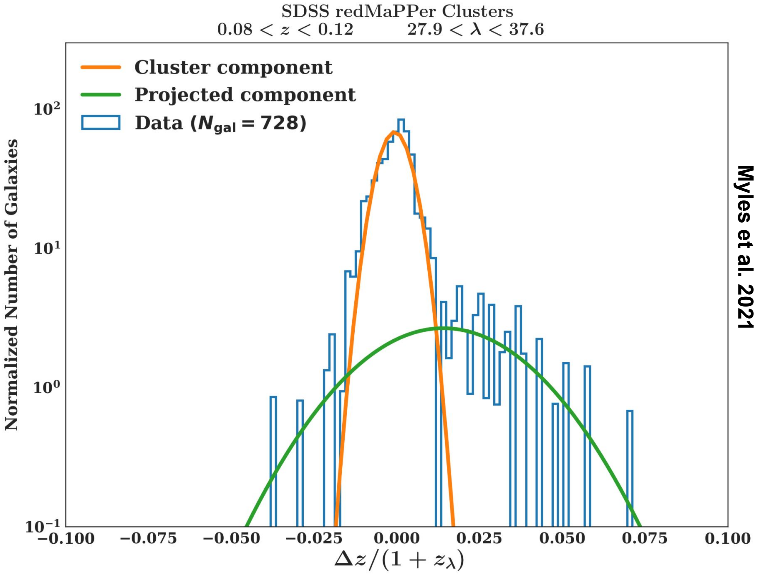


Cao et al. 2025

$\delta\lambda$ CALIBRATION: SPEC-Z DATA

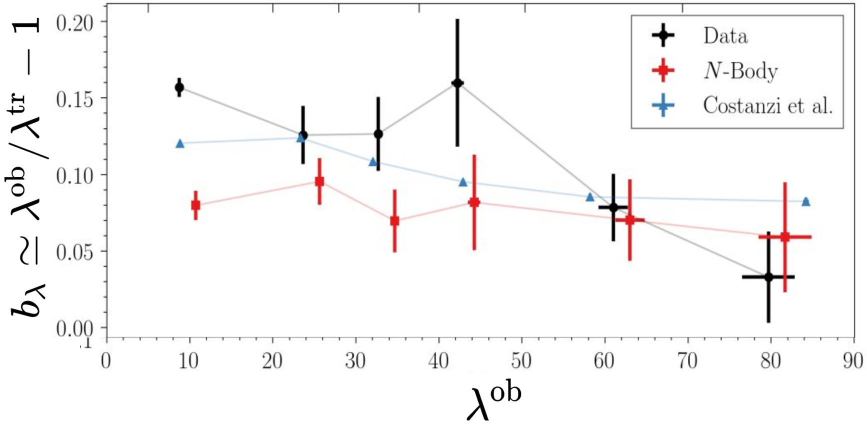
- **Spectroscopic data of putative cluster members allow to distinguish between a population of true cluster galaxies and projected interlopers**

Member galaxy redshift distribution from stacked spec-z data



Myles et al. 2021

Fraction of λ contributed by contaminants: Spec-z data vs simulation

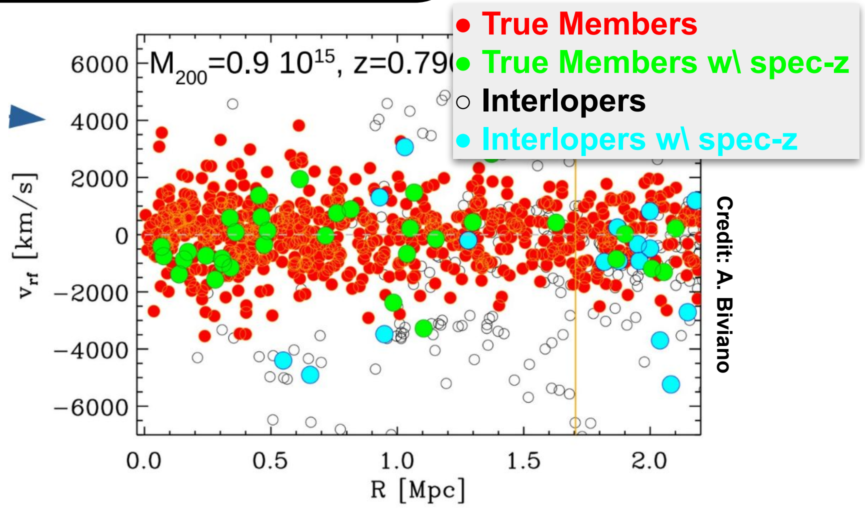


Myles et al. 2021

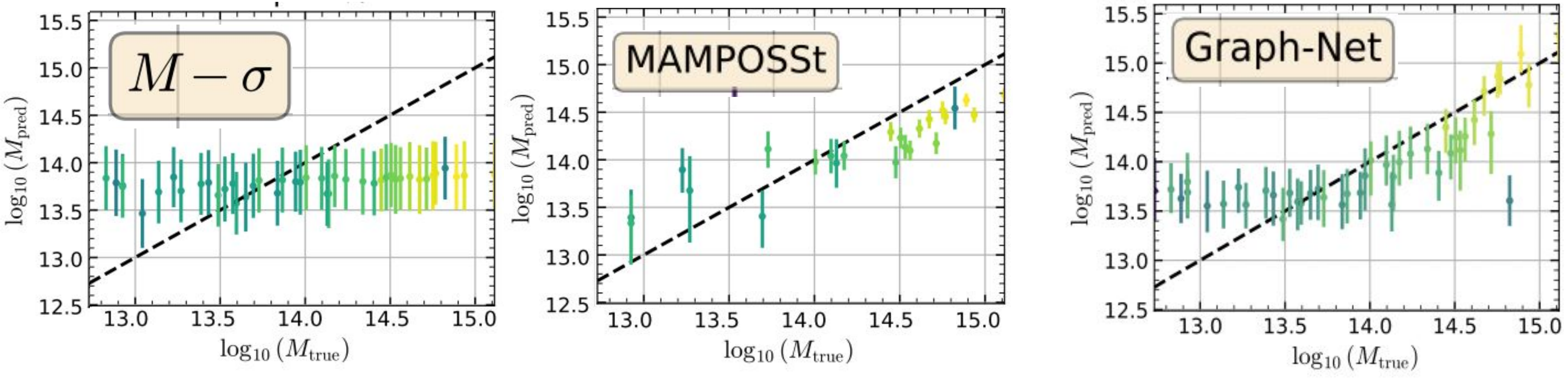
See also: Myles et al. 2025

MASS CALIBRATION WITH SPEC-Z

- **Euclid slitless spectroscopic data can be used to improve redshift estimates, and calibrate cluster masses in the redshift range 0.9<z<1.8.**
- **Low completeness and biased population of tracers prevent the use of traditional methods to derive dynamical masses**

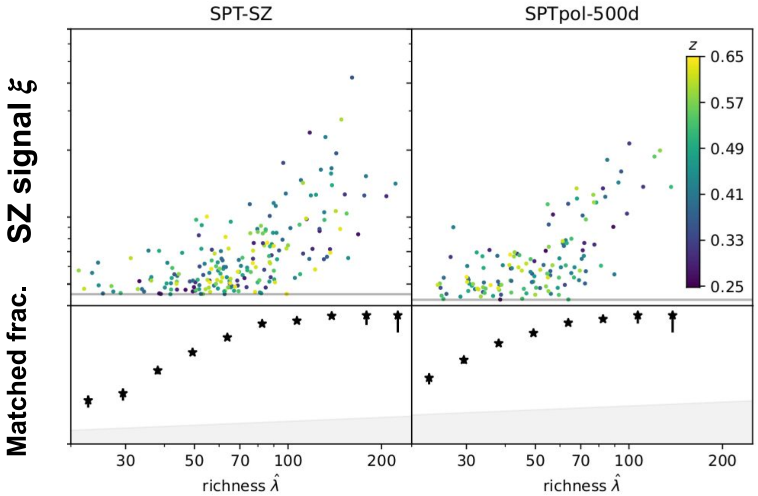


Machine Learning based estimates (Ho et al in prep.)

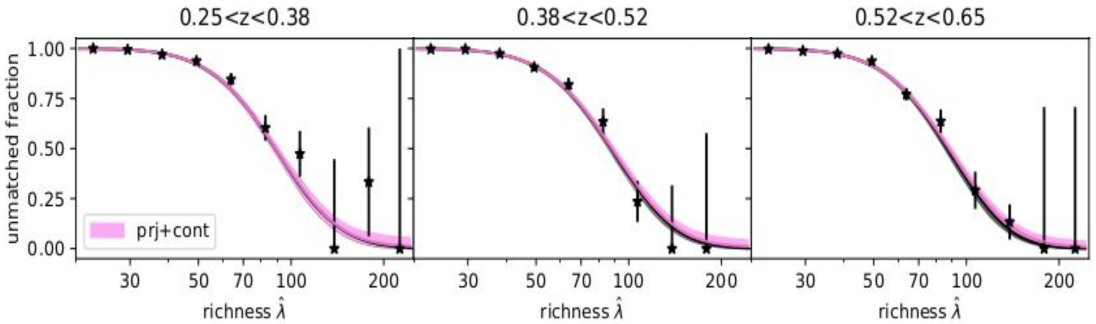


Ho et al. in prep

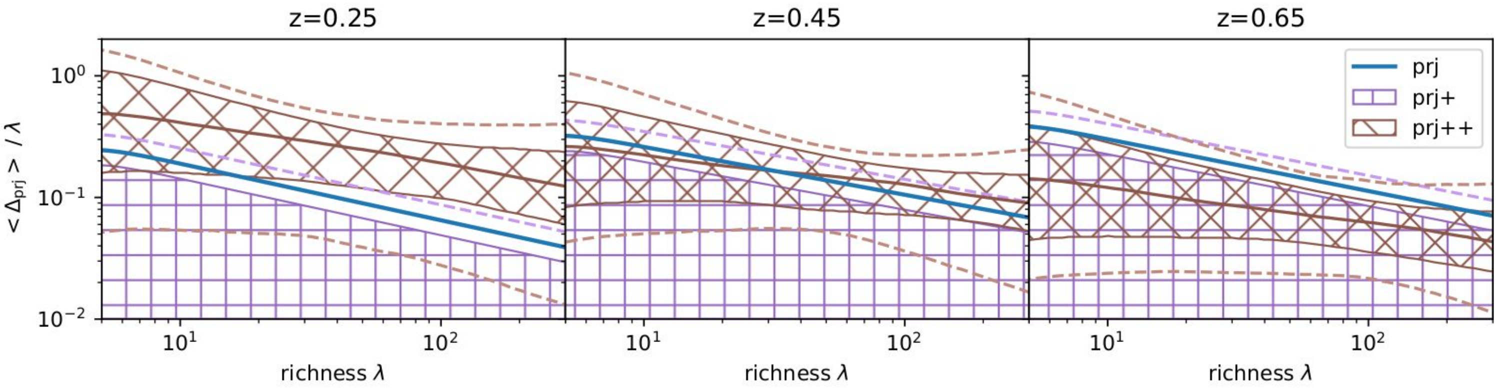
$\delta\lambda$ CALIBRATION: SZ DATA



- **Use redMaPPer DES Y3 x SPT-SZ/500d/ECS matched and unmatched sample to calibrate projection effects: (Grandis et al 2025; see also Grandis+21)**



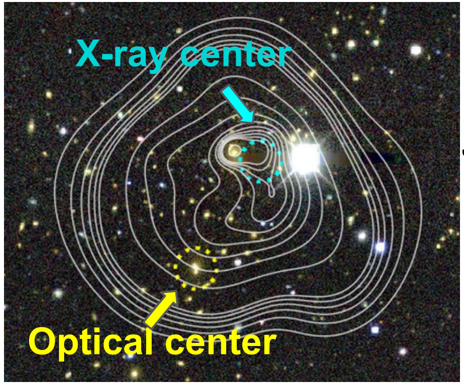
Calibration of richness contamination for different projection models



CLUSTER MISCENTERING: X-RAY CALIBRATION

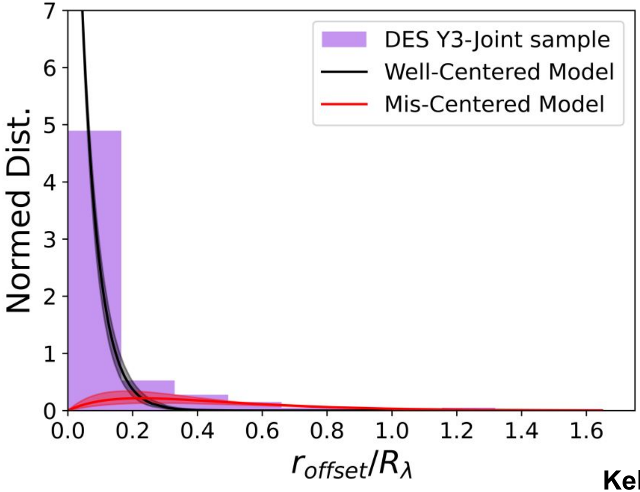
Cluster miscentering caused by: masked data, merging/disturbed clusters, “blue” BCG

Miscentering tends to bias low the lensing signal and other cluster observables (e.g. richness)

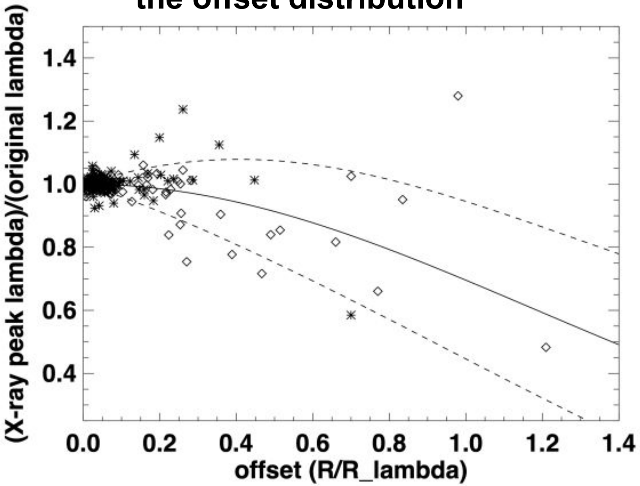


Kelly+24

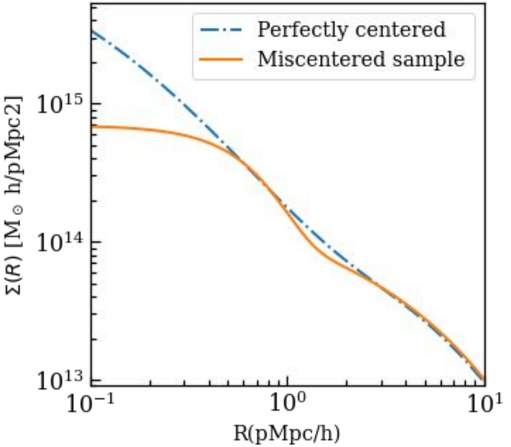
Radial offset distribution calibration using X-ray vs optical center



Richness perturbation as a function of the offset distribution

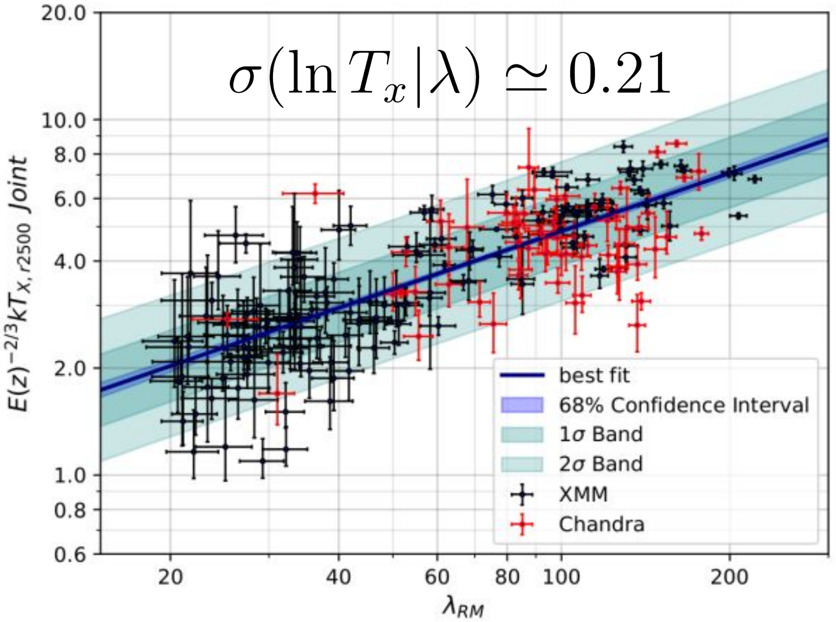


Kelly+24

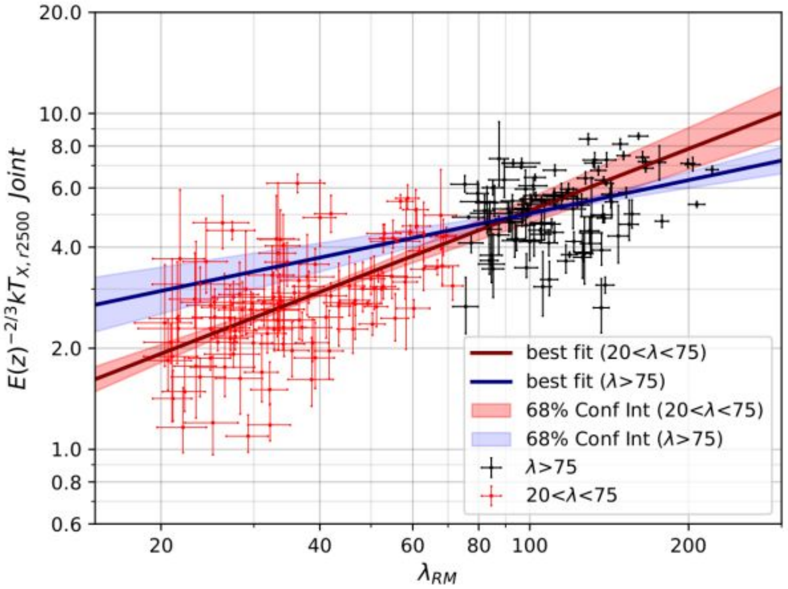


OPTICAL vs X-RAY OBSERVABLES

T_x - λ relation



T_x - λ relation: different λ bins



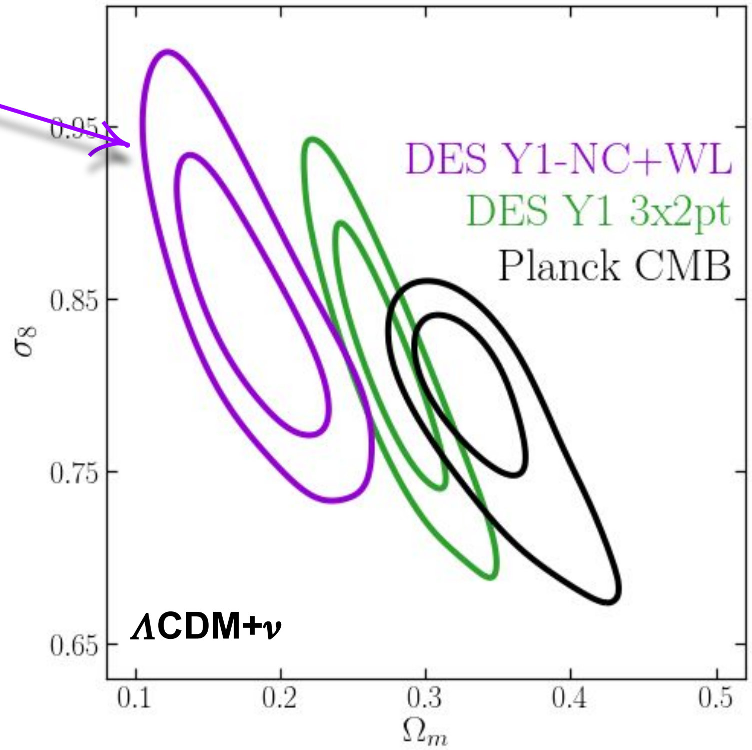
Kelly+24

SELECTION EFFECT BIAS: LESSON FROM DES Y1

DES Y1 NC+WL mass calibration from stacked shear profiles below 30 Mpc (DES collaboration 2020)

- 2.4σ tension with DES Y1 3x2pt
- 5.6σ tension with Planck 18

Suggests a flawed modeling of the stacked WL signal



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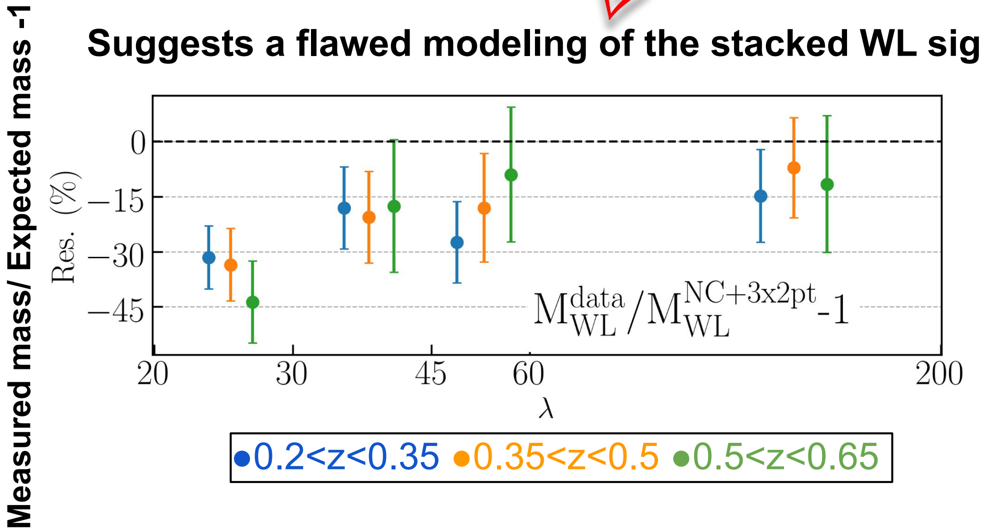

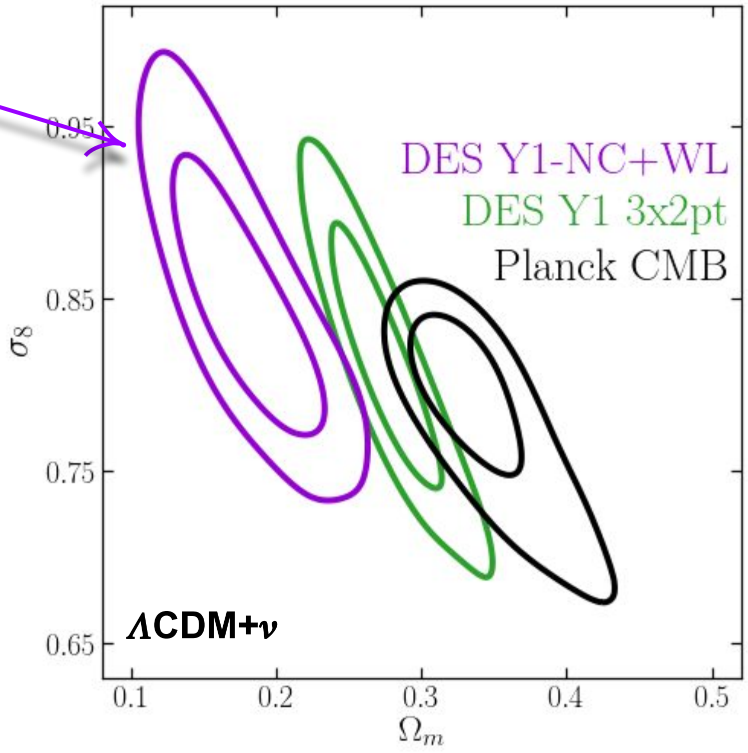

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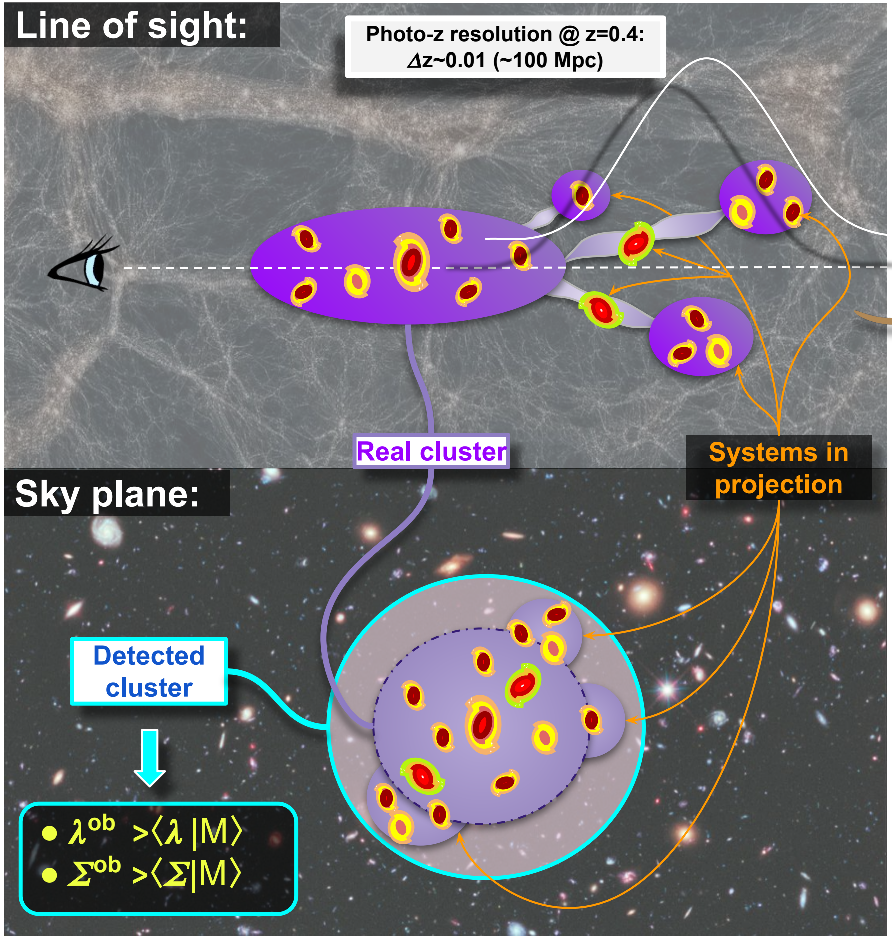
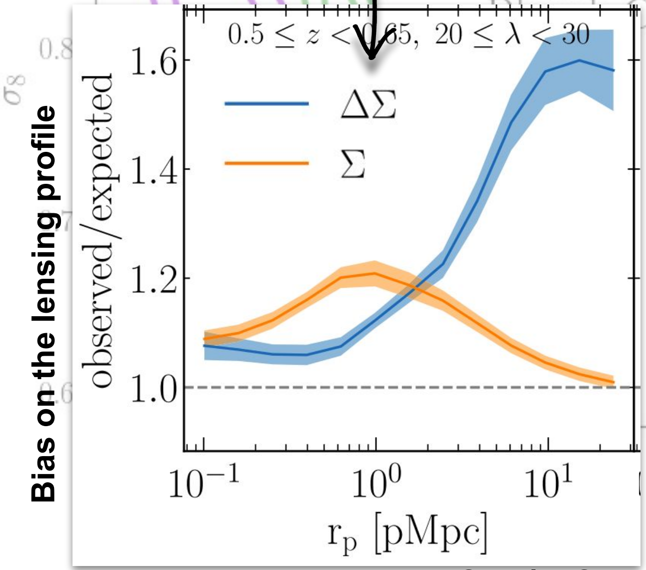


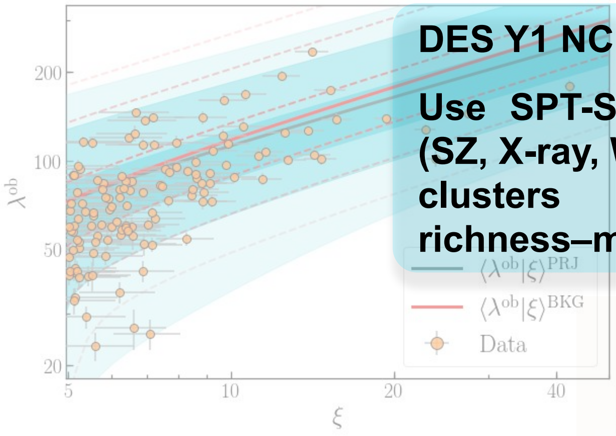
$$\lambda^{ob} = \lambda(M) + \delta\lambda(\lambda, \ldots)$$

$$\Sigma^{ob} = \Sigma(M) + \delta\Sigma(\delta\lambda, \ldots)$$



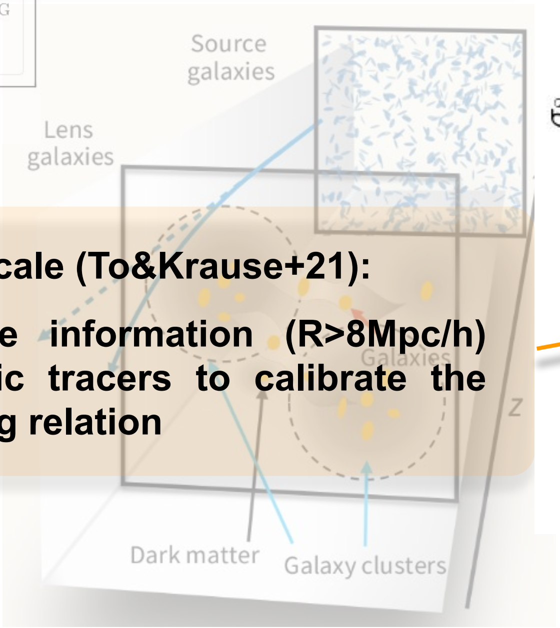
See also Sunayama+2020

SELECTION EFFECT BIAS: LESSON FROM DES Y1



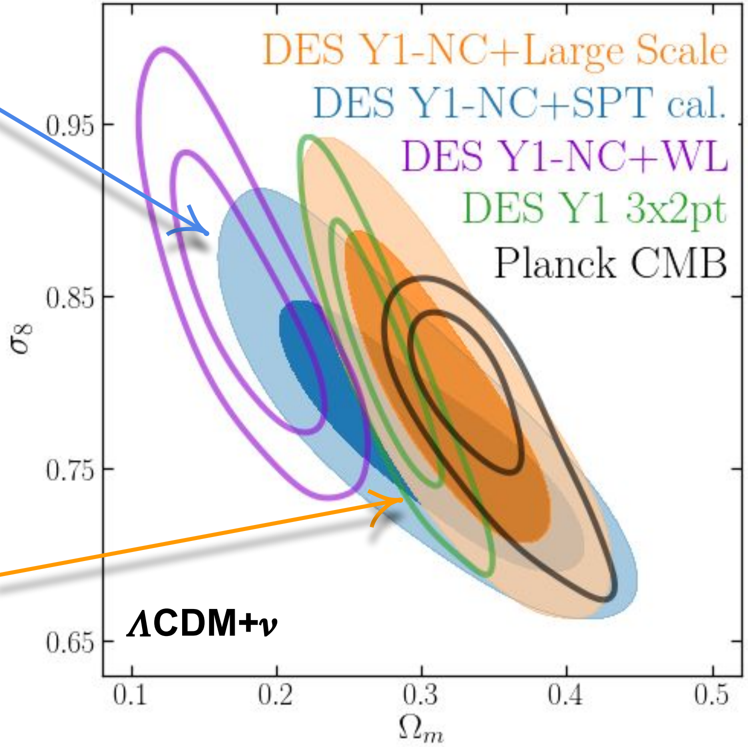
DES Y1 NC X SPT data (Costanzi+21):

Use SPT-SZ multi-wavelengths data (SZ, X-ray, WL) of cross-matched DES clusters to constrain the richness–mass scaling relation



DES Y1 NC x Large Scale (To&Krause+21):

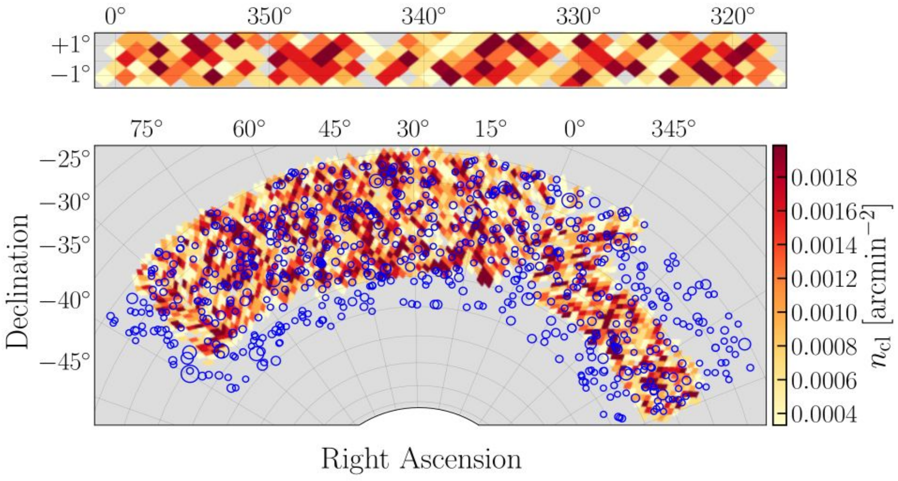
Use only large-scale information (R>8Mpc/h) from different cosmic tracers to calibrate the richness-mass scaling relation



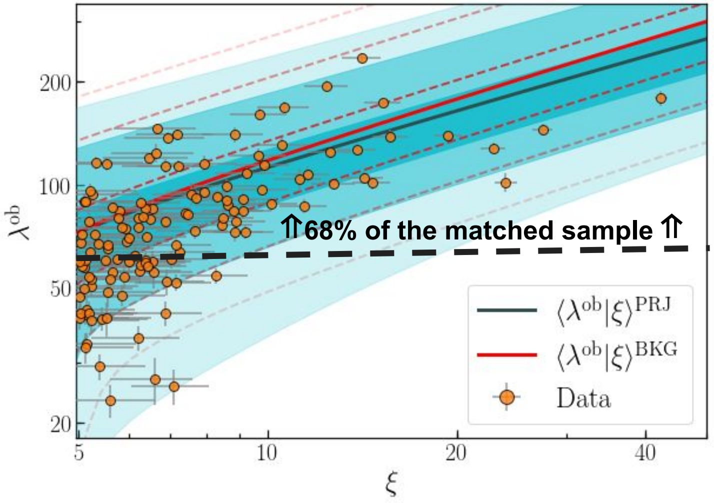
DES Y1 CLUSTER COUNTS x SPT MULTI-λ DATA

- **Idea: Remove DES WL data and use SPT-SZ multi-wavelengths data (SZ, X-ray, WL) to constrain the richness–mass scaling relation**
- **Use DES Y1 Number Counts to constrain cosmology**
- **Add high-z SPT NC to test consistency between abundance and follow-up data sets and assess possible cosmological gain**

DES Y1 cluster density and SPT-SZ clusters



DES Y1-SPT SZ cross matched sample

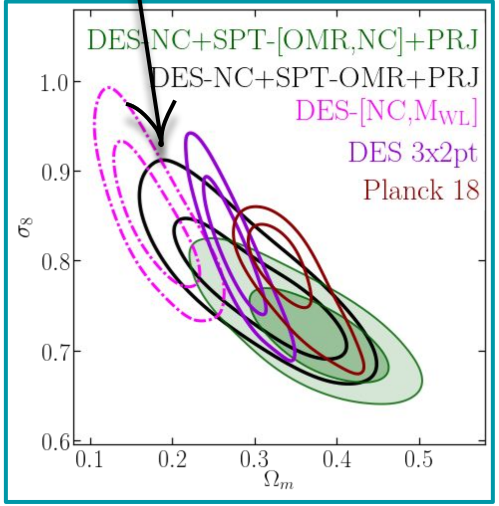


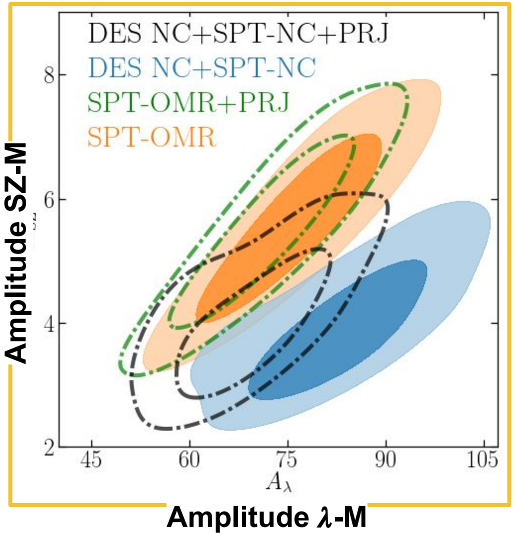
Costanzi+21

DES CLUSTER COUNTS x SPT MULTI-λ DATA

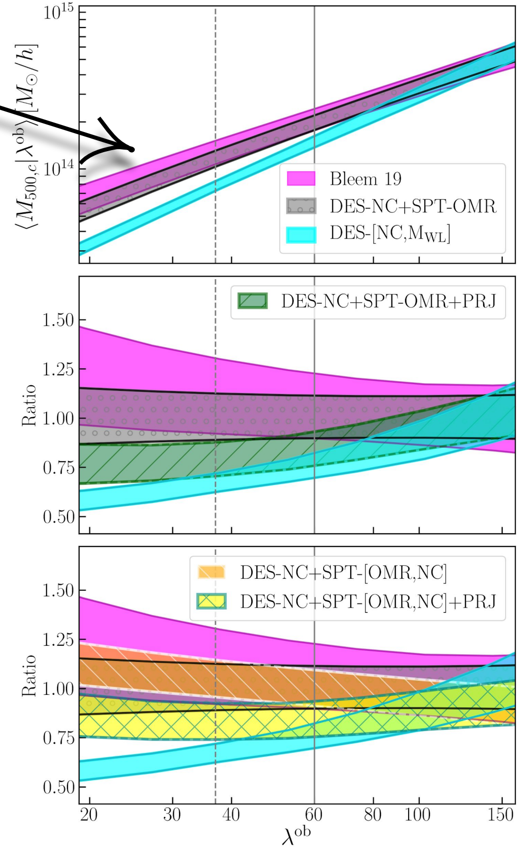
DES-NC x SPT-multi-λ yields results consistent with multiple cosmological probes.

Inclusion of high-redshift SPT NC data serves as a test of different scatter models for λ^{ob}





Mass-richness relations for different data combinations



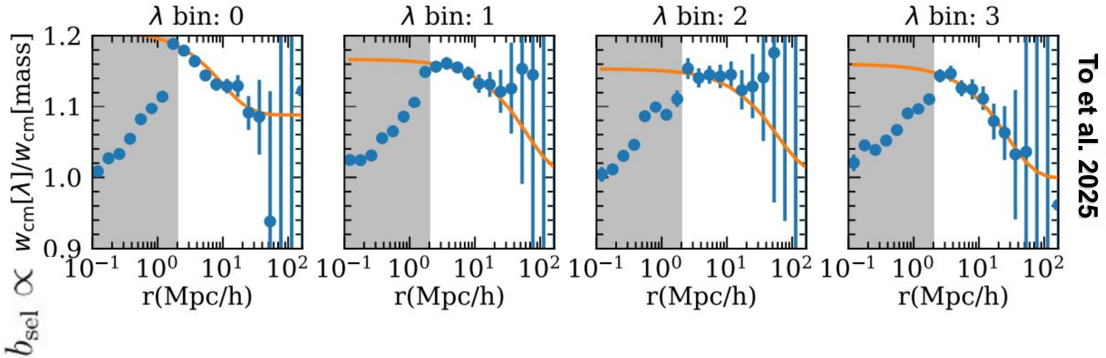
Costanzi+21

CLUSTER COUNTS x LARGE SCALE TRACERS

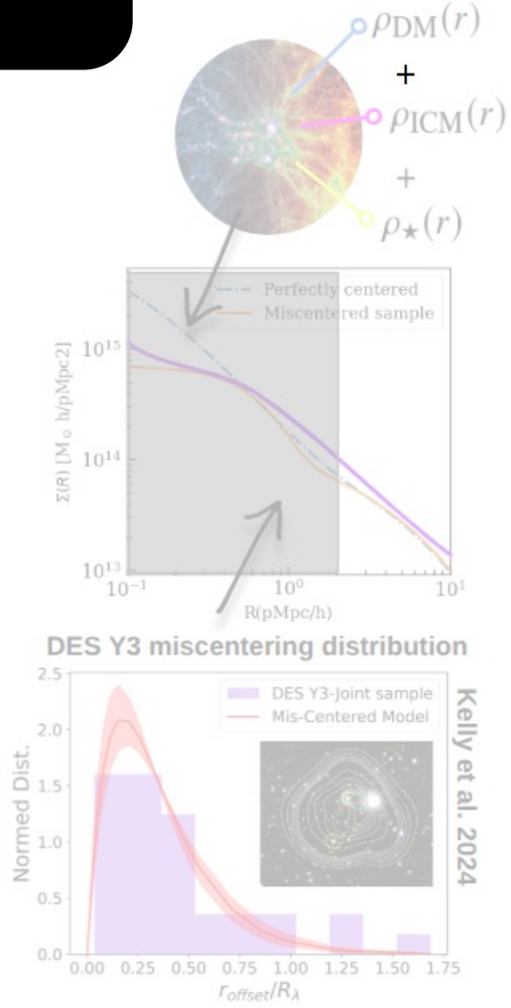
By dropping small-scale data we get:

- **Simpler model for selection bias:** $b_{\rm sel} \propto b_1 + b_2 \exp\left[-\frac{r}{r_0}\right]$

$b_{\rm sel}$ from mock data vs model template



- By-pass several small-scale systematics (e.g. baryonic feedback, cluster miscentering)
- Loss of information (especially related to the lensing one-halo term for the mass calibration)



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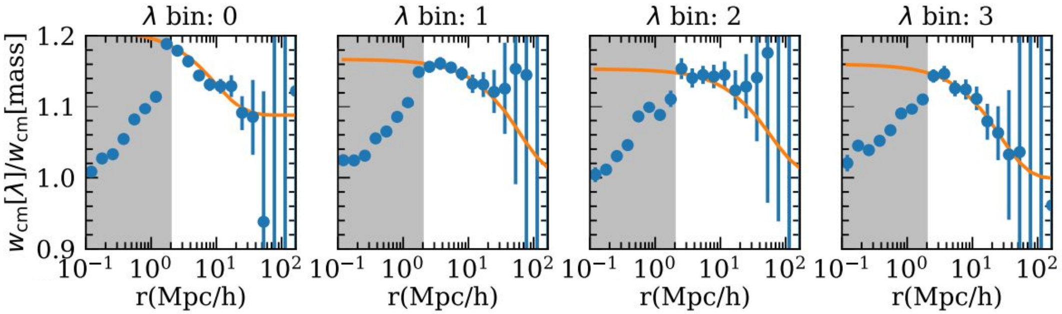
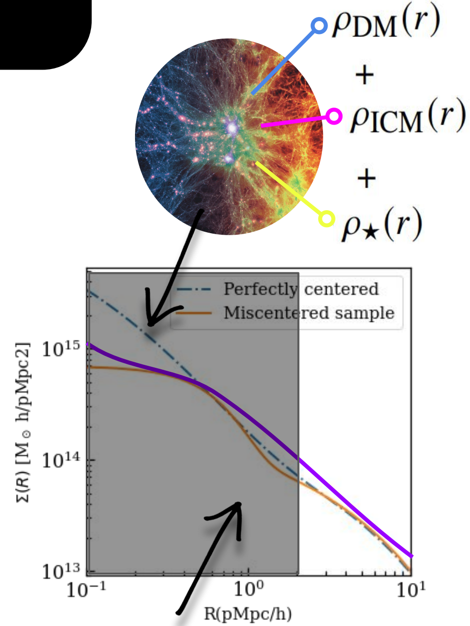
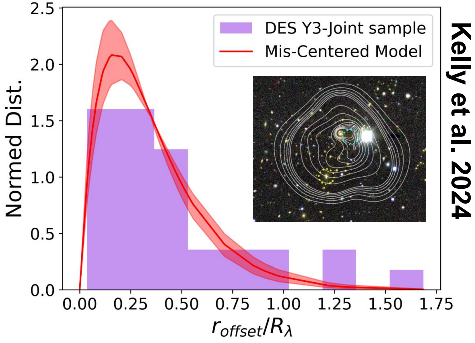


To et al. 2025



DES Y3 miscentering distribution



Kelly et al. 2024

- **By-pass several small-scale systematics (e.g. baryonic feedback, cluster miscentering)**
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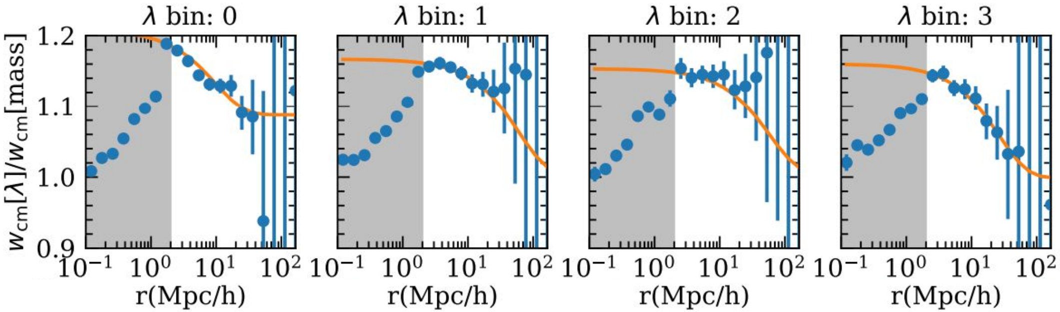

To et al. 2025

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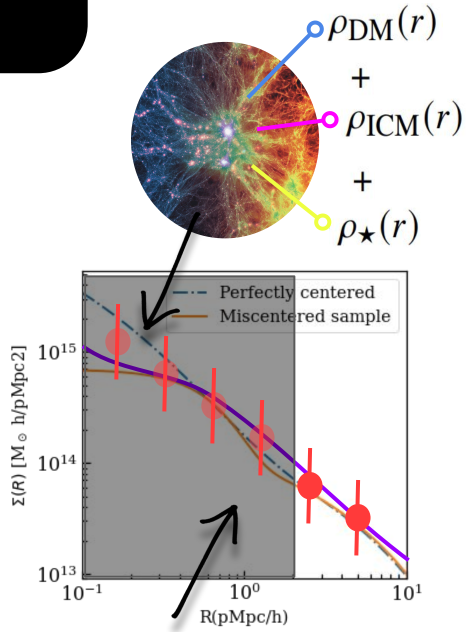

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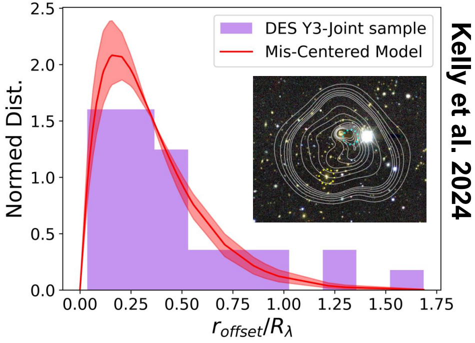

Kelly et al. 2024

CLUSTER COUNTS x LARGE SCALE TRACERS

By dropping small-scale data we get:

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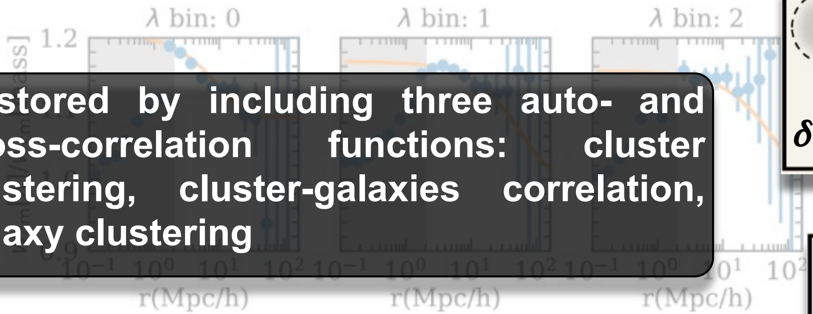
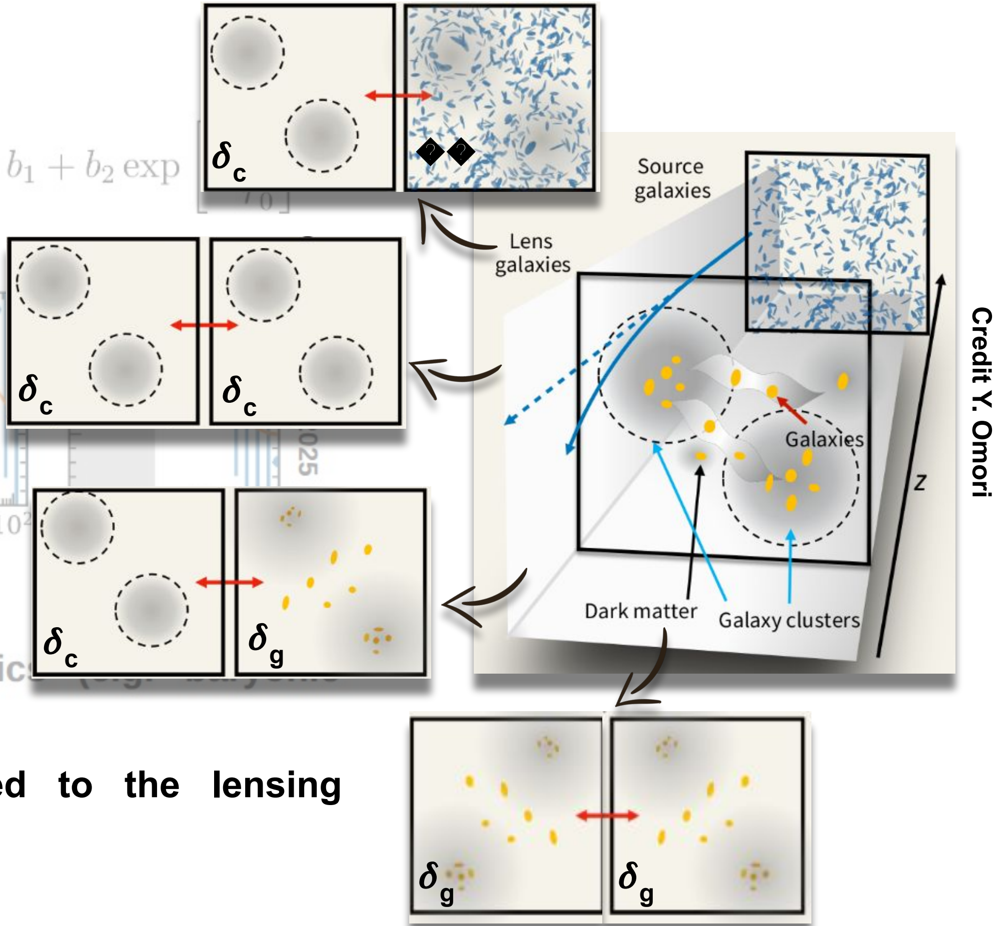


Restored by including three auto- and cross-correlation functions: cluster clustering, cluster-galaxies correlation, galaxy clustering

- By-pass several small-scale systematics (e.g. baryonic feedback, cluster miscentering)

- **Loss of information (especially related to the lensing one-halo term for the mass calibration)**



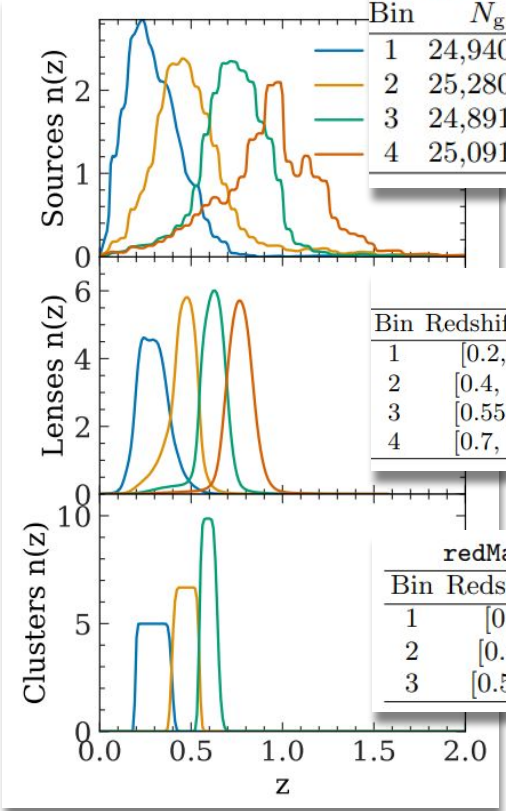
DES Y3 CLUSTER x LARGE SCALE ANALYSIS

Unified analysis framework described by:

- **15 astrophysical parameters describing the connection between observables and matter fluctuations: linear galaxy bias, optical-cluster bias, intrinsic alignment, richness-mass relation**
- **17 parameters to account for observational systematics (photo-z uncertainties, shear measurements)**

From DES Y1 to DES Y3:

- **~3 times larger area (➪ x 3 clusters)**
- **Weak lensing noise lower by ~30%**
- **Cluster lensing data analysis pushed down to 2 Mpc/h**



Metacalibration source galaxies			
Bin	$N_{\rm gal}$	$n_{\rm eff}$ (arcmin^{-2})	σ_ϵ
1	24,940,465	1.476	0.243
2	25,280,405	1.479	0.262
3	24,891,859	1.484	0.259
4	25,091,297	1.461	0.301

Maglim galaxies			
Bin	Redshift range	$N_{\rm gal}$	$n_{\rm gal}$ (arcmin^{-2})
1	[0.2, 0.4]	2,236,473	0.1499
2	[0.4, 0.55]	1,599,500	0.1072
3	[0.55, 0.7]	1,627,413	0.1091
4	[0.7, 0.85]	2,175,184	0.1458

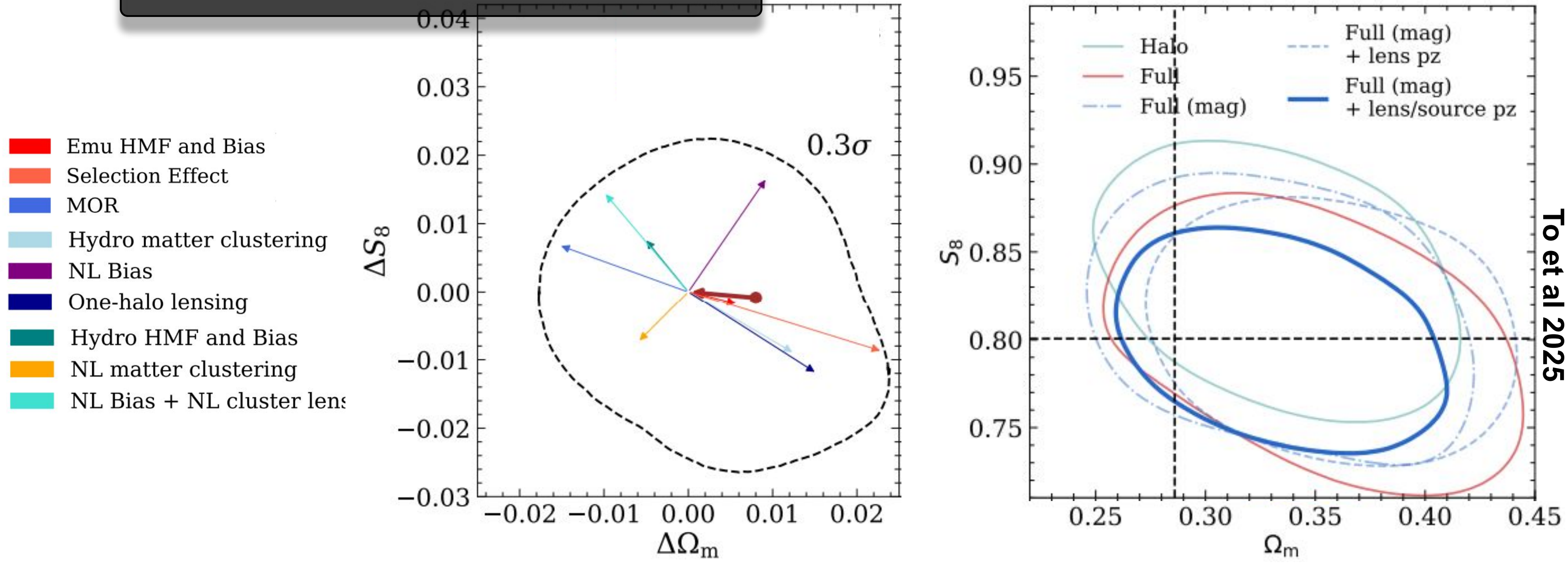
redMaPPer clusters		
Bin	Redshift range	$N_{\rm cluster}$
1	[0.2, 0.4]	5,632
2	[0.4, 0.55]	6,308
3	[0.55, 0.65]	4,551

To et al 2025; DES Collaboration 2025

DES Y3 CLUSTER x LARGE SCALE: ROBUSTNESS TESTS

- **9 different systematics were tested individually using a simulated-likelihood approach**
- **Overall validation performed on simulated data (Cardinal; To+23): 5 different levels of complexity were tested to assess the performance of the cluster finder and model choices**

Unblinding requirement: $\Delta\vartheta < 0.3\,\sigma_{stat}$



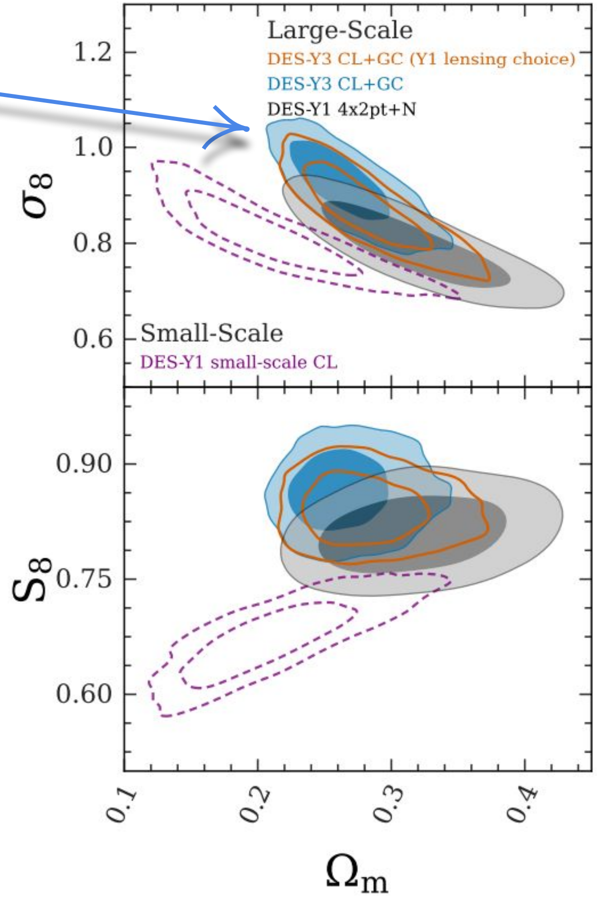
To et al 2025

DES Y3 CLUSTER x LARGE SCALE: RESULTS

- **DES Y3 cluster cosmological constraints consistent with DES Y1 results, and improved by ~50%.**

$$\Omega_m = 0.27^{+0.02}_{0.03} \qquad \sigma_8 = 0.92^{+0.06}_{0.05} \qquad S_8 = 0.86 \pm 0.04$$

- **Results are robust against different catalog cuts and model choices**



DES Collaboration 2025

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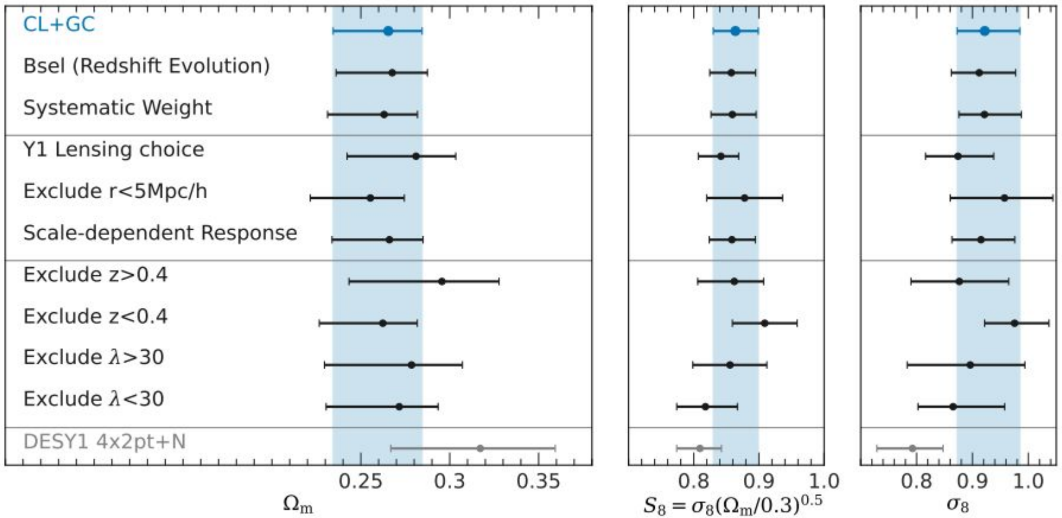
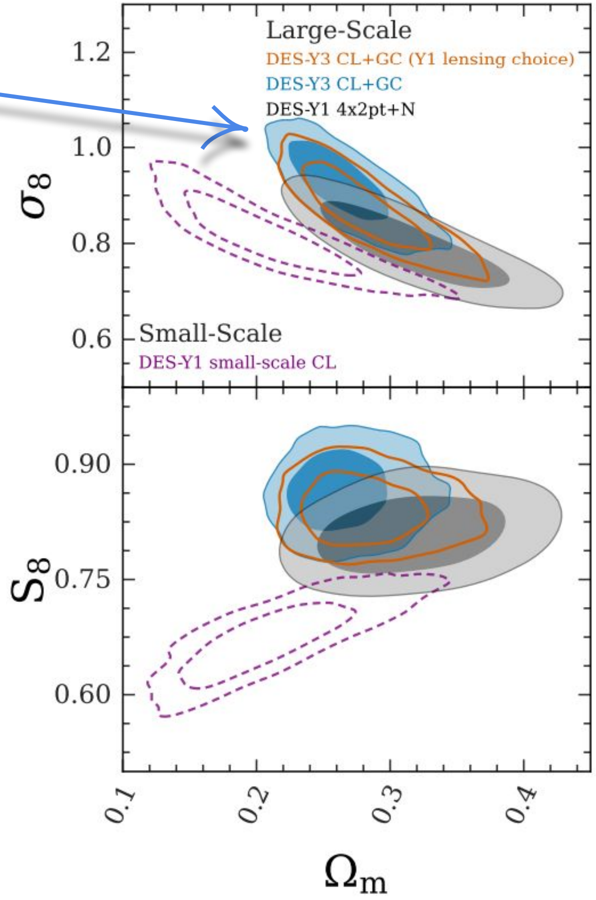




DES Collaboration 2025

DES Y3 CLUSTER x LARGE SCALE: RESULTS

- **Results are also consistent and competitive with other cluster cosmology studies at different wavelengths**

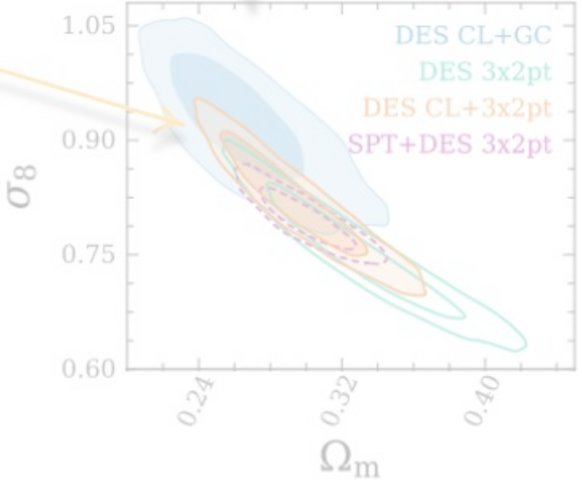
- DES Y3 cluster is also consistent with joint analysis of galaxies and weak lensing (3x2pt)

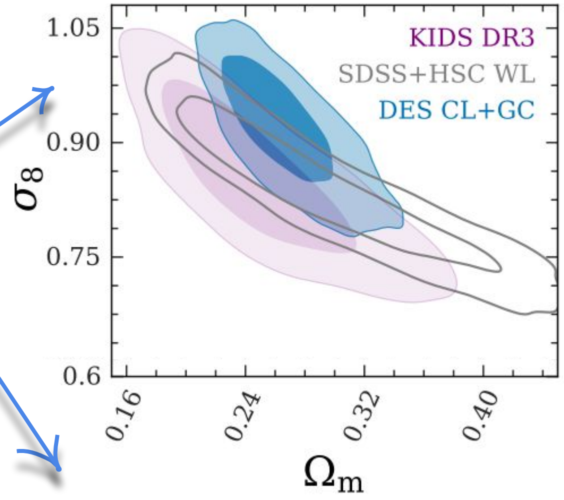
- The combination of all the DES probes entails a further 24% improvement of the cosmological constraints compared to 3x2pt:

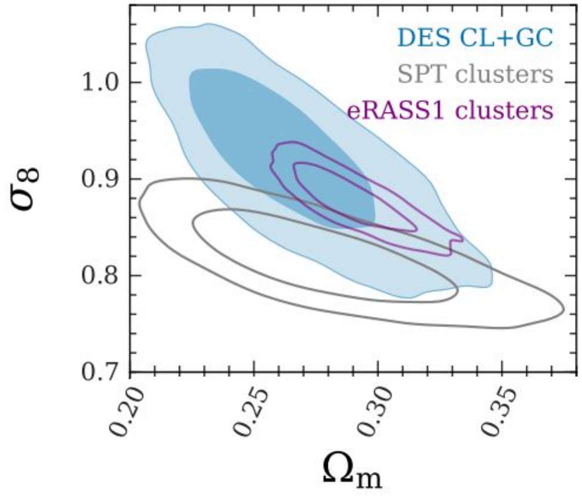
$$\Omega_m = 0.29^{+0.02}_{-0.03}$$

$$\sigma_8 = 0.82 \pm 0.05$$

$$S_8 = 0.81 \pm 0.02$$







DES Collaboration 2025

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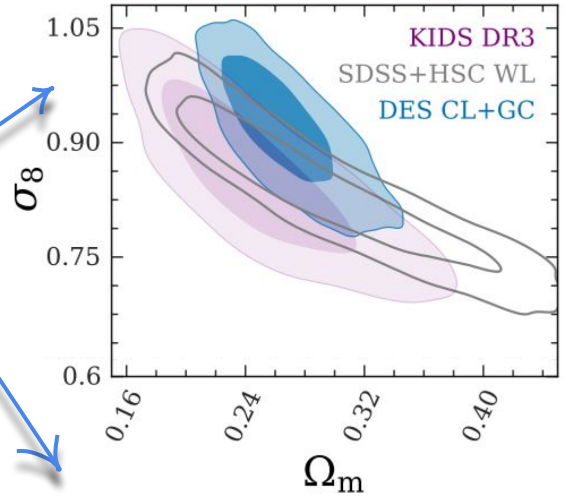

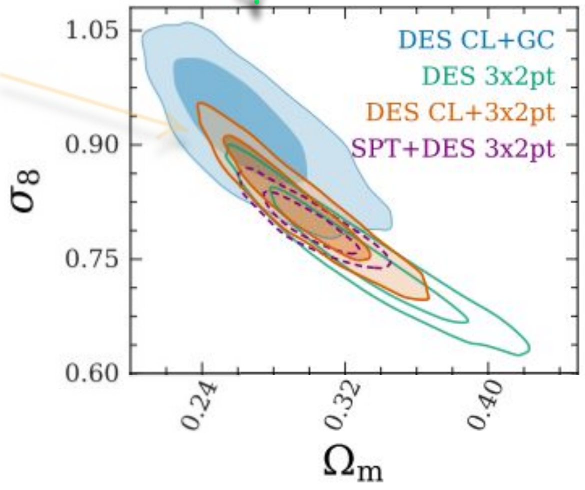

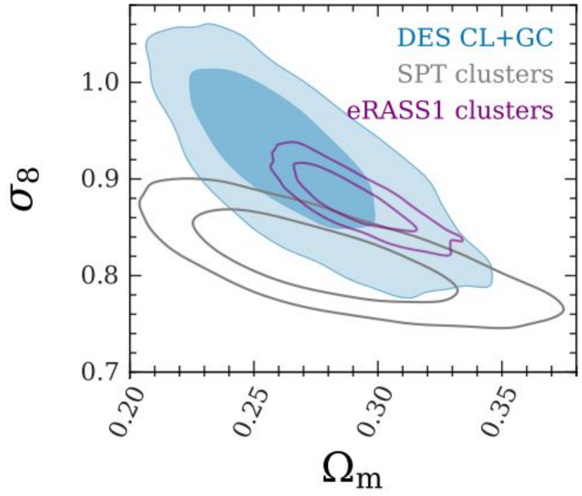

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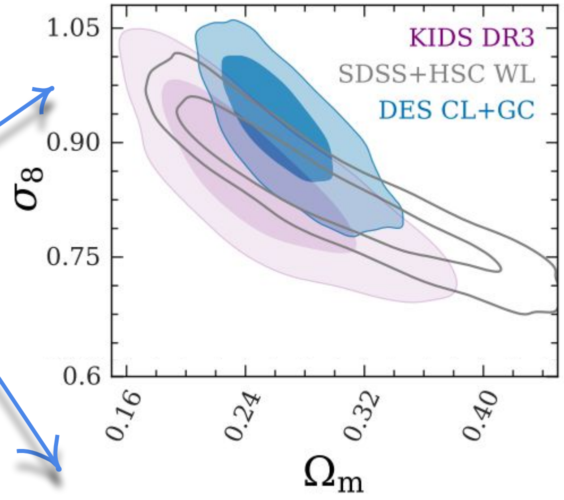
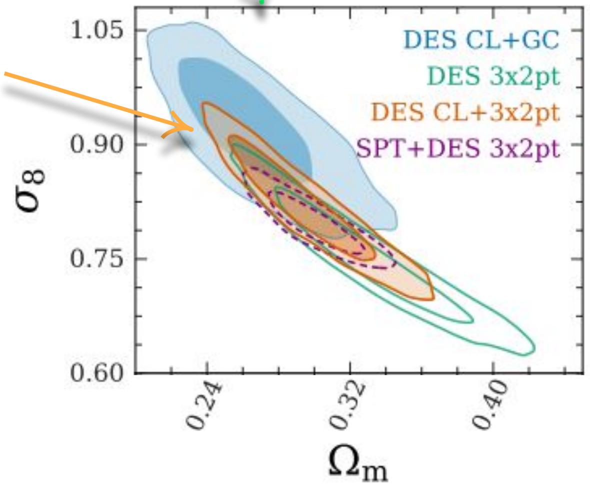
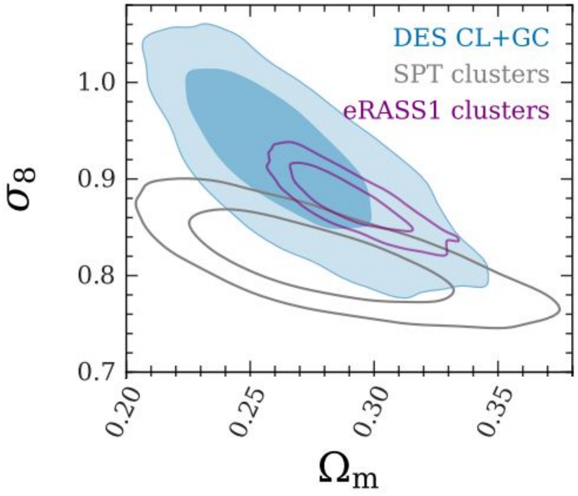
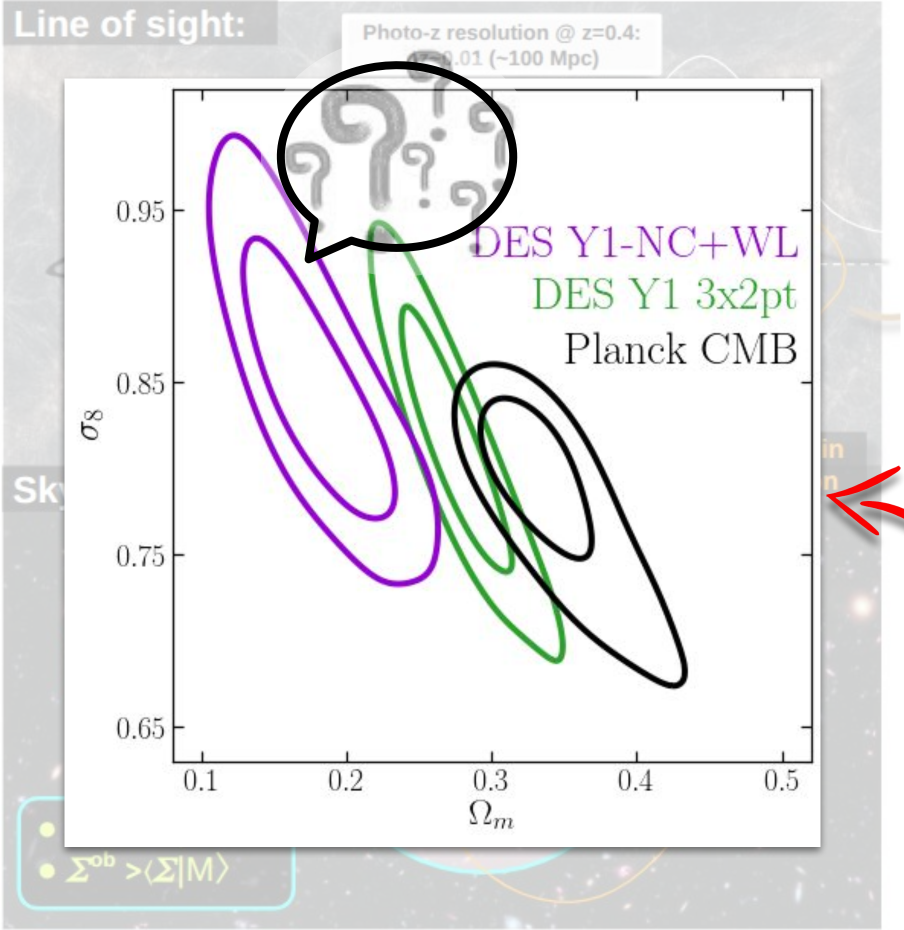






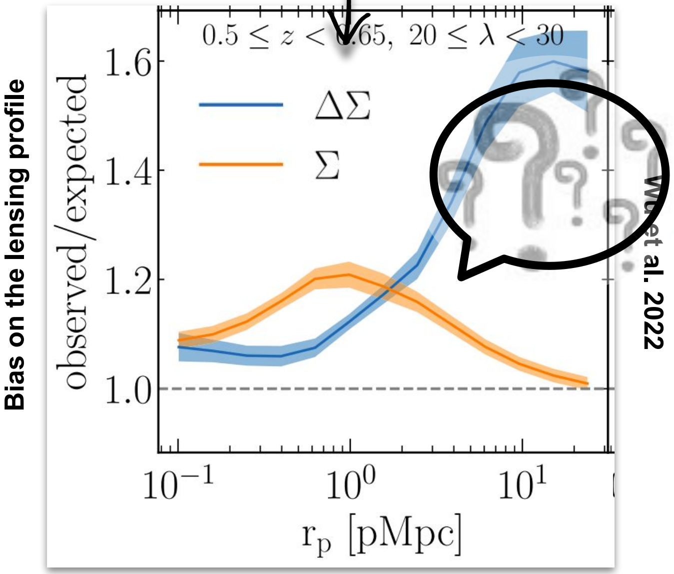
DES Collaboration 2025

CLUSTER COUNTS x SMALL SCALE LENSING



$$\lambda^{ob} = \lambda(M) + \delta\lambda(\lambda, \ldots)$$

$$\Sigma^{ob} = \Sigma(M) + \delta\Sigma(\delta\lambda, \ldots)$$



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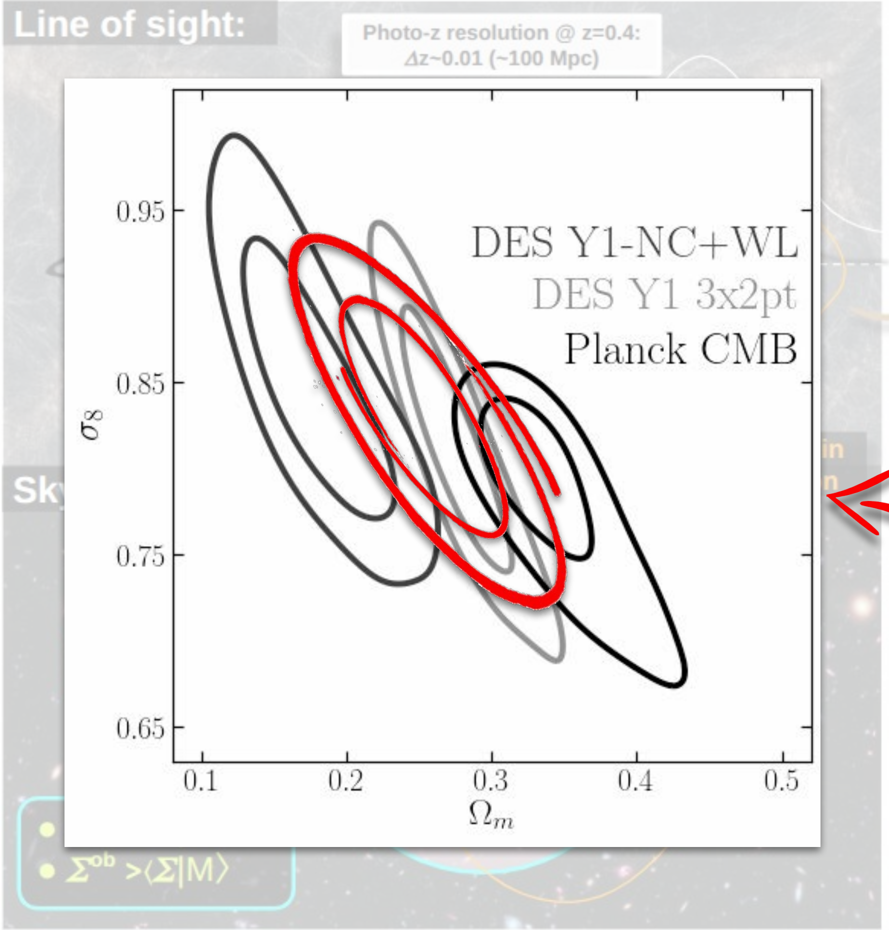

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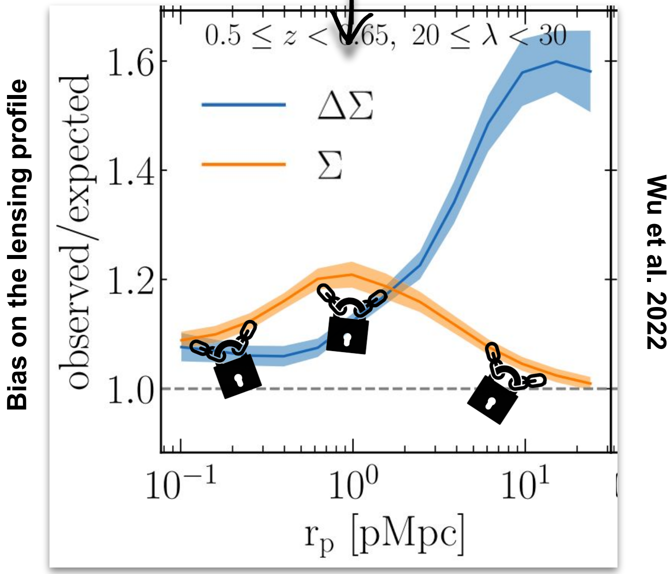
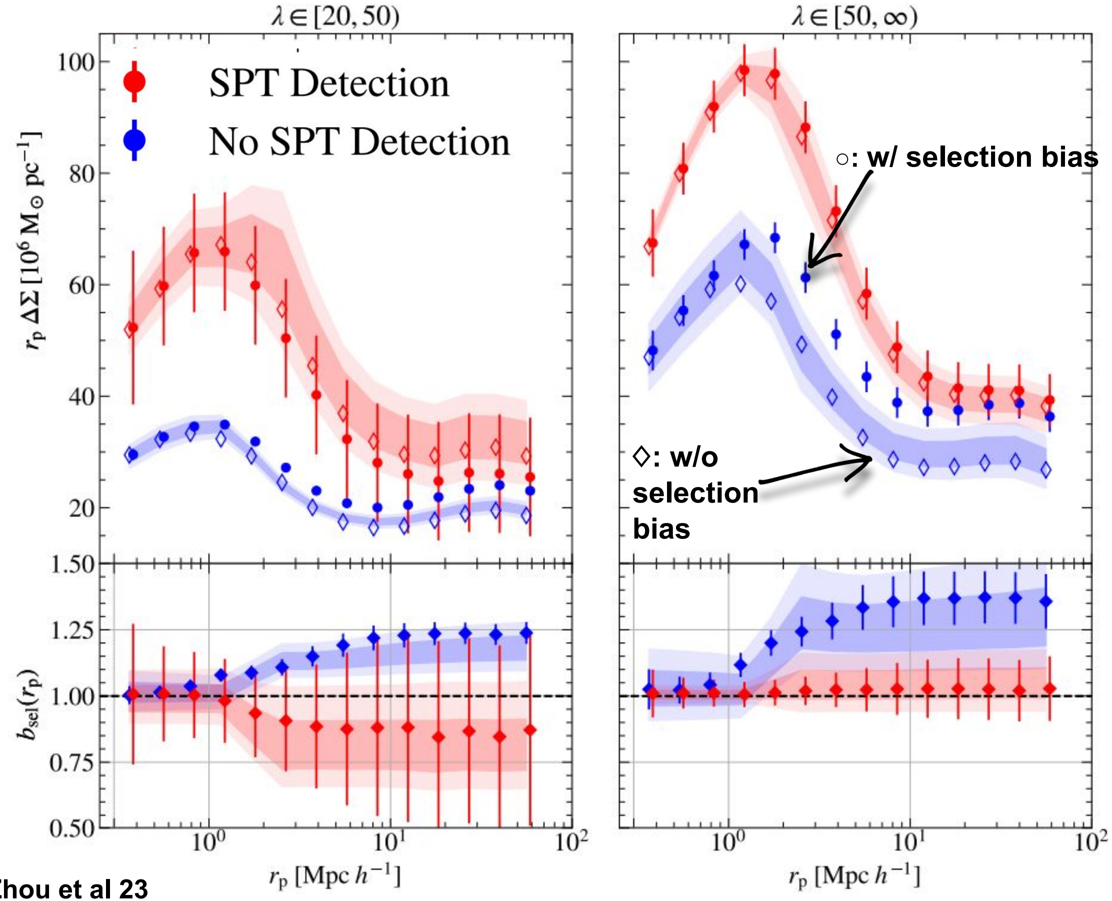


MULTI-λ SELECTION EFFECT BIAS CALIBRATION

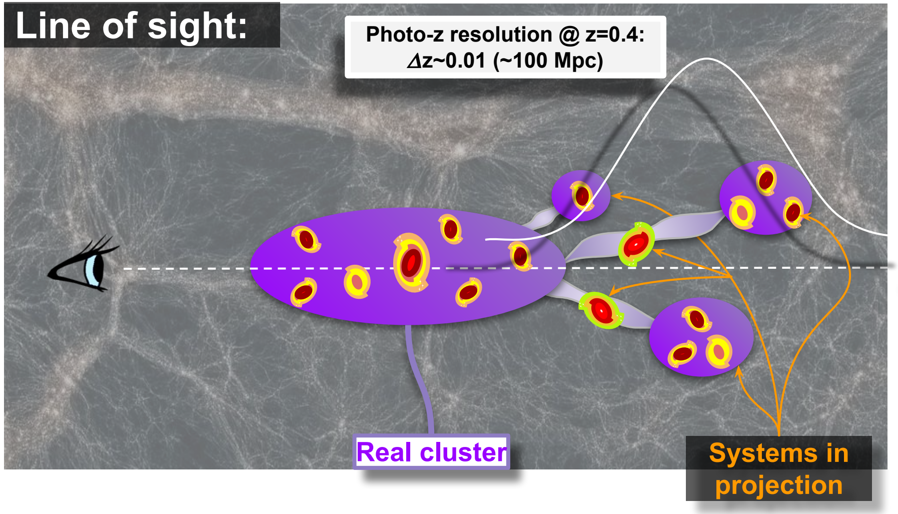
Mock lensing profile of DES clusters matched and unmatched to SPT-SZ



Zhou et al 23

- **Cross match optical and SZ cluster samples and calibrate simultaneously the richness, SZ and WL - mass scaling relations, scatters and correlations**
- **The SZ signal, being less affected by projection effects, can be effectively used to calibrate the WL selection bias, b_{sel}.**

MODELING SMALL SCALE SELECTION EFFECT BIAS



$$\lambda^{ob} = \lambda(M) + \delta\lambda(\lambda, \dots)$$

$$\Sigma^{ob} = \Sigma(M) + \delta\Sigma(\delta\lambda, \dots)$$

Both $\delta\lambda$ and $\delta\Sigma$ can be expressed as weighted sums of the number of halos in projection, N^{PRJ}:

$$\delta\lambda(\lambda^{ob}, \lambda^{true}) \sim \int dz d\lambda d\theta w(\lambda, z) \bar{N}^{prj}(\lambda, z) \left[1 + b_h(\lambda) b_{sel}(\lambda^{true}, \lambda^{ob}) w(\theta)\right]$$

Fraction of λ contributed to the target cluster

Optical cluster bias

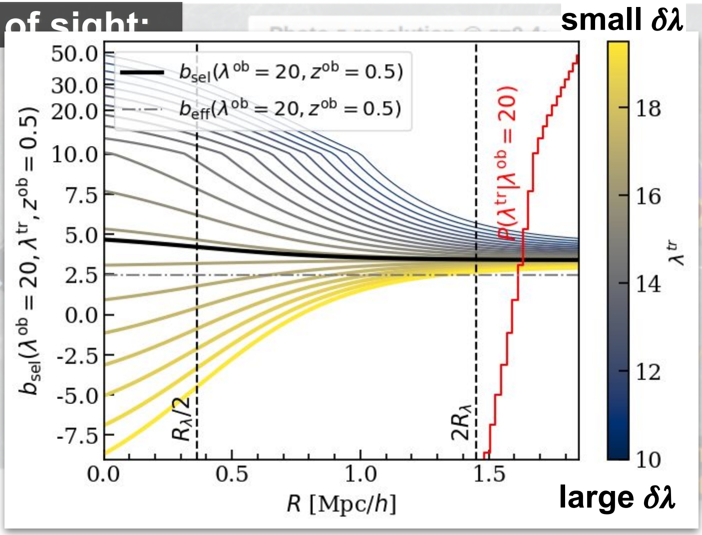
$$\delta\Sigma(\lambda^{ob}, \lambda^{true}) \sim \int dz d\lambda d\theta \Sigma(M(\lambda)) \bar{N}^{prj}(\lambda, z) \left[1 + b_h(\lambda) b_{sel}(\lambda^{true}, \lambda^{ob}) w(\theta)\right]$$

Halo density profile

Costanzi et al in prep.

MODELING SMALL SCALE SELECTION EFFECT BIAS

Line of sight:



$$\lambda^{ob} = \lambda(M) + \delta\lambda(\lambda, \ldots)$$

$$\Sigma^{ob} = \Sigma(M) + \delta\Sigma(\delta\lambda, \ldots)$$

Inverting the equation we can derive an expression for b_{sel} as a function of $\delta\lambda$

$$\delta\lambda(\lambda^{ob}, \lambda^{true}) \sim \int dz d\lambda d\theta w(\lambda, z) \bar{N}^{prj}(\lambda, z) \left[1 + b_h(\lambda) b_{sel}(\lambda^{true}, \lambda^{ob}) w(\theta)\right]$$

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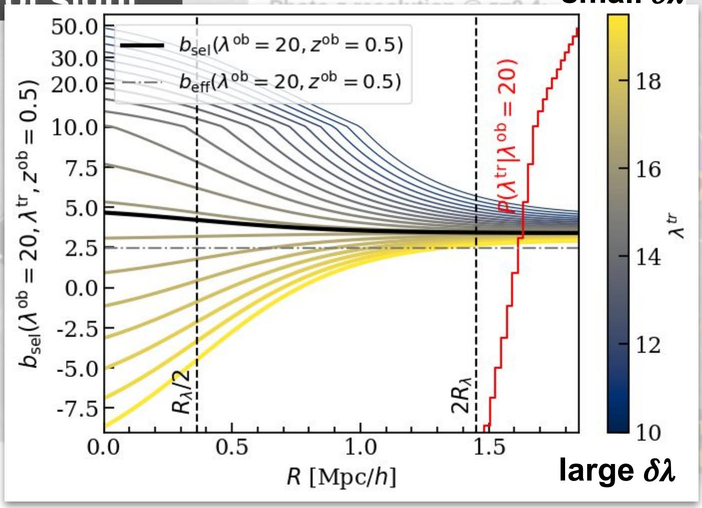
Costanzi et al in prep.

MODELING SMALL SCALE SELECTION EFFECT BIAS

Line of sight:

Optical cluster bias

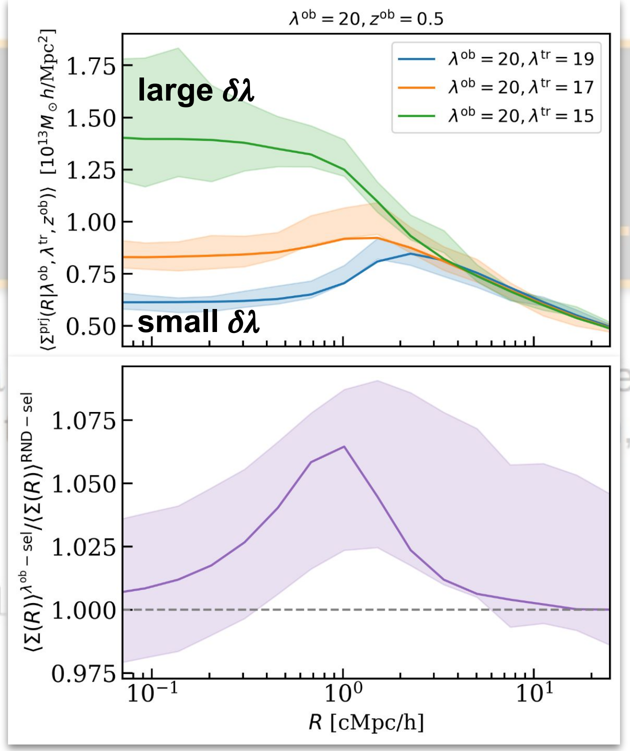


small $\delta\lambda$

large $\delta\lambda$

Density profile from projected structures

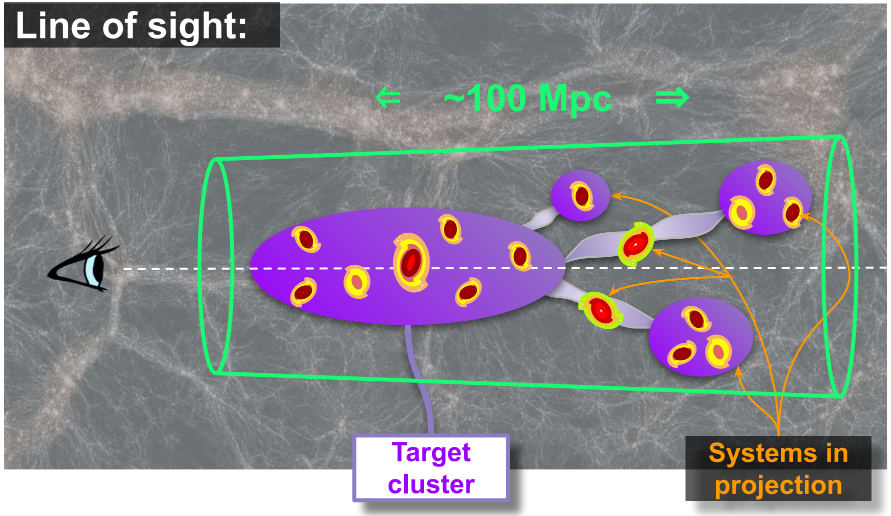
Boost of the lensing profile

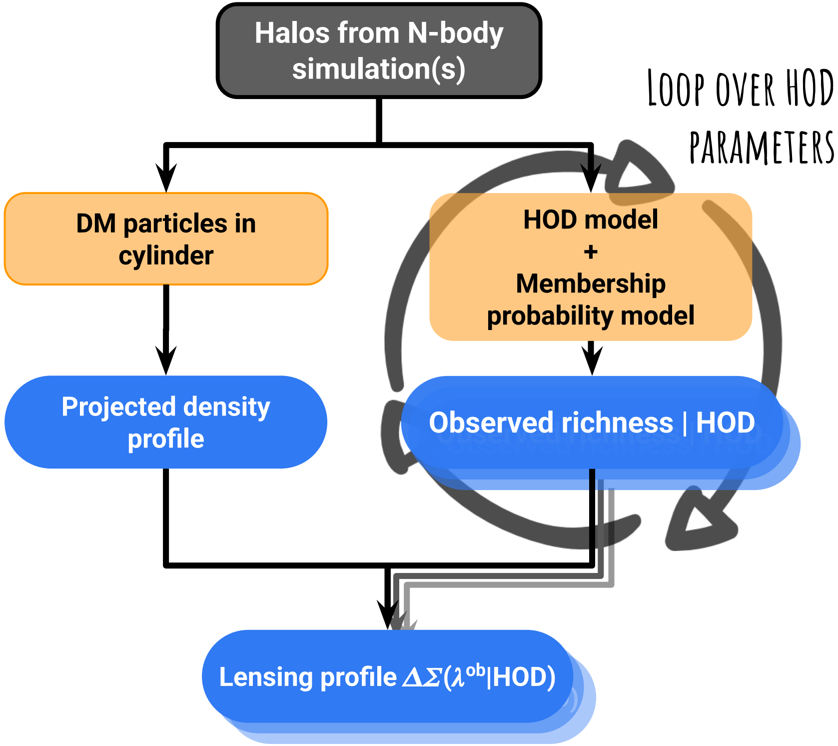


$$\delta\Sigma(\lambda^{ob}, \lambda^{true}) \sim \int dz d\lambda d\theta \Sigma(M(\lambda)) \bar{N}^{prj}(\lambda, z) \left[1 + b_h(\lambda) b_{sel}(\lambda^{true}, \lambda^{ob}) w(\theta)\right]$$

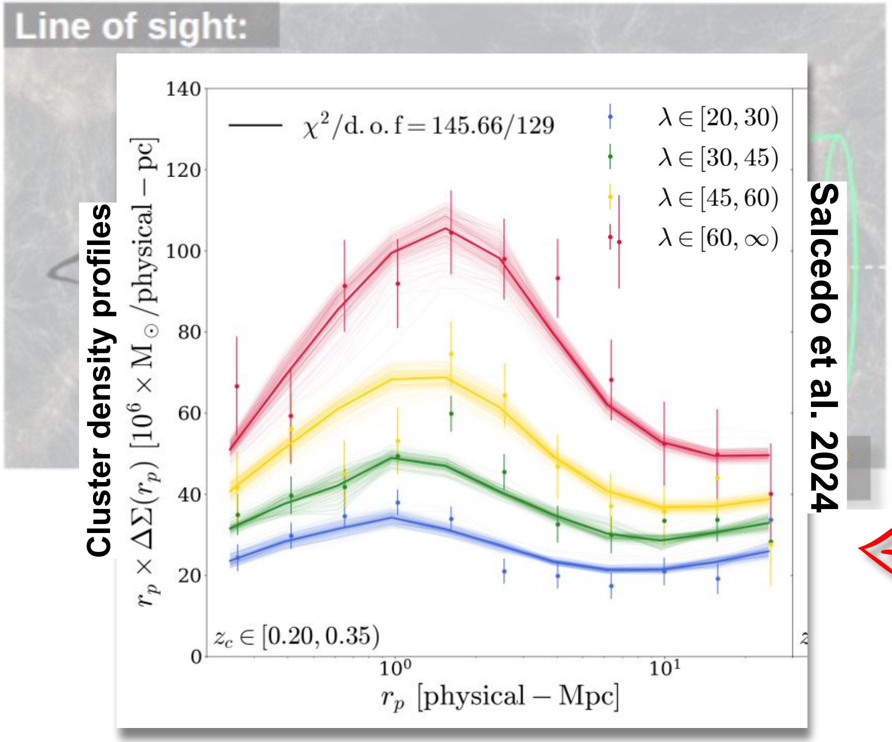
Costanzi et al in prep.

MODELING SMALL SCALE SELECTION EFFECT BIAS

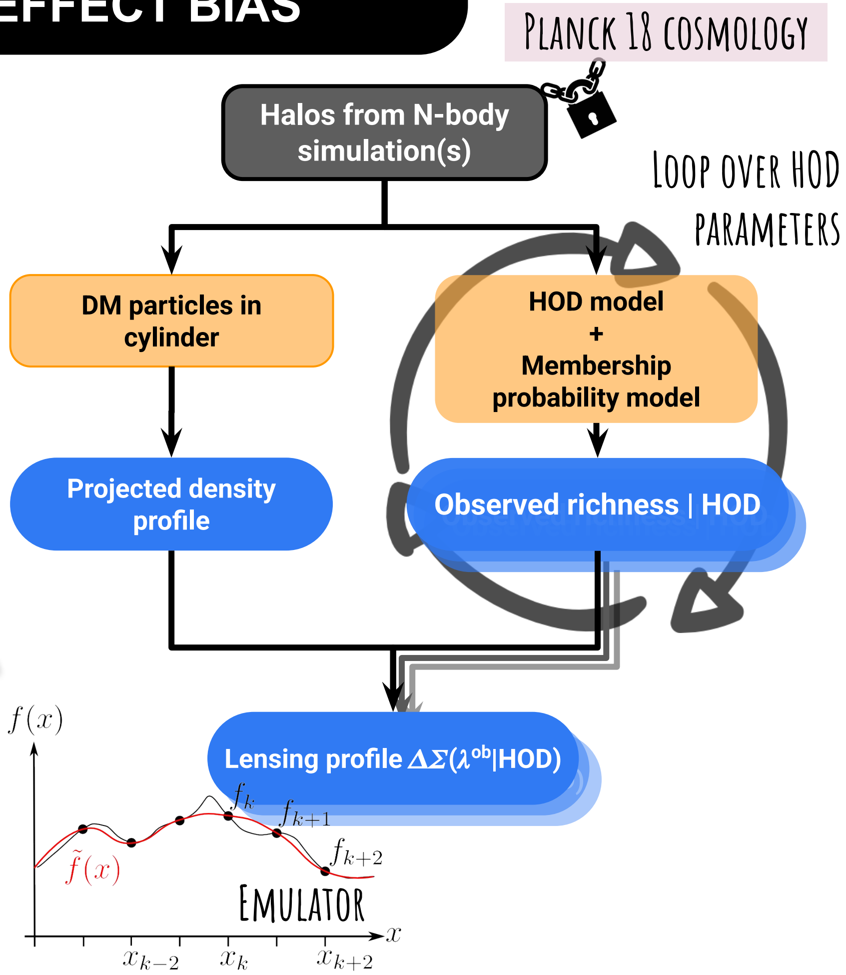




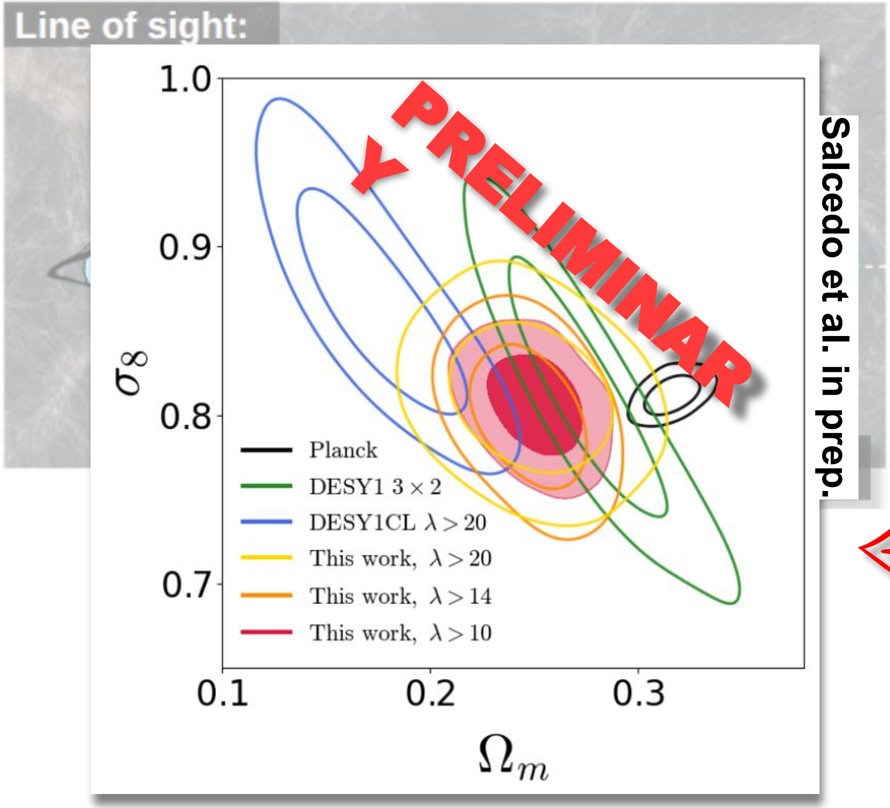
MODELING SMALL SCALE SELECTION EFFECT BIAS



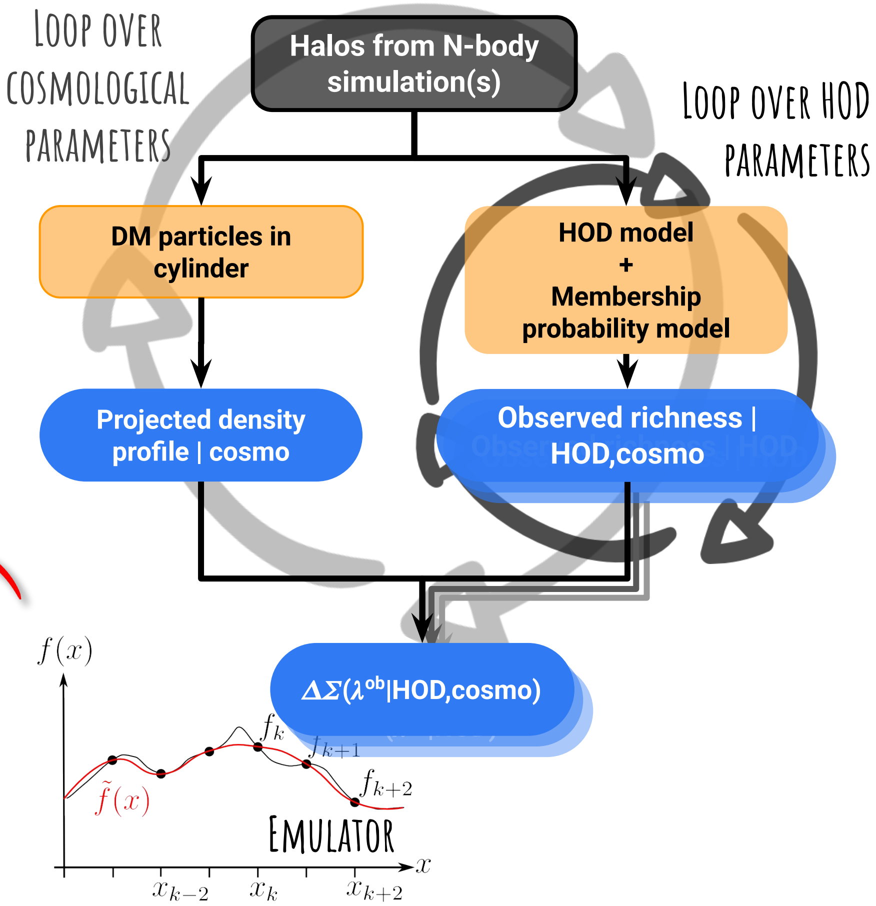
Emulated lensing profiles fitted to DES Y1 cluster lensing profiles



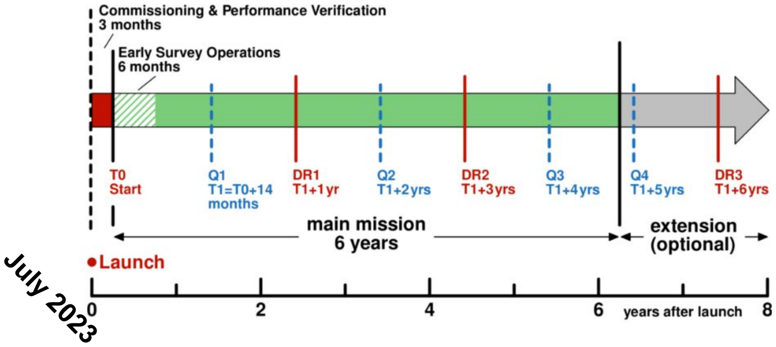
MODELING SMALL SCALE SELECTION EFFECT BIAS



Simulation Based Inference constraints from DES Y1 cluster lensing

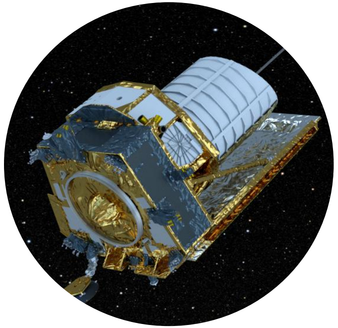


THE EUCLID MISSION



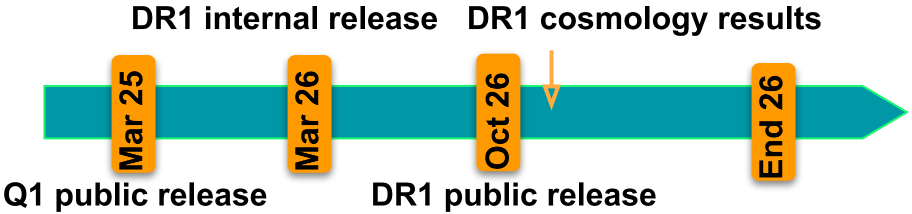
- **Wide Survey: 15.000 deg^2 Deep Survey: 40 deg^2**
- **Main mission: 6 years**
- **Instruments:**

Instrument	VIS	NISP			
Field-of-View	0.787×0.709 deg^2	0.763×0.722 deg^2			
Capability	Visual Imaging	NIR Imaging Photometry			NIR Spectroscopy
Wavelength range	550– 900 nm	Y (920-1146nm),	J (1146-1372 nm)	H (1372-2000nm)	1100-2000 nm
Sensitivity	24.5 mag 10σ extended source	24 mag 5σ point source	24 mag 5σ point source	24 mag 5σ point source	3 10^{-16} erg cm-2 s-1 3.5σ unresolved line flux



- **Cosmological probes:**
  - **Galaxy clustering (projected and 3D), cosmic shear, Galaxy Clusters**

EUCLID CLUSTER COSMOLOGY

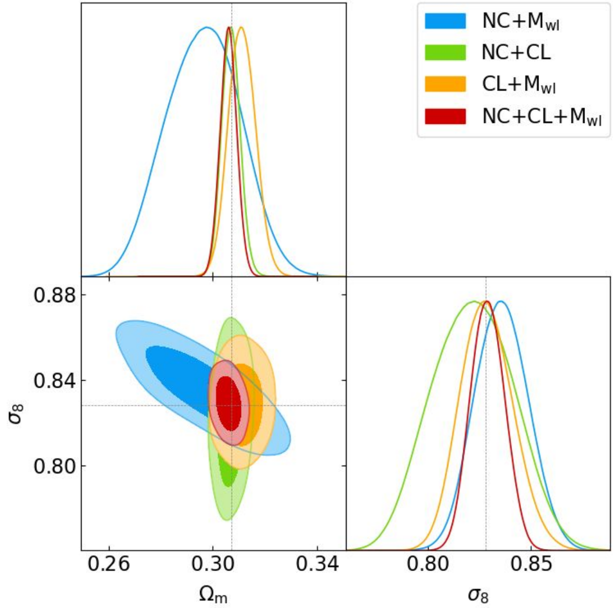


Euclid DR1 Cluster Catalog:

- ~1900 deg^2 up to z~1.5
- Based on two cluster finders (Euclid preparation: Adam+19):
  - AMICO , PZwav
- Mass proxy: Richness (Castignani&Benoist 2016)

Euclid Cluster Cosmology Probes:

- Cluster counts
- Stacked Cluster Weak Lensing profile
- Clustering of clusters



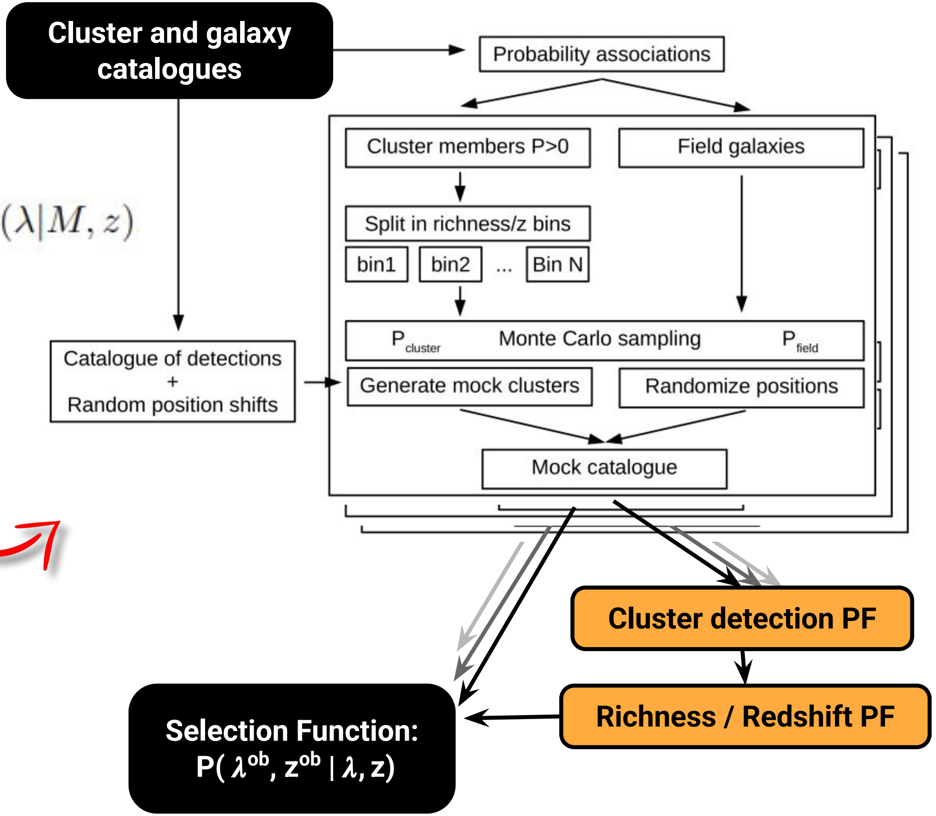
Fumagalli et al in prep.

EUCLID CLUSTER SELECTION FUNCTION

- **Observed richness-mass relation:**

$$P(\lambda^{\rm ob}|M,z) = \frac{1}{\mathcal{P}(\lambda^{\rm ob},z)} \int_0^\infty d\lambda\, \mathcal{C}(\lambda,z)\, P(\lambda^{\rm ob}|\lambda,z)\, P(\lambda|M,z)$$

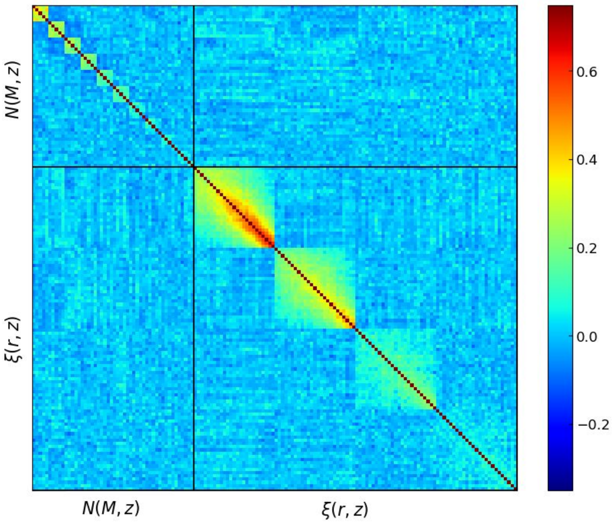
Purity, Completeness and Selection Function empirically calibrated using a simulation based approach applied to the data



EUCLID CLUSTERING OF CLUSTERS CALIBRATION

Top: Cluster counts and clustering auto- and cross-covariance from 1000 mock simulations

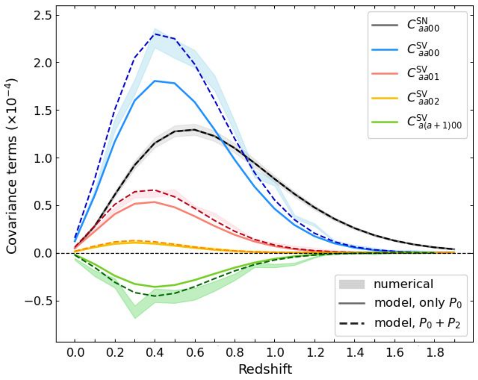
Bottom: Comparison of numerical and analytic cluster counts and clustering covariance terms

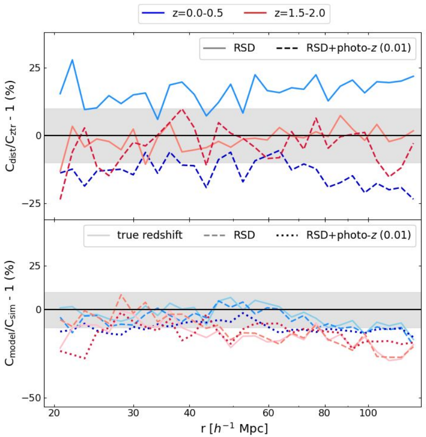


APPROXIMATE MOCKS:
1000 PINOCCHIO (Monaco+13) halo light-cone catalogs at fixed cosmology painted with Euclid-like cluster observables (Fumagalli+22,+in prep)

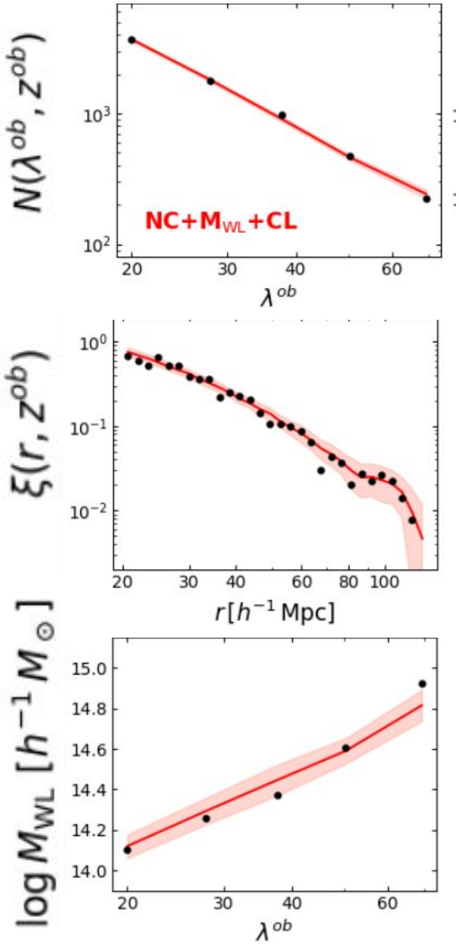
- **Covariance matrix:**
  Cluster counts and 2pt correlation function analytical covariance matrix calibrated and vetted against PINOCCHIO mock catalogs.
  Modeling includes: photo-z uncertainty, richness estimate error and RSD

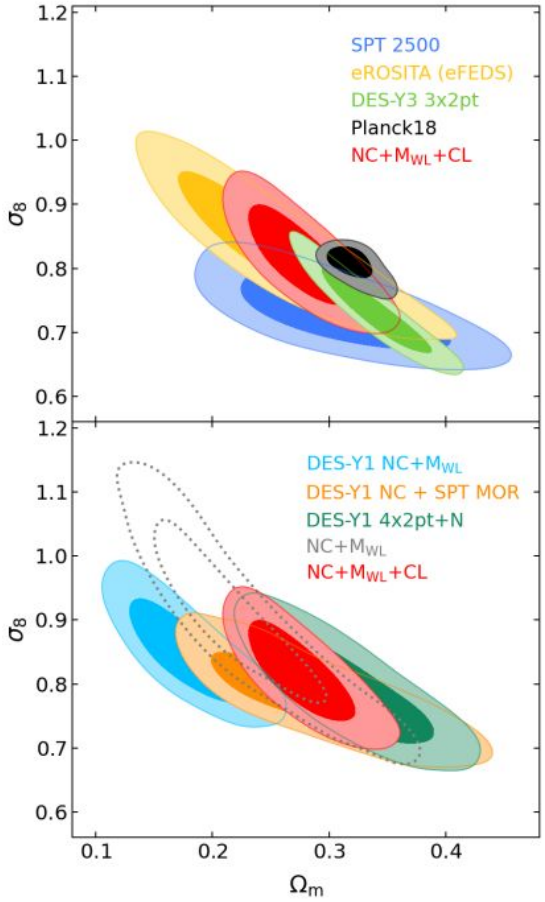
Fumagalli et al in prep.

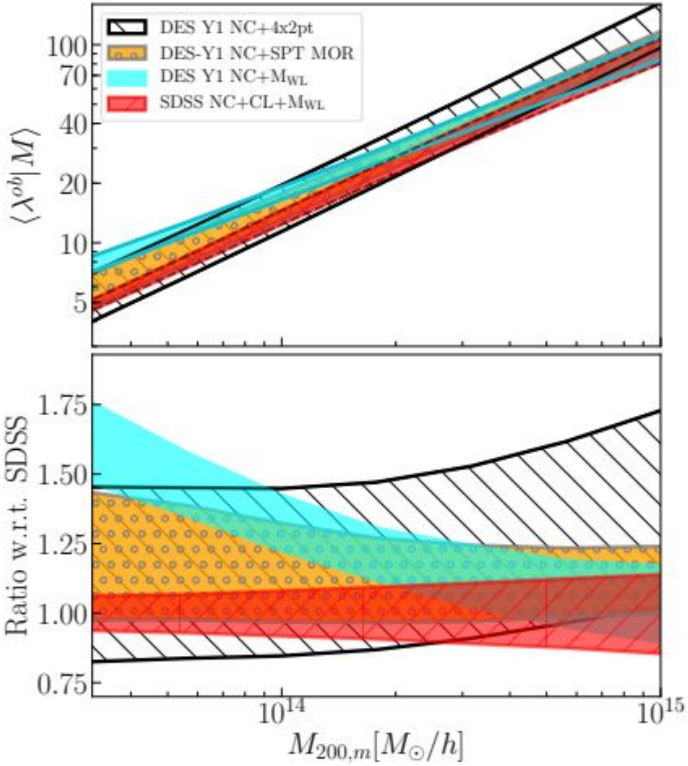




CLUSTERING OF CLUSTERS: TEST ON redMaPPER SDSS



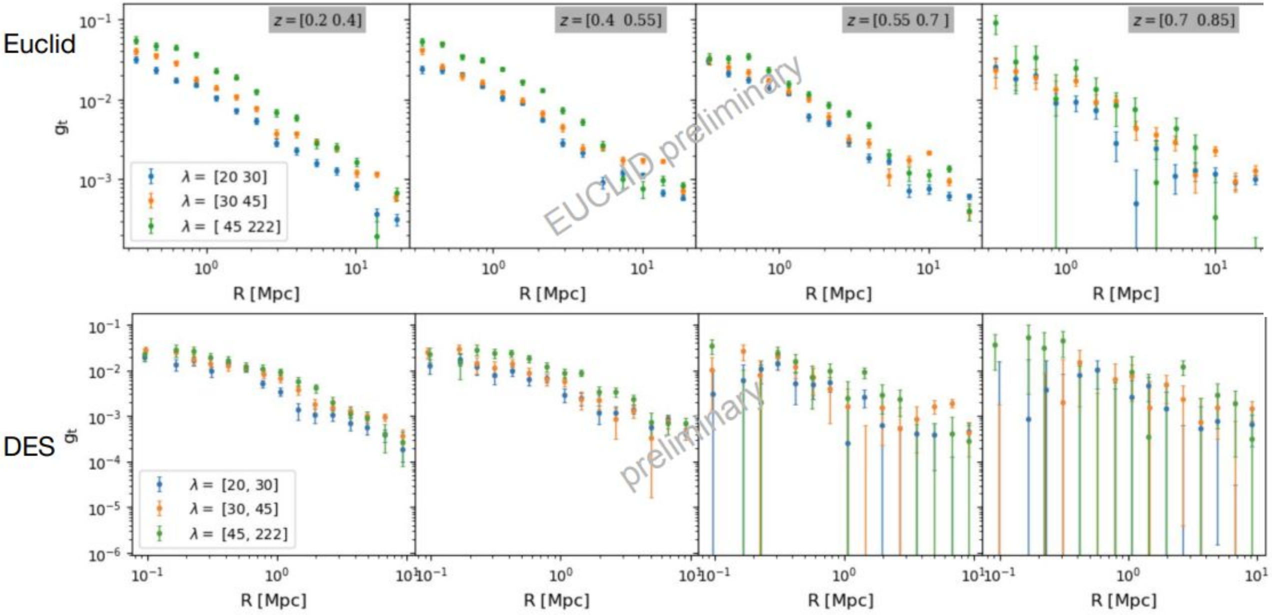




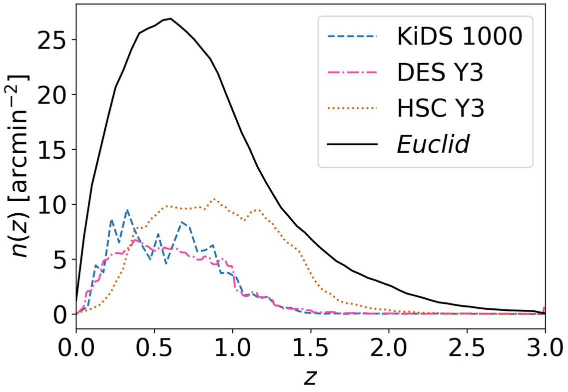
Fumagalli et al 2024

EUCLID CLUSTER LENSING

Comparison of stacked lensing profile of RR2 Euclid clusters using Euclid lensing data or DES lensing data.

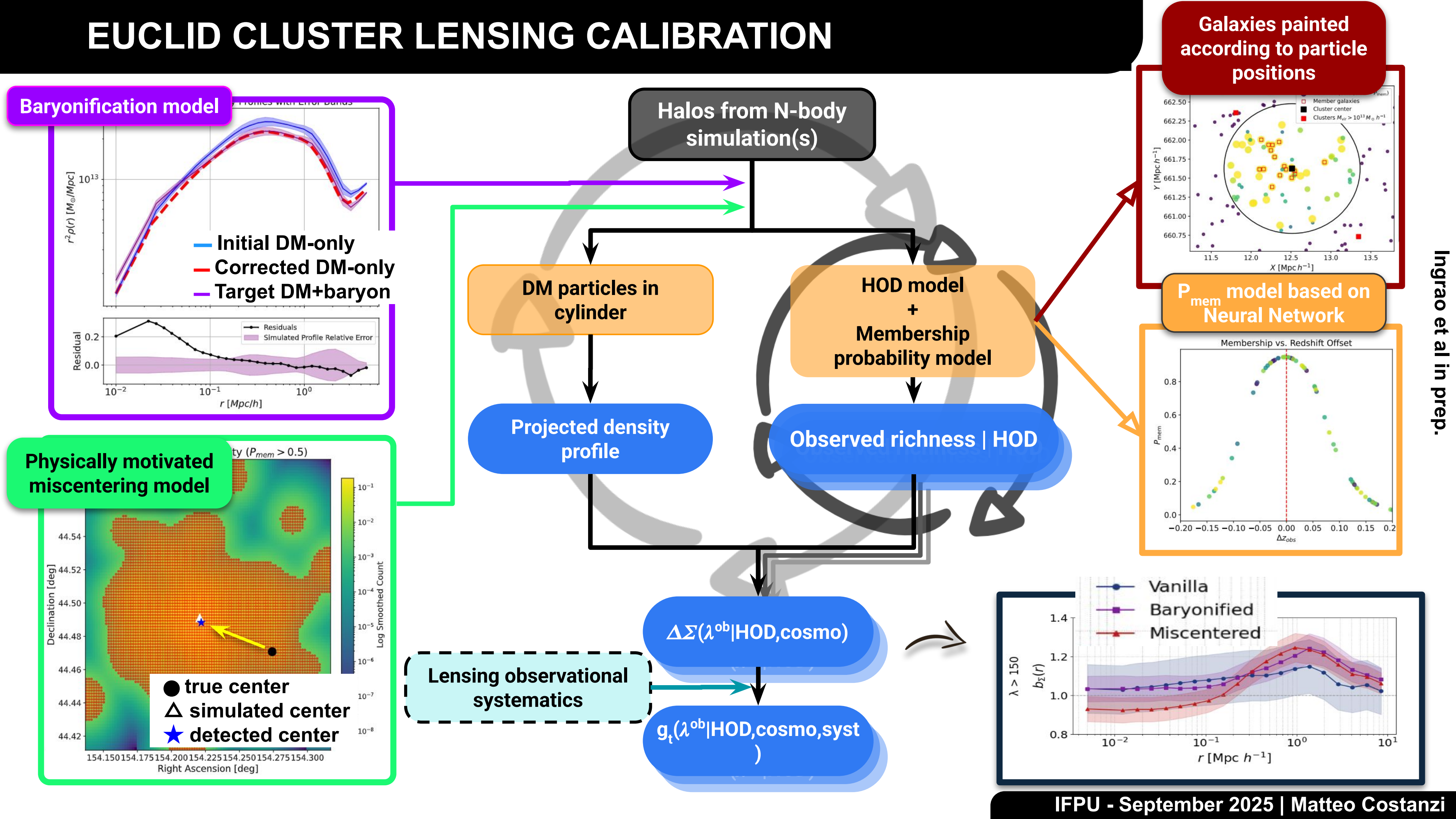


Source density vs redshift



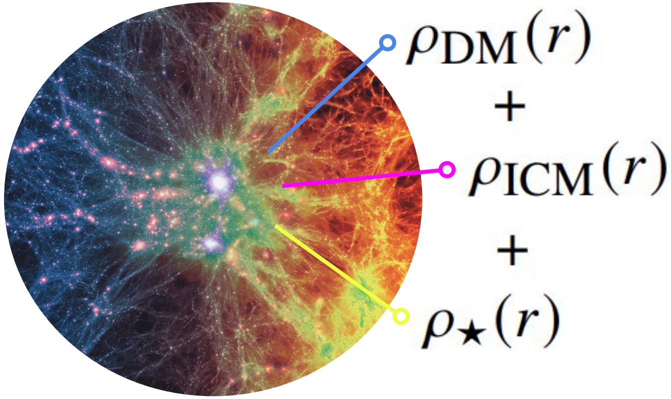
Higher number density of galaxies and many more sources at higher redshifts compared with Stage III surveys!

Credit: Lucie Baumont



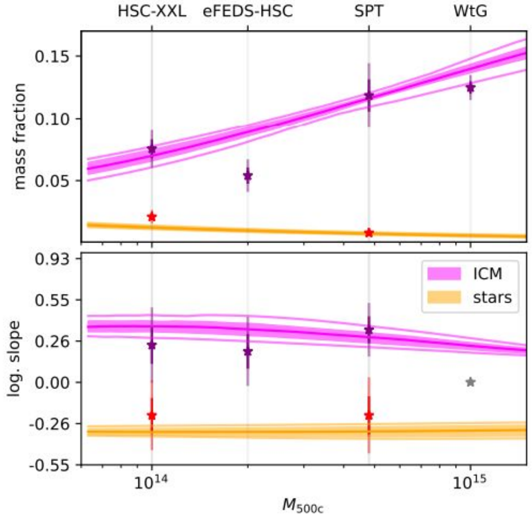
EUCLID CLUSTER LENSING CALIBRATION
Galaxies painted according to particle positions
Baryonification model
Initial DM-only
Corrected DM-only
Target DM+baryon
Residuals
Simulated Profile Relative Error
Residual
r [Mpc/h]
Halos from N-body simulation(s)
DM particles in cylinder
HOD model + Membership probability model
Projected density profile
Observed richness | HOD
Physically motivated miscentering model
true center
simulated center
detected center
Right Ascension [deg]
Declination [deg]
Log Smoothed Count
Lensing observational systematics
ΔΣ(λ^ob|HOD,cosmo)
g_t(λ^ob|HOD,cosmo,syst)
Member galaxies
Cluster center
X [Mpc h^-1]
Y [Mpc h^-1]
P_mem model based on Neural Network
Membership vs. Redshift Offset
Δz_obs
Vanilla
Baryonified
Miscentered
λ > 150
r [Mpc h^-1]
Ingrao et al in prep.
IFPU - September 2025 | Matteo Costanzi

BARYONIC FEEDBACK CALIBRATION WITH GC MULTI-λ

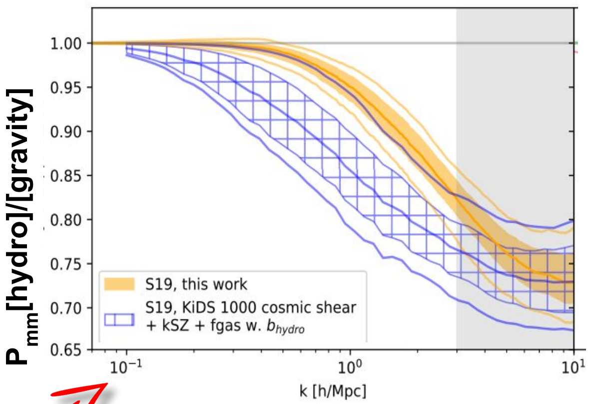


- **Multi-λ data provide a means to probe the gas (X-ray, SZ) and stellar (optical/IR) components of clusters**
- **Combining gas and stellar mass measurements with halo mass estimates (e.g. from WL) it is possible to constrain the modulation of the matter clustering due to baryonic feedbacks**

Stellar/ICM mass fraction measurements vs predicition from X-ray and SZ surveys



Matter power spectrum suppression due to baryonic feedbacks

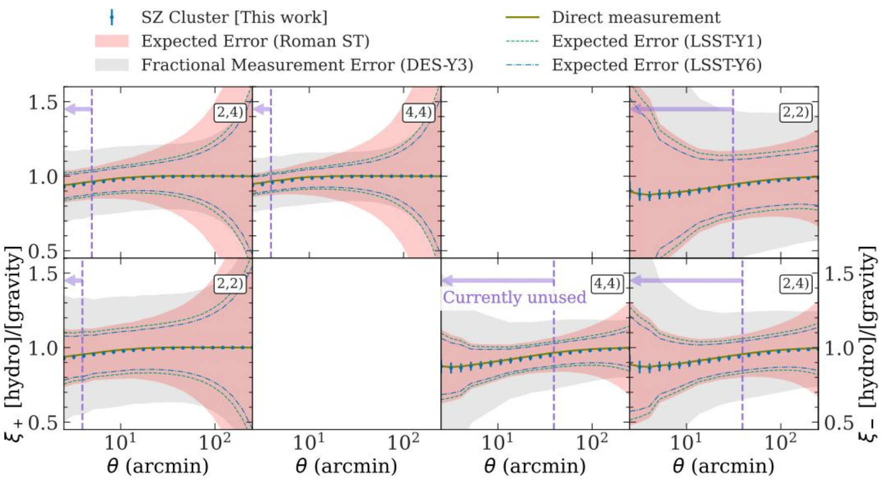


Grandis+24

Also see Pandey+21, Troster+22 , Schneider+22, To+24, Dalal 25

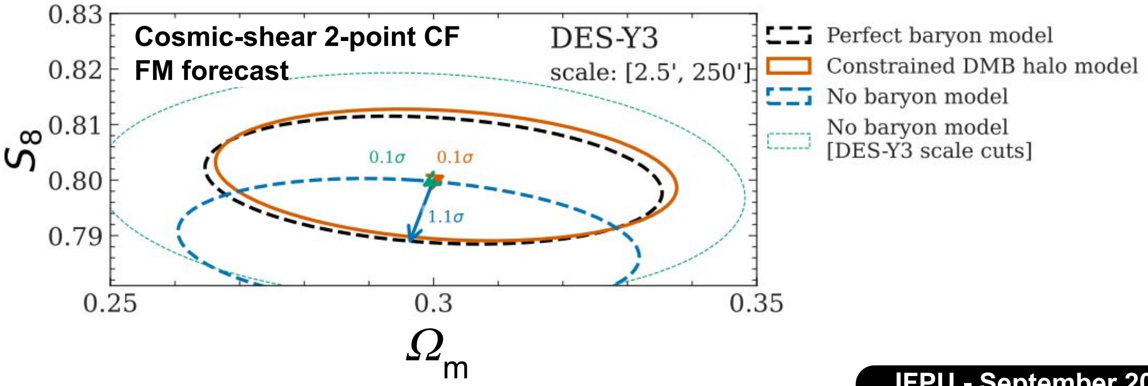
MULTI-PROBE COSMOLOGY WITH GCs

Cosmic-shear 2-point CF mock measurements



To+24

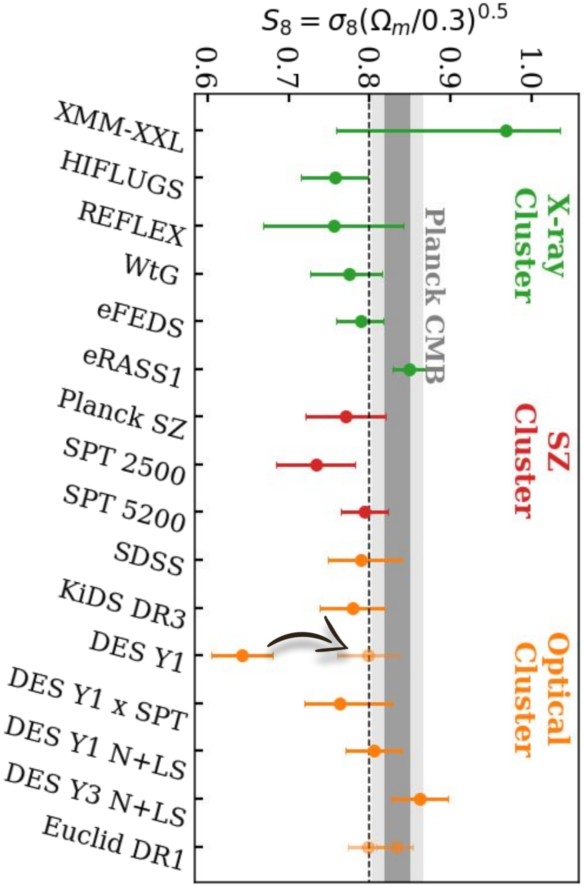
- **Calibration of baryonic feedback on the matter power spectrum allows to push to smaller scale the cosmological analysis of other LSS probes**



SUMMARY & TAKEAWAYS

- **Photometric surveys provide a unique, self-sufficient data set to carry out cluster cosmology studies leveraging a unique range of masses**
- **In DES we pursuit two complementary approaches to mitigate optical selection biases:**
  - **Number Counts + Clustering of Large Scale Tracers**
  - **Number Counts + Small Scale cluster lensing profile**

SBI is emerging as a promising framework to handle complex systematics and push the analysis to lower richness



SUMMARY & TAKEAWAYS

- **Latest DES – and other optical cluster surveys – provide cosmological constraints consistent and competitive with cluster surveys at other wavelengths, as well as with other LSS probes.**
    - **Galaxy clusters should be regarded as a key ingredient of multi-probe analyses: combined with other probes of the LSS, cluster data is capable of constraining astrophysical parameters and breaking cosmological degeneracies improving the overall constraining power.**

- **The Euclid mission is poised to significantly expand cluster cosmology capabilities, thanks to its high-quality lensing data, and by extending observations to higher redshifts (up to z~1.5-2.0) and larger area (~15000 deg2)**

Stay tuned for the upcoming DES Y6 (~end 25) and Euclid DR1 (~end 26) optical cluster analyses!