DARK ENERGY SURVEY

European Commission

erc

AstroParticle Symposium:

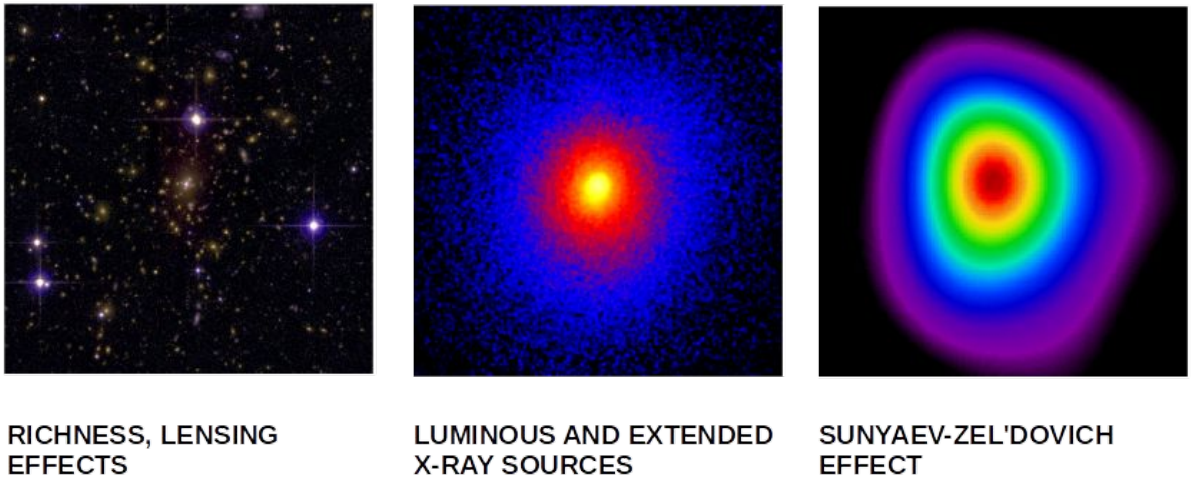
CLUSTER COSMOLOGY WITH THE DARK ENERGY SURVEY

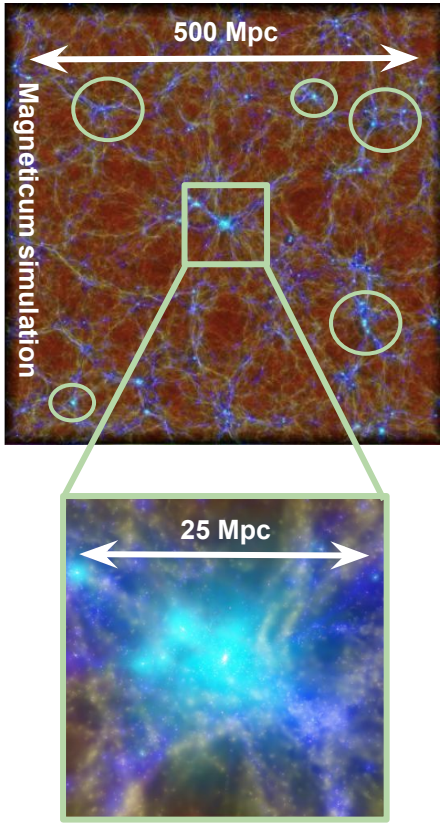
Matteo Costanzi, DES Cluster & WL working groups

GALAXY CLUSTERS

- **Most massive bound objects in the Universe**:
  $M \simeq 10^{13} - 10^{15}\ M_{\odot}$ and $R \simeq 1 - 5$ Mpc

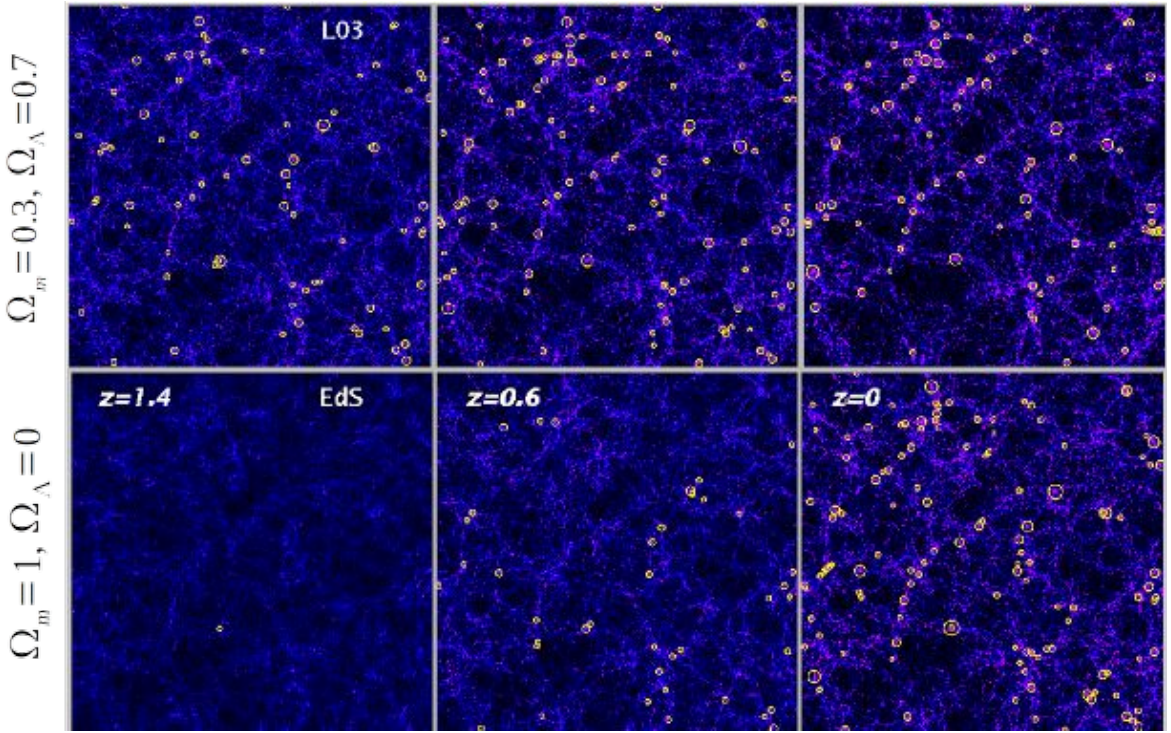
- **Multi-component systems**:
  Galaxies and stars (~5%), ICM (~15%), DM (~80%)





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



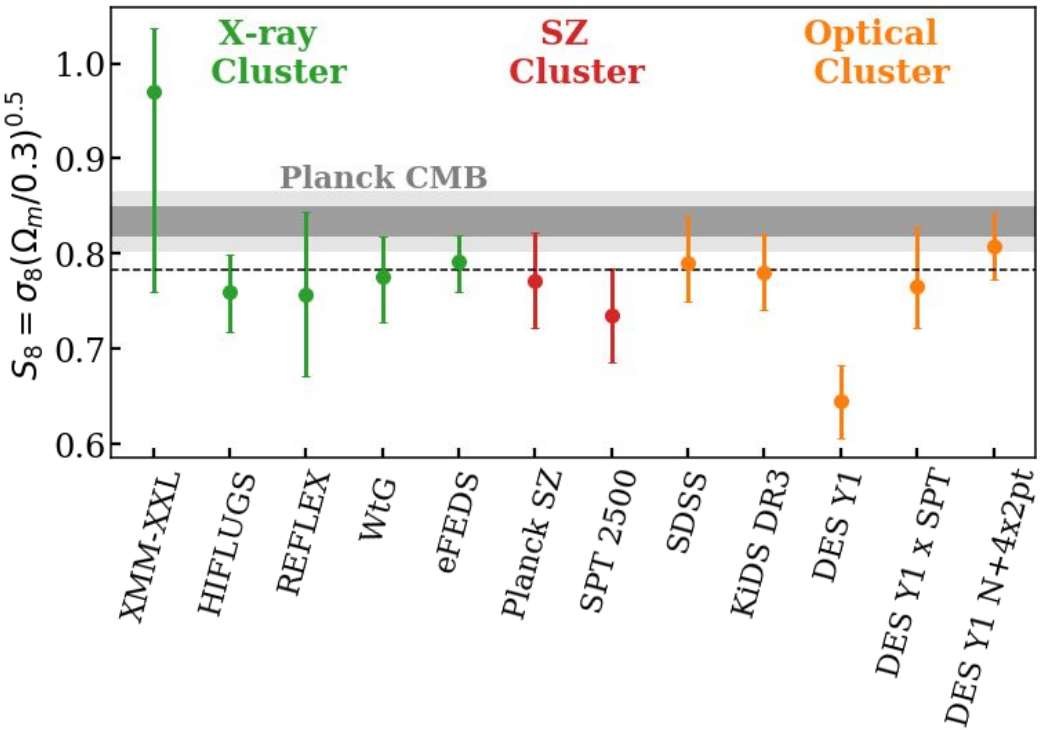
From Borgani, Guzzo 2001

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

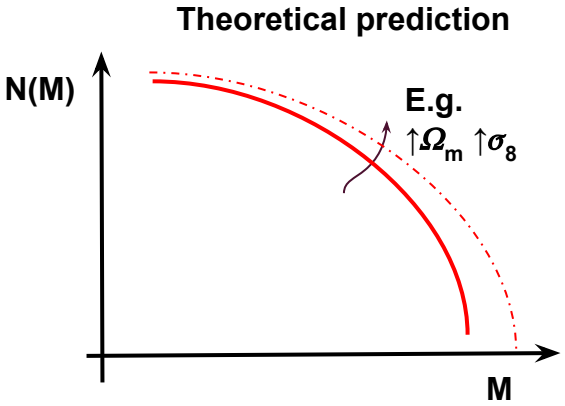
- **Amplitude of matter fluctuations, σ_8**
- **Total matter density, Ω_m**
- **Dark energy equation of state parameter *w***
- **Total neutrino mass, Σm_ν**
- **Modified gravity models**

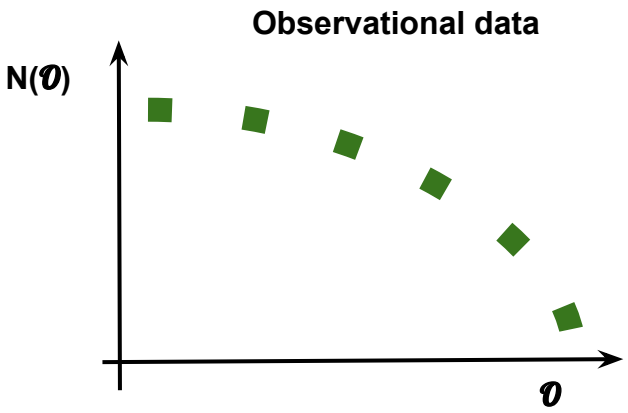
...



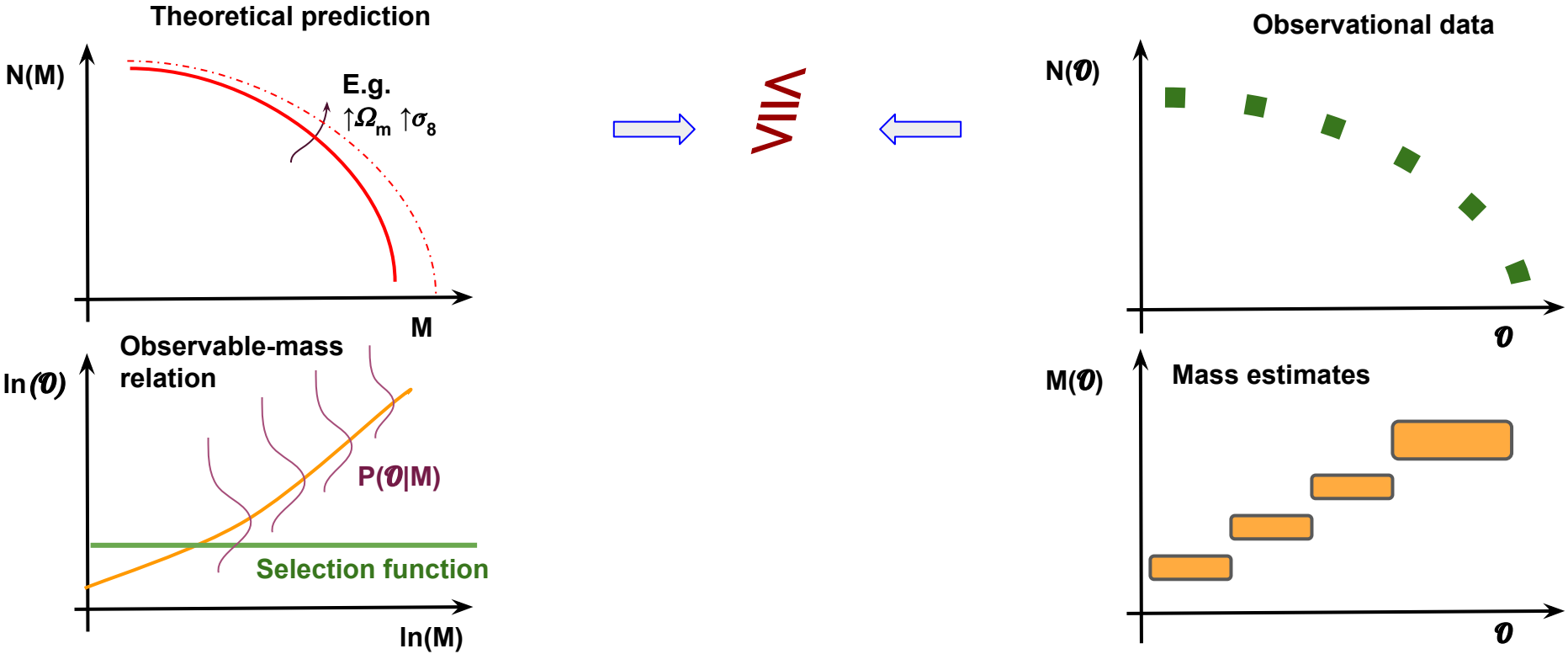
Euclid
Rubin-LSST

FROM OBSERVATION TO COSMOLOGICAL CONSTRAINTS



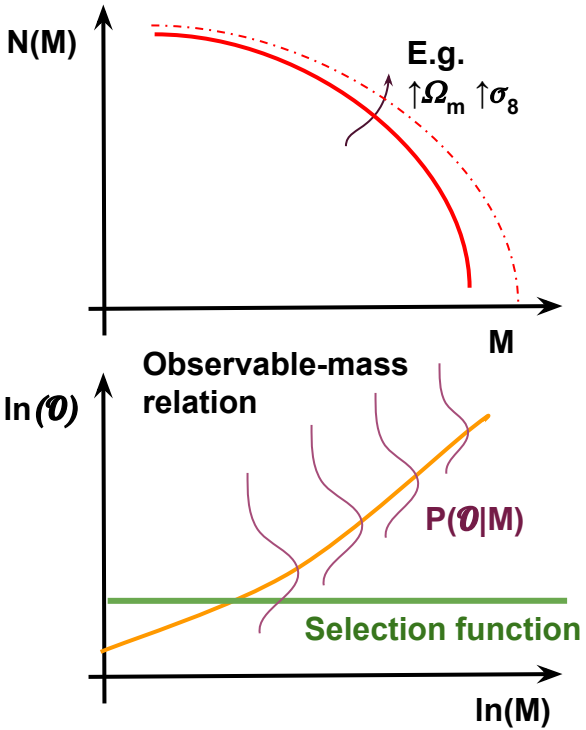


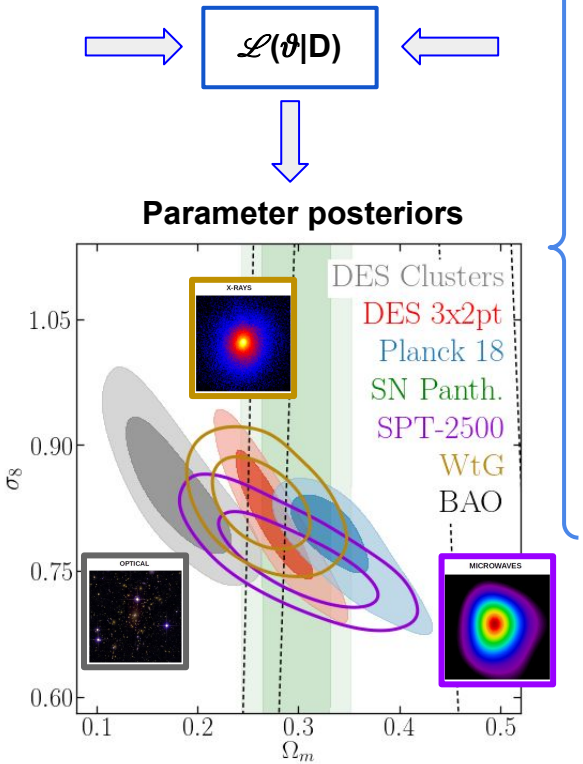
FROM OBSERVATION TO COSMOLOGICAL CONSTRAINTS



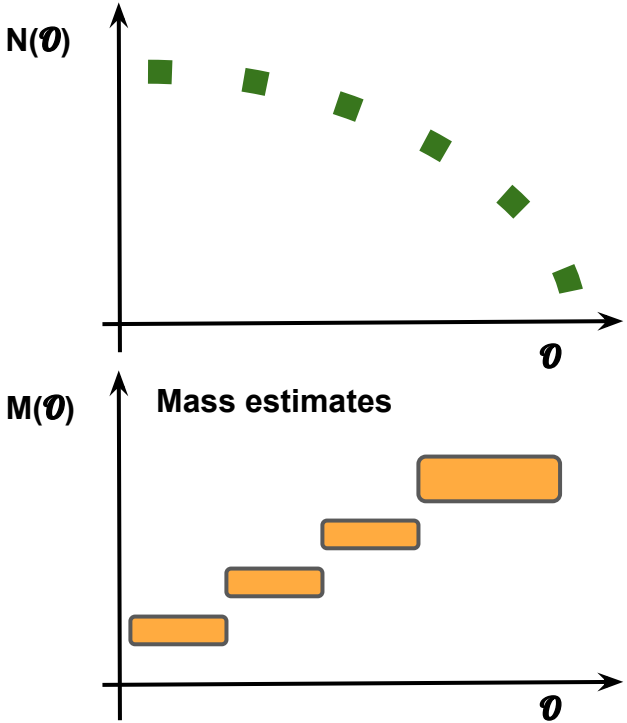
FROM OBSERVATION TO COSMOLOGICAL CONSTRAINTS

Theoretical prediction

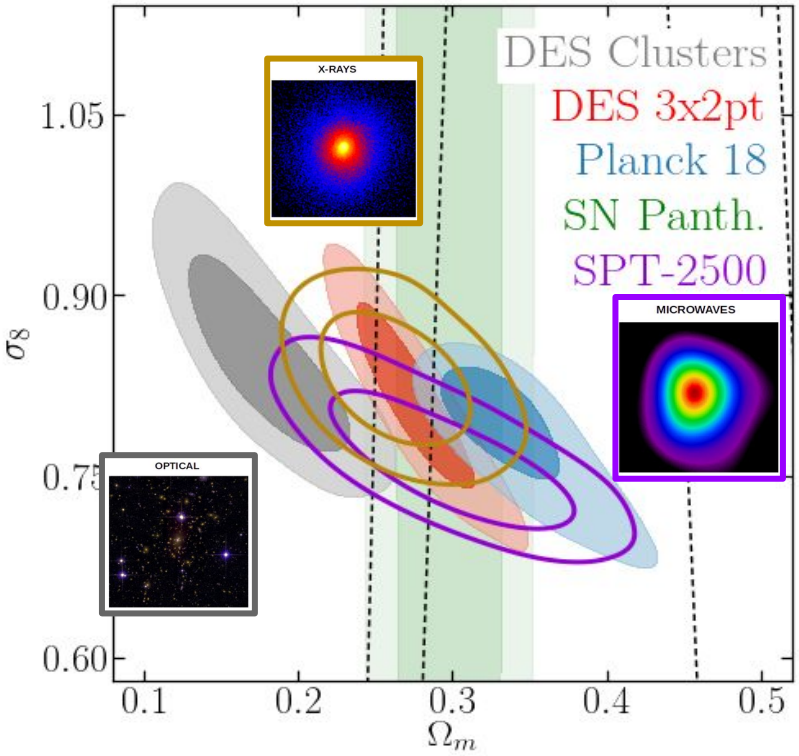




Observational data



MASS CALIBRATION AND COSMOLOGICAL POSTERIORS



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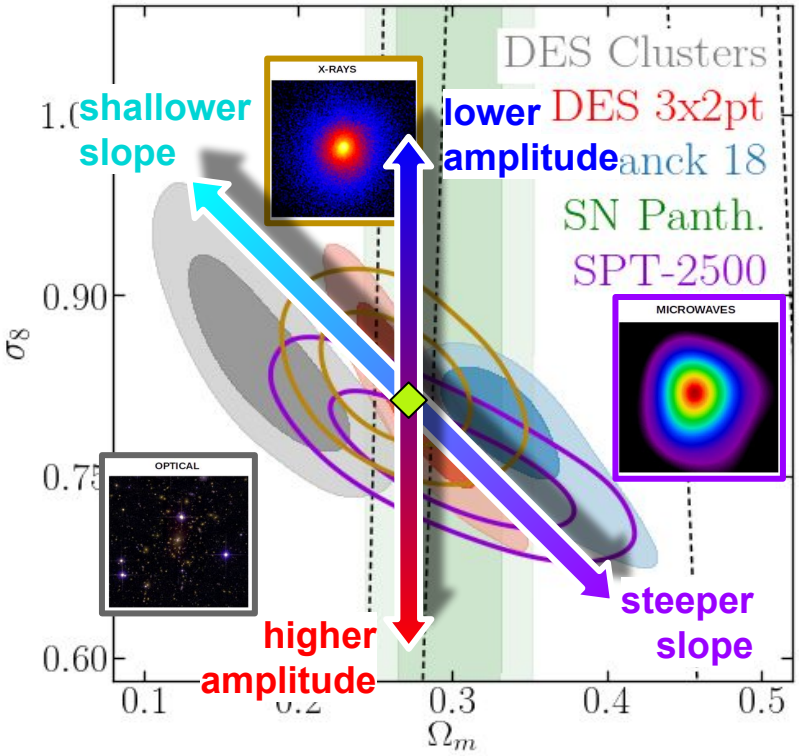
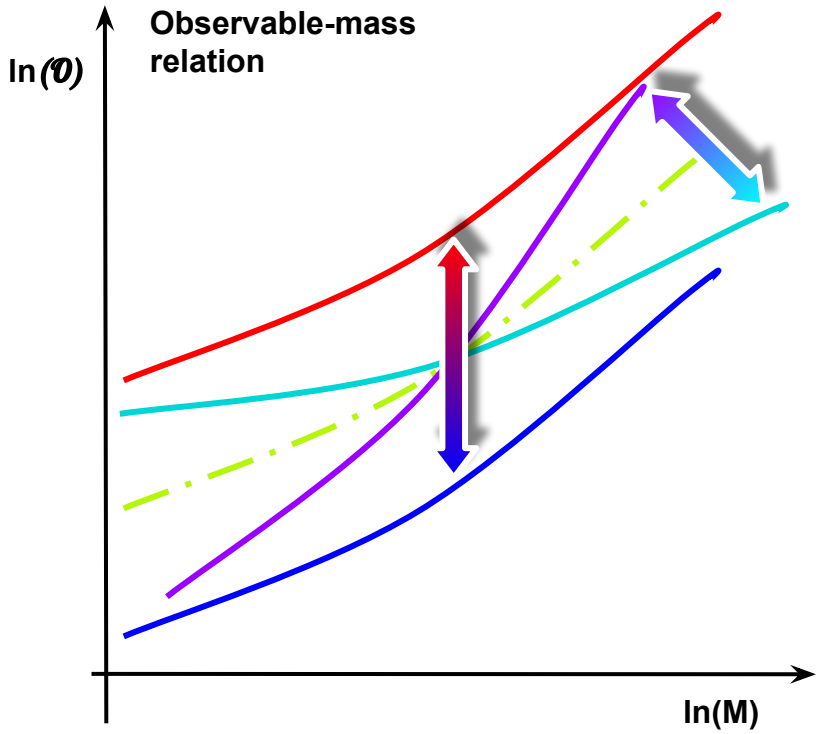




THE DARK ENERGY SURVEY

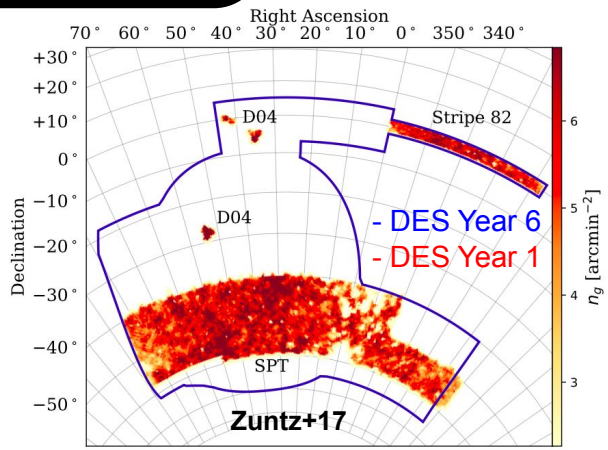
- **DES Survey:**
  - ~5000 deg^2 of southern sky
  - *g*,*r*,*i*,*z*,(Y) bands
  - 10 visits per pointing to reach *i*~24

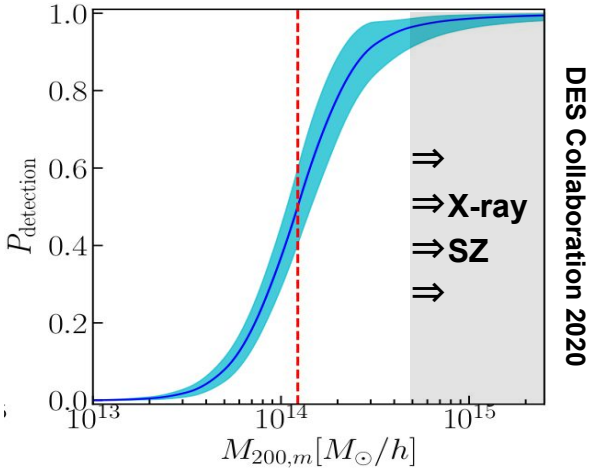
- **DES Year 1 redMaPPer :**

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

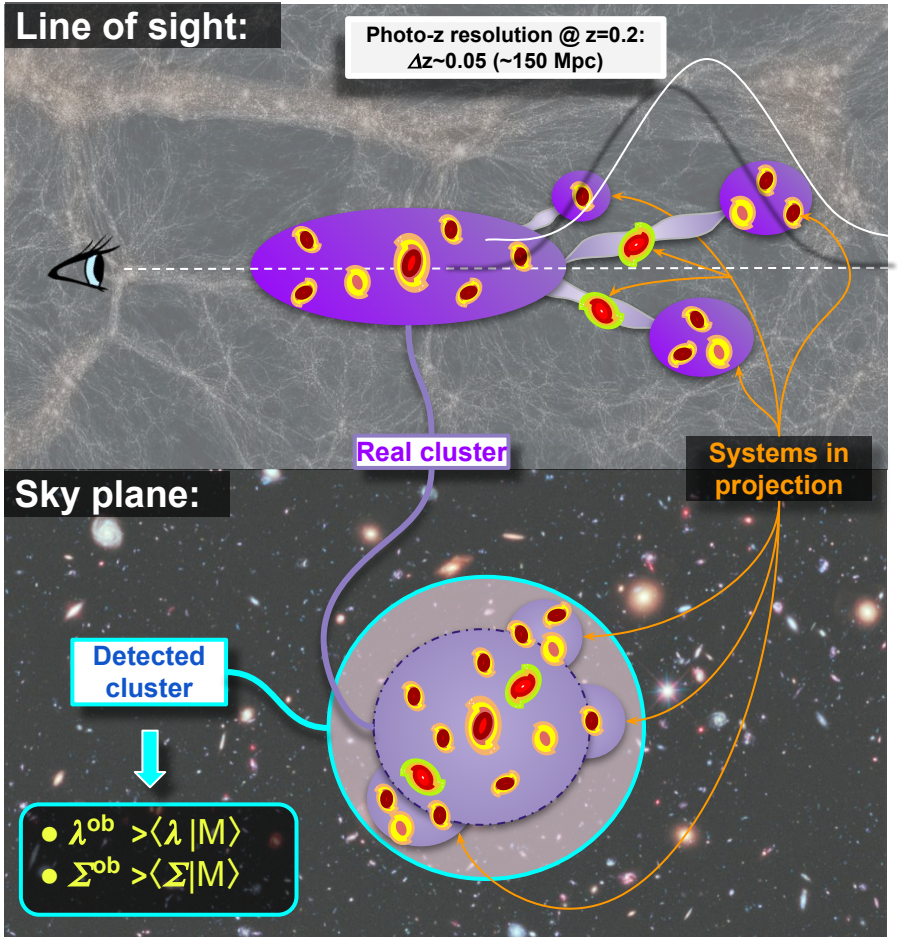
  Mass Proxy: $\lambda^{\rm ob} = \sum_{R<R_\lambda} p_{mem}$

Area [deg^2]	Redshift range	# of clusters λ>20	$\sigma_z/(1+z)$	n_{eff} [arcmin^{-2}]
1470	0.2<z<0.65	~6540	0.006	6.3



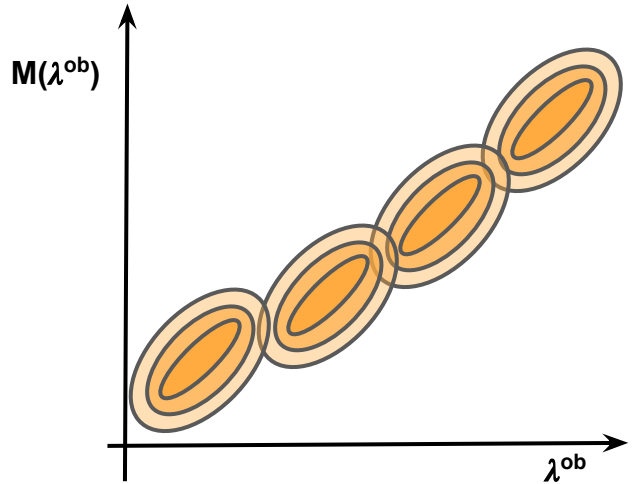


SELECTION EFFECTS IN OPTICAL CATALOGS



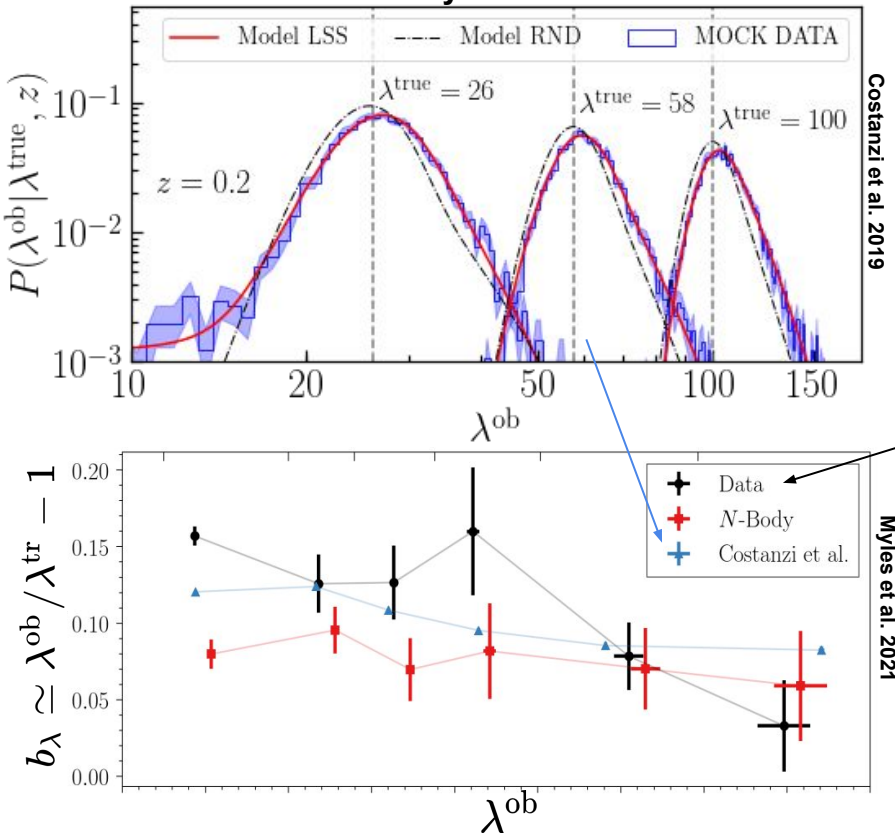
$$\lambda^{ob} = \lambda^{true}(M) + \Delta\lambda(\lambda^{true}, \ldots)$$

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



$\Delta\lambda$ CALIBRATION

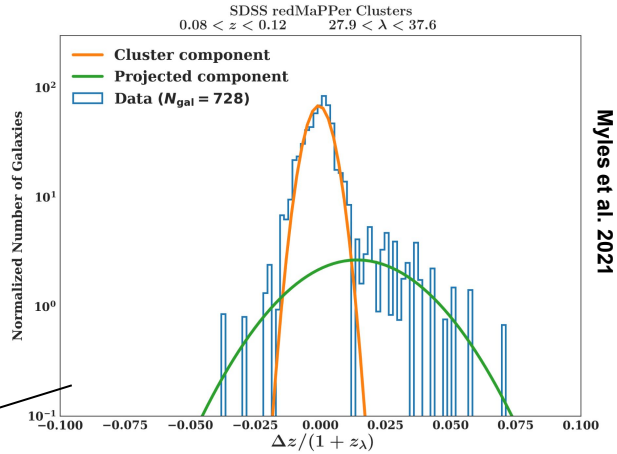
Scatter between true and observed richness from mock/data analysis



Costanzi et al. 2019

Myles et al. 2021

Richness contamination from spec-z data

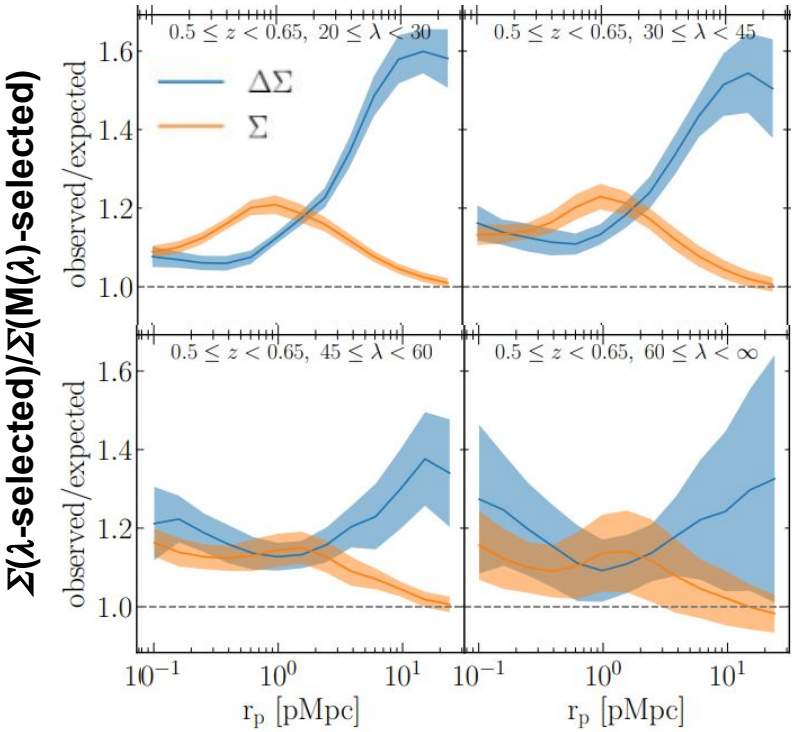


Myles et al. 2021

Calibration currently limited by lack of multi-wavelengths data (especially at low λ and high-z) and reliability of simulated data in reproducing galaxy properties in dense environments

SELECTION EFFECT BIAS ON WL

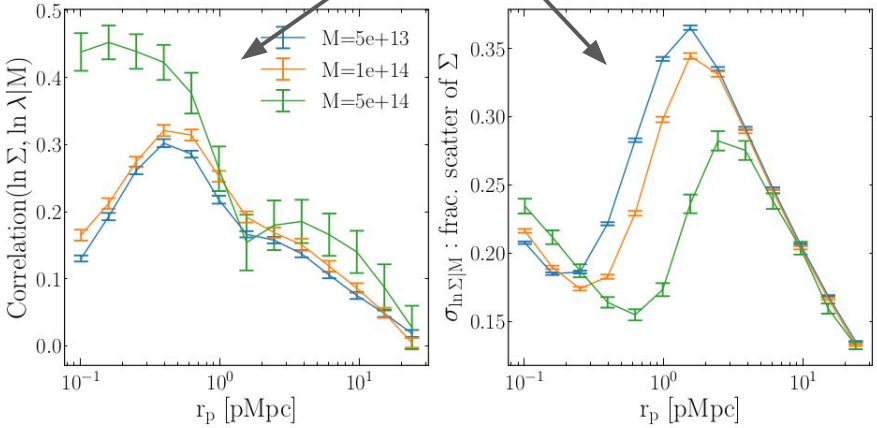
Selection effects bias on WL profile from mock redMaPPer catalogs



Wu et al. 2022

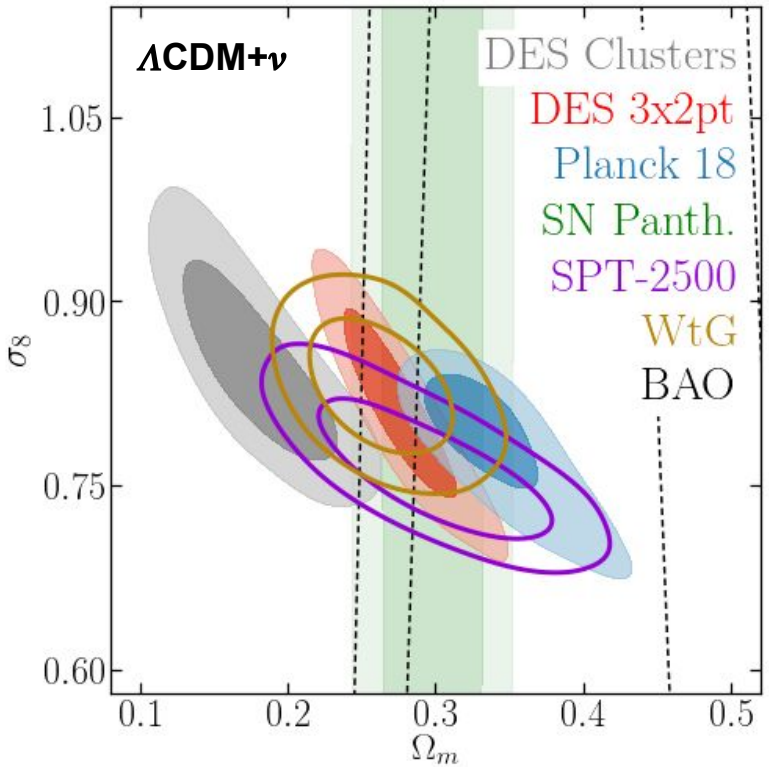
Selection bias term

$$\langle \ln\Sigma | \ln\lambda, M \rangle = \langle \ln\Sigma | M \rangle + r\,\sigma_{\ln\Sigma}\,\frac{\left(\ln\lambda - \langle \ln\lambda | M \rangle\right)}{\sigma_{\ln\lambda}}$$



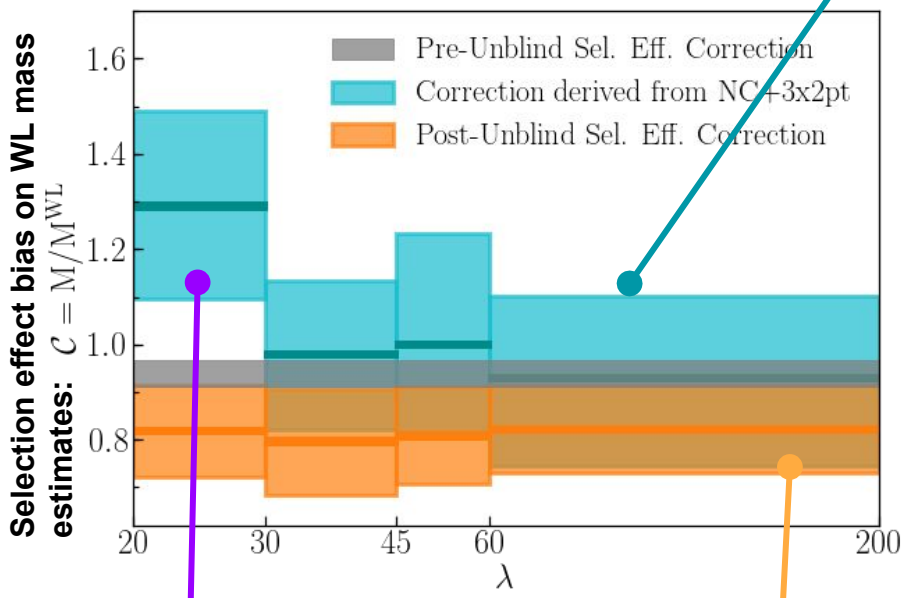
Systematic uncertainty dominating the total error budget in DES Y1 cluster analysis

COSMOLOGICAL CONSTRAINTS DES Y1



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

WL Mass bias needed to recover DES 3x2pt cosmology

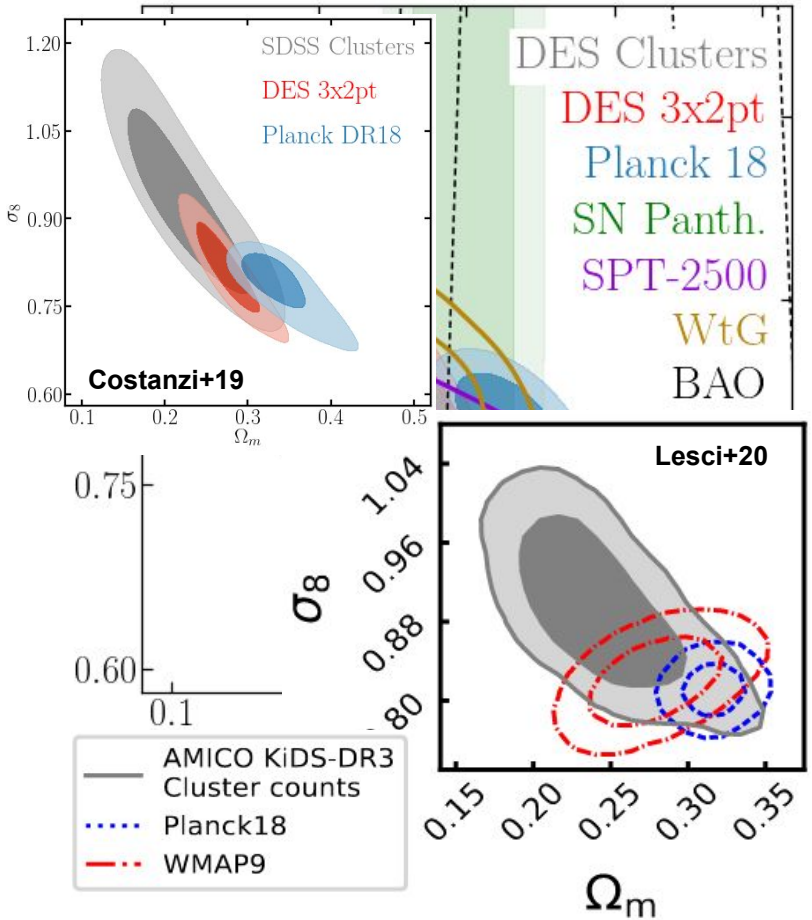


WL signal around λ~20 systems is lower than expected

Selection effect bias calibration from simulations

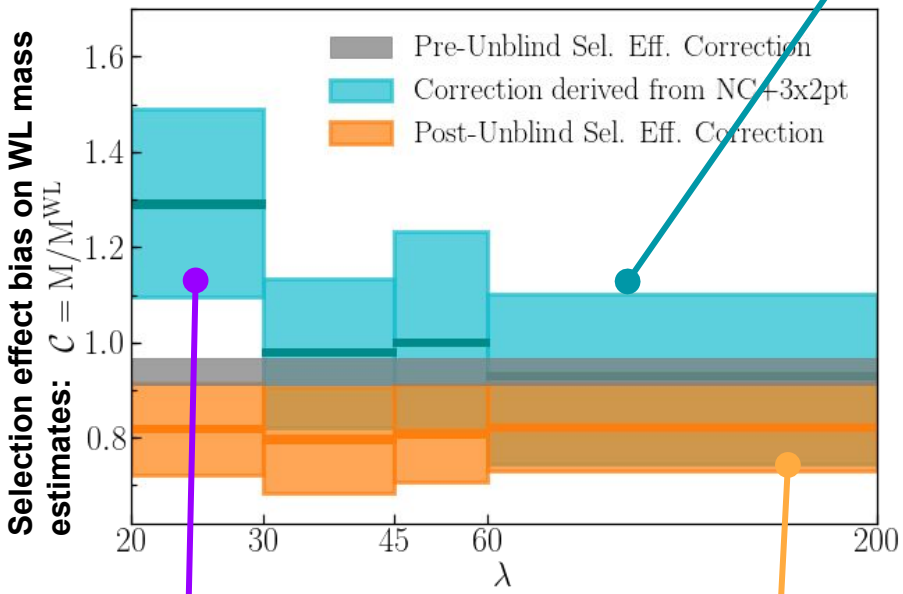
DES Collaboration 2020

COSMOLOGICAL CONSTRAINTS DES Y1



aboration 2020

WL Mass bias needed to recover DES 3x2pt cosmology



WL signal around λ~20 systems is lower than expected

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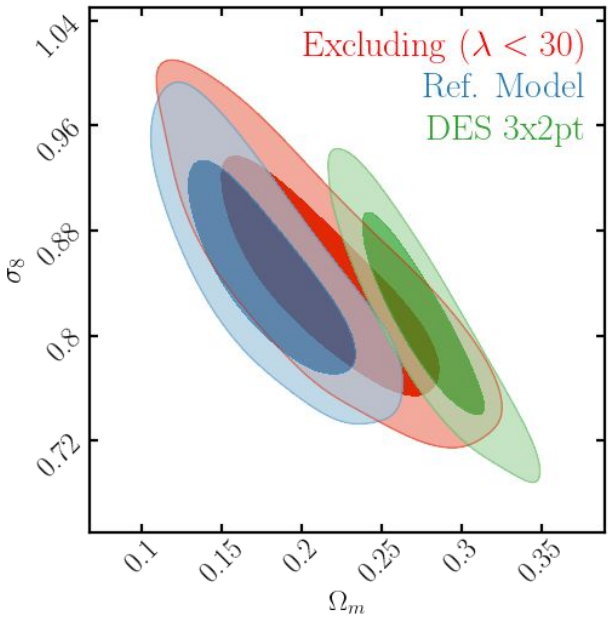
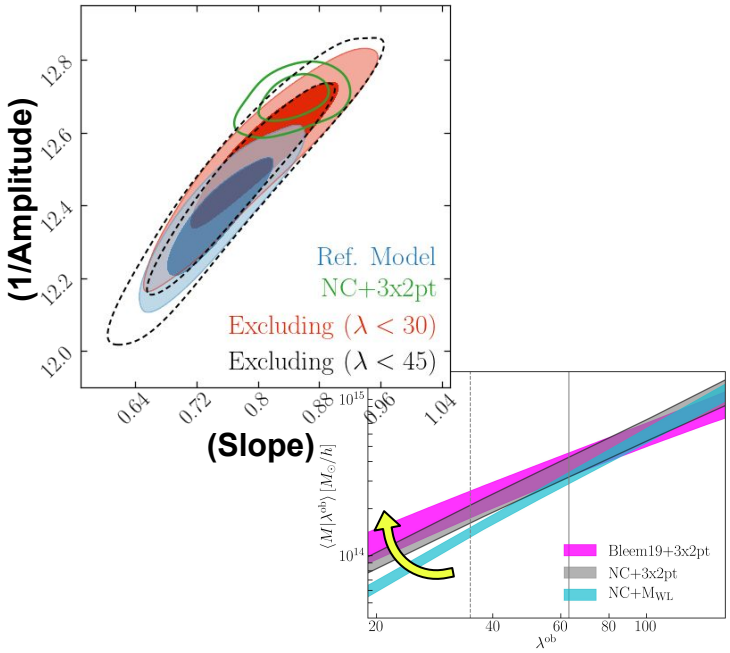
COSMOLOGICAL CONSTRAINTS DES Y1

- **Unmodeled systematic at λ<30 ⇒ Removing the lowest λ-bins reduces the tension with DES 3x2pt cosmology steepening the λ-M relation, but the error on S_8 increase by 18%**





DES Collaboration 2020

- **Is the current modeling of the observational scatter and selection effect sufficient to describe to whole mass and redshift ranges probed by optical cluster surveys?**
- **Is the lower than expected lensing signal of λ<30 clusters due to systematics affecting optically selected clusters or it has a physical origin?**

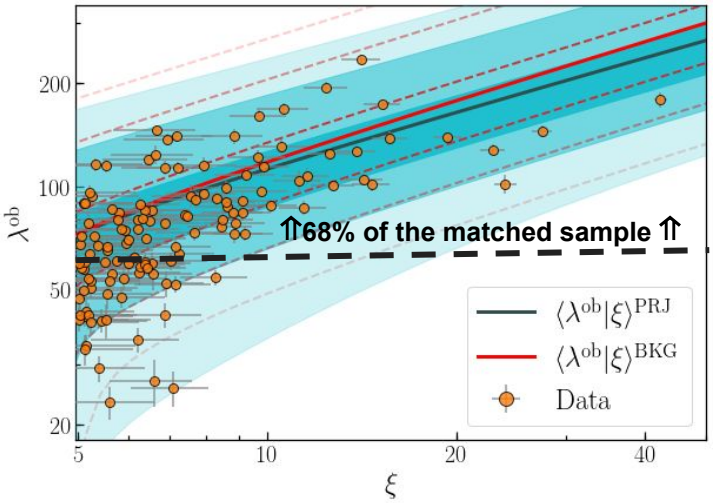
DES NC x SPT MULTI-λ DATA

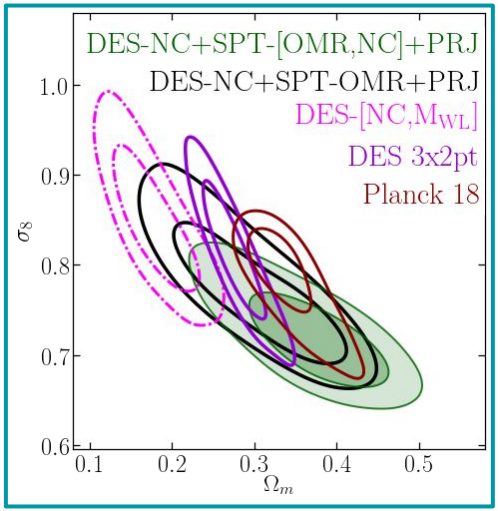
- Use SPT-SZ multi-wavelengths data (SZ, X-ray, WL) of cross-matched DES cluster to constrain the richness–mass scaling relation
- Use DES Y1 Number Counts to constrain cosmology

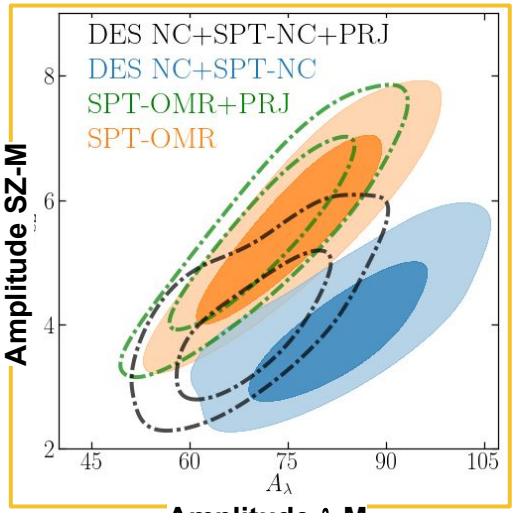
DES-NC x SPT-multi-λ yields results consistent with multiple cosmological probes.

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

DES Y1-SPT SZ cross matched sample





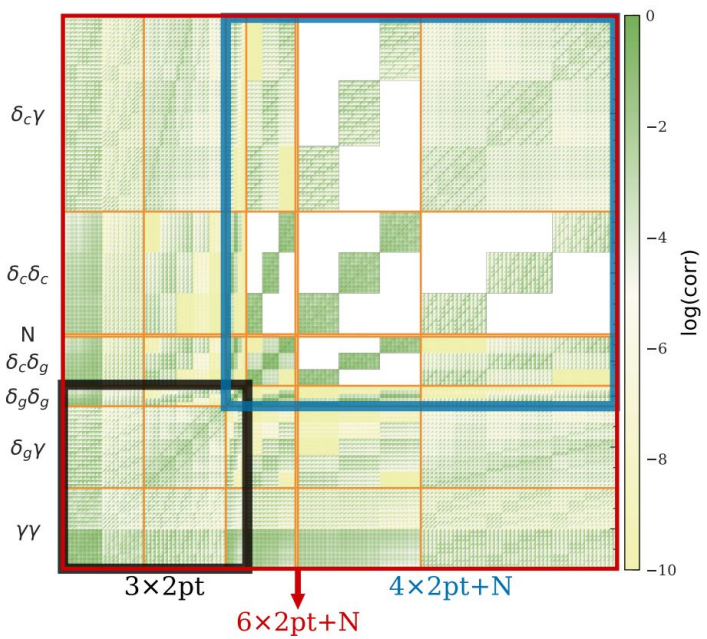


Amplitude λ-M

Costanzi+21

COMBINATION WITH OTHER LSS PROBES

- 4x2pt+N: Combination of DES Y1 cluster counts with 2pt auto and cross correlation functions from different cosmic tracers: $\delta_c\delta_c$, $\delta_g\delta_g$, $\delta_c\delta_g$, $\delta_c\gamma$
- Used only large scale information (>8Mpc; i.e. no 1-halo term)



Correlation matrix for the combined analysis of galaxy, lensing and cluster correlation function and cluster counts

To & Krause et al. 2021

COMBINATION WITH OTHER LSS PROBES

- **4x2pt+N: Combination of DES Y1 cluster counts with 2pt auto and cross correlation functions from different cosmic tracers: $\delta_c\delta_c$, $\delta_g\delta_g$, $\delta_c\delta_g$, $\delta_c\gamma$**
- **Used only large scale information (>8Mpc; i.e. no 1-halo term)**

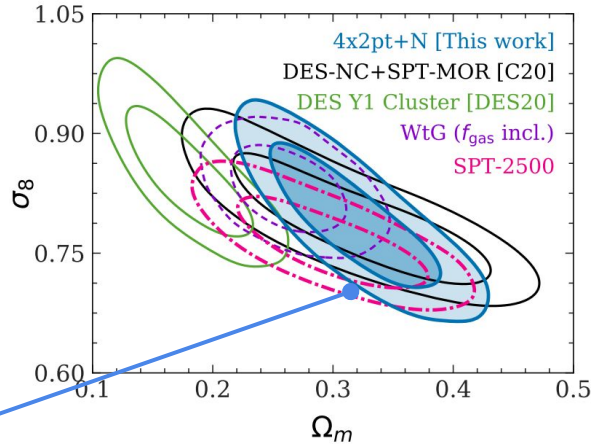
- **Main results:**

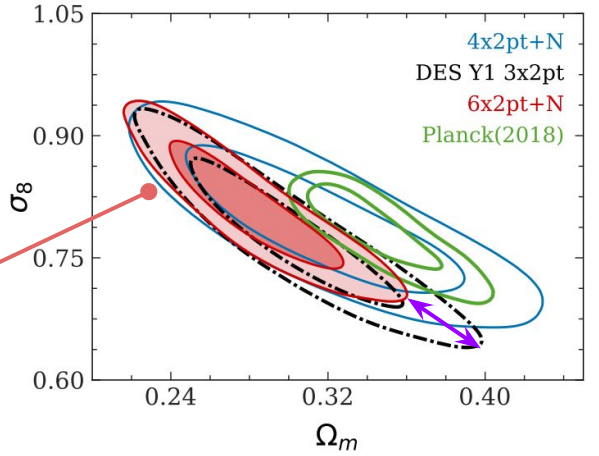
  - **Cosmological posteriors consistent with DES 3x2pt and other cluster abundance studies**

  - **Constraints on (large-scale) selection bias:**

$$b_{\rm sel} = w_{\rm cg}[\lambda]/w_{\rm cg}[M] \simeq 1.2$$

  - **When combined with other probes, cluster data provide 20% improvement on Ω_m constraint over 3x2pt analysis**





To & Krause et al. 2021

TAKEAWAY & FUTURE DIRECTIONS

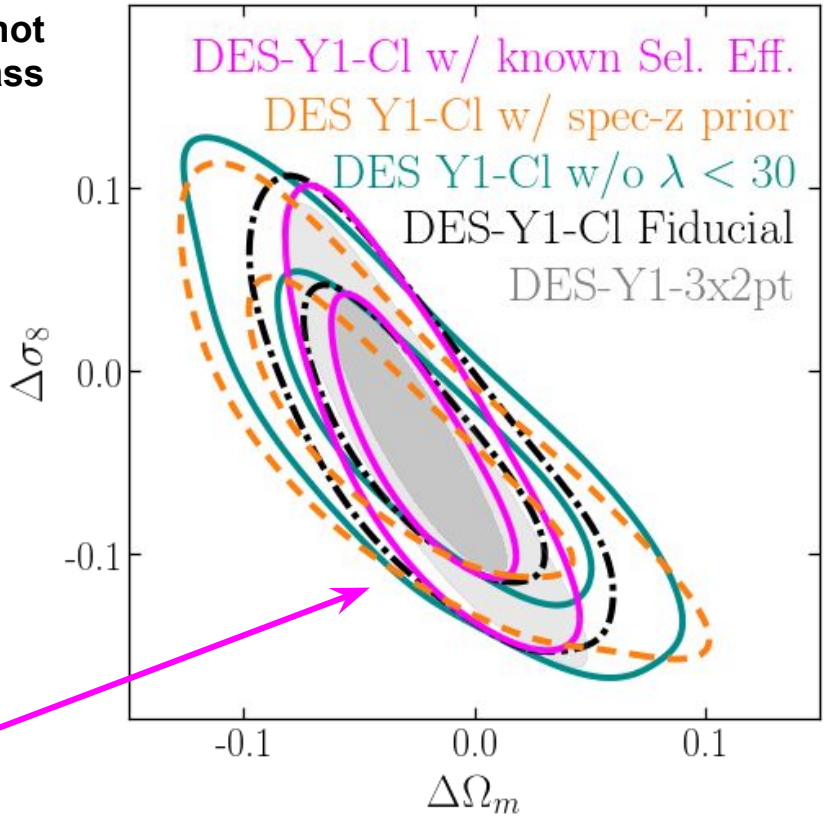
- **DES cluster counts provide cosmological constraints consistent with other probes if we do not rely on stacked WL data to calibrate the (low) λ-mass relation**

Flawed modeling of the stacked WL signal of optically selected clusters in the one-halo regime

- **Optical selection or WL systematic?**
  - **Multi-wavelength follow up data (X-ray, SZ, spec-z) of low-λ systems.**
  - **Improved synthetic galaxy catalogs.**

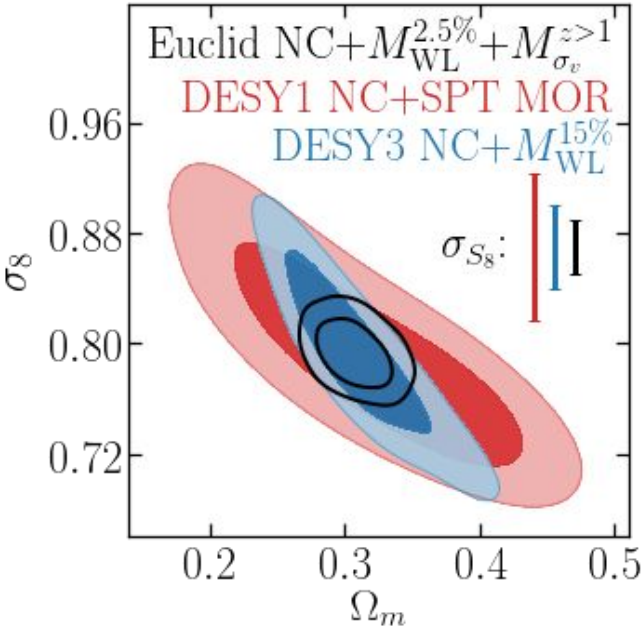
Potentiality to provide the tightest single-probe constraints if we manage to characterize (~2% level) the systematics associated with the mass estimates

Impact of different systematics on DES Y1 cluster constraints

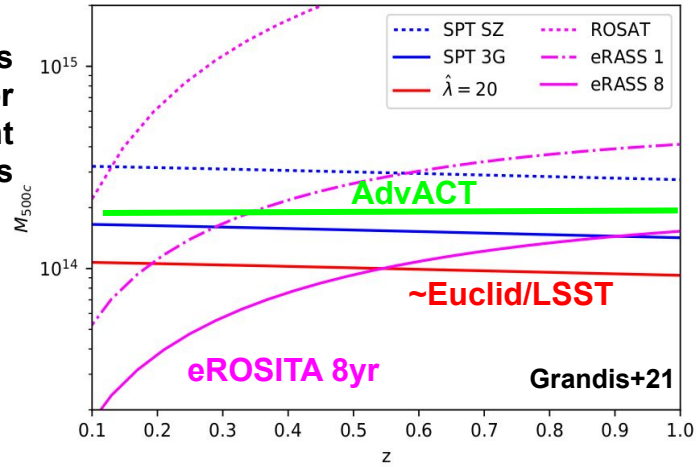


FUTURE PERSPECTIVES

- **DES Y3 and Y6: >3 times more clusters than DES Y1 up to z=0.8 ⇨ DESY6 N+6x2pt ~40% improvement on S8 constraints compared to Y1 assuming the current level of systematic.**
- **Next generation cluster surveys will lower the mass limit and extend the redshift range probed; Euclid ~10^5 systems at z≲2 with mass calibration from WL and glx dynamic ⇨ measure growth rate over cosmic time (w_0, w_a, GR test)**



Mass limit vs redshift for different surveys



- **Large overlap between survey footprints will allow multi-wavelength cluster cosmology ⇨ improved mass calibration and control of systematics.**

(SOME) REFERENCES

- Modelling of miscentering effects: Zhang et al 2018 (arXiv:1901.07119)
- Modeling of membership dilution: Varga et al 2019 (arXiv:1812.05116)
- DES Y1 WL mass calibration: McClintock & Varga et al 2019 (arXiv:1805.00039)
- Modeling of the selection function: Costanzi et al 2019a (arXiv:1807.07072)
- SDSS Cluster Cosmology: Costanzi et al 2019b (arXiv:1810.09456)
- Prior on observable mass relation: Farahi et al 2019 (arXiv:1903.08042)
- DES Y1 results: DES Collaboration 2020 (arXiv:2002.11124)
- DES NC x SPT multi-λ: Costanzi et al 2021 (arXiv:2010.13800)
- DES Y1 N+4x2pt analysis: To & Krause et al 2021 (arXiv: 2010.01138)
- Calibration of projection effects with spec-z data: Myles et al 2021 (arXiv:2011.07070)
- DES-Y1 x SPT calibration of projection effects: Grandis et al 2021 (arXiv:2101.04984)
- On triaxiality and orientation selection bias: Zhang et al. 2022 (arXiv:2202.08211)
- Selection effect bias on stacked WL: Wu et al 2022 (arXiv:2203.05416)