UNIVERSITY OF CALIFORNIA
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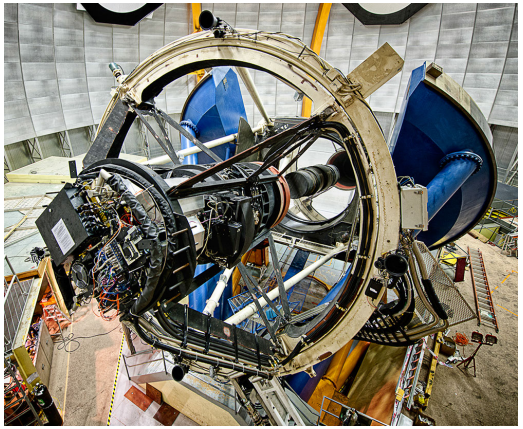
Synergy between optical, SZ, and X-ray: Lessons learned from DES Cluster Cosmology

Tesla Jeltema

Santa Cruz Institute for Particle Physics
University of California, Santa Cruz



Cosmology with Clusters

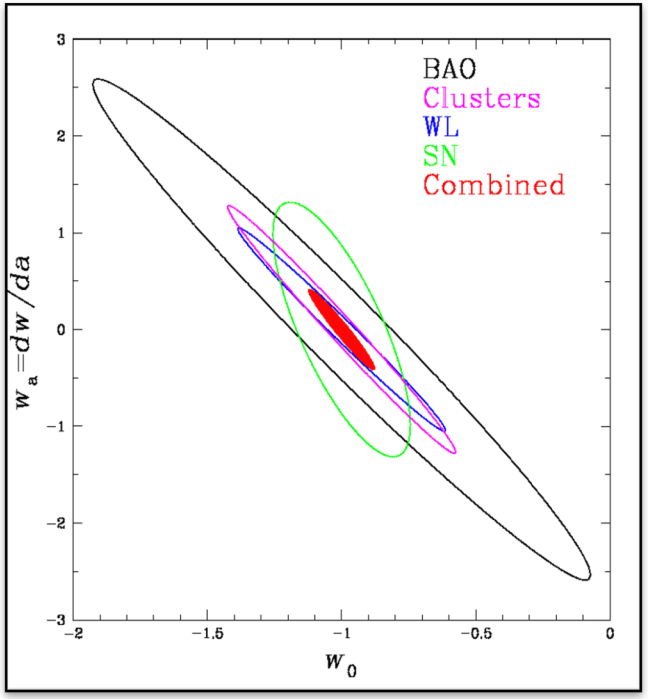
Evolution of cluster mass function sensitive to both growth of structure and geometry of the universe

"The CL technique has the statistical potential to exceed the BAO and SN techniques but at present has the largest systematic errors."

– DETF Final Report

→ We need to combine multiwavelength observations

DES Forecasts



DES proposal 2006

Where are we? - DES Clusters

5000 deg^2 footprint has been covered for 900 secs in griz and 450 sec in Y

Status:

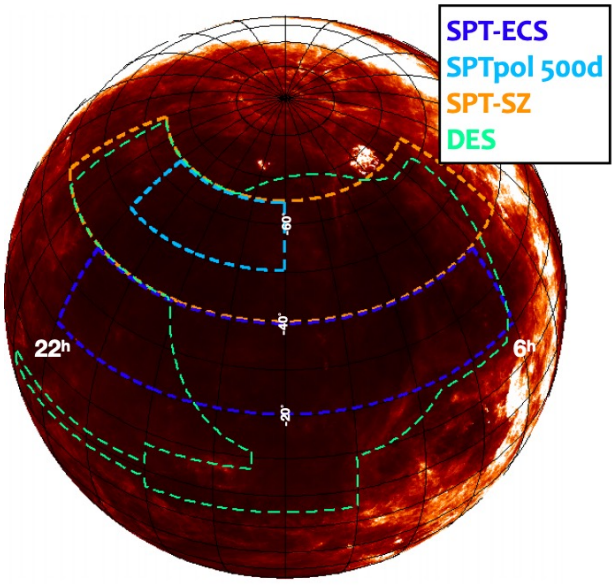
- Y1 (1300 sq. deg, 40% depth) key results published

~ 7,000 clusters

- Y3 (4000 sq. deg, 50% depth) papers in progress

~ 21,000 clusters

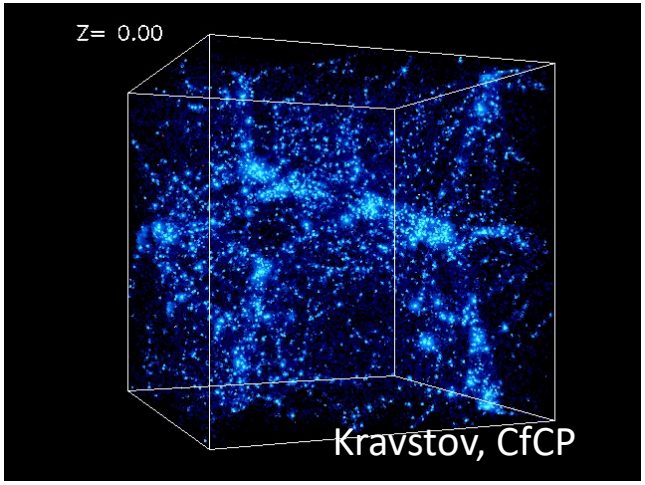
- Y6 (full survey) Y6 Gold v2 complete



Cosmology with Clusters

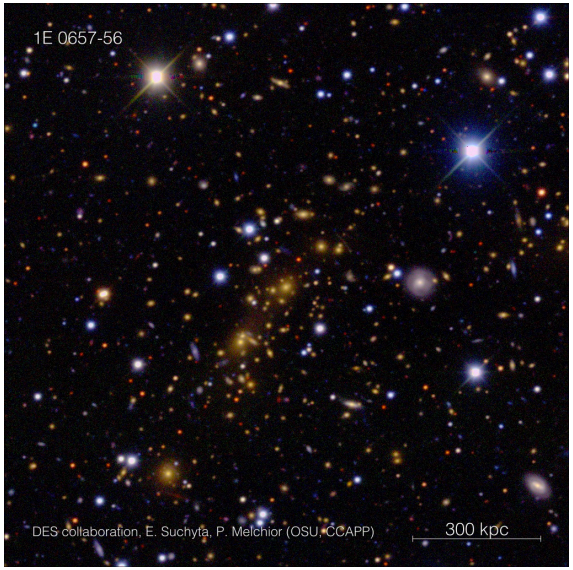
What we can predict:

(# of massive halos)/volume at z



What we see:

Galaxies in survey solid angle at photometric z

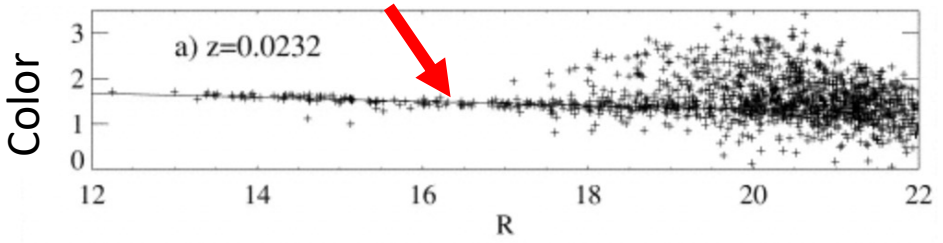


Finding Clusters - redMaPPer

1. Identify clusters as overdensities of galaxies with the same color

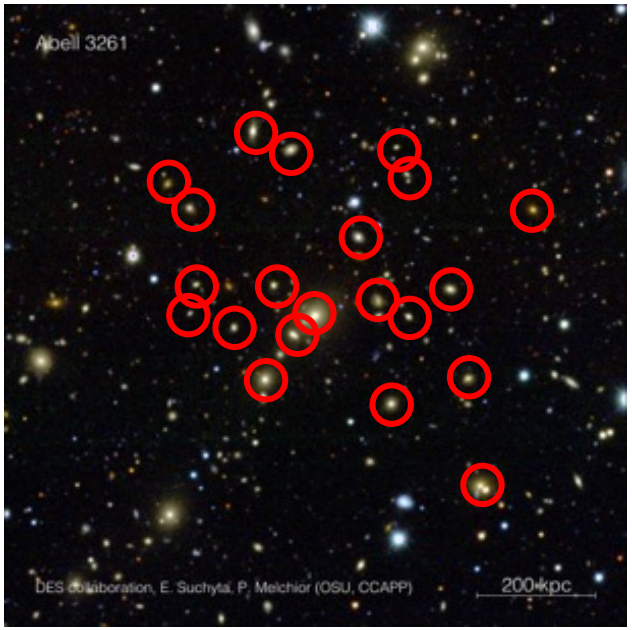
Cluster red sequence

Gladders+ 1998



2. Color of red sequence gives z (accurate to ~1%)

3. Candidate central galaxy → position



4. Assign galaxies a membership probability

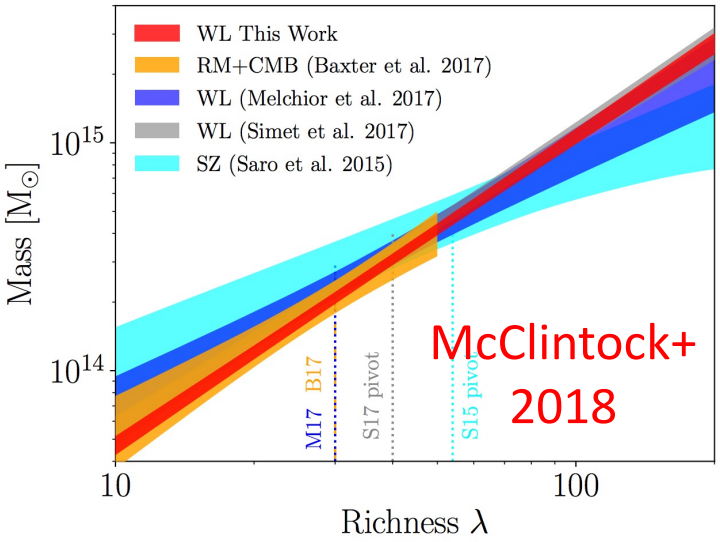
$\lambda_{RM} = \Sigma p_{mem}$ → richness

Rykoff+ 2014, 2016

Mass-Richness Relation

- Mean mass-richness relation from stacked weak lensing

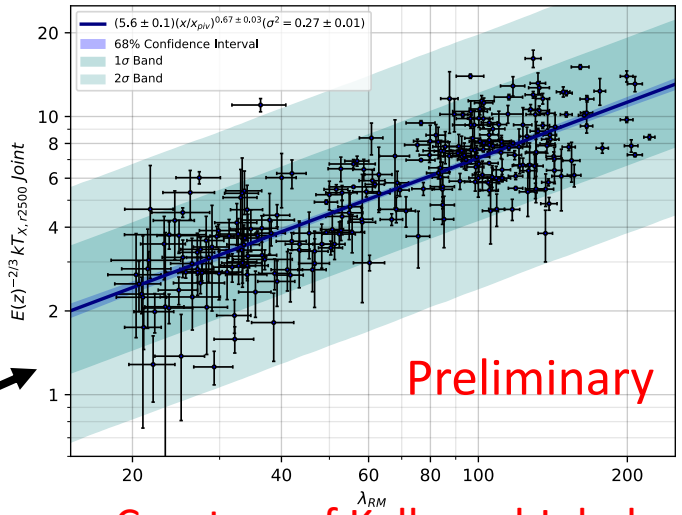
  - Amplitude uncertainty 5% in DES Y1 ☺
  - Systematics dominated ☹



- X-ray and SZ calibration of miscentering and richness scatter

  Zhang+ 2019, Farahi+ 2019, Bleem+ 2020

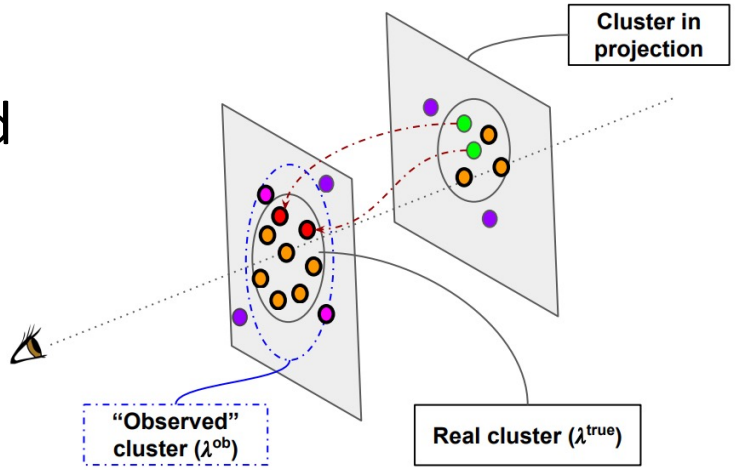
Tx – λ Chandra + XMM for DES Y3 clusters



Courtesy of Kelly and Jobel

Observed vs. True Richness

- Projection effects change observed richness - Costanzi+ 2019
  - Uncertainty in background
  - Correlated structure
  - Masking (percolation)



→ Calibration with spectroscopy underway - Myles+ 2021, Wetzell+ 2021

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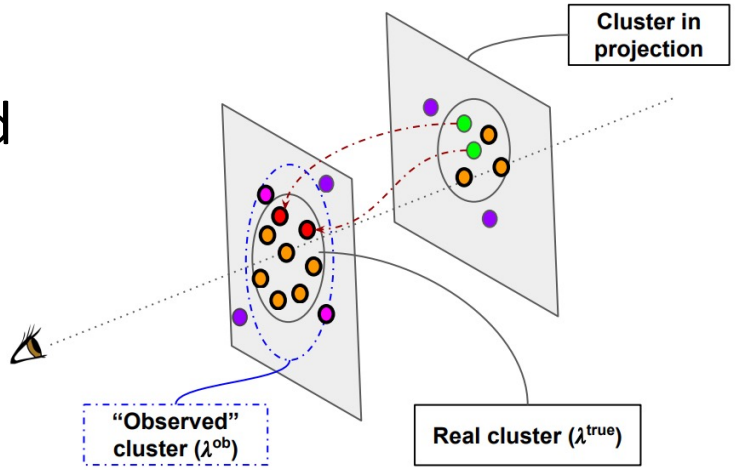
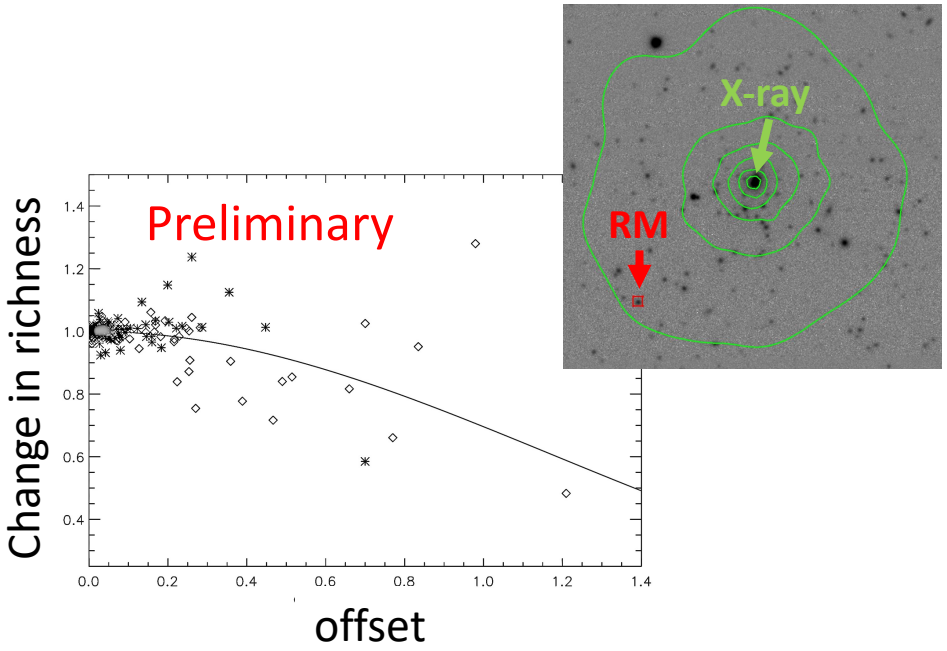


- Richness bias for miscentered clusters - Zhang+ 2019

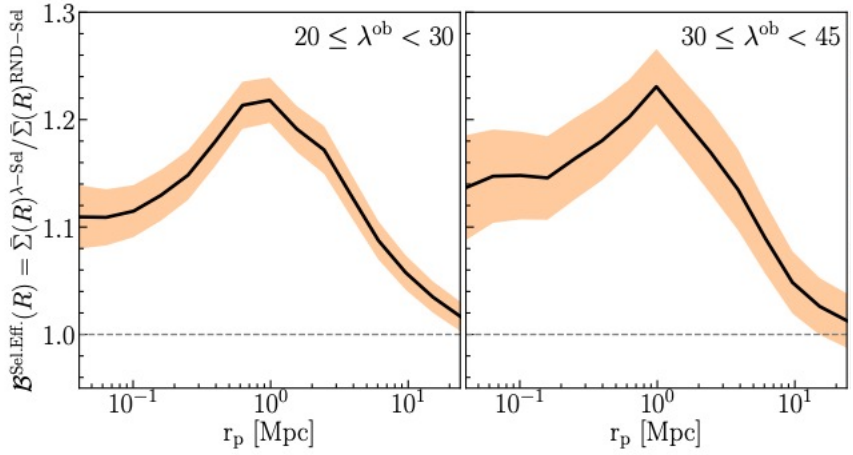
→ calibrate with X-ray and SZ

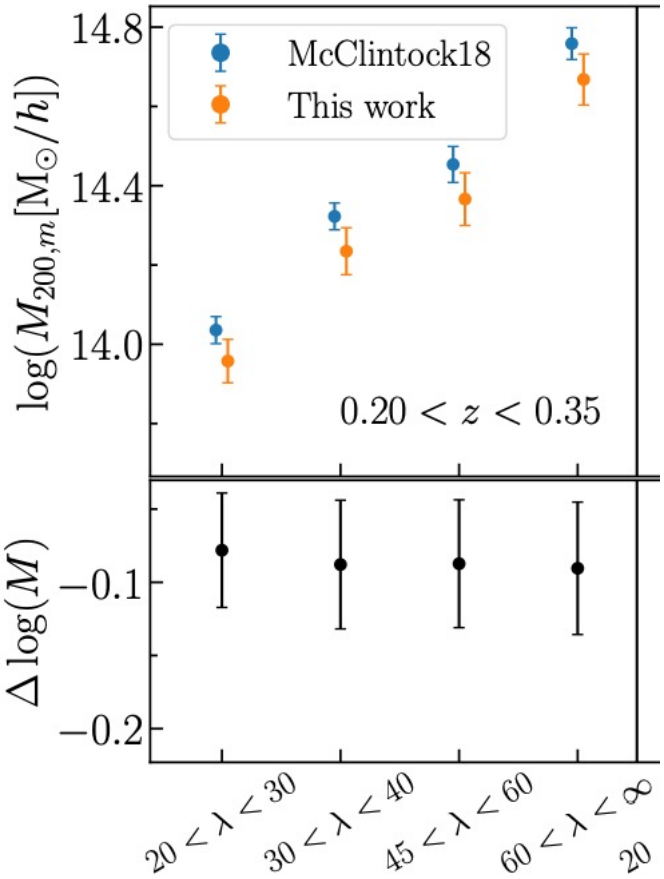


Selection Effects

Richness selection is biased compared to mass selection (e.g. for halos elongated along the line of sight or with correlated structure)

- Biases lensing determined mass





Wu et al. in prep., DES collaboration 2020

DES Year 1 Clusters

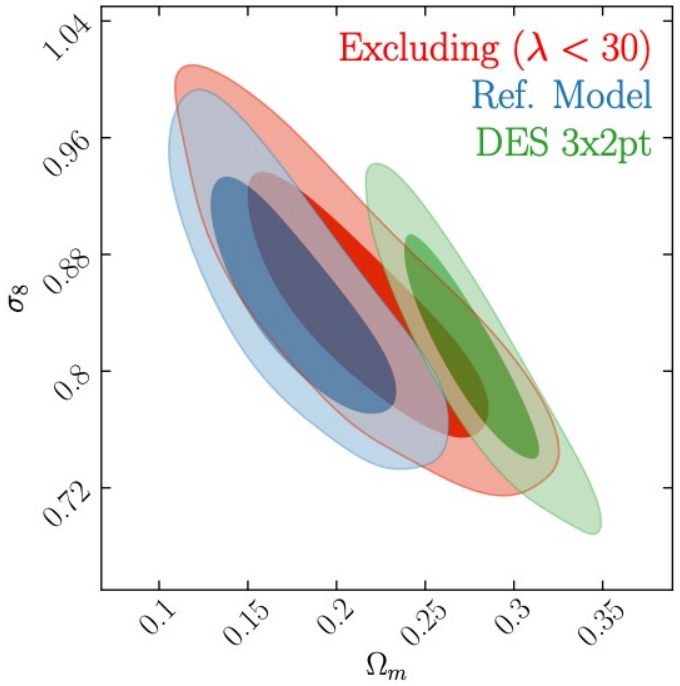
- DES clusters have similar constraining power to DES 3x2pt (g-g, g-s, s-s)

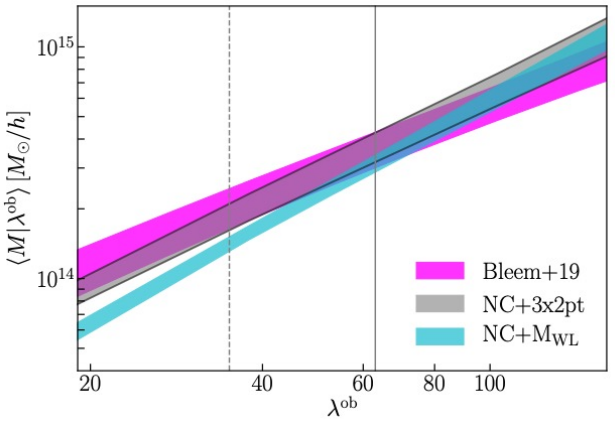
However,

- Selection effect uncertainties add 16% error on S_8
- Tension between number counts and lensing indicate unmodelled systematics for low richness clusters

→ Implies lensing signal too low at $\lambda < 30$

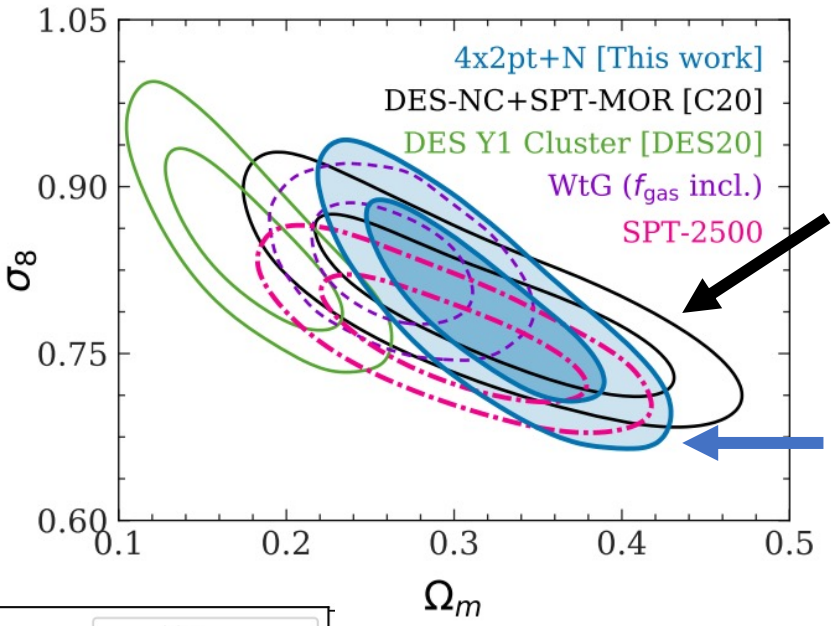
(similar to massive galaxies in Leauthaud+2017)





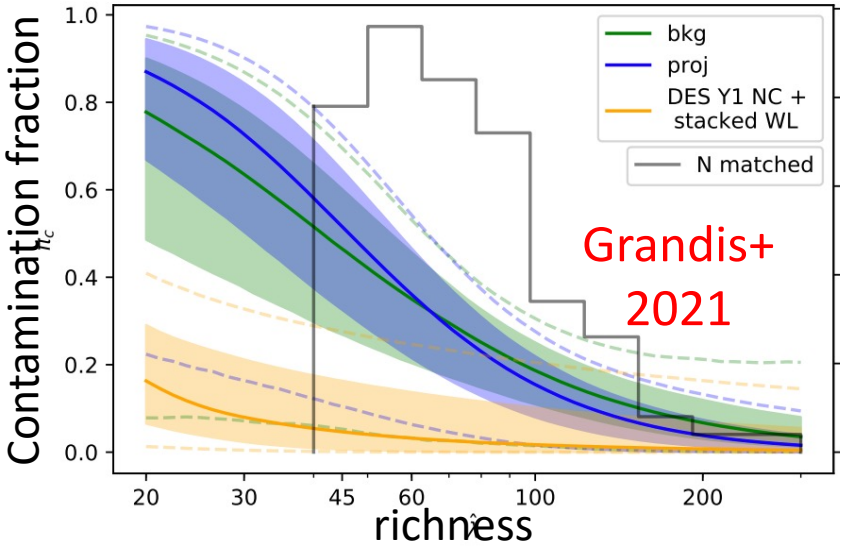
Using SZ Observations

- SPT MOR + DES number counts gives cosmology consistent with previous studies



DES Number Counts + SPT mass-observable relation Costanzi+ 2021

DES NC, Cluster Clustering + c-g, c-s, g-g To+ 2021



- SPTxDES implies a growing contamination fraction or richness scatter at low λ

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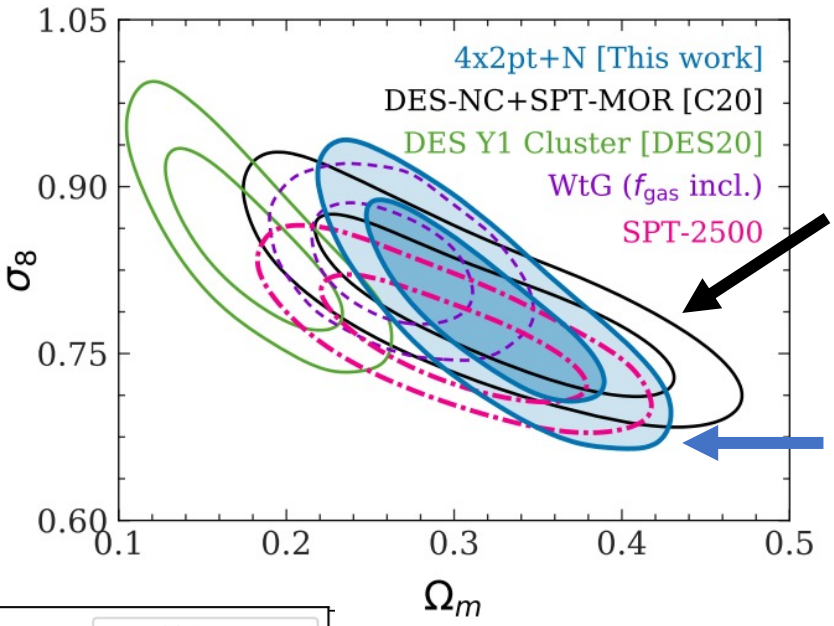

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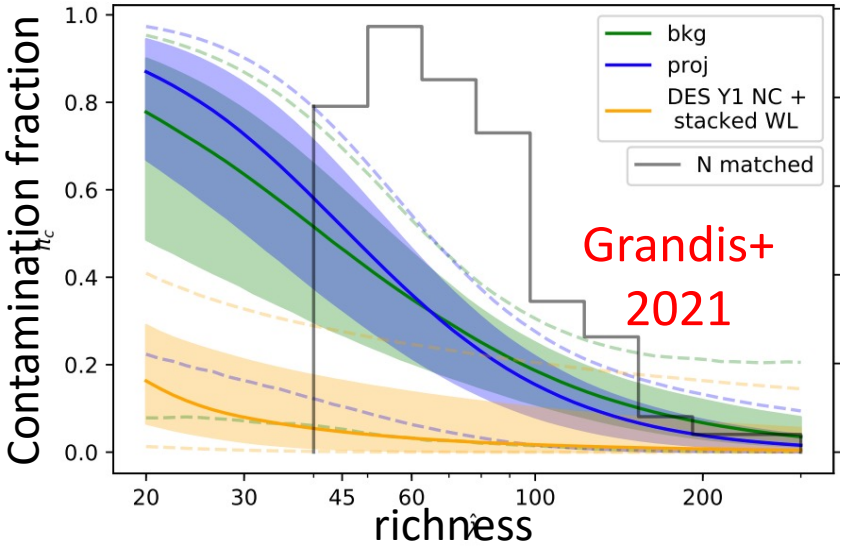


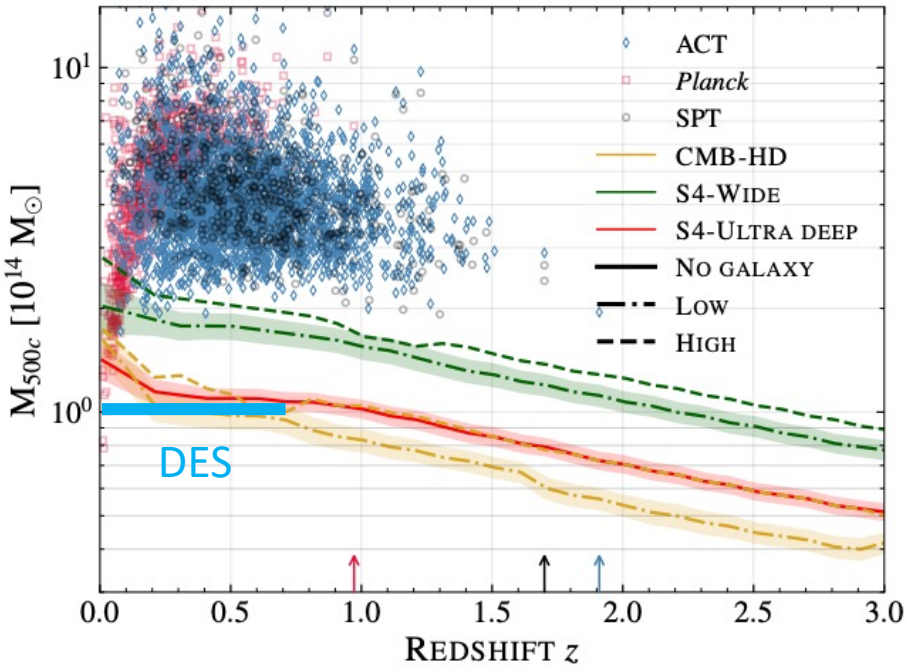
→ Limiting factor is richness range of current SZ samples

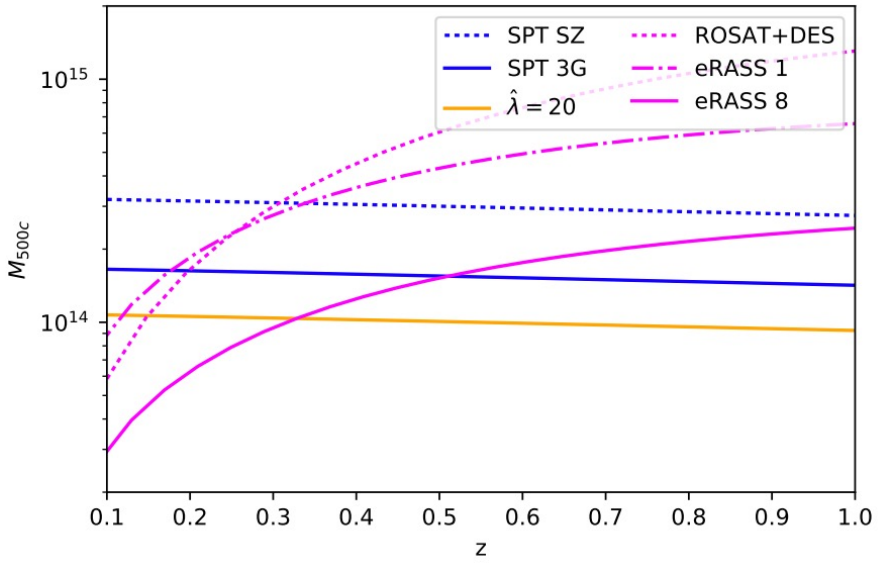
Looking Ahead

CMB-S4: >75,000 clusters to high-z and lower masses

LSST: 4x area of DES + depth, several 100k clusters

Raghunathan+ 2021

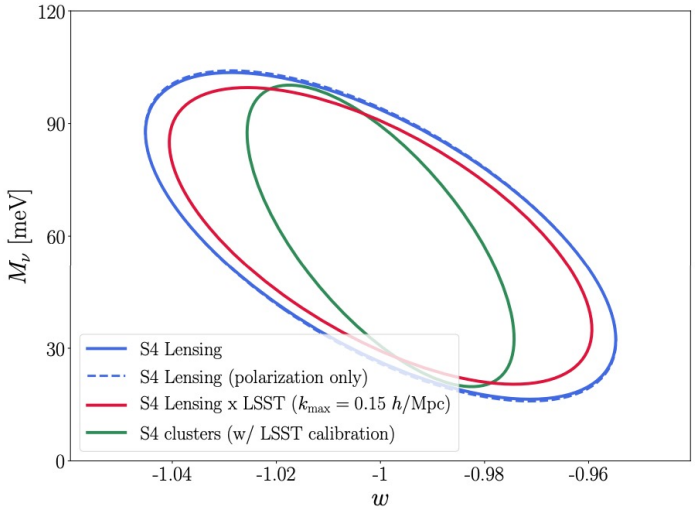




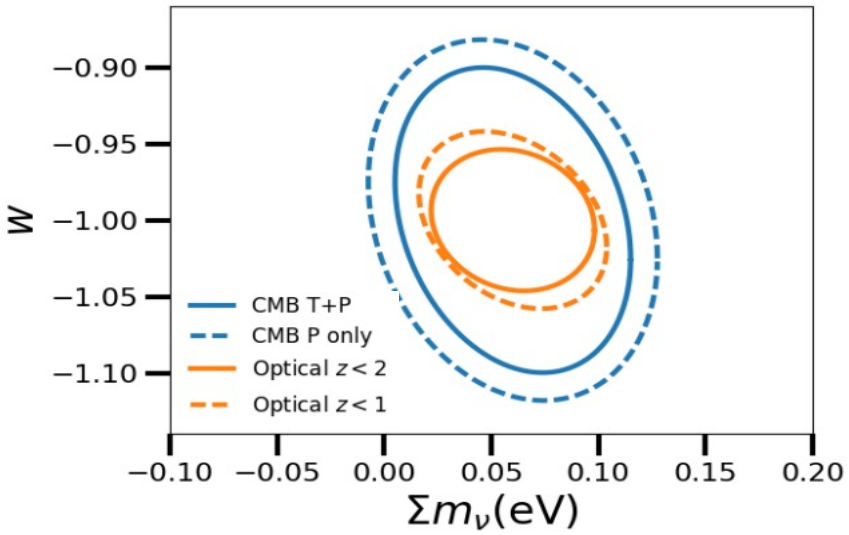
X-ray: eROSITA 50-100k clusters + Athena pointed observations

Looking Ahead

- LSST/optical surveys provide cluster redshifts and lensing
- Powerful combination with CMB-S4 clusters and CMB lensing



CMB-S4 Collaboration 2019



Madhavacheril+ 2018

- X-ray probes to low mass at low-z and combined with CMB probes gastrophysics


Thank you!