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

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

3. Candidate central galaxy $\rightarrow$ position

4. Assign galaxies a membership probability

$$\lambda_{RM} = \Sigma p_{\text{mem}} \rightarrow \text{richness}$$

Rykoff+ 2014, 2016

Cluster red sequence

Gladders+ 1998
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
Observed vs. True Richness

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

- Richness bias for miscentered clusters - *Zhang*+ 2019
  → calibrate with X-ray and SZ

Preliminary
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.

SPTxDES implies a growing contamination fraction or richness scatter at low $\lambda$.
Using SZ Observations

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

Limiting factor is richness range of current SZ samples

Costanzi+ 2021

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

Grandis+ 2021
Looking Ahead

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

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

**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

- X-ray probes to low mass at low-z and combined with CMB probes gasprophysics
Thank you!