# “Studying orientation biases in SZ selected optical clusters (SPT and ACTxDESY3) using the BCG”

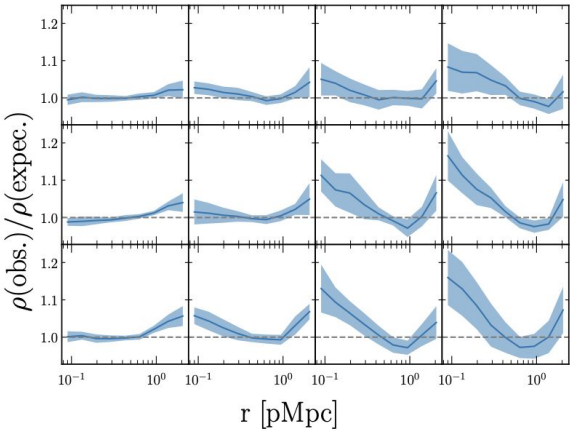
Radhakrishnan[1] (Rad), Tae[1], Anja[1], et al.
[1] Stony Brook University

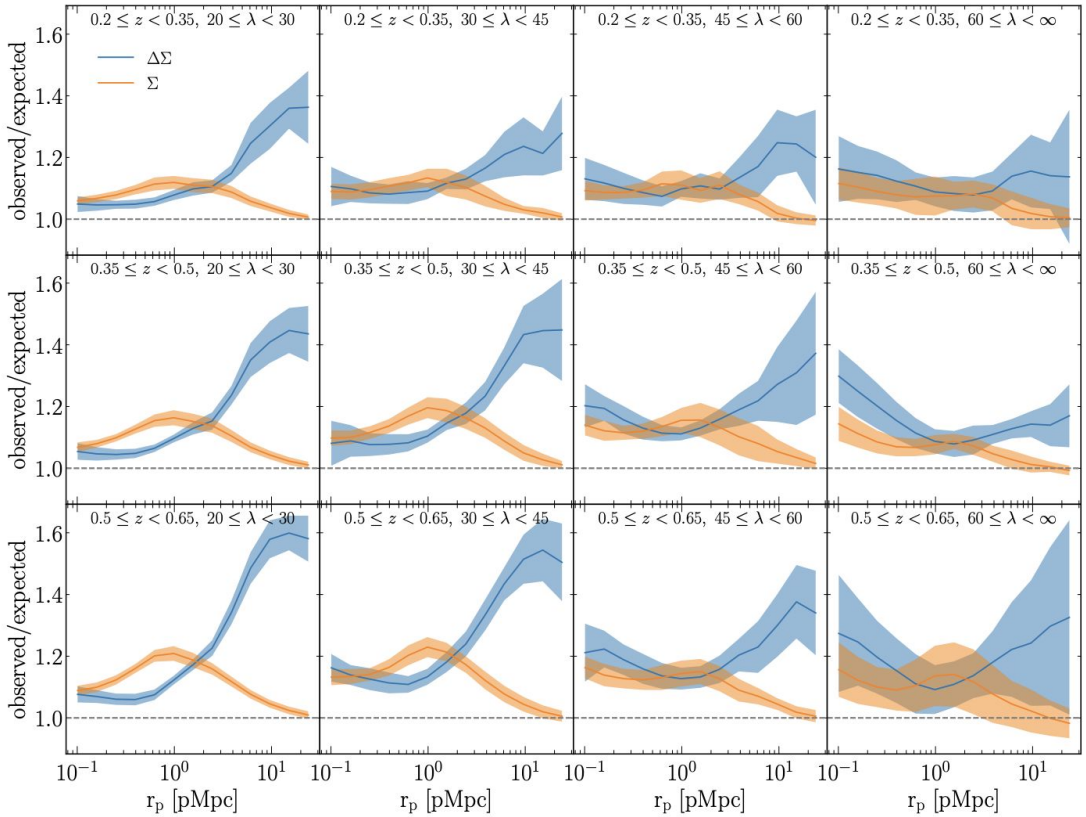
Stony Brook University

# Selection Bias

Source: Wu et al. 2022 (DES Collaboration)

**Projection effects** at small scales for low $\lambda$ <30 clusters



# BCG shape as a proxy

- BCG shape is expected to follow dark matter halo alignment, Split in Roundest-most and Elliptical-most shapes of BCG
- Simulations: Okabe et al. 2020, etc.
- Observations: Herbonnet et al. 2019 (Wtg sample), Donahue et al. 2016, etc.

Elliptical - Along the Plane of sky

Round - Along the Line of sight

# BCG as orientation proxy in Observations

Stony Brook University

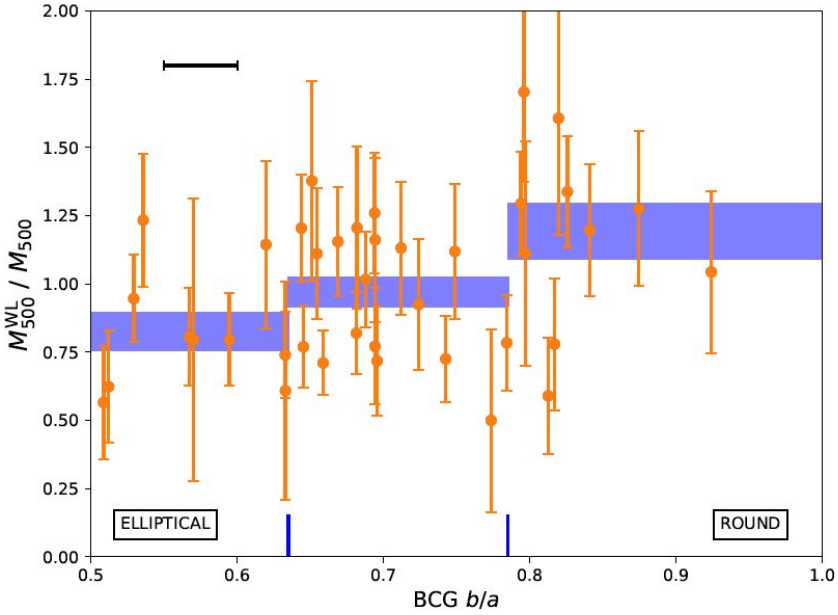
## Observations!

Source: Herbonnet, AvdL, et al. 2019

Correlation of BCG shape with Weak lensing Mass

To-do next:

“Optical & SZ matched clusters” - larger sample size & low scatter mass proxy

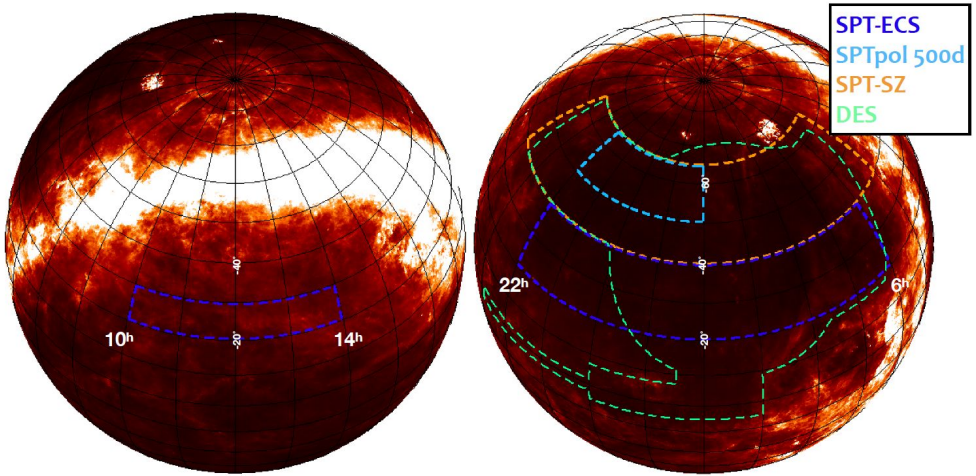


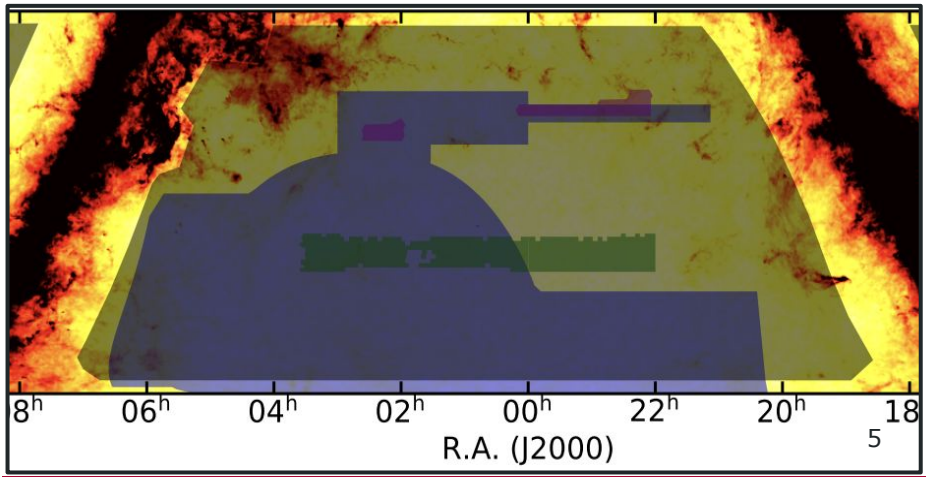
# Datasets

- South Pole Telescope SZ Clusters (Optically confirmed by MCMF ↠ $z_{MCMF}$, $\lambda_{MCMF}$)
  - SPT-SZ Survey (2500 sq.Deg.,; 677 clusters)
  - SPTPol ECS (2700 sq.Deg.; 470 clusters)
- Atacama Cosmology Telescope DR5 SZ Cluster Catalog (13200 sq.Deg.; 4100 clusters)
- Dark Energy Survey -Year 3: redMaPPer Cluster Catalogs (5000 sq.Deg.; 22000 clusters)

Sources: Bleem et al. 2019 (SPT)

Hilton et al. 2020 (ACT)



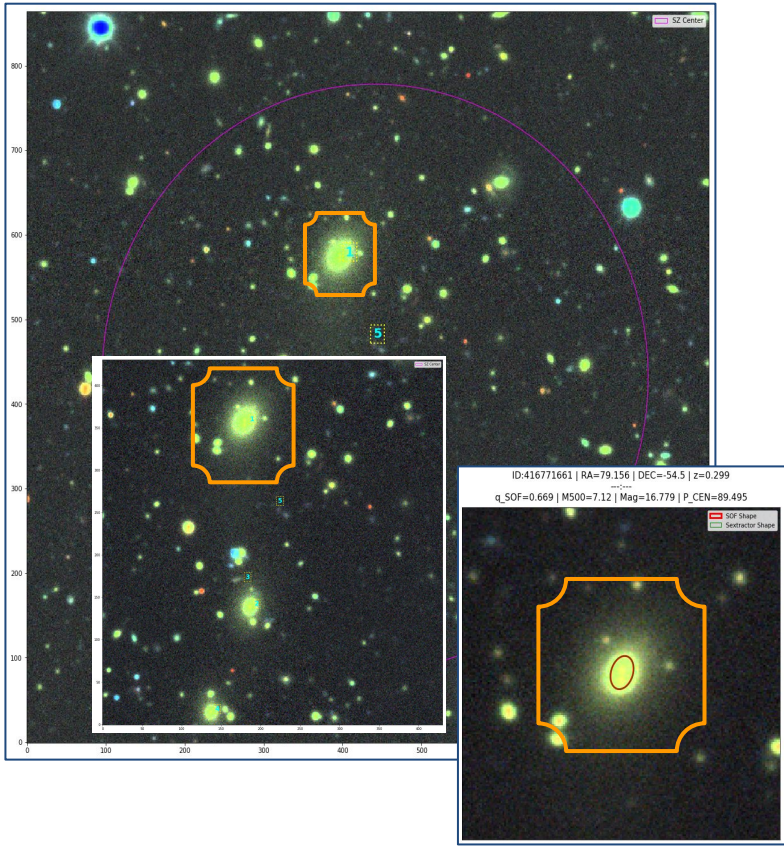



# Data Analysis

- Match SPT SZ and DES Y3 redMaPPer optical catalogs using MCMF z,richness as truths (a likelihood based matching)
- Visually Inspect BCGs (Identification and shape-validation)
- Split sample in BCG shape (Round and Elliptical bins)
- Compare optical observables (richness, lensing profile, galaxy density profile)

# Visual Inspection of SPT BCGs

- Find the “correct” BCG out of the 5 redMaPPer candidates for every SPT-SZ cluster matched to DES-Y3 (~376 Clusters at $\xi > 5.0$ and 100” separation)
- Check the shapes of the BCG for blends, fitting issues, etc.

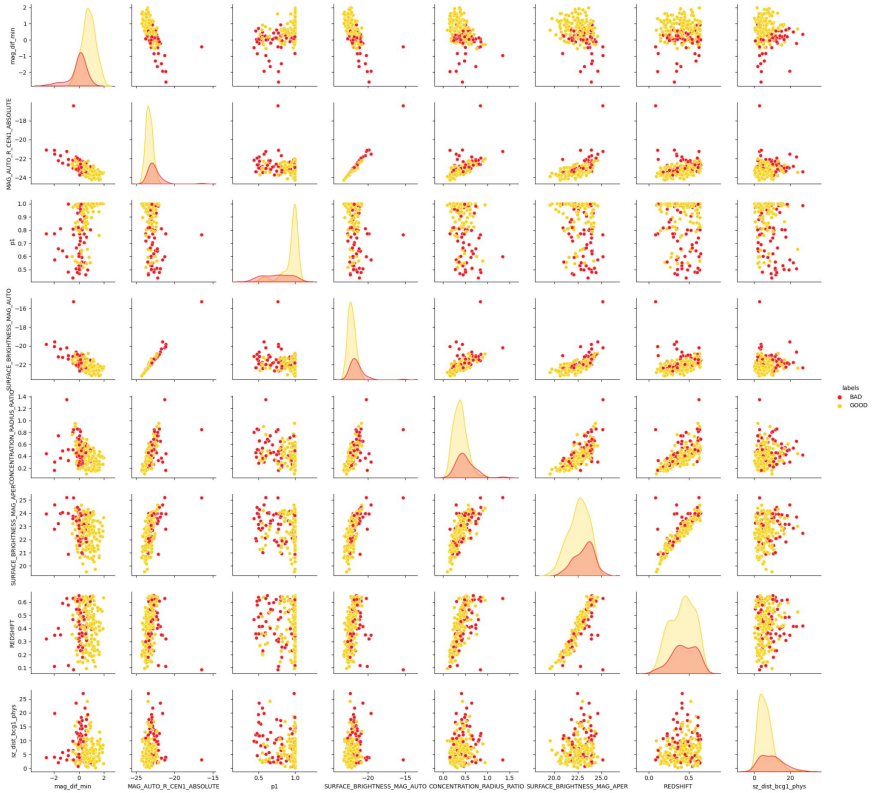



Special Thanks to everybody who contributed in this huge effort!

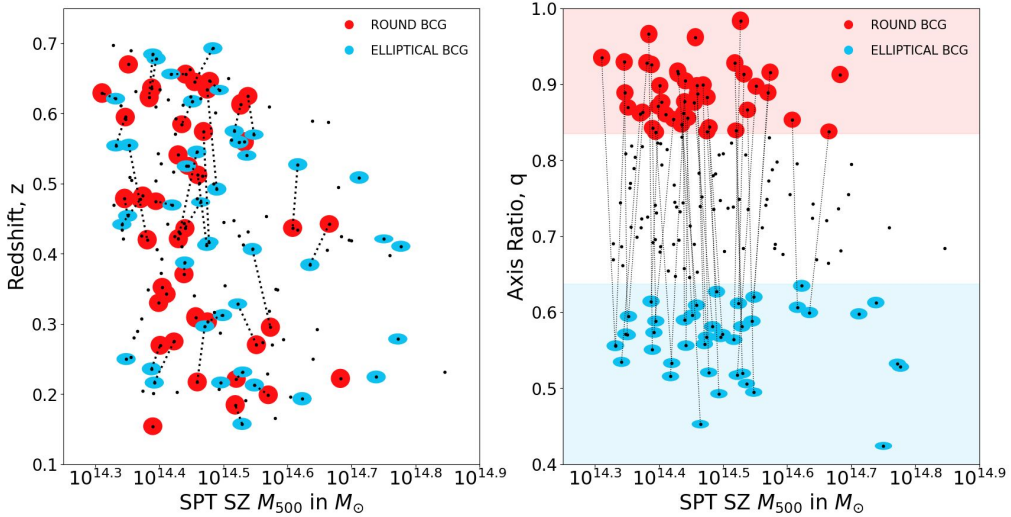
[Anja, Tae, Shuang, Hsin, Antonio, Leo, Prakruth, Ben, Xiangyu, Jiyun, Alden]

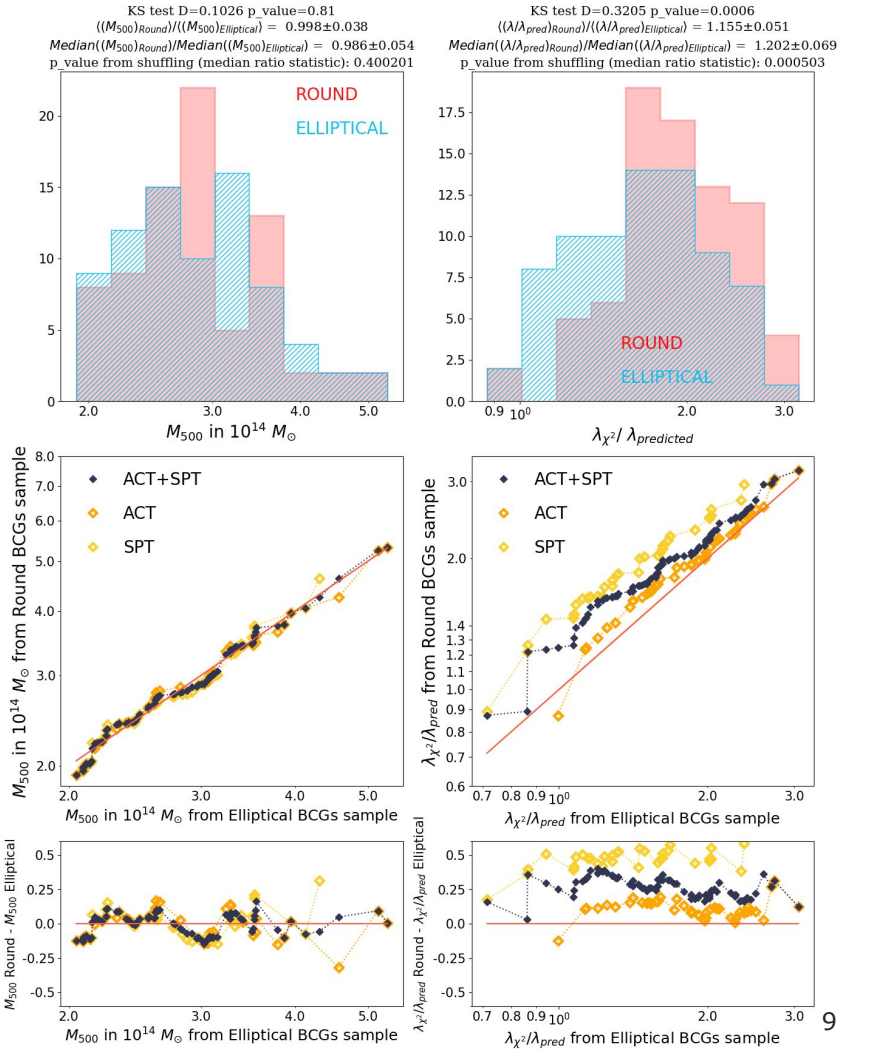
# Feature Engineering of ACT BCGs

- Replace Visual Inspection with most informative observed features per BCG (SZ distance to BCG, Absolute Magnitude, Magnitude Gaps, Redmapper Probabilities, surface brightness, etc.)
- redMaPPer BCG probability the most informative followed by magnitude gaps.
- Probability cut, P > 0.9 gives purity of 84% and completeness of 82%



# Split on BCG shape (q)



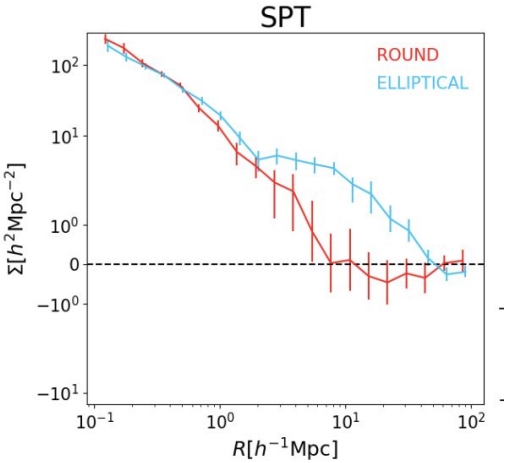



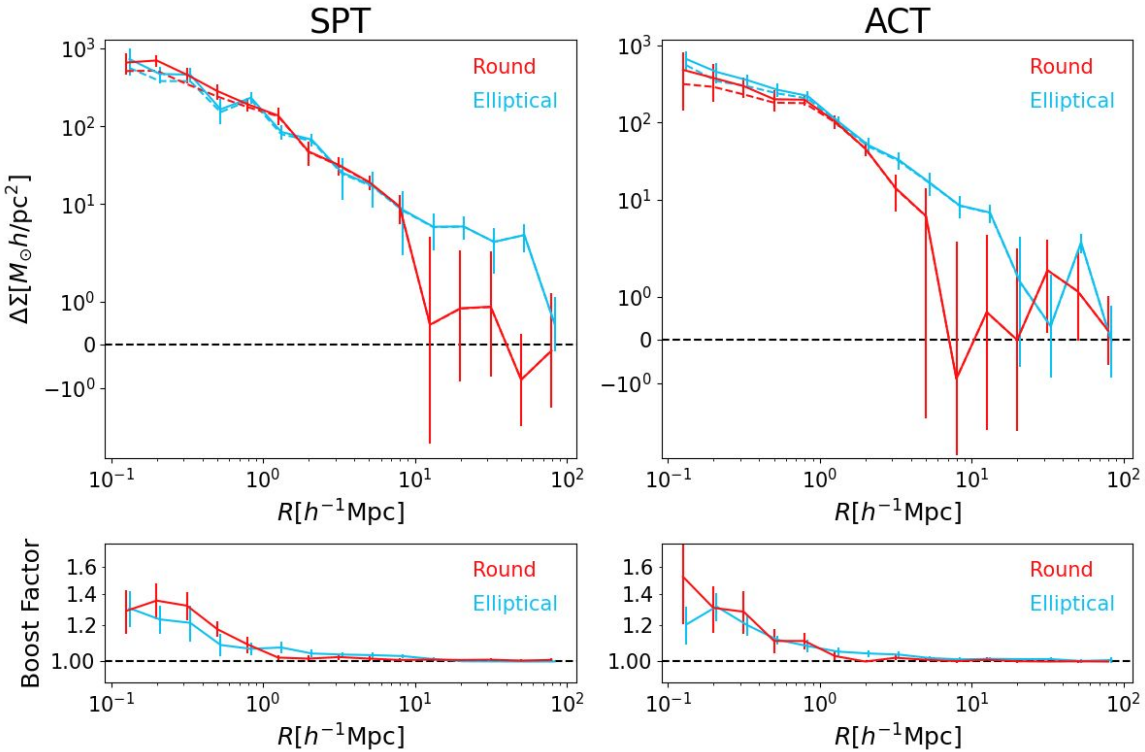

Richness of Round sample > Elliptical sample (10%)

Richness differences: KS 2-sample test and shuffling test measure significance > $3\sigma$

# Results

GALAXY DENSITY PROFILE

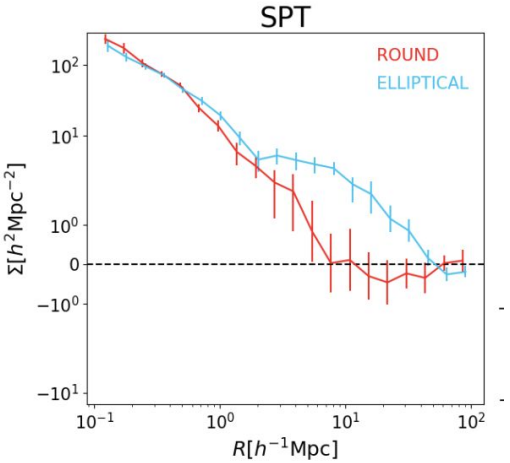


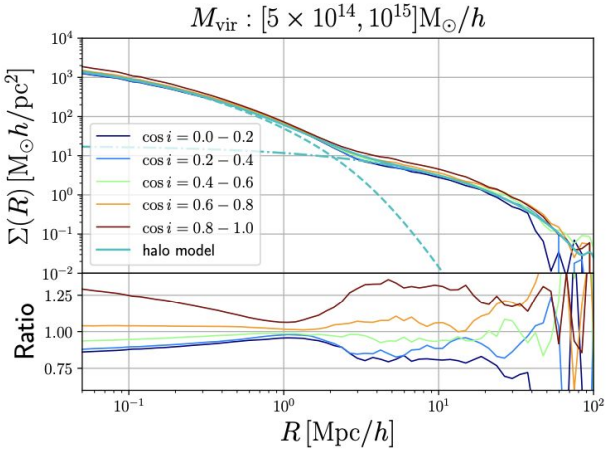




LENSING PROFILE

# Results

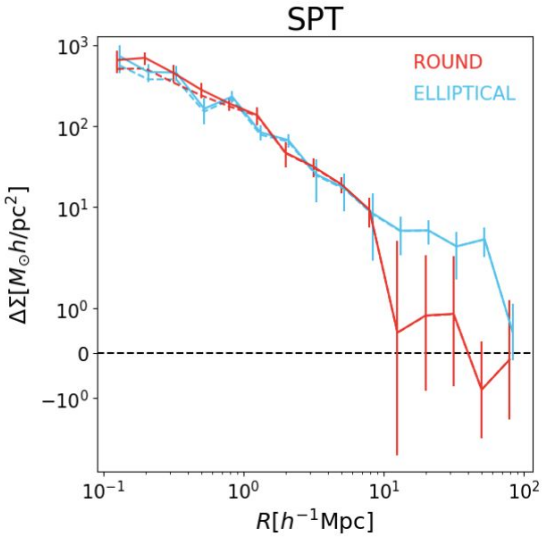
GALAXY DENSITY PROFILE

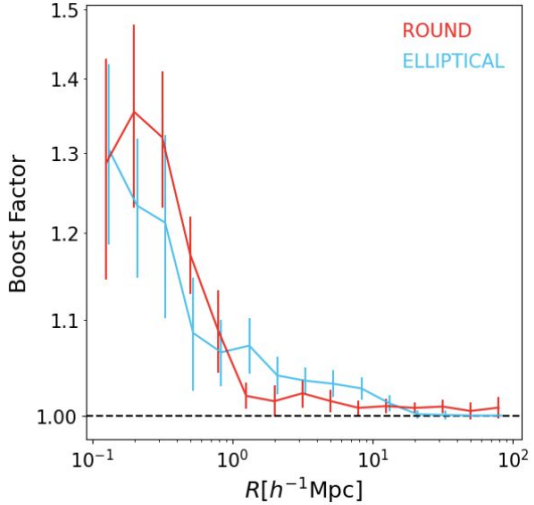



Cluster weak lensing profiles show **2.85 $\sigma$ difference in 2-halo regime** between Round and Elliptical BCG cluster sample.

2-halo regime is different from simulations!

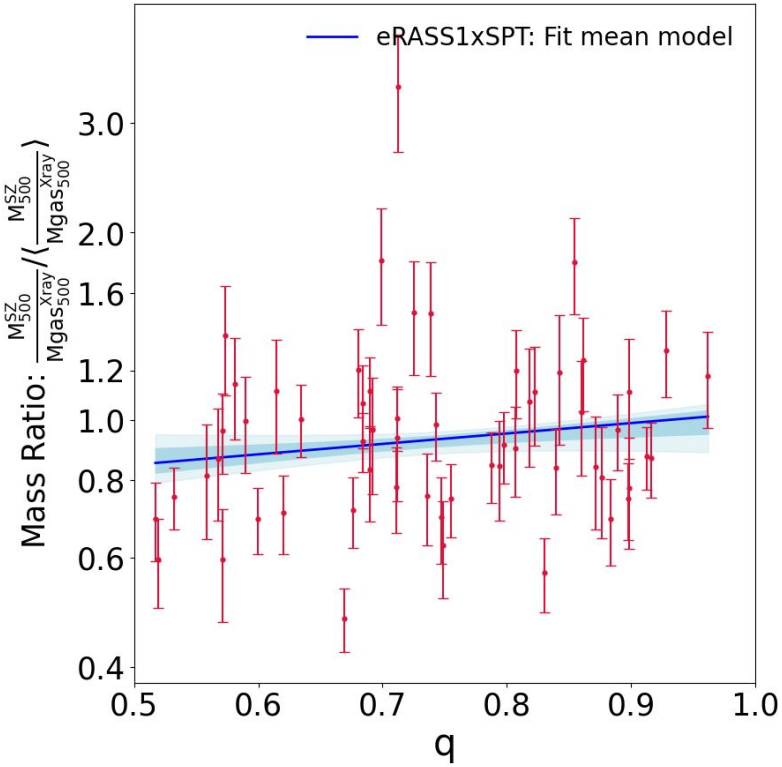



LENSING PROFILE

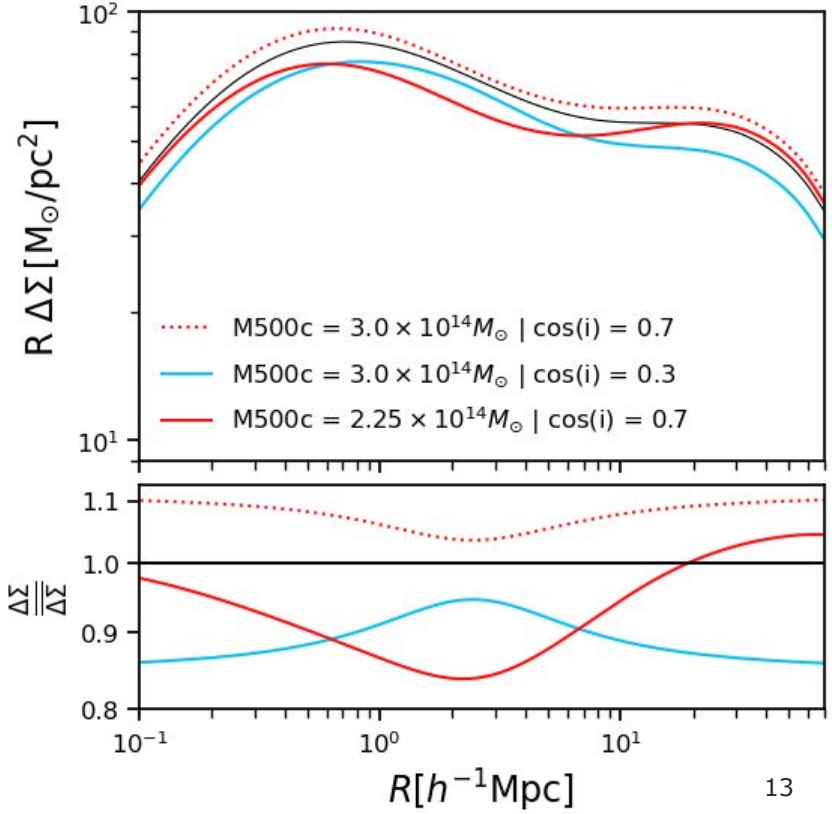
# Discussions

- SZ signal is based on the LOS integral of the electron density.
- Orientation bias could contribute to the intrinsic scatter. If the SZ signal of round-BCG clusters is biased high, the weak lensing signal could be lower.
- But, Small observed effect: the mean SZ to X-ray mass ratio at $q$=0.85 (median of round-BCG sample) is only **10 % higher** than that at $q$=0.6 (median of elliptical-BCG sample)



# Discussions

- Alternatively, the mass ratio of the two samples so that the density profile amplitudes are the same at small scales
- **We find this ratio to be ~ 25%**
- Would explain the richness difference (~ 10%) in this sample is notably smaller than the weak-lensing mass ratio (~ 1.5) (Herbonnet et al. 2019) using WtG X-Ray clusters.
- Halo bias is a strong function of mass, the large-scale bias of the round-BCG is then expected to be lower
- But, not enough to explain the reversal of observed lensing profiles at large scales.



# Discussions

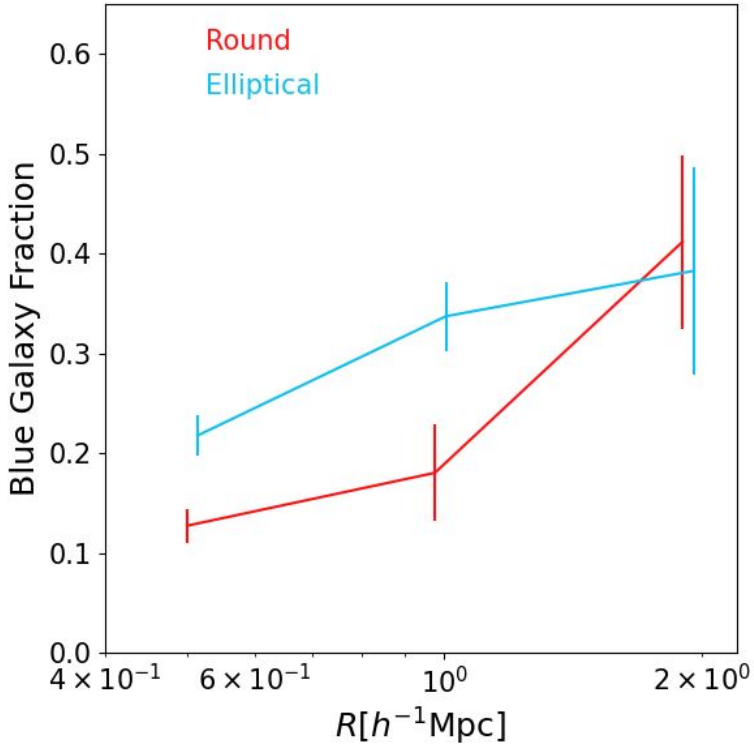
BCG shapes may have correlation with assembly history

- ➔ Intrinsically spherical shape vs Projected Round indistinguishable
- ➔ The large scale bias **b**, is dependent on Mass primarily

Round sample: Intrinsic mass ↓, **b** ↓

- ➔ b is also dependent on concentration (assembly bias) | Higher concentration/Age for lower b.

Round sample: Concentration ↑, **b** ↓



# Implications

- **Round-BCG clusters have higher richnesses and are overrepresented** in optically selected cluster samples, as expected for clusters aligned along the LOS.
- **Round-BCG clusters have low large-scale galaxy bias**, requiring to be careful when utilizing the 2-halo regime for weak-lensing.
- **Selection biases present in SZ selected clusters**. Comparison with X-ray data suggests that the LOS orientation causes variations in the observed SZ signal of the order of 5-10%.
- Other selection biases are at play, such as towards more concentrated, older clusters as part of the Round sample. **BCG shape could be a sensitive tracer of halo assembly history**

# Future

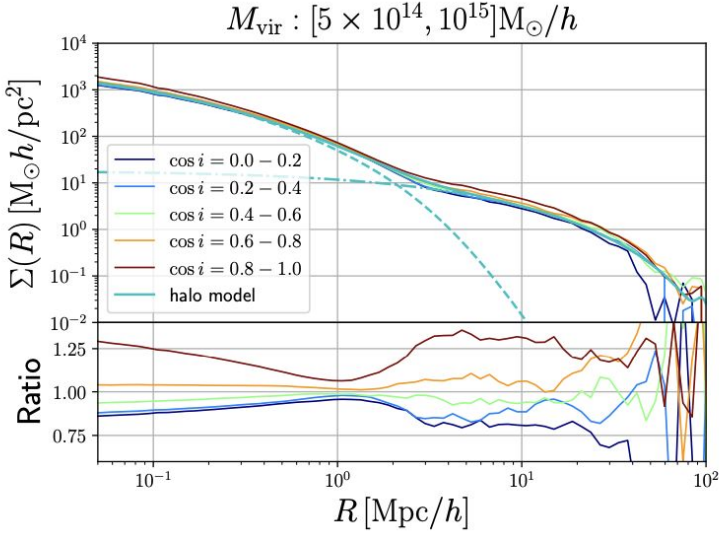
- ➔ Measurements affected by line-of-sight projections (**Spectroscopy** can help with better selection)
- ➔ **A larger cluster sample** will help in tightening the error bars on the lensing profiles ↠ (LSST, Euclid, SPT-3G x DES-Y3 sample)
- ➔ **Hydrodynamic Simulations** (The300 Project): Mimic the BCG shape selection to study effect on assembly bias
- ➔ **X-ray sample selection**: eROSITA cluster sample matched to optical cluster catalogs

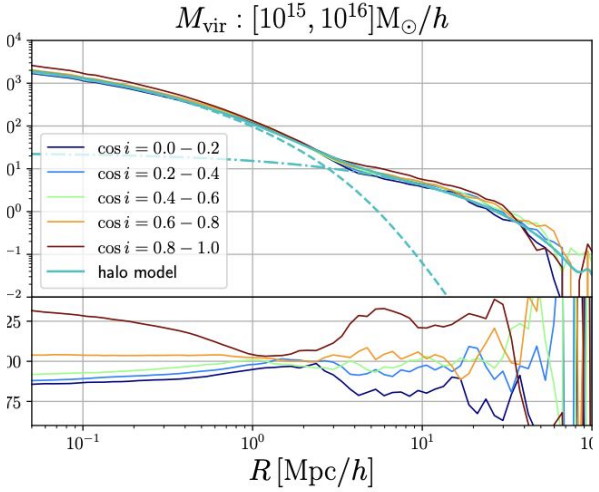
# Appendix

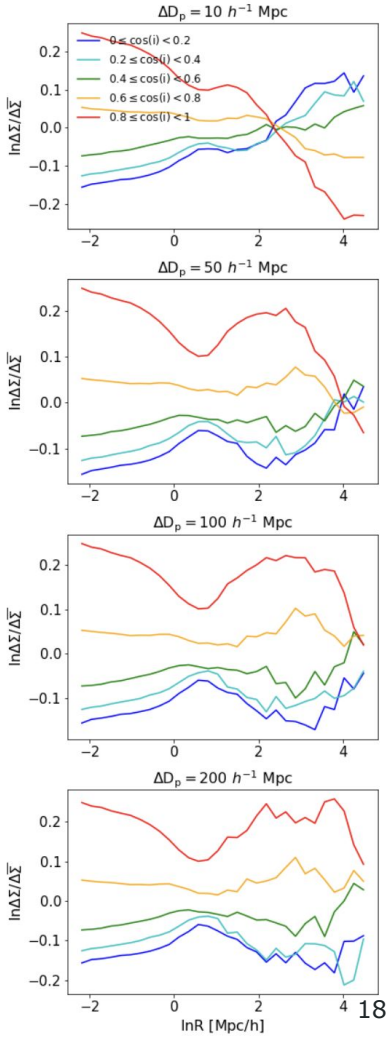
# Projection effects: Orientation Bias

## Correlation between orientation and WL mass profiles

Sources: Osato et al. 2018 (GADGET-2) ; Zhang et al. 2022 (Buzzard simulations for DES)



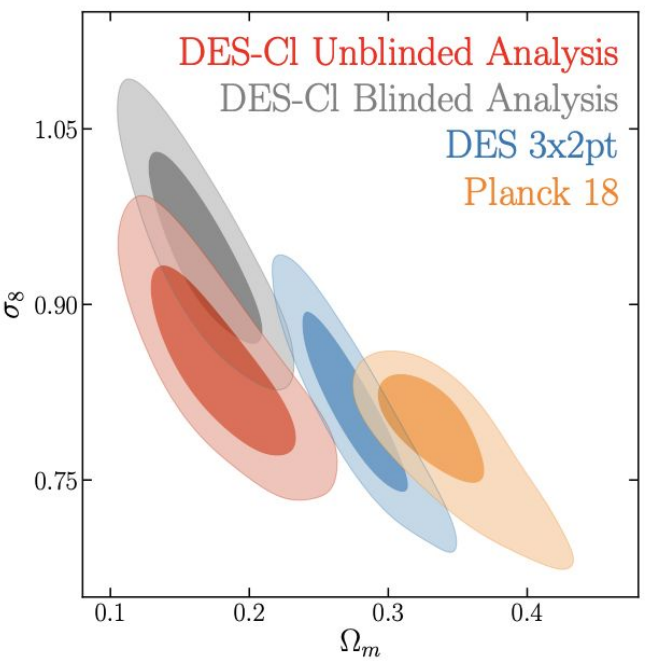



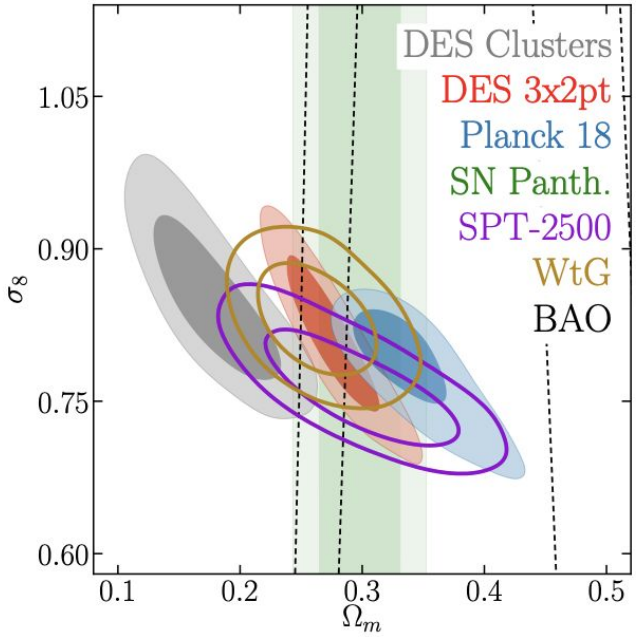



# Background …

We have measured cosmology from clusters many times using SZ, X-ray and optical data. However, **optically-selected cluster** sample disagree with the rest.

5.6 $\sigma$ tension in $S_8$ (DES-Y1 vs Planck)



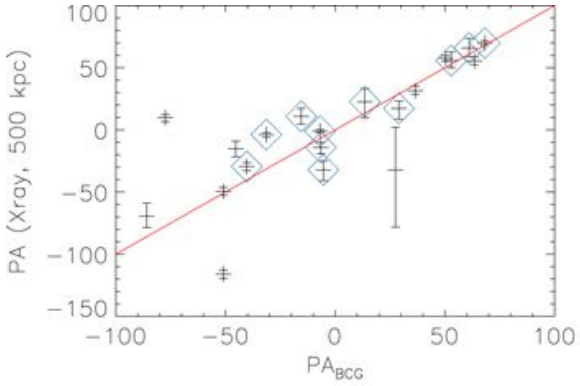

Source: Abbott et al. 2020 (DES Collaboration)

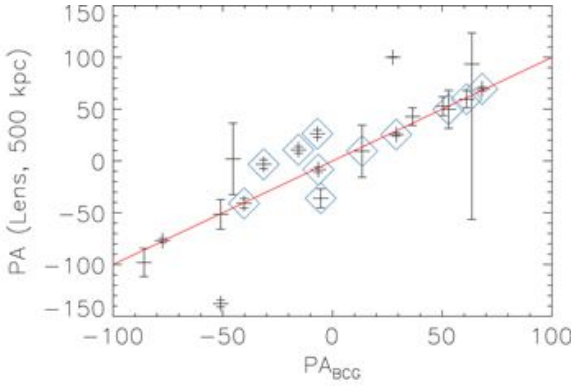
# BCG as orientation proxy in Observations

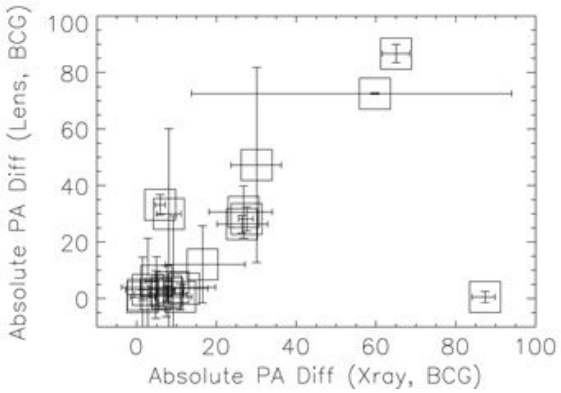
BCG – Halo PA alignment

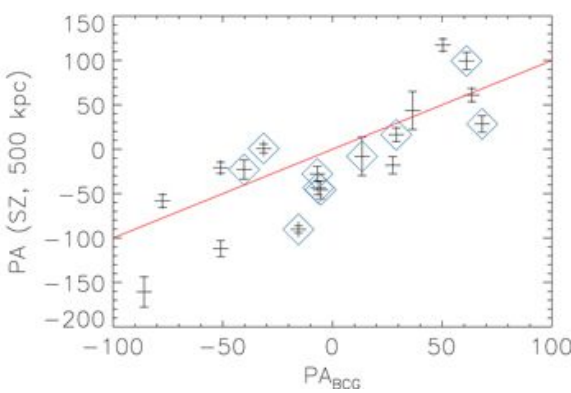
for

25 CLASH Clusters



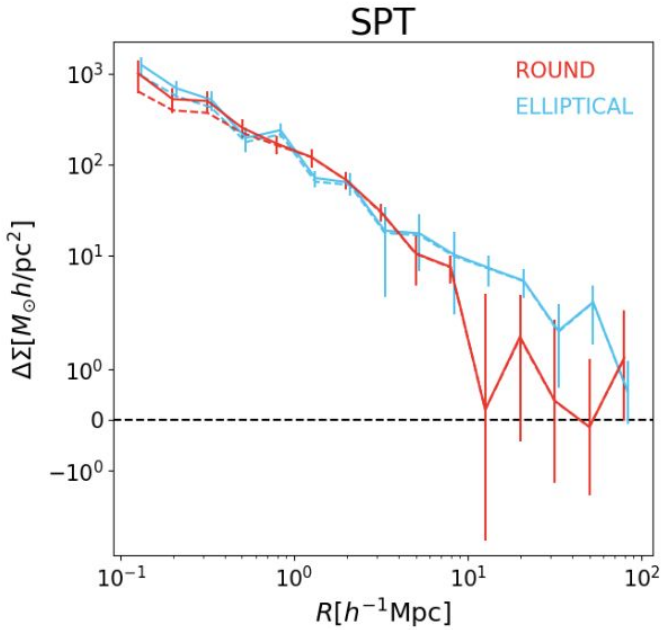




Credits: Donahue et al. 2016

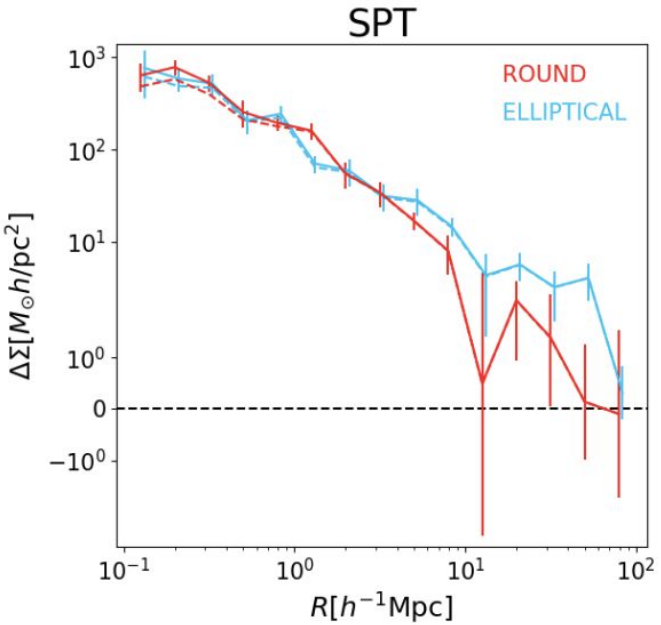
# Robustness Checks

Stony Brook University

Remove - Visual Inspection




Replace with Random Forest Classifier



# Matching SPT SZ clusters in (M,z)

Dividing visually inspected clusters into Round and Elliptical bins (25rd-75th percentile)

and matching in M,z.