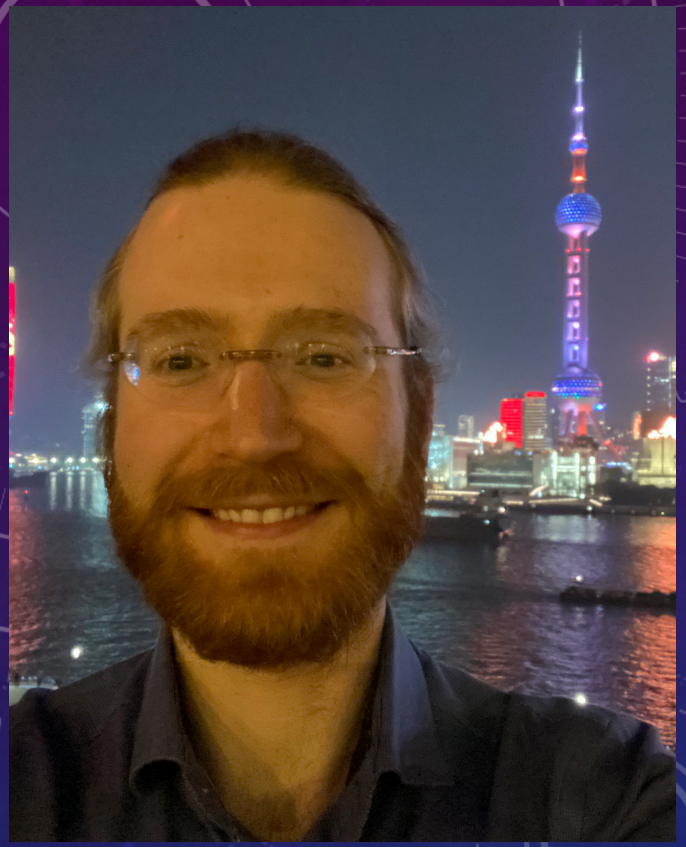


Jesse is on the job market this fall!

Characterizing Intra-cluster Light with optical images and a tSZ cluster sample

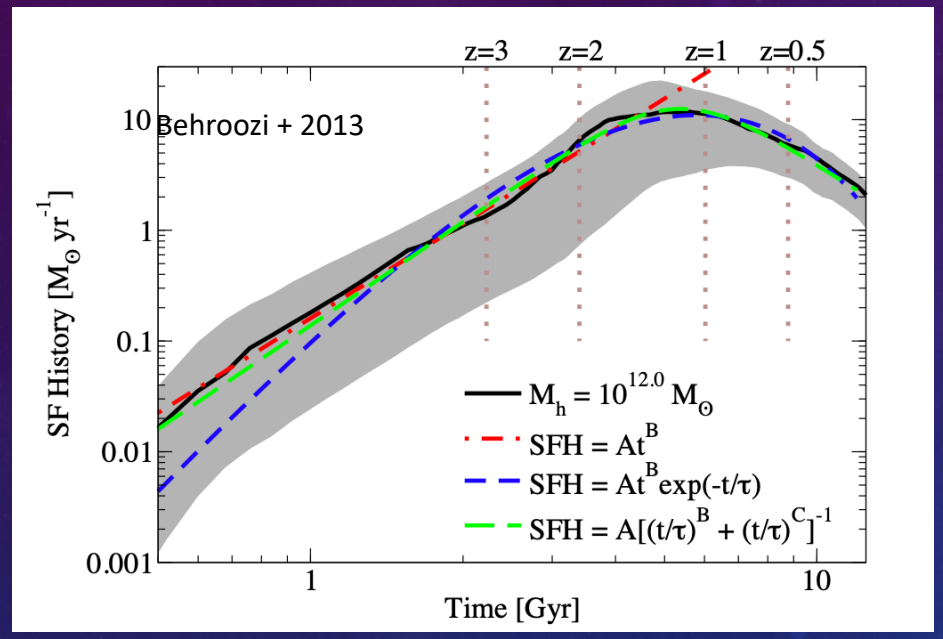
Jesse Golden-Marx (Shanghai Jiao Tong University)

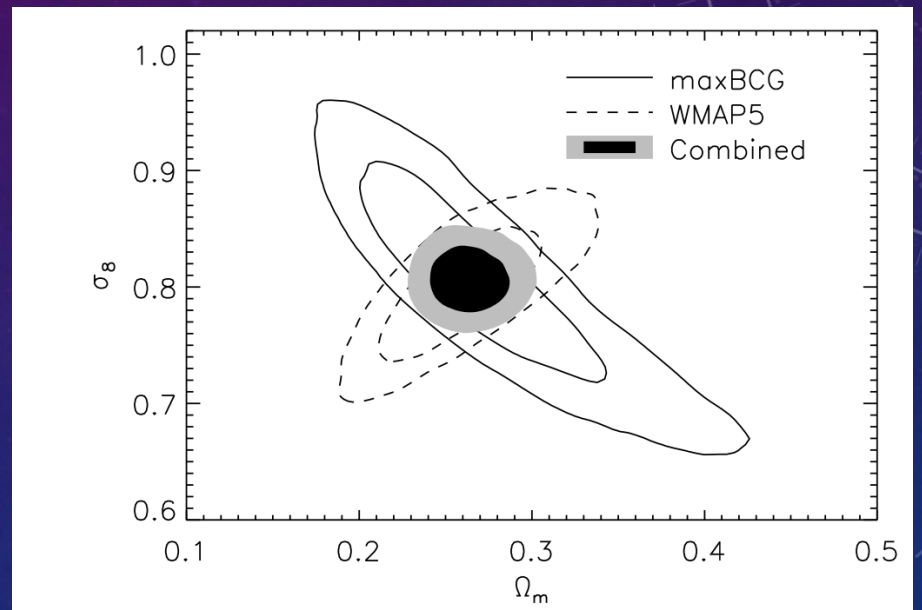
Yuanyuan Zhang, Ricardo Ogando
Rubin 2022 PCW

Paper coming soon (Golden-Marx et al. in prep.)

Science Goals and Questions around Intra-Cluster Light (ICL)

- **How does incorporating the ICL impact the galaxy cluster's Stellar Mass – Halo Mass (SMHM) Relation?**





… "the best thing to do at this point is probably to focus on constructing new richness estimators that better correlate with halo mass" — Rozo+ 2009.

- An important relation for modeling how galaxies occupy halos and the Universal star formation history (Behroozi + 2013, 2018).

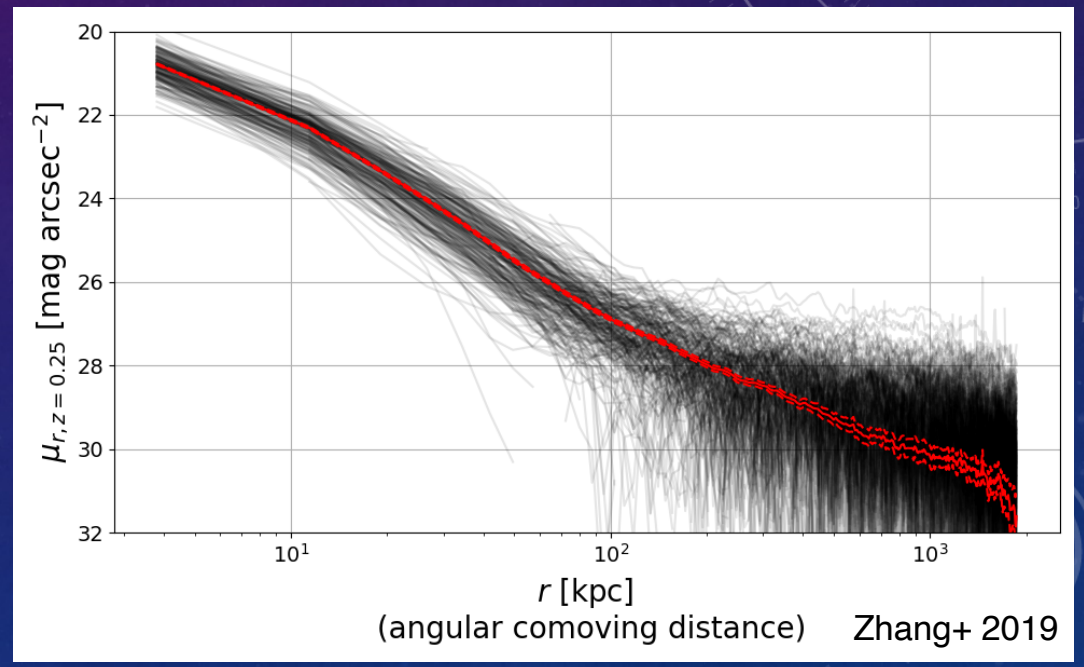
- Helps us infer the galaxy cluster's halo mass, which is important for cosmology (Rozo+ 2009, DES+ 2020).

Science Goals and Questions around Intra-Cluster Light (ICL)

- How does incorporating the ICL impact the galaxy cluster's Stellar Mass – Halo Mass Relation?
- **Does the ICL's stellar content evolve over cosmic time?**
- **How does the color of the ICL vary with radius, cosmic time, and halo mass?**

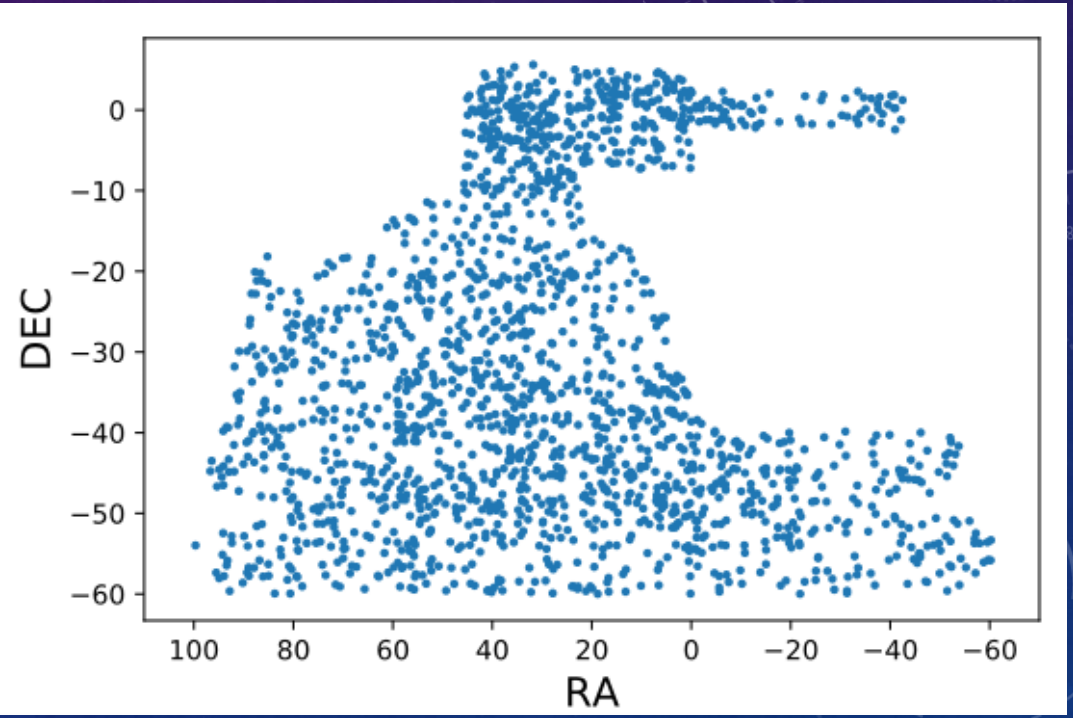
ICL Measurements

- To measure the ICL's light profile in DES data, we use the infrastructure previously developed by Zhang et al. 2019.
  - Use the light profiles to measure different physical apertures for the BCG+ICL system.
  - **Sky background is estimated over the full 3 deg^2 (Bernstein 2017).**
  - Additionally subtract the measurements beyond 500 kpc.
- Define the ICL as the stellar content between 50-300 kpc.
- Estimate BCG+ICL system stellar masses using EzGal (Mancone & Gonzalez 2012)
  - Assume passive evolution, Bruzual & Charlot (2003) SPS Model, Salpeter (1955) IMF, a low metallicity, and a formation redshift of 4.9



The DES-ACT Cluster Sample

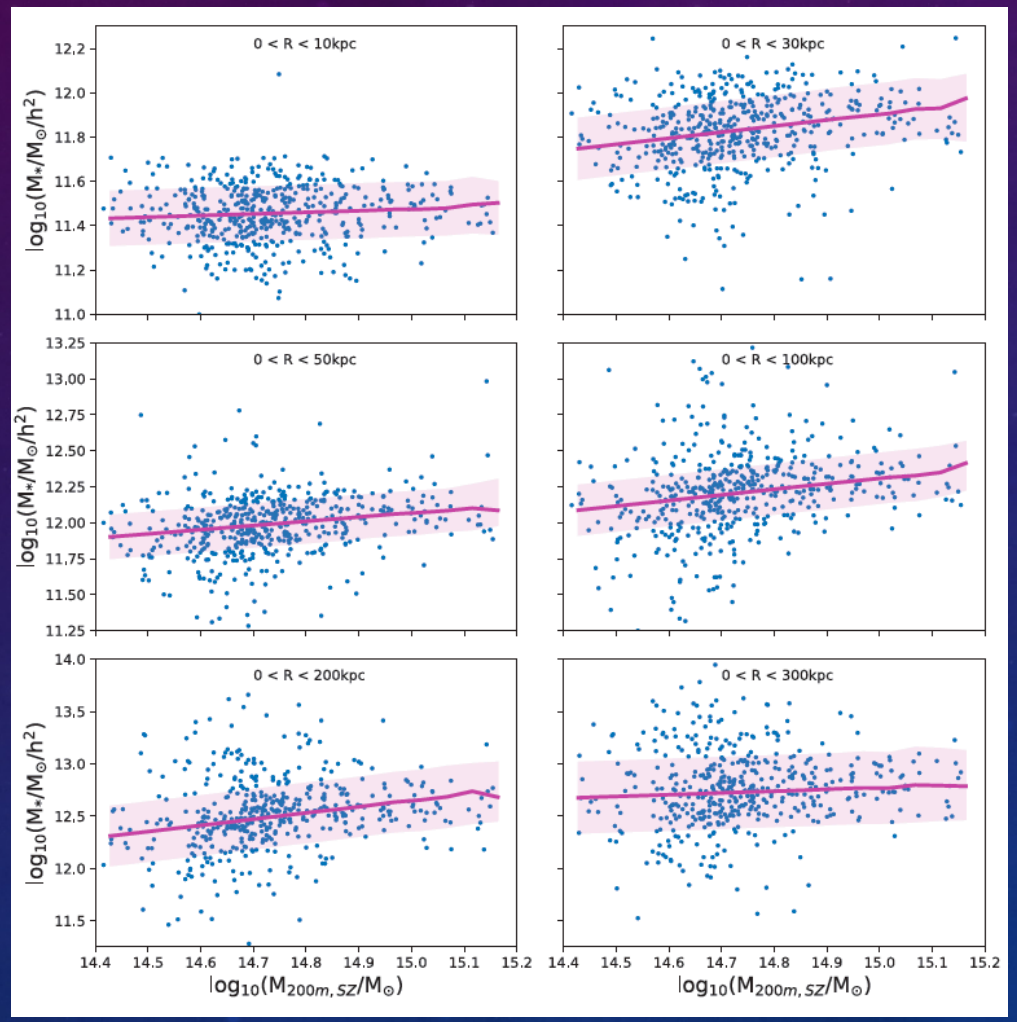
- 4566 deg^2 overlap between DESY3 and ACT (Hilton et al. 2021)
  - 1433 clusters confirmed **out to z = 0.9**.
  - **Halo mass estimated** based on the tSZ effect (Hilton et al. 2021).
- Each cluster has an optically (redMaPPer algorithm) estimated richness, photometric redshift.



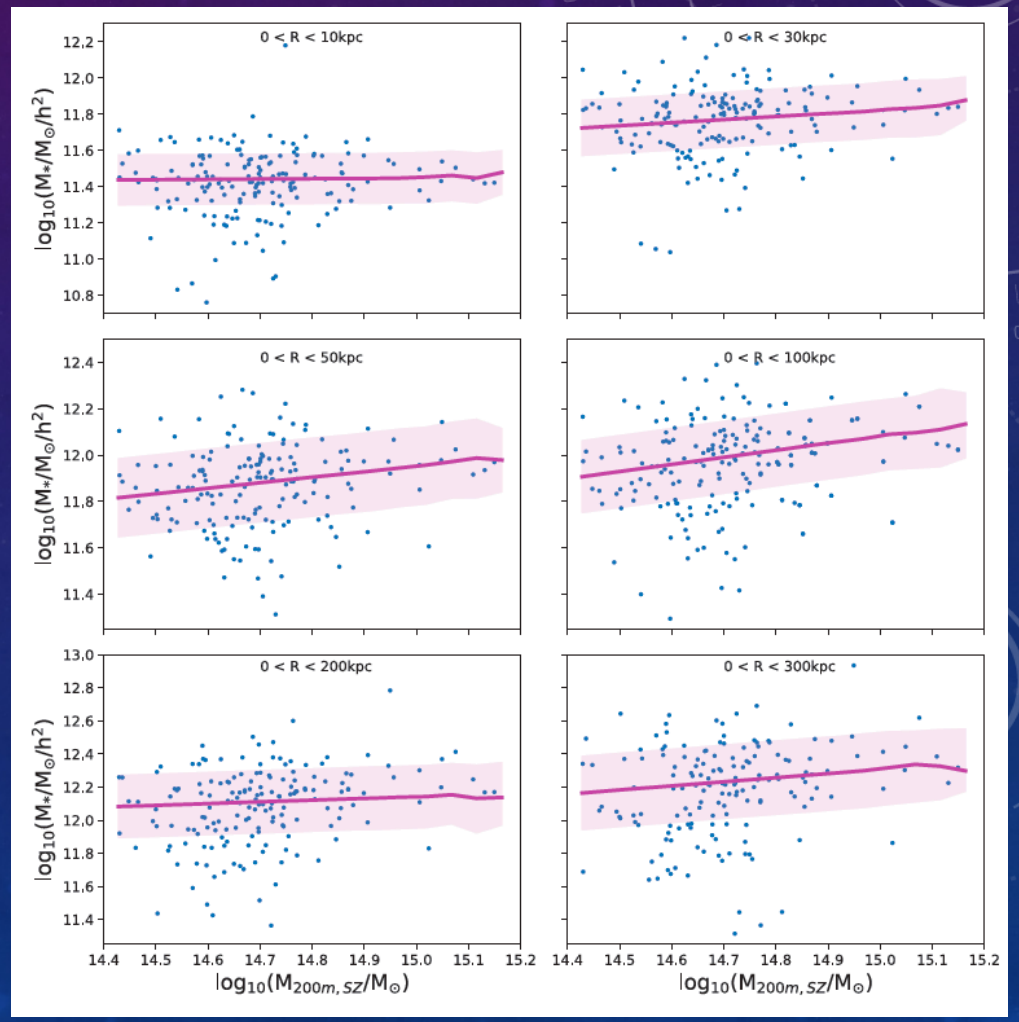
THE ICL in the Stellar Mass-Halo Mass Relation — Slope

- Stellar mass measurements for each distinct radial bin plotted against $M_{200m,SZ}$
- Overlay the results of our MCMC analysis in pink, which we use to measure the parameters of the SMHM relation

Total stellar mass in clusters

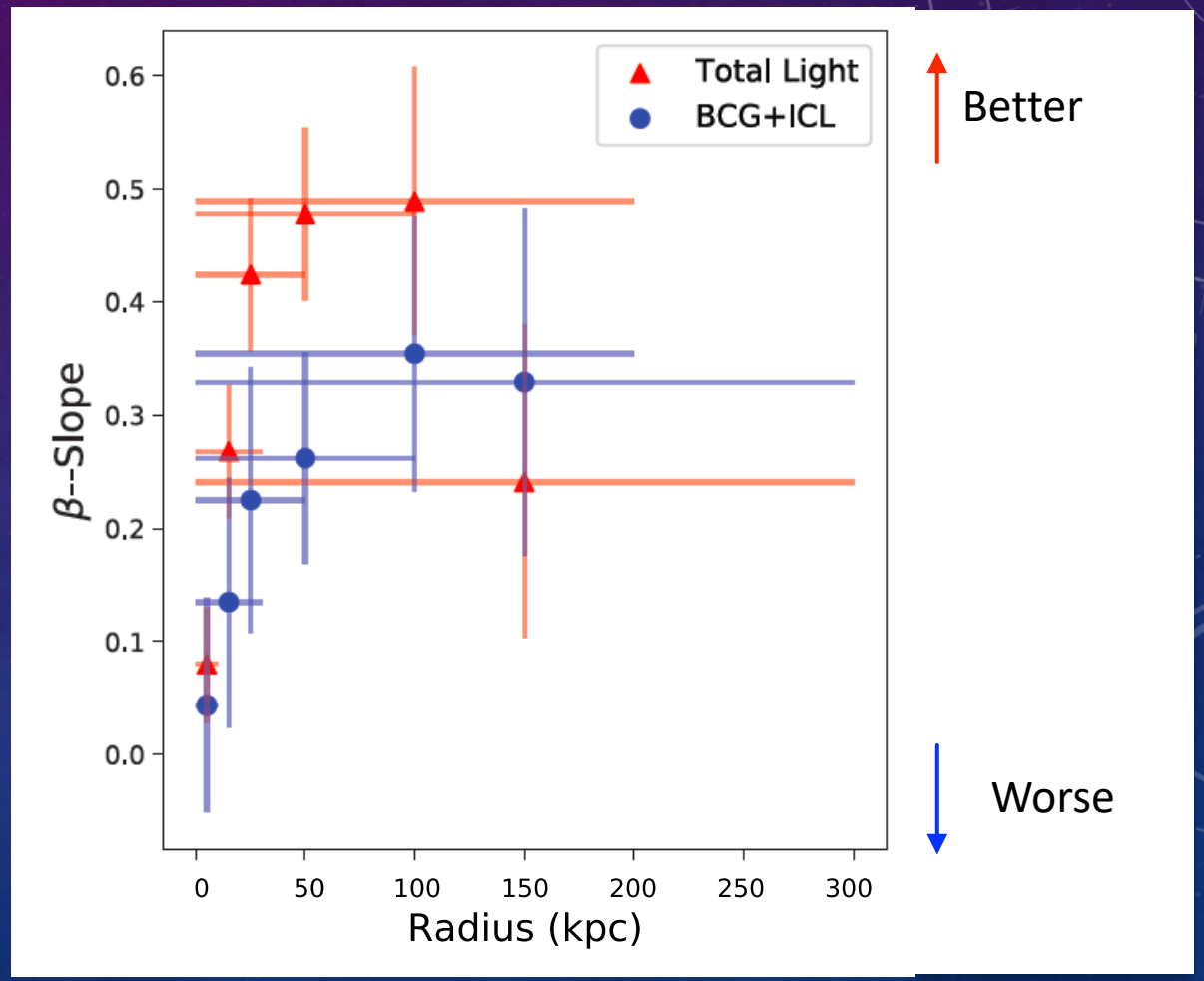


BCG+ICL



The Statistical results of the SMHM relation — Slope

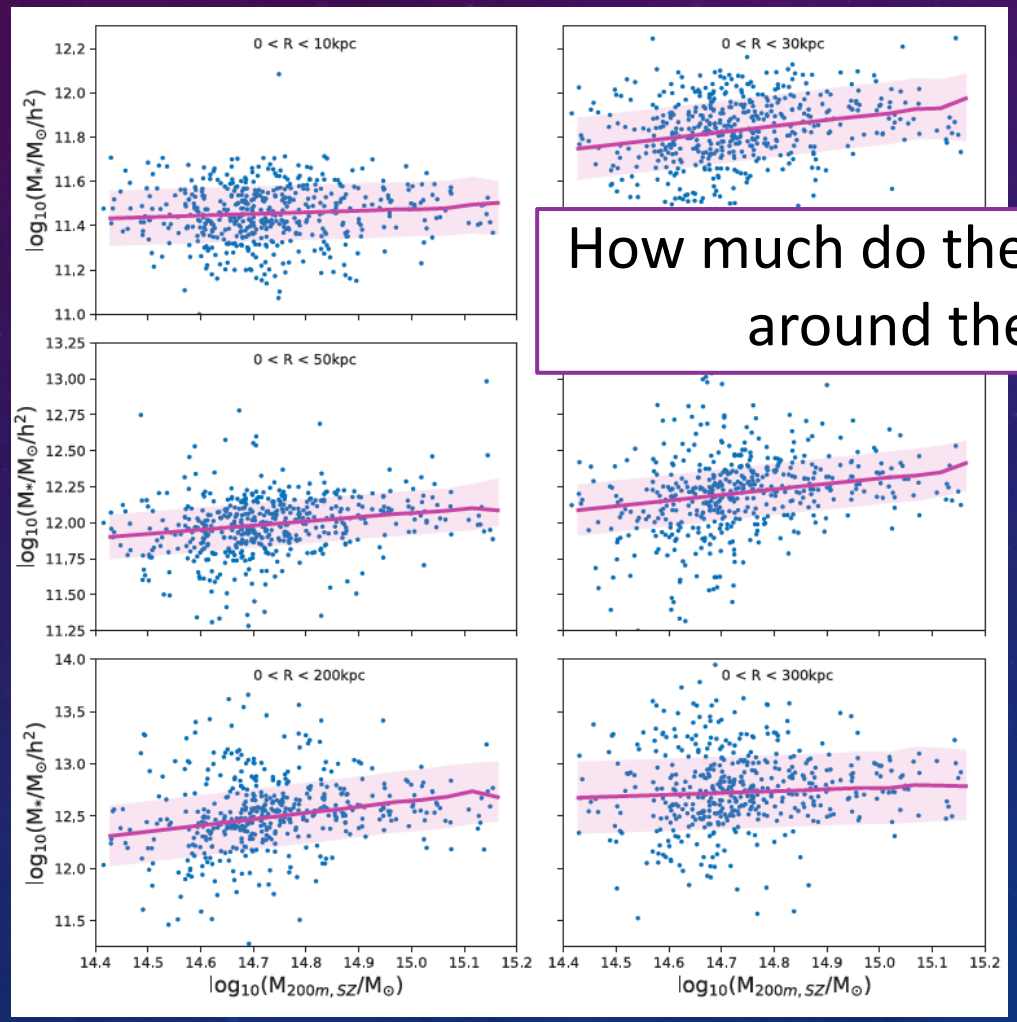
- As we move to larger radii, the slope of the SMHM relation increases.
  - Consistent with the two-phase formation scenario (Oser et al. 2010; van Dokkum et al. 2010). Also see this result in Golden-Marx & Miller (2019).
  - The core of the BCG is relatively uniform and does not correlate well with halo mass.



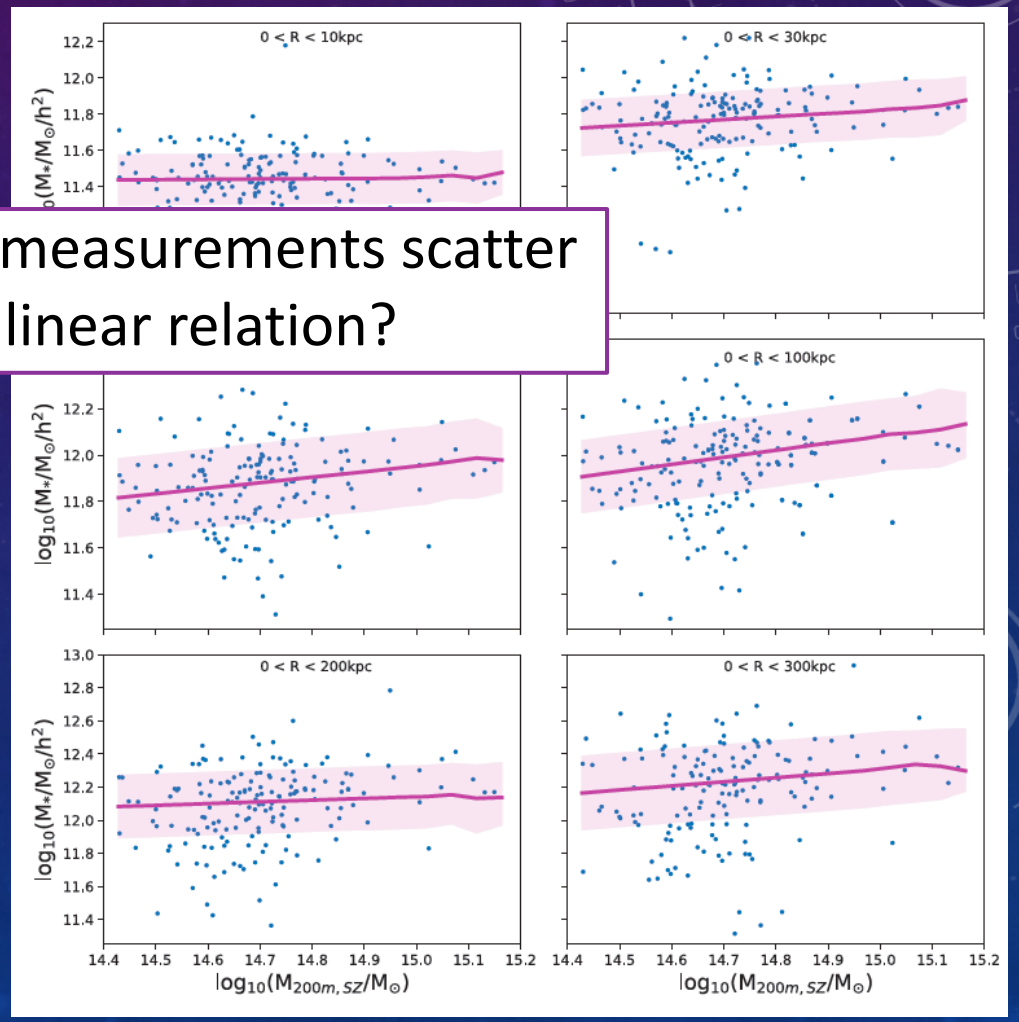
THE ICL in the Stellar Mass-Halo Mass Relation — Scatter

- Stellar mass measurements for each distinct radial bin plotted against $M_{200m,SZ}$
- Overlay the results of our MCMC analysis in pink, which we use to measure the parameters of the SMHM relation

Total stellar mass in clusters



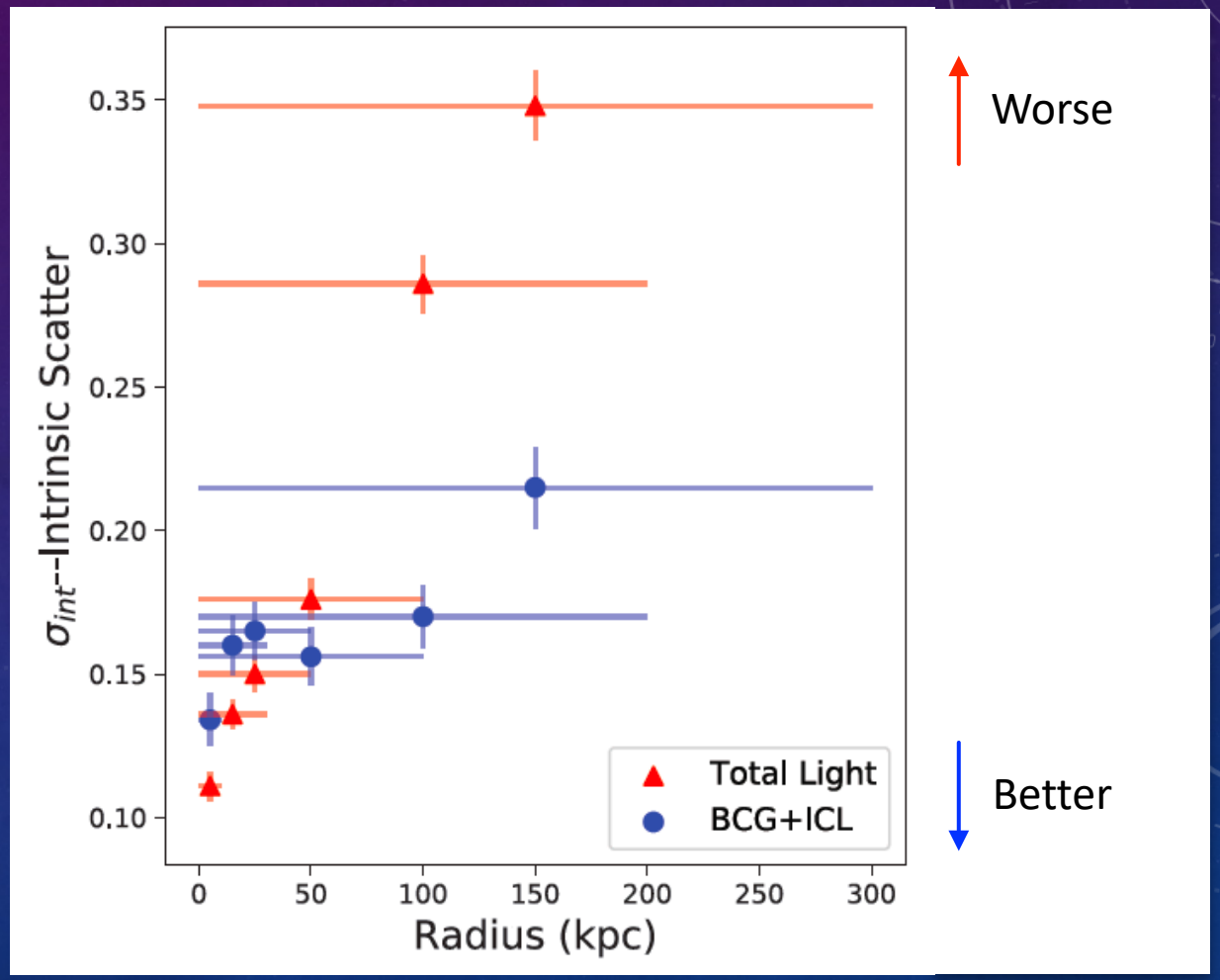
BCG+ICL



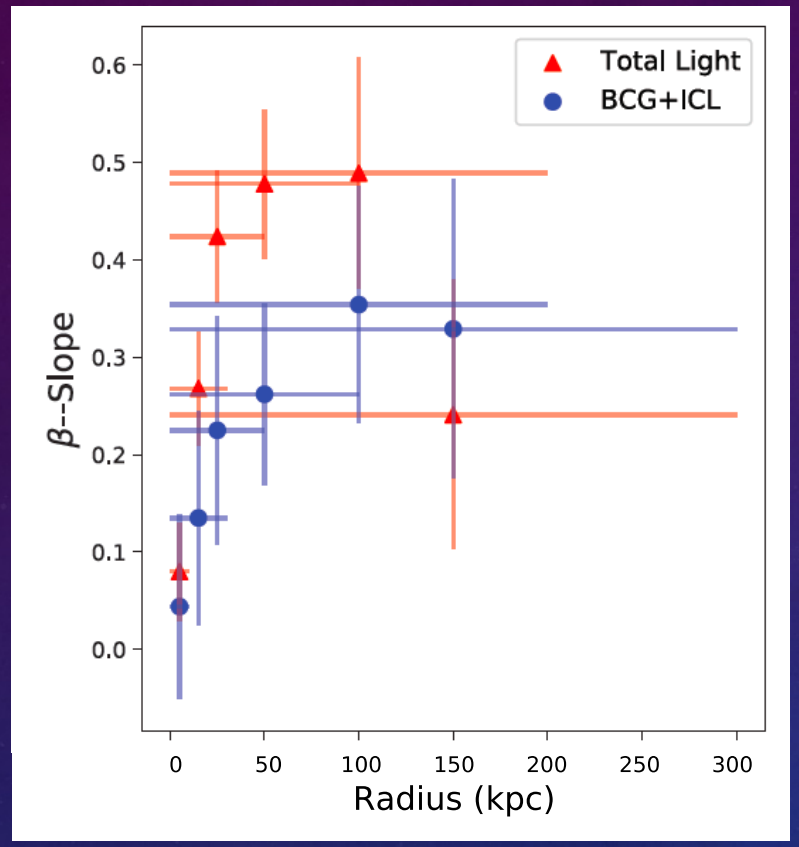
How much do the measurements scatter around the linear relation?

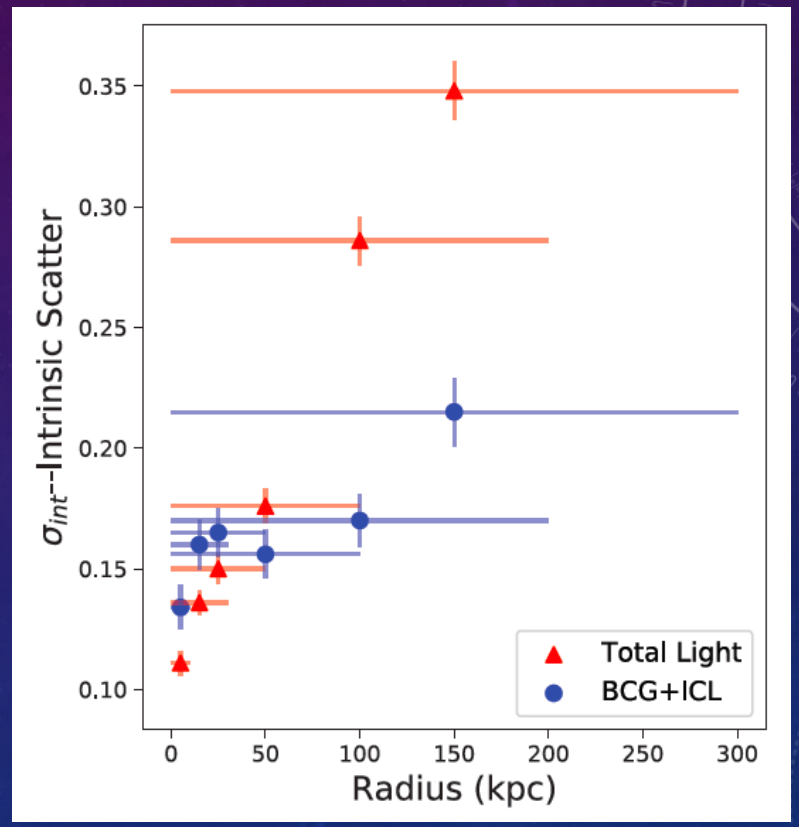
The Statistical results of the SMHM relation — Slope

- As we expand to larger radii, the intrinsic scatter increases.
  - Possibly a result of differences in the growth history of the BCG+ICL system, and increasing measurement noise.
  - BCG and ICL has lower intrinsic scatter because it excludes foreground/background light.



The Statistical results of the SMHM relation

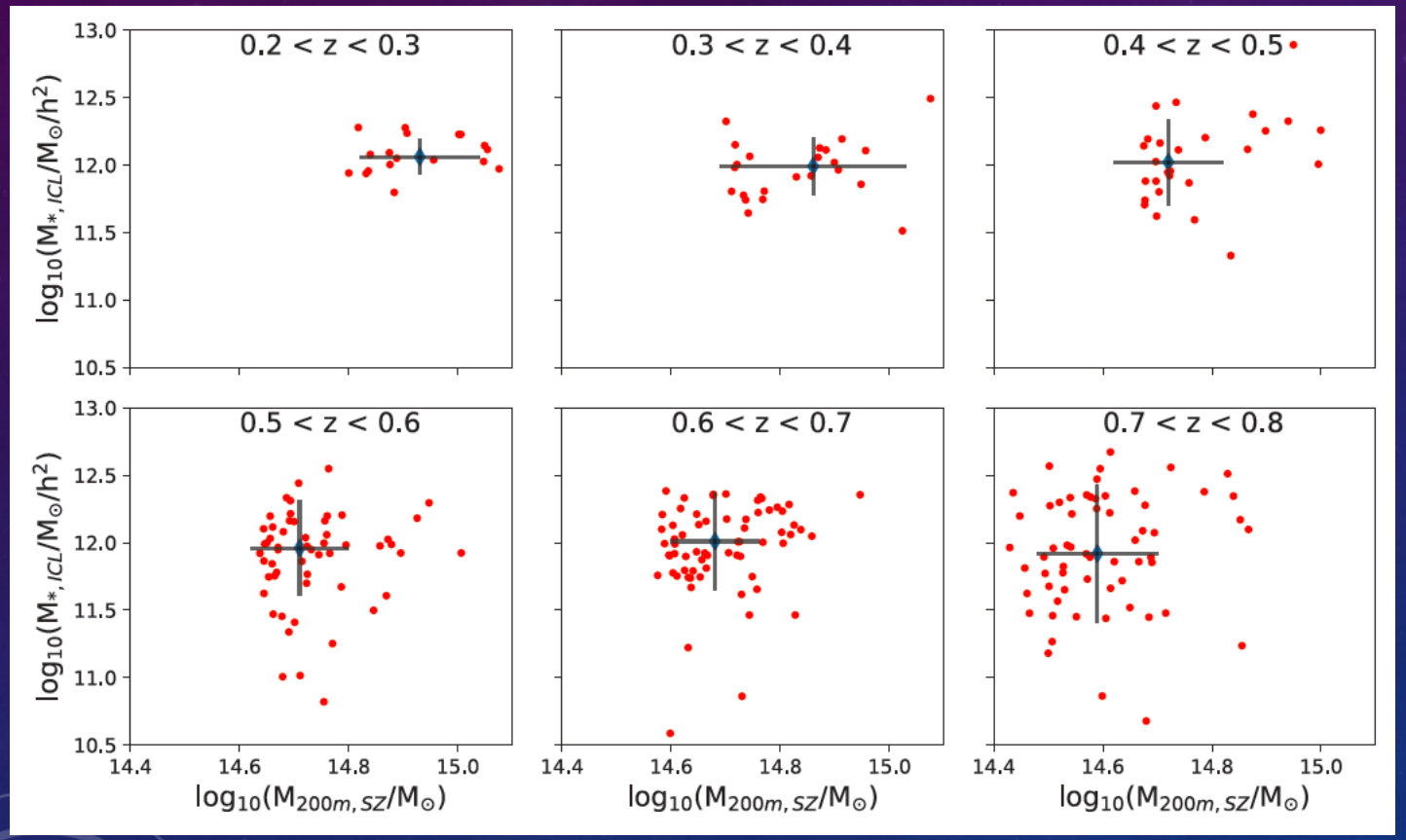




- Need steeper slope?
  - Total cluster stellar mass is better.
  - Large radius is better.

- Need Lower scatter?
  - BCG+ICL is better.
  - Lower radius is better.

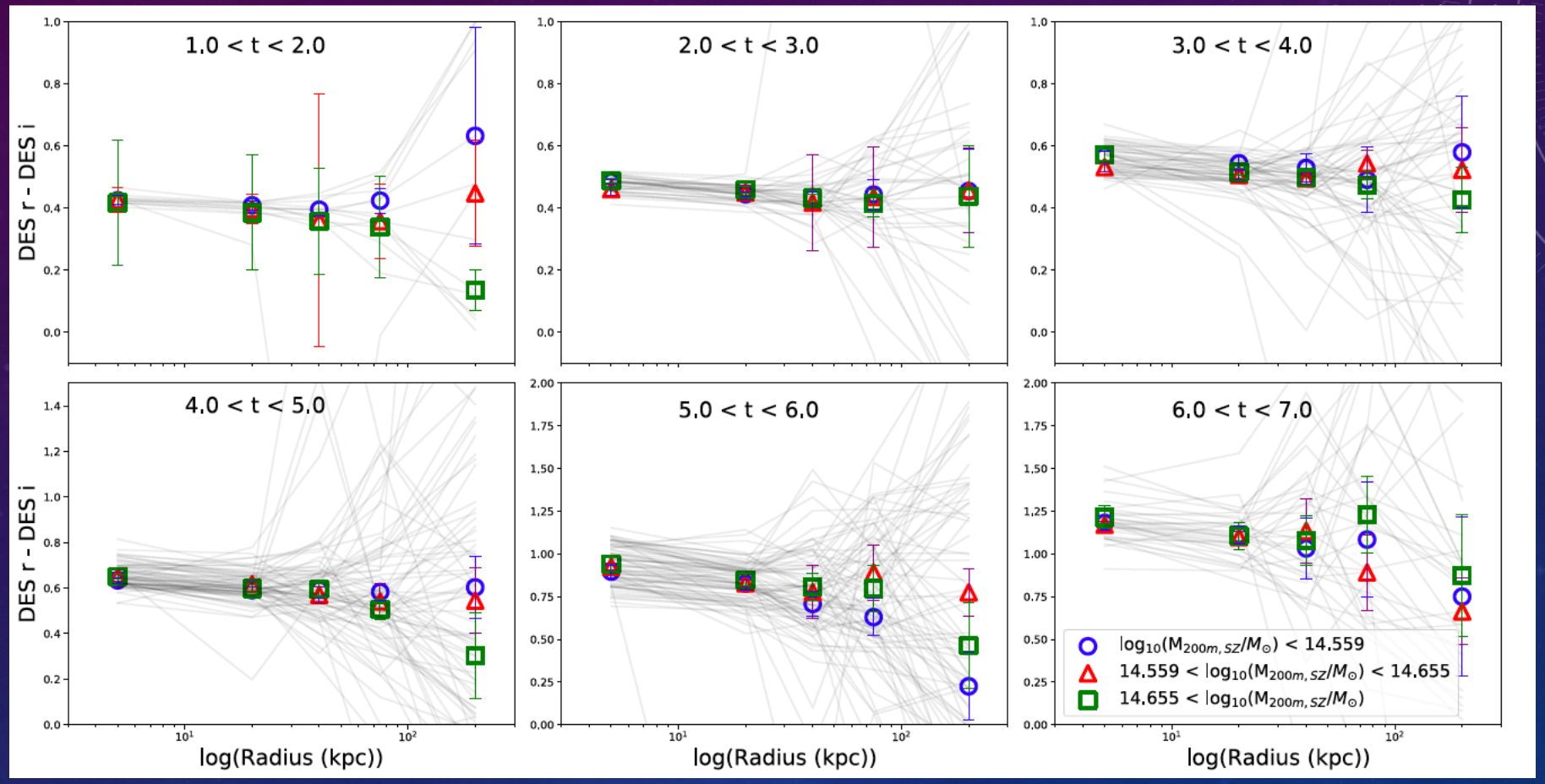
Does the ICL evolve over cosmic time?



- **We are currently unable to detect any redshift evolution in the stellar mass of the ICL across cosmic time.**
  - Using our density-constant sample, we show the ICL stellar mass and halo mass distribution for $0.2 < z < 0.8$.
  - The average stellar mass of the ICL remains constant.
  - The average halo mass increases as we move to lower redshifts (as a result of our density-constant sample).

The Color of the ICL

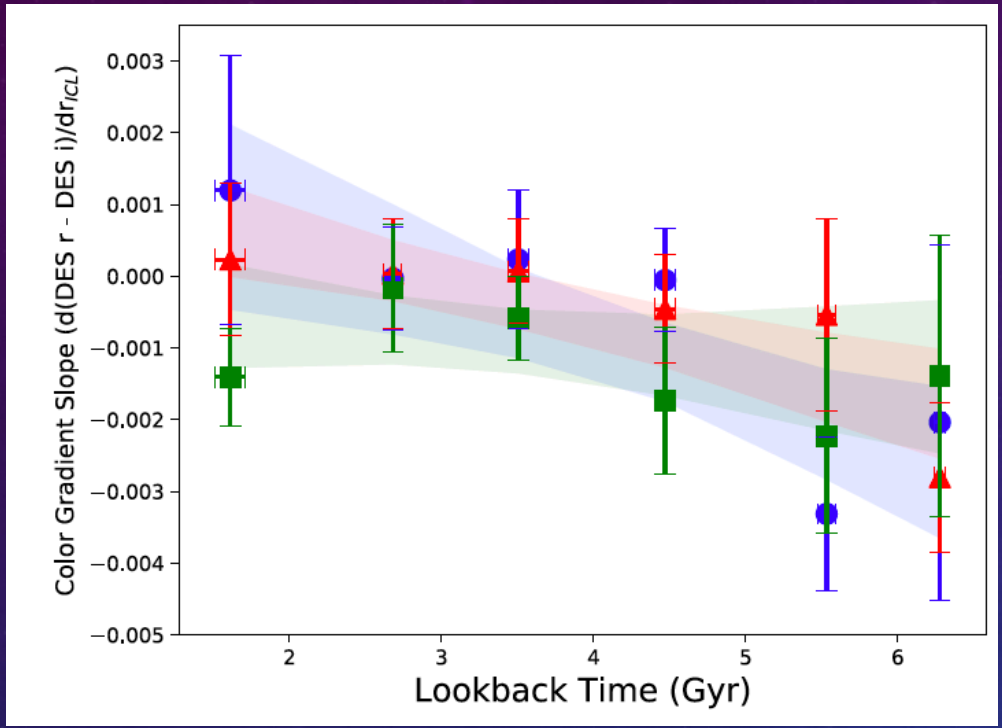
The r-i color vs radius for the DES-ACT clusters

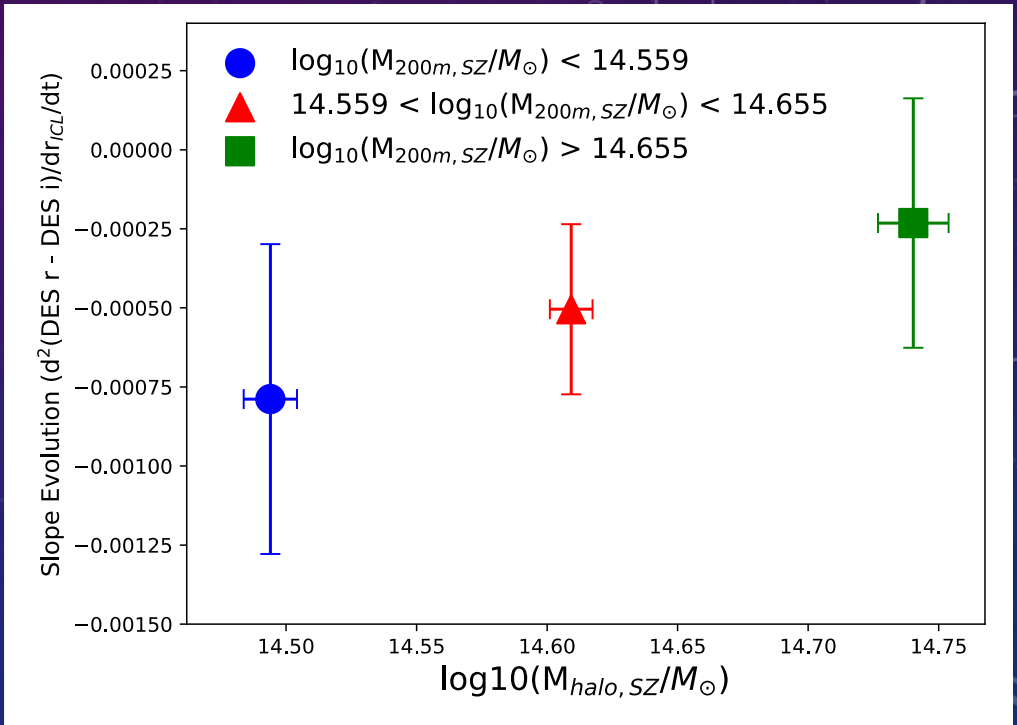


A moderate color gradient across the ICL, such that the outskirts are bluer.

- It follows from the two-phase formation of ICL (e.g., DeMaiao et al. 2015, 2018; Huang et al. 2018; Morishita et al. 2018; Chen et al. 2022), indicating stripping of metal poor satellites (Montes & Trujillo 2019; Contini et al. 2019) as an origin.

Does the Color Evolve with redshift and mass?





- The median color gradient is non-zero and generally negative
  - Possible with both mergers (which yield no gradient) and stripping (which yield a gradient occur) as origins.
- For more massive clusters, we see a more negative radial gradient. For the lowest mass bin, we see a larger change in the color gradient's slope with redshift.

Conclusions

- **How does incorporating the ICL impact the Stellar Mass – Halo Mass Relation?**
  - The slope of the SMHM relation continues to increase out to radii of ~ 100kpc.
  - See a stronger correlation in the outskirts than just the core in agreement with Huang et al. (2022).
  - Supports that the ICL also forms via the two-phase formation scenario such that the stellar content contained in the outskirts, which is related to the recent merger or stripping growth, is more directly tied to the growth of the underlying host halo.
- **Does the ICL's stellar mass evolve over cosmic time?**
  - We are unable to detect such evolution in our sample.
- **How does the Color of the ICL vary with cosmic time and halo mass?**
  - Detect a color gradient such that the ICL's outskirts are bluer, in agreement with DeMaio et al. (2015; 2018) and Morishita et al. (2018) and others.

Additional lessons We learned

- Intra-cluster light has increasing connection to how we can improve both the astrophysical and cosmological studies of galaxy clusters.
  - This study is based on DES data. We may see a stronger connection for LSST.
- Synergies between multi-wavelength and optical surveys are helpful, as usual.