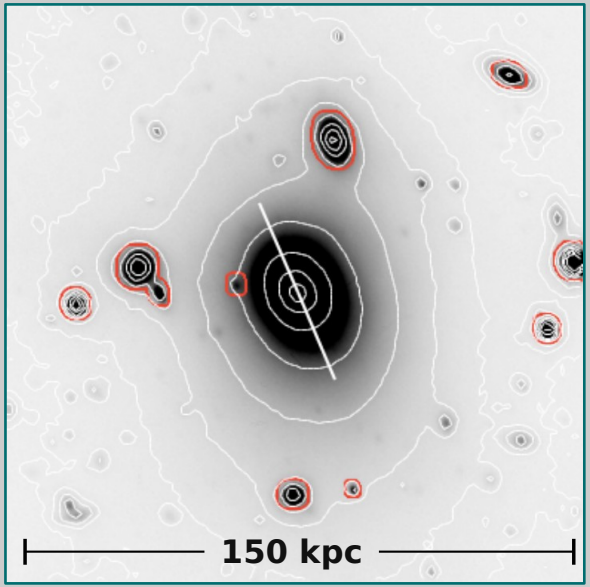
Evolution of the BCG-Cluster Alignment in Cosmological Hydro-Simulations



Wittman et al. (2019)

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and collaborators in Trieste

Astro@Ts 2019

Motivations

- Evidences of BCG-Cluster Alignment **in the Local Universe**

  e.g. Niederste-Ostholt et al. (2010):
  - 10.000 Sloan clusters and 1st, 2nd and 3th brightest galaxies
  - BCGs uniquely undergo some alignment process
  - More dominant BCGs exhibit stronger alignments

  e.g. Donahue et al. (2016):
  - BCG-cluster alignment is preserved if cluster shapes are measured with X-ray and/or gravitational lensing

- Mechanism driving the alignment is not clear
  - Anisotropic infall along filaments
  - Primordial alignment with the distribution of surrounding matter
  - Gradual gravitational torques

  (West 1994; Catelan & Theuns 1996; Libeskind et al. 2013; Wittman, Foote & Golovich 2019)

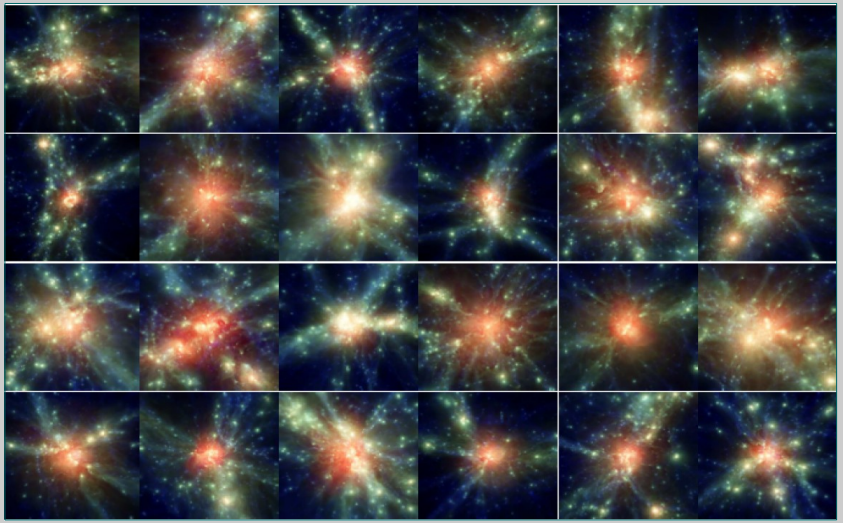
- **Very little observational indications of alignment at z~1** (West et al. 2017)

The Simulated Clusters

24 most massive clusters

$M_{200} > 1x10^{15}\ h^{-1}M_{\odot}$ at z=0

Identified in a parent gravity only sim
box: 1 Gpc h^{-1}
Re-simulations at much higher resolution in boxes of about 60 Mpc, including hydro and typical sub-resolution baryonic physics.



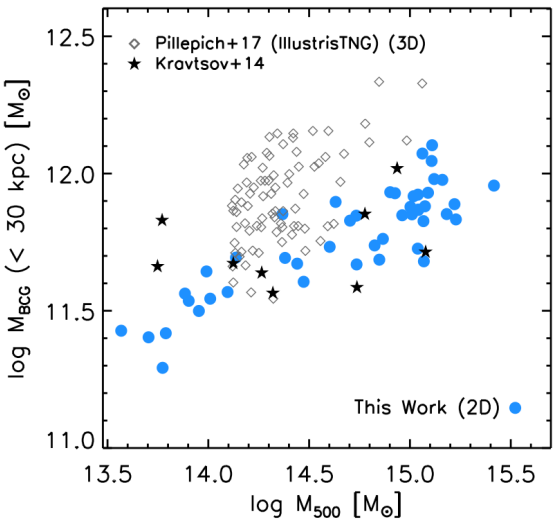
Cooling, star formation, stellar feedback (energetic and chemical), SMBH growth, AGN feedback

Mass Resolutions:

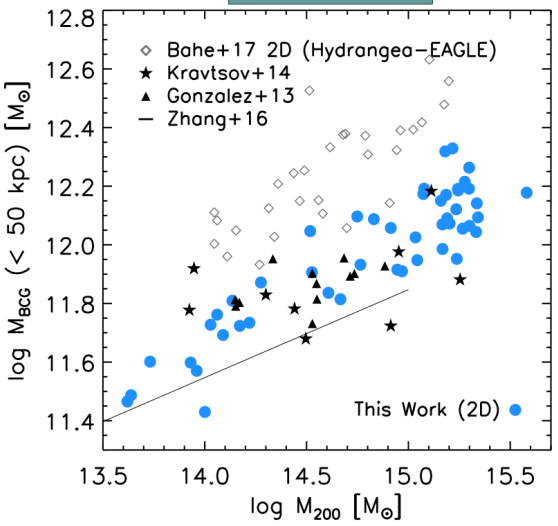
dm: $8.4 \times 10^{8}\ h^{-1}\ M_{\odot}$ gas: $1.6 \times 10^{8}\ h^{-1}\ M_{\odot}$ star: $4.5 \times 10^{7}\ h^{-1}\ M_{\odot}$

Evolution of ASSEMBLED and CREATED BCG masses:

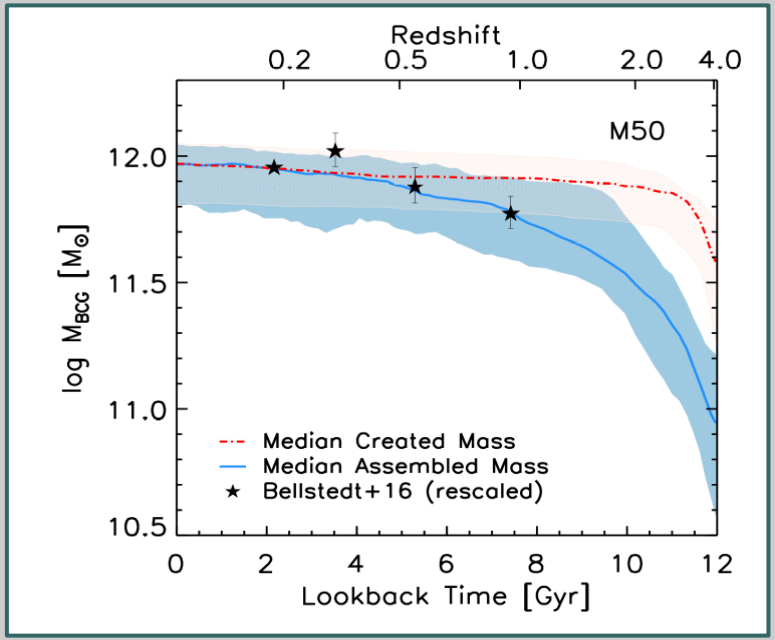
M30



M50



Ragone-Figueroa et al. (2018)

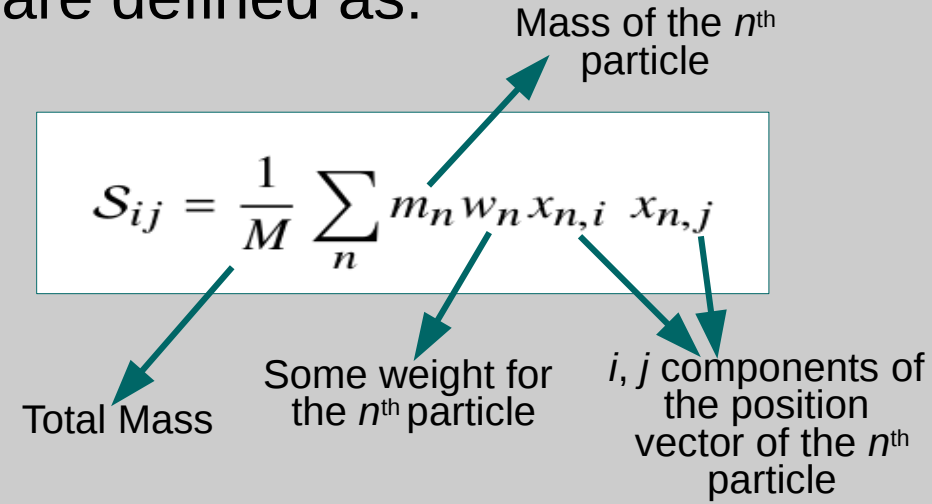


- Nice agreement with the data (selected to mimic cluster evolutionary sequence)
- Stall at z<~ 0.5 as in Lin et al. (2013); Oliva-Altamirano et al. (2014)

3D

BCG and Cluster Principal Axes

For a discrete set of ***n*** particles the elements of the shape tensor are defined as:



BCGs
stellar particles
Inside 10% R_{500}

Clusters
(1) DM particles
(2) Galaxies
inside R_{200}

eigen-values and eigen-vectors are related to the elongation and position angles of the ellipsoid that best describes the spatial distribution of particles.

Time evolution of DM Halo Shape

- **Gravity only** (c/a) ~ 0.4–0.6 (Ragone-Figueroa & Plionis 2007; Macciò, Dutton & van den Bosch 2008; Muñoz-Cuartas et al. 2011; Bryan et al. 2013).
- **Hydro-sims with feedback:**
  ➔ More spherical DM haloes for less efficient feedback (Bryan et al. 2013)

  ➔ Henson et al. (2017) BAHAMAS and MACSIS:
  - z=0 clusters have larger c/a (~0.55) than z=1 clusters (~0.50)
  - Non Iterative method
  - Two samples of clusters, not necessarily progenitors

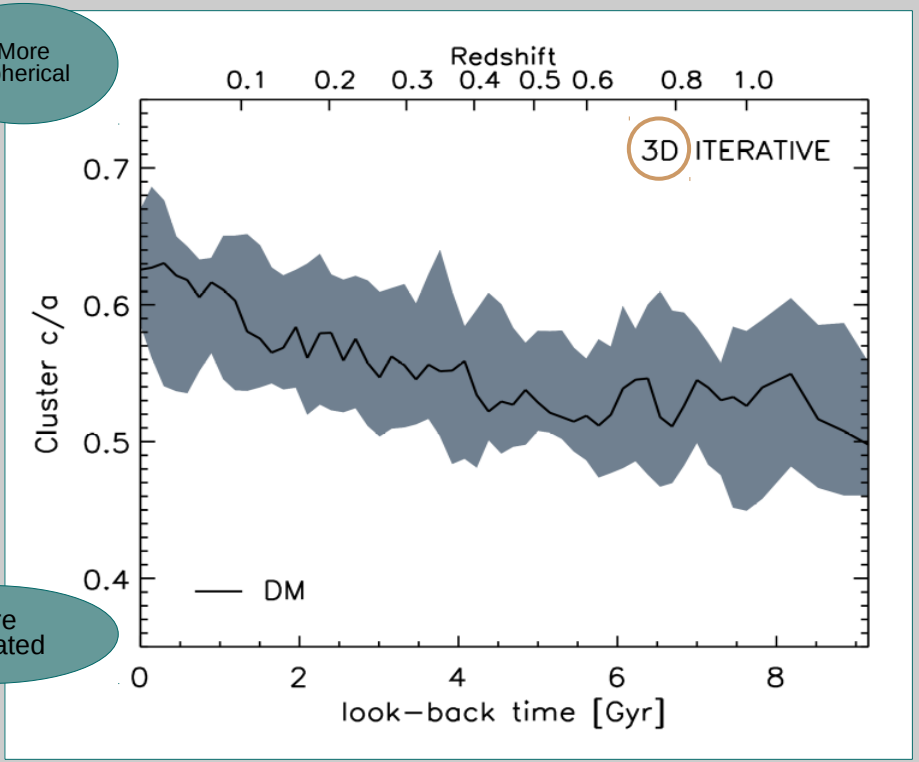
Shape Tensor:

$$\mathcal{S}_{ij} = \frac{1}{M} \sum_n m_n w_n x_{n,i} \; x_{n,j}$$

Zemp et al. (2011):
- Iterative computation in an ellipsoidal volume
- No $1/r^2$ weights
- Remove substructures

More spherical

More elongated



In our AGN Hydro-Sim
DM haloes are more spherical at lower z

Time evolution of Cluster Shape

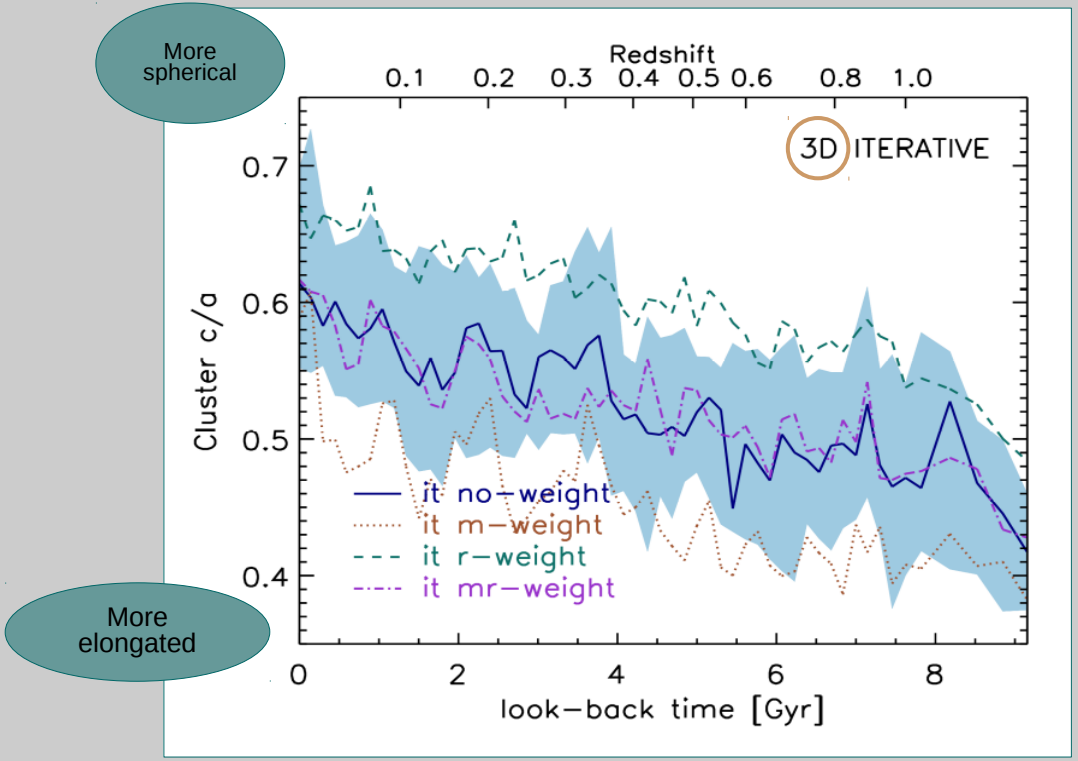
Shape Tensor:

$$\mathcal{S}_{ij} = \frac{1}{M} \sum_n m_n w_n x_{n,i} \; x_{n,j}$$

m-weight = Galaxy mass

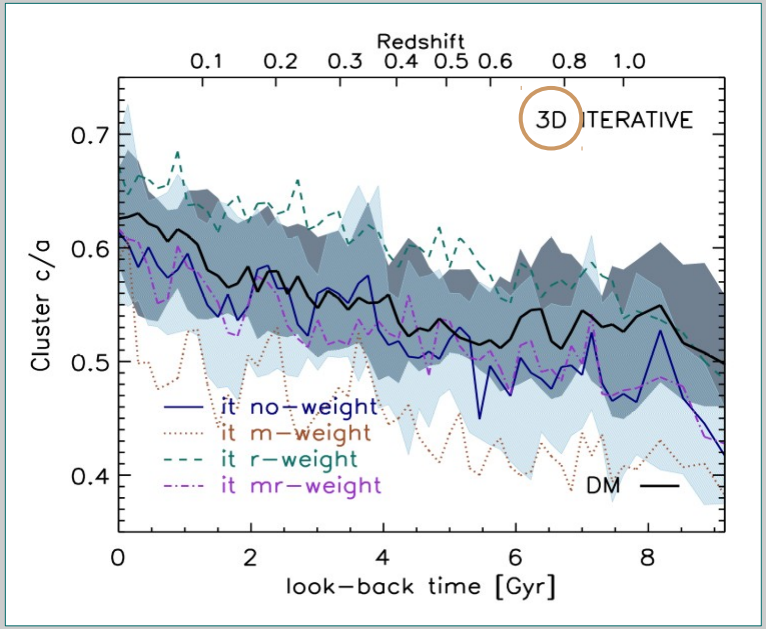
r-weight =1/r²

In our AGN Hydro-Sim
- Galaxies inside clusters trace a more spherical distribution at lower z
- Holds true no matter m_n or w_n

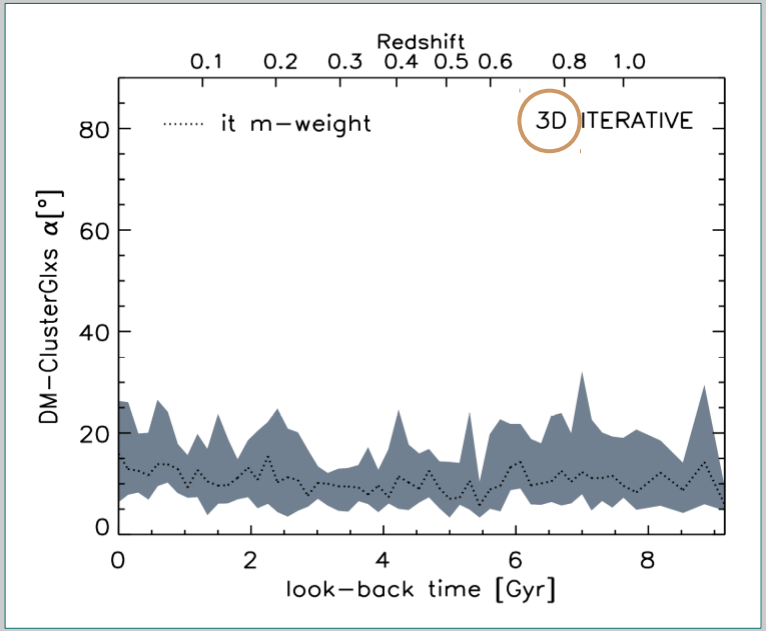


Do Galaxies Trace the Cluster Mass Distribution?

Many studies on alignment rely on this assumption
e.g. West et al. (2017)



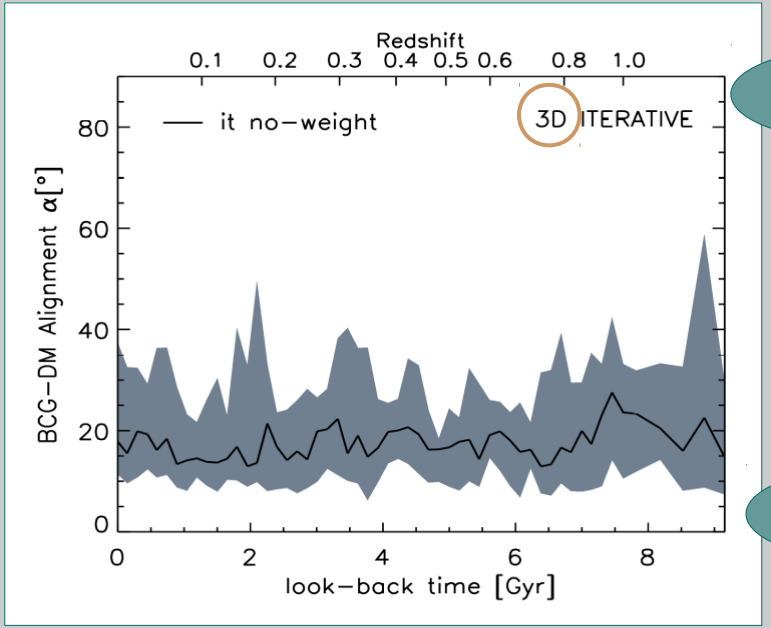
Only explored for the most massive cluster regime!!!



- DM seems to have a more spherical distribution
- Alignment between DM and cluster galaxies is ~ 12°
- No dependence of alignment on z

3D Alignment

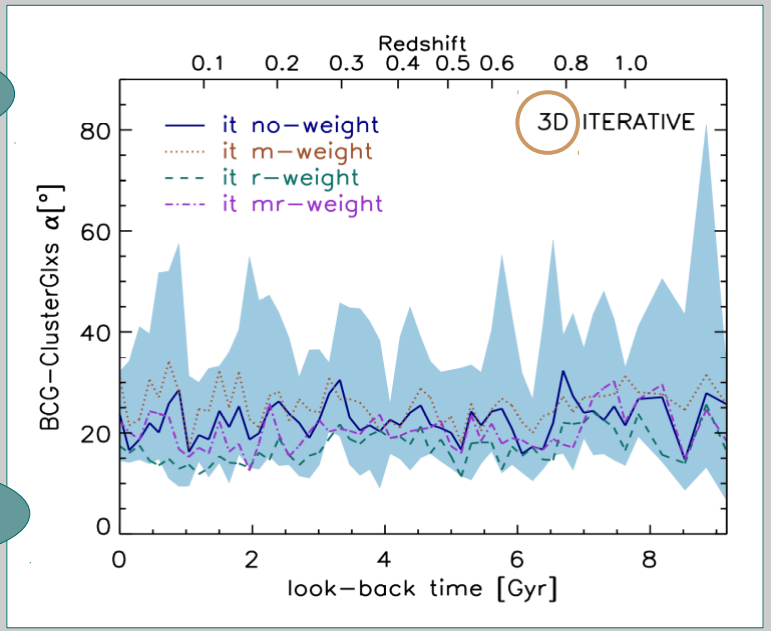
BCG-DM



Perpendicular

Aligned

BCG-Cluster Glxs



- Both DM and Cluster Galaxies are aligned with the BCG
- BCGs better aligned with the DM
- No dependence of alignment on z

2D

Observational Side

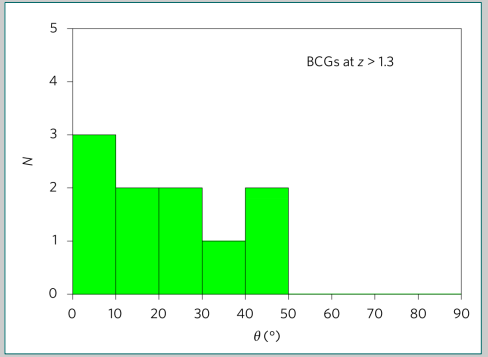
Cluster Shape

- **Using Galaxies (Usually)**
  e.g. West et al. (2017)
  Caveats:
  - Do galaxies trace the shape of the cluster?
  - Foreground/Background contamination
  - Discreteness noise
- **Using X-ray Emitting Gas**
  e.g. Hashimoto, Henry & Boehringer (2008)
- **Using Lensing**
  e.g. Evans & Bridle (2009)

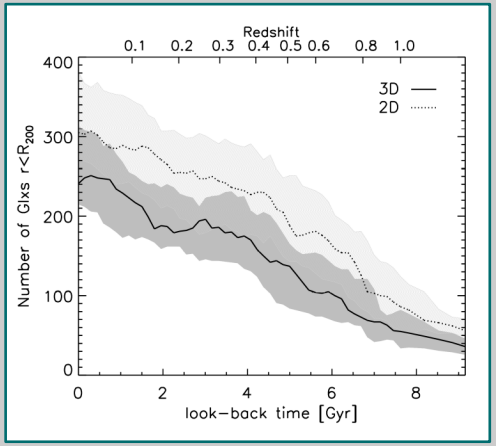
BCG Shape

- **Surface Brightness Fitting**

Cluster mergers do not disrupt or may help building the BCG-Cluster alignment Wittman, Foote & Golovich (2019)

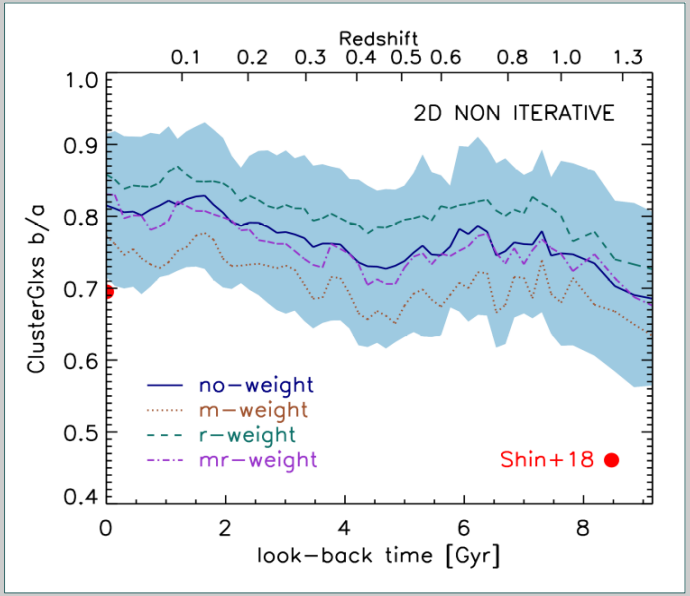


West et al. (2017)
Cluster shapes obtained with ~ 12 red-sequence galaxies

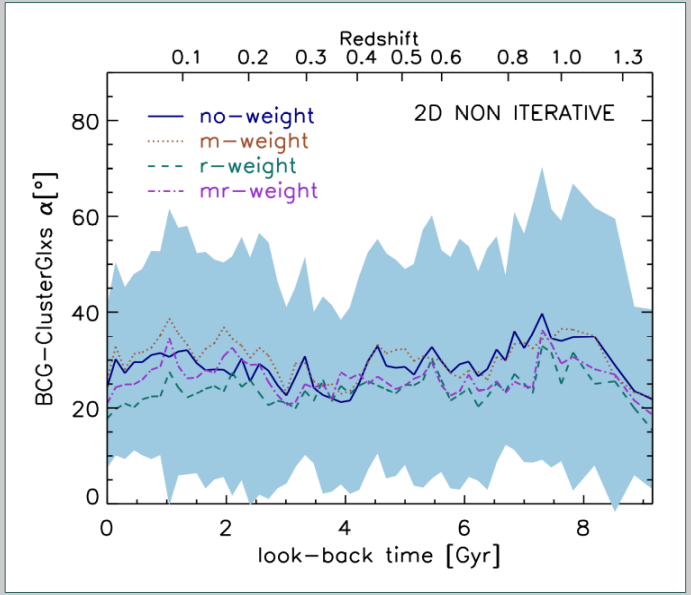


2D Shape and Alignment

Cluster Shape



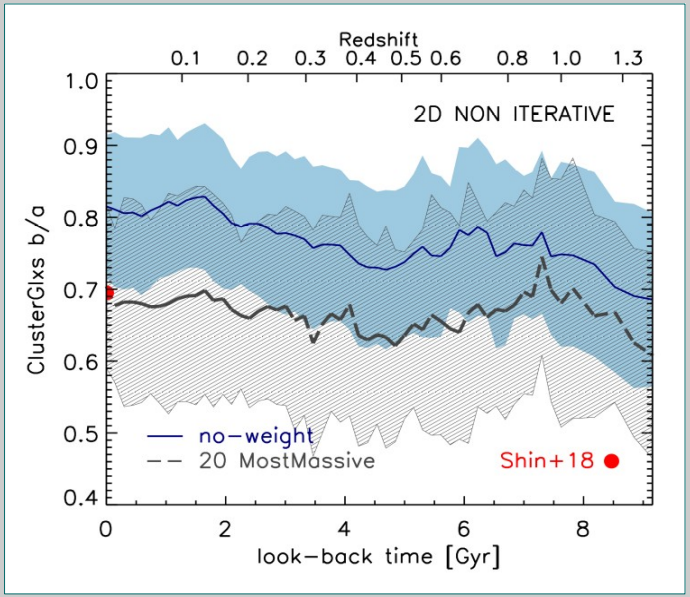
BCG-Cluster Glxs



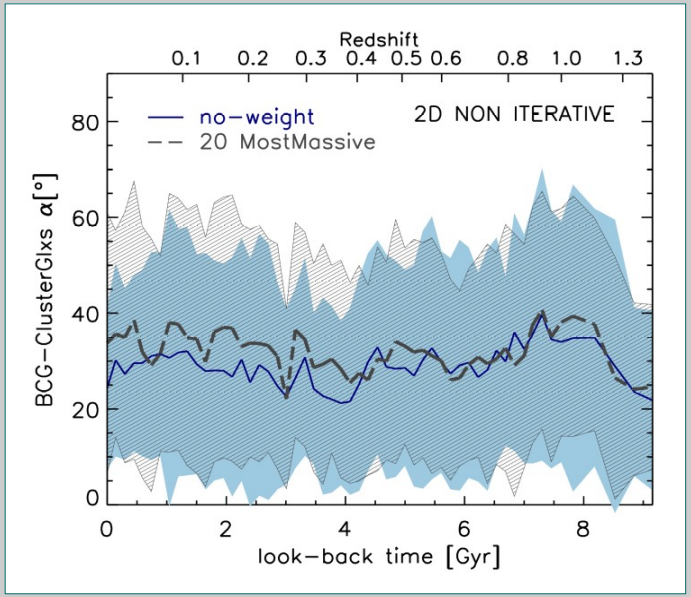
- No evident evolution of b/a with time
- Projected alignment still existent at any z
- **No evident evolution of BCG-Cluster alignment with time**
- For nglxs=20: agreement with observed mean b/a at z=0 for similar mass clusters
- For nglxs=20: alignment persists

2D Shape and Alignment

Cluster Shape



BCG-Cluster Glxs



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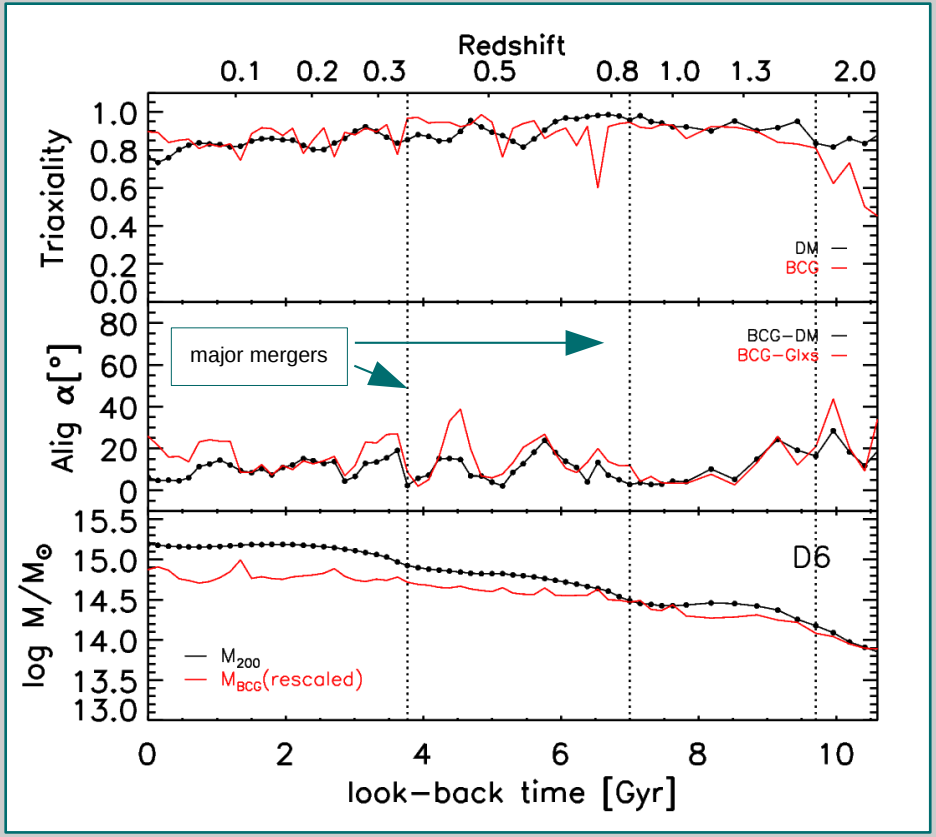
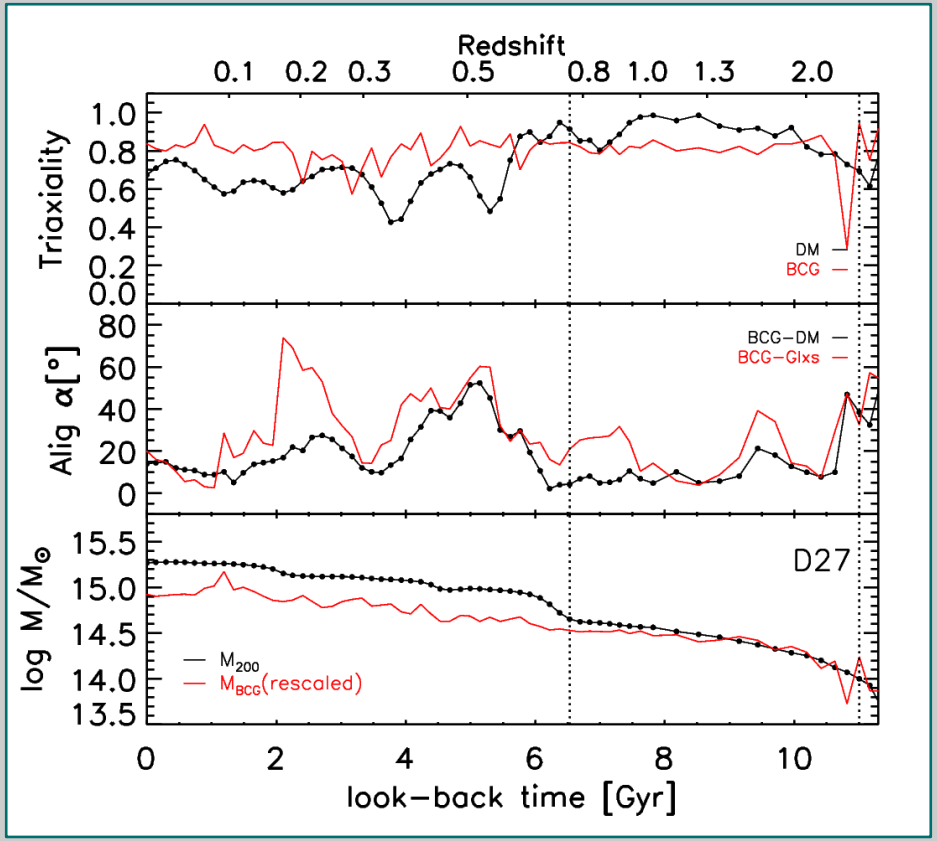
Merger does not disrupt Alignment



Cluster mergers do not disrupt or may help building the BCG-Cluster alignment
Wittman, Foote & Golovich (2019)

Merger disturbs Alignment



Mergers on radial orbits produce prolate remnants, while mergers on tangential orbits produce oblate remnants.
Drakos et al. (2019)

Conclusions

- **BCG-Cluster Alignment can be found since at least z~1**
  (no evidences of evolution with time)
- BCG-Cluster alignment might depend only on the individual formation history of each cluster
- Alignments are resilient to mergers
- Alignment still exists if cluster shape is computed with only 20 galaxies
  (as in observations)