Brightest Cluster Galaxies (BCGs) Evolution in Cosmological Hydro-Simulations

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Motivations

- BCGs occupy special positions and have particular properties
(e.g. Von Der Linden et al. 2007; Bernardi 2009)

- The BCG population is inconsistent with the luminosity function of galaxies (e.g. Tremaine & Richstone 1977)

Peculiar Formation Paths ?

Mass Assembly

BCG-Cluster Alignment

Mass Assembly

- ✔ Little or no change since z∼1
  (e.g. Zhang et al. 2016)
- ✔ Little or no change since z∼1.5
  (e.g. Stott et al. 2010)
- ✔ Growth factor of ∼2 between z = 1 and z = 0 with a stall at z∼0.5
  (e.g. Bellstedt et al. 2016)

The lack of consensus could arrive at least in part from the **different methods that are used to estimate the mass and the growth factors** of the BCGs; and **dissimilarities in the sample selection.**

BCG-Cluster Alignment

✔ 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

Very little observational indications of alignment at z~1

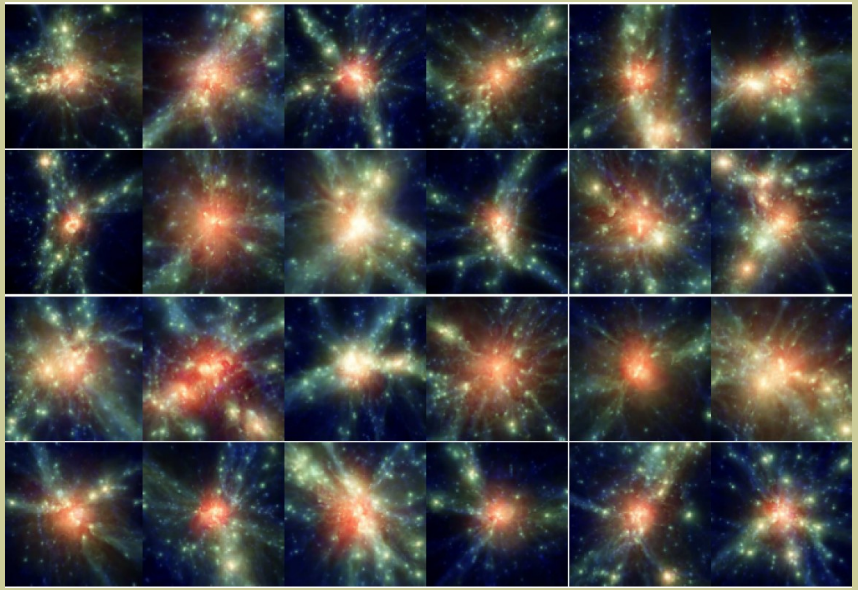
The Cluster Simulations

24 most massive clusters
in 1Gpc^3 Box

(M_{200} > 1e15 h^{-1} $M_\odot$ at z=0)

Mass Resolutions:

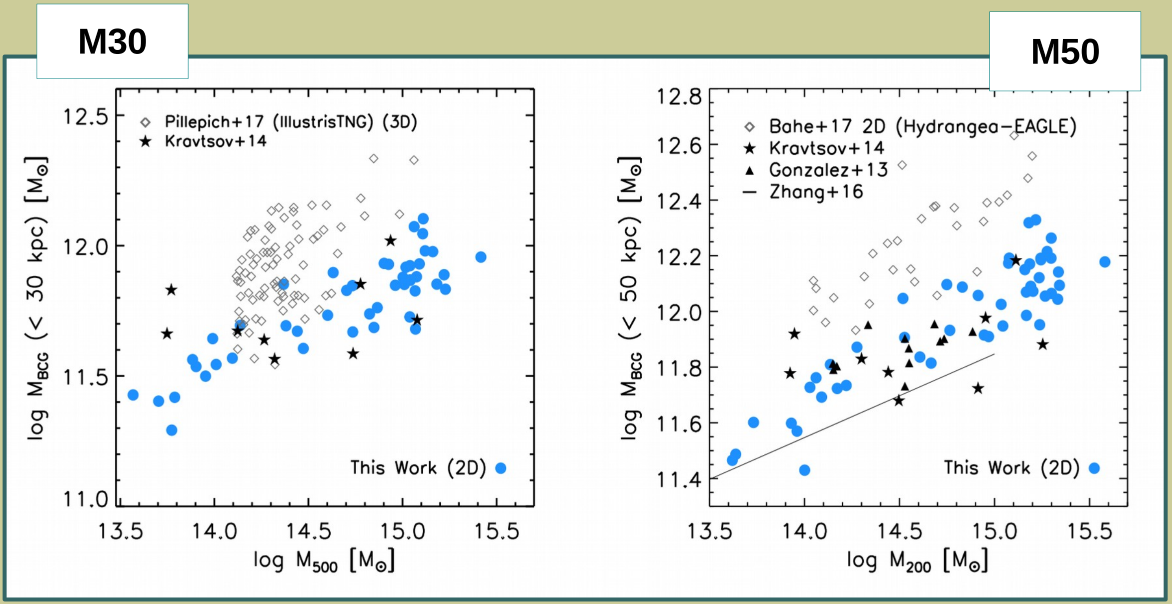
dm: 8.4 x 10^8 h^{-1} $M_\odot$
gas: 1.6 x 10^8 h^{-1} $M_\odot$
star: 4.5 x 10^7 h^{-1} $M_\odot$



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

z=0 BCG-Cluster mass Relation

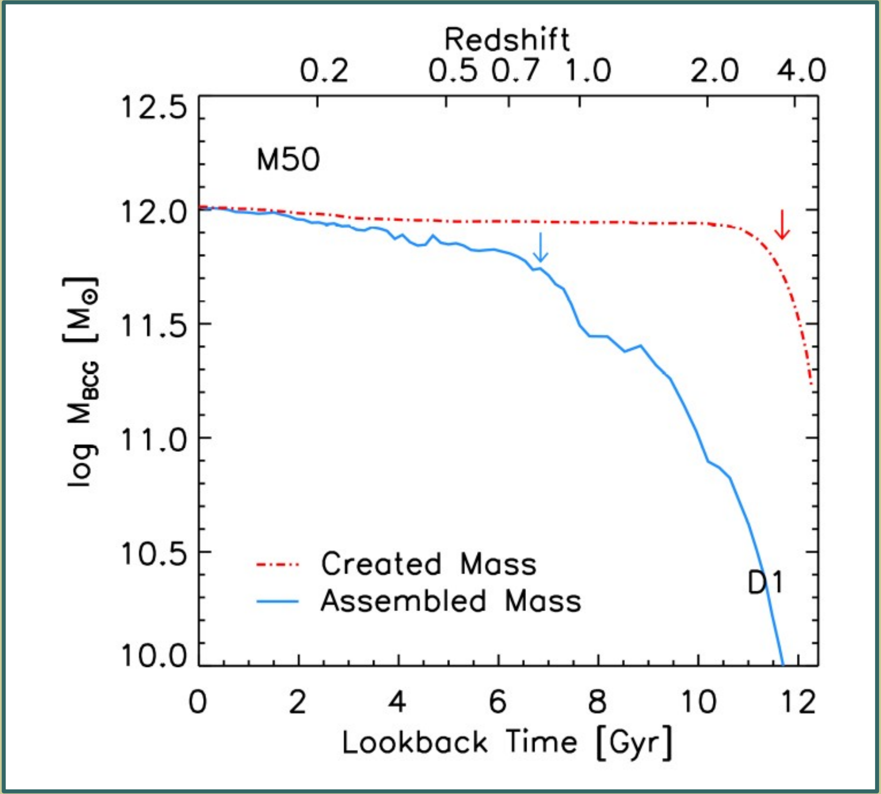
- **Not “total” BCG masses** but masses inside **30 and 50 kpc**
- 6 test cases: stable final masses when increasing mass resolution (3x)
- Smaller masses wrt other state of the art simulations (100x)
- More in agreement with the data



Ragone-Figueroa et al. (2018)

Large BCG mass problem could be resolved by more realistic AGN feedback models, which should be more efficient at expelling gas from massive halos at high redshift (Ragone-Figueroa et al. 2013; Bahe et al. 2017)

Evolution of ASSEMBLED and CREATED masses (One Case Study):



Main Progenitor BCG Mass Evolution

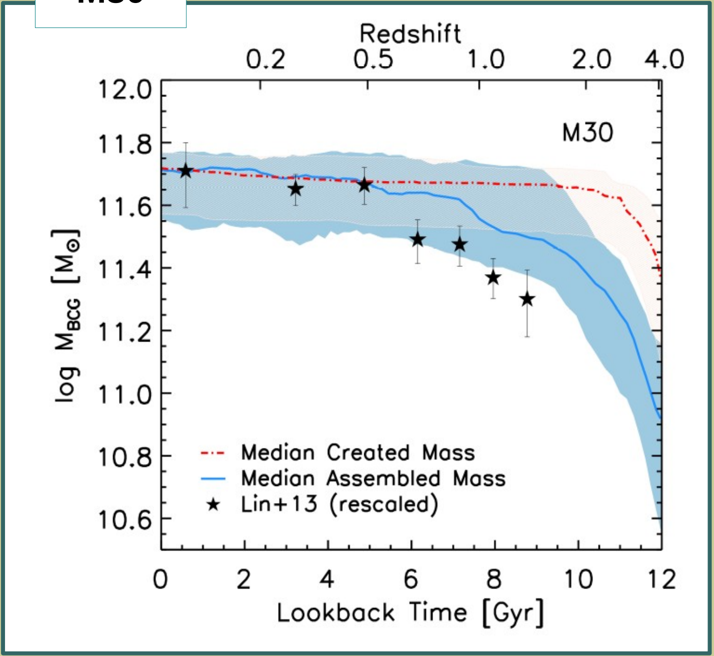
We seek for
BCG MAIN PROGENITORS
and
CLUSTER MAIN PROGENITORS

- 50% of the stars that end-up in the BCG (50 kpc) are already formed by z~4
- Assembly oh half mass occurs ~ 5Gyr later

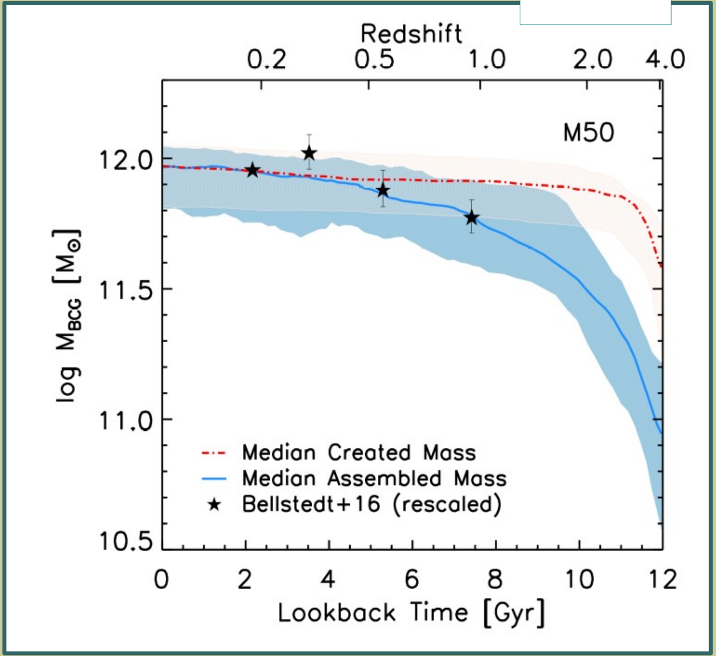
Dataset	M30		M50		M10%	
	z_a	z_c	z_a	z_c	z_a	z_c
Prog. Clus.	$1.8^{0.3}_{2.7}$	$4.0^{3.5}_{4.7}$	$1.4^{0.4}_{2.2}$	$3.7^{3.3}_{4.5}$	$0.5^{0.1}_{0.7}$	$3.1^{2.9}_{3.5}$
Prog. BCG	$2.1^{1.4}_{3.0}$	$4.0^{3.5}_{4.7}$	$1.5^{0.9}_{2.6}$	$3.7^{3.3}_{4.5}$	$0.6^{0.3}_{0.7}$	$3.1^{2.9}_{3.5}$

Evolution of ASSEMBLED and CREATED masses (24 clusters):

M30



M50



- Lin et al. (2013) IRAC clusters are smaller than ours by a factor ~4. At low z our larger BCGs might be losing more mass than in the data

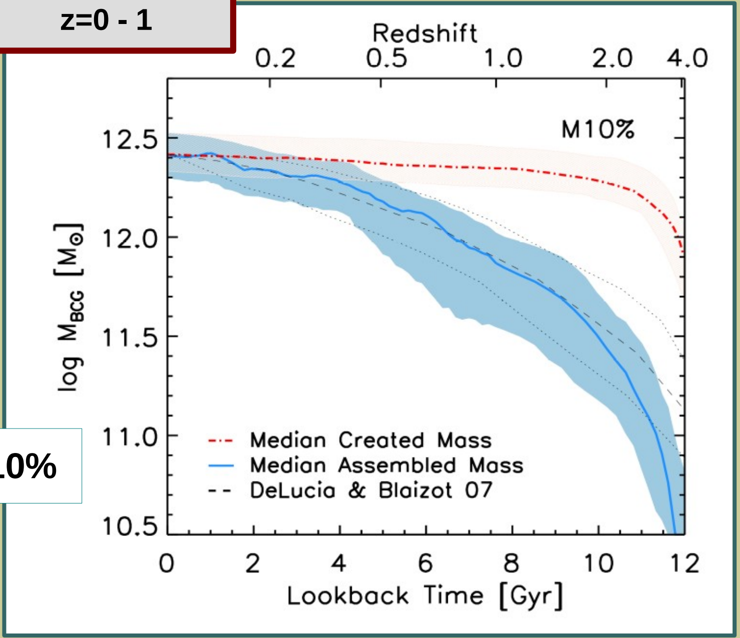
- Stall at z<~ 0.5 as in Lin et al. (2013); Oliva-Altamirano et al. (2014)

Nice agreement with the data (selected to mimic cluster evolutionary sequence)

GF_{M30}= 1.3 , GF_{M50}= 1.6 from z=0 to 1

Evolution of ASSEMBLED and CREATED masses (24 clusters):

GF$_{M10\%}$= 3.8
z=0 - 1



M10%

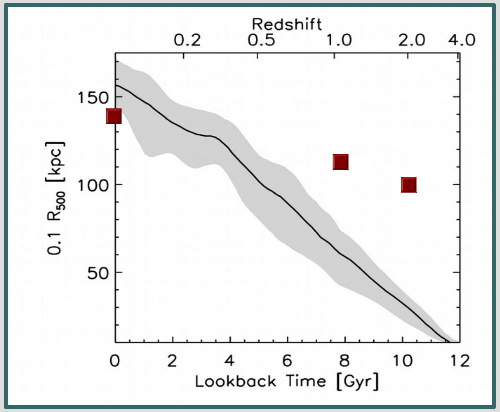
- **M10%** has a more pronounced mass growth than **M50** and **M30**
- Simulations in good agreement with SAM growth prediction, if we consider the stellar mass within (say) 10% or R_{500} (a radius evolving with z)

Most observational works compare their results with DL&B07

Misleading?

No ICL contamination inside R10% provided ICL is defined as in observations

μ_B = 25 mag arcsec^{-2}
at R ~ 130, 110, 100 kpc
for z = 0, 1, 2, resp.

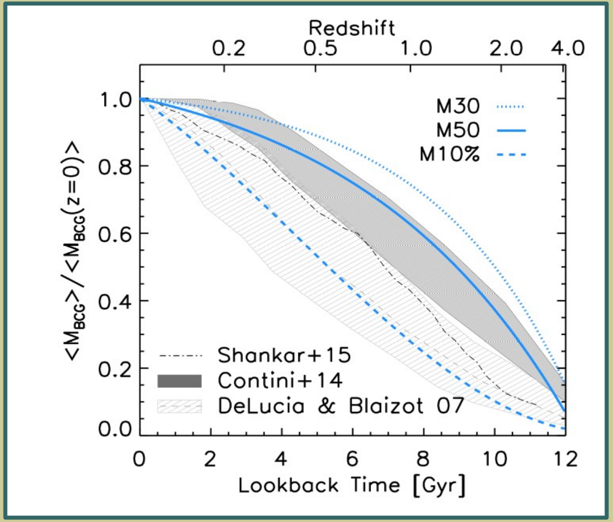


ICL Considerations

- Contini et al. (2014) SAM is a re-make of DL&B07 SAM but considering different prescriptions for the formation of the ICL component

- The inclusion of the ICL results in a milder mass evolution. More in keep with observational data.

Comparison between SAMs and observations are not straightforward



DL&B07: ~ 3.5
Contini+14: ~ 1.5-2.5
Shankar+15: >~2.5

Growth Factors

Δz	Dataset	M30 MGF	M30 GMM	M50 MGF	M50 GMM	M10% MGF	M10% GMM
0 - 1	Progenitor Cluster	$1.2^{0.97}_{1.9}$	$\boxed{\mathbf{1.3}} \pm \mathbf{0.3}$	$1.4^{1.1}_{2.4}$	$\boxed{\mathbf{1.6}} \pm \mathbf{0.2}$	$3.6^{2.6}_{6.3}$	$\boxed{\mathbf{3.6}} \pm \mathbf{0.6}$
	Progenitor BCG	$1.3^{1.0}_{1.9}$	1.4 ± 0.2	$1.6^{1.1}_{2.5}$	1.6 ± 0.3	$4.9^{2.6}_{7.4}$	3.5 ± 1.0
0 - 2	Progenitor Cluster	$2.2^{1.5}_{3.2}$	$\mathbf{2.1 \pm 0.3}$	$2.7^{1.8}_{4.5}$	$\mathbf{2.9 \pm 0.5}$	$11.7^{6.5}_{21.4}$	$\mathbf{11.0 \pm 2.0}$
	Progenitor BCG	$2.3^{1.3}_{7.0}$	1.9 ± 0.2	$3.5^{1.7}_{12.8}$	2.5 ± 0.4	$12.9^{7.4}_{30.9}$	9.5 ± 2.0

Larger GFs for larger apertures. Compatible with Inside-Out mass assembly scenario.

Ragone-Figueroa et al. (2018)

BCG and Cluster Principal Axes

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

Mass of the n^{th} particle

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

Total Mass

Some weight for the n^{th} particle

i, *j* components of the position vector of the n^{th} particle

BCGs
stellar particles
inside 10% R_{500}

Clusters

(1) ~~DM particles~~
(2) Galaxies

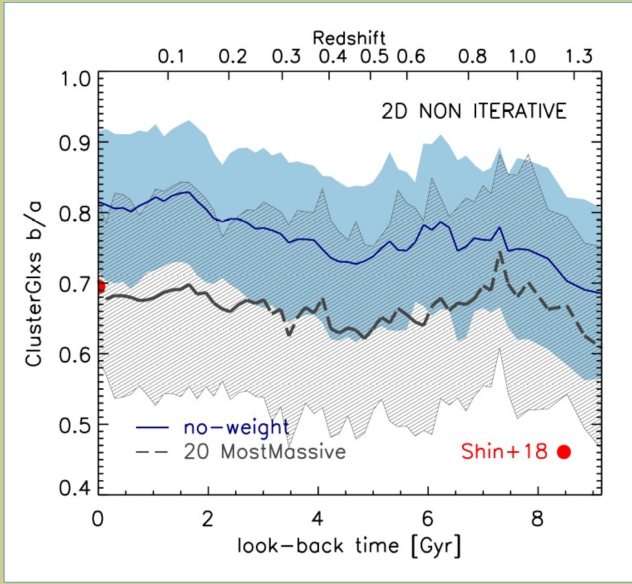
inside R_{200}

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

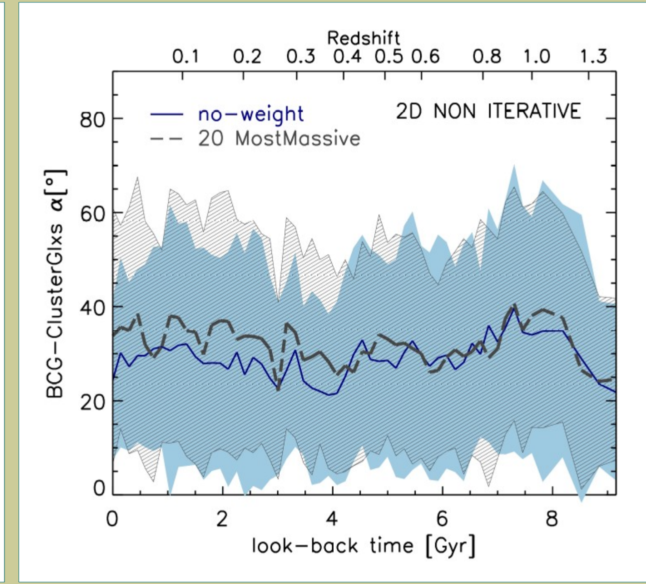
2D

Shape and Alignment

Cluster Shape



BCG-Cluster Glxs



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

Summary

- Simulated BCG final masses as a function of cluster mass are in reasonable agreement with observations

- Main Prog. BCG and Main Prog. Cluster Samples lead to similar mass evolution (at least up to z ~ 1.5)

- Up to z ~ 0.5 we find very little mass growth within 30 and 50 kpc (as in e.g. Lin et al. 2013; Oliva-Altamirano et al. 2014; Inagaki et al. 2015)

- Up to z~1 the Growth Factors increase with the aperture. For 30 and 50 kpc the GFs are 1.3 and 1.6 resp., in good agreement with most recent observations with equivalent apertures (e.g. Lin et al. 2013; Zhang et al. 2016; Bellstedt et al. 2016)

- These observational GFs should not be compared to the DL&B07 ones (ICL here). The later is instead similar to our M10% GF (NO ICL here). Coincidence?

GFs

Summary

- BCGs have been typically aligned with their host clusters since at least z~1
- Alignment still exist if cluster shape is computed with only 20 galaxies
- There are no evidences of evolution with time of the BCG-Cluster alignment