A Surprising Lack of Evolution in the Most Massive Galaxies Since z = 1

John P. Stott (Durham), Chris Collins (LJMU)
and members of the XCS

Abstract

We find the surprising result that the average stellar mass of Brightest Cluster Galaxies (BCGs) has remained constant at ~ 9e11 $M_{\odot}$ since z ~ 1.5. The large stellar masses imply that the assemblage of these galaxies took place at the same time as the initial burst of star formation. This result leads us to conclude that dry merging has had little effect on the average stellar mass of BCGs over the last 9 - 10 Gyr in stark contrast to the predictions of semi-analytic models, based on the hierarchical merging of dark matter haloes, which predict a more protracted mass build up over a Hubble time.

In a parallel study we present the first estimates for the scale sizes of BCGs at z ~ 1 as recent reports suggest that elliptical galaxies have increased their size dramatically over the last ~ 8 Gyr. This would point to a major re-think of the processes dominating the late-time evolution of galaxies. We compare an analysis of deep *Hubble Space Telescope* imaging to a well matched local sample at z ~ 0.2. Comparing either the de Vaucouleurs, Sersic or Petrosian radii indicates little (up to 30% increase since z = 1) or no evolution in scale size between the two samples.

We conclude that this lack of size evolution, particularly when coupled with recent results on the lack of BCG stellar mass evolution, demonstrates that major merging is not an important process in the late-time evolution of these systems. The homogeneity and maturity of BCGs at z = 1 continues to challenge galaxy evolution models.

Key Points:

- Brightest Cluster Galaxies (BCGs) have not grown significantly in mass since z = 1.5
- The morphology and size of BCGs have not evolved significantly over the same period
- Theoretical models predict a more protracted build up in stellar mass through merging
- The homogeneity and maturity of BCGs at z ~ 1 continues to challenge galaxy evolution models

Stellar Masses

We performed a deep J and K band photometry survey of 20 high redshift galaxy clusters between z = 0.8 - 1.5, with the MOIRCS instrument on the Subaru Telescope. By using near-infrared light as a proxy for stellar mass we find the surprising result that the average stellar mass of Brightest Cluster Galaxies (BCGs) has remained constant at ~ 9e11 $M_{\odot}$ since z ~ 1.5. We investigate the effect on this result of differing star formation histories generated by three well known and independent stellar population codes (Bruzual & Charlot 2003; Maraston 2005; Pietrinferni et al. 2004) and find it to be robust for reasonable, physically motivated choices of age and metallicity (e.g. Loubser et al. 2009 - solar and super-solar metallicity and formation redshift z_f > 2).

The large stellar masses imply that the assemblage of these galaxies took place at the same time as the initial burst of star formation. This result leads us to conclude that dry merging has had little effect on the average stellar mass of BCGs over the last 9 - 10 Gyr in stark contrast to the predictions of semi-analytic models, based on the hierarchical merging of dark matter haloes, which predict a more protracted mass build up over a Hubble time (De Lucia & Blaizot 2007).

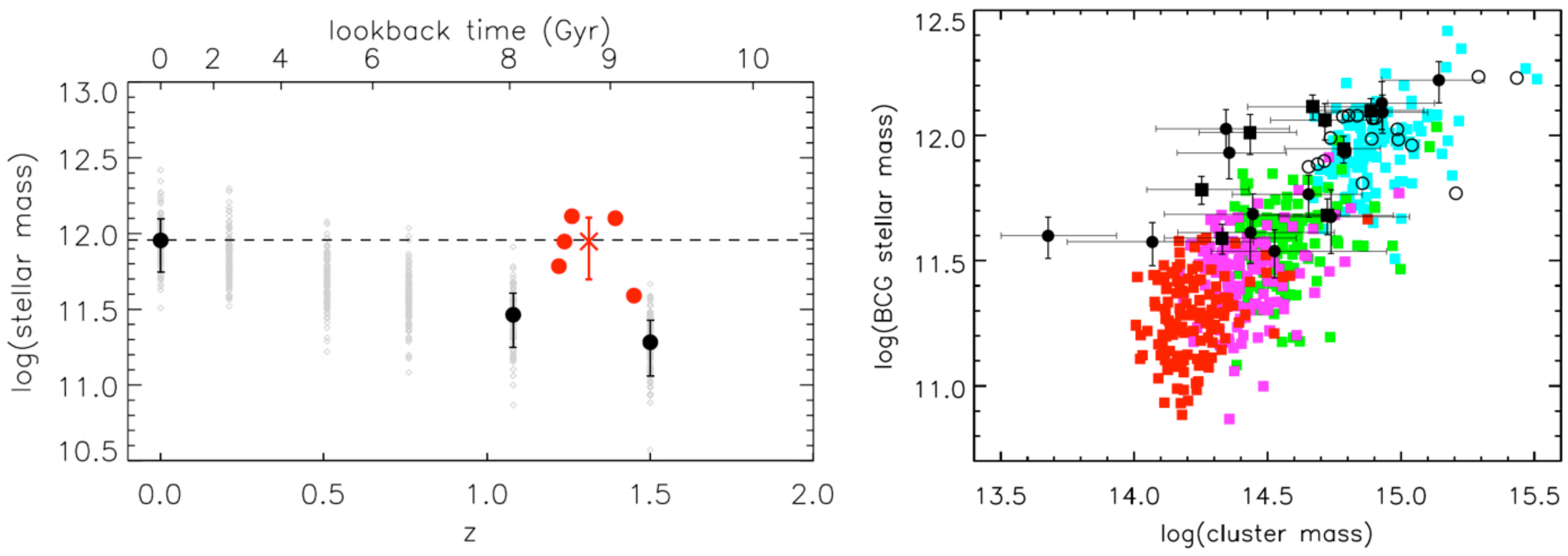
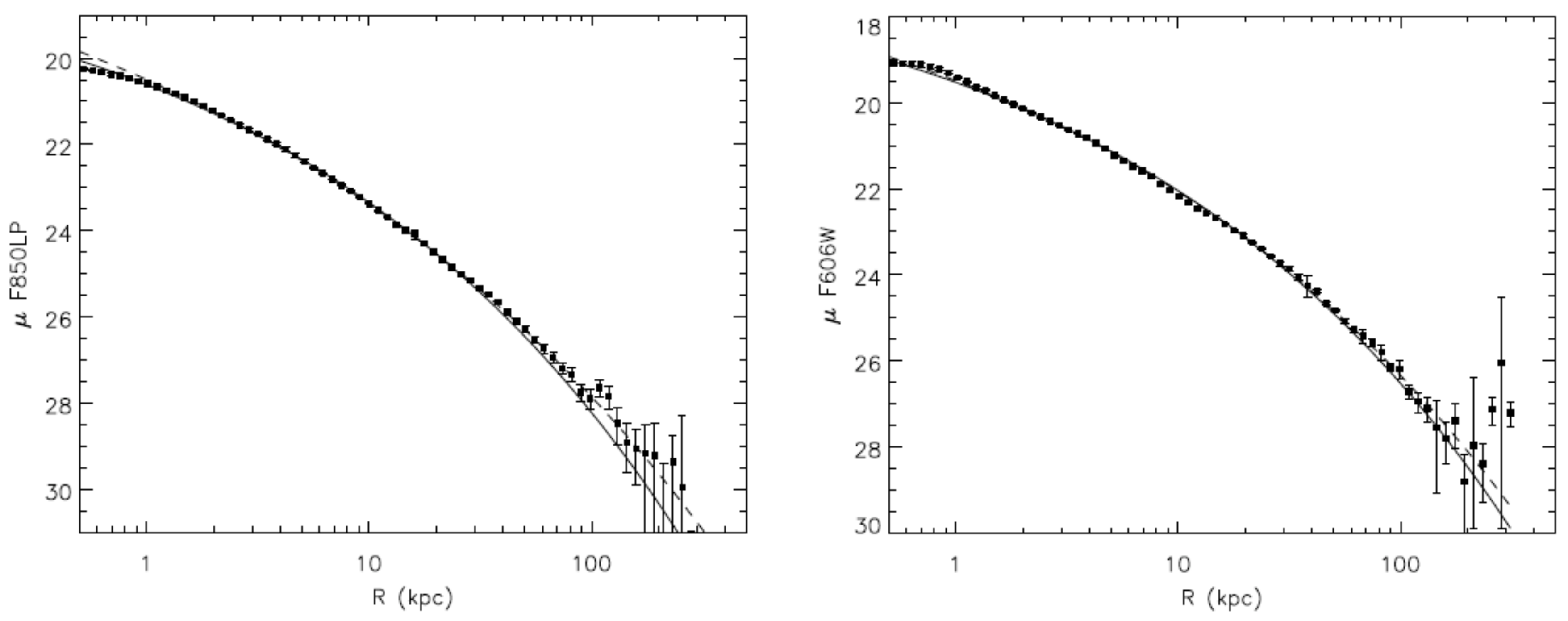


Figure 1. Left: BCG stellar mass plotted against redshift from Collins et al. 2009. Dashed line is low redshift observed average, Red points are observed BCGs. Black points are average masses from De Lucia and Blaizot (2007).
Right: BCG stellar mass plotted against cluster mass from Stott et al. 2010. Black filled points are observed BCGs. Coloured squares are BCGs from De Lucia and Blaizot (2007) snapshots (Cyan: z = 0, Green: z = 0.7, Magenta: z = 1 and Red: z = 1.5). It is clear that the observed BCGs with average redshift z = 1 are significantly more massive than the prediction.



	average				stack			
z	$r_e(n=4)$ (kpc)	r_e (free) (kpc)	n	$r_e(n=4)$ (kpc)	r_e (free) (kpc)	n	r_{pet} (kpc)	$r_{1/2}$ (kpc)
0.23	43.8 ± 5.4	45.5 ± 6.9	4.0 ± 0.4	43.2 ± 1.0	57.9 ± 4.5	4.8 ± 0.2	61.7	27.0 ± 3.3
1.00	26.9 ± 2.3	57.3 ± 15.7	4.3 ± 0.9	32.1 ± 2.5	47.6 ± 13.7	5.4 ± 0.9	41.9	23.6 ± 9.6

Figure 2. Left: Stacked surface brightness profile of z = 1 BCGs. Right: Stacked surface brightness profile of z = 0.2 BCGs illustrating lack of evolution.
Table 1. The fit parameters to the high and low redshift BCG surface brightness profiles.

Conclusion & Discussion

We conclude that this lack of mass or size evolution demonstrates that major merging is not an important process in the late time evolution of BCGs. There is potential for reconciliation between observation and theory if there is a significant growth of very low surface brightness material at large radii in the intra-cluster light over the same period. An alternative, which would explain the co-evolution of the BCG stellar mass and stellar population, is that galaxies at the centres of the largest dark matter halos form via a cold stream process that can efficiently dump gas into the centres of dark matter halos leading to an intense period of star formation at high redshift (Dekel et al. 2009).

Galaxy Sizes

Recent reports suggest that elliptical galaxies have increased their size dramatically over the last ~ 8 Gyr (e.g. Van Dokkum et al. 2009). This result points to a major re-think of the processes dominating the late-time evolution of galaxies. We present the first estimates for the scale sizes of brightest cluster galaxies (BCGs) in the redshift range 0.8 < z < 1.3 from an analysis of deep *Hubble Space Telescope* imaging, comparing to a well matched local sample taken from the Local Cluster Substructure Survey at z ~ 0.2 (LoCuSS, Smith et al. 2010).

For a small sample of 5 high redshift BCGs we measure half-light radii ranging from 14 - 53 kpc using de Vaucouleurs profile fits, with an average determined from stacking of 32.1 +/- 2.5 kpc compared to a value 43.2 +/- 1.0 kpc for the low redshift comparison sample. This implies that the scale sizes of BCGs at z = 1 are ~ 30% smaller than at z = 0.25. Analyses comparing either Sersic or Petrosian radii also indicate little or no evolution between the two samples.

The detection of only modest evolution at most out to z = 1 argues against BCGs having undergone the large increase in size reported for massive galaxies since z = 2 and in fact the scale-size evolution of BCGs appears closer to that reported for radio galaxies over a similar epoch (Targett et al. 2011).

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Contact: John Stott, j.p.stott@durham.ac.uk