Tracing the Origin of Galaxies in the Land of our Ancestors
Proceedings IAU Symposium No. 277, 2010
Carignan, C., Combes, F. & Freeman, K. C., eds.

doi:10.1017/S174392131102299X

Breaking down the link between luminous and dark matter in massive galaxies

Sébastien Foucaud[1] **& Christopher J. Conselice**[2]

[1]National Taiwan Normal University, Taiwan
email: `foucaud@ntnu.edu.tw`
[2]University of Nottingham, UK
email: `conselice@nottingham.ac.uk`

Abstract. We present a study on the clustering of a stellar mass selected sample of galaxies with stellar masses $M_* > 10^{10} M_\odot$ at redshifts $0.4 < z < 2.0$, taken from the Palomar Observatory Wide-field Infrared Survey. We examine the clustering properties of these stellar mass selected samples as a function of redshift and stellar mass, and find that galaxies with high stellar masses have a progressively higher clustering strength than galaxies with lower stellar masses. We also find that galaxies within a fixed stellar mass range have a higher clustering strength at higher redshifts. We further estimate the average total masses of the dark matter haloes hosting these stellar-mass selected galaxies. For all galaxies in our sample the stellar-mass-to-total-mass ratio is always lower than the universal baryonic mass fraction and the stellar-mass-to-total-mass ratio is strongly correlated with the halo masses for central galaxies, such that more massive haloes contain a lower fraction of their mass in the form of stars. The remaining baryonic mass is included partially in stars within satellite galaxies in these haloes, and as diffuse hot and warm gas. We also find that, at a fixed stellar mass, the stellar-to-total-mass ratio increases at lower redshifts. This suggests that galaxies at a fixed stellar mass form later in lower mass dark matter haloes, and earlier in massive haloes. We interpret this as a 'halo downsizing' effect.

Keywords. galaxies: evolution, galaxies: halos.

1. Introduction

Stellar masses are now becoming a standard measure for galaxies, and are being used to trace the evolution of the galaxy population in terms of star formation rates and morphologies (e.g. Bundy *et al.* 2005; Conselice *et al.* 2008; Cowie & Barger 2008). However, stellar masses only trace one aspect of the masses of galaxies, and ideally and ultimately, we aim to measure galaxy total masses, that include contributions from stars, gas, and dark matter. Galaxies are believed to be hosted by massive dark matter haloes that make up more than 85% of their total masses, and thus clearly tracing the co-evolution of galaxies and their haloes is a major and important goal. One very powerful method for measuring the total masses of galaxies is to measure their clustering. Clustering measurements are independent of photometric properties, and as such they can be used to highlight fundamental properties of galaxy populations without assumptions concerning stellar populations or mass profiles. Halo clustering is a strong function of halo mass, with more massive haloes more strongly clustered, providing a mean to study the relationship between galaxy properties and dark matter halo masses.

We present the first general study of the clustering properties for a stellar mass selected sample of galaxies up to $z \sim 2$. We carry this out by measuring the correlation length and amplitude for galaxies selected with stellar masses $M_* > 10^{10} M_\odot$ within the Palomar Observatory Wide-field Infrared Survey (POWIR).

2. The Palomar/DEEP2 Survey

The Palomar Observatory Wide-Field survey (Bundy *et al.* 2006; Conselice *et al.* 2007) was designed to obtain deep Near-Infrared photometry over a 1.5deg^2 area, using the Wide Field Infrared Camera (WIRC) on the Palomar 5m telescope. It covers the Extended Groth Strip (Davis *et al.* 2007) and three other fields covered by the DEEP2 survey (Davis *et al.* 2003). Optical imaging from the Canada-France-Hawaii Telescope cover all fields, using the CFH12k camera in B-, R- and I-band (Coil *et al.* 2004). DEIMOS spectroscopy was acquired as part of the DEEP2 survey on the Keck Telescope. Around 20% of our K-band selected galaxies have a secure redshift (up to z=1.4). For the galaxies without spectroscopic redshift, we have determined their photometric redshifts based on our BRIJK photometry and our spectroscopically confirmed sample.

Using our photometry we also derived stellar mass estimation for our sample of galaxies (Bundy *et al.* 2006; Conselice *et al.* 2007). Based on models from Bruzual & Charlot (2003), we derived accurate stellar masses in the range $10^{10.0}M_{\odot} < M_{*} < 10^{12.0}M_{\odot}$ over our range of redshifts with an error of 0.2-0.3 dex. In this work, we are studying the properties of galaxies selected according to their stellar-masses and their redshift.

3. Clustering properties of mass selected samples

In order to link these galaxies with their environment and their large scale structures, we quantify their distribution in the sky at different scales. We first measure the 2-point angular correlation function $\omega(\theta)$ for our sample using the Landy & Szalay (1993) estimator, as shown in Figure 1(a). In order to fit the clustering reliably, we avoid the small-scale excesses due to possible multiple galaxy occupation of a single dark matter halo. Assuming a Top-Hat redshift distribution for galaxies in each of our narrow redshift bins, we also derive the correlation length r_0 from the amplitude of the angular correlation using the relativistic Limber equation (Magliocchetti & Maddox 1999). As shown if Figure 1(b), we find that correlation lengths vary from $5h^{-1}$Mpc to $15h^{-1}$Mpc for galaxies selected by stellar masses with $M_{*} > 10^{10}M_{\odot}$. The correlation measurements of our different mass-selected samples indicate that the most massive galaxies are more clustered than less massive ones at all redshifts. Furthermore higher redshift samples are more clustered than lower redshift ones at a given mass range (Foucaud *et al.* 2010).

The standard Cold Dark Matter model predicts that at any redshift more massive dark matter haloes are on average more clustered than lower mass systems. To better understand where galaxies reside, their spatial distribution can be directly compared with the distribution of the dark matter haloes predicted by Mo & White (2002). The very strong clustering shown by $z > 1$ massive galaxies implies that they are hosted by very massive dark matter halos, consistent with progenitors of present-day elliptical galaxies (Foucaud *et al.* 2010). Furthermore we can directly extract the mass of the dark matter haloes from the models, and compare directly the mass of the host halo with the stellar mass of the hosted galaxy, deriving the stellar-to-dark matter mass fraction for our different samples.

4. Stellar-to-Dark Matter mass fraction

In Figure 2(a), we compared the stellar-to-dark matter mass fraction with measurements from different studies in the literature based on various methods to estimate the masses of dark matter Haloes (rotation curves, galaxy-galaxy lensing, groups). As expected, the stellar-mass-to-total-mass ratio is far lower than the universal baryonic mass

https://doi.org/10.1017/S174392131102299X Published online by Cambridge University Press

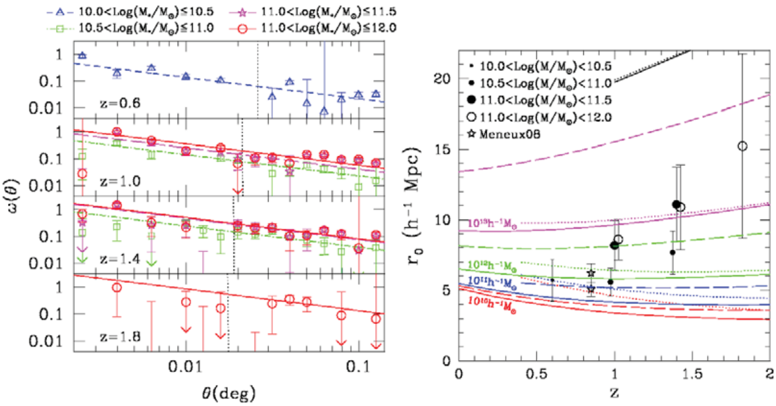

Figure 1. (a) Two-point correlation function of our mass-selected samples in different redshift ranges, in one of our field (Foucaud *et al.* 2010). The vertical dotted line corresponds to the lower limit at $\sim 1h^{-1}$Mpc of the range over which our data are fitted, in order to avoid any excess of pairs due to multiple halo occupation. **(b)** Evolution of the spatial correlation length r_0 with redshift, for our different mass-selected samples (Foucaud *et al.* 2010). The measurements are compared with prediction of the evolution for dark matter haloes (Mo & White 2002) and from the literature (Meneux *et al.* 2008).

fraction, measured from WMAP5 (Komatsu *et al.* 2009). Furthermore we confirm at high redshift the tight correlation found between the stellar-to-dark matter mass fraction and dark matter halo masses in the higher mass regime. Overall, we find that, in all our redshift ranges, more massive systems have a lower ratio of stellar-to-halo-mass. This implies that at $z > 2$ galaxies in the centres of the most massive dark matter halo stop increasing their stellar mass while their halos keep growing. This also implies a limit to how much stellar mass a galaxy can have, with a cut off at a few times $10^{11} M_{\odot}$. Similarly, a decreasing stellar mass fraction with increasing halo mass has been observed in groups and clusters (e.g. Gonzalez *et al.* 2007), with the majority of the baryonic mass taking the form of galaxy satellites, while the remaining being under the form of warm and hot gas.

As shown in Figure 2(b), the stellar-to-dark matter mass fraction is also increasing with redshift at a given stellar mass. This effect is likely linked with contamination of the stellar-mass selected sample by galaxies hosted by less massive haloes. Therefore, as the stellar masses of the most massive galaxies do not increase much with time, due to a quenching of their star formation and a weak merging rate (Drory & Alvarez 2008), the average mass of the haloes for these galaxies decreases while the stellar mass ratio increases. This is in agreement with a 'Halo downsizing' effect (Neistein *et al.* 2006), i.e. more massive galaxies are formed earlier than in more massive haloes.

5. Conclusions

We have exploited the near infrared data set from the Palomar/DEEP2 survey to investigate the clustering evolution of the most massive galaxies observed from $z = 2$ to $z = 0$. By deriving the mass of the host dark matter haloes from clustering analyses, we show that the stellar fraction is lower in more massive dark matter haloes, and that more massive galaxies inhabit more massive dark matter haloes which form earlier, in agreement with downsizing effects. The global picture resulting from this study is that the most massive galaxies are formed early in massive dark matter halos. At some stage the evolution of these massive galaxies stops and henceforth evolves passively, while their

https://doi.org/10.1017/S174392131102299X Published online by Cambridge University Press

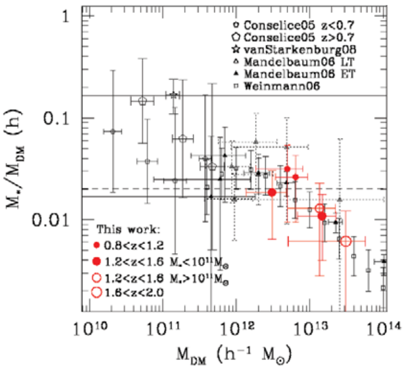

Figure 2. Evolution of the stellar to dark matter mass ratio with **(a)** the mass of the dark matter halo in different redshift bins, and with **(b)** the redshift in different stellar mass bins (Foucaud *et al.* 2010). We compared our measurements with literature (Conselice *et al.* 2005; Mandelbaum *et al.* 2006; van Starkenburg *et al.* 2008; Weinmann *et al.* 2006). The continuous line represents the baryonic fraction measured from WMAP5 (Komatsu *et al.* 2009), and the dashed line the mean stellar fraction in the local Universe estimated by Cole *et al.* (2001).

halo keep growing in mass, with their baryonic mass taking form of satellite galaxies or warm and hot gas.

References

Bruzual & Charlot 2003, *MNRAS*, 344, 1000
Bundy, Ellis & Conselice 2005, *ApJ*, 625, 621
Bundy, Ellis, Conselice *et al.* 2006, *ApJ*, 651, 120
Coil, Newman, Kaiser *et al.* 2004, *ApJ*, 617, 765
Cole, Norberg, Baugh *et al.* 2001, *MNRAS*, 326, 255
Conselice, Bundy, Ellis *et al.* 2005, *ApJ*, 628, 160
Conselice, Bundy, Trujillo *et al.* 2007, *MNRAS*, 381, 962
Conselice, Bundy, U *et al.* 2008, *MNRAS*, 383, 1366
Cowie & Barger 2008, *ApJ*, 686, 72
Davis, Faber, Newman *et al.* 2003, *SPIE*, 4834, 161
Davis, Guhathakurta, Konidaris *et al.* 2007, *ApJ*, 660, L1
Drory & Alvarez 2008, *ApJ*, 680, 41
Foucaud, Conselice, Hartley *et al.* 2010, *MNRAS*, 406, 147
Gonzalez, Zaritsky & Zabludoff 2007, *ApJ*, 666, 147
Komatsu, Dunkley, Nolta *et al.* 2009, *ApJS*, 180, 330
Landy & Szalay 1993, *ApJ*, 412, 64
Magliocchetti & Maddox 1999, *MNRAS*, 306, 988
Mandelbaum, Seljak, Kauffmann *et al.* 2006, *MNRAS*, 368, 715
Meneux, Guzzo, Garilli *et al.* 2008, *A&A*, 478, 299
Mo & White 2002, *MNRAS*, 336, 112
Neistein, van den Bosch, & Dekel 2006, *MNRAS*, 372, 933
van Starkenburg, van der Werf, Franx *et al.* 2008, *A&A*, 488, 99
Weinmann, van den Bosch, & Yang, Mo 2006, *MNRAS*, 366, 2

https://doi.org/10.1017/S174392131102299X Published online by Cambridge University Press