Formation and Evolution of Galaxy Bulges
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Intense starbursts at z∼5: first significant stellar mass assembly in the progenitors of present-day spheroids

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Abstract. High redshift galaxies play a key role in our developing understanding of galaxy formation and evolution. Since such galaxies are being studied within a Gyr of the big bang, they provide a unique probe of the physics of one of the first generations of large-scale star-formation. We have performed a complete statistical study of the physical properties of a robust sample of z∼5 UV luminous galaxies selected using the Lyman-break technique. The characteristic properties of this sample differ from LBGs at z∼3 of comparable luminosity in that they are a factor of ten less massive (∼few$\times 10^9$ $M_\odot$) and the majority (∼70%) are considerably younger (<100Myr). Our results support no more than a modest decline in the global star formation rate density at high redshifts and suggest that ∼1% of the stellar mass density of the universe had already assembled at z∼5. The constraint derived for the latter is affected by their young ages and short duty cycles which imply existing z∼5 LBG samples may be highly incomplete. These intense starbursts have high unobscured star formation rate surface densities (∼100s $M_\odot\,yr^{-1}\,kpc^{-2}$), suggesting they drive outflows and winds that enrich the intra- and inter-galactic media with metals. These properties imply that the majority of z∼5 LBGs are *in formation* meaning that most of their star-formation has likely occurred during the last few crossing times. They are experiencing their first (few) generations of large-scale star formation and are accumulating their first significant stellar mass. As such, z∼5 LBGs are the likely progenitors of the spheroidal components of present-day massive galaxies (supported by their high stellar mass surface densities and their core phase-space densities).

Keywords. galaxies: formation, galaxies: evolution, galaxies: high-redshift, intergalactic medium

1. Introduction

When did galaxies form their first generations of stars? Through a comprehensive analysis of the physical properties of a large sample of high-redshift galaxies, we have made steps towards answering this question and present evidence that UV-luminous compact starbursts at high redshift are the likely progenitors of the spheroidal components of present-day massive galaxies (Verma *et al.* 2007). We have used the multiwavelength data of unparalleled depth in the Chandra Deep Field South to uniformly select a large sample of galaxies at z∼5 using the Lyman-break technique. Through an extensive analysis of their rest-frame UV-to-visible spectral energy distributions, we simultaneously derive photometric redshifts and the key properties of age, extinction, SFR and stellar mass using evolutionary spectral synthesis modelling (e.g. Sawicki & Yee 1998).

We find that LBGs at z∼5 are less massive and younger than equivalently luminous LBGs at z∼3, while the SFRs are similar. They are also more compact ($r_e\sim$ 1kpc), in line with the expected size evolution of UV-selected galaxies with redshift. The z∼5 LBGs have extremely high SFRs per unit area, exceeding the limit above which all

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local starbursts host winds. Thus, z∼5 LBGs are likely to drive winds and enrich the intergalactic medium with metals, supporting the lack of evolution seen in the density of metal ions in the IGM with redshift (e.g. Songaila 2005 and references therein).

2. Progenitors of old bulges and early-type galaxies

Interestingly, the physical properties of these compact luminous galaxies suggest they are plausibly the building blocks of the old spheroidal components of present-day massive galaxies. Notably, rather than high stellar mass which is often taken as evidence for the progenitor scenario, we find z∼5 LBGs to have high stellar mass surface densities, which has been shown to be the overriding parameter that describes a galaxy's morphology (Kauffmann *et al.* 2006). The fact that the high stellar mass densities we find are comparable to present-day early type galaxies, and do not fall on the relation seen for late-type systems, adds weight to the progenitor scenario. Kauffmann *et al.* hypothesize that with increasing compactness and surface density of a galaxy, stars were formed in short vigorous bursts at higher redshift with extended periods of inactivity.

The star formation that dominates the UV-to-visible SEDs of the z∼5 LBGs is likely to originate from such a burst in which a significant fraction of the stellar mass in the system has been formed. For our systems with $r_e \sim 1\,\mathrm{kpc}$ and $M \sim 2 \times 10^9 \mathrm{M}_\odot$, a simple estimate of the dynamical time-scale is $t_{dyn} = r\,/\,V = (n\,r^3\,/\,M\,G)^{1/2} \sim 20\,\mathrm{Myr}$. Therefore the intense star formation in these young z∼5 LBGs (age∼100Myr) has been typically proceeding for approximately 1 to ∼5 dynamical time-scales. A system that has assembled a significant fraction of its stellar mass over the last few dynamical time-scales is in essence *a galaxy in the process of formation.*

In the hierarchical merging scenario, phase-space density arguments suggest that massive, present-day elliptical galaxies have formed from the merging of high redshift disk galaxies, which are smaller and denser than disk galaxies seen today (Mao & Mo 1998). Following Carlberg (1986) and Mao & Mo (1998), the core phase-space density of the typical z∼5 LBG in our sample is $\sim 10^{-6} \mathrm{M}_\odot\,(\mathrm{pc\ km\ s}^{-1})^{-3}$. This is consistent with the core phase-space densities of massive, bright present day ellipticals and the central region of the Milky Way (Carlberg 1986, Avila-Reese *et al.* 2005). This similarity strongly suggests that the central population of these systems is already in place at high redshift.

Young z∼5 LBGs may represent the formation of the central regions of present-day massive galaxies at the earliest stages of their evolution. Given the circumstantial evidence that the z∼5 LBGs drive winds, have young ages and short duty cycles, it is plausible that these galaxies will grow in bursts of star formation. While we cannot know the evolutionary path of these galaxies, their dynamical time-scales, mass surface and core-phase space densities suggest that they are the progenitors of early-type galaxies or bulges. If so, their abundance at a look-back time of 12-13 Gyr is consistent with the age of the dominant stellar population in the Galactic Bulge (Rich *et al.* 2005) and its proposed formation in short bursts 1-2 Gyr after the big bang (Zoccali *et al.* 2006).

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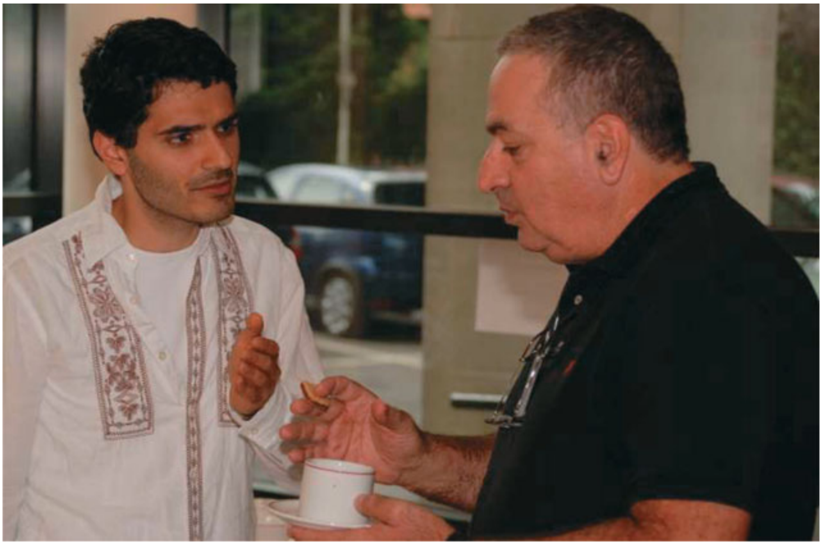

Figure 1. Sadegh Khochfar and Avishai Dekel discussing during a coffee break.

Figure 2. Sebastian Perez and LOC member Millier Maier manning the front desk.

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Figure 3. LOC member Marc Sarzi, Igor Chilingarian, Jochen Liske, Genevieve Graves and Roger Davies discussing during a coffee break.

Figure 4. Roger Davies and SOC member David Koo at high table during the symposium dinner.

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Figure 5. Carlos López San Juan, Lilian Domínguez-Palmero, and Javier Alonso García during the symposium dinner.

Figure 6. Christopher Conselice, Duncan Forbes and Russell Smith during the symposium dinner.

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Figure 7. Lauren MacArthur, Brad Gibson, Patricia Sánchez-Blázquez and Stéphane Courteau during the symposium dinner.

Figure 8. SOC members Dante Minnite, Lia Athanassoula and SOC and LOC chair Martin Bureau at high table during the symposium dinner.

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