Highlights of Spanish Astrophysics VII, Proceedings of the X Scientific Meeting of the Spanish Astronomical Society held on July 9 - 13, 2012, in Valencia, Spain. J. C. Guirado, L. M. Lara, V. Quilis, and J. Gorgas (eds.)

Massive galaxies: a gate to large area very deep galaxy surveys

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Abstract

Massive ($M_{\rm stellar} \geq 10^{11} h_{70}^{-2} {\rm M}_\odot$) galaxies are privileged probes to explore galaxy evolution, as their high luminosities allow us to track them over a large span of cosmic time. They suffer dramatic modifications in their sizes, star formation histories and number densities from high to low redshift. This must be also reflected in their structural parameters and thus we present here how their Sérsic indices and visual morphologies change since $z = 3$. This has been confirmed by analysing the rotational support for 10 of these objects at $z = 1.4$. Future large area and deep surveys as UltraVISTA will unveil the relation of this galaxy population with their lower mass companions, and hence constraining the ΛCDM paradigm.

1 Introduction

Massive ($M_{\rm stellar} \geq 10^{11} h_{70}^{-2} {\rm M}_\odot$) galaxies have drawn a great deal of attention in the recent years because of being already in place at high-z ($z \sim 1.5$, e.g. [31, 29]), showing in many cases no ongoing star formation even at this early cosmic epoch (e.g. [32, 12]) and having very small sizes (3–5 times on average smaller than their local Universe counterparts, e.g. [34, 8]). These properties have been satisfactorily explained by a combination of very dissipative formation and a later evolution mainly driven by dry (little gas content) merging (e.g. [33, 24, 7]). In addition, simulations are now able to reproduce their observational characteristics ([35, 30]). However, certain questions remain controversial, namely finding their progenitors at even higher redshift [2], the existence of cold gas streams which fed the massive galaxies with material to sustain high star formation rates at $z > 1.5$ [13] or how these galaxies quench so abruptly their star formation activity [3] to become the large early type massive galaxies at $z = 0$ [4]. For more information, we refer the reader to the communication of I. Trujillo, in this current proceedings volume.

Certainly, the dramatic changes we observe between the low and high redshift massive galaxy population must be accompanied by a morphological evolution, but so far this has not been properly quantified. Here we describe a series of studies which attempt to shed some light into this matter. We assume throughout the present communication a "concordance" cosmology, AB magnitudes and Chabrier [14] IMF unless otherwise stated.

2 Morphological change of massive galaxies since $z = 3$

Firstly, we have studied a sample of 1082 galaxies at $0 < z < 3$ (having a total 875 spectroscopic redshifts) coming from SDSS DR7[1], POWIR/DEEP2[16] and GNS[17]. For the SDSS data we use the NYU catalog[5], with masses coming from [6]. In the other two surveys, photometric masses and redshifts are calculated based on the standard multi-color stellar population fitting techniques[11]. For details in the photometry, uncertainties or any other part of this work please read [9]. We have studied these large samples in the optical restframe both quantitatively (using the Sérsic index n as a morphological proxy) and qualitatively (by visual inspection). Furthermore, we ran extensive simulations [34, 9] in order to asses the reliability of our structural parameter determination.

Our results unequivocally show a decrease in the overall Sérsic index for this galaxy population (Fig. 1). At high-z, very large Sérsic indices are almost non-existent, while at low redshift even late type massive spiral galaxies posses most of the times $n > 2$. Overall, Sérsic indices become progressively smaller as we go back in cosmic time. Figure 2 illustrates the evolution with redshift of Sérsic index and visual morphology for massive galaxies. The upper row takes into account the evolution in the percentage of objects, while the bottom row uses their number densities. It is clear that, when taking Sérsic index as a fiducial parameter, there is a drastic modification in the properties of these galaxies at different cosmic epochs. If we split between disk ($n < 2.5$) and spheroid-like ($n > 2.5$) galaxies, these latter objects are more common at low-z, while the opposite is true for the former. Looking at the number densities, the first lesson to learn is that not all the local Universe massive galaxies come from $z > 2$. Moreover, whatever mechanism is creating those galaxies must account for the fact that their Sérsic index is progressively higher. Paying attention now to the visual morphologies, we want to highlight the fact that not all the massive galaxies are early-types at low-z (one third of them are well described as spirals) and also that, joining the contributions from late-types and peculiar/merging galaxies, they account for $\sim$80% of the high redshift massive galaxies. Massive galaxies are predominantly early-types only since $z = 1$.

We attribute these changes in the visual morphologies and the luminosity profiles to several reasons. There is a development of the galaxy outskirts with redshift. We associate this with minor merging, as it has been demonstrated these massive galaxies have many low-mass companions, with lately must been accreted and hence increase the Sérsic indices and sizes of the major objects (e.g. [25]). In addition, a bulge growth is also expected considering

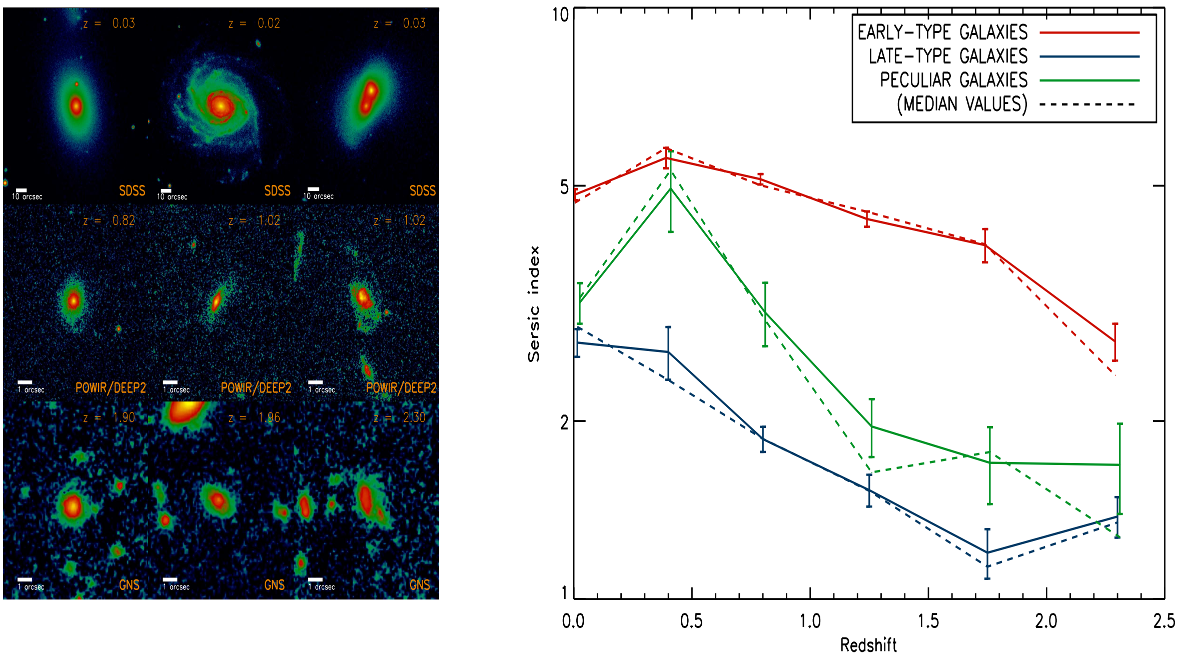

Figure 1: *Left panel:* Some examples illustrating our morphological criteria (columns) for different galaxies in our sample. Each row shows galaxies from the different surveys. Despite the decrease in angular resolution and the cosmological surface brightness dimming with redshift, the exquisite HST depth and resolution (∼10 times better than ground-based SDSS imaging) allow us to explore the morphological nature of the high-z galaxies. Note that irregulars and mergers are in the same morphological class (peculiars). *Right panel:* Evolution of the mean Sérsic index values over redshift according the visual classifications of the galaxies within our sample. Data points for early-types and peculiars are slightly offset for the sake of clarity. Dashed lines are similar but taking median values instead. Errors bars stand for the uncertainty of the mean $(\sigma/\sqrt{(N-1)}$, being σ the standard deviation and N the total number of galaxies for each bin). These bars are slightly larger at $0.2<z<0.6$ because of the comparatively poor statistics at this redshift interval. From that epoch to higher redshifts there is a clear separation between early-type massive galaxies and the rest of visual types, being all the average Sérsic indices lower at increasing redshift.

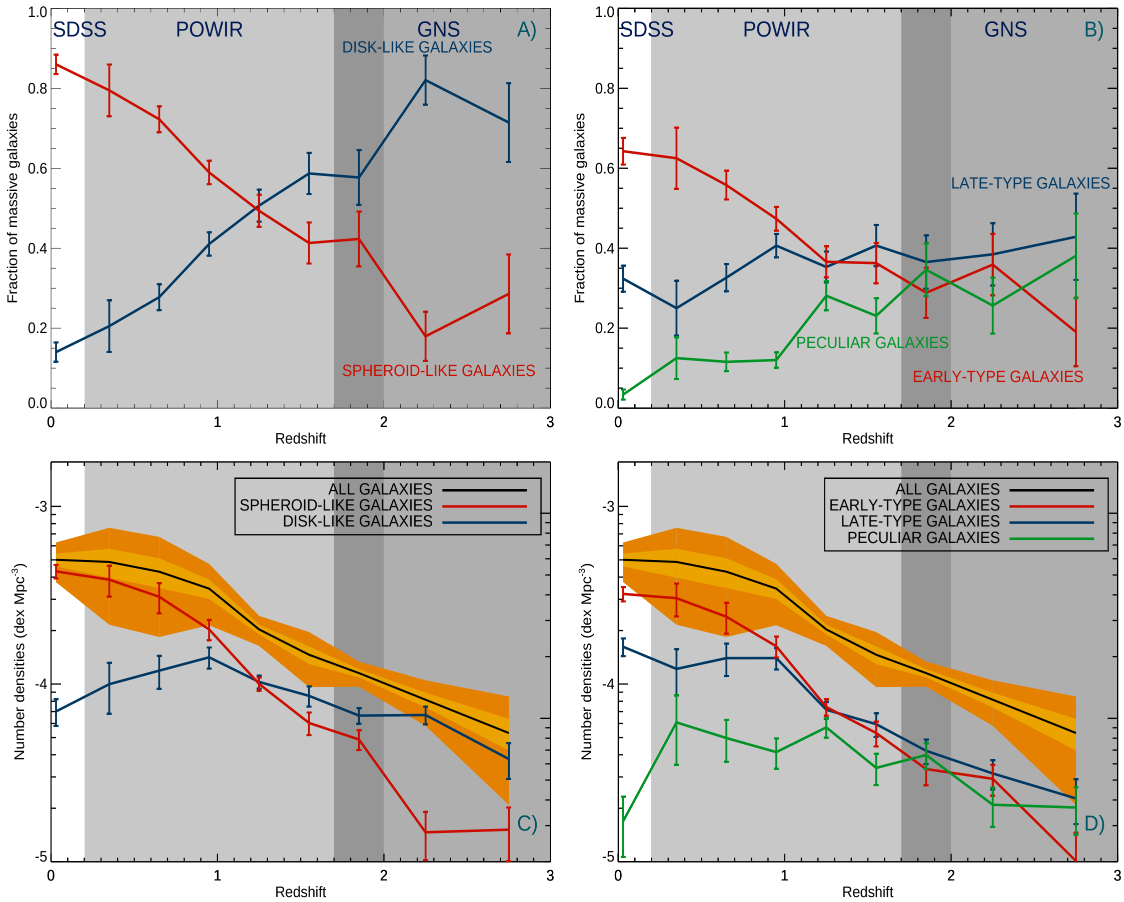

Figure 2: Panel A): Fraction of massive ($M_* \geq 10^{11} h_{70}^{-2} \mathrm{M}_\odot$) galaxies showing disk-like surface brightness profiles ($n < 2.5$) and spheroid-like ones ($n > 2.5$) as a function of redshift. Different color backgrounds indicate the redshift range expanded for each survey: SDSS, POWIR/DEEP2 and GNS. Error bars are estimated following a binomial distribution. Sérsic indices are corrected based on our simulations[34, 8] B): Same as Panel A) but segregating the massive galaxies according to their visual morphological classification. Blue color represents late type (S) objects and red early type (E+S0) galaxies, while peculiar (ongoing mergers and irregulars) galaxies are tagged in green. Panel C): Comoving number density evolution of massive galaxies splitted depending on the Sérsic index value.The solid black line corresponds to the total number densities (the sum of the different components), with yellow and orange contours indicating 1σ and 3σ uncertainties in their calculation. Panel D): Same as panel C) but segregating the massive galaxies according to their visual morphological type.

passive evolution for many of these massive galaxies.

3 3D spectroscopy confirmation of the rotational support of massive galaxies at $z = 1.4$

All the previous evidence we have shown for the transition of massive galaxy properties with redshift stem from photometric measurements. However, spectroscopy is needed to validate to what extent the depicted scenario is plausible. Integral field spectroscopy is the perfect tool for addressing these questions, as the observed kinematics help us understand whether rotational velocity or chaotic motions are responsible for the gravitational support of massive galaxies. Besides, the access to the extra spatial dimension allow us to follow the elusive minor merging, and thus understanding how galaxy assembly takes place.

We have observed 10 massive galaxies ($M_* \geq 10^{11}\mathrm{M}_\odot$) at $z \sim 1.4$ with the Integral Field Spectrograph SINFONI at VLT. For a further explanation we refer to [10]. Our sample of galaxies have selected by their stellar mass and EW[OII]$>$ 15 Å, to secure their kinematical measurements, but without accounting by any morphological criteria a priori. The parent survey was once again the POWIR/DEEP2 survey[11, 16], with spectroscopic redshifts presented in [15]. SINFONI was utilised in seeing limited mode ($0.125'' \times 0.25''$). Observations were carried out in the H-band in order to map the Hα emission line at a resolution $R = 3000$ to disentangle OH sky emission lines. Our observational strategy was the so-called 'butterfly pattern' or 'on-source dithering', by which the galaxy is set in two opposite corners of the detector to remove sky background using contiguous frames in time. The mean seeing value was 0.56 arcsec.

The ESO-SINFONI pipeline version 2.5.0 [27, 28] was utilised in order to reduce our data. We analyse the final datacube with IDL routines we constructed. Basically, we located the Hα line in each spaxel according to the known spectroscopic redshift of the target galaxy, and then fit a Gaussian profile, taking into account the sky spectrum. We fit (according the prescriptions in [21]) rotating disk models to the velocity fields that allowed to derive rotation velocities and correct the velocity dispersion maps from beam smearing. Hence we minimize potential error sources as the uncertainty in the inclination of the galaxies or the broadening of the spectral lines by velocity shear.

The massive galaxies in our sample show remarkably ordered rotational velocity gradients and high velocity dispersions, as has been seen before in star-forming but less-massive 3D spectroscopy samples at high redshift. All galaxies from our sample show $V_{max}/\sigma > 1$, where this ratio in most cases is greater than 2.4 (see Fig. 3). These large V_{max}/σ ratios are however at odds with local Universe counterparts, which either display $V_{max}/\sigma < 1$ (e.g. [19]) for early-type galaxies or $V_{max}/\sigma > 10 - 20$ (e.g. [18]) in case of spirals. We agree with the explanation given in previous high redshift 3D spectroscopy studies [20, 23, 22] such that, at high redshift, galaxy formation and evolution is a more turbulent process because of the larger amounts of cold gas involved, which at the same time leads to higher star formation rates than in the present day Universe.

We conclude that massive galaxies acquire more rapidly a given morphology and grav-

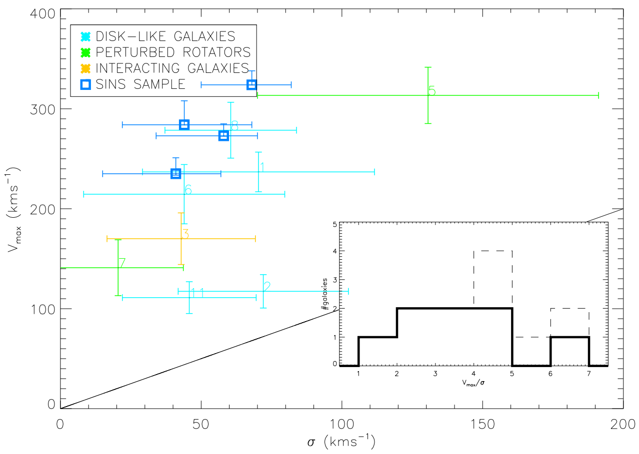

Figure 3: Maximum rotational velocity inferred from our modeling versus the integrated velocity dispersion after correcting it for beam smearing. Numbers depict each one of the massive galaxies from our sample, whereas the blue squares come from the SINS sample[22]. We also attach the histogram of the V_{max}/σ of our massive galaxies with and without the SINS galaxies (solid or dashed histogram respectively). For all these massive galaxies $V_{max}/\sigma > 1$, as they lay above the 1:1 solid line, with most of them showing ratios even greater than 2.4 which corroborates their gravitational support.

itational equilibrium than less-massive objects, accounting for what we call a morphological downsizing. We attribute this characteristic to the fact that, as we are dealing with the most massive galaxies at their redshifts, their high masses help protect them from being perturbed. Mass has not only a profound impact in the galactic assembly and the star formation history of these galaxies, but it is also crucial for understanding their eventual morphological development, whereby they progressively join the observational properties of the massive galaxies in the nearby Universe.

4 Large area and deep surveys: the future for exploration of massive galaxies

Only thinking of a Press-Schechter formalism, it is easy to realize massive galaxies are inherently scarce objects. If one wants to probe statistically significant numbers of them, exploring their impact in the surrounding environment and reaching relatively high redshifts, the only way forward is conducting large area and very deep galaxy surveys. Our group is working using a so-called "wedding-cake" approach, by which one uses larger but shallower surveys for detecting massive galaxies, and then as fainter details are needed one concentrates in a smaller but deeper region of the images.

In our case, we work with the nobel UltraVISTA survey [26], whose total field of view is 1.5×1.2 square degrees. When finished, its deep stripes will reach limiting magnitudes $H = 26.1$ and $K = 25.6$. Besides, it is located in the COSMOS filed, and thus it benefits from the extensive multi-wavelength coverage of it. At the moment, we are building galaxy mass functions and performing morphological studies in an analogous fashion as in Sect. 1. Constraining how the high mass end of the galaxy mass function evolves with redshift is mandatory to fully understand the ΛCDM paradigm.

Acknowledgments

We are thankful to all the co-authors in [9, 10], as these papers are the base of the present communication.

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