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Massive compact galaxies in the local Universe: what are they?

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Abstract

Recent investigations have provided evidences that many massive ($M_* > 10^{11}$ M$_\odot$) spheroid galaxies in the early universe ($z \geq 1.5$) were extremely compact ($r_e \sim 1$ kpc). According to some galaxy formation theories, a fraction of these massive galaxies in the local Universe would represent surviving relics of the high-z massive galaxies. We present a detailed study of the kinematics and the stellar populations for seven local compact galaxies for which we obtained high-quality long-slit spectra. We find that these galaxies show metallicity values around solar. However, unlike common, average-sized local ellipticals of similar velocity dispersion, they show young (< 2 Gyr) mean luminosity weighted ages as well as a clearly different abundance ratio pattern. In addition, almost all these massive compact local galaxies show strong rotation curves. The stellar population findings point that these local objects cannot be the relics of high-z compact ellipticals. The most stricking result we have found is that our full spectrum-fitting analysis shows that the stellar populations of our galaxies are mainly contributed by young populations.

1 Introduction

During the last years, several studies have found that most massive ($M_* \geq 10^{11}$ M$_\odot$) galaxies, independently of their star formation rate, were more compact on the past (a factor of ~ 4 at $z > 1.5$) than their equally massive local counterparts ([10, 23, 21, 9, 2] and others). Many works have focused on this high-z massive galaxies, but it is crucial to address the question of how these high-z galaxies have evolved into present-day massive population. There are several scenarios proposed to explain how the high-z massive galaxies form and evolve, but the most popular ones suggest that "dry mergers" are the dominant mechanism for the size and stellar mass growth [14, 13]. As cosmic time evolves, the high-z compact galaxies are thought to evolve into present-day cores of the brightest cluster galaxies. But this should not happen for all compact galaxies, so we should find few massive relic compact galaxies in the local universe having old stellar populations. Another posssible scenario was described by [11], were they claimed that the size evolution is related to the quasar feedback, which removes huge amounts of cold gas from the central regions, quenching the star formation.

High-z massive compact objects are being hardly debated as some of their properties, such as velocity dispersions and ages, have not been totally accepted for all the community ([5, 24, 26] and others). In fact, [5] found that there is only a mild velocity dispersion evolution of these objects since $z \sim 2$. Thus a detailed kinematical and stellar population analysis for these objects turns out to be crucial, and still lacking, for providing unique clues for understanding their nature and evolution.

If superdense massive galaxy relics exist in the nearby Universe ($z < 0.2$) we should be able to find several thousands in the SDSS DR6 spectroscopic survey, according to some models [13]. In [24], 29 such superdense massive galaxies were found using the NYU Value-Added Galaxy Catalog [1]. A stellar population study employing spectra from the SDSS was carried out, showing that the mean luminosity-weigthed ages for the local compact objects were significantly smaller than the ones obtained for a control sample of average-sized galaxies of similar masses, challenging the expectations. Unfortunately the modest quality of the SDSS prevented them to perform a more detailed study of their stellar populations.

We present new high-quality spectra for seven of this local compact galaxies, with a detailed kinematical and stellar populations analysis [12], that includes, appart from line-strength measurements to derive mean luminosity weighted ages, metallicities and abundance ratios, the study of their star formation histories using the full spectrum-fitting approach. Moreover, we obtained high sub-kpc quality imaging with adaptative optics at GEMINI-N [25] for some of our candidates.

2 Data sample and reduction

The galaxies analyzed here were taken from an original sample of 29 local compact galaxies (see [24] for more information about the sample selection). They were chosen with $0 < z < 0.2$ and they have mean $M_{*} > 9.2 \times 10^{10}$ $M_{\odot}$ and mean effective radius $r_{\mathrm{e}} \sim 1.3$ kpc. From this sample of 29 compact galaxies, we obtained high-quality longslit spectra for seven compact galaxies in the 4.2 m William Herschel Telescope with the blue arm of the ISIS spectrograph with the grating 600B. Several exposures of 30 minutes were taken for each galaxy depending on their redshift, with the slit positioned along the major axis. Some spectrophotometric standards and stars from the MILES library [19, 6] were taken for flux calibration. We performed a standard data reduction (bias substraction, flat-fielding, cosmic-ray removal, C-and S- distortion correction, wavelenght calibration, sky substraction and flux calibration) using `REDUCEME` [4], an optimized reduction package for long-slit spectra that gives the error that is propagated as the data is handled.

Table 1: Galaxies properties

ID NYU	r_e(kpc)	z	S/N (Å^{-1})	σ (km s^{-1})	b/a	n	χ^2
54829	1.10	0.085	41	136	0.90	4.60	0.566
321479	1.20	0.128	62	221	0.51	5.81	1.175
685469	1.48	0.149	70	203	0.45	3.03	0.599
796740	1.24	0.182	26	203	0.35	2.40	0.556
890167	0.81	0.143	32	233	0.63	3.72	0.547
896687	1.64	0.130	50	222	0.91	7.64	0.432
2434587	1.13	0.172	46	205	0.40	5.45	0.838

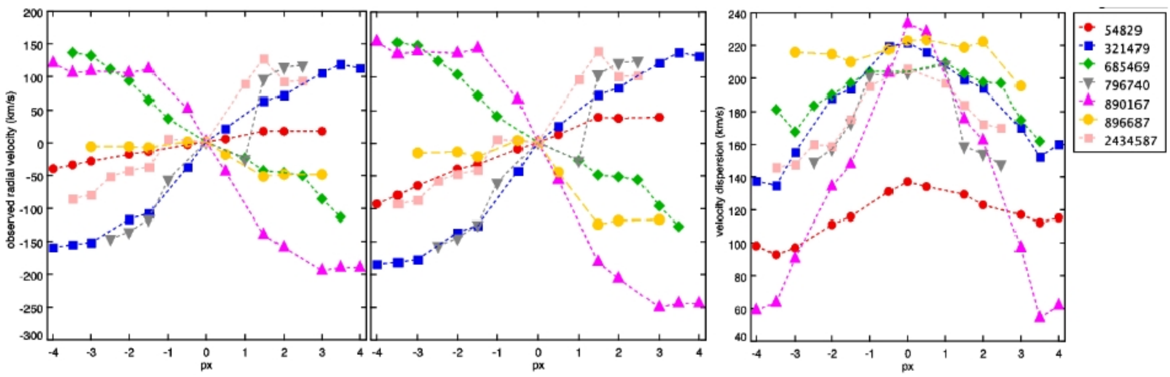

Figure 1: a) Observed radial velocity (km s^{-1}) derived with `PPxF`; b) Radial velocities corrected from inclination effects. It can be seen that galaxies 2434587 and 54829, which do not show rotation in the first panel now appear to rotate; c) Velocity dispersion (km s^{-1}) from `PPxF`.

3 Kinematics

We used `galfit` [17] to obtain the values of the major and minor axis, the effective radius, the Sérsic index and the axis ratio b/a (see Table 1, where the value of the χ^2 for the best fit is also shown). For the kinematical study we used the penalized pixel fitting method (`PPxF`, [3]) to measure the radial velocity and the velocity dispersion. For all the galaxies, we first corrected from emission lines effects using `GANDALF` [20], although we only found nebular emission in one galaxy, 685469. Due to the differences in redshift and S/N, different aperture extractions were applied to each galaxy to derive the rotation curve. We find strong rotation curves in five of these galaxies (see Fig.1 a). Galaxies 890167 and 321479 are the ones that show stronger rotation curves as well as among the highest σ values. For the remaining two galaxies no significant rotation is found. However, if we take into account the inclination angles that we derived for these objects, we see that they also rotate (see Fig.1 b).

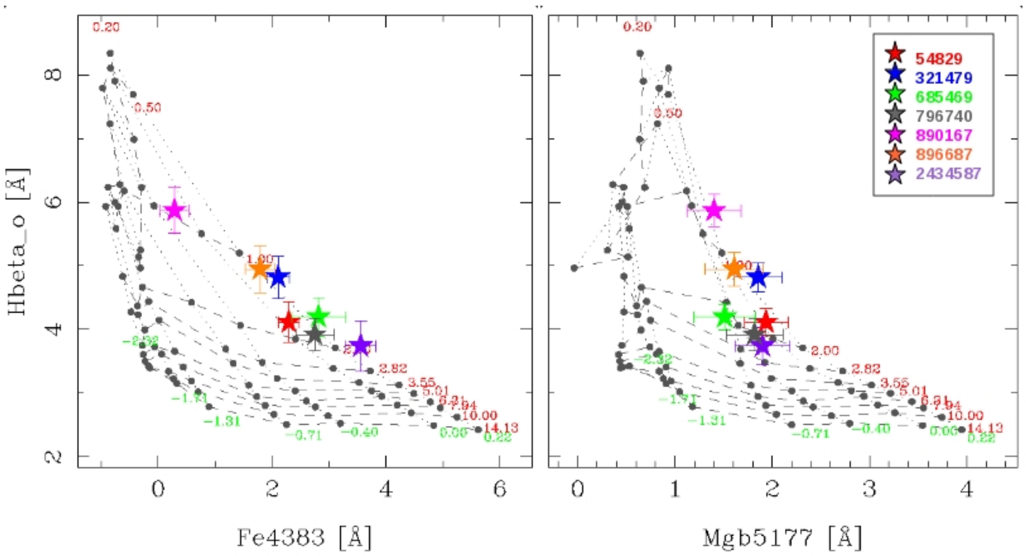

Figure 2: The age-sensitive indicator Hβ_o is plotted against various metallicity indices. The SSP model grids of [27] are plotted. Age increases from top to bottom and metallicity from left to right. Note that all these compact objects show mean luminosity-weighted ages smaller than 2 Gyr and most show metallicity values around solar.

4 Stellar populations and star formation histories

We performed our stellar population analysis using the models of [27] and the newly-defined LIS-14.0 Å system of indices introduced in that paper, which is characterized for having a constant resolution, i.e. 14 Å (FWHM), and a flux-calibrated response. Therefore all our line-strength measurements, including the Lick indices [28, 22], are performed on this system. We also used the newly-defined metallicity-insensitive index Hβ_o [7]. Unlike with the standard Hβ Lick index, these model grids are rather orthogonal and thus the measured ages are similar in all the panels. Figure 2 shows that all our 7 compact galaxies present young mean luminosity-weighted ages (< 2 Gyr), being the galaxy 890167 younger than 1 Gyr. These results are in good agreement with the analysis performed in [24], where the 29 compact galaxies present ages ~ 2 Gyr, whereas a control sample of local ellipticals with similar mass present very old ages (~ 14 Gyr). Overall we find metallicity values around solar for most of our compact galaxies, though a scatter in the metallicity inferred among the panels of Fig. 2 is seen for a given galaxy. Precisely these metallicity values can be used to estimate on a relative scale the abundance ratio pattern of these objects [27]. We generally find that [C/Fe] $\sim$ 0, [CN/Fe] $\sim$ 0, [Mg/Fe] $\leq$ 0 and [Ca/Fe] $<$ 0. Such pattern differs from that observed in local ellipticals with similar velocity dispersions.

Next we investigate whether the young mean luminosity-weighted ages obtained for these compact galaxies are due to the contribution of recent bursts that mask the old population, which is dominant in mass, or, alternatively, they are genuinely young objects. Therefore we apply the full spectrum-fitting approach to estimate their star formation histories (SFHs).

We used for this purpose three different and widely used algorithms: `ULySS` [15], `STARLIGHT` [8] and `STECKMAP` [16], using for all them the [27] SSP SED library. We find that the three codes provide very consistent results for each galaxy: four objects are found to be genuinely young, i.e., without any significant contribution of an old population, either in light or mass. For the remaining three objects we find that the younger stellar populations contribute with at least 70% of the light.

It is worth noting that this work has been done by extracting a central aperture of size $1r_{\rm e}$. Taking advantage of the spatial information provided by our high-quality long-slit spectra we are currently carrying out a similar analysis to obtain the stellar population gradients of these objects [12].

5 Results and discussion

We provide further evidences that at least 7 out of the 29 objects of the compact and massive galaxy sample identified by [24] in the Local Universe represent a peculiar type of objects, as inferred from a detailed analysis of their kinematical and stellar population properties. These galaxies were initially thought to be the low-z counterparts of high-z massive compact ellipticals. Although these galaxies present central velocity dispersions around $\sim$200 km s^{-1}, as in local large-sized massive ellipticals, we find strong rotation curves, which would resemble the spirals.

From the point of view of the stellar populations, we find that all our objects present young mean luminosity-weighted ages (≤ 2 Gyr), as is often found in dwarf galaxies. Furthermore, a full spectrum-fitting analysis by means of three different algorithms, shows that either these objects are genuinely young (four objects) or the contribution of the younger bursts represent a 70% of light without a significant contribution of very old stellar populations. This is the first time that massive objects genuinely young have been found.

We also find that our galaxies have total metallicities around the solar value, as in massive ellipticals, but with [C/Fe] ~ 0, [CN/Fe] ~ 0, [Mg/Fe] ≤ 0 and [Ca/Fe] < 0. Except for the Ca abundance, the rest are values more alike to dwarf ellipticals or spirals than to massive ellipticals.

In summary, our local compact galaxies cannot be the low-z counterpart of the high-z compact ellipticals. Various scenarios have been proposed to explain their origin. From one side, the young stellar populations found in this work are in contradiction with the "dry merger" scenario because it assumes that the populations should be old [14], but tend to be in agreement with the "puffing up" scenario [11]. Nevertheless, our age estimates for these local compact galaxies are slightly younger than predicted by this scenario. According to the Fan et al. model, after the quenching of the star formation, the galaxy needs some time to reach its new equilibrium configuration, which would be $\sim$2 Gyr for massive galaxies. This represents an upper limit for our ages but our objects are still very compact, which makes this scenario less plausible. Finally, the gas rich "disk merging" [18] is in agreement in terms of number density of objects, as we should not find many of them in the local universe since their current disk population has not enough gas. However, this scenario is in tension with the extremely compactness of our objects.

To sum up, if these local counterparts are not their descendants, how were they formed? Is their formation equivalent to the ones at high-z? In order to solve these questions we will have to wait until high-quality spectra for the high-z compacts is obtained, so we can compare, appart from their kinematics their relevant stellar population properties.

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