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The intriguing properties of local compact massive galaxies: what are they?

A. Ferré-Mateu[1,2], A. Vazdekis[1,2], I. Trujillo[1,2], P. Sánchez-Blázquez[3], E. Ricciardelli[4], and I.G. de la Rosa[1,2]

[1] Instituto de Astrofísica de Canarias, La Laguna, SPAIN
[2] Departamento de Astrofísica, Universidad de La Laguna, Spain
[3] Departamento de Física Teórica, Univ. Autónoma de Madrid, Madrid, SPAIN
[4] Departament d'Astronomia i Astrofísica, Universitat de València

Abstract

Studying the properties of the few compact massive galaxies that exist in the local Universe might provide a closer look to the nature of their high redshift ($z \geq 1.0$) massive counterparts. By this means we have characterized their kinematics, structural properties, stellar populations and star formation histories with a set of new high quality spectroscopic and imaging data. These galaxies seem to be truly unique, as they do not follow the characteristic kinematical, density profiles and stellar population patterns of present-day massive ellipticals or spirals. Summarizing, local compact massive galaxies are rare, unique and the perfect laboratory to study their high redshift counterparts.

1 Introduction

The recent discovery that massive spheroid-like galaxies ($M_* \geq 10^{11} M_\odot$) at $z \geq 1$ were approximately four times more compact that their local equivalent massive counterparts (e.g., [9, 22, 21, 8]) has opened a strong debate on which are the possible formation processes and consequent evolutionary paths for those such compact massive objects. Several models have been debated, such as the "puffing up" [10, 11] or the "minor mergers" [14, 15, 13], or the "minor/late accretion" [24, 16]. However, the observational results seem to favor this last one. According to most of these models, it would be possible that some of the massive compact high-z galaxies should have survived untouched since their formation epoch, hence being still compact ($\leq$1.5 kpc) with old stellar populations. There has been some efforts to find them in the nearby Universe ([23], T09), [20, 26], and turned out to represent only a tiny fraction ($\sim$0.03%) of the massive objects in the nearby universe ($z<0.2$; T09). Studying the properties of these nearby galaxies opens the possibility of exploring the galaxy formation mechanisms of the early universe in great detail.

For these means, we have obtained new high-quality spectroscopic data and deep K-band imaging, to properly characterize these intriguing objects.

2 The data

- *Imaging*: the high spatial resolution imaging was obtained with the GEMINI North telescope with the NIRI/ALTAIR/LGS adaptive optics system. We obtained deep K-band (2.2 μm) images for four local compact massive galaxies ([25], T12), listed on Table 2.
- *Spectra*: the high quality long-slit spectra was obtained with the WHT telescope using the blue arm in ISIS. We obtained high S/N ($\sim$40) spectra for seven T09 galaxies (two in common with T12; [12], AFM12), positioning the slit along the major axis. Due to the compactness of the objects, we could reach up to $\sim$3 R_e, which permitted to study possible gradients, apart of deriving the central measurements

NYU ID	Source	z	R_e (kpc)	n	b/a	V_r ($\mathrm{km\,s^{-1}}$)	σ ($\mathrm{km\,s^{-1}}$)	<Age>$_L$ (Gyr)	[Z/H] (dex)
54829	1	0.085	1.12	4.60	0.90	80*	137	1.40	0.00
265845	2	0.143	1.33	3.55	0.32	..	266	..	..
321479	1,2	0.128	1.35	2.66	0.28	150	221	1.12	0.30
415405	2	0.167	1.23	2.20	0.36	..	197	..	..
685469	1	0.149	1.48	3.13	0.45	90	204	..	..
796740	1	0.182	1.24	2.40	0.35	160	203	1.50	0.45
890167	1,2	0.143	0.95	2.18	0.47	200	233	0.75	0.10
896687	1	0.130	1.63	5.44	0.95	100	223	0.95	0.40
2434587	1	0.172	1.13	5.45	0.40	100*	206	2.00	0.15

Table 1: Main derived properties of the local compact massive galaxies: column 1 – galaxy ID from the NYU Value-Added Galaxy Catalog [3, 4]; column 2 – Values from AFM12 (= 1) and T12 (= 2); columns 3 to 5 – structural parameters, if both work exist, we take them from T12; column 6 – Maximal rotational velocity, the asterisk marks those galaxies in which the Vmax is not reach, thus gives only a lower limit; column 7– velocity dispersion from PPxF; columns 8 and 9 – mean luminosity-weighted age and metallicity from the classical index-index grids.

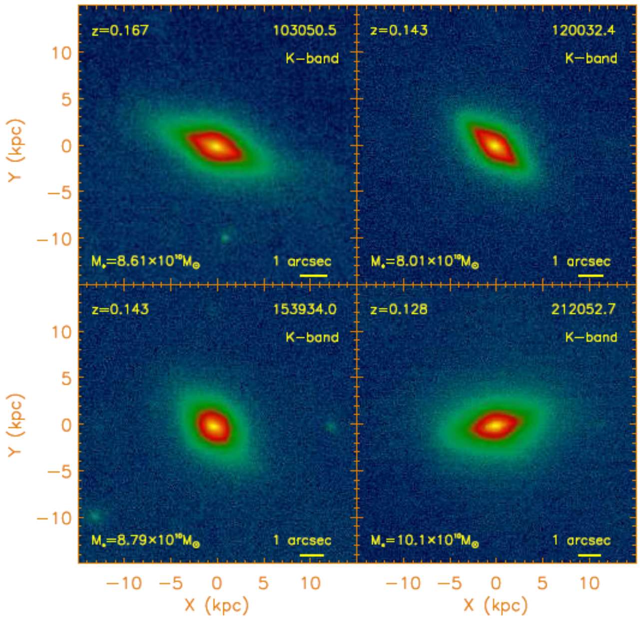

Figure 1: K-band Gemini high resolution (FWHM$\sim$0.002) imaging of four nearby (z$\sim$0.15) massive compact galaxies. Listed on each figure is the galaxy name, its stellar mass and its spectroscopic redshift. The solid line indicates 1 arcsec angular size.

3 The intriguing properties

3.1 Structural parameters

We used the 2-D fitting code `GALFIT` [17, 18] to obtain the effective radius (R_e), the Sérsic index (n) and the axis ratio (b/a), fitting a single Sérsic model. Table 2 shows that they are well fitted by a moderately low Sérsic index ($2< n <4$), giving extremely compact sizes (R_e <1.42 kpc) on these rather elongated objects (see Fig. 1). This shows no evidence of any extended faint component altering the size estimate.

Their stellar mass density profiles are significantly more dense in their inner regions than any galaxy with similar stellar mass and normal size in the local universe. Instead, they follow the exact same surface density profile as their high-z counterparts (see Fig. 2).

3.2 Kinematics

The PPxF code (Penalized Pixel Fitting, [5]) with the model templates from [27] (V10) was used to derive the kinematics of these intriguing galaxies. In many cases, they show strong radial velocities (V_r $<200\,\mathrm{km\,s^{-1}}$), even if we correct them from inclination effects, and all of them present high velocity dispersions (σ $\sim$200 km s^{-1}). Plotting them into the anisotropy diagram shows that they can all be considered fast-rotators (see Fig. 3).

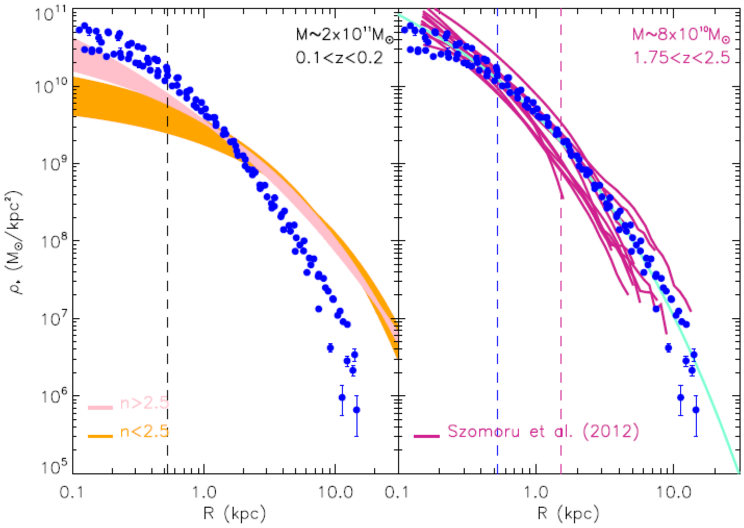

Figure 2: Stellar surface mass density profiles of our sample of nearby massive compact galaxies (blue points). *Left Panel*: The observed profiles of the compact massive galaxies are compared with the stellar mass density profiles of SDSS DR7 $M_* \geq 2\times 10^{11} M_\odot$ and $0.1 < z < 0.2$ disk-like galaxies (Sérsic index $n < 2.5$; orange region) and with spheroid-like (Sérsic index $n > 2.5$; pink region) galaxies. The vertical line shows the equivalent size in kpc of a FWHM PSF of 0.2 arcsec at $z = 0.15$. Right Panel The nearby massive compact galaxies profiles are compared with profiles $z\sim 2$ massive compact galaxies (violet lines) of the same stellar mass [19]. The agreement is remarkable. The dashed vertical blue line shows the equivalent size in kpc of a FWHM PSF of 0.2 arcsec at $z = 0.15$ (our Gemini PSF) and the red vertical line the equivalent size in kpc of a FWHM PSF of 0.18 arcsec at $z = 1.9$ (HST WFC3 PSF).

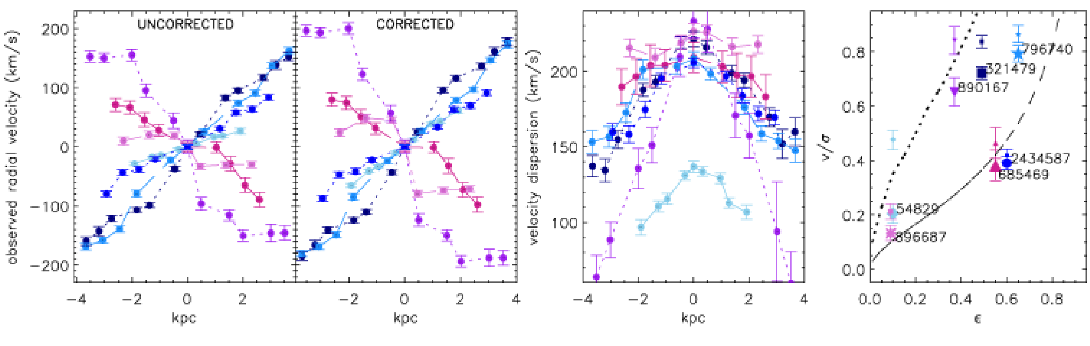

Figure 3: Radial velocities derived with `PPxF`: first panel shows the observed radial velocities, while in the second one, radial velocities corrected from inclination effects are plotted; *b)* Velocity dispersions from `PPxF`; *c)* The anisotropy diagram (V/σ, ε). Big symbols correspond to the objects without correcting from inclination effects, while the small symbols are the same galaxies but correcting the inclination effect, in case they should be corrected. The dotted black line corresponds to the location of models for oblate edge-on isotropic ($\delta = 0$) galaxies, the dashed one to the linear relation $\delta = 0.7\varepsilon_{intr}$. Relations from [6]. For those galaxies in which we do not reach the flat part of the rotation curve, these values should be considered lower limits.

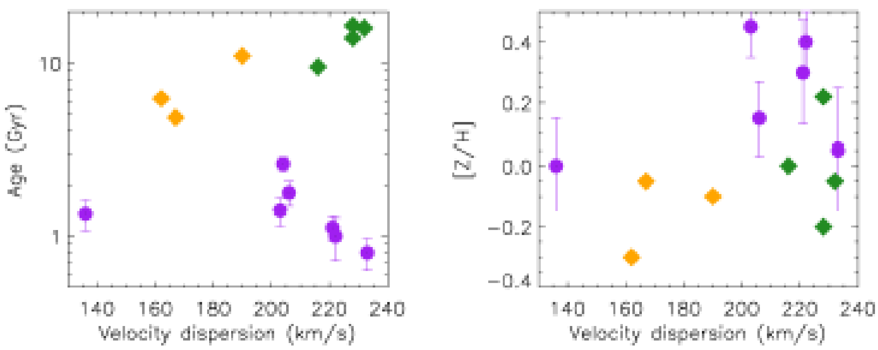

Figure 4: Derived stellar population parameters plotted *vs* the velocity dispersion for our compact galaxies (purple circles). Control ellipticals (green diamonds) and control spirals (yellow diamonds) are also shown. Note that for a given velocity dispersion, our compact objects do not show similar ages as their local large-sized counterparts, either elliptical or spiral galaxies. Moreover, their total metallicities are systematically richer.

3.3 Stellar populations

With the new LIS indices system (V10) we have confirmed that these objects present luminosity-weighted ages extremely younger than those of local normally-sized ellipticals or spirals of similar velocity dispersion. Their metallicities are also in discrepancy, showing on average, higher values (see Fig. 4).

Moreover, with the spatial information from our data we have studied possible radial gradients, if any. Except for a mild trend of the centers to be slightly younger, no specific trends are found, meaning that these objects were formed in a single event.

However, the study of the line-strengths offers only a biased estimate towards the youngest populations (dominating in light, but not in mass). To reveal the true history of a galaxy, other approaches need to be performed, such as the full-spectral-fitting. We have recovered the Star Formation Histories of these objects with the code `STARLIGHT` [7] and found that they present unusually large fractions of young stellar populations, both luminous and mass weighted. This result is surprising and no explanation is yet found to explain how is it possible to form all these mass in a single recent burst of star formation.

4 Conclusions

We have characterized the properties of a set of local compact massive galaxies in the local Universe with need high quality data. We have shown that they are genuinely compact with S0-like shapes, with no evidence of extended faint components. Their density profiles resemble only to the ones of massive compact galaxies at high-z, and showing similar kinematics to those (noticeable radial velocities, high velocity dispersions, fast-rotation nature). From the stellar populations, they also resemble to the high-z analogs with the young luminosity-weighted ages and SFHs.

Summarizing, we have shown that they are rare, unique and a perfect laboratory to study the massive compact galaxies at high redshift.

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