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Growth in size of the massive ellipticals galaxies by dry mergers

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Abstract

Massive galaxies have grown a factor of 4 in size since $z = 2$ to the present. The reasons of this growth remain unclear. Within the possible mechanisms that have been suggested to explain this evolution, the accretion of satellites by the massive galaxies seems to be the most promising one. To understand the details of this growth we have performed a suite of 8 N-body simulations in which merger times, mass ratios and orbital parameters were extracted from self-consistent cosmological simulations and reproduced in high-resolution, prepared mergers. Our simulations show that accretion of satellites is able to produce a growth in size by a factor of $\sim 4-6$ and a growth in mass by a factor of ~ 2; the growth in size occurs because satellite material is deposited in the outer part of the main galaxy. Thus, cosmological motivated dry minor mergers are sufficient to explain the size evolution of the massive elliptical galaxies.

1 Introduction

Observations have revealed that massive galaxies ($M \geq 10^{11}$ M$_\odot$) at high redshift were more compact, showing smaller effective radius and consequently higher densities than present-day massive galaxies [6, 34, 35, 38, 3]. About 60% of all compact massive galaxies are red and are evolving passively [28]. These "red and dead" galaxies show a typical size of $r_e \sim 1$ kpc [3] and velocity dispersion ranging from ~ 280 to ~ 540 km s^{-1} [39]. Such galaxies are very uncommon in the nearby universe [1, 36, 8], which means that the present-day early-type galaxies were not fully assembled at $z \approx 2$ and underwent significant structural evolution until the present day.

Minor "dry" mergers with less dense galaxies seems the most promising mechanism to turn a compact high-z galaxy into an early-type present-day galaxy [21, 16, 12, 27, 42, 11]. However, it remains unclear whether galaxy formation simulations in the context of the ΛCDM model can reproduce not only the existence of extremely compact galaxies at hight redshift but also the fact that a large spread in the properties of massive galaxies exists at low and high redshift [15]. Therefore, it is necessary to test whether minor mergers in a fully cosmological context are able to generate the observed properties of the present-day massive elliptical galaxies. We present the results of eight high-resolution N-body re-simulations in which we have used self-consistent cosmological simulations as initial conditions and we have followed observationally-derived mass-size relations.

2 Model

Our galaxy model consists of two components: a live dark matter halo with a Hernquist density profile [10] and an isotropic Jaffe profile for the luminous matter [14]. In order to resemble a massive galaxy at high redshift with an effective radius of ~ 1 kpc [35, 3] and baryon dominated in the inner part, we set a mass ratio between the luminous and the dark matter component of $10 : 1$ [9] and an initial luminous radius of 1 and a length scale of 4.8 length units for the dark matter. We built our galaxy model using $250,000$ particles including luminous and dark matter.

The simulations used to extract the initial conditions for the galaxy merger trees are part of the GALFOBS project. They are N-Body + SPH simulations that were performed using an OpenMP parallel version of DEVA code [30] and the methods for star formation and cooling described in [19]. The merger trees of the largest 8 objects with final masses $M_{\rm star} \geq 10^{11}$ $M_{\odot}$ (see Table 1) were built and the initial conditions for each merger were computed by assuming keplerian orbits.

Since the cosmological simulations lack the required resolution to recover the characteristics of the accreted galaxies, we assumed that they have the same shape as the progenitor, i.e. two components with the same parameters. We built them with a variable number of particles in order to have the same mass irrespective of the galaxy they initially come from. Given that the density contrast during the merger determines the disruption radius and, therefore, merger-induced size growth, we set satellite radii using observational mass-size relationships [31], as well as size trends with redshift [34].

All the simulations were executed by means of the public version of the GADGET-2 [33] code. We set a softening length of 0.02 and 0.04 for the luminous matter and dark matter, respectively (in internal units), and an accuracy parameter of 0.005. In all our runs, energy is preserved within $\sim 0.2\%$.

Table 1: Masses and number of satellites for all the merger histories

ID (1)	$M_{\rm i}$ [10^{11} M$_\odot$] (2)	$M_{\rm f}$ [10^{11} M$_\odot$] (3)	$M_{\rm s}$ [10^{11} M$_\odot$] (4)	N(s) (5)
1	0.833	1.000	0.167	1
2	0.674	1.260	0.584	2
3	0.521	1.580	1.06	3
4	1.38E	1.990	0.613	2
5	0.923	2.510	1.58	5
6	1.160	2.510	1.35	4
7	1.670	3.980	2.30	3
8	2.180	5.010	2.82	8

Notes: (1) identification number of the progenitor galaxy; (2): initial mass; (3): mass of the remnant; (4): total accreted mass; (5): number of accreted satellites.

3 Results

3.1 Redshift-size evolution

We plot the effective radii against redshift for all our remnants against redshift in Fig. 1 (left panel), showing the individual measurements of the effective radius each time the remnant undergoes an accretion, whereas median values are plotted at six specific redshifts. We fitted a power law to the individual measurements (OLS bisector) and found a relationship given by $r_e \propto (1+z)^{-1.738\pm0.121}$. This result is similar to that found by [27], more akin to his quiescent galaxies than for his entire sample. For the velocity dispersion (Fig. 1, right panel) we find a slight increase with respect to the initial value due to the sequential accretion events, $\sigma/\sigma_i \propto (1+z)^{-0.123\pm0.018}$, in contrast to the weak decrease found by other studies [11, 27].

3.2 Observed size-mass evolution

We have over-plotted the sample of high-concentrated (spheroid like) galaxies from [35] to our simulated galaxies in Fig. 2, where we have divided the data (spanning the range $0 < z < 2.1$) into six redshift slices. We find that, by $z < 0.8$, our eight fiducial galaxies, which started out as ultra-compat at $z = 2.5$, cover the entire size distribution of early-type galaxies once they have accreted their companions.

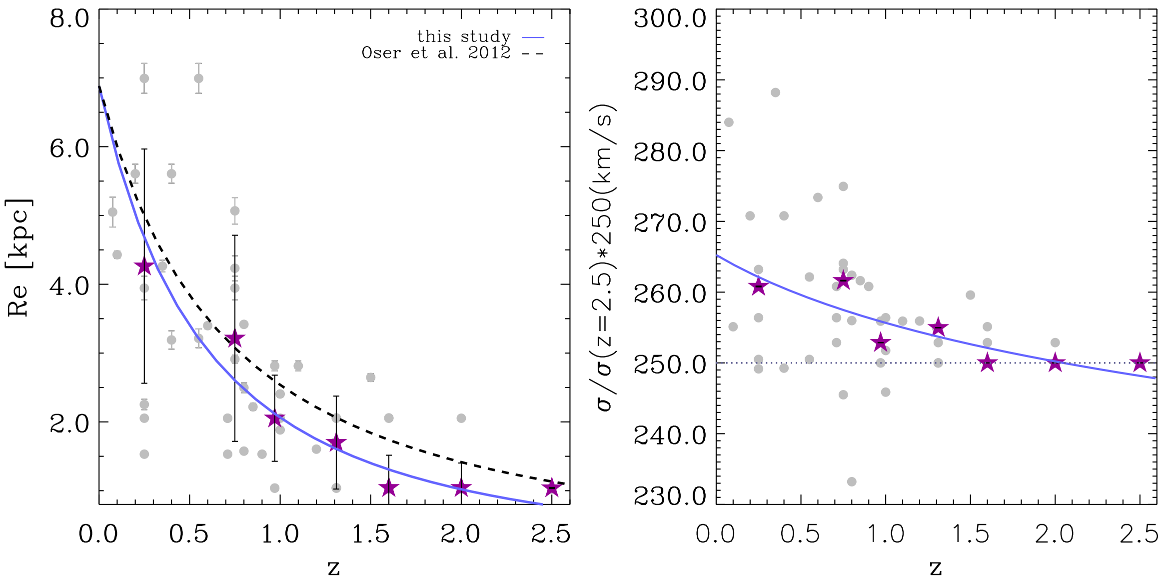

Figure 1: *Left panel:* Effective radius of the remnants as a function of redshift. Gray points correspond to the individual measurements each time an accretion occurs; the magenta stars correspond to the median values of each of the seven redshift slices. Over-plotted on the distribution of points is our power law fit (blue line) and the fit of [27] for his quiescent galaxies (dashed line). *Right panel:* Velocity dispersion of the remnants as a function of redshift. Here, each individual measurement is normalized by the initial velocity dispersion of the progenitor at $z = 2.5$ and multiplied by 250 km s^{-1}. The blue line corresponds to our power law fit.

4 Conclusions

We analyzed eight different high-resolution merger histories of massive elliptical galaxies. In all the simulations, only the most massive galaxy (the progenitor) survives until $z = 0$. These remnants, being less compact than their $z = 2$ counterparts, result from the merging and interactions with the accreted satellites, which loose their structure and deposit their material in the outer part of the main galaxy, producing its size growth. We found that our galaxies grow in size on average by a factor of 4.3208 ± 0.040 with nearly constant velocity dispersions which increase by a factor of 1.043 ± 0.055. These findings are in agreement with diverse observational works (e.g. [40, 37]), as well as with simulations [20, 12, 26], although the size increase is marginally smaller than that predicted from simple virial arguments [22].

The increase of the mass in the outer parts occurred with little or no increase in the central velocity dispersion of our remnants, which supports the scenario whereby elliptical galaxies grow inside-out.

Observational estimates of [39] indicate a size growth of $r_e \propto M^{2.4}$. The size growth that we find is given by $r_e \propto M^{1.5}$ which, in spite of being more rapid than other studies [24, 25], does not fully match the observations.

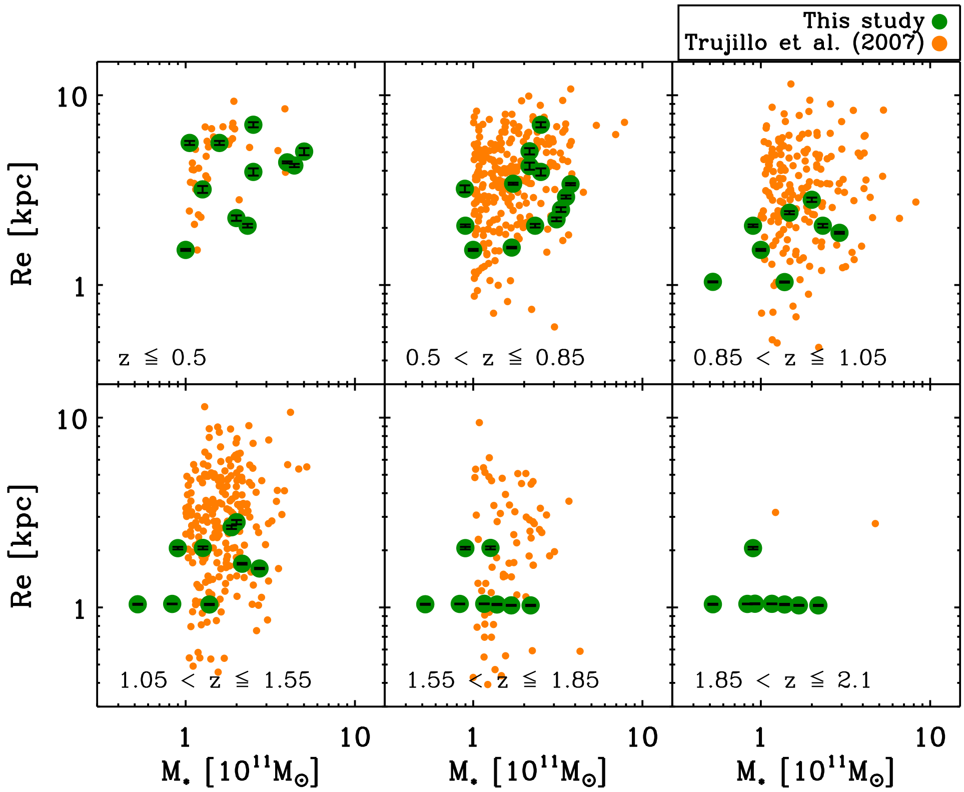

Figure 2: Effective radius distribution of our models. The stellar mass size distribution of the spheroid like galaxies from [35] are over-plotted.

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