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The Dominant Role of Mergers in the Size Evolution of Massive Galaxies since $z \sim 1$

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Abstract. We estimate the merger rate, both major (stellar mass ratio $\mu \equiv M_{\star,2}/M_{\star,1} \geq 1/4$) and minor ($1/10 \leq \mu < 1/4$), of massive ($M_\star \geq 10^{11}\ M_\odot$) early-type galaxies (ETGs) in the COSMOS field by close pairs statistics. The merger rate of massive ETGs evolves as a power-law $(1+z)^n$, showing the minor merger little evolution with redshift, $n_{\rm mm} \sim 0$, in contrast with the increase of major mergers, $n_{\rm MM} = 1.8$. Our results shows that massive ETGs have undergone 0.89 mergers (0.43 major and 0.46 minor) since $z \sim 1$, leading to a mass growth of $\sim 30\%$. In addition, $\mu \geq 1/10$ mergers can explain $\sim 55\%$ of the observed size evolution of these galaxies since $z \sim 1$. Another $\sim 20\%$ is due to the progenitor bias (younger galaxies are more extended) and we estimate that very minor mergers ($\mu < 1/10$) could contribute with an extra $\sim 20\%$. The remaining $\sim 5\%$ should come from other processes (e.g., adiabatic expansion or observational effects). These results suggest that mergers are the main contributor to the size evolution of massive ETGs, accounting for $\sim 55\%-75\%$ of that evolution in the last 8 Gyr. Nearly half of this merging evolution is related with minor ($\mu < 1/4$) events.

1. Introduction

It is now well established that massive early-type galaxies have, on average, lower effective radius ($r_{\rm e}$) at high redshift than locally, being ~ 2 and ~ 4 times smaller at $z \sim 1$ and $z \sim 2$, respectively (e.g., Trujillo et al. 2007; Buitrago et al. 2008; Cassata et al. 2011). These high-redshift compact galaxies are sparse in the local universe (Trujillo et al. 2009), suggesting that they evolve since $z \sim 2$ to the present. It has been proposed that high redshift compact galaxies are the cores of present day ellipticals, and that they increased their size by adding stellar mass in the outskirts of the galaxy (van Dokkum et al. 2010). Several studies suggest that repeated minor mergers, with mass ratio lower than 1/4, could explain the observed size evolution (e.g., Bezanson et al. 2009), while other processes, as adiabatic expansion due to AGNs or to the passive evolution of the stellar population, having a mild role at $z \lesssim 1$ (Ragone-Figueroa & Granato 2011).

Despite of their expected importance, a detailed study of the minor merger fraction of massive ($M_\star \gtrsim 10^{11}\ M_\odot$) early-type galaxies (ETGs) have not been presented in the literature yet. We present the merger history, both minor and major, of massive galaxies since $z \sim 1$ by close pair statistics in the Cosmological Evolution Survey (COSMOS, Scoville et al. 2007) field, and use it to infer the role of minor mergers in the mass assembly and in the size evolution of these systems in the last ~ 8 Gyr.

2. Data and methodology

We define two samples selected in stellar mass from the COSMOS catalog with photometric redshifts derived from 30 broad and medium bands described in Ilbert et al. (2009), version 1.8. We restrict ourselves to objects with $i^+ \leq 25$. We supplement the previous photometric catalog with the spectroscopic information from zCOSMOS survey (Lilly et al. 2007). This is a pure magnitude selected sample with $I_{\rm AB} \leq 22.5$. The fist sample comprises 2047 principal massive galaxies with $M_\star \geq 10^{11}\ M_\odot$ in the zCOSMOS area, where spectroscopic information is available, at $0.1 \leq z < 1.1$. The second sample comprises the 23992 companion galaxies with $M_\star \geq 10^{10}\ M_\odot$ in the full COSMOS area and in the same redshift range. The mass limit of the companion sample ensures completeness for red galaxies up to $z \sim 0.9$. We segregate morphologically our principal sample thanks to the morphological classification defined in Tasca et al. (2009). Our principal sample comprises 1285 (63%) ETGs and 632 (31%) spiral galaxies. The remaining sources are half irregulars and half massive galaxies without morphological classification.

To compute close pairs we looked for those galaxies in the companion sample that fulfil the close pair criterion for each galaxy of the principal sample. We define close pairs as those galaxies with a projected separation $10h^{-1}$ kpc $\leq r_{\rm p} \leq 30h^{-1}$ kpc in the sky plane and a relative velocity $\Delta v \leq 500$ km s^{-1}. In addition, we impose a mass difference between the pair members. We denote the ratio between the mass of the principal galaxy, $M_{\star,1}$, and the companion galaxy, $M_{\star,2}$, as

$$\mu \equiv \frac{M_{\star,2}}{M_{\star,1}} \tag{1}$$

and looked for those systems with $M_{\star,2} \geq \mu M_{\star,1}$. We define as major companions those close pairs with $\mu \geq 1/4$, while minor companions those with $1/10 \leq \mu < 1/4$. We use both spectroscopic and photometric redshifts in the samples to measure the merger fraction thanks to the methodology developed in López-Sanjuan et al. (2010).

To translate the measured merger fractions into merger rates (i.e., the number of mergers per galaxy and Gyr) we use the prescriptions in López-Sanjuan et al. (2011). The most important uncertainty is the merger time scale, that we estimate from Kitzbichler & White (2008) cosmological simulations (see also de Ravel et al. 2009).

3. The merger rate of massive ETGs since $z \sim 1$

The evolution of the merger rate with redshift up to $z \sim 1.5$ is well parametrized by a power-law function (e.g., Le Fèvre et al. 2000; López-Sanjuan et al. 2009; de Ravel et al. 2009),

$$R_{\rm m}(z) = R_{\rm m,0}\,(1+z)^n. \tag{2}$$

We find $n_{\rm mm} \sim 0$ for minor mergers, with a median merger rate of $R_{\rm mm}^{\rm ETG} = 0.060 \pm 0.008$ Gyr^{-1} at $z \lesssim 1$. This confirms the tendency found by López-Sanjuan et al. (2011) for bright galaxies in the VIMOS VLT Deep Survey (VVDS, Le Fèvre et al. 2005) and by Lotz et al. (2011) for less massive ($M_\star \geq 10^{10}\ M_\odot$) galaxies, and extend it to the high mass regime. The evolution of the major merger rate of massive ETGs is

$$R_{\rm MM}^{\rm ETG} = (0.030 \pm 0.006)\,(1+z)^{1.8\pm0.3}\ {\rm Gyr}^{-1}. \tag{3}$$

Our results imply that the minor merger rate is higher than the major merger one at $z \lesssim 0.5$.

4. The role of mergers in size evolution since $z \sim 1$

Integrating the merger rates in previous section over cosmic time, we obtain the number of mergers per massive ETG, $N_{\rm m}^{\rm ETG}$. We estimate $N_{\rm m}^{\rm ETG} = 0.89 \pm 0.14$, with $N_{\rm MM}^{\rm ETG} = 0.43 \pm 0.13$ and $N_{\rm mm}^{\rm ETG} = 0.46 \pm 0.06$ between $z = 1$ and $z = 0$. This is, the number of minor mergers per massive ETGs since $z = 1$ is similar to the number of major ones. We estimate the assembled mass due to mergers by weighting the number of mergers with the average major ($\overline{\mu}_{\rm MM} = 0.48$) and minor merger ($\overline{\mu}_{\rm mm} = 0.15$). We obtain that *mergers with* $\mu \geq 1/10$ *increase the stellar mass of massive ETGs by* $\delta M_\star = 28 \pm 8\%$ *since* $z = 1$. In addition, an extra mass growth of $\delta M_\star \sim 10\%$ due to very minor mergers ($\mu < 1/10$) since $z = 1$ is compatible with the observed mass assembly of massive galaxies (van Dokkum et al. 2010; Brammer et al. 2011).

The size evolution is usually parametrized as

$$\delta r_{\rm e}\,(z) \equiv \frac{r_{\rm e}\,(z)}{r_{\rm e}(0)} = (1+z)^{-\alpha}, \tag{4}$$

where $r_{\rm e}$ is the effective radius of the galaxy. In the following we assume as fiducial α value that one reported by van der Wel et al. (2008) from the combination of several works, $\alpha = 1.2$ ($\delta r_{\rm e} = 0.43$ at $z = 1$).

Following the prescriptions in this section, we trace the mass growth of massive ETGs with redshift both for minor, $\delta M_{\star,\rm mm}(z)$, and major mergers, $\delta M_{\star,\rm MM}(z)$. Then, we translate these mass growths to a size growth,

$$\delta r_{\rm e}\,(z) = [1 + \delta M_{\star,\rm MM}(z)]^{-1.30} \times [1 + \delta M_{\star,\rm mm}(z)]^{-1.65}. \tag{5}$$

This model yields a size evolution due to mergers of $\delta r_{\rm e}(1) = 0.70$ ($\alpha = 0.52 \pm 0.12$). This implies that *observed major and minor mergers can explain* $\sim 55\%$ *of the size evolution in massive early-types since* $z \sim 1$. We take into account the progenitor bias (i.e., those ETGs that have reached the red sequence at later times are systematically more extended than those appeared at high redshift, van der Wel et al. 2009; Saglia et al. 2010) by applying a linear function $1 - 0.2z$ to the previous size growth due to mergers. We obtain $\delta r_{\rm e}(1) = 0.56$ ($\alpha = 0.84 \pm 0.12$), thus explaining $\sim 75\%$ of the size evolution with our current observations. The remaining $\sim 25\%$ of the evolution should be explained by other physical process (e.g., very minor mergers with $\mu < 1/10$ or adiabatic expansion) or by systematic errors in the measurements (e.g., lower merger time scales or an overestimation of the size evolution).

As we shown previously, a mass growth of $\delta M_\star \sim 10\%$ due to very minor mergers ($\mu < 1/10$) since $z = 1$ is compatible with the observed mass assembly of massive galaxies. Applying the same prescription than for major and minor mergers, we obtain an extra size growth of $\sim 20\%$. That is, $\delta r_{\rm e}(1) = 0.58$ and $\alpha = 0.78 \pm 0.12$ when all μ values are taking into account. Hence, mergers since $z \sim 1$ may explain $\sim 75\%$ of the observed size evolution, while $\sim 95\%$, $\delta r_{\rm e}(1) = 0.47$ and $\alpha = 1.1$, when the progenitor bias is taking into account. In addition, this model also reproduces the observed evolution in the velocity dispersion of massive ETGs, $\delta\sigma_\star = (1+z)^{0.4}$ (e.g., Cenarro & Trujillo 2009). Finally, we explore all the possible uncertainties in our assumptions and in all cases merging is still the principal process in the size evolution of massive ETGs since $z \sim 1$.

In summary, our best model, capable of explain mass, size and velocity dispersion evolution of massive ETGs since $z = 1$, suggests *that* $\sim$ *75% of the evolution in size is due to mergers,* $\sim$ *20% to the progenitor bias and* $\sim$ *5% to other processes (e.g, adiabatic expansion)*. Nearly half of the evolution due to mergers is related with minor ($\mu < 1/4$) events.

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References

Bezanson, R., van Dokkum, P. G., Tal, T., Marchesini, D., Kriek, M., Franx, M., & Coppi, P. 2009, ApJ, 697, 1290

Brammer, G. B., Whitaker, K. E., van Dokkum, P. G., Marchesini, D., & et al. 2011, ApJ, 739, 24

Buitrago, F., Trujillo, I., Conselice, C. J., Bouwens, R. J., Dickinson, M., & Yan, H. 2008, ApJ, 687, L61

Cassata, P., Giavalisco, M., Guo, Y., Renzini, A., & et al. 2011, ApJ, 743, 96

Cenarro, A. J., & Trujillo, I. 2009, ApJ, 696, L43

de Ravel, L., Le Fèvre, O., Tresse, L., Bottini, D., & et al. 2009, A&A, 498, 379

Ilbert, O., Capak, P., Salvato, M., Aussel, H., & et al. 2009, ApJ, 690, 1236

Kitzbichler, M. G., & White, S. D. M. 2008, MNRAS, 1300

Le Fèvre, O., Abraham, R., Lilly, S. J., Ellis, R. S., & et al. 2000, MNRAS, 311, 565

Le Fèvre, O., Vettolani, G., Garilli, B., Tresse, L., & et al. 2005, A&A, 439, 845

Lilly, S. J., Le Fèvre, O., Renzini, A., Zamorani, G., & et al. 2007, ApJS, 172, 70

López-Sanjuan, C., Balcells, M., Pérez-González, P. G., Barro, G., Gallego, J., & Zamorano, J. 2010, A&A, 518, A20

López-Sanjuan, C., Balcells, M., Pérez-González, P. G., Barro, G., García-Dabó, C. E., Gallego, J., & Zamorano, J. 2009, A&A, 501, 505

López-Sanjuan, C., Le Fèvre, O., de Ravel, L., Cucciati, O., & et al. 2011, A&A, 530, A20+

Lotz, J. M., Jonsson, P., Cox, T. J., Croton, D., Primack, J. R., Somerville, R. S., & Stewart, K. 2011, ApJ, 742, 103

Ragone-Figueroa, C., & Granato, G. L. 2011, MNRAS, 414, 3690

Saglia, R. P., Sánchez-Blázquez, P., Bender, R., Simard, L., & et al. 2010, A&A, 524, A6+

Scoville, N., Aussel, H., Brusa, M., Capak, P., & et al. 2007, ApJS, 172, 1

Tasca, L. A. M., Kneib, J.-P., Iovino, A., Le Fèvre, O., & et al. 2009, A&A, 503, 379

Trujillo, I., Cenarro, A. J., de Lorenzo-Cáceres, A., Vazdekis, A., de la Rosa, I. G., & Cava, A. 2009, ApJ, 692, L118

Trujillo, I., Conselice, C. J., Bundy, K., Cooper, M. C., Eisenhardt, P., & Ellis, R. S. 2007, MNRAS, 382, 109

van der Wel, A., Bell, E. F., van den Bosch, F. C., Gallazzi, A., & Rix, H.-W. 2009, ApJ, 698, 1232

van der Wel, A., Holden, B. P., Zirm, A. W., Franx, M., Rettura, A., Illingworth, G. D., & Ford, H. C. 2008, ApJ, 688, 48

van Dokkum, P. G., Whitaker, K. E., Brammer, G., Franx, M., & et al. 2010, ApJ, 709, 1018