The size function of massive satellites from the $R_e - R_h$ and $M_{star} - M_h$ relations: constraining the role of environment.

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ABSTRACT
In previous work we showed that a semi-empirical model in which galaxies in host dark matter haloes are assigned stellar masses via a stellar mass-halo mass (SMHM) relation and sizes (R_e) via a linear and tight $R_e - R_h$ relation, can faithfully reproduce the size function of local SDSS central galaxies and the strong size evolution of massive galaxies (MGs, $M_{\rm star} > 10^{11.2} M_\odot$). In this third paper of the series, we focus on the population of satellite MGs. We find that without any additional calibration and irrespective of the exact SMHM relation, fraction of quenched galaxies or level of stellar stripping, the same model is able to reproduce the local size function of quiescent satellite MGs in SDSS. In addition, the same model can reproduce the puzzling weak dependence of mean size on host halo mass for both central and satellite galaxies. The model also matches the size function of starforming satellite MGs, after assuming that some of them transform into massive lenticulars in a few Gyr after infalling in the group/cluster environment. However, the vast majority of satellite lenticulars is predicted to form before infall. The $R_e - R_h$ appears to be fundamental to connect galaxies and their host haloes.

Key words: galaxies: fundamental parameters – galaxies: abundances – galaxies: elliptical and lenticular, cD – galaxies: spiral – galaxies: haloes

1 INTRODUCTION

In the ΛCDM cosmogony, galaxies form and evolve in dark matter haloes (White & Rees 1978). Thus, it is believed that the scaling relations between galaxy and host halo properties are a crucial probe of galaxy evolution. In particular, the relationship between galaxy stellar mass and host dark matter halo mass (the stellar-mass-halo-mass relation, SMHM) has attracted much attention in the past decade (Leauthaud et al. 2012; Behroozi et al. 2013; Shankar et al. 2014b; Rodríguez-Puebla et al. 2017; Lapi et al. 2018a). In addition, several works suggest empirical evidence for a tight and universal galaxy effective radius-halo virial radius (i.e., $R_e - R_h$) relation (Kravtsov 2013; Huang et al. 2017; Somerville et al. 2018; Lapi et al. 2018b), which holds for both starforming and quenched galaxies, with a different normalization but similar scatter (Zanisi et al. 2020).

Stringer et al. (2014) outlined a semi-empirical model where dark matter haloes obtained from N-body simulations are populated with galaxies of a given size and stellar mass, using the SMHM and the $R_e - R_h$ relations. We applied this framework to central galaxies in two recent papers (Zanisi et al. 2020, 2021, Paper I and Paper II respectively). In Paper I we characterized the normalization and dispersion of the $R_e - R_h$ relation for nearby (i.e., $z \sim 0.1$) central galaxies. The inferred scatter of the $R_e - R_h$ relation was found to be as small as 0.1 dex for Massive Galaxies (MGs, $M_{\rm star} > 10^{11.2} M_\odot$), which suggests a strong link between galaxy size and halo virial radius in this stellar mass regime. In Paper II we found that a constant $R_e - R_h$ relation is able to explain the puzzling steady size increase of MGs up to $z \sim 3$. The relative proportion of compact MGs (irrespective of the definition of compactness, see e.g. Damjanov et al. 2015) was found to be a strong function of the shape and scatter of the SMHM.

While in Papers I and II we calibrated and deployed the semi-empirical framework described above only for central galaxies, in this paper we will focus on the population of *satellite* MGs. In particular, we will mainly focus on the following two still open issues:

- The environmental dependence of the sizes of MGs. Previous work (e.g., Huertas-Company et al. 2013; Shankar et al. 2014a; Sonnenfeld et al. 2019) showed that, at the present cosmic time, the sizes of all MGs should not differ, in terms of a "mass-normalised" size ($\log\gamma = \log R_e + 0.83(11 - \log M_{star})$, which cancels the dependence on underlying differences in stellar mass on the average size difference, e.g., Huertas-Company et al. 2013), by more than $\Delta\gamma \lesssim 30-40\%$ between low-mass groups and massive clusters. We will test this trend within the framework of the $R_e - R_h$ relation.
- The formation of lenticular (S0) galaxies within the cluster environment (e.g., Bekki & Couch 2011). We aim to probe the viability of a model in which massive spirals transform into massive S0s over a given timescale (e.g., Smith et al. 2005; Deeley et al. 2020).

This Letter is organised as follows. We describe the comparison

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data in Section 2, the modelling in Section 3 and the main results in Section 4. We give final remarks in Section 5.

2 DATA

Our reference data is the Sloan Digital Sky Survey (SDSS) Data Release 7 (Abazajian et al. 2009) as presented in Meert et al. (2015, 2016). We use the best-fitting `Sérsic-Exponential` or `Sérsic` profile to r-band observations, and adopt the mass-to-light ratios from Mendel et al. (2014).We adopt the truncation of the light profile as prescribed in Fischer et al. (2017). We also match the Meert et al. catalogs with both the Yang et al. (2012) group catalogs, complete in the halo mass range of interest here, which allows us to identify central and satellite galaxies, and the Domínguez Sánchez et al. (2018) deep-learning based morphological catalog. The matching, we checked, preserves full completeness in the stellar and halo mass functions of MGs. We use TType<=0 to select Early Type Galaxies, which we assume to be quenched (Massive Quenched Galaxies, MQGs), and TType>0 for late type galaxies, which we assume to be star forming (Massive Star Forming Galaxies, MSFGs). We also consider massive S0 galaxies (MS0s), which in the Domínguez Sánchez et al. (2018) catalog are identified with a probability of being S0, P_{S0}. Using standard V_{max} weighting, we produce the size function $\phi(R_e)$ of central and satellite MQGs and MSFGs, which are the targets for our model to reproduce. The size function of MS0s is produced by weighting the MQGs size function by P_{S0}. The errorbars are computed using jackknife resampling.

3 METHODS

We here closely follow the modelling approach of Papers I and II[1]:

(i) **Dark matter catalogues.** We start from the publicly available[2] data products from the MultiDark-Planck (MDPL) simulation (Klypin et al. 2016). For (unmerged) subhaloes at $z \sim 0.1$ we adopt the peak virial mass M_{peak} attained during their mass assembly history, before accretion. Dark matter halo masses M_h are defined as virial overdensities within a radius R_h (Bryan & Norman 1998).

(ii) **The SMHM relation.** We model the link between galaxies and dark matter via the SMHM, which is a monotonically increasing function of halo mass (e.g., Vale & Ostriker 2006; Shankar et al. 2006). We further assume the SMHM to follow a Gaussian distribution in $\log M_{\rm star}$ at fixed halo mass, $\sigma_{\rm SMHM} = 0.15$dex (Grylls et al. 2019). As our benchmark SMHM relation, we assume the $z \sim 0.1$ SMHM relation by Grylls et al. (2019), which was obtained by fitting the Bernardi et al. (2017) 'PyMorph' `SerExp` stellar mass function (SMF). The stellar mass of Bernardi et al. (2017) are obtained without the truncation of the light profile (e.g., Fischer et al. 2017). However, the truncation adopted in this work (see Section 2) results in the high mass end of the SMF being slightly less populated, requiring fine-tuning in two of the Grylls et al. (2019) parameters, namely $\gamma_0 \approx 0.57$ and $M_{10} \approx 11.95$.

(iii) **The $R_e - R_h$ relation.** We assign a half light radius R_e to each galaxy according to the ansatz:

$$R_e = A_k R_h, \tag{1}$$

which is based on the empirical findings by Kravtsov (2013), and that we call the *K13 model*. Here A_k is the normalization which in principle may vary galaxy stellar mass and/or morphology (e.g., Huang et al. 2017).

(iv) **Star formation activity.** MGs are a bimodal population in terms of star formation activity.

- **Relative fraction of MSFGs and MQGs**. In Paper II we modelled explicitly the probability of a central galaxy being quiescent by adopting the parametrization by Rodríguez-Puebla et al. (2015), which is valid at $z \sim 0.1$:

$$f_{Quench}(M_h) = \frac{1}{b_0 + [\mathcal{M}_0 \times 10^{12}/M_h(M_\odot)]}, \tag{2}$$

where $b_0 = 1$. f_{Quench} is a monotonically increasing function of halo mass, with a characteristic mass scale $\mathcal{M}_0$ above (below) which more (less) than 50% of galaxies are quiescent (star forming). We further assumed that $\mathcal{M}_0$ evolves as $\mathcal{M}(z) = \mathcal{M}_0 + (1+z)^\mu$ which qualitatively reproduces the quenching downsizing phenomenon (e.g., Behroozi et al. 2019). Here $\mu > 0$ is a free parameter that controls the quenched fraction in dark matter haloes at a given cosmic time. By using current estimates of the galaxy stellar mass function for quenched and star forming galaxies (Davidzon et al. 2017, McLeod et al. 2020), in Paper 2, we have found that μ is likely to lie at intermediate values, $\mu \approx 2.5$. We will use $\mu = 2.5$ as a reference but we will explore other possible values in the next Section. Following paper 2, we also set $\mathcal{M}_0$=1.5. It is important to note that *the f_{Quench} model applies strictly only to central galaxies*. In particular, satellites have their star formation activity set at a time when they were central, z_{peak}, but may be modified by environmental effects (see bullet v).
- **The sizes of MSFGs and MQGs** The effective radii of MSFGs are observed to be higher than those of MQGs by a roughly constant factor (Mowla et al. 2018). We capture this feature by assuming that the normalization of the K13 model differs for MSFGs and MQGs. Likewise, we will assume that the scatter of the K13 model differs for MSFGs ($\sigma_{K,SF}$)and MQGs ($\sigma_{K,Q}$). Following Paper II, we calibrate $A_{K,SF}, \sigma_{K,SF}$ and $A_{K,Q}, \sigma_{K,Q}$ on the size function of central galaxies at $z \sim 0.1$ (see Figure 1).

(v) **Environmental effects.** In what follows we will include models with stellar stripping following the results from the N-body simulations by Smith et al. (2016), who suggest a mass loss given by $M_{\rm star,strip}/M_{\rm star} = \exp[1 - 14.2 f_{\rm DM}]$, with $f_{\rm DM}$ the dark matter fraction. We then update the sizes following Shankar et al. (2014a) and Hearin et al. (2019), who assume that R_e decreases proportionally to the decrease in stellar mass along the $R_e - M_{\rm star}$ relation. We will also consider models in which some MSFGs are quenched and morphologically transformed in S0 galaxies by the environment (e.g., Smith et al. 2005) over a given timescale $\Delta T_{\rm transf}$.

4 THE LOCAL SIZE FUNCTION OF STARFORMING AND QUENCHED MASSIVE SATELLITE GALAXIES

We will adopt as a reference throughout a basic "Frozen & Stationary" (F+S) model in which the SMHM relation does not depend on cosmic time and satellites do not evolve after infall. We will discuss below the possible impact of relaxing any of the assumptions in the F+S model. The left and right panels in Figure 1 show, respectively, the size function of starforming (MSFGs) and quiescent (MQGs) MGs extracted from SDSS and divided into central (orange diamonds) and satellite (blue triangles) galaxies. We compare these data with our F+S model (solid coloured lines). We

[1] We make extensive use of the `COLOSSUS` Python package (Diemer 2017).
[2] https://www.cosmosim.org/cms/simulations/mdpl/

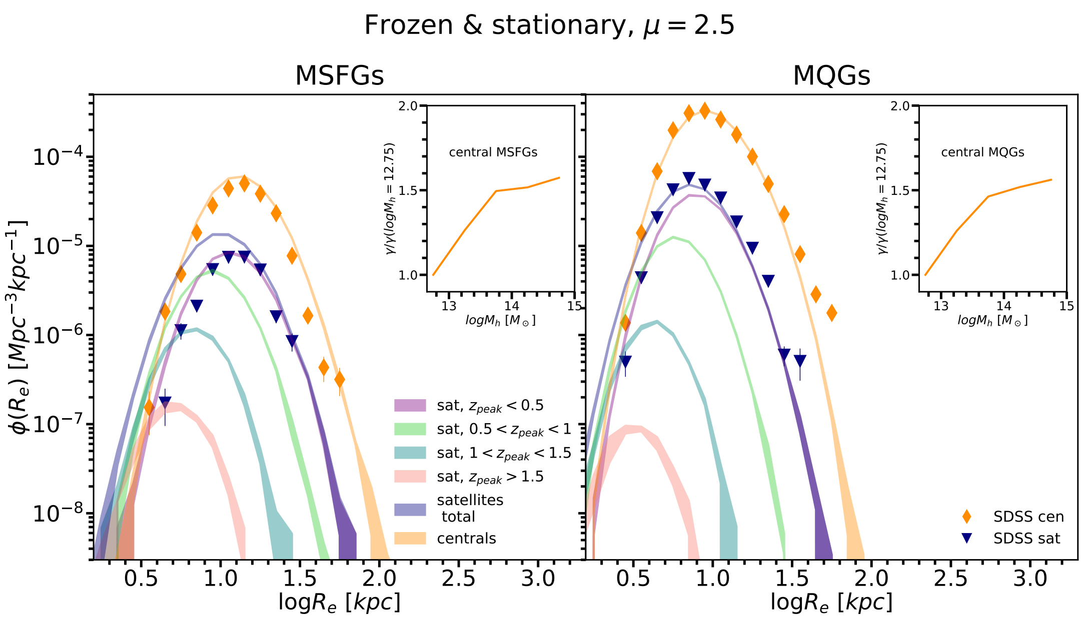

Figure 1. Size function of MSFGs (left) and MQGs (right) for SDSS central (orange diamonds) and satellites (blue triangles). The solid lines and filled regions show our "frozen & stationary" model, i.e. satellites do not evolve after infall and the SMHM relation (adapted from Grylls et al. 2019, see Section 3) is taken at $z \sim 0.1$ and it is assumed not to evolve at high redshift. We calibrate the free parameters of the model on the size functions of central galaxies: $\sigma_{K,SF}$=0.13 dex, $A_{K,SF}$=0.024, $\sigma_{K,Q}$=0.10 dex, $A_{K,Q}$=0.013 and $\mathcal{M}_0$=1.5. The blue filled regions indicate the total surviving population of satellites accreted by $z \sim 0.1$.

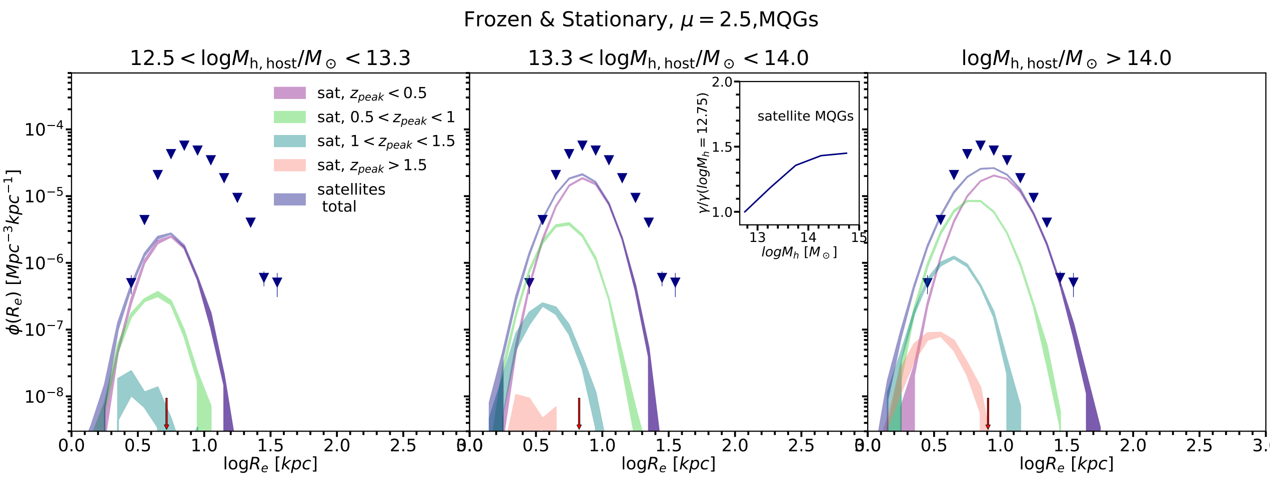

Figure 2. The size functions of satellite MQGs from the "frozen & stationary" model, computed in different bins of halo mass corresponding to low-mass groups (left panel), groups and low-mass clusters (central panel) and massive clusters (right panel). The mean sizes in each environment are shown with an arrow. Lines are as in Figure 1 but here they refer to each halo mass bin, and symbols refer to the total SDSS satellite MQGs size function.

first confirm the results of Paper I, our model provides an excellent match to the size function of central MGs. Here we show that, in addition, without any extra fine-tuning, the same model provides a good match also to the size function of satellite MGs, especially for the quenched population. It is also clear from Figure 1 that the vast majority of satellite MGs have been accreted at $z_{peak} < 0.5$ (violet lines). In Figure 2 we further dissect the size function of the model MQGs in bins of host halo mass that are representative of low-mass groups (12.5< $\log M_h/M_\odot < 13.3$), groups and low-mass clusters ($13.3 < \log M_h/M_\odot < 14$), and massive clusters ($\log M_h/M_\odot > 14$). The mean size (arrows at the bottom) show a weak dependence on parent halo mass, with an increase in normalised size of $\Delta\gamma \lesssim 45\%$ (inset in Figure 2), in line with what seen for central galaxies for which $\Delta\gamma \lesssim 55\%$ (insets in Figure 1). As emphasized by several groups (e.g., Huertas-Company et al. 2013; Sonnenfeld et al. 2019), the mass-normalized mean size γ of central and satellite MGs has a weak dependence on host halo mass, amounting to $\Delta\gamma \lesssim 40\%$, when moving from field to clusters and after accounting for statistical measurements errors in host halo mass. Our models naturally generate a weak trend of mean size with halo mass mainly induced by the underlying assumption of a universal $R_e \propto R_h \propto M_h^{1/3}$ relation, in which the halo mass dependence is further washed out by dispersions in the relations and, in the case of satellites, by the stochastic assembly of haloes. As discussed by

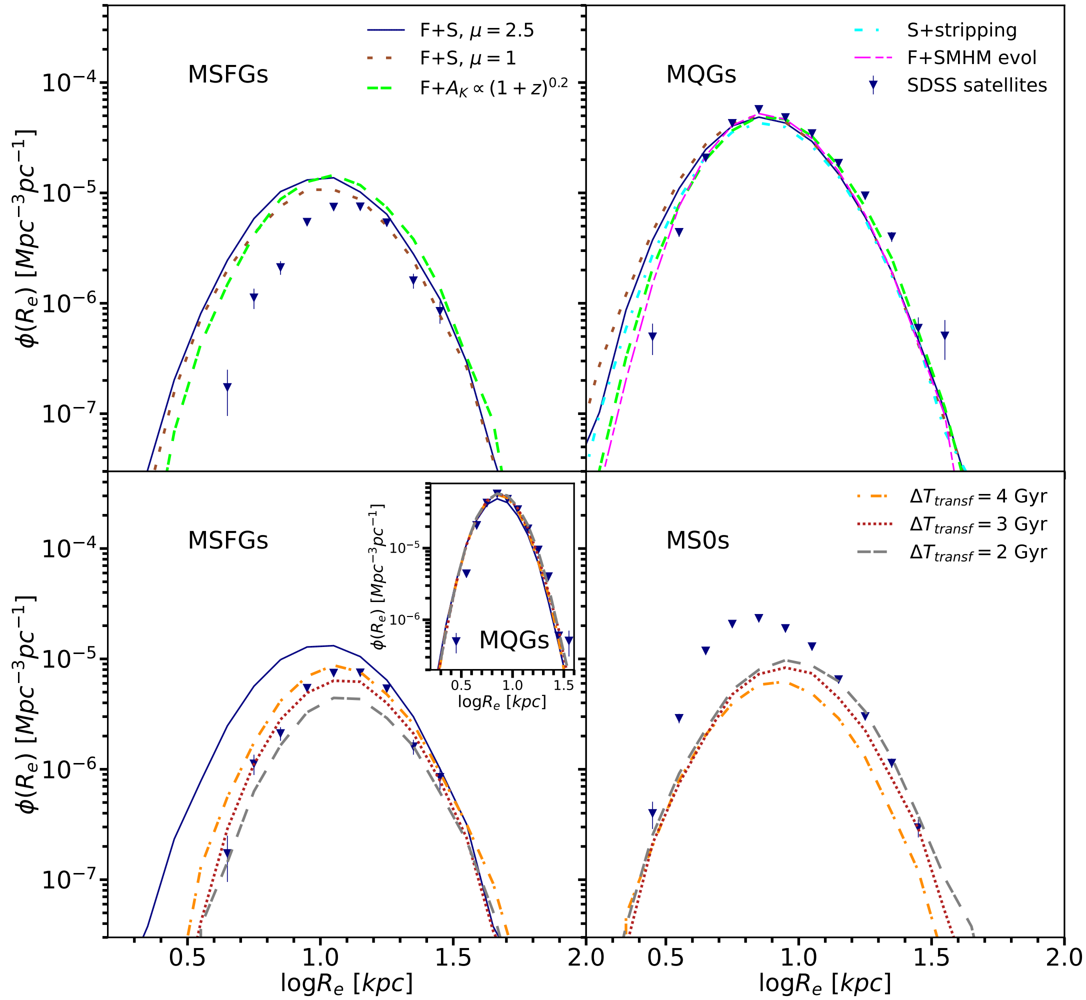

Figure 3. *Top row*: Variants to the benchmark "Frozen & Stationary" (F+S) model (solid blue lines). The dotted brown lines show a model with $\mu = 1$. In the right panel, the cyan dot-dashed lines show the result of a model with stellar stripping. The long-dashed green line is a model with redshift-dependent $R_e - R_h$ relation, and the dashed magenta line is a model with an evolving SMHM relation (see text). *Bottom row:* The size functions of MSFGs, and S0 satellite galaxies assuming that, due to environmental effects, the MSFGs are transformed in S0 galaxies after a timescale ΔT_{transf} , as labelled (MQGs shown in the inset).

Shankar et al. (2014a), a weak dependence of the mean size with halo mass contrasts instead with some galaxy formation models, especially those characterised by strong disc instabilities. Figure 2 also shows that most of the "relic" satellites (formed at $z_{peak} > 1.5$) live today in massive clusters. Our results are largely independent of the specific inputs of the F+S model. For example, the top panels of Figure 3 show that similar size functions are generated when varying the quenching model (brown dotted lines, as labelled), or when allowing for some redshift evolution in the $R_e - R_h$ relation with $A_K \propto (1+z)^{0.2}$, still broadly allowed by the high-redshift data on the sizes of MGs (long-dashed, green lines, see Paper 2).

Despite the successes described so far, our model predictions are not perfect and present two main discrepancies from the data. Firstly, the predicted number density of satellite MSFGs tends to be progressively overestimated with respect to the SDSS data by a factor of $2-10$ below $R_e \sim 10$ kpc (e.g., left top panel of Figure 3). Secondly, the model predicts a size function of MQGs very similar in shape to the measured one but shifted by ~ 0.05 dex towards lower sizes (see right panels of Figure 3). Despite being relatively small discrepancies, especially in the case of the MQG population, it is a non-trivial task to reconcile the models with the data by simply fine-tuning some of the input parameters. To prove this point, the magenta dashed line in the top right panel of Figure 3 marks the outcome of a model in which we allow the input SMHM relation to vary with redshift. More specifically, we used a Markov Chain Monte Carlo algorithm (Foreman-Mackey et al. 2013) which we run for 150,000 steps with 96 walkers with Gaussian priors centred on the mean of the posterior distributions shown in Appendix A of Grylls et al. (2019). Although the resulting best-fit SMHM relation provides an improved fit to the low-size tail of the size function of MQGs, it still falls somewhat short at the high-size end and, more importantly, the implied stellar mass function, we verified, appears in stark disagreement with current data (Davidzon et al. 2017; Kawinwanichakij et al. 2020). Even a model in which we include stellar stripping at the rate suggested by Smith et al. (2016), does not significantly alter the predicted size function of MQGs from the benchmark F+S model (cyan dashed line, top right panel of Figure 3). Simpler solutions to the (small) discrepancy in the predicted size function of MQG with respect to the data can be ascribed to, e.g., a possible overestimation of the sizes in satellite galaxies due to background subtraction effects, and/or a small deviation in the adopted $R_e - R_h$ relation in satellite galaxies with respect to their central counterparts.

As anticipated above, the most prominent discrepancy with the data lies in the overproduction of the number density of MSFGs, progressively increasing towards lower sizes (left panels of Figure 3). Although part of the mismatch may in part also be caused by incompleteness due to fiber collisions(e.g., Taylor et al. 2010) , in what follows we will only focus on the modelling side. Simply varying the relevant input parameters has no noticeable impact on the shape of the predicted size function of MSFGs (top left panel), thus calling for additional assumptions in the model. In the bottom panels of Figure 3 we explore the impact of a physically-motivated hypothesis (e.g., Cava et al. 2017; Joshi et al. 2020) in which MSFGs are morphologically transformed, without any change in size, into massive lenticulars (MS0s) via the effect of the gas in the intra-group and intra-cluster media on a typical timescale of $\Delta T_{transf} \approx 2-4$ Gyr since z_{peak} (coloured lines as labelled). This simple addition to our baseline model provides a nearly perfect match to the size function of MSFGs when adopting $\Delta T_{transf} \approx 3-4$ Gyr. The number of MS0 formed via this channel amounts, however, to only a few percent of the total population of MQGs (inset in bottom-left panel) and $\sim 10\%$ of the population of SDSS MS0 galaxies (bottom right panel), suggesting that the vast majority of MS0s may preferentially form before accreting in the cluster environment (e.g., Hopkins et al. 2009; Saha & Cortesi 2018), as opposed to what is seen at lower $M_{\rm star}$ observationally (e.g., Desai et al. 2007).

5 CONCLUSIONS

In previous work we showed that assuming a universal $R_e - R_h$ relation provides an excellent match to the local size function of SDSS galaxies and to the strong size evolution of massive galaxies. In this Letter we further demonstrate that a basic "frozen & stationary" model where (i) the SMHM and the $R_e - R_h$ relations remain unchanged since $z \sim 1.5$ and (ii) the environment does not affect galaxies after infall, predicts a local size function of massive satellite galaxies in good agreement with the data, particularly for massive quenched galaxies (MQGs). The same model generates an overall mild dependence of galaxy sizes on host halo mass for satellites , amounting to $\Delta\gamma \lesssim 45\%$, in agreement with observational studies (Huertas-Company et al. 2013). Our results are robust against sensible (time) variations in the $R_e - R_h$ and/or SMHM relation, inclusion of stellar stripping, or variations in the quenching model. On the other hand, our model overpredicts the number density of massive star forming galaxies (MSFGs), especially at lower sizes. We find that by allowing for MSFGs to quench and transform into massive S0 galaxies in a timescale of $\Delta T_{transf} \approx 3-4$ Gyr, yields a nearly perfect match to the size function of MFGs. However, the fraction of S0 galaxies formed via the environmental channel would only amount to $\sim 10\%$ of the total number of massive S0s in SDSS, the vast majority of which must have preferentially formed in situ. The $R_e - R_h$ appears as a fundamental relation in regulating the size growth and environmental dependence of MGs.

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DATA AVAILABILITY

Data will be shared upon request to the authors.

REFERENCES

Abazajian K. N., et al., 2009, ApJS, 182, 543
Behroozi P. S., Wechsler R. H., Conroy C., 2013, ApJ, 770, 57
Behroozi P., Wechsler R. H., Hearin A. P., Conroy C., 2019, MNRAS, 488, 3143
Bekki K., Couch W. J., 2011, MNRAS, 415, 1783
Bernardi M., Meert A., Sheth R. K., Fischer J. L., Huertas-Company M., Maraston C., Shankar F., Vikram V., 2017, MNRAS, 467, 2217
Bryan G. L., Norman M. L., 1998, ApJ, 495, 80
Cava A., et al., 2017, A&A, 606, A108
Damjanov I., Geller M. J., Zahid H. J., Hwang H. S., 2015, ApJ, 806, 158
Davidzon I., et al., 2017, A&A, 605, A70
Deeley S., et al., 2020, MNRAS, 498, 2372
Desai V., et al., 2007, ApJ, 660, 1151
Diemer B., 2017, preprint, (arXiv:1712.04512)
Domínguez Sánchez H., Huertas-Company M., Bernardi M., Tuccillo D., Fischer J. L., 2018, MNRAS, 476, 3661
Fischer J. L., Bernardi M., Meert A., 2017, MNRAS, 467, 490
Foreman-Mackey D., Hogg D. W., Lang D., Goodman J., 2013, PASP, 125, 306
Grylls P. J., Shankar F., Leja J., Menci N., Moster B., Behroozi P., Zanisi L., 2019, MNRAS, p. 2560
Hearin A., Behroozi P., Kravtsov A., Moster B., 2019, MNRAS, 489, 1805
Hopkins P. F., Cox T. J., Younger J. D., Hernquist L., 2009, ApJ, 691, 1168
Huang K.-H., et al., 2017, ApJ, 838, 6
Huertas-Company M., Shankar F., Mei S., Bernardi M., Aguerri J. A. L., Meert A., Vikram V., 2013, ApJ, 779, 29
Joshi G. D., Pillepich A., Nelson D., Marinacci F., Springel V., Rodriguez-Gomez V., Vogelsberger M., Hernquist L., 2020, MNRAS, 496, 2673
Kawinwanichakij L., et al., 2020, ApJ, 892, 7
Klypin A., Yepes G., Gottlöber S., Prada F., Heß S., 2016, MNRAS, 457, 4340
Kravtsov A. V., 2013, ApJ, 764, L31
Lapi A., et al., 2018a, ApJ, 857, 22
Lapi A., Salucci P., Danese L., 2018b, ApJ, 859, 2
Leauthaud A., et al., 2012, ApJ, 744, 159
McLeod D. J., McLure R. J., Dunlop J. S., Cullen F., Carnall A. C., Duncan K., 2020, arXiv e-prints, p. arXiv:2009.03176
Meert A., Vikram V., Bernardi M., 2015, MNRAS, 446, 3943
Meert A., Vikram V., Bernardi M., 2016, MNRAS, 455, 2440
Mendel J. T., Simard L., Palmer M., Ellison S. L., Patton D. R., 2014, ApJS, 210, 3
Mowla L., et al., 2018, preprint, (arXiv:1808.04379)
Rodríguez-Puebla A., Avila-Reese V., Yang X., Foucaud S., Drory N., Jing Y. P., 2015, ApJ, 799, 130
Rodríguez-Puebla A., Primack J. R., Avila-Reese V., Faber S. M., 2017, MNRAS, 470, 651
Saha K., Cortesi A., 2018, ApJ, 862, L12
Shankar F., Lapi A., Salucci P., De Zotti G., Danese L., 2006, ApJ, 643, 14
Shankar F., et al., 2014a, MNRAS, 439, 3189
Shankar F., et al., 2014b, ApJ, 797, L27
Smith G. P., Treu T., Ellis R. S., Moran S. M., Dressler A., 2005, ApJ, 620, 78
Smith R., Choi H., Lee J., Rhee J., Sanchez-Janssen R., Yi S. K., 2016, ApJ, 833, 109
Somerville R. S., et al., 2018, MNRAS, 473, 2714
Sonnenfeld A., Wang W., Bahcall N., 2019, A&A, 622, A30
Stringer M. J., Shankar F., Novak G. S., Huertas-Company M., Combes F., Moster B. P., 2014, MNRAS, 441, 1570
Taylor E. N., Franx M., Glazebrook K., Brinchmann J., van der Wel A., van Dokkum P. G., 2010, ApJ, 720, 723
Vale A., Ostriker J. P., 2006, MNRAS, 371, 1173
White S. D. M., Rees M. J., 1978, MNRAS, 183, 341
Yang X., Mo H. J., van den Bosch F. C., Zhang Y., Han J., 2012, ApJ, 752, 41
Zanisi L., et al., 2020, MNRAS, 492, 1671
Zanisi L., et al., 2021, arXiv e-prints, p. arXiv:2105.09969

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