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On the size evolution of early type galaxies

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Abstract. We present numerical simulations of the effect of baryonic mass loss on the structure of a spheroidal stellar system, embedded in a dark matter halo. This process, invoked as a possible explanation of the observed size increase of ETGs since $z \sim 2$, could be caused either by QSO/starburst driven galactic winds, promptly ejecting from Early Type Galaxies (ETGs) the residual gas and halting star formation (galactic winds), or by stellar mass returned to the ISM in the final stages of stellar evolution. Indeed, we find that a conceivable loss of $\sim 50\%$ of the baryonic mass can produce a significant size increase. However, the puffing up due to galactic winds occurs when the stellar populations are much younger than the estimated ages > 0.5 Gyr of compact high-z ETGs. Therefore, while it may have had a role in deciding the final structure of ETGs, it cannot explain the evolution observed so far of their size-mass relation. Conversely, the mass loss due to stellar evolution could cause a modest expansion of passively evolving stellar systems, contributing to, without dominating, the observed evolution of their mass-size relationship.

1. Introduction

During the last years it has been established that most massive early-type galaxies (ETGs) observed at redshift $z \gtrsim 1$ exhibit sizes smaller by a factor of a few than local ETGs of analogous stellar mass. Nowadays most authors agree that the observational results are dominated by a real size evolution, rather than by some subtle systematic effect. Proposed interpretations are related either to the effects of mergers or to the loss of a substantial fraction of mass from the galaxy.

The only promising *merging* mechanism to explain the size increase seems to be a series of minor dry merging events. Indeed, in *wet* mergers, the presence of a dissipative gas component limits the gain in size, while major dry mergers move galaxies too slowly toward the local size-mass relationship (the size increases linearly with the mass) to explain the evolution in a reasonable number of events. By converse minor dry mergers would add stars in the outer parts of passive high-z galaxies, in such a way to produce a size increase that can scale, optimistically, as steep as M^2. However, recent detailed analysis concluded, from different points of view, that even minor mergers fall short to explain the observed size evolution, particularly at redshift greater than 1.5 (Newman et al. 2012; Nipoti et al. 2012. But see e.g. Lopez et al. 2012).

In this context, we tested, by means of controlled numerical experiments, the possible contribution of the *puffing-up* process. This envisages that the expansion in size is driven by the expulsion of a substantial fraction of the gas out of the galaxy either by AGN and/or supernova driven galactic winds (Fan et al. 2008), or by the expulsion of gas associated to stellar evolution (Damjanov et al. 2009). In the former case the expulsion timescale would be short, likely not much longer than the dynamical timescale, at least when driven by the AGN, whilst in the latter an important mass loss could last even $\sim 0.5-1$ Gyr. Virtually all modern models of galaxy formation give a prominent role to AGN and/or SNae driven galactic wind, ejecting from the galactic region a substantial fraction of gas. Thus, it is very likely that this puffing up played a role in deciding the final sizes of ETGs, at some point over their history. However, it is still an open question whether this role has been major, and, in particular, whether it can explain the available observations. Additionally, during the passive evolution of ETGs, it is conceivable that the they lost another significant fraction of its baryonic mass, due to stellar evolution (supernova explosions and stellar winds). The aim of the present work is to provide a step to clarify these issues.

2. Numerical method and setup

We refer the reader to Ragone & Granato (2011) and to Ragone, Granato & Abadi (2012) for all the technical details of our simulations, providing here just a quick overview. The purpose is to investigate the evolution of collision-less particles (stars and DM) under a change of gravitational potential due to a loss of baryonic mass of the system. The escaping mass can be either the gas which has not been converted into stars during the star forming phase of the spheroid, or the mass lost from stars in form of stellar winds and SNae explosions. In any case, we assume as given, and due to causes external to the simulations (such as SNae and AGN feedbacks, or stellar evolution), the temporal dependence of this mass loss, and we simulate the ensuing evolution of collision-less mass distributions. Therefore we don't have to treat the gas dynamics.

We used the $N-$body code *GADGET-2* (Springel 2005) to perform simulations with 10^6 particles. The density distribution of DM particles follows the NFW shape, while for the baryonic particles (stars and gas), we adopted an Hernquist profile. Given the density runs, we obtain the 1D velocity dispersion by integrating the Jeans equation. Starting from this initial setup, we introduce a mass loss, intended to emulate the various possible effects described above, by removing exponentially over an ejection time Δt a fraction $1-\epsilon$ of the baryonic mass. The mass loss is attained by decreasing in time the mass of the baryonic particles. After the end of the mass loss period Δt, we let the system to evolve till it reaches a new equilibrium configuration.

The initial conditions have been thought to get a configuration, after the loss of a substantial fraction of baryons, consistent with our basic knowledge of the properties of local large ETGs. Thus, we adopted a reference value for the initial ratio of virial mass to baryonic mass is $M_{\rm vir}/M_{\rm B(t=0)} = 25$. We set $M_{\rm vir} = 10^{13}{\rm M}_\odot$ in all simulations. We adopt a concentration parameter $c = 4$, a typical value at galactic halo formation, and $R_{\rm vir} \simeq 170$ kpc, as expected for a $M_{\rm vir} = 10^{13}{\rm M}_\odot$ halo virialized at $z = 3$. The baryon scale-length has been set

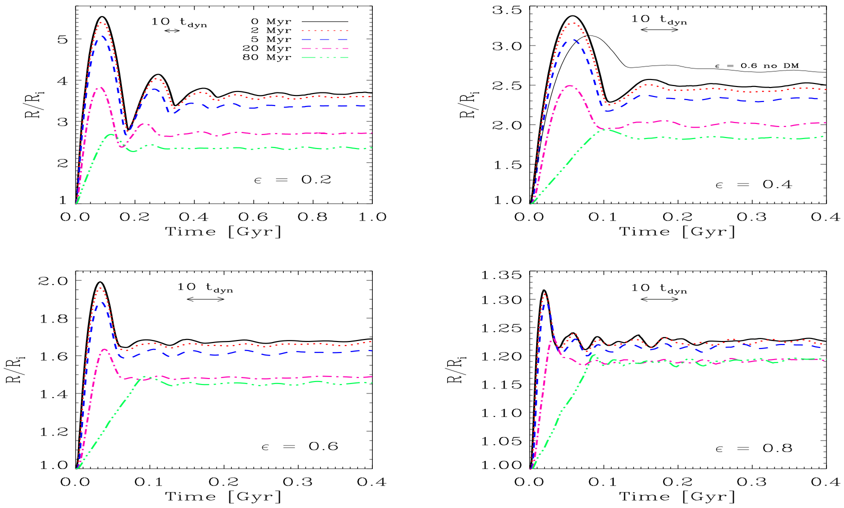

Figure 1. Ratio $R/R_{\rm i}$ of the current to the initial half-mass radius as a function of time, for different values of the diet parameter ϵ and of the ejection times Δt. The thin solid line in the top right panel shows the evolution of a model not including the DM halo, for $\epsilon = 0.6$.

to $a = 1.5$ kpc ($R_e \simeq 2.7$ kpc). Assuming that about half of the initial baryonic mass is in form of stars, the system would lie initially a factor $\simeq 2.5$ below the local mass-size relationship for ETGs. The parameters affecting the results of our simulations are the ratios $M_{\rm vir}/M_{\rm B(t=0)}$ and $R_{\rm vir}/a$; the fraction of baryonic mass lost $(1-\epsilon)$, and the time Δt over which the loss occurs. We performed simulations covering broad ranges of the latter two quantities, while in most runs we kept the former two at the values reported above. None of our conclusion is affected by reasonable variations of them.

3. Results: why puffing up cannot explain observed size evolution

Fig. 1 reveals the main problem to explain the *observed* size evolution of ETGs with the puffing-up scenario. On one hand, our simulations confirm that, even in presence of a DM component, a factor ~ 2 increase in size can be expected in any galaxy formation model in which the spheroid quickly loses $\sim 50\%$ of its baryonic mass. However, if this mass is constituted by the star forming gas, in scenarios in which a galactic wind suddenly sterilizes the galaxy, the puffing-up occurs far too close to the last episode of star formation. The galaxy is predicted to be smaller than the final size only for a very short time after expulsion, less than $\sim 20-30$ Myr, i.e. a factor 20 less than the minimum estimated ages of stellar populations in high-z compact galaxies ($> 0.5-1$ Gyr). Even in the case of expansion driven by stellar mass loss the problem of the excessive shortness of the expansion timescale is important, though less clear cut. Indeed, the majority of the mass loss and ensuing expansion still occurs in less than 0.5 Gyr.

To better illustrate this, Fig. 2 shows the result of a sample simulation, applied to a specific semi-analytic galaxy formation model including both processes

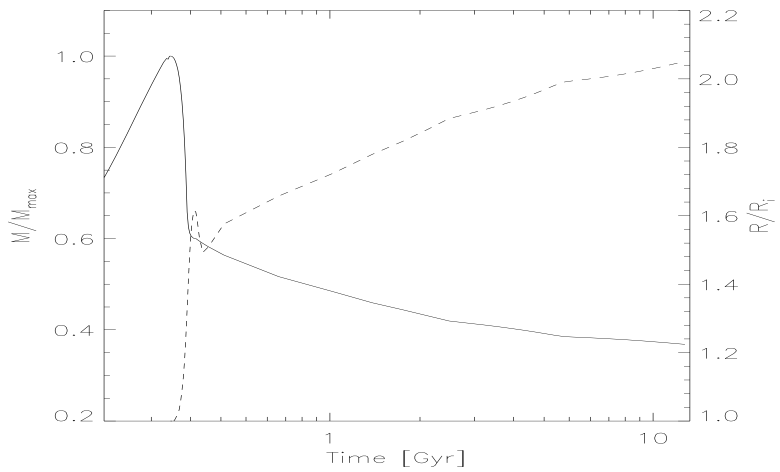

Figure 2. Evolution of the total baryonic mass (star forming gas+stars) in an ETG, according to the Granato et al. (2004) model for co-evolution of SMBH and spheroids (solid line, left axis), and the corresponding size increase (dashed line, right axis) predicted by our simulation.

(Granato et al. 2004). The abrupt decrease of the mass after ~ 0.3 Gyr marks the ejection of gas by the AGN-driven wind. The later slow decrease of mass and moderate increase in size, is due to stellar mass returned to the ISM, assuming that the galaxy potential cannot retain it. The size expansion achieved after the epoch in which stellar populations are older than $\sim 0.5 - 1$ Gyr is about 20%,

In conclusion, the puffing up related to large scale galactic winds, quickly ejecting a substantial fraction of baryonic mass, can be an important phenomenon, but is still not observed. By converse, the secular adiabatic expansion, related to the mass returned to the ISM by dying stars, could contribute, but not dominate, the observed size evolution of ETGs. Nevertheless, it is relevant to investigate this contribution, since it seems that none of the processes considered so far can explain alone the expansion (e.g. Newman et al. 2012; Nipoti et al. 2012).

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