Reconciling a significant hierarchical assembly of massive early-type galaxies at z≤1 with mass downsizing

M. Carmen Eliche-Moral[1], Mercedes Prieto[2,3], Jesús Gallego[1], & Jaime Zamorano[1]

[1]Universidad Complutense de Madrid, [2]Instituto de Astrofísica de Canarias, [3]Universidad de La Laguna (Spain)

ABSTRACT

Recent studies derive opposite conclusions about the role of major mergers in the buildup of the present-day massive early-type galaxies (mETGs, i.e., E-S0a's with M>10^{11} Msun at z~0, [1-4]). We have tested their possible hierarchical origin through semi-analytical modelling, by studying how the local mETGs would have evolved back-in-time under the hypothesis that each observed major merger has generated an early-type galaxy (ETG, [5,6]).

The model is able to explain the observed buildup of field mETGs since z~1 just considering the coordinated effects of the wet/mixed/dry major mergers strictly reported by observations, in agreement with global mass downsizing trends <u>at the same time</u>. Mass downsizing and a recent hierarchical assembly of mETGs can be reconciled just accounting for: 1) the typical contamination of red galaxy samples by dust-reddened star-forming galaxies (DSFs) at z>~0.8, and 2) the fact that the majority of mETGs existing at z~1 are not necessarily "in place" since then. **Accordingly to data, the model predicts that the number density of mETGs has increased by a factor of ~2-2.5 since z~1, but that very few present-day mETGs have been really in place since z~1 (<~5%), being most of the mETGs existing at z~1 the gas-poor merger progenitors of the present-day ones.**

The model suggests that major mergers have driven the observed mass migration from the massive end of the blue galaxy cloud to that of the red sequence in the last ~9 Gyr.

I.- HIERARCHICAL SCENARIO VS. GALAXY MASS DOWNSIZING

Hierarchical models predict that the present-day most massive galaxies (basically, mETGs with M*>10^{12} Msun) must be the final remnants of the richest merging sequences in the Universe, and thus, the latest to be in place into the cosmic scenario (at z<~0.3, [7]). However, recent observations support that they are already in place at z~2, and that less-massive systems get their actual volume densities at later epochs ([8]). **This phenomenon (known as galaxy mass downsizing) seems to conflict directly with the scenario proposed by hierarchical models for the evolution of mETGs.**

Does it mean that the hierarchical paradigm of galaxy evolution is wrong? Not necessarily, as recent observations on the buildup of mETGs are not conclusive either and observational errors could be biassing the results ([9-13]).

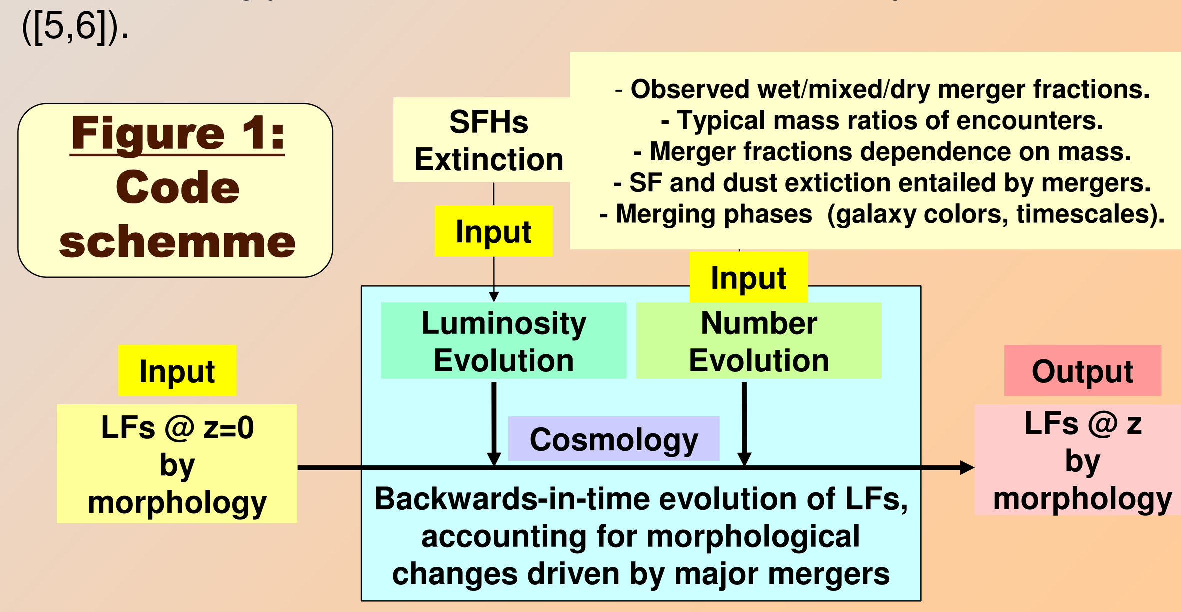
Can the observational major merger fractions really account for the assembly of mETGs? Although they seem to be compatible with those predicted by hierarchical models within errors ([14]), a direct verification of the feasibility of the hierarchical scenario accounting strictly for the observed major mergers had not been carried out yet.

Can mass downsizing and a significant recent hierarchical assembly of mETGs be reconciled? Our model suggests that they could, at least globally.

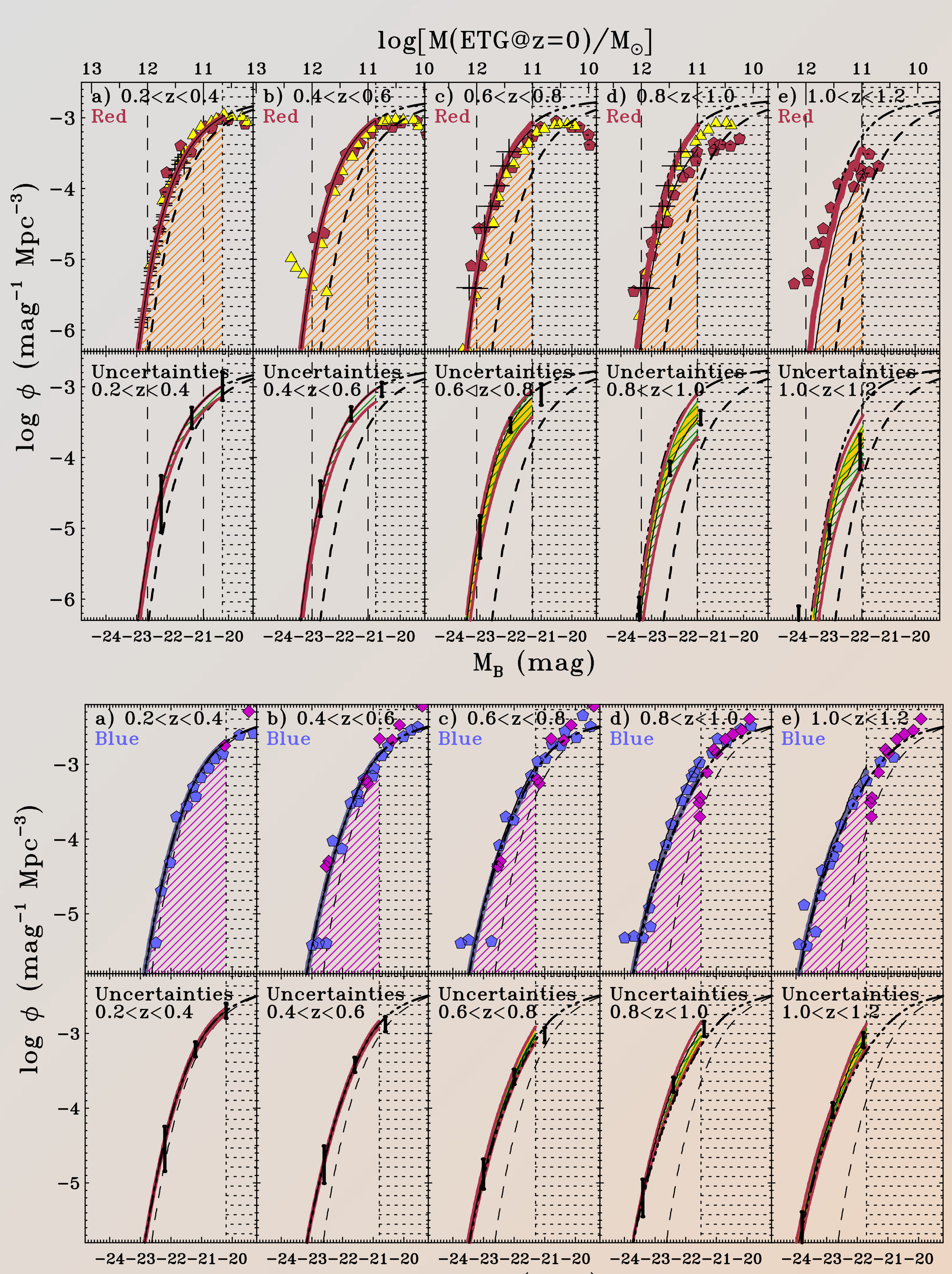
II.- THE MODEL

Being an improved version of the NCMOD code [15], **the model traces <u>backwards-in-time</u> the evolution of the local luminosity functions (LFs) by morphological types, considering the number evolution driven by observational merger fractions at each redshift z and the luminosity evolution of each galaxy type due to its assumed SFH** (see <u>Fig.1</u>). The novelty of the model is the realistic treatment of the effects of major mergers on this evolution. Two main hypotheses are assumed: 1) each major merger has formed an ETG, and 2) gas-rich major mergers undergo transitory phases as DSFs. An ETG (supposedly coming from a major merger) is decomposed into its two merging progenitors (ETGs and/or disks, depending on whether the merger is wet, mixed, or dry) when the merger is "reversed" in time. All the model parameters are set accordingly to robust observational and computational results ([5,6]).

<u>Figure 1:</u> Code schemme



III – EVOLUTION OF GALAXY LFs AT z<~1, BY COLOUR AND MORPHOLOGY



<u>Figure 2:</u> Evolution of the B-band LFs of red and blue galaxies @ z<~1

The model explains naturally why z~0.8 is a transition epoch in the formation of mETGs ([17]). Their assembly is nearly "frozen" at z<~0.8 due to the decrease of merger fractions and the more relevant role played by mixed/dry mergers than by wet ones, which remove existing ETGs to generate other (more massive) ones.

<u>Figure 2</u> shows the observed LF evolution of field red and blue galaxies in the B-band, as derived by different authors (different symbols, references in [5]). A pure luminosity evolution (PLE) model is also overplotted (dashed-dotted lines in each panel). The dashed line represents the LFs at 0<z<0.2 in all panels, just for comparison. All authors agree in the negligible number evolution undergone by red galaxies at z<~0.8 (note that the PLE model and the data agree in panels a-c of red galaxies in <u>Fig.2</u>). However, <u>data on the LF of red galaxies disagree at 0.8<z<1 up to a factor of ~2.5</u> (compare crosses and pentagons in panel d of red galaxies in the figure). <u>Why</u>?

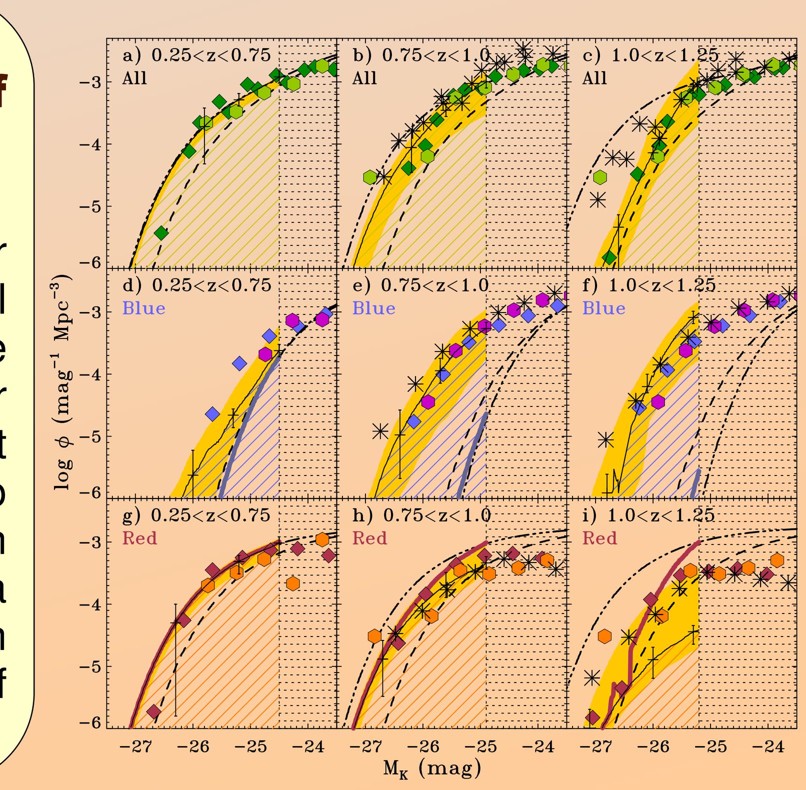
The predictions of our model are overplotted, only considering ETGs as red galaxies (thin solid lines with shaded-lined area below them). **The model can explain the observed LF evolution of field red and blue galaxies up to z~1**, just accounting for the effects of the major mergers strictly reported by observations (<u>Fig.2</u>). It predicts that ~50-60% of the present-day mETGs number density **has appeared during the ~1Gyr period elapsed at 0.8<z<1 through major mergers**, agreeing with some observational data (pentagons in panel d of red galaxies in <u>Fig.2</u>). However, if DSFs are also considered as red galaxies (thick solid lines in the same panels), the model now reproduces the data supporting a negligible evolution of massive red galaxies at 0.8<z<1 (compare with crosses and yellow triangles in panel d of red galaxies in <u>Fig.2</u>). So, **the model proves that apparently contradictory results on the recent number evolution of massive red galaxies can be reconciled, just considering that observational samples of red galaxies can be significantly contaminated by DSFs at z>0.8.** Notice that data for M>10^{12} Msun mETGs are reproduced within errors for red and blue galaxies in <u>Fig.2</u>, although their number density decreases by a similar factor of at 0.8<z<1 too.

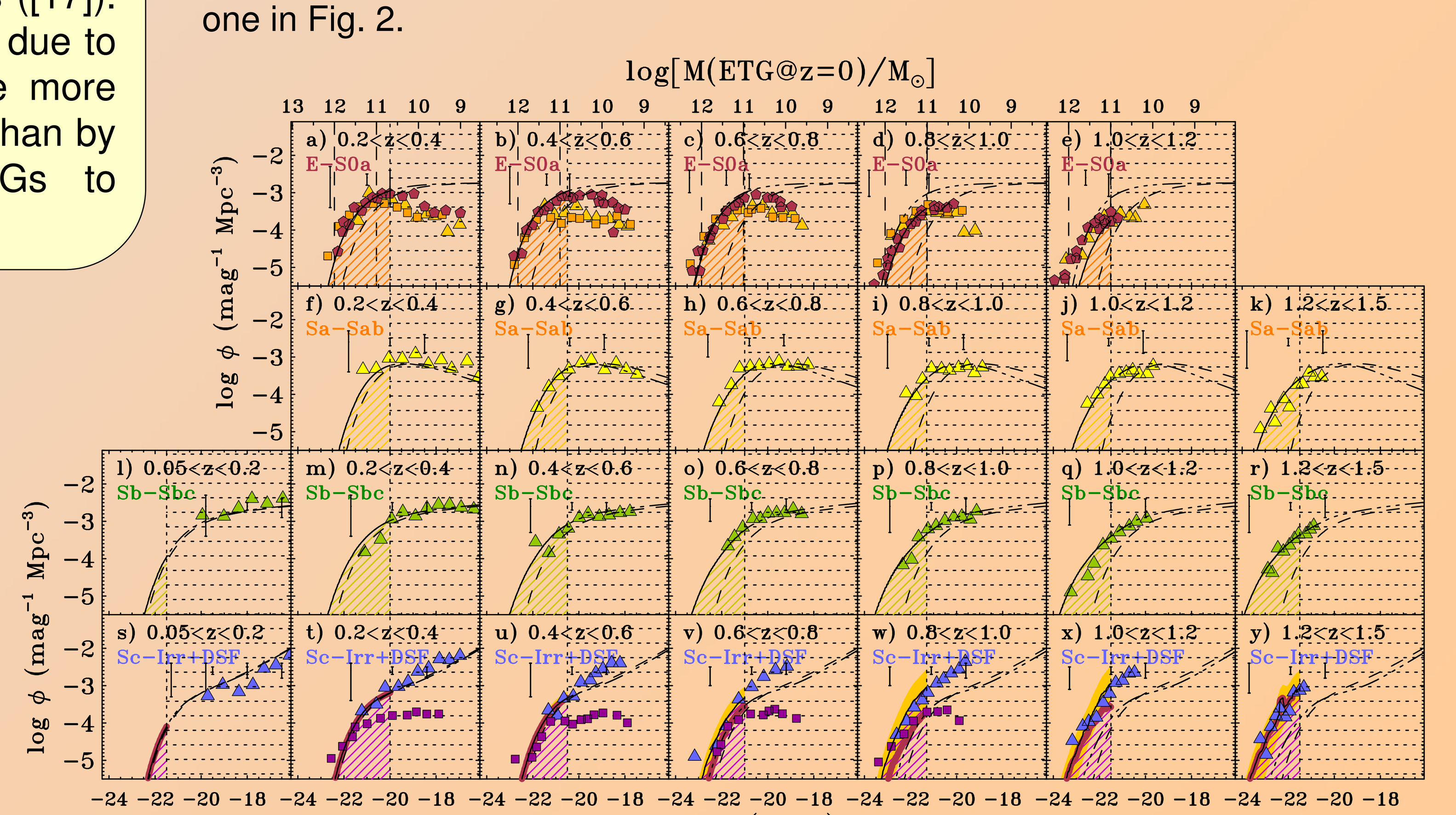
This also provides a straightforward explanation to the observational fact that ~50% of the galaxies in the massive end of the red sequence at z~1 are DSFs ([16]). The model explain them as earlier transitory evolutionary phases of gas-rich major mergers at those redshifts (panel d of red galaxies in <u>Fig.2</u>).

The model reproduces <u>simultaneously</u> the global observed evolution of galaxy LFs at z<~1 in different rest-frame bands (as in I and K, see <u>Fig.3</u>) and using selection criteria different to color (as by morphology or spectral type, see <u>Fig.4</u>). The legends of Figs. 3 and 4 are analogous to the one in Fig. 2.

<u>Figure 3:</u> Evolution of the K-band LFs of red and blue galaxies @ z<~1

DSFs coming from major mergers become essential to explain the huge rise observed in the number density of blue galaxies at 0.75<z<1 with respect to PLE (compare the thin solid line with shaded area below it of the model with the dashed&dotted line of the PLE model in panel e).

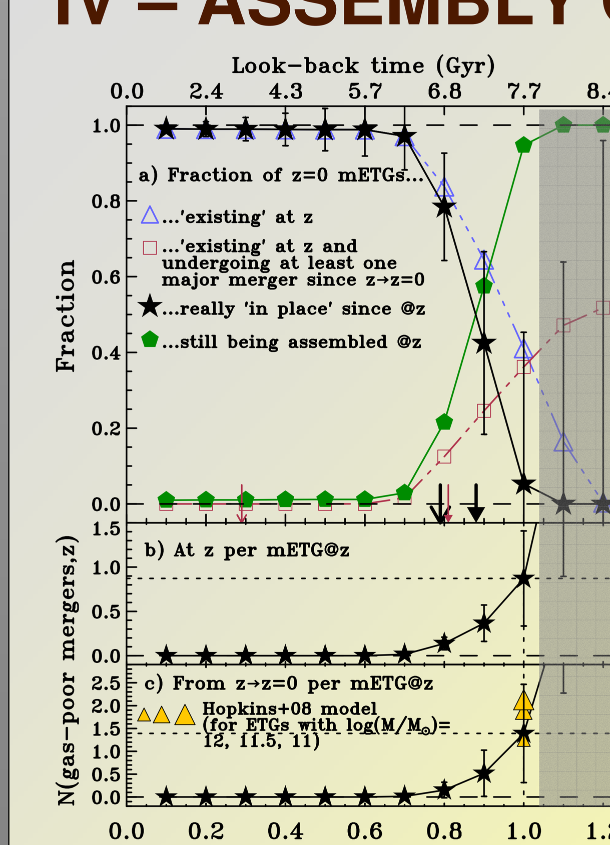




<u>Figure 4:</u> Evolution of the B-band LFs by morphological types @ z<~1

The gas-rich progenitors of the mETGs assembled at 0.8<z<1 reproduce naturally the excess by a factor of ~4 of late type galaxies reported by observations at those redshifts, as compared to PLE models (panels w,x,y).

IV – ASSEMBLY OF mETGS @ z<~1



<u>Figure 5:</u> Predicted number of mETGs at each z (referred to their local value) and fraction of local mETGs really in place since then

An ETG is in place at a certain z basically if it has not undergone any major merger since then. The model predicts that most of the mETGs existing at z~1 (~85%) are not the passively-evolved high-z counterparts of present-day mETGs, but their gas-poor progenitors instead ([6]). **This implies that very few (<~5%) present-day mETGs <u>have been really in place</u> since z~1** (see <u>Fig.5</u>). Accounting for this and for typical errors, the model can derive a final assembly z of mETGs in better agreement with hierarchical models (z~0.5, considering relaxation, [6,7]) than without considering it (z>~1, as most studies do). Accounting for this, **mass downsizing and hierarchical models can be compatible.**

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