The buildup of E-S0 galaxies at $z < 2$ from Pure Luminosity Evolution models

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Abstract Considering that the recent history of E-S0's can be approximated by Pure Luminosity Evolution (PLE), we have examined a set of PLE models in order to delimit the epoch in which the majority of the red galaxy population moved away this simple evolution framework. The models assume that they were assembled and formed most of their stars at a given formation redshift (z_{f}), and that they have evolved without merging or substantial dust obscuration since then. Comparing the model predictions with real data, we conclude that most of E-S0's at low and intermediate luminosities must have been progressively built up at $1 < z < 2$, being the bulk of formation at $z \sim 1.5$, as recently claimed by several observational studies.

1 Introduction

The build up of the galaxy Red Sequence (RS) is one of the most discussed topics in Extragalactic Astronomy nowadays. Part of the difficulty of understanding the chronology of its formation arises in that it is a mixture of early-type systems (E-S0) and dust-reddened spirals, in different proportions depending on the redshift ([16, 2, 27]). Nevertheless, the RS at $z < 1$ can be considered to be mostly made up of early-type galaxies, basically S0's ([9]); so the entry of the lenticular population into the cosmic scenario as known today is a critical issue, since it might have driven the setting up of the major part of the RS. It is known that colors, redshift distributions and luminosity functions (LFs) of the E-S0's can be reproduced since $z \sim 1$ just considering PLE for these galaxies ([25]); but at higher redshifts models and data disagree ([20]). Some authors have claimed that considering PLE models for E-S0's fails to reproduce galaxy number counts (GNCs) in the nIR and optical bands unless their formation is pushed to $z \sim 1.5$ ([8, 12]). In these models, the slope change in the nIR GNCs observed at $K \sim 17.5$ mag ([15]) is reproduced by the E-S0 galaxies

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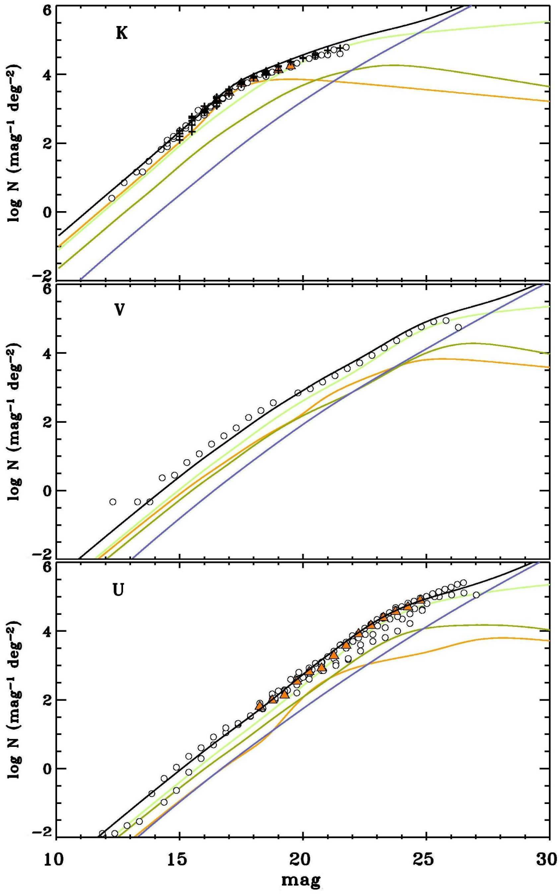

Fig. 1 GNCs predicted by the PLE model with $z_f(\mathrm{E-S0}) = 1.5$ in the K, V, and U bands, compared to observational data. The slope change in the observational K GNCs can be reproduced if the bulk of the E-S0 population has evolved passively from relatively recent epochs (see the top panel). This also happens for lower values of z_f (in the range $1 < z_f < 1.5$), although the fit is worse. PLE for the E-S0 population from $z_f > 2.0$ can be ruled out, as it can not reproduce global and morphological GNCs, unless an extreme dust extinction is fading the brighter E-S0s at high redshift ([10]). *Lines*: GNCs model predictions. *Black*: Predicted GNCs for all the morphological types. *Orange*: For the E-S0 population. *Light green*: For the S0/a-Sb's. *Dark green*: For the Sbc-Sd's. *Blue*: For the Im's. *Symbols*: Data. *Open circles*: Data from several authors (see references in [12]). *Red triangles*: Data from [8] and [12]. *Crosses*: Data from [1].

placed at $1 < z < 1.5$, brightened by its recent formation. Nevertheless, observational GNCs by redshift bins have shown that the galaxies responsible for the K-band slope change are basically objects with $L \sim L^*$ at $z < 1$ ([1]), posing a strong constraint to the previous models. We intend to analyse this apparent contradiction.

2 Models and Results

We have developed a set of simple PLE models in order to delimit the epoch in which the bulk of the red galaxy population (basically S0's at $L \sim L^*$) moved away this simple evolution framework. We have used the NCMOD code ([14]) to build galaxy GNCs and LF predictions. The code evolves the local LFs back in time for a set of galaxy types using the spectral energy distributions (SEDs) derived from GALAXEV ([4]). A ΛCDM concordance cosmological scenario has been considered in the models. Local, morphologically-dependent LFs in the r^*-band are used

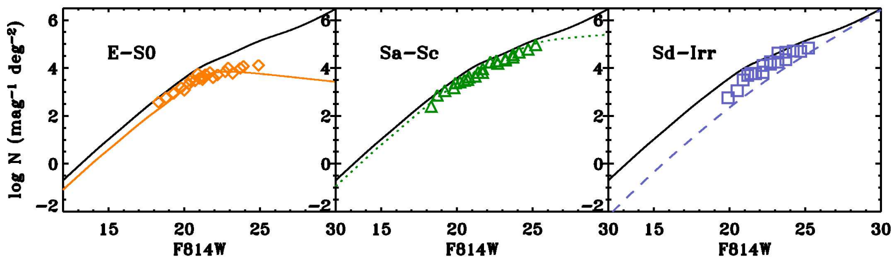

Fig. 2 GNCs by morphological type predicted by the model with $z_f(E-S0) = 1.5$, compared to those observed by [11]. Predicted GNCs are shown using lines, while observational data are plotted using different symbols for three different morphological type bins: E-S0, Sa-Sc, and Sd-Irr (this last bin can not be comparable, due to the morphological bins in which the LF is described).

for describing the local galactic population, considering four main representative galactic types: E-S0, S0/a-Sb, Sbc-Sd, and Im ([22]). All the galaxies within a certain type are considered to share a common evolutionary history. The evolutionary parameterization and properties of each galactic type have been adopted following standard, observationally-based, star formation histories and properties for each galactic type ([12]). Time-dependent dust obscuration is considered in the evolving SEDs. No merging events are considered in the models, just PLE. The formation redshift (z_f) of the E-S0 population is considered as a free parameter, whereas we fix $z_f = 4$ for all the other galactic types. The position in magnitude of the slope change in the K-band GNCs is extremely sensitive to $z_f(E-S0)$. Only the models with $1 < z_f < 1.5$ can reproduce the GNCs globally in several bands and morphological GNCs in the I-band (see Figs. 1 and 2). The model reproduces GNCs by redshift bins in the K-band for $z < 1$, but fails in higher redshift bins (see Fig. 3). Observationally, the GNCs slope change in the K-band comes from a mixture of galaxies at $z < 1$ ([1]), whereas the main contributors to the faint end of the slope change in the models are the E-S0's at $1 < z < 1.5$ that disappear at $z > 1.5$ in the model (not shown here). In fact, the model reproduces the slope change by making the colors of the bulk of the RS population (E-S0's) a bit bluer at $z \sim$1-1.3 than those expected by imposing PLE from $z > 2$ for this galaxy population. These colors are consistent with the median colors observed for the RS galaxies at these redshifts ([7, 17]).

3 Summary and Discussion

The models indicate that the colors exhibited by the bulk of E-S0 population at $z < 1$ (basically, S0's at low and intermediate luminosities) are traces of a strong star-forming burst in these galaxies, occurred $\sim$ 1-2 Gyr before $z \sim 1$ (i.e., at $1 < z < 2$). This star formation episode must have supposed an inflection point in the evolution of these systems, as these galaxies harbour extremelly old populations (with $\sim$10-11 Gyr, [24]); and it must have been short in time, as they are required to

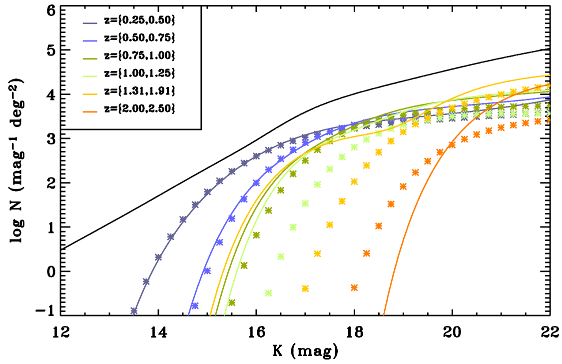

Fig. 3 GNCs in the *K*-band by redshift bins for the models with $z_f(\mathrm{E}-\mathrm{S0}) = 1.5$, compared to observational results ([1]). *Crosses:* Data. *Lines*: Model predictions. Different redshift bins are represented by different colors (see the legend). Setting $z_f(\mathrm{E}-\mathrm{S0}) = 1.5$ implies a bump in the bright end of the LF at $z \sim$ 1-1.5 that is not observed ([3]), pointing to a more progressive appearance of this population.

fade and become quite red at $z < 1$ in order to reproduce GNCs by morphological types and redshift bins. The present models add another evidence to the gradual buildup of early-type galaxies at $z < 2$, posed by several recent studies ([19, 6, 18]), indicating that the noticeable mass growth in the red galaxy population observed between $1 < z < 2$ ([26, 13, 21, 23]) could be due to the apparition of the bulk of the S0 population.

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