

The formation and evolution of field massive galaxies

Andrea Cimatti

INAF - Osservatorio Astrofisico di Arcetri, Italy

Abstract. The problem of the formation and evolution of field massive galaxies is briefly reviewed from an observational perspective. The motivations and the characteristics of the K20 survey are outlined. The redshift distribution of $K_s < 20$ galaxies, the evolution of the rest-frame K_s -band luminosity function and luminosity density to $z \sim 1.5$, the nature and the role of the red galaxy population are presented. Such results are compared with the predictions of models of galaxy evolution.

Keywords: galaxies; cosmology

1. Introduction

Despite the recent developments in observational cosmology, one of the main unsolved issues remains how and when the present-day massive elliptical galaxies ($\mathcal{M}_{\text{stars}} > 10^{11} \text{ M}_{\odot}$) built up and what type of evolution characterized their growth across the cosmic time.

There are two main proposed scenarios. In the first, such systems formed at high redshifts (e.g. $z > 2-3$) through a “monolithic” collapse accompanied by a violent burst of star formation, then followed by a passive and pure luminosity evolution (PLE) of the stellar population to nowadays (Eggen, Lynden-Bell & Sandage 1962; Tinsley 1972; Larson 1974; van Albada 1982). Such a scenario makes some critical and rigid predictions that can be tested with the observations: *(i)* the comoving number density of massive spheroids should be conserved through cosmic times, *(ii)* massive galaxies should evolve only in luminosity, *(iii)* old passively evolving spheroids should exist at least up to $z \sim 1-1.5$, *(iv)* there should be a population of progenitors at $z > 2-3$ characterized by large amounts of gas (and dust) and strong star formation rates in order to be compatible with the rapid formation scenario and with the properties (e.g. masses, ages, metallicities) of the present-day “fossils” resulting from that formation process.

In a diametrically opposed scenario, massive spheroids formed at later times through a slower process of hierarchical merging of smaller galaxies (e.g. White & Rees 1978; Kauffman, White, & Guiderdoni 1993; Kauffmann 1996) characterized by moderate star formation rates, thus reaching the final masses in more recent epochs (e.g. $z < 1-1.5$) (e.g. Baugh et al. 1996, 1998; Cole et al. 2000; Baugh et al. 2002). As a consequence, the hierarchical merging models (HMMs) predict



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that massive systems should be very rare at $z \sim 1$, with the comoving density of $\mathcal{M}_{\text{stars}} > 10^{11} \text{ M}_{\odot}$ galaxies decreasing by almost an order of magnitude from $z \sim 0$ to $z \sim 1$ (Baugh et al. 2002; Benson et al. 2002).

Several observations were designed over the recent years in order to test such two competing models.

One possibility is to search for the starburst progenitors expected at $z > 2 - 3$ in the “monolithic”+PLE scenario. In this respect, submm and mm continuum surveys unveiled a population of high- z dusty starbursts which may represent the ancestors of the present-day massive galaxies (see Blain et al. 2002 for a recent review).

The other possibility is to search for passively evolving spheroids to the highest possible redshifts and to study their properties both in clusters and in the field. This latter approach provided so far controversial results.

Because of their color evolution, fundamental plane and stellar population properties, cluster ellipticals are now generally believed to form a homogeneous population of old systems formed at high redshifts (e.g. Stanford et al. 1998; see also Renzini 1999; Renzini & Cimatti 1999; Peebles 2002 for recent reviews).

However, the question of field spheroids is still actively debated. It is now established that old, passive and massive systems exist in the field out to $z \sim 1.5$ (e.g. Spinrad et al. 1997; Stiavelli et al. 1999; Waddington et al. 2002), but the open question is what are their number density and physical/evolutionary properties with respect to the model predictions.

Some surveys based on color or morphological selections found a deficit of $z > 1 - 1.4$ elliptical candidates (e.g. Kauffmann et al. 1996; Zepf 1997; Franceschini et al. 1998; Barger et al. 1999; Rodighiero et al. 2001; Smith et al. 2002; Roche et al. 2002), whereas others did not confirm such result out to $z \sim 1 - 2$ (e.g. Totani & Yoshii 1998; Benitez et al. 1999; Daddi et al. 2000b; Im et al. 2002; Cimatti et al. 2002a). Part of the discrepancies can be ascribed to the strong clustering (hence field-to-field variations) of the galaxies with the red colors expected for high- z elliptical candidates (Daddi et al. 2000a).

Other approaches made the picture even more controversial. For instance, Menanteau et al. (2001) found that a fraction of morphologically selected field spheroidals show internal color variations incompatible with a traditional PLE scenario and stronger than cluster spheroidals at the same redshifts. Similar results have been obtained with photometric, spectroscopic and fundamental plane studies of field ellipticals to $z \sim 0.7 - 1$ (e.g. Kodama et al. 1999; Schade et al. 1999; Treu et al. 2002). Such observations suggest that, despite the mass of massive spheroids seems not to change significantly from $z \sim 1$ to $z \sim 0$ (Brinchmann & Ellis 2000), field early-type systems at $z \sim 0.5 - 1$ do not

form an entirely homogeneous population, some looking consistent with the PLE scenario, whereas others with signatures of recent secondary episodes of star formation (see also Ellis 2000 for a review).

A more solid and unbiased approach is to investigate the evolution of massive galaxies by means of spectroscopic surveys of field galaxies selected in the K -band (e.g. Broadhurst et al. 1992), and to push the study of massive systems to $z > 1$. Since the rest-frame optical and near-IR light is a good tracer of the galaxy *stellar* mass (Gavazzi et al. 1996), K -band surveys provide the important possibility to select galaxies according to their mass up to $z \sim 2$. The advantages of the K -band selection also include the small k -corrections with respect to optical surveys (which are sensitive to the star formation activity rather than to the stellar mass), and the minor effects of dust extinction. Once a sample of faint field galaxies has been selected in the K -band, deep spectroscopy with 8-10m class telescopes can then be performed to shed light on their nature and on their redshift distribution. Several spectroscopic surveys of this kind have been and are being performed (e.g. Cowie et al. 1996; Cohen et al. 1999; Stern et al. 2001; see also Drory et al. 2001, although mostly based on photometric redshifts).

In this paper, the main results obtained so far with a new spectroscopic survey for K -selected field galaxies are reviewed, concentrating on the redshift distribution, the evolution of the near-IR luminosity function and luminosity density, the very red galaxy population, and on the comparison with the predictions of the most recent scenarios of galaxy formation and evolution. $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$ are adopted.

2. The K20 survey

Motivated by the above open questions, we started an ESO VLT Large Program (dubbed “K20 survey”) based on 17 nights distributed over two years (1999-2000) (see Cimatti et al. 2002c for details).

The prime aim of such a survey was to derive the redshift distribution and spectral properties of 546 K_s -selected objects with the *only* selection criterion of $K_s < 20$ (Vega). Such a threshold is critical because it selects galaxies over a broad range of masses, i.e. $\mathcal{M}_{\text{stars}} > 10^{10} M_\odot$ and $\mathcal{M}_{\text{stars}} > 4 \times 10^{10} M_\odot$ for $z = 0.5$ and $z = 1$ respectively (according to the mean $\mathcal{M}_{\text{stars}}/L$ ratio in the local universe and adopting Bruzual & Charlot 2000 spectral synthesis models with a Salpeter IMF). The $K_s < 20$ selection has also the observational advantage that most galaxies have magnitudes still within the limits of optical spectroscopy of 8m-class telescopes ($R < 25$).

The targets were selected from K_s -band images (ESO NTT+SOFI) of *two independent fields* covering a total area of 52 arcmin². One of the fields is a sub-area of the Chandra Deep Field South (CDFS; Giacconi et al. 2001). Optical multi-object spectroscopy was made with the ESO VLT UT1 and UT2 equipped with FORS1 and FORS2. A fraction of the sample was also observed with near-IR spectroscopy with VLT UT1+ISAAC in order to attempt to derive the redshifts of the galaxies which were too faint for optical spectroscopy and/or expected to be in a redshift range for which no strong features fall in the observed optical spectral region (e.g. $1.5 < z < 2.0$). In addition to spectroscopy, $UBVRIZJK_s$ imaging was also available for both fields, thus providing the possibility to estimate photometric redshifts for all the objects in the K20 sample, to optimize them through a comparison with the spectroscopic redshifts and to assign a reliable photometric redshift to the objects for which it was not possible to derive the spectroscopic z . The overall spectroscopic redshift completeness is 94%, 92%, 87% for $K_s < 19.0$, 19.5, 20.0 respectively. The overall redshift completeness (spectroscopic + photometric redshifts) is 98%.

The K20 survey represents a significant improvement with respect to previous surveys for faint K -selected galaxies (e.g. Cowie et al. 1996; Cohen et al. 1999) thanks to its larger sample, the coverage of two independent fields (thus reducing the cosmic variance effects), the availability of optimized photometric redshifts, and the spectroscopic redshift completeness, in particular for the reddest galaxies.

3. The redshift distribution of $K_s < 20$ galaxies

The observed differential and cumulative redshift distributions for the K20 sample are presented in Fig. 1 (see Cimatti et al. 2002b), together with the predictions of different scenarios of galaxy formation and evolution, including both hierarchical merging models (HMMs) from Menci et al. (2002, M02), Cole et al. (2000, C00), Somerville et al. (2001, S01), and pure luminosity evolution models (PLE) based on Pozzetti et al. (1996,1998 PPLE) and Totani et al. (2001, TPLE). The redshift distribution can be retrieved from <http://www.arcetri.astro.it/~k20/releases>. The spike at $z \sim 0.7$ is due to two clusters (or rich groups) at $z = 0.67$ and $z = 0.73$. The median redshift of $N(z)$ is $z_{med} = 0.737$ and $z_{med} = 0.805$, respectively with and without the two clusters being included. Without the clusters, the fractions of galaxies at $z > 1$ and $z > 1.5$ are 138/424 (32.5%) and 39/424 (9.2%) respectively. The high- z tail extends beyond $z = 2$. The contribution of objects with only a photometric redshift becomes relevant only for

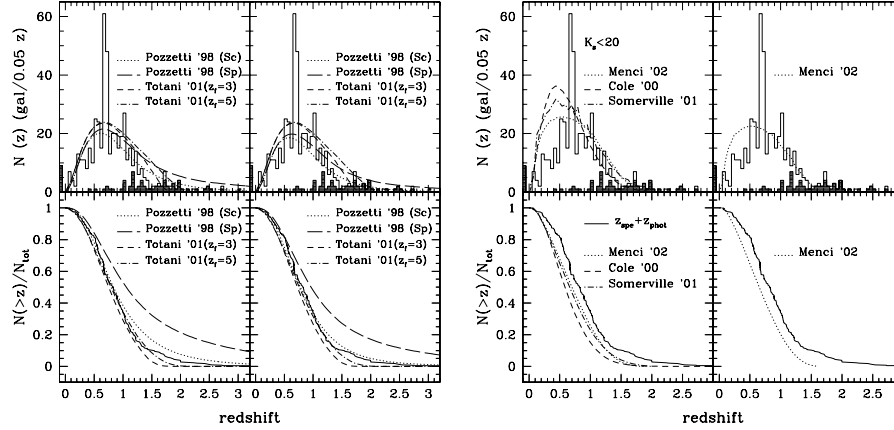


Figure 1. **Fig. 1a** – *Top panels*: the observed differential $N(z)$ for $K_s < 20$ (histogram) compared with the PLE model predictions. *Bottom panels*: the observed fractional cumulative redshift distribution (continuous line) compared with the same models. The shaded histogram shows the contribution of photometric redshifts. The bin at $z < 0$ indicates the 9 objects without redshift. The *left* and *right* panels show the models without and with the inclusion of the photometric selection effects respectively. Sc and Sp indicate Scalo and Salpeter IMFs respectively. **Fig. 1b** – same as Fig. 1a, but compared with the HMM predictions. *Right panels*: the M02 model with the inclusion of the photometric selection effects.

$z > 1.5$. The fractional cumulative distributions displayed in Fig. 1 (bottom panels) were obtained by removing the two clusters mentioned above in order to perform a meaningful comparison with the galaxy formation models which do not include clusters (PLE models), or are averaged over very large volumes, hence diluting the effects of redshift spikes (HMMs). No best tuning of the models was attempted in this comparison, thus allowing an unbiased *blind test* with the K20 observational data. The model predicted $N(z)$ are normalized to the K20 survey sky area.

Fig. 1a shows a fairly good agreement between the observed $N(z)$ distribution and the PLE models (with the exception of PPLE with Salpeter IMF), although such models slightly overpredict the number of galaxies at $z \gtrsim 1.2$. However, if the photometric selection effects present in the K20 survey (Cimatti et al. 2002b) are taken into account, the PLE models become much closer to the observed $N(z)$ thanks to the decrease of the predicted high- z tail. According to the Kolmogorov-Smirnov test, the PLE models are acceptable at 95% confidence level, with the exception of the PPLE model with Salpeter IMF.

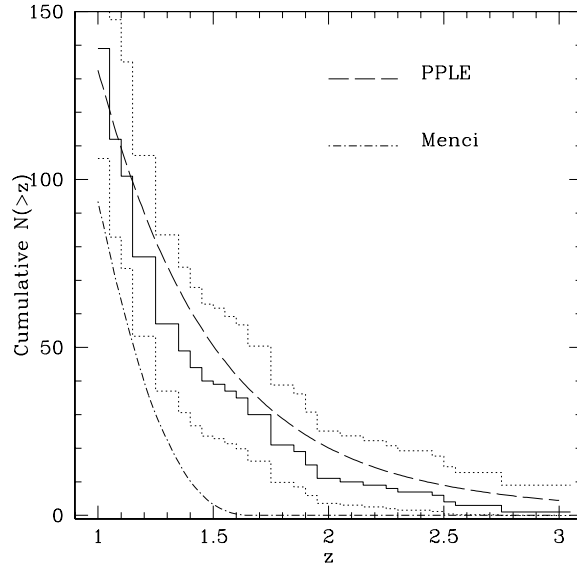


Figure 2. The observed cumulative number of galaxies between $1 < z < 3$ (continuous line) and the corresponding poissonian $\pm 3\sigma$ confidence region (dotted lines). The PPLE (Scalo IMF) and the M02 models are corrected for the photometric biases.

On the other side, all the HMMs underpredict the median redshift ($z_{med}=0.59, 0.70$ and 0.67 for the C00, M02 and S01 models respectively), overpredict the total number of galaxies with $K_s < 20$ by factors up to $\sim 50\%$ as well as the number of galaxies at $z < 0.5$, and underpredict the fractions of $z > 1-1.5$ galaxies by factors of 2–4 (Fig. 1b). Fig. 1b (bottom panels) illustrates that in the fractional cumulative distributions the discrepancy with observations appears systematic at all redshifts. The Kolmogorov-Smirnov test shows that all the HMMs are discrepant with the observations at $> 99\%$ level. The inclusion of the photometric biases exacerbates this discrepancy, as shown in Fig. 1b (right panels) for the M02 model (the discrepancy for the C00 and S01 models becomes even stronger). The deficit of high-redshift objects is well illustrated by Fig. 2, where the PPLE model is capable to reproduce the cumulative number distribution of galaxies at $1 < z < 3$ within $1-2\sigma$, whereas the M02 model is always discrepant at $\geq 3\sigma$ level (up to $> 5\sigma$ for $1.5 < z < 2.5$). This conclusion is not heavily based on the objects with only photometric redshifts estimates, as the mere presence of 7 galaxies with spectroscopic redshift $z > 1.6$ is already in substantial contrast with the predictions by HMMs of basically no galaxies with $K_s < 20$ and $z > 1.6$.

4. The evolution of the luminosity function

The luminosity function (LF) of galaxies has been estimated in the rest-frame K_s -band and in three redshift bins which avoid the clusters at $z \sim 0.7$ ($z_{mean}=0.5, 1, 1.5$; see Fig. 3) (Pozzetti et al. 2003), using both the $1/V_{max}$ (Schmidt 1968; Felten 1976) and the STY (Sandage, Tammann & Yahil 1979) formalisms. The LF observed in the first two redshift bins is fairly well fit by Schechter functions. A comparison with the local K_s -band LF of Cole et al. (2001) shows a mild *luminosity* evolution of $LF(z)$ out to $z = 1$, with a brightening of about -0.5 magnitudes from $z = 0$ to $z = 1$ (Fig. 3). Similar results have been found by Drory et al. (2001), Cohen (2002), Bolzonella et al. (2002) and Miyazaki et al. (2002) (see also Cowie et al. 1996).

The study of the LF by galaxy spectral or color types shows that red early-type galaxies dominate the bright-end of the LF already at $z \sim 1$, and that their number density shows only a small decrease from $z \sim 0$ to $z \sim 1$ (Pozzetti et al. 2003). This is consistent with the independent study of Im et al. (2002) based on morphologically selected spheroidals.

Fig. 4 shows a comparison of the observed luminosity function with PLE and HMM predictions. The PLE models describe reasonably well the shape and the evolution of the luminosity function up to the highest redshift bin, $z_{mean} = 1.5$, with no evidence for a strong decline of the most luminous systems (with $L > L^*$). This is in contrast, especially in the highest redshift bin, with the prediction by the HMMs of a decline in the number density of luminous (i.e. massive) systems with redshift. Moreover, hierarchical merging models (namely M02 and C00) result in a significant overprediction of faint, sub- L^* galaxies at $0 < z < 1.3$. This problem, also hinted by the comparison of $N(z)$ between models and data, is probably related to the so called “satellite problem” (e.g. Primack 2002).

However, it is interesting to note that at $z \sim 1$ the HMMs seem not to be in strong disagreement with the observations relative to the bright end of the galaxy luminosity function (with the possible exception of the highest luminosity point). Thus, the key issue is to verify whether the bright $L > L^*$ galaxies in the K20 survey have the same nature of the luminous galaxies predicted by the HMMs, in particular for their mass to light ratios (\mathcal{M}_{stars}/L).

Fig. 5 compares the $R - K_s$ colors and luminosity distributions of galaxies with $0.75 < z < 1.3$ (a bin dominated by spectroscopic redshifts) as observed in our survey to the predictions of the GIF¹ simulations (Kauffmann et al. 1999). Such a comparison highlights

¹ [http:// www.mpa-garching.mpg.de/GIF/](http://www.mpa-garching.mpg.de/GIF/)

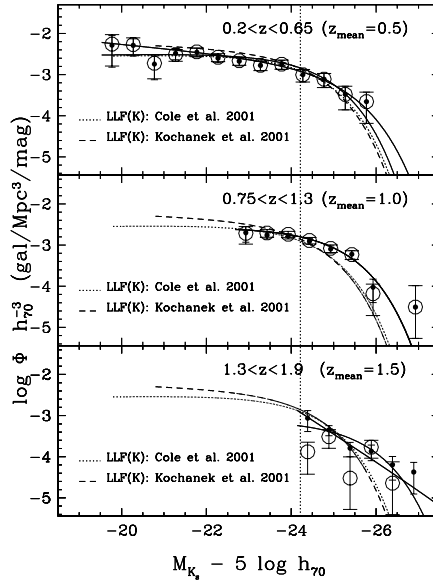


Figure 3. The rest-frame K_s -band Luminosity Function in three redshift bins. Data points derive from $1/V_{max}$ analysis. Solid curves: the Schechter fits derived from maximum likelihood analysis (thin solid lines are the fit assuming local α parameter). Dotted and dashed curves: the local K_s -band LFs of Cole et al. (2001) and Kochanek et al. (2001) respectively. The vertical dotted line indicates the local M^* of Cole et al. (2001). Open circles: spectroscopic redshifts, filled circles: spectroscopic + photometric redshifts.

that a relevant discrepancy is present between the two distributions: real galaxies with $M_K - 5\log h_{70} < -24.5$ in the K20 sample have a median color of $R - K_s \sim 5$, whereas the GIF simulated galaxies have $R - K_s \sim 4$, and the two distributions have very small overlap. Given that red galaxies have old stellar populations and higher \mathcal{M}_{stars}/L ratios, the apparent agreement with HMM predictions of the $z \sim 1$ bright end of the luminosity function (Fig. 4) is fortuitous and probably results from an underestimate of the \mathcal{M}_{stars}/L present in the same models. This is equivalent to say that the number density of massive galaxies at $z \sim 1$ is underpredicted by HMMs, and the predicted colors, ages and star formation rates do not agree with the observations.

5. The evolution of the luminosity density

Tracing the integrated cosmic emission history of the galaxies at different wavelengths offers the prospect of an empirical determination of

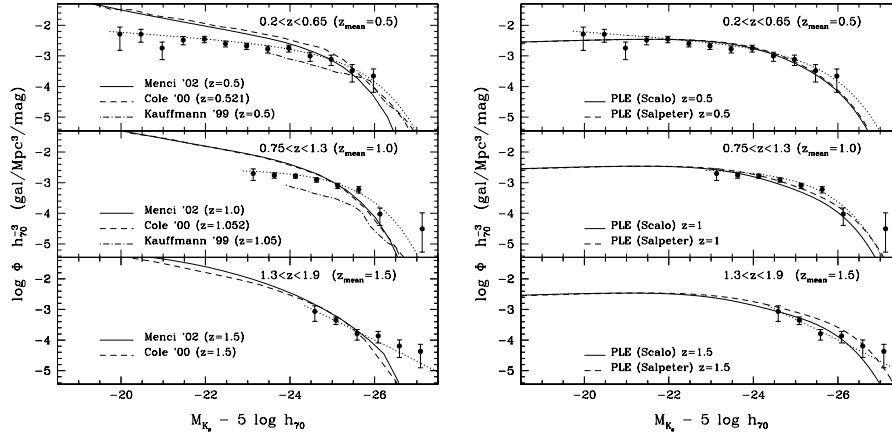


Figure 4. Left: the K_s -band LF compared to hierarchical merging model predictions. Right: the K_s -band LF compared to PLE (PPLE) model predictions. Dotted curves are the Schechter best fits to the observed LFs (spectroscopic + photometric redshifts).

the global evolution of the galaxy population. Indeed it is independent of the details of galaxy evolution and depends mainly on the star formation history of the universe (Lilly et al. 1996, Madau, Pozzetti & Dickinson 1998). Attempts to reconstruct the cosmic evolution of the comoving luminosity density have been made previously mainly in the UV and optical bands, i.e. focusing on the star formation history activity of galaxies (Lilly et al. 1996, Cowie et al. 1999).

Our survey offers for the first time the possibility to investigate it in the near-IR using a LF extended over a wide range in luminosity, thus providing new clues on the global evolution of the stellar mass density (Pozzetti et al. 2003). Using the local luminosity density at $z \sim 0$ as derived from Cole et al. (2001) complemented with the estimates at higher redshifts based on the K20 survey, it is found that the rest-frame K_s -band luminosity density up to $z \sim 1.3$ is well represented by a power law with $\rho_\lambda(z) = \rho_\lambda(z=0)(1+z)^\beta$, with $\beta = 0.37$. Compared to the optical (rest-frame UV-blue) bands, the near-IR luminosity density evolution is much slower ($\beta = 3.9 - 2.7$ from 0.28 to $0.44 \mu\text{m}$ by Lilly et al. 1996 and $\beta = 1.5$ at 0.15 - $0.28 \mu\text{m}$ by Cowie et al. 1999, for $\Omega_m = 1$). The slow evolution of the observed K_s -band luminosity density suggests that the stellar mass density should also evolve slowly at least up to $z \sim 1.3$. This is in agreement with a recent analysis by Bolzonella et al. (2002) (see also Cowie et al. 1996 and Brinchmann & Ellis 2000).

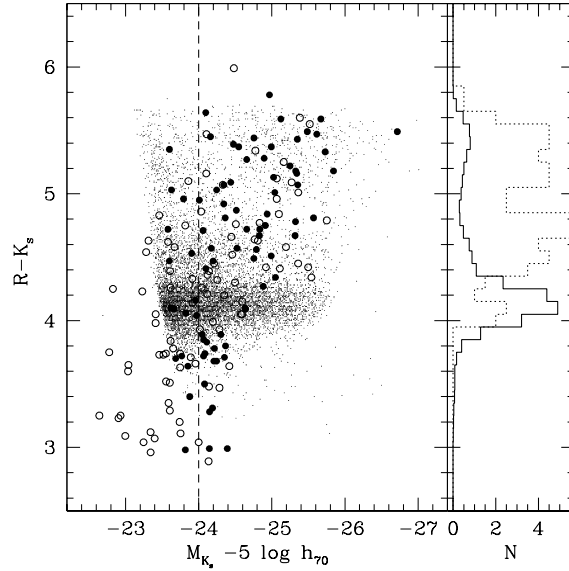


Figure 5. Left panel: $R - K_s$ colors vs. rest-frame absolute K_s magnitudes for $z = 1.05$ GIF simulated catalog (small dots) and data (circles) at $0.75 < z < 1.3$ (spectroscopic + photometric redshifts; $z_{mean} = 1$) (empty and filled circles refer to $z < 1$ and $z > 1$ respectively). The vertical dashed line represents approximately the completeness magnitude limit of GIF catalog corresponding to its mass limit (see text). Right panel: Color distribution of luminous galaxies ($M_{K_s} - 5 \log h_{70} < -24.5$) observed (dotted line) and simulated (continuous line), normalized to the same comoving volume.

The analysis of the stellar mass function and its cosmic evolution is in progress and will be presented elsewhere.

6. Extremely Red Objects (EROs)

Extremely Red Objects (EROs, $R - K > 5$) are critical in the context of galaxy formation and evolution because their colors allow to select old and passively evolving galaxies at $z > 0.9$.

For a fraction of EROs (70% to $K_s < 19.2$) present in the K20 sample it was possible to derive a spectroscopic redshift and a spectral classification (Cimatti et al 2002a). Two classes of galaxies at $z \sim 1$ contribute nearly equally to the ERO population: old stellar systems with no signs of star formation, and dusty star-forming galaxies.

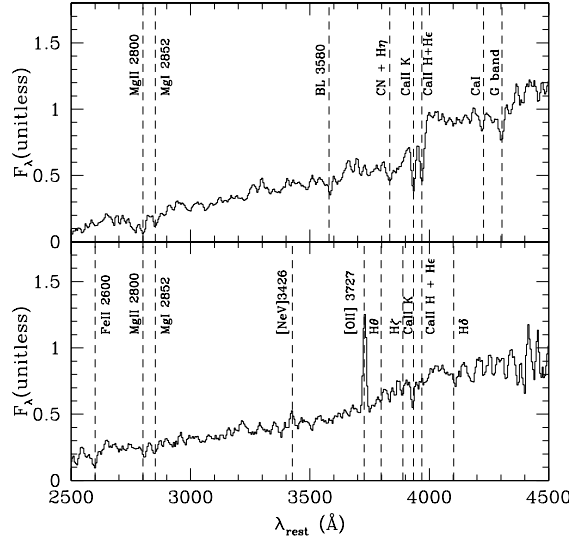


Figure 6. The average rest-frame spectra (smoothed with a 3 pixel boxcar) of old passively evolving (top; $z_{\text{mean}} = 1.000$) and dusty star-forming EROs (bottom; $z_{\text{mean}} = 1.096$) with $K_s \leq 20$ (Cimatti et al. 2002a).

6.1. OLD EROs

The colors and spectral properties of old EROs are consistent with ≥ 3 Gyr old passively evolving stellar populations (assuming solar metallicity and Salpeter IMF), requiring a formation redshift $z_f > 2.4$. The number density is $6.3 \pm 1.8 \times 10^{-4} \text{h}^3 \text{Mpc}^{-3}$ for $K_s < 19.2$, consistent with the expectations of PLE models for passively evolving early-type galaxies with similar formation redshifts (Cimatti et al. 2002a). HMMs predict a significant deficit of such old red galaxies at $z \sim 1$, ranging from a factor of ~ 3 (Kauffmann et al. 1999) to a factor of ~ 5 (Cole et al. 2000). Preliminary analysis of recent HST+ACS imaging shows that old EROs have indeed spheroidal morphologies with surface brightness profiles typical of elliptical galaxies.

6.2. DUSTY STAR-FORMING EROs

The spectra of star-forming EROs suggest a dust reddening of $E(B - V) \sim 0.5$ –1 (adopting the Calzetti 2001 extinction law), implying typical star-formation rates of 50 – $150 \text{ M}_\odot \text{yr}^{-1}$, and a significant contribution (> 20 – 30%) to the cosmic star-formation density at $z \sim 1$ (see

also Smail et al. 2002). A recent analysis based on their X-ray emission provided a similar estimate of the SFRs (Brusa et al. 2002).

The comoving density of dusty EROs is again $\sim 6 \times 10^{-4} \text{ h}^3 \text{Mpc}^{-3}$ at $K_s < 19.2$. The GIF simulations (Kauffmann et al. 1999) predict a comoving density of red galaxies with $SFR > 50 \text{ M}_\odot \text{yr}^{-1}$ that is a factor of 30 lower than the observed density of dusty EROs.

Such moderate SFRs suggest that the far-infrared luminosities of dusty star-forming EROs are generally below $L_{FIR} \sim 10^{12} \text{ L}_\odot$, and would then explain the origin of the low detection rate of EROs with $K_s < 20 - 20.5$ in submm continuum observations (e.g. Mohan et al. 2002; see also Smail et al. 2002). However, the fraction of dusty ultraluminous infrared systems may be higher in ERO samples selected at fainter K_s -band magnitudes (e.g. Wehner et al. 2002).

6.3. CLUSTERING

Taking advantage of the spectroscopic redshift information for the two ERO classes, we compared the relative 3D clustering in real space (Daddi et al. 2002). The comoving correlation lengths of dusty and old EROs are constrained to be $r_0 < 2.5$ and $5.5 < r_0 < 16 \text{ h}^{-1} \text{ Mpc}$ comoving respectively, implying that old EROs are the main source of the ERO strong angular clustering. It is important to notice that the strong clustering measured for the old EROs is in agreement with the predictions of hierarchical clustering scenarios (Kauffmann et al. 1999).

7. Summary and discussion

The high level of completeness of the K20 survey and the relative set of results presented in previous sections provide new implications for a better understanding of the evolution of “mass-selected” field galaxies. **(1)** The redshift distribution of $K_s < 20$ field galaxies has a median redshift of $z_{med} \sim 0.8$ and a high- z tail extended beyond $z \sim 2$. The current models of hierarchical merging do not match the observed median redshift because they significantly overpredict the number of low luminosity (hence low mass) galaxies at $z < 0.4 - 0.5$, and underpredict the fraction of objects at $z > 1 - 1.5$. Instead, the redshift distributions predicted by PLE models are in reasonable agreement with the observations. It is relevant to recall here that early predictions of the expected fraction of galaxies at $z > 1$ in a $K_s < 20$ sample indicated respectively $\approx 60\%$ and $\approx 10\%$ for a PLE case and for a (then) standard $\Omega_m = 1$ CDM model (Kauffmann & Charlot 1998). This version of PLE was then ruled out by Fontana et al. (1999). The more recent PLE models

and HMMs consistently show that for $z > 1$ the difference between the predictions of different scenarios is much less extreme. These results come partly from the now favored Λ CDM cosmology which pushes most of the merging activity in hierarchical models at earlier times compared to τ CDM and SCDM models with $\Omega_m = 1$ (structures form later in a matter-dominated universe, thus resulting in an even lower fraction of galaxies at high- z), and partly to different recipes for merging and star formation modes, which tend to narrow the gap between HMMs and the PLE case (e.g. Somerville et al. 2001; Menci et al. 2002). In this respect, the observed $N(z)$ provides an additional evidence that the universe is not matter-dominated ($\Omega_m < 1$).

(2) The rest-frame K_s -band luminosity function shows a mild luminosity evolution up to at least $z \sim 1$, with a brightening of about 0.5 magnitudes. Significant density evolution is ruled out up to $z \sim 1$. Current hierarchical merging models fail in reproducing the shape and evolutionary properties of the LF because they overpredict the number of sub- L^* galaxies and predict a substantial density evolution. PLE models are in good agreement with the observations up to $z \sim 1$.

(3) At odds with the HMMs, the bright-end of the LF at $z \sim 1$ is dominated by red and luminous (hence old and massive) galaxies.

(4) The rest-frame K_s -band luminosity density (hence the stellar mass density) evolves slowly up to $z \sim 1.3$.

(5) Old passive systems and dusty star-forming galaxies (both at $z \sim 1$) equally contribute to the ERO population with $K_s < 19.2$.

(6) The number, luminosities and ages of old EROs imply that massive spheroids formed at $z > 2.4$ and that were already fully assembled at $z \sim 1$, consistently with a PLE scenario.

(7) Dusty EROs allow to select (in a way complementary to other surveys for star-forming systems) a population of galaxies which contribute significantly to the cosmic star formation budget at $z \sim 1$.

(8) HMMs strongly underpredict the number of both ERO classes.

Overall, the results of the K20 survey show that galaxies selected in the K_s -band are characterized by little evolution up to $z \sim 1$, and that the observed properties can be successfully described by a PLE scenario. In contrast, HMMs fail in reproducing the observations because they predict a sort of “delayed” scenario where the assembly of massive galaxies occurs later than what is actually observed. We recall here that the discrepancies of HMMs in accounting for the properties of even $z = 0 \rightarrow \sim 1$ early-type galaxies have been already emphasized in the past (e.g., Renzini 1999; Renzini & Cimatti 1999). Moreover, among low-redshift galaxies there appears to be a clear anti-correlation of the specific star formation rate with galactic mass (Gavazzi et al. 1996; Boselli et al. 2001), the most massive galaxies being “old”, the low-mass

galaxies being instead dominated by young stellar populations. This is just the opposite than expected in the traditional HMMs, where the most massive galaxies are the last to form. The same anti-correlation is observed in the K20 survey at $z \sim 1$.

It is important to stress here that the above results do not necessarily mean that the whole framework of hierarchical merging of CDM halos is under discussion. For instance, the strong clustering of old EROs and the clustering evolution of the K20 galaxies (irrespective of colors) seem to be fully consistent with the predictions of CDM models of large scale structure evolution (Daddi et al. 2001; Firth et al. 2002; Daddi et al. in preparation).

It is also important to stress that the K20 survey allows to perform tests which are sensitive to the evolutionary “modes” of galaxies rather than to their formation mechanism. This means that merging, as the galaxy main formation mechanism, is not ruled out by the present observations. Also, it should be noted that PLE models are not a physical alternative to the HMMs, but rather tools useful to parameterize the evolution of galaxies under three main assumptions: high formation redshift, conservation of number density through cosmic times, passive luminosity evolution of the stellar populations.

Thus, if we still accept the Λ CDM scenario of hierarchical merging of dark matter halos as the *basic framework for structure and galaxy formation*, the observed discrepancies highlighted by the K20 survey may be ascribed to how the *baryon assembly* is treated and, in particular, to the heuristic algorithms adopted for the star formation processes and their feedback, both within individual galaxies and in their environment. Our results suggest that HMMs should have galaxy formation in a CDM dominated universe to closely mimic the old-fashioned *monolithic collapse* scenario. This requires enhancing merging and star formation in massive halos at high redshift (say, $z \gtrsim 2 - 3$), while in the meantime suppressing star formation in low-mass halos. For instance, Granato et al. (2001) suggested the strong UV radiation feedback from the AGN activity during the era of supermassive black hole formation to be responsible for the suppression of star formation in low-mass halos, hence imprinting a “anti-hierarchical” behavior in the baryonic component. The same effect may well result from the feedback by the starburst activity itself (see also Ferguson & Babul 1998).

In summary, the redshift distribution of $K_s < 20$ galaxies, together with the space density, nature, and clustering properties of the ERO population, and the redshift evolution of the rest-frame near-IR luminosity function and luminosity density provide a new set of observables on the galaxy population in the $z \sim 1 - 2$ universe, thus bridging the properties of $z \sim 0$ galaxies with those of Lyman-break

and submm/mm-selected galaxies at $z \geq 2-3$. This set of observables poses a new challenge for theoretical models to properly reproduce.

Deeper spectroscopy coupled with HST+ACS imaging and SIRTf photometry will allow us to derive additional constraints on the nature and evolution of massive stellar systems out to higher redshifts.

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