Probing the evolution of massive galaxies with the K20 survey*

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Abstract. The motivations and the status of the K20 survey are presented. The first results on the evolution of massive galaxies and the comparison with the predictions of the currently competing scenarios of galaxy formation are also discussed.

1   Introduction

Understanding the evolution of massive galaxies (e.g. $M_{stellar} \gtrsim 10^{11}$ $M_\odot$) is important because to constrain the different scenarios of structure and galaxy formation. In particular, the question on the formation of the present-day massive spheroidals is still one of the most debated issues of galaxy evolution (see [1] for a review). In one scenario, massive spheroidals are formed at early cosmological epochs (e.g. $z > 3$) through a short and intense episode of star formation (with $SFR \sim 100 - 1000$ $M_\odot yr^{-1}$), followed by a passive evolution (or pure luminosity evolution, PLE) of the stellar population to nowadays. In marked contrast, the hierarchical scenarios predict that massive spheroidals are the product of rather recent merging of pre-existing disk galaxies taking place mostly at lower redshifts and with moderate star formation rates [2,3]. In hierarchical merging scenarios, fully assembled massive field spheroidals with $M_{stellar} \gtrsim 10^{11}$ $M_\odot$ at $z \gtrsim 1$ are very rare objects [4] (see also Baugh, this volume).

   From an observational point of view, a direct way to test the above scenarios is to study the evolution of massive galaxies by means of spectroscopic surveys of field galaxies selected in the K-band [5,6,7,8]. Since the near-IR light is a good tracer of the galaxy mass[9,4], K-band imaging allows to select massive galaxies at high-z. A galaxy with a stellar mass of about 10^{11} $M_\odot$ is expected to have $18 < K < 20$ for $1 < z < 2$ [4], thus implying that moderately deep K-band surveys can efficiently select massive galaxies in that redshift range. Deep spectroscopy with 8-10m class telescopes can then be used to search for massive systems and to constrain their redshift distribution.

2   The K20 survey

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2.1   The observations and the database

In order to investigate the evolution of massive galaxies and to constrain the currently competing galaxy formation scenarios, we started in 1999 a project that was called "K20 survey". For such a project, 17 nights were allocated to our team in the context of an ESO VLT Large Program distributed over a period of two years (1999-2000) (see also http://www.arcetri.astro.it/~k20/).

The prime aim of such a survey is to derive the redshift distribution of about 550 K-selected objects with $Ks \leq 20$. The targets were selected from a 32.2 arcmin^2 area of the Chandra Deep Field South (CDFS; [10]) using the images from the ESO Imaging Survey public database (EIS; http://www.eso.org/science/eis/; the raw Ks-band images were reduced and calibrated by our group), and from a 19.8 arcmin^2 field centered at 0055-269 using NTT+SOFI Ks-band imaging (Fontana et al. in preparation).

Optical multi-object spectroscopy was made with the ESO VLT UT1 and UT2 equipped with FORS1 (October-November 1999) and FORS2 (November 2000) during $0.5''$-$1.5''$ seeing conditions and with $0.7''$-$1.2''$ wide slits depending on the seeing. The grisms 150I, 200I, 300I were used with typical integration times of 1-3 hours. Dithering of the targets along the slits between two fixed positions was made for most observations in order to efficiently remove the CCD fringing and the strong OH sky lines at $\lambda_{obs} > 7000$ Å. The spectra were calibrated using standard spectrophotometric stars, dereddened for atmospheric extinction, corrected for telluric absorptions and scaled to the total R-band magnitudes. A small fraction of the K20 sample was observed with near-IR spectroscopy using the VLT UT1+ISAAC in order 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. $1.5 < z < 2.0$). However, due to the lack of a multi-object spectroscopy mode in ISAAC, it turned out very hard and inefficient to obtain redshifts of faint galaxies in this manner, which was successful only for a few galaxies at $1.3 < z < 1.9$ with strong Hα in emission.

In addition to spectroscopy, $UBVRIzJKs$ imaging is also available for both fields, thus providing the possibility to estimate photometric redshifts for all the objects in the K20 sample, to "calibrate" them through a comparison with the spectroscopic redshifts and to assign reliable photometric redshifts to the objects for which it was not possible to derive the spectroscopic z (see Fontana et al., these proceedings).

The spectroscopic observations were completed in December 2000. The spectral analysis was done by means of automatic software (IRAF: `rvidlines` and `xcsao`) and through visual inspection of the 1D and 2D spectra. Because of four nights lost due to the bad weather, only 94% of the sample with $Ks < 20$ could be observed. The efficiencies in deriving the specroscopic redshifts for the observed targets was high: $N_{identified}/N_{observed}$=95%, 93%, 91% for $Ks < 19.0$, 19.5, 20.0 respectively. The overall spectroscopic redshift completeness is still rather high, with $N_{identified}/N_{total}$=93%, 91%, 85% for $Ks < 19.0$, 19.5, 20.0 respectively (where $N_{total} = N_{observed} + N_{unobserved}$). The size of

the sample, the spectroscopic redshift completeness, and the availability of tested and reliable photometric redshifts make the K20 sample one of the largest and most complete database to study the evolution of K-selected galaxies available to date.

## 2.2   The scientific aims

Kauffmann & Charlot (1998) estimated that $\sim 60\%$ and $\sim 10\%$ of the galaxies in a $K < 20$ sample are expected to be at $z > 1$, respectively in a PLE and in a standard CDM hierarchical merging model (cf. their Fig. 4). Such a large difference was in fact one of the main motivations of our original proposal to undertake a redshift survey for all objects down to $K < 20$. However, more recent models consistently show that the difference between the predictions is less extreme than in the KC98 realization (Menci et al., Pozzetti et al., Somerville et al., in preparation). Part of the effect is due to the now favored ΛCDM cosmology which pushes most of the merging activity at earlier times compared to τCDM and SCDM models, and therefore get closer to the PLE case. Moreover, a different tuning of the star-formation algorithms (to accomodate for more star formation at high z) also reduces the differences between the two scenarios. Our database is currently being used to perform a stringent comparison between the observed redshift distribution and the ones predicted by the most recent models of galaxy formation (Cimatti et al., in preparation).

Besides the main goal described here above, our unique database is also being used to address other important questions on galaxy evolution: *(1)* the evolution of the Luminosity and Mass Functions (see Pozzetti et al., this volume), *(2)* the evolution of ellipticals, *(3)* the fraction of dusty starbursts and high-z ellipticals in the ERO population, *(4)* the evolution of galaxy clustering (see Daddi et al., this volume), *(5)* the spectral properties of a large number of galaxies and their evolution as a function of redshift, *(6)* the volume star formation density using different indicators, *(7)* the fraction of AGN in K-selected samples, *(8)* the brown dwarf population at high Galactic latitude.

3   First results on Extremely Red Objects

A fraction of the galaxies selected in the near-infrared show very red colors (e.g. $R - K > 5$). Such galaxies are known as Extremely Red Objects (EROs), and the most recent surveys demonstrated that they form a substantial field population [11,12,13]. Since their colors are consistent with being either old passively evolving galaxies or dusty starbursts or AGN, it is therefore of prime importance to determine their nature in order to exploit the stringent constraints that EROs can place on the galaxy formation scenarios. In this section we adopt a cosmology with $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$.

From our total $Ks < 20$ sample, 78 EROs with $R - Ks \geq 5.0$ were extracted. About 70% of the EROs with $R - Ks \geq 5.0$ and $Ks \leq 19.2$ was spectroscopically identified with *old* and *dusty star-forming* galaxies at $0.7 < z < 1.5$ [14]. The two
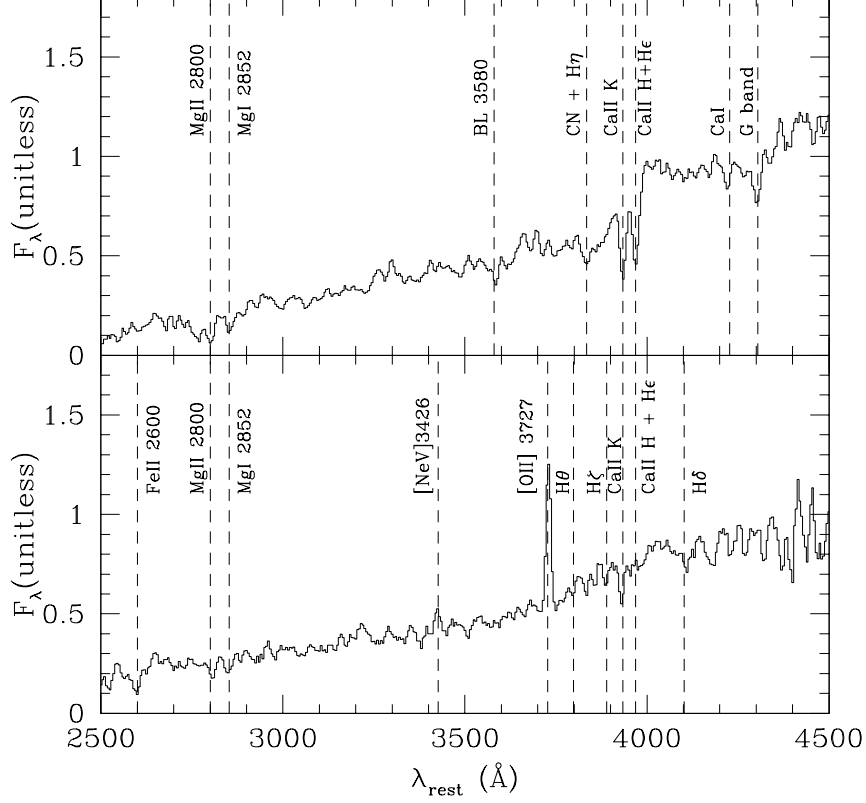
Fig. 1. The average rest-frame spectra (smoothed with a 3 pixel boxcar) of old passively evolving (top; $z_{mean} = 1.000$) and dusty star-forming EROs (bottom; $z_{mean} = 1.096$) with $Ks \leq 20$.

classes are about equally populated and for each of them we derived the average spectrum (Fig. 1).

Old EROs have an average spectrum consistent with being old passively evolving ellipticals, and it can be well reproduced with Bruzual & Charlot (2000) spectral synthesis models with no dust extinction and ages $\gtrsim 3$ Gyr if $Z = Z_\odot$, thus implying an average formation redshift $z_f \gtrsim 2.4$ for such a metallicity.

The average spectrum of star-forming EROs can be reproduced only if a substantial dust extinction is introduced, typically in the range of $0.5 < E(B - V) < 1$. Their star formation rates, corrected for the average reddening, suggest a significant contribution ($>20\%$) of EROs to the cosmic star-formation density at z~1. However, the detection of [NeV]$\lambda 3426$ emission suggests that a fraction of star-forming EROs also host some AGN activity obscured by dust.
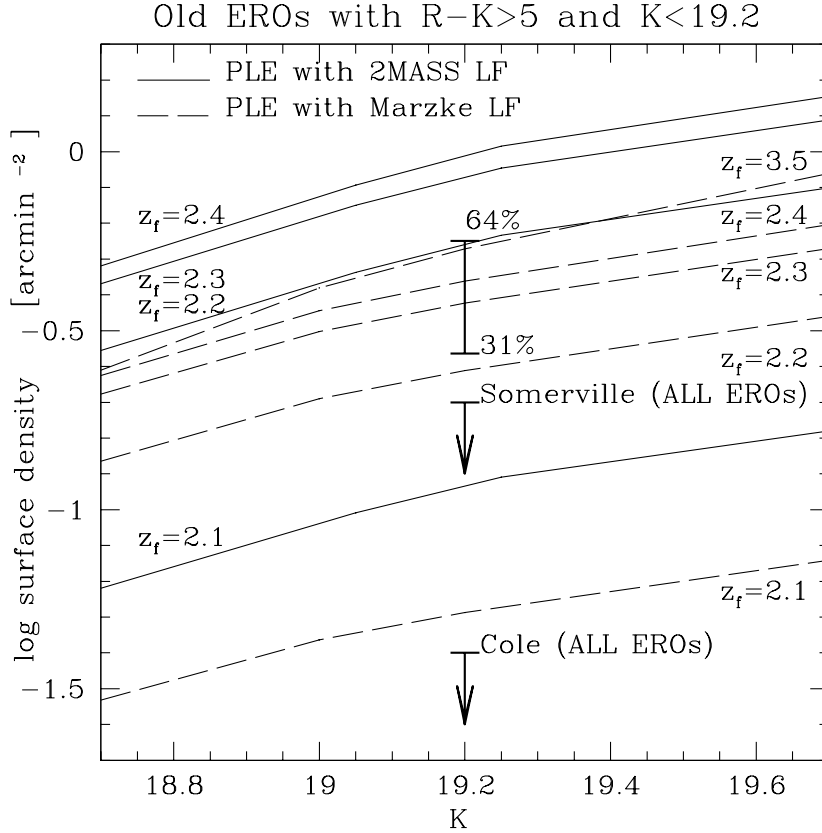
Fig. 2. Comparison between the observed density of old EROs with the predictions of PLE models (see [14] for more details). The range of observed density of old EROs with $Ks < 19.2$ is shown with a vertical bar ranging from the minimum observed density (32% of the total density of EROs observed in the K20 survey) and the maximum possible density (64% of the total density of EROs assuming that all the spectroscopically unidentified EROs are old passive systems). The dashed and solid lines show the predictions of PLE models adopting respectively the local luminosity function of ellipticals [17] and of early-type galaxies (2MASS, [18]), and using Bruzual & Charlot spectral synthesis models with solar metallicity, Salpeter IMF, e-folding time of the star formation $\tau = 0.3$ Gyr, and a set of formation redshifts (z_f). See also [19] for more details on PLE models. The arrows indicate the predicted densities of EROs in two recent hierarchical merging models (the Somerville et al. model shown in Firth et al. 2001, and the Cole et al. 2000 model presented in Smith et al. 2001). Since such models predict the total density of *all* EROs (i.e. old + dusty star-forming) they actually represent upper limits to the predicted density of old passive systems.

Since old EROs have spectra consistent with being passively evolving ellipticals, we compared their density with different model predictions (see Fig. 2). The main result is that the density of old EROs observed in our survey is strongly underpredicted by the current hierarchical merging models (a factor of $\sim$4–10 for the models presented by [15] and [16] respectively). On the other hand, PLE models with a reasonable choice of input parameters predict surface and comoving densities in agreement with the observations and imply that massive spheroidals formed at $z_f > 2 - 3$ (see [14] for more details).

Since the luminosities and the stellar masses of the observed old EROs are in the range of 0.5-4L^* and 1-6$\times 10^{11}$ M$_\odot$, this means that fully assembled massive systems were already in place up to $z \sim 1.3$.

The existence of such galaxies with a comoving density of $\gtrsim 2 \times 10^{-4}$ Mpc^{-3} at $z \sim 1$ ([14]) is in contrast with the ΛCDM hierarchical model of [20], where the comoving density of *all galaxy types* with M$> 10^{11}$ M$_\odot$ is about one order of magnitude lower, whereas the difference is less dramatic with the model of [21] (see Fig. 1 of [22]).

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