Is the deficit of $z > 1$ field ellipticals real?

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Abstract. The results of a 700 arcmin$^2$ survey for EROs are presented. The sky distribution of EROs is very inhomogeneous and their two point correlation function shows a very high amplitude, a factor of 10 larger than that of the field galaxy population. Such a clustering can explain the strong variance found in previous works, and provides evidence that ERO are mostly made of high–$z$ ellipticals. The surface density of EROs found in our large survey is in good agreement with that expected for passively evolving ellipticals formed at high redshift ($z \gtrsim 2.5$).

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A fundamental test of the models for the evolution of the elliptical galaxies is the measure of their comoving density at high redshift as compared to the local value. Existing realizations of the hierarchical galaxy formation models predict a substantial decline of the elliptical’s number density with redshift, as they should form by merging of lower-mass spirals at intermediate redshifts (see e.g. Baugh et al. 1996, Kauffmann 1996).

Passively evolving ellipticals with $1 \lesssim z \lesssim 2$ are expected to have very red colors, i.e. $R - K > 5-6$, which qualify them as EROs (Extremely Red Objects). Thus, the search for EROs and the measure of their surface density in deep near-IR surveys provide clues on the number density evolution of ellipticals. Anyway EROs can also be strongly dust–reddened starburst galaxies (e.g. Cimatti et al. 1998). The density of EROs therefore provides an upper limit to that of high–$z$ ellipticals, even if marginal indications exist that the fraction of dusty objects among EROs may be small (Cimatti et al. 1999).

Several groups have claimed that there is a significant deficit of $z > 1$ evolved field ellipticals (e.g. Zepf 1998, Barger et al. 1999), based on the very low surface density of EROs recovered in $K$–selected samples. However, others found results consistent with a constant comoving density, even up to $z \sim 2$ (e.g. Benitez et al. 1999, Broadhurst & Bowens 2000). A wide consensus on the reality of this alleged deficit could not be reached, as very discrepant results were obtained from works on different fields, suggesting that the cosmic variance could be strong for high–$z$ ellipticals and that results based on small area surveys (ranging

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Figure 1. The sky distribution of EROs with $K_s \leq 18.8$ and $R - K \geq 5$. Several tests showed that the inhomogeneities and the large void in the bottom part of our survey are real features (see Daddi et al. 2000 for more details).

from about 1 arcmin$^2$ of the NICMOS HDFS to $\sim 60$ arcmin$^2$ of Barger et al.) are not sufficient to reach a definitive conclusion.

A large area survey in the $R$ and $K$ band was therefore planned and carried out (Daddi et al. 2000), covering about 700 arcmin$^2$ to $K \sim 19$, with the selection of a sample of $\sim 400$ ($\sim 50$) EROs with $R - K \geq 5$ ($R - K \geq 6$). Fig. 1 shows very clearly that the sky distribution of EROs is very inhomogeneous with overdensities and large underdense regions, providing evidence that the discrepant results on the ERO surface density were indeed due to the cosmic variance.

A quantitative analysis of the two point correlation function showed that the ERO distribution is clustered, resulting in the first quantitative measurement of such function for the ERO population, and it was found to have an amplitude larger by a factor of $\sim 10$ than that of the field $K$-selected galaxies at the same $K$ magnitude limits (Fig. 2).

The clustering of EROs provides the natural explanation of the large field-to-field variations of their surface density, as their variance is increased by an additive factor proportional to the clustering amplitude and to the square of the average number of EROs expected. Our measure allows us to give a reliable estimate of the ERO variance, with the
Is the deficit of \( z > 1 \) ellipticals real?

Figure 2. The measured two point correlation function for the EROs of Fig. 1. The solid line is the fitted function, with amplitude \( A(1^\circ) = 0.014 (\pm 0.002) \) and (fixed) slope \( \delta = -0.8 \). The dashed line is for the field galaxies at the same \( K \) level.

**caveat** that, because of the existence of the large underdense regions, it is much probable, on average, to underestimate the true ERO surface density with small area surveys.

Even more interesting, since we expect the dusty EROs not to have a correlation length as strong as that of ellipticals and to be distributed on a much wider redshift range, the large–amplitude clustering is strong evidence that most EROs are ellipticals, and it allows to perform a direct comparison between the surface density of EROs and that of the passively evolving high–\( z \) ellipticals selected with the same color and luminosity threshold (Daddi, Cimatti & Renzini 2000).

In Fig. 3 such a comparison is shown for the EROs selected in our survey. The PLE models were computed using the Bruzual & Charlot 1997 synthesis models with Salpeter IMF, solar metallicity and no dust reddening. The Marzke et al. (1994) pure–elliptical LF was used and the cosmological parameters were chosen to be \( \Omega_0 = 0.1, H_0 = 70 \) \( \text{km s}^{-1} \text{Mpc}^{-1} \). The results do not significantly change with a \( \Omega = 0.3, \Lambda = 0.7 \) cosmology.

The surface density of EROs with \( R - K \geq 5.3 \) (expected colors of passively evolving ellipticals with \( z \gtrsim 1 \)) is fully consistent with the passive evolution predictions, even if we allow for a reasonable fraction of \( \sim 20–30\% \) of EROs not to be high–\( z \) ellipticals. Thus, we
Figure 3. Comparison between the surface density of EROs measured in our survey with the passive models predictions. The error bars are (from left to right) the 1σ poissonian and 2σ and 1σ true (i.e. considering the clustering) confidence regions for the models. In order to estimate the variance for the \( R - K \geq 6 \) EROs their clustering amplitude was derived on the basis of the color–amplitude relation (see Daddi et al. 2000).

conclude that the data are consistent with all the field ellipticals being in place and very red at \( z \gtrsim 1 \) implying high formation redshift for such population \((z \gtrsim 2.5)\). The data on the \( R - K \geq 6 \) EROs (expected for \( z \gtrsim 1.3 \)) are much more uncertain, because of the poorer statistic, but they are still consistent with the models at about 1σ.

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