The Clustering Evolution of Distant Red Galaxies
In The GOODS South Field

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Abstract

We use a catalog of $\sim 3000$ Ks–selected galaxies with extended multi–wavelength coverage (from 0.3 to 8 micron) and accurate estimates of the photometric redshifts to select 179 DRGs with $J - Ks \geq 1.3$ in the GOODS South field. We first show that the $J - Ks \geq 1.3$ criterion selects a rather heterogeneous sample of galaxies, going from the targeted high-redshift luminous evolved systems, to a significant fraction of lower redshift ($1 \leq z \leq 2$) and less luminous dusty starbursts. These low-redshift DRGs are significantly less clustered than higher-z DRGs. With the aid of extreme and simplified theoretical models of clustering evolution we show that it is unlikely that the two samples are drawn from the same population observed at two different stages of evolution. High-z DRGs likely represent the progenitors of the more massive and more luminous galaxies in the local Universe and might mark the regions that will later evolve into structures of intermediate mass, like groups or small galaxy clusters. Low-z DRGs, on the other hand, will likely evolve into slightly less massive field galaxies.
Introduction

Finding and studying large samples of distant luminous and evolved galaxies is fundamental to challenge cosmological models of structure formation and evolution.

Galaxies with red colours in optical/infrared bands are particularly important because they sample either the population of massive and evolved galaxies or the highly reddened star-forming galaxies at high redshifts.

The so-called Distant Red Galaxies (DRGs) are selected through a $J - K > 1.3$ criteria, designed to be sensitive to galaxies with a large 4000 Å break at $z \geq 2$. Franx et al. (2003) used this technique in the FIRES survey (Labbé et al., 2003) selecting 14 DRGs in the HDFS, down to faint $K_s$ magnitudes ($K_s \leq 24.5$ in AB mag).

Our Work

We have used the GOODS-MUSIC sample (Grazian et al., 2006) to select 179 DRGs with a typical magnitude of $K_s = 23.5$.

GOODS-MUSIC is an ideal dataset because of:

- Large spectral coverage, with 14 photometric bands from 0.3 to 8.0 μm.
- Wide and Deep area (135 sq. arcmin at $K_s = 23.5$).
- Precise photometric redshifts ($\sigma_z = 0.06$).

We use this sample of DRGs to study in particular their number density, their redshift distribution and their spatial distribution (clustering).
The spectroscopic vs photometric redshifts for 973 galaxies in the GOODS-MUSIC sample. The accuracy is $\sigma_z = 0.06$ and $\frac{\sigma_z}{1+z} = 0.03$ in the redshift range $0 < z < 6$.

The spectroscopic vs photometric redshifts for 340 red galaxies with $J - Ks \geq 0.7$ in the GOODS-MUSIC sample. The accuracy is $\sigma_z = 0.08$ and $\frac{\sigma_z}{1+z} = 0.05$ in the redshift range $0 < z < 4$. There are only 13 galaxies with $J - Ks \geq 1.3$ and spectroscopic redshifts (red crosses).
Selection of DRGs

Selection of $J - K_s \geq 1.3$ objects in the GOODS-South Field. Upper limits in the $J$ band are shown as vertical arrows. The horizontal line shows the selection criteria for DRGs in the GOODS-South area, while dashed line indicates the completeness on the DRG selection due to the depth of the $J$ band (26.8 AB at $S/N = 1$).

The surface density of selected DRGs in the GOODS-South Field (triangles), compared with the estimate obtained in the HDFS (squares, Labbé et al. (2003)).
Redshift distribution of DRGs

The redshift distribution of GOODS DRGs is slightly different from that drawn for HDFS by Franx et al. (2003) and Daddi et al. (2003). In the GOODS-MUSIC sample there are DRGs at low redshifts ($1 \leq z \leq 2$) with bright apparent $Ks$ magnitudes ($Ks \leq 22$), which are in practice absent in small and deep pencil beam surveys, like the HDFS.

The SEDs of these low-redshift DRGs are dominated by power-law spectra with a tilt at $\lambda \sim 6\mu m$, which are mostly fitted by relatively young galaxies (age/$\tau \leq 1$) and a substantial amount of extinction ($E_{B-V} \sim 0.5 - 1.0$) as described in Papovich et al. (2005).

The DRG criterion is effective in selecting galaxies at $z > 2$ that formed their stars in a short starburst $\tau \leq 1$Gyr. At the same time, large $J - Ks$ colours may be obtained by star-forming, dusty models down to lower redshift $z \simeq 1$.

All low-$z$ DRG are dominated by actively star-forming, relatively young objects, while higher-$z$ DRGs have a broader distribution of age/$\tau$, including several objects (30% of the high-$z$ DRG sample) that are fitted by passively evolving models.

This highlights why the DRG population is not a unique class of $z > 2$ objects, but it is contaminated by dusty starbursts with $z \sim 1.5$, whose strong dust absorption is responsible for their red infrared colours.
Upper panel: the distribution of spectroscopic and photometric redshifts of DRGs in the GOODS-South Field. The dotted curve is the redshift distribution obtained for the DRGs using the probability function for the photometric redshift for each object. The long-dashed line represents the redshift distribution for the HDFS, peaked at $z \sim 3$. Lower panel: the photometric redshift distribution for bright ($Ks < 22$; long-dashed line) and faint ($Ks > 22$; solid line) DRGs. Deep pencil beam surveys (HDFs) preferentially select objects at $z \sim 2$, while large area surveys are biased towards lower-redshift ($z \leq 2$) and bright ($Ks < 22$) DRGs (short-dashed line).

The $J - Ks$ colour of objects in the GOODS-South field as a function of their (spectroscopic or photometric) redshift. Upper limits in the $J$ band are displayed as vertical arrows. The long-dashed horizontal line shows the selection criteria adopted for DRGs in this paper. The two blue solid lines show the $J - Ks$ colour for passively evolving galaxies formed at $z = 20$ and with an e-folding star formation rate with timescale $\tau = 0.1$ and $\tau = 1$ Gyr (upper and lower curves, respectively). The red short-dashed lines show the same colour for a star-forming galaxy with $E(B-V) = 1.1$ and $E(B-V) = 0.5$ (upper and lower curves, respectively).
Spatial distribution of DRGs: the clustering properties

DRGs are not uniformly distributed on the sky, but they are clustered on scales of several Mpc. The analysis of the HDFs shows that the DRGs are strongly affected by cosmic variance, such that the small area covered by surveys like HDFN or FIRES prevents to derive a robust measurement of their clustering properties and their redshift evolution.

We have used the Landy-Szalay estimator (Landy & Szalay, 1993) to obtain the two-point correlation function (TPCF) for DRGs in the GOODS-MUSIC database. We find a clear evidence of a strong positive evolution with redshifts for DRGs, $r_0 = 7.41^{+3.45}_{-4.84} h^{-1}$ Mpc and $r_0 = 13.36^{+2.99}_{-3.20} h^{-1}$ Mpc, for the sub-samples at $1 < z < 2$ and $2 < z < 4$, respectively.

It is possible to constrain the clustering evolution of the descendents of the DRG population using two extreme, simplified models, as proposed by Matarrese et al. (1997) and Moscardini et al. (1998). In the object-conserving model, DRGs do not undergo any subsequent phase of merging with other objects. This scenario, which corresponds to have an extremely long merging or disruption time, provides an upper limit to the evolution of the clustering properties of DRG descendents. On the other side, we use a merging model, where the - even more extreme - assumption is that galaxies continue the merging process down the lowest redshifts, with the same (high) merger rate of their parent halos. This clearly extreme model provides a lower limit of the evolution of the clustering properties of DRG descendents.

DRGs are among the mostly clustered objects at galactic scales, and suggests that they might be related to the progenitors of similarly clustered objects at lower redshifts, such as EROs, local massive ellipticals or small groups of galaxies.
The angular distribution of selected DRGs in the GOODS-South Field. The symbols are coded according to the redshift: DRGs at $z \geq 2$ and at $z \leq 2$ are shown by red triangles and blue circles, respectively; black dots refer to normal galaxies at all redshifts. For comparison, the size of the HDF is also shown. The DRGs are clustered and not uniformly distributed over areas larger than the HDFs: this shows that the cosmic variance for DRGs is dramatic at small scales.

The integrated clustering strength as a function of redshifts for different objects. Filled squares show the results for low- and high-$z$ DRGs in the GOODS region, while void square represents the whole DRG sample. The solid lines show the predicted evolution of the clustering according to the object-conserving model, tuned to the DRGs at low- and high-$z$, while the dashed lines reproduce the clustering evolution according to the merging model. The plot suggests that high-redshift DRGs can be the progenitors of local ellipticals, but may evolve into more massive objects, like EROs at $z \sim 1$ and groups/clusters of galaxies in the local universe.
Summary

We have used the GOODS-MUSIC sample to select 179 DRGs at a typical magnitude limit of $K_s = 23.5(AB)$. We find a clear evidence of a strong positive evolution with redshifts for the clustering of DRGs, $r_0 = 7.41^{+3.45}_{-4.84}\, h^{-1}\, \text{Mpc}$ and $r_0 = 13.36^{+2.99}_{-3.20}\, h^{-1}\, \text{Mpc}$, for the sub-samples at $1 < z < 2$ and $2 < z < 4$, respectively.

This behaviour is not due to a physical evolution of the DRG population, observed at two different stages of evolution. It is the result of a selection criterion which provides an heterogeneous group of dusty starburst and massive/evolved galaxies with different redshift distribution.

We constrain the clustering evolution of the descendents of the DRG population using two extreme and simplified models, the *object-conserving model* and the *merging model*, for the merging of DRGs inside CDM halos. High-redshift DRGs likely represent the progenitors of the more massive galaxies (luminous ellipticals) in the local Universe, and might mark the regions that will later evolve into structures of intermediate mass, like groups or small clusters. On the other hand, low-redshift DRGs will likely evolve into slightly less massive field galaxies, approximately around the characteristic luminosity $L^*$ of local ellipticals.

Our observations provide further evidence for the so called “downsizing” scenario that has emerged in many different aspects of high redshift galaxies, providing evidences that more massive galaxies have formed referentially at higher redshifts than less massive ones. Here we find the same trend, since high redshift DRGs are more clustered, more luminous, and most likely to evolve into more massive galaxies than their lower-$z$ counterparts.
References


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