Red Galaxies in the GOYA Photometric Survey: Passive and Dusty Star-Forming Galaxies

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1 Introduction

The main goal of this work is to study the nature of red galaxies at low and intermadiate redshifts in the GOYA photometric survey.

There are two types of stellar populations in red galaxies: evolved stars and young stars reddened by dust. The evolution of these galaxies and their relation remain an open issue. The first task is to separate both types of galaxies. Spectroscopycally, one type shows absorption lines and the other emission lines in their spectra. The types are difficult to separate photometrically because their SEDs show have similar trends due to the extinction by dust being inversely proportional to the wavelength, as determined by the extinction law. Tradicionally, photometric criteria have depended on the interval of z under study, based on the presence of Balmer 4000A break in the SED of passive galaxies; for example, the BzK technique for galaxies at $1.4 < z < 2.5$ (Daddi et al. 2004) or $R-K > 5$ or $J-K > 4$ for $1 < z < 2$ (Pozzetti & Mannucci 2000). Here, we present a different approach, based on the shape of the photometric SEDs of the galaxies, which are of course marked by the 4000A break in the passive galaxies.

2 DATA

For this study we have used the catalogue generated in the GOYA (*Galaxy Origins and Young Assembly*) Photometric Survey of a 113 arcmin^2 area of in the Groth-Westphal Strip field (Balcells et al. 2002).

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The observations were obtained in the infrared in the J and Ks passbands using INGRID on the William Herschel Telescope(WHT) (Cristóbal-Hornillo et al. 2003.) and in the optical in the U and B bands using the Wide Field Camera (WFC) mounted on the prime focus of the 2.5 m Isaac Newton Telescope (INT) (Eliche-Moral et al. 2006), both at Roque de Los Muchachos Observatory, in La Palma. The HST/WFPC2 images were used to get the information in the F606W(V) and F814W (I) passbands.

Table 1 Star Formation Histories

Type	SFR	Z	$z_f(Gy)$
Elliptical	SSP	0.02	0.8-3.0
Spiral	expo. declining	0.02	3.0
Star-Forming	constant	0.008	–
Dusty Star-forming	constant	0.008	–

3 Selection of the Red Galaxies

We have selected the red galaxies in the catalogue based on their apparent magnitudes. The color indices used to separate the red galaxies from the others depend on the redshift (z) of the galaxies. This study is restricted to the interval $0.3 < z < 1.5$ in order to have representative samples at both low and high redshift. We have divided

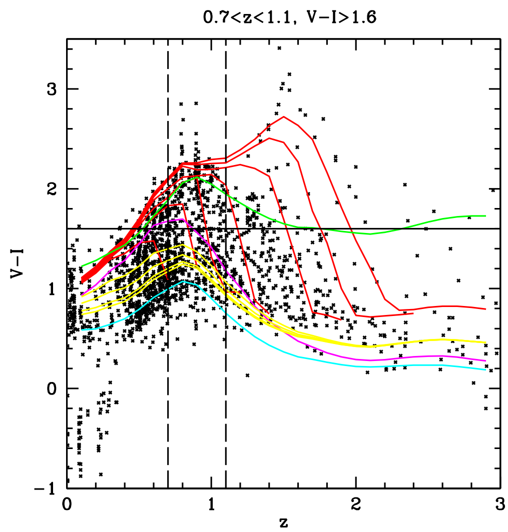

Fig. 1 V-I color index distribution with redshift of galaxies in the GOYA photometric survey. The lines represent the V-I color for stellar population synthesis models of B&C03 for different types of galaxies. From top to bottom, the lines represent the elliptical and spiral galaxies formed at different redshifts. The horizontal line is the cut separating red galaxies from the others. We consider red galaxies as those having a dominant population SSP older than a 1 Gyr. The vertical black line limits the interval of redshift.

the galaxies into several redshift intervals and we have used a different color index for every interval to obtain the same wavelength range in their rest-frame SEDs. We have performed simulations on the evolution of the $U-B, V-I, I-K$ color indices with z in galaxies of different morphological types. These have been chosen based on galaxy spectral synthesis models (Bruzual&Charlot2003). The galaxy types and their star formation history are given in Table I. As an example, the results for the range $0.7 < z < 1.1$, together with the catalogue data, are presented in Figure 1. We adopt as our selection criterion those red galaxies whose dominant population has an SSP older than 1 Gyr. This is represented by the horizontal black line in Figure 1. With this separation criterion, the red galaxies include both evolved and dusty star-forming galaxies. Both types of galaxies are indistinguible by the criterion of color index alone. But we shall subsequently separate these two types with a new criterion based on two color indexes.

The red galaxies in this study are those which meet the following conditions:

$$0.3 \leq z < 0.7, \quad U-B > 0.3$$
$$0.7 \leq z < 1.1, \quad V-I > 1.6$$
$$1.1 \leq z < 1.5, \quad I-K > 3.0$$

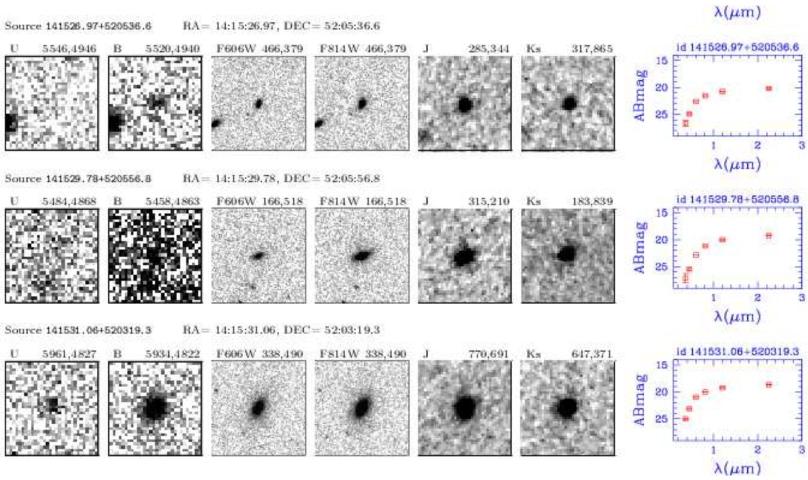

Fig. 2 Example of images and SEDs of passively evolving galaxies. From left to right: The U, B, F606W, F814W, J, and Ks 10×10 arcsecond square images. The graphs on the right represent the photometric SEDs of the galaxies.

4 Separation of Passive and Dusty Star-Forming Galaxies: The "p" index

We propose a new method based on the different shapes of photometric SEDs to separate passively evolving (PSV) galaxies from dusty star-forming (DSF) galaxies and we used two color indices to separate them.

When closely observing the photometric SEDs of the red galaxies (Figures 2 and 3) we see that there are two different types: some have curved SEDs and others show a linear or irregular trend. We can demostrate that these two types of SEDs correspond to the two types of galaxies. The curved SED has all the features of that of a passive galaxy, and linear spectra are characteristic of galaxies with young dominant population obscured by dust.

Based on this fact, we define an index, p, that allows us to separate PSV from DSF galaxies. Basically, the idea is that those galaxies with a linear trend in their SEDs are DSFs and those that do not have such trends in their SEDS are PSVs.

The p index represents divergence from the linear behavior of the redder filter and its form is the following:

$$p = (m_{AB}1 - m_{AB}3) - (m_{AB}1 - m_{AB}2)/b, \qquad (1)$$

where

$$b = (\lambda 2 - \lambda 1)/(\lambda 3 - \lambda 1) \qquad (2)$$

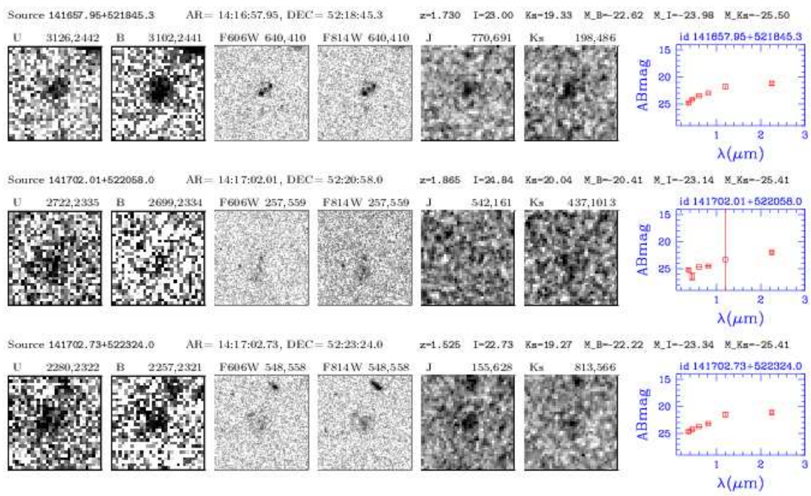

Fig. 3 An example of images and SEDs of dusty star-forming galaxies. From left to right: The U, B, F606W, F814W, J, and Ks 10x10 arcsecond square images. The graphs on the right represent the photometric SEDs of the galaxies.

m_{AB} is the AB magnitude in filters 1, 2 and 3 corresponding to each range of z, and λ is the effective wavelength of each of these filters. The p values, which are used to separate PSV from DSF galaxies in the three z intervals, are -2.0 for $0.3 < z < 0.7$, -0.2 for $0.7 < z < 1.1$ and -9.0 for $1.1 < z < 1.5$.

5 Masses of the Ev and DSF

We have used the mass code developed by R. Guzmán and D. Cristóbal-Hornillos (Guzmán at al. 2003). Stellar masses are estimated by fitting the observed photometry to the model flux obtained from the convolution of a redshifted synthetic galaxy spectrum with the filter transmission functions. The two-component synthetic galaxy consists of a young burst, modeled by a single stellar population and an underlying exponentially decreasing SFR population. GISSELLXXI (Bruzual & Charlot 2003) is used to create the two components at different ages as a function of the model parameters (IMF, SFH, metallicity and extinction).

The best-fit models are a simple burst with $Z = 0.02$ and an extinction of $A_V = 0.6$ mag for the passive galaxies and a bulge+disk-exp7, $Z = 0.008$ and $A_V = 1.5$ mag for the dusty star-forming galaxies. The results are shown in Figure 4. We observe two things: the passively evolving galaxies dominate the space at the lowest z of the whole rank and the DSFs dominate at the hightest ones; and at $z < 1$ red galaxies with stellar mass>10e11 $M_\odot$ are evolved galaxies.

As a result of the ages of the galaxies given by the mass code, the ages of the bulk of the early type galaxies at $0.3 < z < 1.5$ had their last starburst between $1 < z < 2$.

Another result is that the evolution with redshift of number (and stellar mass) densities shows an decreasing of passive galaxies and an increase in dusty star-forming galaxies in the range $0.3 < z < 1.5$ (Figure 5).

6 Conclusions

- A new photometric index has been developed based on apparent magnitudes to separate red galaxies dominated by old populations from those dominated by star formation.
- These two types of galaxies have differences in their masses, age and number densities.
- The red galaxies at $z < 1$ with masses greater than 10e11 $M_\odot$ are passive galaxies.
- The bulk of the passive galaxies at $0.3 < z < 1.5$ had their last starburst between $1 < z < 2$.
- The number densities decrease for passive galaxies and increase for dusty star-formating galaxies in the range $0.3 < z < 1.5$.

All these results are compatible with a scenario in which dusty star-forming galaxies are transitional galaxies between blue and passive galaxies.

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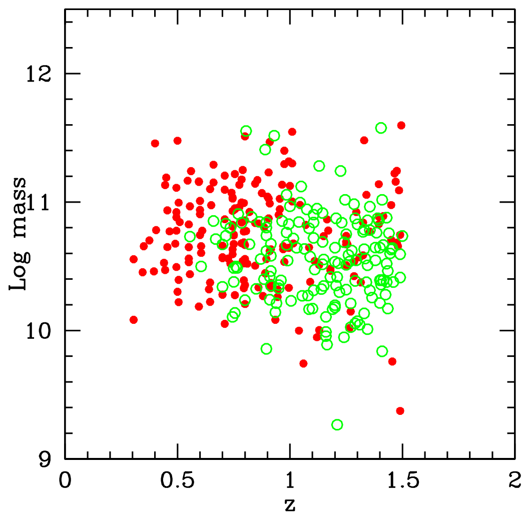

Fig. 4 Stellar mass distribution of red galaxies with redshift. The full and the empty circles represent the passive and the dusty star-forming galaxies respectively

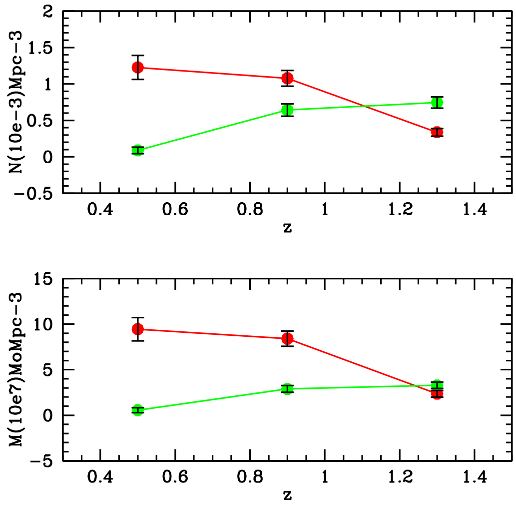

Fig. 5 Number and stellar mass space density distribution of both types of galaxies with redshift, showing a decrease in passive galaxies and an increase in dusty star-forming galaxies in the range $0.3 < z < 1.5$.