The evolution of Balmer jump selected galaxies in the ALHAMBRA survey. *

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ABSTRACT

Context. Samples of star-forming galaxies at different redshifts have been traditionally selected via color techniques. The ALHAMBRA survey was designed to perform a uniform cosmic tomography of the Universe, and we will exploit it here to trace the evolution of these galaxies.

Aims. Our objective is to use the homogeneous optical coverage of the ALHAMBRA filter system to select samples of star-forming galaxies at different epochs of the Universe and study their properties.

Methods. We present a new color-selection technique, based on the Bruzual & Charlot 2003 models convolved with the ALHAMBRA bands, and the redshifted position of the Balmer jump to select star-forming galaxies in the redshift range 0.5 < z < 1.5. These galaxies are dubbed Balmer jump Galaxies (BJGs). We apply the iSEDfit Bayesian approach to fit each detailed SED and determine star-formation rate (SFR), stellar mass, age and absolute magnitudes. The mass of the halos where these samples reside are found via a clustering analysis.

Results. Five volume-limited BJG sub-samples with different mean redshifts are found to reside in haloes of median masses ~ 10^{12.5} M⊙, slightly increasing toward z = 0.5. This increment is similar to numerical simulations results which suggests that we are tracing the evolution of an evolving population of haloes as they grow to reach a mass of ~ 10^{12.7} M⊙ at z = 0.5. The likely progenitors of our samples at z < ~3 are Lyman Break Galaxies, which at z < ~2 would evolve into star-forming BzK galaxies, and their descendants in the local Universe are elliptical galaxies. Hence, this allows us to follow the putative evolution of the SFR, stellar mass and age of these galaxies.

Conclusions. From z ~ 1.0 to z ~ 0.5, the stellar mass of the volume limited BJG samples nearly does not change with redshift, suggesting that major mergers play a minor role on the evolution of these galaxies. The SFR evolution accounts for the small variations of stellar mass, suggesting that star formation and possible minor mergers are the main channels of mass assembly.

Key words. extragalactic astronomy – galaxy evolution – star formation

1. Introduction

Most of the recent observational efforts to understand galaxy evolution have been focused on determining the history of cosmic star formation, gas density evolution, metallicity evolution and mass growth of the Universe (Daddi et al. 2004; Mannucci et al. 2010; Madau & Dickinson 2014; Tomczak et al. 2014; Bouwens et al. 2015). These multiwavelength observational constraints have been usually summarized as galaxy scaling relations that might change or not with redshift (Mannucci et al. 2010, Elbaz et al. 2011, Bouwens et al. 2014; Troncoso et al. 2014), in high or low density environments, in extreme physical conditions (starburst, AGN galaxies), and in spatially resolved data due to internal variations of the galaxy properties (Sanchez et al. 2013). In parallel, theoretical works and simulations have tried to explain the physical mechanisms that reproduce the measured global properties (Daddi et al. 2010, Dave et al. 2011, Lilly et al. 2013, Lagos et al. 2014, Padilla et al. 2014). Despite these efforts, the completeness and cleanness of the sample are still chal-

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lenging issues that depend on the sample selection-method, instruments limit, and telescope time. The aforementioned issues make the comparison between observational and theoretical works even more difficult. For example, [Campbell et al. 2014] compared the stellar mass of GALFORM galaxies predicted by the model with the ones obtained via the fit of their predicted broad-band colors. They find that, for an individual galaxy, both quantities differ, hence the clustering of mass-selected samples can be affected by systematic biases. Therefore, mass-selected samples might provide erroneous conclusions regarding their progenitors and descendants. Besides, the evolution of scaling relations is constrained with observations of galaxy samples, selected with luminosity or stellar-mass thresholds, located at different redshifts, which does not necessarily constitute causally connected populations (i.e. do not follow a progenitor-to-descendant relationship). Clustering selected samples overcome this issue because, in a hierarchical clustering scenario, a correlation analysis allows us to estimate the bias and hence statistically determine the progenitors and descendants of galaxy samples. The bias parameter measures the clustering difference between the galaxy spatial distribution and underlying dark-matter distribution. Thus, it relates the typical mass of haloes hosting the galaxies ([Sheth, Mo & Tormen 2001]). Hence, measuring it in galaxy samples at different redshifts, determines whether we are following the evolution of baryonic processes occurring on haloes of similar masses or not. This fact is of extreme importance because once it is determined we can use the multiwavelength data to study the evolution of the baryonic processes at certain halo mass, establishing a direct link between observations and galaxy formation models. [Padilla et al. 2010] selected early-type galaxies according to their clustering and luminosity function in the MUSYC survey. So far, no study that selects star-forming galaxies according their clustering and luminosity function has been reported.

Star-forming galaxies are of particular interest, because they allow us to study the mechanisms that switch on/off the star formation and its evolution with redshift. Considering the lack of wide spectroscopic surveys, in the sense of wavelength coverage and surveyed area, the majority of the star-forming galaxy samples have been chosen using two-color selection techniques. The so-called “dropout” technique is based on selecting galaxy samples have been chosen using two-color selection methods, in the sense of wavelength coverage and surveyed area, the majority of the star-forming galaxy samples have been chosen using two-color selection techniques. The so-called “dropout” technique is based on selecting galaxy samples according their clustering and luminosity function in the MUSYC survey. So far, no study that selects star-forming galaxies according to their clustering and luminosity function has been reported.

To select star-forming galaxies, we base our two-color selection technique on the Bruzual & Charlot (2003) models and apply it to the GOLD ALHAMBRA catalogs ([Molino et al. 2014]). In the following, the galaxies selected by this method are dubbed Balmer jump Galaxies (BJGs) and their physical properties are investigated. Based on a clustering study, we find the progenitors and descendants of galaxies in these samples, allowing us to study the evolution of the SED fit derived properties as a function of redshift on haloes of certain mass. This paper is organized as follows: in section §2 we summarize the ALHAMBRA observations and introduce the nomenclature of the ALHAMBRA filter system used throughout the paper. In section §3 the selection method is described and attested with the Bruzual & Charlot (2003) models. The BJG samples are defined here. In section §4 each galaxy SED is modeled using $\text{iSEDfit}$ ([Moustakas et al. 2013]) and the physical properties of each sample are characterized as a whole. In section §5 the clustering properties are calculated. In section §6 the main results are discussed. Finally, in section §7 our conclusions are exposed. Throughout the paper, we use a standard flat cosmology with $H_0 = 100h \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_m(z = 0) = 0.3$, $\Omega_{\Lambda}(z = 0) = 0.7$, $\sigma_8 = 0.824 \pm 0.029$, and the magnitudes are expressed in the AB system.

### 2. Data: the ALHAMBRA survey

The Advanced Large Homogeneous Area Medium-Band Redshift Astronomical (ALHAMBRA)1 survey provides a kind of cosmic tomography for the evolution of the contents of the Universe over most of the cosmic history. [Benitez et al. 2009] have especially designed a new optical photometric system for the ALHAMBRA survey, which maximizes the number of objects with an accurate classification by the Spectral

### Table 1. Name and effective wavelength of each ALHAMBRA filter.

| Name | $\lambda_{\text{eff}}$ [nm] | Name | $\lambda_{\text{eff}}$ [nm] | Name | $\lambda_{\text{eff}}$ [nm] |
|------|-----------------------------|------|-----------------------------|------|-----------------------------|
| $U_1$ | 365.5                        | $U_2$ | 396.5                        | $B_3$ | 427.5                        |
| $B_4$ | 458.5                        | $B_5$ | 489.5                        | $B_6$ | 520.5                        |
| $R_7$ | 551.5                        | $R_8$ | 582.5                        | $R_9$ | 613.5                        |
| $R_{10}$ | 644.5                    | $R_{11}$ | 675.5                        | $R_{12}$ | 706.5                        |
| $I_{13}$ | 737.5                    | $I_{14}$ | 768.5                        | $I_{15}$ | 799.5                        |
| $I_{16}$ | 830.5                    | $z_{17}$ | 861.5                        | $z_{18}$ | 892.5                        |
| $z_{19}$ | 923.5                    | $z_{20}$ | 954.5                        |      |                              |

Notes: Cols. 1, 3, and 5 indicate the adopted filter name that will be used throughout the paper; Cols. 2, 4, and 6 show the effective wavelength of each ALHAMBRA band.
Energy Distribution (SED) and photometric redshift. It employs 20 contiguous, equal-width ~ 310 Å, medium-band covering the wavelength range from 3500 Å to 9700 Å, plus the standard JHK near-infrared bands. Moles et al. (2008), and Aparicio Villagrasa et al. (2010) presented an extensive description of the survey and filter transmission curves. The observations were taken in the Calar Alto Observatory (CAHA, Spain) with the 3.5-m telescope using the two wide-field imagers in the optical (LAICA) and NIR (Omega-2000). The total surveyed area is 2.8deg^2 distributed in eight fields that overlap areas of other surveys such as SDSS, COSMOS, DEEP-2, and HDF-N. The typical seeing of the optical images is 1.1arcsec, while for the NIR images is 1.0arcsec. For details about the survey and data release, please refer to Molino et al. (2014), and Cristóbal-Hornillos et al. (2009). In this work, we use the public GOLD catalogs, which contains data of seven, out of the eight, ALHAMBRA fields. The magnitude limits of these catalogues are (m_AB) ~ 25 for the four blue bands and from (m_AB) ~ 24.7 mag to 23.4 mag for the redder ones. The NIR limits at AB magnitudes are J ~ 24 mag, H ~ 23 mag, K ~ 22 mag. In the following, the filter nomenclature presented in Table 1 is used and the ALH-4 and ALH-7 fields are excluded from our analysis. Previous authors have shown that overdensities reside in these fields and they might alter the redshift distribution of the selected samples as well as the clustering measurements (see section 5). Arnalte-Mur et al. (2014) obtained the clustering properties of ALHAMBRA galaxies and studied the sample variance using the seven independent ALHAMBRA fields. They quantified the impact of individual fields on the final clustering measurements, using the Norberg et al. (2011) method, to the COSMOS field. Previous works have shown that this region is dominated by some large-scale structures (LSS), the most prominent are peaking at z ~ 0.7, and 0.9 (Scoville et al. 2007). These structures have X-ray counterparts and a probability higher than 30% of being LSS. Guzzo et al. (2007) studied the clusters located at the center of the LSS (at z ~0.7), while Finoguenov et al. (2007) found diffuse X-ray emission in the most compact structures. There are other LSS found in the COSMOS field, but they fall out of the redshift range of the samples studied in this paper.

3. Sample selection

To exclude the stars from the original ALHAMBRA Gold catalog we use the stellarity index given by SExtractor (CLASS-Star parameter (C)) and the statistical star/galaxy separation (Molino et al. 2014, Section 3.6) encoded in the variable Stellar-Flag (S_dah) of the catalogs. Throughout the present paper, we define as galaxies those ALHAMBRA sources with C(K) ≤ 0.8 and S_dah ≤ 0.5. The ALHAMBRA Gold catalog is an F814W (i.e. almost an I-band) selected catalog. This band was created by the ALHAMBRA team as a linear combination of ALHAMBRA bands (see Eq. 5 in Molino et al. 2014), and it was used for their source detection. Objects with faint features in this band are not detected, it might affect the completeness of the selected samples as will be discussed further in sections 3.3 and 4.1. This catalogue is complete up to F814W = 23 (Molino et al. 2014), hence we use this limit to build our complete sample. On the other hand, the NIR completeness has been studied previously (Cristóbal-Hornillos et al. 2009). Using the early release of the first ALHAMBRA field, they determined a change in the slope of the K-band number counts in the magnitude range 18.0 < K Vega < 20.0 and that the data is complete until K Vega = 20 or K AB = 21.8. We have checked the K-band numbers counts of the 48 individual pointing that compose the ALHAMBRA GOLD catalog. Every single pointing tends to falls at K AB ~ 22. Hereafter, we use the K AB=22 limit to define our complete samples.

3.1. Selection of star-forming galaxies

We use the models of Bruzual & Charlot (2003) convolved with the ALHAMBRA filter system to define a two-color criteria to select star-forming galaxies analogously to the work of Daddi et al. (2004). They created the BzK color-selection technique to cull star-forming galaxies at z > 1.4. This technique is based on the Balmer jump, which is an indicator of recent star formation. They used the models of Bruzual & Charlot (2003) to identify the redshifted Balmer jump in the z-band, creating the color selection criteria BzK ≡ (z − K) AB − (−J − K) AB = −0.2; where BzK ≥ −0.2 selects star-forming galaxies at z > 1.4. Our approach is analogue to the BzK method, in the sense that we also use the Bruzual & Charlot (2003) models, whereas we recorded redshifted Balmer jumps in various (diverse) medium-bands selecting galaxies at different redshifts. In Fig 1 this situation is illustrated, the typical spectrum of a star-forming galaxy redshifted to z ∼ 0.5, z ~ 1.0 and z ~1.5 is shown. The ALHAMBRA bands are overplotted from the optical to NIR ranges. We choose the U2-band to sample the region before the Balmer jump instead of the B-band. We select the U2 band because it reaches a higher completeness level with respect to U1. Objects that are not detected in the U2 band are also considered in our selection and its magnitude limit is used. Redder bands might sample weak features bluewards to the Balmer jump of low redshift galaxies z < 0.4. The K band is exactly the same used by Daddi et al. (2004). While, the z-band is replaced with the variable X9-band, which covers the optical range from 613Å to 954Å, i.e. X9 can be any ALHAMBRA filter from R9 to z20 (see Table 1). The X9-band samples the region directly redwards to the Balmer jump, hence the U2−X9 color indicates the galaxy redshift range depending on the selected n. The other hand, the X9−K color registers the duration of the star-formation age. The different panels in Fig 2 and Fig 3 show the theoretical evolution Bruzual & Charlot (2003) of the U2X9K ≡ (X9 − K) − (U2 − X9) color as a function of redshift with 0 < n < 20 (X9 = R9, ..., z20). The red, green and blue solid lines show the U2X9K= color-evolution of constant star-formation rate models for ages 0.2, 1, and 2 Gyr and reddening E(B − V) = 0.3. The red, green and blue dashed lines show the U2X9K= color-evolution of passively evolving models for formation redshift of z_f = 2.3 and 6. In each panel, the star-forming models always lie in the region U2X9K > 0. Consequently, in order to select a sample at redshift higher than z ~0.5, a combination that involves a X9 filter redder than R9 must be used, as it is shown in the bottom panels of Fig 2 and Fig 3.

3.2. BJS samples

We use the condition U2X9K ≡ (U2 − X9) − (X9 − K) > 0 and the homogeneous coverage in the optical range of the ALHAMBRA filter system, where n is ranging from 9 to 20 (X9 = R9, ..., z20), to select galaxies at redshift z > 0.5, 0.6, 0.7, 0.8, 0.85, 0.95, 1.05, 1.1, 1.2, 1.25, 1.3, respectively.

http://cosmo.iaa.es/content/ALHAMBRA-Gold-catalog
4.1. Photometric redshifts

In each ALHAMBRA filter set $U_jX_nK$, this color condition selects star-forming and passive galaxies in the wide mentioned redshift range. Theoretically, these selected passive galaxies lie always at higher redshift (i.e., $\Delta z > 0.25$) with respect to the selected star-forming galaxies. In order to select galaxies in a narrow redshift range, we use more than one color condition; first the $(U_j - X_n) - (X_n - K) > 0$ condition with $n = j$, to select all galaxies above certain redshift $z_j$ and secondly we subtract the higher-redshift samples, selected with $n = j + 1$ (passive and star-forming), from the first galaxy selection. For example, our lowest redshift sample was selected by imposing the condition $U_jR_0K = 0$ (i.e. select galaxies at $z > 0.5$) and subtracting the galaxy samples selected by $U_jX_nK > 0$ with $n \geq 10$, which select all galaxies at $z > 0.6$. In this way, only the star-forming galaxies in the redshift range $0.5 < z < 0.6$ were selected (see yellow shaded region in Fig. 3 and Fig. 4). Following this method and using the homogeneous separation between each ALHAMBRA band, we select eleven star-forming galaxy samples peaking at $z \sim 0.55, 0.65, 0.75, 0.8, 0.9, 1.0, 1.05, 1.15, 1.2, 1.25$, and $z \sim 1.4$. It by culling the galaxies that satisfy the star-forming criteria $U_jX_nK \equiv (U_j - X_n) - (X_n - K) > 0$, where $X_n = R_0, ..., X_{19}$ and “cleaned” of higher redshift galaxies by subtracting the samples that satisfy $U_jX_nK > 0$, with $n \geq 10, ..., 20$, respectively. Table 2 summarizes the properties of the selected samples using the method described above. We ensure that all samples are roughly independent of each other by removing the high redshift samples, whose are selected using the $X_n$ filters with $n \geq j + 1$ (see column 3 of Table 2), from the sample selected with the filter $X_{n_{obs}}$.

4. Physical properties of the BJG samples

In this section, we aim to characterize each BJG sample, providing a mean characteristic value of its redshift, absolute magnitude, stellar mass, age, star formation rate, etc.

4.1. Photometric redshifts

We use the Bayesian photometric redshift (zBPZ) published in the Gold ALHAMBRA catalogs (Molino et al. 2014) to verify our selection method. The BPZ code was optimized to determine photometric redshifts, for details on the zBPZ calculations see Molino et al. (2014) and Benitez et al. (2009). Fig. 1 shows the zBPZ distribution of the eleven BJG samples. For a better visualization of the distribution tails, the upper panel shows the BPZ distribution of the BJG1, BJG3, BJG5, BJG7, BJG9, and BJG11 samples, while the lower panel presents the BJG2, BJG4, BJG6, BJG8, and BJG10 samples. The vertical colored lines show the median of the zBPZ distribution for the selected samples. The median of zBPZ distribution, reported on Table 2, clearly agree with the median of the expected redshift range estimated via the two-color selection criteria that are reported on Table 2.

4.2. SED fitting

For each galaxy of the BJG samples, we fit the 20 optical bands plus the three NIR bands, using the Bayesian SED modeling code iSEDfit (Moustakas et al. 2013). Once we fix the redshift to the best-fit value given by BPZ in the ALHAMBRA code (Moustakas et al. 2013). Once we fix the redshift to the best-fit value given by BPZ in the ALHAMBRA catalog (Molino et al. 2014), iSEDfit calculates the marginalized posterior probability distributions for the physical parameters, in certain model space that is previously defined by the user. Using a Monte Carlo technique, we generate 20,000 model SEDs with delayed star-formation histories SFH= $te^{-t/\tau}$, where $\tau$ is the star formation timescale. The SEDs were computed employing the Flexible Stellar Population Synthesis models (FiSPS, v 2.4. Conroy, Gunn & White 2009, Conroy & Gunn 2010) based on the mixins (Sanchez-Bazquez et al. 2006) and Basel (Lejeune et al. 1997, 1998, Westera et al. 2002) stellar libraries. We assume a Chabrier (2003) initial mass function from $0.1 \sim 100 M_\odot$, and a time-dependent attenuation curve of Charlot & Fall (2000). We adopt uniform priors on stellar metallicity $Z/Z_\odot \in [0.04, 1.0]$, galaxy age $t \in [0.01, age(z_{BPZ})]$ Gyr, rest-frame V-band attenuation $A_V \in [0 \sim 3]$ mag, and star formation timescale $\tau \in [0.01, age(z_{BPZ})]$ Gyr, where age(z_{BPZ}) is the age of the Universe at each galaxy’s photometric redshift. Figures 2 and 10 show the SEDs of a galaxy randomly picked out of each BJG sample. The filled green dots show the photometric data, the red line shows the model that

Table 2. Properties of the BJG selected samples.

| Sample Name | Initial set $U_jX_nK$ | Clean sets $U_jX_nK$ | $N$ | <z> |
|-------------|---------------------|---------------------|-----|-----|
| BJG1        | R$_9$               | $n \geq 10$         | 5489| 0.5-0.6 |
| BJG2        | R$_{10}$            | $n \geq 11$         | 5174| 0.6-0.7 |
| BJG3        | R$_{11}$            | $n \geq 12$         | 4497| 0.7-0.8 |
| BJG4        | I$_{12}$            | $n \geq 13$         | 4012| 0.8-0.85 |
| BJG5        | I$_{13}$            | $n \geq 14$         | 3550| 0.85-0.95 |
| BJG6        | I$_{14}$            | $n \geq 15$         | 2878| 0.95-1.05 |
| BJG7        | I$_{15}$            | $n \geq 16$         | 2231| 1.05-1.1 |
| BJG8        | I$_{16}$            | $n \geq 17$         | 2325| 1.1-1.2 |
| BJG9        | I$_{17}$            | $n \geq 18$         | 2058| 1.2-1.25 |
| BJG10       | I$_{18}$            | $n \geq 19$         | 2140| 1.25-1.3 |
| BJG11       | I$_{19}$            | $n = 20$            | 3391| 1.3-1.5 |

Notes. Col. 1, Name of the selected sample; Col. 2, Initial filter set used for selection; Col. 3, Second filter sets used to subtract higher redshift galaxies from the initial sample; Col. 4, Number of galaxies selected. Col. 5, Expected redshift range of the sample.
minimizes the $\chi^2$ using iSEDfit, the black squares mark the convolution between this model and the ALHAMBRA filters. The blue shading shows the universe of models, generated by iSEDfit using the previously described priors, scaled by their reduced $\chi^2$. The color bar indicates the reduced $\chi^2$ scale.

In Table 3, for each BJG sample, the median value of the sum of the posterior probability distributions for some physical properties are reported. The uncertainties indicate the 1-$\sigma$ confidence level, to account for asymmetric distributions we determine the percentiles 16 and 84.

4.3. Comparison between BJG samples

In this subsection, we aim to compare the properties, derived from SED fitting, of the BJG samples for galaxies of similar $K$-band absolute magnitude, i.e. similar stellar mass. Therefore, in addition to restricting the BJG samples within the magnitude survey limit (see section §3) we also apply an absolute magnitude limit for all samples. In the following, we search for the most appropriate absolute magnitude limit that allows us to build these samples. Fig. 5 shows the $K$-band absolute magnitude, obtained via iSEDfit, as a function of BPZ redshift. The red, or-
Fig. 3. Criteria to select star-forming galaxies. The solid and dashed lines show the color evolution of star-forming and passive galaxies, respectively. The red, green, blue color of each line indicates the formation redshift of the galaxy $z_f = 2, 3, 6$, respectively. The horizontal dashed line indicates the color cut $U_2 X_n K \equiv (U_2 - X_n) - (X_n - K) = 0$. At each panel, the star-forming galaxies are located above this threshold. The yellow shaded regions mark the redshift range of the selected BJG samples in each color combination. Dashed vertical lines indicate the redshift 0.5 and 1.5.

ange, green, cyan, light blue and blue dots indicate the galaxies in the BJG$_1$, BJG$_4$, BJG$_6$, BJG$_7$, BJG$_9$, and BJG$_{11}$ samples with apparent magnitude brighter than the magnitude survey limit $K = 22$, respectively. We can note that partly due to Malquist bias, the farthest sample BJG$_{11}$ is roughly complete only until $K_{abs} = -22.5$ (blue dots). However, by choosing this bright absolute limit to compare all BJG samples we restrict our study only to the most massive and bright objects as well as enormously reduce the statistics for each sample, specially at low redshift. Hence, we decide to study all objects brighter than $K_{abs} = -21.2$, which correspond to the absolute limit where the BJG$_5$ sample at $z \sim 1$ is complete and comparable, in terms of $K_{abs}$ luminosity, to the other lower redshift BJG$_{n < 6}$ samples. In Fig 5 the black solid line shows the absolute magnitude limit $K_{abs} = -21.2$. We have chosen the $z \sim 1$ limit because the AL-HAMBRA Gold data is an $F_{814W}$ (i.e. almost an I-band) selected catalog and thus less sensitive to galaxies at $z \geq 1$ with a pronounced Balmer jump. For galaxies at $z \geq 1$, the spectral region directly bluewards of the Balmer jump is barely or not detected in the $F814W$ because the Balmer jump falls in the $I_{13}$.
and the region directly bluewards to it falls in the $R_{12}$ band. Since the F814W image detection is a linear combination involving the $R_{12}$ band, this kind of galaxies are barely or not detected as sources in the final catalog. We expect a deeper selection of galaxies with a pronounced Balmer jump at $z < 1$. Said that, the BJG samples at $z < 1$ selected from $X_{\text{reg,3}}$ bands are optimized to be complete according to the F814W selection, whereas the samples at $z \geq 1$ are incomplete. The level of incompleteness of the BJG$_{\text{reg,6}}$ samples is difficult to quantify because there may be many effects working together (e.g. the F814W is a linear combination of ALHAMBRA bands, undetectable bluewards regions of the Balmer jump due to intrinsic galaxy properties such as redshift, dust excess, etc.).

To minimize the incompleteness of our samples in the comparison of the physical properties at different redshifts, in the following we re-define the first five BJG samples selecting all galaxies brighter than $K_{\text{abs}} = -21.2$. Furthermore, the BJG$_{n}$ samples, with $n \geq 6$, are not considered in the following analysis. Table 4 presents the properties of the final sample definition (BJG$_{n}$, with $n < 6$), which takes into account the absolute luminosity cut ($K_{\text{abs}} = -21.2$). In Fig. 5 the comparison of the physical properties of galaxies with similar $K$-band luminosity is shown. Red squares show the properties of the BJG$_{n}$ (with $n < 6$), the dashed lines show the results of van Dokkum et al. (2013) for galaxies of similar stellar mass. The colored areas indicate the dispersion of each sample, while the error bars show the median error of the physical properties derived via sSedfit. In section 6.3 these results are discussed.

### Table 3. Median physical properties of the BJG samples.

| Name  | N   | zBPZ | $<M_{*}>$ | SFR $M_{\odot} yr^{-1}$ | Age [Gyr] |
|-------|-----|------|-----------|-----------------------|-----------|
| BJG$_{1}$ | 5489 | 0.52$^{+0.16}_{-0.14}$ | 10.15$^{+0.11}_{-0.13}$ | 0.08$^{+0.22}_{-0.28}$ | 5.5$^{+1.62}_{-1.87}$ |
| BJG$_{2}$ | 5174 | 0.64$^{+0.18}_{-0.11}$ | 10.25$^{+0.12}_{-0.13}$ | 0.27$^{+0.23}_{-0.22}$ | 5.1$^{+1.50}_{-1.76}$ |
| BJG$_{3}$ | 4497 | 0.74$^{+0.10}_{-0.14}$ | 10.30$^{+0.13}_{-0.14}$ | 0.38$^{+0.23}_{-0.24}$ | 4.8$^{+1.40}_{-1.68}$ |
| BJG$_{4}$ | 4012 | 0.81$^{+0.12}_{-0.14}$ | 10.37$^{+0.13}_{-0.15}$ | 0.42$^{+0.25}_{-0.26}$ | 4.6$^{+1.29}_{-1.62}$ |
| BJG$_{5}$ | 3550 | 0.90$^{+0.12}_{-0.18}$ | 10.36$^{+0.14}_{-0.16}$ | 0.49$^{+0.24}_{-0.25}$ | 4.3$^{+1.24}_{-1.54}$ |
| BJG$_{6}$ | 2878 | 0.98$^{+0.12}_{-0.19}$ | 10.41$^{+0.15}_{-0.17}$ | 0.52$^{+0.26}_{-0.27}$ | 4.1$^{+1.15}_{-1.46}$ |
| BJG$_{7}$ | 2231 | 1.07$^{+0.12}_{-0.20}$ | 10.46$^{+0.15}_{-0.17}$ | 0.63$^{+0.25}_{-0.26}$ | 3.8$^{+1.09}_{-1.40}$ |
| BJG$_{8}$ | 2325 | 1.15$^{+0.12}_{-0.21}$ | 10.45$^{+0.16}_{-0.19}$ | 0.69$^{+0.26}_{-0.27}$ | 3.6$^{+1.05}_{-1.36}$ |
| BJG$_{9}$ | 2058 | 1.24$^{+0.14}_{-0.25}$ | 10.45$^{+0.18}_{-0.20}$ | 0.72$^{+0.25}_{-0.27}$ | 3.4$^{+1.01}_{-1.32}$ |
| BJG$_{10}$ | 2140 | 1.29$^{+0.21}_{-0.33}$ | 10.38$^{+0.19}_{-0.23}$ | 0.72$^{+0.24}_{-0.26}$ | 3.1$^{+1.05}_{-1.29}$ |
| BJG$_{11}$ | 3391 | 1.33$^{+0.28}_{-0.42}$ | 10.34$^{+0.20}_{-0.24}$ | 0.72$^{+0.23}_{-0.24}$ | 2.9$^{+1.05}_{-1.32}$ |

**Notes.** Col. 1, Name of the selected sample; Col. 2, number of galaxies selected; Col. 3, BPZ photometric redshift; Col. 4, logarithm of the stellar mass (Chabrier IMF); Col. 5, logarithm of the star formation rate; Col. 6, galaxy age.

### 5. Halo masses through clustering analysis

In hierarchical clustering, structures build up in time from small density fluctuations. Small structures agglomerate to build larger structures. Dark matter haloes are biased tracers of the underlying matter density field. Massive haloes lie in higher and rarer density peaks and are more clustered than lower mass haloes. If a galaxy population is hosted by haloes of a given mass, then the clustering amplitude of the galaxy population, compared to the expected dark matter clustering at the same redshift, can be used to derive the typical halo mass corresponding to that galaxy population. This is encapsulated in the bias parameter, $b$, defined as $b = \xi_{g}(r) / \xi_{DM}(r)$, where $\xi_{g}$ and $\xi_{DM}$ are the 2-point spatial correlation function for galaxies and dark matter, respectively. The correlation function at a certain redshift, $\xi(z)$, can be char-
Fig. 6. Evolution of the physical properties of the BJGK_{n<6} samples. The panels show the median of the probability distribution of, from up to down and left to right, the specific star formation rate, star formation rate, age, B-band luminosity, K-band luminosity, and stellar mass, respectively. Red squares show the evolution of BJGK_{n<6} galaxies brighter than K = -21.2. The colored areas indicate the dispersion of each sample, while the error bars show the median error of the physical properties determined by iSEDfit. Dashed lines show the fit to the CANDELS analysis taken from van Dokkum et al. (2013) for galaxies of stellar masses similar to the Milky Way.

Table 4. Median physical properties of the BJGK samples considering the absolute magnitude limit K = -21.2.

| Name  | N   | zBPZ | M_0           | SFR   | Age [Gyr] |
|-------|-----|------|---------------|-------|-----------|
| BJGK_1| 3322| 0.56^+0.18^-0.14 | 10.50^+0.10^-0.11 | 0.24^+0.29^-0.30 | 5.80^+1.43^-1.87 |
| BJGK_2| 3778| 0.67^+0.11^-0.10 | 10.46^+0.11^-0.12 | 0.40^+0.27^-0.26 | 5.31^+1.37^-1.74 |
| BJGK_3| 3576| 0.75^+0.10^-0.12 | 10.45^+0.12^-0.13 | 0.46^+0.26^-0.26 | 4.92^+1.31^-1.67 |
| BJGK_4| 3480| 0.83^+0.14^-0.12 | 10.45^+0.13^-0.14 | 0.49^+0.27^-0.28 | 4.69^+1.24^-1.60 |
| BJGK_5| 3150| 0.92^+0.10^-0.12 | 10.44^+0.14^-0.15 | 0.55^+0.26^-0.26 | 4.37^+1.19^-1.52 |

Notes. Col. 1. Name of the selected sample; Col. 2. Number of galaxies selected from the BJG samples after the K-band absolute cut; Col. 3. BPZ photometric redshift; Col. 4. stellar mass (Chabrier IMF); Col. 5. star formation rate; Col. 6. galaxy age.

actereized with a power law and a correlation length, r_0, through \( \xi(r, z) = (r/r_0(z))^\gamma \), where \( \gamma \) is the power index. For sparse samples and at small scales this representation is typically used. In larger surveys and simulations the correlation function is usually modelled combining terms for galaxies in the same halo and in different ones (Zehavi et al. 2011; Contreras et al. 2013).

In the following, we measure the bias and masses of the halos that host the BJGK_{n<6} samples. Specifically, for each BJGK_{n<6} sample, we calculate the 2-point angular correlation function, and then, using Limbers’ de-projection, given a redshift distribution and a cosmological model, we calculate the correlation length. The bias parameter follows from \( r_0 \) through \( b^2 = \sigma_{\text{gal}}^2 / \sigma_{\text{DM}}^2 \), where \( \sigma_{\text{gal}} \) and \( \sigma_{\text{DM}} \) is the root mean square fluctuation amplitude in 8h^{-1} Mpc spheres of galaxies (dark matter). The halo mass is obtained from the bias by using the models of Sheth, Mo & Tormen (2001). We have chosen this procedure and the 8 h^{-1} Mpc scale, in order to directly compare our results with previous works that connected progenitors and descendants of samples of star-forming galaxies (see Fig. 7).

To determine the angular correlation function, we use the Landy and Szalay (1993) prescription

\[
\theta(\theta) = (N_{gg} - 2N_{gr} + N_{rr})/N_{rr},
\]

where \( N_{gg} \) and \( N_{rr} \) are the number of pairs at a separation \( \theta \) of galaxies in the catalog and points in a random catalog with the same layout as the galaxy sample, respectively. \( N_{gr} \) is the cross number of points between the galaxy and random distributions. For our calculations we consider five ALHAMBRA fields (see section §3) that encompass 36 pointing catalogs. Errors were estimated by a jackknife method, which has been shown as a robust error estimator (Zehavi et al. 2013; Cabré et al. 2007), although it can overestimate the variance on small scales (Norberg et al. 2009). We have calculated the angular correlation function 36 times, each time eliminating one
Table 5. Clustering properties of the BJGK samples.

| Name   | N_{gal} | <z>         | <K_{alty}>  | A_y | r_0 (r=8 h^{-1} Mpc) | Bias | log M_h (h^{-1} M_{\odot}) |
|--------|---------|-------------|------------|-----|----------------------|------|--------------------------|
| BJGK1  | 3332    | 0.56±0.2    | -0.1       | -22.3 | 4.2±0.2 | 4.67±0.33 | 1.36±0.09 | 12.71^{+0.13}_{-0.15} |
| BJGK2  | 3778    | 0.67±0.2    | -0.1       | -22.3 | 4.3±0.5 | 4.58±0.39 | 1.41±0.11 | 12.66^{+0.15}_{-0.17} |
| BJGK3  | 3576    | 0.75±0.1    | -0.1       | -22.4 | 4.0±0.2 | 3.79±0.25 | 1.24±0.07 | 12.27^{+0.14}_{-0.16} |
| BJGK4  | 3480    | 0.83±0.1    | -0.1       | -22.4 | 4.2±0.1 | 4.15±0.23 | 1.40±0.07 | 12.45^{+0.10}_{-0.12} |
| BJGK5  | 3150    | 0.92±0.1    | -0.1       | -22.5 | 3.7±0.2 | 4.01±0.23 | 1.40±0.07 | 12.37^{+0.11}_{-0.12} |

Notes. Col. 1, Name of the selected sample; Col. 2, number of galaxies selected from the BJG samples after the K-band absolute cut and image mask; Col. 3, BPZ photometric redshift; Col. 4, medium K-band absolute magnitude; Col. 5, amplitude of correlation; Col. 6, correlation length; Col. 7, bias factor calculated with the variance at 8 h^{-1} Mpc. Col. 8, logarithm of the halo mass in units of [h^{-1} M_{\odot}].

catalog out of the 36 available. The uncertainty is estimated as the variance of w(r). We follow the method of [Infante et al. 1994; Quadri et al. 2007] to correct for the integral constraint. As mentioned above, to calculate r_0 we use the power law approximation \xi(r,z) = (r / r(z))^{-\gamma} that depends on the spatial separation and redshift. Likewise, the 2-point angular function turns out to be w(\theta) = A_y (\theta (1 + z)^{-\gamma}), where A_y is the angular amplitude. By fitting the correlation function to this power law, between 0.005 and 0.2 degree, the A_y is inferred. The angular amplitudes are reported in Table 5. To calculate the spatial from the angular function, we use the Limber’s (1953) inversion, which requires a redshift distribution N(z), and assume a cosmological model. Limber’s inversion involves solving the following integral (Kovac et al. 2007).

\[ r_0^2 = \frac{A_y (c / H_0) \int N(z) dz}{C_\gamma \int F(z) D(z)^{1-\gamma} N(z) g_d(z) dz}, \]

where the cosmology plays the role in the Hubble parameter H_0, g_d(z) = (1 + z)^{-1} \sqrt{1 + \Omega_m z + \Omega_L (1 + z)^{-2} - 1}, and in the angular diameter distance D_\theta. The parameter C_\gamma depends on the power index such that C_\gamma = \Gamma(5/3)^{[10^{0.5} - 1]} [10^{0.5}]. In order to be consistent internally and compare with other works (Adelberger et al. 2005; Duchi et al. 2005; Kashikawa et al. 2006; Hattori et al. 2006; Hildebrandt et al. 2007; Gawiser et al. 2007; Blanc et al. 2008; Hartley et al. 2008; Yoshida et al. 2008; Guaita et al. 2010; McCracken et al. 2010; Lin et al. 2012), the value of \gamma was fixed to the canonical \gamma = 1.8. This value is fully justified by experiments where \gamma was left free and is consistent with the clustering of luminosity-selected ALHAMBRA samples (Arnalte-Mur et al. 2014). F(z) accounts for the redshift evolution of the correlation function, where F(z) = (1 + z)^{-3(1+z)}, and we use e = -1.2 that corresponds to the value adopted for a constant clustering in comoving coordinates (Quadri et al. 2007). For the calculation of the correlation length error, the error contribution from the amplitude of the angular correlation function, the Poissonian errors (~ \sqrt{N(z)}), and the effects of the photometric redshift error in shifting and broadening N(z) are taken into account.

5.2. Bias and mass measurements

In turn we estimate the bias parameter, b, from the correlation length. As pointed out above, b is related to r_0 through the spatial correlation function by b^2 \approx \xi_{gal}(r,z)/\xi_{DM}(r,z) or b^2 \approx \sigma^2_{gal}(r,z)/\sigma^2_{DM}(r,z). The numerator \xi_{gal}(r,z) \approx J_2(\sigma_{gal}(r,z)) is taken from Peebles (1980), Eq. 9.3, where J_2 is a parameter defined in terms of y as J_2 = 72/[3(3 - y)(4 - y)(6 - y)^2]. We fix the spatial scale at 8 h^{-1} Mpc such that \xi_{gal}(8) = (r_0 / 8h^{-1} Mpc)^{1-\gamma}. The evolution of the dark matter density variance in a comoving sphere of radius 8 h^{-1} Mpc is \sigma^2_{DM}(8,z) = \sigma^2_0 D(z), where D(z) is the linear growth factor at redshift z. The bias measured for each BJGK sample, at the scale of 8 h^{-1} Mpc, is reported in Table 5.

The figure 7 shows the evolution of the bias factor as a function of redshift for the BJGK samples (red squares). The lines show the bias evolution for different halo masses (Sheth, Mo & Tormen 2001), whose are indicated below of each line in the right side of the panel. Approximately, the BJGK samples follows the bias evolution of haloes of masses \sim 10^{12.5} h^{-1} M_{\odot}. Finally, we calculate the halo mass using equation (8) of [Sheth, Mo & Tormen 2001] that relates the bias with the peak height, \nu = \delta_c(z)/\sigma(M,z), where \delta_c is the critical overdensity computed using the spherical collapse model. Here we assume \delta_c = 1.69. Then, the halo mass M_h is obtained through \sigma(M,z) evaluated at the redshifts of the BJGK samples listed in Table 4. In fig. 8 the halo mass of the BJGK samples as a function of redshift is shown. Squares show the median values of the halo mass, polygons show a conservative limit, drawing the mass limits taking into account the 1σ deviation of the redshift and bias. These results are presented in Table 5.

6. Discussion

6.1. Selection technique

The new two-color selection technique I_2X_iK based on ALHAMBRA medium-bands, allows us to extract eleven samples of star-forming galaxies at z >0.5 in narrower redshift ranges with respect to previous studies (Daddi et al. 2004; Steidel et al. 2004; Adelberger et al. 2005). This selection method is based purely on the ALHAMBRA photometric data and it does not depends on the models assumptions, methodology or templates used to determine the photometric redshifts or properties derived from SED fit. We have validated this technique with the Bruzual & Charlot (2003) models as well as checked with other stellar population synthesis models giving consistent results.
The ALHAMBRA GOLD data is an F814W-selected catalog, thus is less sensitive to detect the regions bluewards of the Balmer jump of galaxies at \( z > 1 \). The \( R_{12} \) band contributes only to 10% of the final F814W detection image, while the \( I_{14} \) and \( I_{34} \) bands contribute 18% each one. Hence, the detection in the F814W image becomes worse for galaxies at \( z \geq 1 \) with a pronounced Balmer jump.

In order to avoid any contamination of low-redshift galaxies in our samples, we are inclined to use the bluest band available in our samples. Hence, we studied the detection level of the \( U_1 \) and \( U_2 \) that reaches 97% and 99.7%, respectively. Since the \( U_2 \) has a higher detection level with respect to \( U_1 \), we have tailored the selection technique using the \( U_2 \) band.

To select samples at \( z < 0.5 \), we tried to use filters bluer than the \( R_0 \), whose central wavelength is lower than 613.5 Å. Nevertheless, the theoretical evolution of the color \( U_2X_{n<9}K \) of passive and star-forming galaxies, based on the models, tend to occupy the same locus in the color-redshift \( (U_2X_{n<9}K - z) \) plane. Hence, it does not allow to separate the star-forming from the passive galaxies as clear as for the \( U_2X_9K \) selection with \( n > 9 \) (see Fig. 2 and Fig. 3).

The number density of each \( BJG \) sample decreases with redshift, probably due to the nature of these objects or also related to a non-considered Malquist-bias selection effect in the \( U_2 \)-band. Besides, we verify our selection method with the BPZ photometric redshifts, whose uncertainty increase with redshift, and therefore the number densities might be underestimated according to \( \delta_z(BPZ) = 0.014z(BPZ) \).

According to this colour technique (visual inspection of Fig. 2 and Fig. 3), the redshift distributions should be narrower than in Fig. 4. The distributions can become wider if the errors of the photometric redshifts are properly taken into account. The mean formal BPZ error of the \( BJG_1 \) and \( BJG_{11} \) samples are 0.02 and 0.03, corresponding to 20% and 30% of the total expected width (\( \leq 0.1 \)), respectively. We performed simulations considering Gaussian redshift distributions filled randomly using the same amount of galaxies found in each sample, the expected width (0.1) and the formal BPZ error \( \delta_z(BPZ) = 0.014(1 + z(BPZ)) \). By perturbing the photometric redshift with its corresponding error, and choosing randomly a positive or negative variance the width of the distributions increase by a factor of 1.5 for the first \( BJG_1 \) sample, and up to 2 times this value for the \( BJG_{11} \) sample, with increasing redshift. Clearly, higher photometric redshift errors increase the distribution width. In the AHAMBRA data, BPZ tends to decrease its precision at I +1.5Mpc, as function of redshift for samples of star-forming galaxies. Red diamonds indicates the \( BJG_{Kw} \) samples. At \( z \approx 2 \), the grey, blue, red, green, and light green squares show the \( sBzK \) samples of \cite{Hayashi2007}, \cite{Blanc2008}, \cite{Hartley2008}, \cite{Lin2012}, and \cite{McCracken2010}, respectively. Yellow squares show the BM, BX selected galaxies of \cite{Adelberger2005}, \cite{Kashikawa2006}, \cite{Hildebrandt2007}, \cite{Ouchi2005}, respectively. Gray squares show the Ly-\( \alpha \) emitters selected by \cite{Guaita2011} and \cite{Gawiser2007}. The lines show the bias evolution for different halo masses \cite{Sheth2001}, whose are indicated below of each line in the right side of the panel.

**Fig. 7.** Evolution of the bias factor, calculated with the variance at 8 h\(^{-1}\)Mpc, as function of redshift for samples of star-forming galaxies. Red diamonds indicates the \( BJG_{Kw} \) samples. At \( z \approx 2 \), the grey, blue, red, green, and light green squares show the \( sBzK \) samples of \cite{Hayashi2007}, \cite{Blanc2008}, \cite{Hartley2008}, \cite{Lin2012}, and \cite{McCracken2010}, respectively. Yellow squares show the BM, BX selected galaxies of \cite{Adelberger2005}, \cite{Kashikawa2006}, \cite{Hildebrandt2007}, \cite{Ouchi2005}, respectively. Gray squares show the Ly-\( \alpha \) emitters selected by \cite{Guaita2011} and \cite{Gawiser2007}. The lines show the bias evolution for different halo masses \cite{Sheth2001}, whose are indicated below of each line in the right side of the panel.
band absolute magnitude reside on haloes of $10^{12.5\pm0.2}M_\odot$. In terms of progenitors and descendents for the median halo mass, the progenitors are the LBGs with $R < 25$ at $z \sim 3$ (Adelberger et al. 2005, Hildebrandt et al. 2007), the $sBzK$ galaxies with $K \leq 23$ at $z \sim 2$ (Hayashi et al. 2007, Hartley et al. 2008, McCracken et al. 2010, Lin et al. 2012) and the descendents in the local Universe are “elliptical” galaxies with luminosities around 2 $L_*$ (see Fig. 7). For haloes around the upper limit $10^{12.7}M_\odot$, we find as progenitors at $z \sim 3$ the LBGs (Hildebrandt et al. 2007) with $R < 24$, while at $z \sim 2$ the sBzK galaxies with $K \leq 23$ (Hartley et al. 2008, Lin et al. 2012) and the descendents are elliptical galaxies with luminosities around 3 $L_*$.

For the haloes around the lower limit $10^{12.3}M_\odot$, the progenitors are the LBGs at $z \sim 4$ (Kashikawa et al. 2004, Ouchi et al. 2005) with I or $z \leq 27$, the LAE galaxies at $z \sim 3$ (Gawiser et al. 2007), the $sBzK$ galaxies (Hayashi et al. 2007) with $K < 23$ at $z \sim 2$, the descendents are “elliptical” with luminosities around 1 $L_*$. The increment of the median halo mass of $0.4$ dex, between $z = 1.0$ and $z = 0.5$, follows the observed mass increment in numerical simulations (Millennium, Fakhouri et al. 2010). It suggests that we are tracing the evolution of the haloes of masses around $\sim 10^{12.5}$ from $z = 1.0$ to $z = 0.5$, and hence the evolution of the physical properties as it is shown in Fig. 6. So far, via clustering measurements, we have argued that our five sets of galaxies $BJGK_{n<6}$ represent a coeval and homogeneous population of star-forming galaxies.

The bias and hence halo mass of the $BJGK$ samples are on average higher than the one’s found in Hurtado et al. (2016) for star-forming galaxies. For all redshift ranges studied, our correlation lengths are 20% higher with respect to their work suggesting that we are selecting more massive galaxies. It might be due to the different galaxy selection methods as well as the absolute magnitude thresholds used to define complete samples. Nevertheless, the main difference relies on the method and the scale that we have chosen to calculate the bias, and hence the halo mass. In Hurtado et al. (2016), they calculate the bias for the scale range $1.0 < r < 10$ Mpc, while in this work we evaluate the bias in the scale $8 h^{-1}$Mpc in order to compare with previous works that also studied the progenitors and descendents of star-forming galaxies. By taking this approach, we obtain halo masses $0.7$ dex higher than in Hurtado et al. (2016).

6.3. Physical properties

We perform an accurate estimation of the physical properties derived from SED fitting (e.g. absolute magnitude, stellar mass, star formation rate, etc.) and characterize each sample as a whole with the median of each properties. Figure [4] shows the median values of the probability distribution of stellar mass, absolute magnitude, star formation rate for the $BJGK_{n<6}$ (red squares) samples as a function of redshift. In the stellar mass panel, the dashed line shows the evolution of the stellar mass for galaxies with present-day stellar masses of $log(M_*) \approx 10.7$, as our Milky way galaxy, taken from the analysis of the CANDELS survey by van Dokkum et al. (2013). There is a good agreement between the observed mass growth determined by van Dokkum et al. (2013), which slightly increase by a factor of 0.1 dex from $z = 1$ to $z = 0.5$ and the flat behavior found in this work. In the star formation rate panel, the dashed line shows the evolution of the implied star formation rate due to the evolution of the stellar mass of galaxies with present-day stellar masses of $log(M_*) \approx 10.7$, as our Milky way, also taken from van Dokkum et al. (2013). Our results falls slightly below suggesting that $SFR$ is sufficient to account for the increment in stellar mass between $z = 1$

![Fig. 8. Halo mass, calculated with the variance at 8 $h^{-1}$Mpc, as function of redshift for the $BJGK_{n<6}$ samples. Squares show the median values of the halo mass, polygons show a conservative limit, drawing the mass limits taking into account the 1σ deviation of the redshift and bias.](image_url)
forming galaxies (Rodighiero et al. [2011]). The $BJGK$ evolution, from $z \sim 1$ to $z=0$, of the $B$-band absolute luminosity agrees with the evolution measured by Tasca et al. [2014]. They found that the contribution of disks to the total $B$-band luminosity decreases by 30% from $z \sim 1$ to $z=0$, while the $BJGs$ decrease their median $B$-band luminosity by a factor of 0.5 dex. The distribution of galaxy ages obtained by iSEDfit has a large dispersion, even so, its increment between two epochs corresponds to the Universe age increment indicated by the redshift. According to the models of Lagos et al. [2014], galaxies of properties similar to the $BJGs$ host most of the neutral gas at $0.5 < z < 1.5$. Hence the $BJGs$ samples contain tentative targets to sample the neutral gas with sub-millimeter surveys.

7. Conclusions

We have selected eleven samples of star-forming galaxies by using a two-color technique based on the Bruzual & Charlot (2003) models convolved with the ALHAMBRA filters. Using clustering arguments, we have confirmed that five out of the eleven sets of galaxies, i.e. the $BJGK_{acs}$, represent a coeval and homogeneous population of star-forming galaxies. The properties derived from SED fitting, such as stellar mass, star formation rate, age, absolute luminosity, of each $BJGK_{acs}$ sample are characterized as a whole allowing us to study their putative evolution as a function of redshift. The main results can be summarized as follows:

- We tailor a two-color selection technique, based on the Bruzual & Charlot (2003) models and the Balmer jump that select star-forming galaxies in the redshift range $0.5 < z < 1.5$. We select eleven samples composed of Balmer jump Galaxies, dubbed $BJG$. The amount of photometric-redshift outliers in these color-selected samples increases with redshift ranging from 1% to 15%.

- We create a sub-sample of $BJG$, dubbed $BJGK_{n < 6}$, which considers only the $BJG_{acs}$ galaxies brighter than $K_{abs} \sim -21.2$. The stellar mass of the $BJGK_{acs}$ samples nearly does not change with redshift, suggesting that major mergers played a minor role on the evolution of the $BJGK$ galaxies. The SFR evolution accounts for the small variations of the stellar mass, from $z \sim 1$ to $z=0.5$, suggesting that star formation and minor mergers are the main channels of mass assembly. Although the distribution of galaxy ages obtained by iSEDfit has a large dispersion, the evolution of the galaxy age agrees with the evolution of the Universe age.

- The $BJGK_{acs}$ samples reside on haloes of $10^{12.5 \pm 0.2} M_{\odot}$, which progenitors are the LBGs with $R \leq 24$ at $z \sim 3$ (Hildebrandt et al. [2007]), the $sBzK$ galaxies (Lin et al. 2012; Hartley et al. 2008; McCracken et al. 2010) with $K \leq 23$ at $z \sim 2$ and descendents are elliptical galaxies with luminosities around $L_*$, for details see Fig. 7.

- The similar increment of the median halo mass between $z = 1.0$ and $z = 0.5$ of our observational results and numerical simulations (Millennium, Fakhouri et al. [2010], suggest that we are tracing the evolution of haloes of masses around $10^{12.5}$ from $z = 1.0$ to $z=0.5$, and hence the putative evolution of the physical properties of the galaxies hosted by these haloes (see Fig. 6).

The homogeneous coverage of the ALHAMBRA optical bands from $R_0$ to $z_0$, allows us to trace the evolution of the baryonic processes occurring on star-forming galaxies, from $z \sim 1.0$ to $z \sim 0.5$, which reside on haloes of masses $\sim 10^{12.5} M_{\odot}$. It corresponds roughly to a stellar mass upper (lower) limit of $\sim 10^{11} M_{\odot}$ ($10^{10} M_{\odot}$). Deeper ALHAMBRA data as well as near-infrared selected catalogs, would allow us to study the evolution of the physical properties on haloes of masses lower than $10^{12.5} M_{\odot}$ from $z \sim 0.5$ to $z \sim 1.5$.

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Fig. 9. Spectral Energy Distribution of a star-forming galaxy in the ALHAMBRA survey. From left to right and up to bottom, the panel shows the SED of a galaxy randomly picked out from the \textit{BJG}$_1$, \textit{BJG}$_2$, \textit{BJG}$_3$, \textit{BJG}$_4$, \textit{BJG}$_5$, and \textit{BJG}$_6$ samples, respectively. The filled green dots show the ALHAMBRA photometric data. The red line shows the model that minimizes the $\chi^2$ found by iSEDfit, the minimum reduced $\chi^2$ is indicated in the upper left corner, beside the BPZ photometric redshift. The black squares mark the ALHAMBRA photometry of the best model. The blue shading shows the Universe of models, generated by iSEDfit (see Section §4.2), scaled by their reduced $\chi^2$. The color bar indicates the reduced $\chi^2$ scale.

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Fig. 10. Spectral Energy Distribution of a star-forming galaxy in the ALHAMBRA survey. From left to right and up to bottom, the panel shows the SED of a galaxy picked out from the BJG7, BJG8, BJG9, BJG10, and BJG11 samples, respectively. The filled green dots show the ALHAMBRA photometric data. The red line shows the model that minimizes the χ² found by iSEDfit, the minimum reduced χ² is indicated in the upper left corner, beside the BPZ photometric redshift. The black squares mark the ALHAMBRA photometry of the best model. The blue shading shows the Universe of models, generated by iSEDfit (see Section 4.2), scaled by their reduced χ². The color bar indicates the reduced χ² scale.

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