VIPERS: Stellar population properties of early-type galaxies

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We present stellar population properties of early-type galaxies from the VIMOS Public Extragalactic Redshift Survey (VIPERS) based on the spectral measurements of ~ 4000 galaxies with stellar masses from 10^{10} to 10^{12} [$M_\odot$] in the redshift range $0.4 < z < 1.0$. We quantify relations between their age, stellar metallicity, duration of star burst, and stellar mass. We compare the properties of VIPERS intermediate redshift galaxies with galaxies found in the Local Universe.

1 Introduction

Tracing ages and chemical abundances of stellar populations of early-type galaxies (ETGs) at different redshifts as a function of their mass puts additional constraints on mechanisms leading to the global suppression of star formation and the build-up of the quiescent galaxy population. According to the "downsizing" scenario (Cowie et al., 1996; Cimatti et al., 2006), the evolution of galaxies is controlled by their mass, i.e. stars are formed earlier and faster in massive galaxies, which, as a consequence, complete their star formation at higher redshifts than lower mass galaxies. The arguments in favor for the downsizing scenario were delivered by a number of authors (e.g. Renzini, 2006; Pozzetti et al., 2010; Fritz et al., 2014). The analysis of physical properties of high-mass red sequence galaxies at $z \leq 0.7$ shows that their evolution is passive (e.g. Choi et al., 2014; Gallazzi et al., 2014). Unfortunately, studies of properties of stellar populations at intermediate redshift (i.e $z \geq 0.5$) are still limited due to the necessity of deep spectroscopy in the rest-frame parts of the spectra where absorption features sensitive to age and metallicity are located. VIMOS Public Extragalactic Redshift Survey (VIPERS, Guzzo et al., 2014), an European South Observatory (ESO) Large Program, has the potential to change this situation, providing a dataset of nearly 100,000 distant galaxies at redshift $0.5 < z < 1.2$ (five to ten times larger than any other datasets ever assembled at this redshift range).

2 Data

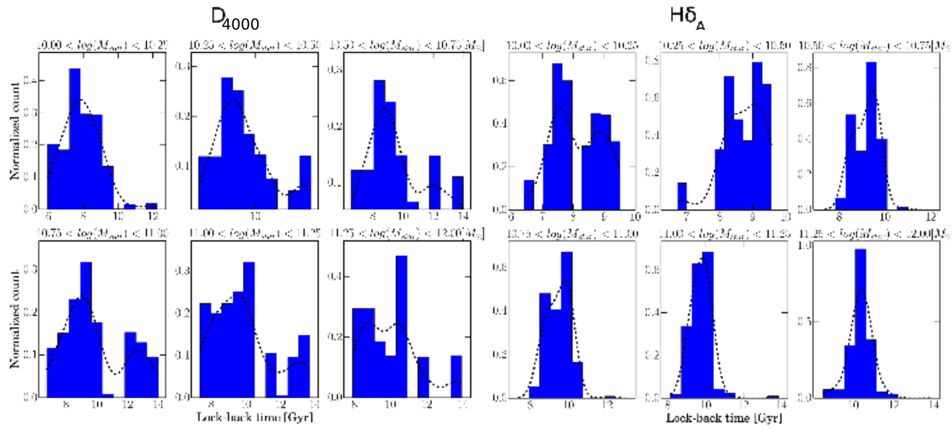
We present results for a sample of $\sim$ 4,000 ETGs selected from the VIPERS survey. Our analysis is based on the VIPERS internal Data Release version 5. We have selected 3,991 ETGs using the bimodal U-V color criterion with the evolving cut in (U-V) color (Fritz et al., 2014), and with additional criteria to obtain a reliable and uniform sample (for a detailed description we refer the reader to Siudek et al., 2016). We have divided this set of rest-frame galaxy spectra into a 2-dimensional grid of redshift-stellar mass bins: 6 redshift bins from 0.4 to 1.0 with δz=0.1, and 7 stellar mass bins from $\log(\mathrm{M_{star}}) = 10.00$ up to 11.25 [$\mathrm{M_\odot}$] with $\delta\log(\mathrm{M_{star}}) = 0.25$ dex, and one additional bin $11.25 < \log(\mathrm{M_{star}}) < 12.00$ [$\mathrm{M_\odot}$], as the sample is less numerous in the high stellar mass range. In each bin the rest-frame spectra were co-added using an average combination and a median scaling computed in a wavelength region between 4010 and 4600Å. We consider only composite spectra of more than 20 single spectra, since, according to our tests, this limit allows to obtain a satisfactory signal-to-noise (S/N) ratio to measure spectral features used in this paper. Finally, for 32 composite spectra of early-type galaxies from the redshift range $0.4 < z < 1.0$ with stellar mass between 10^{10} and 10^{12}[$\mathrm{M_\odot}$], we have calculated spectral indicators: the 4000 Å break (D_{4000}) (Balogh et al., 1999), and an absorption strength of high-order Balmer line $H\delta$ at 4101Å ($H\delta_A$) (Worthey & Ottaviani, 1997; for a detailed description we refer the reader to Siudek et al., 2015). Our cosmological framework assumes the density parameter $\Omega_\mathrm{m} = 0.25$, cosmological constant $\Omega_\Lambda = 0.75$, and reduced Hubble constant $\mathrm{h_{70} = H_0/(70\ kms^{-1}Mpc^{-1})}$.

3 Method and results

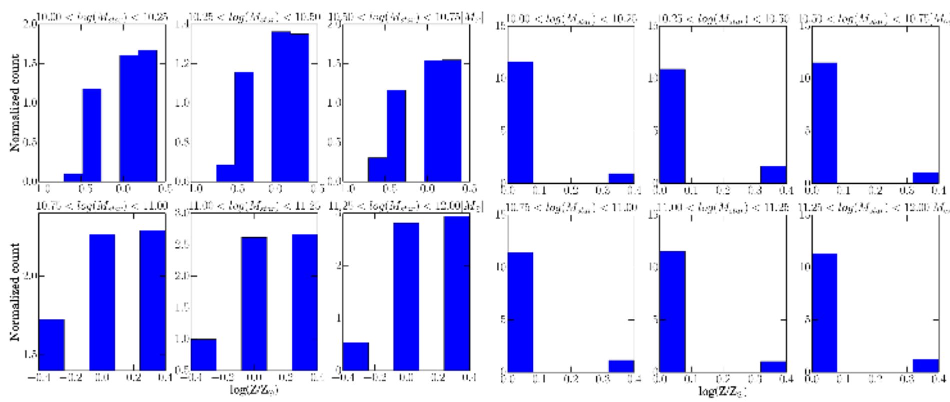
We have estimated the mean look-back time, stellar metallicity, and duration of burst adopting the approach proposed by Gallazzi et al. (2005). We have compared the strengths of the spectral features ($H\delta_A$ and D_{4000}) to the measurements made on a grid of synthetic spectra based on Bruzual & Charlot (2003) models. To create a library of synthetic spectra in the stellar synthesis modeling code we have used the following initial conditions: (1) initial mass function from Chabrier (2003), (2) Padova 1994 stellar evolutionary tracks, (3) high-resolution spectral library (STELIB), (4) the range of metallicities from sub- to super-solar (Z = 0.004, 0.008, 0.02, and 0.05), (5) star formation scenario with a single stellar burst of length between $0.1 \leq \tau \leq 1$ Gyrs (6) the range of ages from 1 up to 10 Gyrs since the beginning of the burst.

The comparison of the strengths of the absorption features in the observed VIPERS stacked spectra with those obtained for a library of templates allows us to build the probability density functions (PDFs) of physical properties of stellar populations, such as the look-back time, the metallicity, and the length of the burst (see Fig. 1). Following Gallazzi et al. (2005), the PDF is defined by the distribution of a given parameter with the weights $w = exp(-\chi^2/2)$, where χ^2 is based on the measurement errors of all the models in the library. Finally, we have established the mean values of parameters with errors corresponding to 1σ.

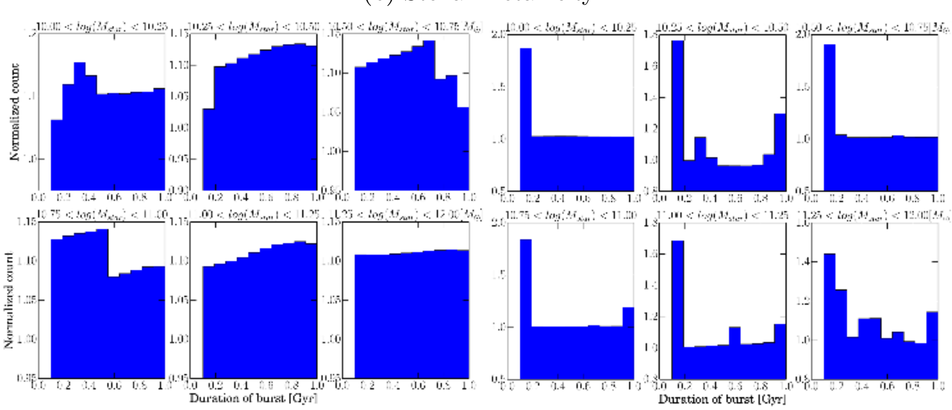
The spectral indicators used to characterize the ETGs properties (D_{4000} and $H\delta_A$) are well known as a good galaxy age indicators (e.g. Balogh et al., 1999; Kauffmann et al., 2003). The strength of D_{4000} depends strongly on metallicity, while $H\delta_A$ depends on the α/Fe ratio, and therefore it may affect the age derivation of elliptical galaxies. However, Gallazzi et al. (2014) have shown that there is no indication of a bias in the estimation of ages if only age indicators were used (D_{4000}, Hβ, and $H\delta_A$+$H\gamma_A$). The look-back times for VIPERS ETGs, estimated from these two spectroscopic features, stay in agreement with each other for each stellar mas bin (see Tab. 1). The obtained look-back time–mass relation or ETGs since $z \sim 1$ is also



(a) Look-back time.



(b) Stellar metallicity.



(c) Duration of star burst.

Fig. 1: Distribution of physical properties of stellar populations (look-back time, stellar metallicity, and duration of star burst) based on D_{4000} (three left panels) and $H\delta_A$ measurements (three right panels) of VIPERS ETGs. The dashed lines correspond to the probability density function.

M_{star} $[M_{\odot}]$	D_{4000} Look-back time [Gyr]	σ_{Age} [Gyr]	$H\delta_A$ Look-back time [Gyr]	σ_{Age} [Gyr]
$10.00 < \log(\mathrm{M_{star}}) < 10.25$	7.80	1.08	7.57	1.16
$10.25 < \log(\mathrm{M_{star}}) < 10.50$	8.48	1.30	9.08	0.66
$10.50 < \log(\mathrm{M_{star}}) < 10.75$	8.81	1.27	9.47	1.06
$10.75 < \log(\mathrm{M_{star}}) < 11.00$	9.00	1.10	9.81	0.57
$11.00 < \log(\mathrm{M_{star}}) < 11.25$	9.53	1.35	9.86	1.10
$11.25 < \log(\mathrm{M_{star}}) < 12.00$	8.82	1.95	10.39	0.85

Table 1: Mean look-back time estimated from the strength of D_{4000} and $H\delta_A$ in different stellar mass bins for our ETGs sample.

consistent with results of Moresco et al. (2010) and Thomas et al. (2010) (see Fig. 2). Following Gallazzi et al. (2014) we have estimated the slope for the age-mass relation for $0.6 < z < 0.8$ (0.130 +/- 0.116), which is perfectly matched with slope observed for local galaxies (0.112+/-0.098) (Gallazzi et al., 2006). Distributions of the metallicity and the duration of the star burst do not reveal favoring values when comparing the strength of the 4000Å break of VIPERS ETGs with the models (see left panel of Fig. 1b, and 1c). However, if we take into consideration the distribution of $H\delta_A$, which is not so sensitive to the mean stellar metallicity, we find that galaxies with metallicity close to the solar metallicity and the length of burst $\tau = 0.1$ dominate the VIPERS ETGs sample at $0.4 < z < 1.0$ in all stellar mass bins. Our estimated length of the burst ($\tau \sim 0.1$) has been also observed before for local ETGs (Moresco et al., 2011). Gallazzi et al. (2006) have shown that metallicities for local ETGs vary in the range $-0.2 < log(Z/Z\odot) < 0.2$. Comparing to their results, we have found that the VIPERS ETGs in the redshift range $0.4 < z < 1.0$ have stellar metallicity consistent with local quiescent galaxies, which implies no evolution in this parameter since $z \sim 1$. However, we note that the estimation of the metallicity based on age-sensitive indices only, may be biased low (Gallazzi et al., 2014).

4 Conclusions

We have estimated the look-back time of VIPERS ETGs based on stellar population synthesis models of Bruzual & Charlot (2003), using the mean values of D_{4000} and $H\delta_A$ for VIPERS composite spectra. Our results show that 4000Å break alone is not sufficient to determine the physical parameters of stellar population, such as the metallicity or the length of the burst. However, the usage of both indicators (D_{4000} and $H\delta_A$) allows to estimate stellar populations properties. From the spectral analysis, we have found that:

- The look-back time increases with the increasing stellar mass since $z \sim 1$. This result confirms the downsizing scenario, as massive galaxies have older stellar population than the less massive ones.
- The mean difference in age between high- and low-mass galaxies in our sample is around 2 Gyr (between stellar mass $\sim 1.5 \cdot 10^{10}$ and $\sim 1.2 \cdot 10^{11}$ $[M_{\odot}]$).
- Both D_{4000} and $H\delta_A$ are good age indicators and we do not find any evidence for a bias in their look-back time estimation.

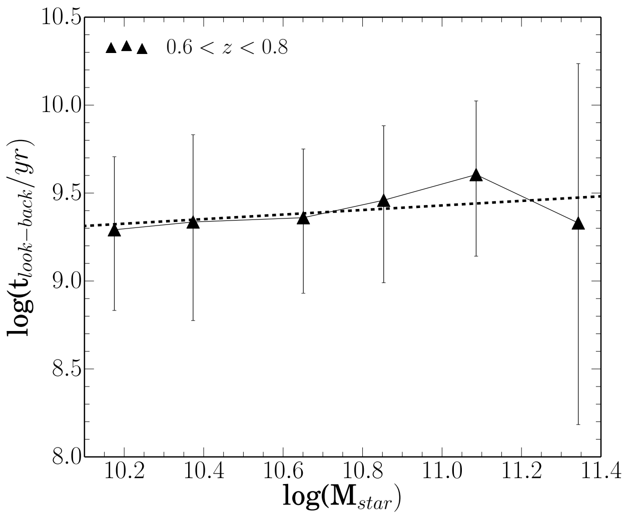


Fig. 2: Look-back time – stellar mass relation for redshift range $0.6 < z < 0.8$. The dashed line corresponds to linear fit.

- A slope obtained from the linear regression fit of the look-back time – stellar mass relation is consistent with the same slope derived for local ETGs.
- Our estimated length of the burst ($\tau \sim 0.1$) and metallicity close to the solar metallicity has been observed also for local, passively evolved ETGs, what implies no evolution in these parameters since $z \sim 1$.

VIPERS intermediate ETGs have stellar properties consistent with passive evolution hypothesis. Star formation history of VIPERS ETGs wil be described in more detail in Siudek at el., 2016.

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