

VIPERS: Stellar population properties of early-type galaxies

Małgorzata Siudek¹, Katarzyna Malek², Bianka Garilli³, Marco Scodreggio³, Alexander Fritz³, Agnieszka Pollo^{2,4} and The VIPERS Team⁵

1. Center for Theoretical Physics, Al. Lotnikow 32/46, 02-668 Warsaw, Poland;
2. National Center for Nuclear Research, ul. A. Soltana 7, 05-400 Otwock, Poland;
3. INAF - Istituto di Astrofisica Spaziale e Fisica Cosmica Milano, via Bassini 15, 20133 Milano, Italy;
4. Astronomical Observatory of the Jagiellonian University, Orla 171, 30-001 Cracow, Poland;
5. The VIPERS Team coauthors are presented at the end of this proceedings

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

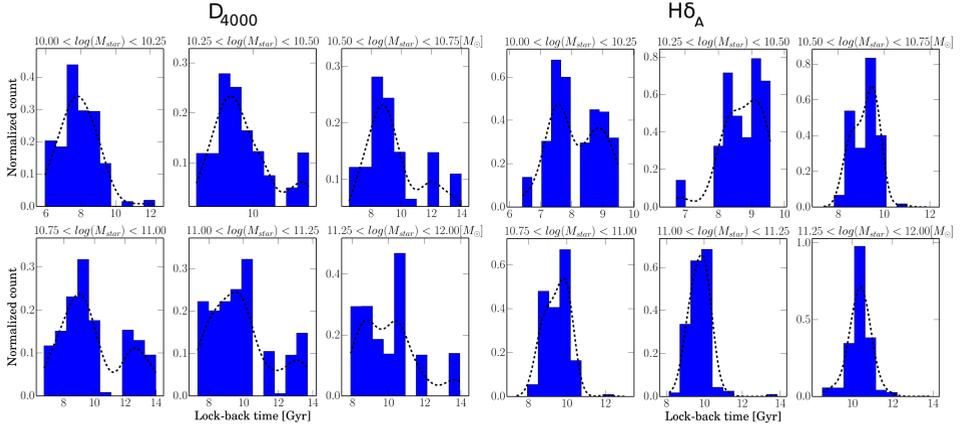
selected 3,991 ETGs using the bimodal U-V color criterion with the evolving cut in (U-V) color (Fritz et al., 2014), and with additional criteria to obtain a reliable and uniform sample (for a detailed description we refer the reader to Siudek et al., 2016). We have divided this set of rest-frame galaxy spectra into a 2-dimensional grid of redshift-stellar mass bins: 6 redshift bins from 0.4 to 1.0 with $\delta z=0.1$, and 7 stellar mass bins from $\log(M_{\text{star}}) = 10.00$ up to 11.25 [M_{\odot}] with $\delta \log(M_{\text{star}}) = 0.25$ dex, and one additional bin $11.25 < \log(M_{\text{star}}) < 12.00$ [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} [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 $\Omega_m = 0.25$, cosmological constant $\Omega_{\Lambda} = 0.75$, and reduced Hubble constant $h_{70} = H_0/(70 \text{ kms}^{-1}\text{Mpc}^{-1})$.

3 Method and results

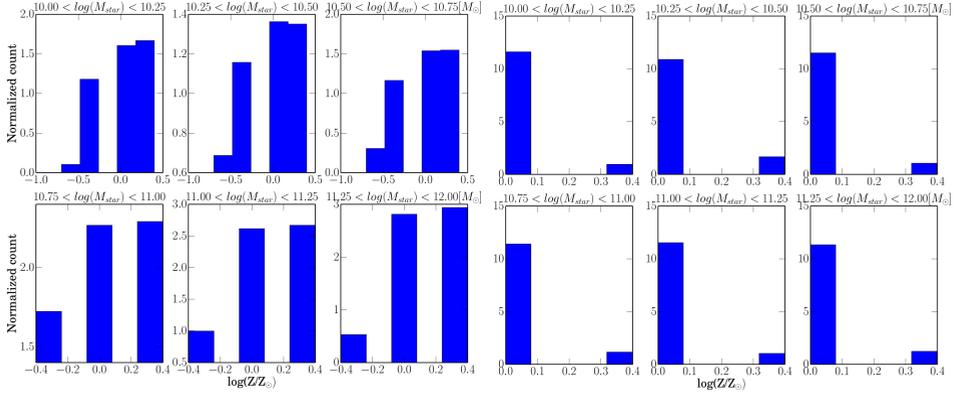
We have estimated the mean look-back time, stellar metallicity, and duration of burst adopting the approach proposed by Gallazzi et al. (2005). We have compared the strengths of the spectral features ($H\delta_A$ and D_{4000}) to the measurements made on a grid of synthetic spectra based on Bruzual & 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 ($Z = 0.004, 0.008, 0.02, \text{ and } 0.05$), (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 .

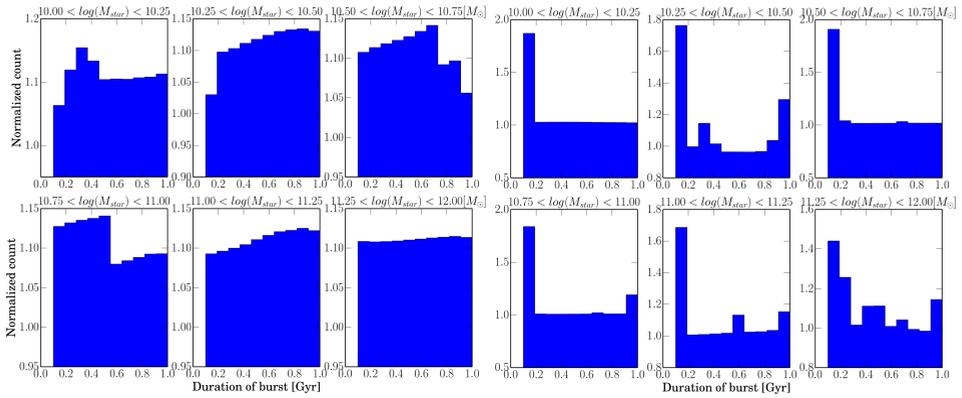
The spectral indicators used to characterize the ETGs properties (D_{4000} and $H\delta_A$) are well known as a good galaxy age indicators (e.g. Balogh et al., 1999; Kauffmann et al., 2003). The strength of D_{4000} depends strongly on metallicity, while $H\delta_A$ depends on the α/Fe ratio, and therefore 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} , $H\beta$, 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 mass bin (see Tab. 1). The obtained look-back time–mass relation for 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} | σ_{Age} [Gyr] | $H\delta_A$ | σ_{Age} [Gyr] |
|----------------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| | Look-back time [Gyr] | | Look-back time [Gyr] | |
| $10.00 < \log(M_{star}) < 10.25$ | 7.80 | 1.08 | 7.57 | 1.16 |
| $10.25 < \log(M_{star}) < 10.50$ | 8.48 | 1.30 | 9.08 | 0.66 |
| $10.50 < \log(M_{star}) < 10.75$ | 8.81 | 1.27 | 9.47 | 1.06 |
| $10.75 < \log(M_{star}) < 11.00$ | 9.00 | 1.10 | 9.81 | 0.57 |
| $11.00 < \log(M_{star}) < 11.25$ | 9.53 | 1.35 | 9.86 | 1.10 |
| $11.25 < \log(M_{star}) < 12.00$ | 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.

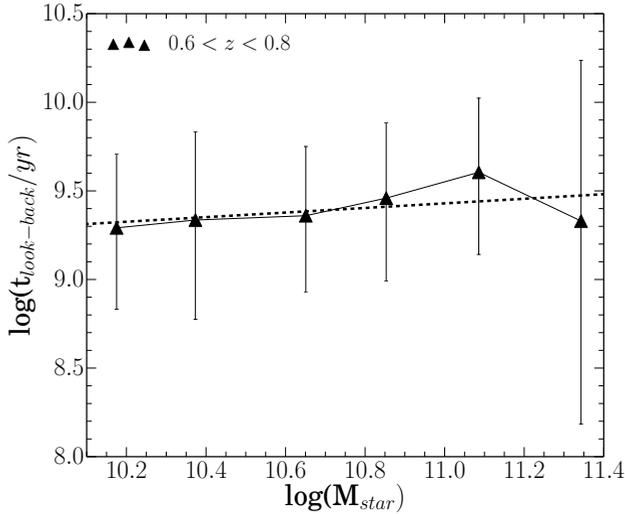


Fig. 2: Look-back time – stellar mass relation for redshift range $0.6 < z < 0.8$. The dashed line corresponds to linear fit.

- 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 will be described in more detail in Siudek et al., 2016.

Acknowledgements. We acknowledge the crucial contribution of the ESO staff for the management of service observations. MS, AP, KM, and JK have been supported by the National Science Centre (grants UMO-2012/07/B/ST9/04425 and UMO-2013/09/D/ST9/04030), the Polish-Swiss Astro Project.

References

- Balogh, M. L., et al., *Differential Galaxy Evolution in Cluster and Field Galaxies at $z \sim 0.3$* , ApJ **527**, 54 (1999), [astro-ph/9906470](#)
- Bruzual, G., Charlot, S., *Stellar population synthesis at the resolution of 2003*, MNRAS **344**, 1000 (2003), [astro-ph/0309134](#)
- Chabrier, G., *Galactic Stellar and Substellar Initial Mass Function*, PASP **115**, 763 (2003), [astro-ph/0304382](#)
- Choi, J., et al., *The Assembly Histories of Quiescent Galaxies since $z = 0.7$ from Absorption Line Spectroscopy*, ApJ **792**, 95 (2014), [1403.4932](#)
- Cimatti, A., Daddi, E., Renzini, A., *Mass downsizing and “top-down” assembly of early-type galaxies*, A&A **453**, L29 (2006), [astro-ph/0605353](#)

- Cowie, L. L., Songaila, A., Hu, E. M., Cohen, J. G., *New Insight on Galaxy Formation and Evolution From Keck Spectroscopy of the Hawaii Deep Fields*, *AJ* **112**, 839 (1996), [astro-ph/9606079](#)
- Fritz, A., et al., *The VIMOS Public Extragalactic Redshift Survey (VIPERS): A quiescent formation of massive red-sequence galaxies over the past 9 Gyr*, *A&A* **563**, A92 (2014), [1401.6137](#)
- Gallazzi, A., Charlot, S., Brinchmann, J., White, S. D. M., *Ages and metallicities of early-type galaxies in the Sloan Digital Sky Survey: new insight into the physical origin of the colour-magnitude and the Mg_2 - σ_V relations*, *MNRAS* **370**, 1106 (2006), [astro-ph/0605300](#)
- Gallazzi, A., et al., *The ages and metallicities of galaxies in the local universe*, *MNRAS* **362**, 41 (2005), [astro-ph/0506539](#)
- Gallazzi, A., et al., *Charting the Evolution of the Ages and Metallicities of Massive Galaxies since $z = 0.7$* , *ApJ* **788**, 72 (2014), [1404.5624](#)
- Guzzo, L., et al., *The VIMOS Public Extragalactic Redshift Survey (VIPERS). An unprecedented view of galaxies and large-scale structure at $0.5 < z < 1.2$* , *A&A* **566**, A108 (2014), [1303.2623](#)
- Kauffmann, G., et al., *The dependence of star formation history and internal structure on stellar mass for 10^5 low-redshift galaxies*, *MNRAS* **341**, 54 (2003), [astro-ph/0205070](#)
- Moresco, M., Jimenez, R., Cimatti, A., Pozzetti, L., *Constraining the expansion rate of the Universe using low-redshift ellipticals as cosmic chronometers*, *J. Cosmology Astropart. Phys.* **3**, 045 (2011), [1010.0831](#)
- Moresco, M., et al., *zCOSMOS 10k-bright spectroscopic sample . Exploring mass and environment dependence in early-type galaxies*, *A&A* **524**, A67 (2010), [1009.3376](#)
- Pozzetti, L., et al., *zCOSMOS - 10k-bright spectroscopic sample. The bimodality in the galaxy stellar mass function: exploring its evolution with redshift*, *A&A* **523**, A13 (2010), [0907.5416](#)
- Renzini, A., *Stellar Population Diagnostics of Elliptical Galaxy Formation*, *ARA&A* **44**, 141 (2006), [astro-ph/0603479](#)
- Siudek, M., et al., *VIPERS view of the star formation history of early-type galaxies*, volume 9662, 966213–966213–15 (2015), URL <http://dx.doi.org/10.1117/12.2202710>
- Thomas, D., et al., *Environment and self-regulation in galaxy formation*, *MNRAS* **404**, 1775 (2010), [0912.0259](#)
- Worthey, G., Ottaviani, D. L., *H γ and H δ Absorption Features in Stars and Stellar Populations*, *ApJS* **111**, 377 (1997)
- ⁵ U. Abbas⁵, C. Adami⁶, S. Arnouts⁷, J. Bel⁸, M. Bolzonella⁹, D. Bottini³, E. Branchini^{10,11,12}, A. Cappi^{9,13}, J. Coupon¹⁴, O. Cucciati^{15,9}, I. Davidzon^{6,9}, G. De Lucia¹⁶, S. de la Torre⁶, P. Franzetti³, M. Fumana³, B. R. Granett⁸, L. Guzzo^{8,17}, O. Ilbert⁶, A. Iovino⁸, J. Krywult¹⁸, V. Le Brun⁶, O. Le Fèvre⁶, D. Maccagni³, F. Marulli^{15,19,9}, H. J. McCracken²⁰, L. Paioro³, M. Polletta³, H. Schlegelhauser^{21,22}, L. A. M. Tasca⁶, R. Tojeiro²³, D. Vergani^{24,9}, A. Zanichelli²⁵, A. Burden²³, C. Di Porto⁹, A. Marchetti^{26,8}, C. Marinoni^{27,12,28}, Y. Mellier²⁰, L. Moscardini^{15,19,9}, R. C. Nichol²³, J. A. Peacock²⁹, W. J. Percival²³, S. Phleps²², M. Wolk²⁰, G. Zamorani⁹.
- [5] INAF - Osservatorio Astronomico di Torino, 10025 Pino Torinese, Italy, [6] Aix Marseille Universit'e, CNRS, LAM (Laboratoire d'Astrophysique de Marseille) UMR 7326, 13388, Marseille, France; [7] Canada-France-Hawaii Telescope, 65-1238 Mamalahoa Highway, Kamuela, HI 96743, USA, [8] INAF - Osservatorio Astronomico di Brera, Via Brera 28, 20122 Milano, via E. Bianchi 46, 23807 Merate, Italy, [9] INAF - Osservatorio Astronomico di Bologna, via Ranzani 1, I-40127, Bologna, Italy, [10] Dipartimento di Matematica e Fisica, Universit' degli Studi Roma Tre, via della Vasca Navale 84, 00146 Roma, Italy, [11] INFN, Sezione di Roma Tre, via della Vasca Navale 84, I-00146 Roma, Italy, [12] INAF - Osservatorio Astronomico di Roma, via Frascati 33, I-00040 Monte Porzio Catone (RM), Italy, [13] Laboratoire Lagrange, UMR7293, Universit'e de Nice Sophia Antipolis, CNRS, Observatoire de la C'ote d'Azur, 06300 Nice, France, [14] Astronomical Observatory of the University of Geneva, ch. d'Ecogia 16, 1290 Versoix, Switzerland, [15] Dipartimento di Fisica e Astronomia - Alma Mater Studiorum Universit' di Bologna, viale Berti Pichat 6/2, I-40127 Bologna, Italy, [16] INAF - Osservatorio Astronomico di Trieste, via G. B. Tiepolo 11, 34143 Trieste, Italy, [17] Dipartimento di Fisica, Universit' di Milano-Bicocca, P.zza della Scienza 3, I-20126 Milano, Italy, [18] Institute of Physics, Jan Kochanowski University, ul. Swietokrzyska 15, 25-406 Kielce, Poland, [19] INFN, Sezione di Bologna, viale Berti Pichat 6/2, I-40127 Bologna, Italy, [20] Institute d'Astrophysique de Paris, UMR7095 CNRS, Universit' Pierre et Marie Curie, 98 bis Boulevard Arago, 75014 Paris, France, [21] Universit'atssternwarte M'unchen, Ludwig-Maximilians Universit'at, Scheinerstr. 1, D-81679 M'unchen, Germany, [22] Max-Planck-Institut f'ur Extraterrestrische Physik, D-84571 Garching b. M'unchen, Germany, [23] Institute of Cosmology and Gravitation, Dennis Sciama Building, University of Portsmouth, Burnaby Road, Portsmouth, PO1 3FX, [24] INAF - Istituto di Astrofisica Spaziale e Fisica Cosmica Bologna, via Gobetti 101, I-40129 Bologna, Italy, [25] INAF - Istituto di Radioastronomia, via Gobetti 101, I-40129, Bologna, Italy, [26] Universit' degli Studi di Milano, via G. Celoria 16, 20130 Milano, Ital, [27] Aix Marseille Universit'e, CNRS, CPT, UMR 7332, 13288 Marseille, France, [28] Universit' de Toulon, CNRS, CPT, UMR 7332, 83957 La Garde, France, [29] SUPA, Institute for Astronomy, University of Edinburgh, Royal Observatory, Blackford Hill, Edinburgh EH9 3HJ, UK.