zCOSMOS 20k sample parameter space characteristics

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We present some of the spectroscopic, morphological and color properties of the still unpublished zCOSMOS spectroscopic survey 20 000 (20k) galaxy sample. Four main classes of galaxies are outlined based on a specific combination of the D4000 break parameter, OII emission line equivalent width, and the Sérsic index Moreover, we postulate a relationship between the above-mentioned galaxy properties and the parameter M_{gal} (distinct from stellar mass M_*), describing the total amount of gas transformed into stars through a particular galaxy's history.

1 Introduction – galaxy stellar activity evolution

According to current knowledge about galaxy evolution (Mo et al., 2010; Spinrad, 2005), there are two main types of galaxies in the Universe: (1) those that are actively forming stars, and (2) those that have ceased to do so (quiescent galaxies). They form two distinct groups, differing in properties. (1) are mostly disk or spiral galaxies, with relatively small masses, low Sérsic indices (Sérsic, 1963), and blue color indices (B-V or similar). In contrast (2) are mostly large elliptical galaxies, with large masses and red color indices. The differences extend also to spectroscopic properties. Galaxies of type (1) have optical spectra with a quite flat continuum and the presence of several emission lines (e.g. Balmer series, OII 3727Å, OIII 4959 and 5007Å, NII 6584Å, SII 6717Å) from the interstellar medium. On the other hand, due to the shortage of gas necessary to produce new stars and introduce ISM input, the spectra of typical quiescent galaxies (2) contain little emission, with mainly absorption lines, and are dominated by peculiar features like the D4000 break (Poggianti & Barbaro, 1997) – resulting from the the spectra of old stars. The evolution of galaxies, the process of transition of star-forming galaxies into quenched ones, is the subject of ongoing studies in cosmology.

2 zCOSMOS 20k sample

zCOSMOS is a deep redshift survey of galaxies covering a field of nearly two square degrees, centered at about 15^{h} RA and 2° Dec. (J2000). Among other similar surveys it is characterized by the availability of Hubble Space Telescope (HST) Advanced Camera for Surveys (ACS) imaging, as part of the COSMOS survey program (Scoville et al., 2007). By 2009 over 10 000 objects within zCOSMOS fields had have their spectral redshifts catalogued, with 88% success rate (secure redshift determinations at a 99% confidence level). This dataset was made public in 2009 (Lilly et al., 2009). The public release of the final dataset of $\sim$ 20 000 galaxies is expected to occur soon; we are using it in collaboration with dr Marco Scodeggio from INAF/IASF (Italy). After preselection based on quality flags the final 'good' sample used contains 5178 galaxies.

3 Classification of galaxies

Looking for a convenient spectroscopic classification we transformed the D4000 break parameter and OII 3727 Å equivalent width[1] into new set of normalised variables, described by equations 1 and 2 below:

$$ZmiennaOII3727 = \frac{\frac{1}{0.93215} \times \sqrt{\log EW[OII]3727\lambda} - D4000 + 0.379841}{0.504047} \qquad (1)$$

$$Zmienna1OII3727 = \frac{0.93215 \times \sqrt{\log EW[OII]3727\lambda} + D4000 - 2.52322}{0.189564} \qquad (2)$$

The variable $ZmiennaOII3727$ is a kind of a measure of stellar activity evolutionary stage; the higher its value the younger the stellar population of the galaxy. The adopted value of borderline classification into quiescent and star-forming galaxies equals -0.75.

The criteria of color segregation are borrowed from Krywult et al. (2016). There, a new variable UBV, based on rest-frame $U - B$ and $B - V$ colors, was introduced, defined in the following way:

$$UBV = (B - V) \times \cos(\theta) - (U - B) \times \sin(\theta) \qquad (3)$$

with $\theta = 58.08°$, as obtained from the analysis of VIPERs data. Based on the local minimum, we adopt the value of 1.2 as the discriminator between blue and red galaxies.

Regarding morphological classification, we adopted a Sérsic index value of 2 as a separator between early and late types.

The distribution of the galaxy sample with regards to those spectroscopic, color and morphology classifiers is presented in Fig. 1.

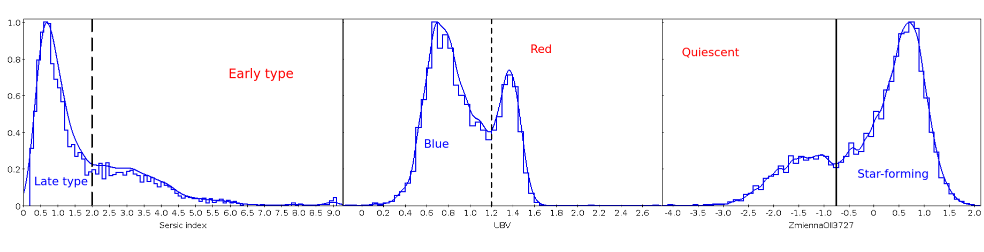

Fig. 1: Bimodalities of galaxy populations with regards to the Sérsic index (left), UBV parameter (middle) and ZmiennaOII3727 parameter (right). Boundary criteria between spectroscopic, color and morphology criteria are marked in each case.

[1] On the OII line as an indicator of star formation, see (Kewley et al., 2004).

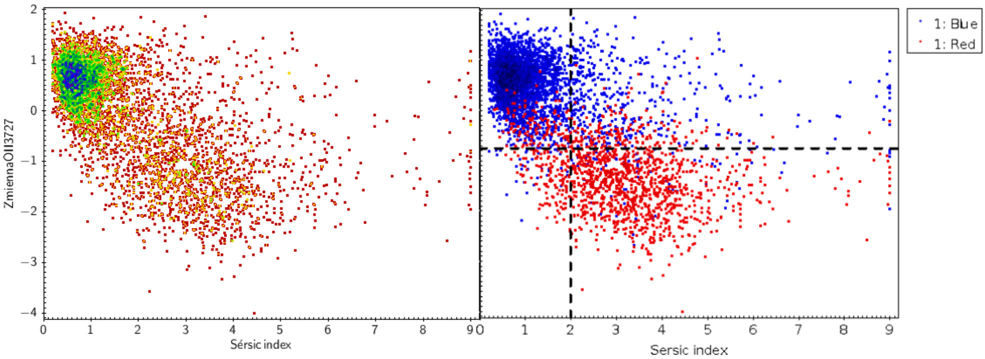

Fig. 2: All 5178 selected galaxies on $ZmiennaOII3727$ vs Sérsic index classification plane. Color density plot on the left panel, on the right different color-morphology-spectroscopic classifications marked by the borders and color dots.

We have discovered that combining the spectroscopic variable $ZmiennaOII3727$ with a Sérsic index into a single classification plane, it is possible to detect an intermediate population in transit between the two primaries. This classification plane is presented on the Fig. 1. The intermediate population is supposedly the tail of the main star-forming population in the left upper corner of the plane. It concentrates around the 0 value of $ZmiennaOII3727$ and ~ 1 Sérsic values (disk galaxies). We applied a Hierarchical Clustering model, using Ward's hierarchical tree algorithm (Ward, 1963), to detect that group as well as potential others. Assuming 4 populations, it has been successfully detected. We can categorize the obtained 4 populations as **Star forming**, **Early star forming** (corresponding to the blue, star-forming early type galaxies previously mentioned), **Intermediate** population extending from the main **Star Forming** group, and **Quiescent**. See Fig. 3, left panel.

4 Importance of the difference between mass transformed into stars and current stellar mass

In the provided catalogue, besides ordinary stellar mass M_* there is a parameter M_{gal}, with slightly higher values than M_*, describing the total mass of gas transformed into stars through galaxy's stellar evolution history. We calculated the ratio $[\log(M_{gal}) - \log(M_*] \times [\log(M_{gal})]^{-1}$ for catalogue galaxies. The results revealed to us that there is a clear dependence of the galaxy evolutionary stage on this ratio; the more evolutionary advanced galaxies (Intermediate and Quiescent groups) have this ratio higher than the Star Forming group. The critical value seems to be 0.02 (see Fig. 3, right panel). All four groups detected using the hierarchical model show different distributions of the ratio, consistent with the previously mentioned property.

We plotted galaxies based on the ratio on $ZmiennaOII3727$ vs Sérsic index classification plane (Fig. 4). This not only confirmed the relationship between galaxy evolutionary stage (represented by $ZmiennaOII3727$) and the ratio, but also revealed that galaxies with small ratios seem more often to drift towards higher Sérsic values (with a concentration of luminosity in the center), while maintaining the level of stellar activity. In contrast, in the galaxies with high ratio this is rare; there is a tendency to quench (represented by lower values of $ZmiennaOII3727$) while keeping their disk morphology (low Sérsic values) and then afterwards they become more elliptical-like,

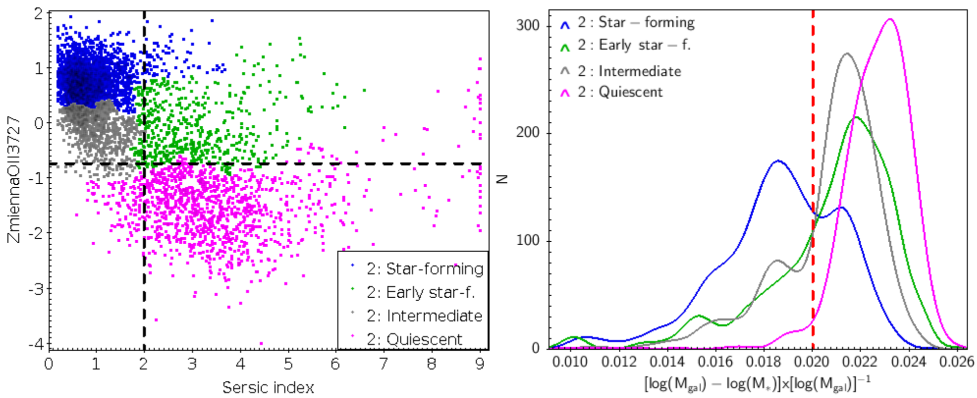

Fig. 3: Left: 4 main populations resulting from applying hierarchical model on the *ZmiennaOII*3727 vs Sérsic index classification plane. Right: the values of $[\log(M_{gal}) - \log(M_*] \times [\log(M_{gal})]^{-1}$ ratio for each of the hierarchical model populations.

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quenched galaxies with high Sérsic values.

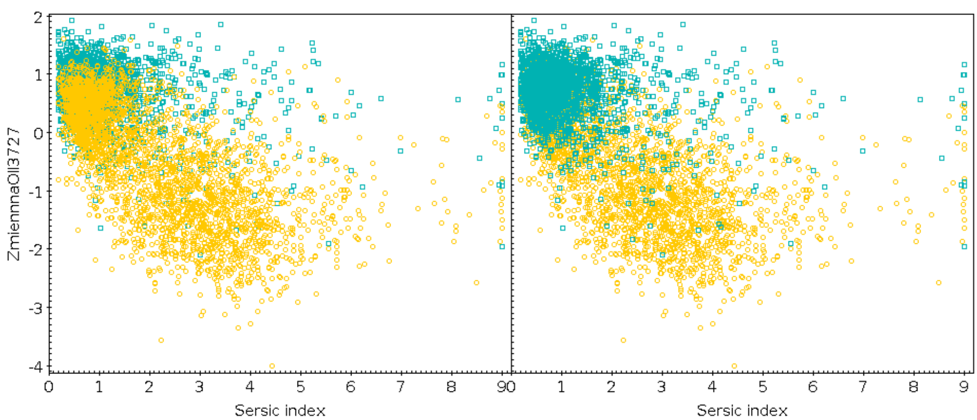

Fig. 4: Galaxies with a ratio $[\log(M_{gal}) - \log(M_*)]x[\log(M_{gal})]^{-1}$ above the value of 0.020 (yellow circles) or below (blue squares). Two plots show overlaying of both groups in the star-forming region in top-left corner.

5 Conclusions

We presented spectroscopic, morphological and color classifications of the 5178 high-quality galaxies from the zCOSMOS 20k sample. We applied new methods of classification to detect an intermediate population between two main classes (blue, star-forming disk galaxies and red, quiescent ellipticals). We discovered a dependence on the ratio between the amount of gas transformed into stars and the current stellar mass, which hinted at differences in evolution of galaxies with different values of this ratio. A low ratio suggests more likely evolution towards star-forming active elliptical galaxies, while a high ratio suggests quenching while preserving disk morphology, at least for some time.

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