zCOSMOS 20k sample

A correlation of spectroscopic and color parameters for zCOSMOS galaxy survey in the redshift interval 0.5-1.0

Oskar Kopczyński [1]

[1]Astronomical Observatory, Jagiellonian University, Kraków

The formulation of the problem

We do want to know how galaxies evolve between late and early types, and between star forming and non-star forming. Some questions to ask:

- How to connect spectral, color and morphological properties of galaxies?
- What are the main groups of galaxies with respect to the above-mentioned properties?
- What can we infere from correlations between them?
- How all those properties change with redshift? We must probe higher and higher redshift intervals to check out.
- **What are convenient parameters to work with?**
- **How to utilize peculiar features of the objects observed (e.g. high redshift of a given galaxy sample) to obtain more information about them?**

These are open problems. This presentation suggests some of the possible solutions.

zCOSMOS survey

- zCOSMOS: a deep ESO redshift survey
  - **area:** $\sim$ 2 square deg around 10 h RA and 2° Dec (J2000)
  - **goal:** to obtain spectra of $\sim$ 28 000 galaxies, $I_{AB} < 22.5$, $0.2 < z \leq 1.2$, and $\sim$ 12 000 galaxies, $1.2 < z \leq 3$, $B_{AB} \leq 25$ (Lilly, S. et al. 2007, ApJS, 172, 7 & Lilly, S. et al. 2009, ApJS, 184, 218)
  - **Availability of Hubble Space Telescope's (HST) Advanced Camera for Surveys (ACS) imaging** (COSMOS survey; Scoville, N. et al. 2007, ApJS, 172, 1)
- The final dataset of $\sim$ 20 000 galaxies- public release expected to occur soon, we are using it in collaboration with dr Marco Scodeggio from INAF/IASF (Italy)
- Out of this, we use a sample of $\sim$ **5000 galaxies** selected on quality spectra, within **redshift interval** 0.45-1.25.

Basics: galaxy spectra

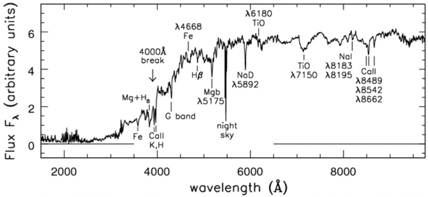
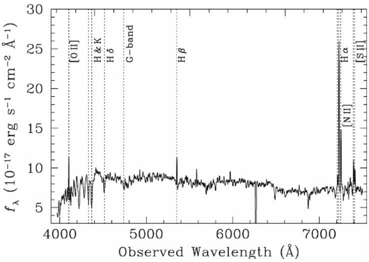


Fig 6.17 (A. Kinney) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007



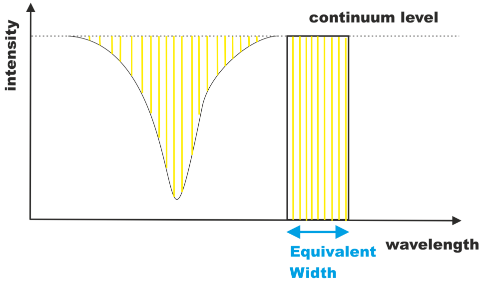
- Spectrum of passive, elliptical galaxy -rise of continuum after 4000 $\AA$, lack of emission, several absorption lines
- Spectrum of star-forming galaxy -flat continuum, lots of emission lines, coming mainly from ISM ionized by hot **OB stars**.

Basic spectroscopic quantities

- **Equivalent Width (EW)**: a flux normalised measure of line prominence

$$EW = \left| \int \frac{F_0 - F(\lambda)}{F_0} d\lambda \right| \quad (1)$$

where F_0 is the continuum level and $F(\lambda)$ is the flux of a line as a function of wavelength. **The higher EW of emission lines (e.g. [OII] 3727 Å) in galaxy spectra, the higher Star Formation Rate**



The illustration of Equivalent Width concept. The area under rectangle equals integrated line profile.

Basic spectroscopic quantities

- **D4000 index**: a ratio of flux after and before 4000 $\AA$

$$D4000 = \frac{(\lambda_2^- - \lambda_1^-) \int_{\lambda_1^+}^{\lambda_2^+} F_\lambda d\lambda}{(\lambda_2^+ - \lambda_1^+) \int_{\lambda_1^-}^{\lambda_2^-} F_\lambda d\lambda} \tag{2}$$

where usually $(\lambda_1^-, \lambda_2^-, \lambda_1^+, \lambda_2^+)$ =(3750, 3950, 4050, 4250) Å

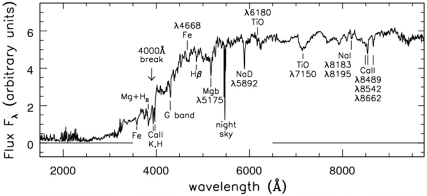
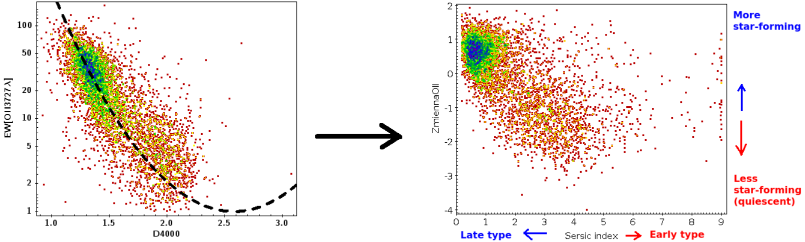


Fig 6.17 (A. Kinney) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

The higher D4000 the older stellar population within galaxy.

Transformation from OII-D4000 plane into ZmiennaOII-Sérsic index plane

$ZmiennaOII3727 = \frac{\frac{1}{0.93215}\times\sqrt{\log EW[OII]3727\lambda} - D4000 + 0.379841}{0.504047}$ **-a combination of OII Equivalent Width with D4000, going along the line of the trend on OII-D4000 plane.** We combine it with Sérsic index to get insight into morphology.



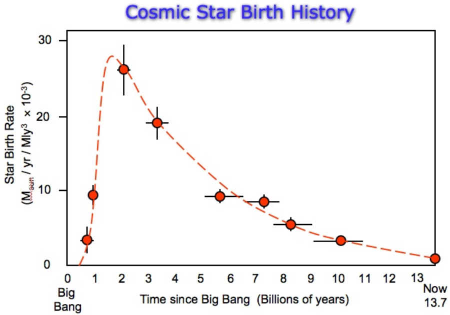
Here we have density plots, showing the areas of galaxy concentration in each parameter space -a core of late, star-forming galaxies, and extended plateau of quiescent earlies. Also suggestion of intermediate population-more info in upcoming publication (Kopczyński et al. in prep.).

Sérsic index n: a parameter of the following formula for intensity profile:

$$\log_{10}\frac{I(r)}{I(r_e)} = -b_n[(\frac{r}{r_e})^{1/n} - 1] \quad (3)$$

where r_e is effective radius, from within half of the galaxy light is emitted, and b_n is the proportionality coefficient. **Just know that $n \sim 1$ for spiral galaxies and $n \sim 4$ for ellipticals.**

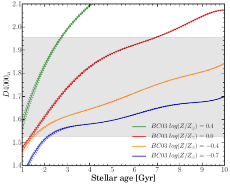
ZmiennaOII3727 -why? Derivation



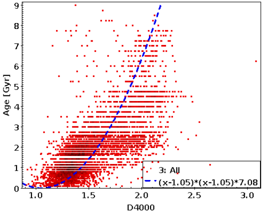
Star formation history of the Universe

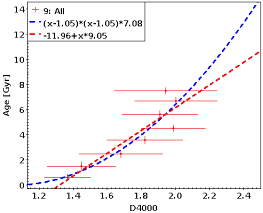
Star Formation Rate (SFR) is usually modelled as exponential decay; $SFR \propto e^{-\frac{t}{\tau}}$ where t -Age, time since star formation starts, τ -characteristic time But also $SFR \propto [OII]$ line intensity (see e.g. Kewley et al.(2004)). And as we will see: $t \propto (D4000)^2$

ZmiennaOII3727 -why? Derivation



(a) $D4000_n$-stellar age relation;





- Top: relation between D4000 and modelled age of galaxy population for different metallicities (from Siudek et al.(2017)).
- Center: distribution of different modelled ages with regards to D4000, with parabolic fit
- Bottom: Distribution of ages in 1 Gyr bins. Linear and parabolic approximations fitted.

ZmiennaOII3727 -why? Derivation

The trend on D4000-OII plane (from which *ZmiennaOII3727* is derived):

$$\sqrt{\log EW[OII]3727\lambda} = -0.98 \times D4000 + 2.573 \tag{4}$$

$$\log EW[OII]3727\lambda = (2.573 - 0.98 \times D4000)^2 \tag{5}$$

$$EW[OII]3727\lambda = e^{\ln 10 \times (2.573 - 0.98 \times D4000)^2} = e^{2.3 \times (2.573 - 0.98 \times D4000)^2} \tag{6}$$

On the other hand:

$$t[Gyr] = 7.08 \times (D4000 - 1.05)^2 \tag{7}$$

$$D4000 = \sqrt{\frac{t}{7.08}} + 1.05 \tag{8}$$

ZmiennaOII3727 -why? Derivation

Then:

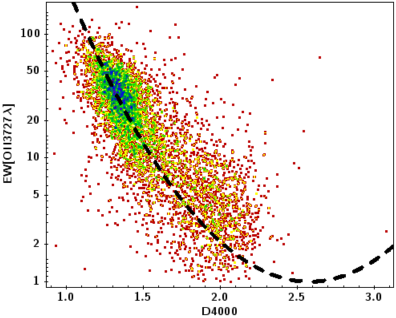
$$EW[OII]3727\lambda = e^{2.3\times(2.573-0.98\times\sqrt{\frac{t}{7.08}}-1.029)^2} \quad (9)$$

$$EW[OII]3727\lambda = e^{2.3\times(0.13565\times t-1.1037\times\sqrt{t}+2.245)} \quad (10)$$

Let's denote: $t_1 = (t-1)[Gyr]$, so $t = t_1 + 1$. Taylor expansion: $\sqrt{t_1+1} \approx 1 + \frac{1}{2} \times t_1$ Then:

$$EW[OII]3727\lambda \approx e^{2.3\times(0.13565\times t_1-0.55185\times t_1+1.27695)} \quad (11)$$

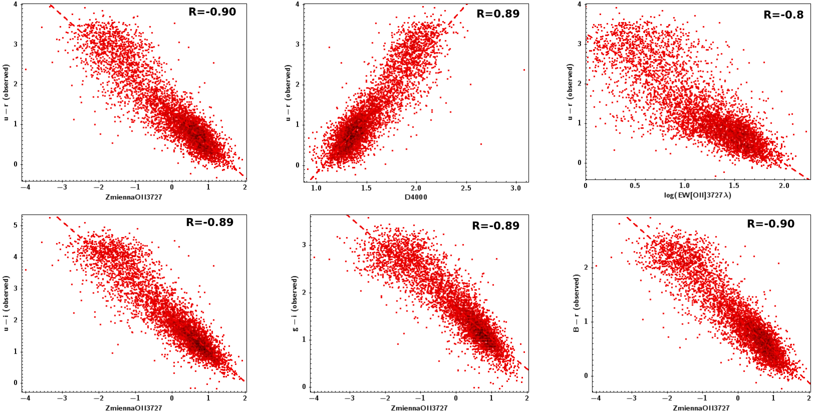
ZmiennaOII3727 -why? Derivation



The result:

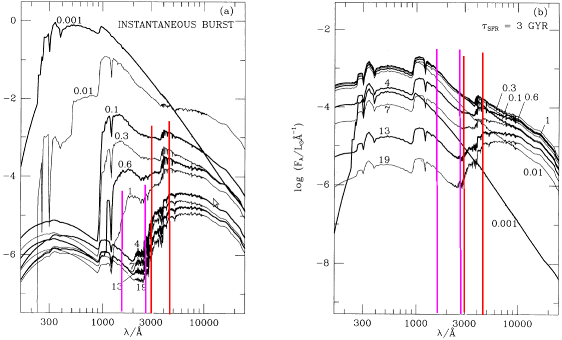
$$EW[OII]3727\lambda = 49.12\mathring{A} \times e^{-0.95 \times t[Gyr]} \qquad (12)$$

Correlations of spectroscopic parameters with observed colors



There is a high correlation (~ 0.9) between spectroscopic parameters (particularly *ZmiennaOII*3727 and its components: D4000 and log $EW[OII]3727\lambda$) and **observed** colors (without k-corrections to the rest-frame colors). This high correlation holds as well in different redshift bins (despite systematic changes in trends), so this is (the correlation) not an effect of systematic red-shifts only.

The potential utilization of redshifted observed magnitudes



From Bruzual & Charlot(1993), with our color markings: a synthetic models of stellar population (simulation of several stellar populations with different scenarios of their generation through time, marked in Gyr, instantenous burst left, exponential decay of Star Formation right on the right).

u filter -rest frame: ∼ 3000-4000 Å -redshifted by $z+1$ factor from ∼ 1500-2700 Å -that is **NUV**, emitted by young OB stars

r filter -rest frame: ∼ 6000-7000 Å -redshifted by $z+1$ factor from ∼ 3000-4700 Å -**thus encompassing D4000 bump. A tool to observe shorter wavelength, unavailable through classical methods without dedicated observations**.

Conclusions

- Well chosen spectroscopic parameters together with morphological parameters can create convenient space to track galaxy evolution.
  - Example: *ZmiennaOII*3727-Sérsic index plane.
- The redshift phenomena can be used to look into shorter, unavailable part of the spectrum.
  - Example: using observed color indices shifted from rest-frame due to the high redshift of observed galaxies, to obtain NUV magnitude estimate
- The high correlation between specific spectroscopic and color features can give us hints about the models of galaxy evolution with regards to its star content, as well as can be useful tool for photemetric preselection of galaxies with given spectroscopic properties
  - Example: *ZmiennaOII*3727 correlation with observed **u-r** color. We want to reproduce that correlations using mock catalogues with different star formation models and input parameters **-a task to do.**
  - Example: Correlation of observed colors with *ZmiennaOII*3727, which contains relation between [OII] and D4000, can allow us to select galaxies with presupposed [OII] and/or D4000 values, without direct measure of them.

Most Important Conclusions

REMEMBER!

- **DO NOT HESITATE** to ask questions -especially ask yourself: what, how, why is this so?
- **DO NOT HESITATE** to follow your own line of though, wherever it brings you.

Most Important Conclusions

- **HAVE COURAGE** to question wisdom your supervisors and established experts in the field -sometimes **YOU** may do have right.
- **DO NOT BE AFRAID** of original solutions -they may be more convenient than conventional line of thought (e.g. lying on the blanket in the corner of the lecture hall).
- **DO BELIEVE** in your skills and mind -no matter if there seems around many more knowledgable in the topic from you. You can do.