Hα and UV luminosities and star formation rates in a large sample of luminous compact galaxies

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Abstract We present the results of a statistical study of the star formation rates (SFR) derived from the Galaxy Evolution Explorer (GALEX) observations in the ultraviolet continuum and in the Hα emission line for a sample of about 800 luminous compact galaxies (LCGs). Galaxies in this sample have a compact structure and include one or several regions of active star formation. Global galaxy characteristics (metallicity, luminosity, stellar mass) are intermediate between ones of the nearby blue compact dwarf (BCD) galaxies and Lyman-break galaxies (LBGs) at high redshifts z > 2 - 3. SFRs were corrected for interstellar extinction which was derived from the optical Sloan Digital Sky Survey (SDSS) spectra. We find that SFRs derived from the galaxy luminosities in the far ultraviolet (FUV) and near ultraviolet (NUV) ranges vary in a wide range from 0.18 M⊙ yr⁻¹ to 113 M⊙ yr⁻¹ with median values of 3.8 M⊙ yr⁻¹ and 5.2 M⊙ yr⁻¹, respectively. Simple regression relations are found for luminosities L(Hα) and L(UV) as functions of the mass of the young stellar population, the starburst age, and the galaxy metallicity. We consider the evolution of L(Hα), L(FUV) and L(NUV) with a starburst age and introduce new characteristics of star formation, namely the initial Hα, FUV and NUV luminosities at zero starburst age.

Keywords Galaxies: irregular — Galaxies: luminosity function, mass function — Galaxies: starburst — Galaxies: star formation — Galaxies: statistics

1 Introduction

Cardamone et al. (2009) first draw attention to galaxies at redshifts z = 0.112 - 0.360 which were named “green peas” because of their compact structure and green colour on the gri composite Sloan Digital Sky Survey (SDSS) images. Specific colours of these galaxies are mainly caused by the very strong [O III] 5007Å optical emission line. The equivalent widths EW(5007) of this line in “green peas” redshifted into the SDSS r band can be as high as ∼1000Å, resulting in a green colour on SDSS images. Cardamone et al. (2009) studied a sample of 251 colour-selected galaxies. Some of the galaxies from this sample are active galactic nuclei (AGN). However, most of “green pea” galaxies are found to be strongly star-forming ones with high star formation rates (SFR) of ∼ 10 M⊙ yr⁻¹. These galaxies are characterised by low metallicity, stellar mass of M* ∼ 10⁸ - 10¹⁰ M⊙, high specific SFR (SSFR) (up to ∼ 10⁻⁸ yr⁻¹) which place them between nearby blue compact dwarf (BCD) galaxies and high-redshift (z > 2 - 3) UV-luminous Lyman-break galaxies (LBGs, see Giavalisco 2002 for a review). The available Hubble Space Telescope (HST) high-angular resolution images of a few “green peas” reveal complex morphology on small spatial scales with several regions of star formation and an extended stellar component likely consisting of older stars (Cardamone et al. 2009; Amorín et al. 2012). Cardamone et al. (2009) suggested that “green
pea” galaxies may be occurrences of the star formation mode prevailing in the early Universe. This galaxy class therefore may provide an excellent opportunity to understand in great detail many processes under physical conditions approaching to those in high-redshift galaxies.

The oxygen and nitrogen chemical abundances in star-forming “green peas” were studied by Amorín et al. (2010). These galaxies are revealed to be genuine metal-poor galaxies with mean oxygen abundances of ~ 20% solar. The N/O ratios are found to be unusually high for galaxies of the same metallicity. Detailed study lead Amorín et al. (2010) to the conclusion that known general properties of “green peas”, namely high SSFR, extreme compactness and stellar mass, seem to be uncommon in the nearby universe, suggesting a short and extreme phase of their evolution. The possible action of both recent and massive interaction-induced inflow of gas, as well as selective metal-rich gas loss driven by supernova winds are discussed here as main drivers of the starburst activity in “green peas” and their oxygen and nitrogen abundances.

The first direct radio detection with low frequency Giant Metrewave Radio Telescope (GRMT) observations and discussion of the “green peas” properties comprising of a new class of sub-mJy sources were reported by Chakraborti et al. (2012). It was shown that this detection may imply large magnetic fields (≥ 30 μG) in “green peas” under reasonable assumption about cosmic ray diffusion and total energy consideration. Chakraborti et al. (2012) concluded that seed fields were amplified significantly (up to μG) because of turbulence as protogalactic and similar structures formed.

Detailed examination of a large sample of 803 star-forming luminous compact galaxies (LCGs) in the redshift range z = 0.02 - 0.63 was carried out by Izotov et al. (2011). These galaxies were selected from the SDSS Data Release 7 (DR7) Abazajian et al. (2009) and comprise a complete spectroscopic SDSS sample of strongly star-forming LCGs with reliably derived chemical abundances. Their global properties are similar to those of the star-forming “green pea” galaxies. However, in contrast to “green pea” galaxies, the LCGs are selected on the base of the both their spectroscopic and photometric properties. Applied selection results in a ~ 10 times larger sample, with galaxies spanning a redshift range about ~ 2 times larger as compared to “green pea” sample Cardamone et al. (2009). For LCGs, the oxygen abundances 12 + log O/H are found to be in the range 7.6 - 8.4 with the median value of ~ 8.11 confirming the results by Amorín et al. (2010) for a subset of the “green pea” sample of Cardamone et al. (2009).

The ranges of oxygen abundances and heavy element abundance ratios in LCGs are similar to those of nearby low-metallicity BCDs. In the [O III]\lambda 5007/Hβ vs. [N II]\lambda 6583/Hα diagnostic diagram (Kaufmann et al. 2003) the LCGs are shown to occupy the region of high-excitation star-forming galaxies. The SFRs, derived from the Hα line emission in the LCGs are revealed to vary in the large range of 0.7 - 60 M⊙ yr\(^{-1}\), with a median value of ~ 4 M⊙ yr\(^{-1}\) which is about 3 times lower as compared to star-forming LBGs at z ~ 3 (Pettini et al. 2001). The SSFR in LCGs is extremely high and it varies in the range ~ 10\(^{-7}\) - 10\(^{-9}\) yr\(^{-1}\). All these properties imply that LCGs are likely the closest local counterparts of the high-redshift LBGs and Lyman-emitting galaxies.

Guseva et al. (2011) carried out the spectroscopic analysis of HG 031203, the host galaxy of a long-duration gamma-ray burst (GRB). The galaxy properties such as the oxygen abundance 12 + log O/H = 8.20 ± 0.03, extinction-corrected Hα luminosity L(Hα) = 7.27×10\(^{41}\) erg s\(^{-1}\), stellar mass M∗ = 2.5×10\(^{8}\) M⊙, SFR(Hα) = 5.74 M⊙ yr\(^{-1}\) and SSFR(Hα) = 2.3×10\(^{-8}\) yr\(^{-1}\) in HG 031203 are found to be in the range covered by the LCGs properties. This fact implies that the LCGs with extreme star-formation, that also comprise “green peas” as a subclass, may harbor GRB.

Pilyugin et al. (2012) analysed the oxygen and nitrogen abundances derived from global emission-line SDSS spectra of galaxies using the direct method based on the electron temperature determination from the [O III] \lambda 4363/(λ4959 + λ5007) emission-line flux ratio and the two strong line O/N and N/S calibrations. Three samples of objects were compared, including the sample of “green pea” galaxies by Cardamone et al. (2009) with the detected [O III] \lambda 4363Å auroral line. Pilyugin et al. (2012) concluded that the high nitrogen-to-oxygen abundance ratios derived in some “green pea” galaxies may be due to the fact that their SDSS spectra are the ones of composite nebulae made up of several components with different physical properties.

The local analogues of the strong Halpha Emitters (HAEs) dominated the z ~ 4 LBG population are identified by Shim & Chary (2012). Using the SDSS spectra authors show that at z < 0.4 only 0.04% of galaxies are classified as HAEs with equivalent widths EW(Hα) of > 500 Å, comparable to that of z ~ 4 HAEs. Local HAEs have lower stellar masses and lower UV luminosities than the z ~ 4 HAEs. On the other hand, their Hα-to-UV luminosity ratios and SSFRs are consistent with those of z ~ 4 HAEs indicating that the local analogues are the scaled-down versions of high-z star-forming galaxies. Compared to the previously studied local Lyman-break analogs (LBAs) of the z ~ 2
LBGs which were selected using rest-frame UV fluxes (Heckman et al. 2005), the local HAEs show similar UV luminosity surface densities, but lower metallicities and lower stellar masses. This supports the idea that local HAEs are less evolved galaxies than the traditional LBAs. Local HAEs show a strong He II λ4686 Å emission line in the stacked spectrum, implying a population of hot young (< 10 Myr) massive stars, similar to that seen in some Wolf-Rayet galaxies. The local HAEs also have properties similar to those of “green pea” galaxies.

In present paper, we extend the study of the properties of the “green peas” by further analysis of about 800 LCGs by Izotov et al. (2011), selected from the SDSS DR7. The selection criteria of galaxy sample are briefly described in Section 2. The correction of LCG fluxes for extinction is discussed in Section 3. In Section 4 we carry out the statistical investigation of dependence of galaxy luminosities on other LCG characteristics. In Section 5 we discuss star formation rates of LCGs. The SFRs are derived from the extinction-corrected luminosities $L$(Hα), $L$(FUV) and $L$(NUV) in the Hα emission line, the far ultraviolet (FUV) and the near ultraviolet (NUV) ranges from Galaxy Evolution Explorer (GALEX) observations. The luminosity function for LCGs is discussed in Section 6. We summarise our results in Section 7. We assume $H_0$=75 km s$^{-1}$ Mpc$^{-1}$ for distance estimates.

### 2 Sample selection, observational data

It is noted in Section 4 that LCGs, in contrast to “green pea” galaxies (Cardamone et al. 2009), are selected on the base of the both their spectroscopic and photometric properties. Selection criteria and LCGs sample properties are described in detail by Izotov et al. (2011). Briefly, these criteria are as follows:

- the extinction corrected luminosity of the Hβ emission line is greater than $L$(Hβ) = $3 \times 10^{40}$ erg s$^{-1}$;
- the equivalent width of the Hβ emission line is high, EW(Hβ) ≥ 50Å. This criterion leads to selection only objects with strong emission lines in their spectra and thus the ones containing young starbursts with ages 3 - 5 Myr;
- only galaxies with well-detected [O III] λλ4363 Å emission line in their spectra, with a flux error less than 50 %, are selected. This criterion allows an accurate abundance determination using the direct method;
- only the star-forming galaxies were selected. Galaxies with obvious evidence of Seyfert 2 features are excluded;
- galaxies on their SDSS images are nearly compact at low redshifts and unresolved at high redshifts. Their typical angular sizes are less than 10′′.

Izotov et al. (2011) used all LCG spectra and Monte Carlo simulations to fit spectral energy distributions in the wavelength range λ3800 – 9200Å. As for star formation history they assumed a single young burst with the age which is varied in the range < 10 Myr, and a continuous star formation with a constant star formation rate, which started at the lookback time $t_1$ and finished at the lookback time $t_2 < t_1$. Parameters $t_1$ and $t_2$ are varied in the range 10 Myr – 13 Gyr. The contribution of gaseous continuum in LCGs is very high, therefore it was fitted first using equivalent width EW(Hβ) of the Hβ emission line and subtracted from the observed spectrum prior fitting of the stellar continuum. The masses of the young and old stellar populations, the age of the young burst and parameters for the old stellar population $t_1$ and $t_2$ were parameters of fitting. More details of fitting can be found in Izotov et al. (2011). We use the results of modelling obtained by Izotov et al. (2011).

We use the GALEX Medium Imaging Survey (MIS) and All-sky Imaging Survey (AIS) data (see http://galex.stsci.edu/GR4) to estimate the galaxy UV SFR for the LCGs sample. GALEX is a NASA Small Explorer mission performed the all sky ultraviolet survey in two bands: far-UV (FUV, $\lambda_{\text{eff}}$ = 1528Å), and near-UV (NUV, $\lambda_{\text{eff}}$ = 2271Å) (Morrissey et al. 2005). MIS and AIS data contain information on fluxes of $\sim 10^7$ galaxies. The prime goal of GALEX is to study star formation in galaxies and its evolution with time. The major science objectives and characteristics of GALEX, and of surveys are described by Martin et al. (2005) and Morrissey et al. (2005). We matched the GALEX data and the sample of LCGs (Izotov et al. 2011) and extracted FUV and NUV fluxes from the GALEX MIS and AIS database. These data combined with the NASA/IPAC Extragalactic Database (NED) data provide the determination of the galaxy UV luminosities.

We excluded the galaxies with the UV flux errors exceeding 50% and the data for the multiple UV sources within the aperture of $\sim 30''$.

### 3 Correction for extinction

Because the radiation of galaxies is reduced by dust extinction, we applied reddening corrections to Hα and UV band fluxes using Cardelli et al. (1989) reddening law. Adopting the $R(V)$-dependent extinction law from Cardelli et al. (1989) with $R(V) = A(V)/E(B-V) = 3.1$, we obtain $A$(Hα) = $2.54 \times E(B-V)$ in Ha, $A$(FUV) = $8.15 \times E(B-V)$ in the FUV band and $A$(NUV) = $9.17 \times E(B-V)$ in the NUV band. The
extinction coefficient $C(H\beta)$, reddening $E(B-V)_{SDSS}$, and the equivalent width of underlying stellar hydrogen absorption lines were obtained by Izotov et al. (2011) from the hydrogen Balmer decrement in the redshift-corrected spectra. All hydrogen line fluxes were corrected for both the reddening and underlying stellar absorption. For comparison, we also use the reddening $E(B-V)_{NED}$ from the NED which was obtained from the Milky Way reddening maps by Schlegel et al. (1998). The $E(B-V)_{SDSS}$ and $E(B-V)_{NED}$ differ because the former quantity is the total reddening along the line of sight which includes extinction from both the Milky Way and the studied galaxy, while the latter quantity is the reddening in the Milky Way only. Izotov et al. (2011) derived $E(B-V)_{SDSS} = 0$ for 65 out of 803 galaxies. For some other galaxies they obtained $E(B-V)_{SDSS} < E(B-V)_{NED}$. To correct galaxy fluxes for extinction we use the $E(B-V)_{SDSS}$ for all LCGs. Alternatively, we analyse all the UV data adopting $E(B-V)_{SDSS}$ if $E(B-V)_{SDSS} > E(B-V)_{NED}$ and $E(B-V)_{SDSS}$ if $E(B-V)_{SDSS} < E(B-V)_{NED}$. The difference between these two approaches is small because of the low extinction in LCGs and does not influence appreciably our results and conclusions (see Sect. 4).

We derive mean redenings $E(B-V)_{SDSS}$ of 0.133 and 0.134 for LCGs detected in the FUV and NUV ranges, respectively. We also find that the mean reddening difference $E(B-V)_{SDSS} - E(B-V)_{NED}$ is 0.106. This difference is the rough average internal galaxy reddening which can be used for galaxies without spectroscopic estimates of reddening. In principle, the correction for the Milky Way and intrinsic reddening should be done separately. This is because the Milky Way correction has to be applied to the fluxes at the observed wavelengths, while the correction for the intrinsic reddening should be applied to the fluxes at the redshift-corrected wavelengths. However, ignoring of the separate correction for the Milky Way and intrinsic reddening would introduce very small additional uncertainties in the extinction-corrected fluxes. All LCGs are located at high galactic latitudes where the Milky Way extinction is very low, with the mean $E(B-V)_{NED}$ of $\sim 0.03$. Most of LCGs are also low-redshift galaxies with $z < 0.2$. Only few galaxies are at redshifts $z > 0.3$. Therefore, the difference between the extinction correction of the flux applied with the observed wavelength and the redshift-corrected wavelength for the galaxy with the redshift $z = 0.3$ and adopting $E(B-V)_{NED}=0.03$ is $\lesssim 10\%$ in the FUV and NUV bands, and $\lesssim 3\%$ for the H$\beta$ and H$\alpha$ emission lines. This difference for galaxies with lower redshifts is lower, e.g. it is only $\sim 5\%$ in the FUV and NUV bands and $\sim 2\%$ for H$\beta$ and H$\alpha$ for the galaxy with $z = 0.2$. Furthermore, Milky Way extinction maps by Schlegel et al. (1998) are obtained for large apertures of 6', which are much larger than the angular sizes of LCGs. Therefore, the extinction derived from the Schlegel et al. (1998) maps may not correspond to the real extinction in the direction on the galaxy if small-scale spatial extinction variations are present. These are reasons why we do not separate correction for the Milky Way and intrinsic reddening and use in a subsequent analysis $E(B-V)_{SDSS}$ derived by Izotov et al. (2011) from the hydrogen Balmer decrement.

Accordingly to Izotov et al. (2011), we split our sample into two subsamples of 276 “regular” galaxies with the round shape and 519 “irregular” galaxies with some sign of disturbed morphology suggesting the presence of two or more star-forming regions and their interaction. For these two subsamples we obtained $E(B-V)_{SDSS} - E(B-V)_{NED}$ of 0.081 and 0.120, respectively. Using the Student criterion we derived $t = 4.98$. This value suggests that the probability of the statistically significant difference of $E(B-V)_{SDSS} - E(B-V)_{NED}$ for two subsamples is greater than 99.9%. Therefore, extinction in galaxies with the non-round morphology is higher. On the other hand, we do not find tight correlation between $E(B-V)_{SDSS} - E(B-V)_{NED}$ and heavy element abundances. Apparently, the extinction is determined not only by the dust mass which is expected to be higher in galaxies with higher metallicity, but also by the spatial distribution of dust. This distribution seems to be different in “regular” and “irregular” galaxies.

We correct the galaxy fluxes for extinction according to $I(\lambda) = F(\lambda) \times 2.512^{A(\lambda)}$, where $F(\lambda)$ and $I(\lambda)$ are the observed and the corrected fluxes, respectively. The extinction-corrected GALEX FUV and NUV fluxes from LCGs are nearly three times higher than the observed fluxes. In addition, H$\alpha$ fluxes were corrected for an aperture comparing the total galaxy apparent magnitude $m$ and the magnitude $m(3''$) inside the SDSS spectroscopic aperture of 3" in a certain SDSS band depending on the galaxy redshift. We compare SDSS magnitudes $m = r$ and $m(3'') = r(3'')$ for galaxies with redshifts $< 0.04$, $i$ and $i(3'')$ for galaxies with redshifts in the range $0.04 - 0.26$, and $z$ and $z(3'')$ for galaxies with redshifts $\geq 0.26$. Then, the aperture H$\alpha$ flux correction is $A=2.512^{m-m(3''})$, where $m = r, i, z$ depending on the galaxy redshift.

4 Relations between galaxy luminosities and other global characteristics

For each galaxy we calculated its H$\alpha$, FUV and NUV luminosities. We use the regression analysis to study
a dependence of the LCG luminosities on other their characteristics. To provide a way for comparing \(L(\text{H}\alpha), L(\text{FUV})\) and \(L(\text{NUV})\) we use some other parameters being proportional to them. Namely, we use the calibration for SFRs averaged over the reasonable timescale for different SFR tracers and defined by Kennicutt (1998) as

\[
\text{SFR} = k \times L.
\]

The conversion factors \(k\) between the SFR and the \(L(\text{H}\alpha), L(\text{FUV})\) and \(L(\text{NUV})\) in Eq. 1 are derived using the evolutionary synthesis models. The coefficient \(k\) depends on the time scale of star formation, initial mass function (IMF) and galaxy metallicity. Adopting the solar metallicity, the IMF with the power-law index 2.35 and mass limits of 0.1 and 100 \(M_\odot\) [Salpeter 1955], SFR in \(M_\odot\) yr\(^{-1}\), \(L(\text{H}\alpha)\) in erg s\(^{-1}\), \(L(\text{FUV})\) and \(L(\text{NUV})\) in erg s\(^{-1}\) Hz\(^{-1}\), Kennicutt (1998) obtained the coefficient \(k\) of \(7.9 \times 10^{-42}\) for the \(\text{H}\alpha\) luminosity and \(1.4 \times 10^{-28}\) for the FUV and NUV luminosities.

There are some other modifications of Eq. 1. In particular, Kennicutt et al. (2009) proposed a composite SFR calibration based on the luminosities of both the \(\text{H}\alpha\) emission line and the UV continuum, adopting the IMF by Kroupa (2001) and obtained \(k = 5.5 \times 10^{-42}\). For clarity, we will use the values of \(k\) derived by Kennicutt (1998) for the solar metallicity and Salpeter IMF. Detailed review and analysis of SFR calibrations based on the \(\text{H}\alpha\) \(\lambda 6563\AA\) and \([\text{O} \text{II}]\) \(\lambda 3727\AA\) emission lines, far infrared and ultraviolet continua are given by Kennicutt (1998) and Calzetti (2012).

While the calibration defined by Eq. 1 holds for continuous or quasi-continuous star formation which is common in the big galaxies with frequent starbursts, the situation is more complicated in the dwarf galaxies like LCGs with the strong and rare bursts of star formation. In these systems with the instantaneous bursts the time interval of the star formation is not well defined, and the observed \(\text{H}\alpha\) luminosity strongly decreases on a time scale of a few Myr. Similar conclusions in lesser extent can be drawn for the SFRs derived from the FUV-band and the NUV-band luminosities. However, again for the clarity, we adopt that Eq. 1 can be applied for the determination of SFR in LCGs.

A set of galaxy parameters includes the primary parameters obtained directly from its SDSS spectrum, such as the redshift, the \(\text{H}\alpha\) flux and the chemical element abundances. For each galaxy we also use secondary parameters obtained by modelling galaxy spectral energy distribution, following Izotov et al. (2011), namely the masses of young \(M(\text{young})\) and old \(M(\text{old})\) stellar populations, the total mass of a stellar population \(M_\ast\), the age of a starburst \(t(\text{young})\), and the lower \((t_2)\) and upper \((t_1)\) limits for the age of old stars. All these parameters are distance-independent. Nevertheless, some nearby galaxies from our sample have angular diameters larger than the 3\(^\prime\) SDSS aperture. Neglecting an aperture correction for these galaxies would result in the underestimation of stellar population masses. To estimate the proper masses we used the aperture correction similar to the one used for luminosities. The luminosities of galaxies with angular diameters greater than 3\(^\prime\) without this correction deviate substantially from regression relations used for approximation of their SFRs as a function of their luminosities. These deviations vanish after taking into account aperture corrections.

We consider all above-mentioned parameters. However, as one can see below, only two secondary parameters, namely \(M(\text{young})\) and \(t(\text{young})\) have the statistically significant impact on the luminosity. Hereafter we will use the brief notations \(m \equiv M(\text{young})\) and \(T \equiv t(\text{young})\) for the mass of the young stellar population and its age, respectively.

Consider distributions of some secondary parameters. The values of the starburst age \(T\) are distributed rather uniformly over the interval \(T < 5\) Myr. Galaxies with \(T \geq 5.6\) Myr are not included in our sample due to the criterion \(\text{EW}(\text{H}\beta) > 50\AA\). This selection is also resulted in a relative decrease of the number of galaxies with \(5 < T < 5.6\) Myr. The distribution of \(m\) depends on \(T\). This is illustrated in Figure 1. One can see that the mean value of \(m\) for \(T > 3.2\)
Myr increases with the increase of $T$ with the best fit \[ \log(m/10^7M_\odot) = -0.57 \pm 0.22 + (0.33 \pm 0.05) \times T(\text{Myr}) \] for the subsample of “regular” galaxies and \[ \log(m/10^7M_\odot) = -0.75 \pm 0.17 + (0.40 \pm 0.04) \times T(\text{Myr}) \] for the subsample of “irregular” galaxies.

Note that both values $m$ and $T$ were calculated assuming a single star-forming region in the galaxy, while several regions of star formation with different $m$ and $T$ sometimes are observed in the galaxies. In this case we cannot rely on single values of $m$, sometimes are observed in the galaxies. In this case we cannot rely on single values of $m$, the latter value would tend to be larger. To prove that we consider a case of the two star-forming regions with equal stellar masses, one is very young and another is older. The young star-forming region would dominate in the H$\alpha$ luminosity because of the strong dependence of the flux of ionising radiation on a starburst age. On the other hand, the intensity of the optical continuum is less sensitive to the starburst age, therefore both star-forming regions equally contribute to the optical continuum, resulting in lower EW(H$\alpha$) as compared to the case with a single young burst. Consequently, this would result in a larger $T$ because it is determined mainly by EW(H$\alpha$). It is natural to expect that galaxies with larger masses of young stellar population with higher probability consist of several regions of star formation at different evolutionary stages. Therefore they would tend to have larger $T$ as compared to the galaxies with smaller masses of the young stellar population. That is why these galaxies concentrate in the upper right corner in Figure 1.

We will show later that the ratio $L/m$ decreases exponentially with increasing $T$ if $T > 3.2$ Myr. As a result, the lower right corner in Figure 1 is empty because the sample is flux-limited $L(\text{H}\beta) > 3 \times 10^{40}$ erg s$^{-1}$. Galaxies with low $m$ and $T > 4$ Myr have luminosities below the threshold and do not enter the sample.

Our goal is to find simple but statistically significant dependences of the galaxy luminosity on other primary and/or secondary galaxy parameters. First, we search for a set of parameters to which the galaxy luminosity is the most sensitive. Later, we will find the best formulae to describe these dependences and analyse them.

At first we do not take into account galaxy metallicities and analyse linear dependences of their luminosities on other parameters and their combinations. Regressors were chosen accordingly to the statistical Fisher test (Fisher 1954). We reject the regressors with statistical significance below the threshold of 99.95% and consider the regressions which are good for all six subsamples by selecting 3 wavelengths (H$\alpha$, FUV and NUV) and 2 morphologies - “regular” and “irregular”. These regressions have the form

$$
\text{SFR} = C_1 + C_2 m + C_3 m T^2 + C_4 m^2. \quad (2)
$$

The values, the errors and the statistical significances of the coefficients $C_i$ obtained by the least squares method (LSM) are shown in Table 1 for $m$ expressed in solar masses and $T$ in yr. The root mean square (RMS) standard deviation $\sigma$ and the number $N$ of the galaxies in each subsample are also shown in the Table. Significances are characterised by the value $F$ obtained by Fisher’s test. The critical $F$ values, corresponding to the statistical significances of 90, 95, 97.5, 99, 99.5, 99.9 and 99.95% are equal to 2.71, 3.84, 5.02, 6.64, 7.88, 10.83 and 12.10, respectively. One can see from Table 1 that the significances of regressors $C_2$ and $C_3$ in Eq. 2 are higher than 99.95%. For the regressor $C_4$ we choose the threshold value $F > 10$. Only for one subsample the threshold attains a higher value. For all other subsamples we assume $C_4 = 0$ and indicate in parentheses the value of $F$ for the case $C_4 \neq 0$.

Consider an implication of Eq. 2. One would expect that SFRs vanish at the low-mass limit $m = 0$. However, Eq. 2 (case (a) in Table 1) implies that SFR is equal to non-zero $C_1$ at this limit with a large statistical significance for the three subsamples out of six. We assume that this is due to the uncertainties in the estimation of $m$. We suggest that this statistical effect resembles the well-known Malmquist bias. A similar effect was studied in connection with the large-scale collective galaxy motion (Parnovsky & Parnowski 2005). To verify this hypothesis we performed some Monte Carlo simulations. For these simulations we need many generated mock catalogues, preferably with the distribution of the parameters similar to that in real subsamples.

First, we adopt the values of $m$ and $T$ from the corresponding real subsamples. Then, we set $C_1 = 0$ and calculate the coefficients $C_2$, $C_3$, and $C_4$ (if the last one is statistically significant) for the regression relation Eq. 2 using the LSM. These coefficients are shown in Table 1, case (b). After that, we derive the SFR values for the case (b) from Eq. 2 with $C_1 = 0$. As a result we obtain the initial “unbiased” set of $m$, $T$ and SFR values. Note that the dependence of SFR on $m$ and $T$ in this sample is functional, not statistical. The real SFR data are taken into account only indirectly via the set of coefficients $C_2$, $C_3$ and $C_4$. Naturally, if we apply the LSM with the regression defined by Eq. 2 to this data we obtain coefficients in the corresponding row of Table 1, case (b), but with $\sigma = 0$.

Next, using the Monte Carlo technique we add a noise, i.e. random errors to the unbiased values of SFR or $m$. We find that random normal errors in SFR values result in the nonshifted distributions of $C_i$ values obtained by the LSM. In this case a random value for $C_1$ has the low statistical significance. A completely different situation arises when random errors in $m$ are
considered. In this case the distributions of \( C_i \) values are shifted relative to the “unbiased” ones and we obtain a non-zero value for \( C_1 \), sometimes with the large false statistical significance. Other coefficients tend to attain values nearer to zero if the noise increases.

Could the effect of uncertainties in the \( m \) determination explain a non-zero value of \( C_1 \) obtained from the real data? To prove this suggestion we compare the values of \( C_i \) in Table 1 (case (a)) with the ones obtained using Monte Carlo simulations. For that, we use the “unbiased” SFR and \( T \) values from the sample calculated with the coefficients from case (b) in Table 1 and add a random noise to \( m \). We obtain the “biased” value \( m_{bias} \). The distribution of \( m_{bias} \) is expected to be log-normal, therefore we added the noise using the equation

\[
m_{bias} = m(1 + s \times \xi),
\]

where \( \xi \) is a normally distributed random value with zero mean and unity dispersion and \( s \) characterises an amplitude of the noise. Then we calculate \( C_i \) values applying LSR to the set of “unbiased” SFR and \( T \) values and the values of \( m_{bias} \). After repeating this procedure 1000 times we obtain the mean values and the distribution of \( C_i \) as well as the mean value of \( \sigma \). The results for different \( s \) are shown in Table 2 for the H\( \alpha \) subsample No. 1 in Table 1. One can see that the calculated values of \( C_1 \) in Table 1 (case (a)) can be explained by the Monte Carlo model with \( s = 0.34 \) (Table 2). In addition to the shift of \( C_1 \) the noise in \( m \) also affects the values of other coefficients \( C_i \). They are shifted closer to the values from Table 1 (case (a)). The value of modelled \( \sigma \) is smaller than that obtained from real data due to the contribution of SFR errors in real data, in addition to errors in \( m \).

We used similar Monte Carlo simulations for other two subsamples with statistically significant non-zero \( C_i \) values (subsamples No. 2 and 4 in Table 1) and obtained similar results attained at \( s = 0.32 \) and \( s = 0.38 \), respectively.

Therefore, we adopt that the true preliminary regression for SFR is Eq. 2 with \( C_1 = 0 \) and non-zero values of \( C_2, C_3 \) and sometimes \( C_4 \) (see case (b) in Table 1). The uncertainties in the estimation of \( m \) lead to the appearance of the first regressor in Eq. 2 with a false statistical significance. Hereafter we will use only the models with \( C_1 = 0 \). Then we can rewrite Eq. 2 in the form

\[
SFR/m = C_2 + C_3T^2 + C_4m,
\]

introducing a new value \( SFR/m \) which gives us a possibility to consider the dependence on \( T \) regardless of the dependence on \( m \). The first term in Eq. 4 is the main one and its meaning is that SFR of a galaxy is approximately proportional to the mass of the young stellar population. This is quite obvious because radiation in the UV continuum and H\( \alpha \) emission line is emitted mainly by young O-stars. We will return later to the consideration of the possible nonlinear dependence of SFR on \( m \).

In Figure 2 we show the dependence of \( L(\text{H}\alpha)/m \) \( \propto \) SFR\( /m \) on the starburst age \( T \). It is seen from the Figure that the ratio \( L(\text{H}\alpha)/m \) is practically constant for \( T < T_0 = 3.2 \) Myr and decreases practically exponentially for larger \( T \). We note that SFR(\( \text{H}\alpha \)), \( m \), and \( T \) are not directly correlated because they are based on the different features in the spectra: SFR(\( \text{H}\alpha \)) is not modelled and is derived from the H\( \alpha \) flux, \( m \) and \( T \) are modelled but they depend on different features. The

| Subsample | \( N \) | \( \sigma \) | \( C_1(F) \) | \( C_2 \times 10^6(F) \) | \( C_3 \times 10^{22}(F) \) | \( C_4 \times 10^{18}(F) \) |
|-----------|------|------|----------|-----------------|-----------------|-----------------|
| 1. H\( \alpha \), “regular” | 276 | 3.4 | 1.15 ± 0.35(10.9) | 18.3 ± 0.8(528) | −43.1 ± 2.6(268) | −33.8 ± 8.0(17.8) |
| 2. H\( \alpha \), “irregular” | 519 | 4.0 | 1.41 ± 0.24(35.3) | 17.0 ± 0.4(1602) | −45.5 ± 1.6(766) | −(0.7) |
| 3. FUV, “regular” | 213 | 4.8 | 0.19 ± 0.45(0.2) | 12.4 ± 1.0(149) | −22.1 ± 4.0(30) | −(3.9) |
| 4. FUV, “irregular” | 418 | 4.4 | 1.29 ± 0.31(17.5) | 8.0 ± 0.6(159) | −14.2 ± 2.4(34) | −(0.4) |
| 5. NUV, “regular” | 233 | 5.6 | 0.42 ± 0.50(0.7) | 14.5 ± 1.1(167) | −20.7 ± 4.4(22) | −(2.3) |
| 6. NUV, “irregular” | 435 | 7.8 | 0.27 ± 0.53(0.3) | 14.8 ± 1.1(180) | −23.5 ± 4.2(31) | −(8.7) |

Table 1 Coefficients \( C_i \) in Eq. 2 and their significance values \( F \) for different galaxy subsamples
mass of young stellar population \( m \) is determined by the luminosity and the shape of the stellar continuum in the visible range, while \( T \) depends mainly on the equivalent width \( \text{EW}(H\beta) \) of the \( H\beta \) emission line. In particular, the equivalent width \( \text{EW}(H\beta) \) is lower by a factor of many times for the burst with the age of 6 Myr as compared to that for the burst with the age of 3 Myr, while the flux of the stellar continuum near \( H\beta \) is decreased by only \( \sim 5\% \) \citep{Leitherer1999}. Therefore, \( \text{SFR}(H\alpha), m, \) and \( T \) can be considered as independent parameters. The most plausible explanation of the \( L(H\alpha)/m - T \) relation is that most massive stars with masses of \( \sim 100 M_\odot \), producing most of the ionising radiation, disappear after the starburst age \( T \sim 3.2 \) Myr, corresponding to their lifetimes. It also implies that stars in LCGs are formed during very short time periods, otherwise, in the case of extended bursts, \( T_0 \) would be greater than \( \sim 3.2 \) Myr. The best fit for \( T > 3.2 \) Myr is \( \log(\text{SFR}/m) = -5.61 \pm 0.07 + (-0.316 \pm 0.016) \times T/(\text{Myr}) \) for the “regular” subsample and \( \log(\text{SFR}/m) = -5.62 \pm 0.05 + (-0.326 \pm 0.011) \times T/(\text{Myr}) \) for the “irregular” subsample.

Is this effect statistically significant? The values of the Fisher coefficients for linear terms in regression relations for both subsamples exceed 398. For additional proof we performed the Student test to compare the mean values of the SFR/\( m \) for \( T < 3.5 \) Myr and \( T > 4 \) Myr. In all cases the Student test gives \( t \) above 3.31, corresponding to the statistical significance of 99.95%. The results are shown in Table 3, where \( \sigma \) is the standard deviation. One can see that mean values of SFR/\( m \) for \( T < 3.5 \) Myr are essentially larger than those for \( T > 4 \) Myr. This effect is more pronounced for the \( H\alpha \) radiation as compared to the FUV and NUV radiation. This is because 1) more massive short-lived stars contribute to the ionising radiation and 2) the luminosity of ionising radiation is much stronger increased with the mass of a star as compared to the UV-radiation. We note, however, that the ratio \( \text{SFR}/m \) decreases more slowly in comparison with the \cite{schaerer1998} population synthesis models for young stellar populations given the appropriate heavy element abundance.

In accordance with the above discussion we introduce the function \( f(T) \)

\[
 f(T) = \begin{cases} 
 1 & \text{if } T < T_0; \\
 \exp(-p \times (T - T_0)) & \text{if } T > T_0,
\end{cases} 
\]  

where \( T_0 = 3.2 \) Myr and \( p = 0.75 \) Myr\(^{-1} \). These values are the preliminary ones obtained from Figure 2. They will be improved later. Using \( f(T) \) and transforming Eq. 4 we obtain the regression relation

\[
 \text{SFR} = C_5 mf(T) + C_4 m^2
\]

and apply LSM to calculate the values and the errors of the coefficients.
The improved dependence of SFR/m on T (dashed and solid lines in Fig. 2) correspond to best fits with the optimal values of p and the existence of the correlation between T and m (Fig. 1) lead us to the following results. For the Hα “regular” subsample the second term becomes statistically insignificant and for Hα “irregular” subsample the second term becomes positive and statistically significant. The values of RMS standard deviations become smaller than those from Eq. 4 because of the better approximation of SFR/m on T.

The dependences of L(FUV)/m and L(NUV)/m on T are more gently sloping and have a larger scattering of L(FUV)/m and L(NUV)/m as compared to L(Hα)/m. The dependences L(FUV)/m on T and L(NUV)/m on T are shown in Figure 3. The shape and application of f(T) to describe these dependences will be discussed below. First of all we will use the function f(T) for the Hα radiation.

We now consider the dependence of L on the galaxy metallicity. As a measure of metallicity we choose the oxygen abundance [O] = 12 + log(O/H). [O] was accurately derived by Izotov et al. (2011) for every galaxy in the LCG sample. We adopt these values for the regression determination. To analyse the trend we restrict ourselves to the linear dependence on [O] only. Oxygen abundances of the galaxies from the LCG sample vary in the range from 7.52 to 8.47 with the median value of 8.06. We note that the use of nonlinear dependences on [O], for example, 10^[O], does not make any additional progress in reducing of the regression RMS standard deviations.

First, we discuss potentially misleading methods of studying the trends in the dependence of L on [O]. The simplest approach is to calculate the mean L for the subsamples with low and high oxygen abundances and to treat the obtained difference as an dependence on the oxygen abundance. Adopting the median value [O] = 8.06 as a value dividing galaxies with low and high oxygen abundances, we find that the subsamples with high [O] have the mean L (or SFR) values ~ 1.5 times larger than for the subsamples with low [O]. However, the mean masses of young stellar population in high-metallicity subsamples are larger by a factor of ~ 1.5 in comparison with subsamples with lower metallicity. Therefore, the differences in SFRs are mostly due to the differences in masses of the young stellar population and are not directly related to the differences in the metallicity.

The best way to investigate the direct impact of galaxy metallicity on its luminosity for the galaxy with the same values of m and T is to include the metallicity directly in the regression relation. Therefore, we fit the SFR values for Hα emission line using the set of regressors

\[
SFR = C_5 m f(T) + C_4 m^2 + C_6 m ([O] - \langle [O] \rangle)
\]

with \( T_0 = 3.2 \) Myr and \( p = 0.75 \) Myr\(^{-1} \). Here \( \langle [O] \rangle \) is the mean oxygen abundance of the sample galaxies. We subtract this value from the galaxy’s oxygen abundance [O] to make the last term in Eq. 7 practically orthogonal to the first one and in this way to keep the results of the Fisher test for the first two regressors. Using the LSM we calculate the coefficients, their errors and statistical significances of the regression defined by Eq. 7. For the Hα “regular” subsample we obtain \( \sigma = 3.42, C_5 = (2.13 \pm 0.05) \times 10^{-7} (F = 1654), C_4 = (3.6 \pm 4.2) \times 10^{-18} (F = 0.7), C_6 = (4.7 \pm 1.0) \times 10^{-8} (F = 20). \) For the Hα “irregular” subsample the derived values are \( \sigma = 3.8, C_5 = (1.94 \pm 0.03) \times 10^{-7} (F = 4415), C_4 = (3.4 \pm 1.6) \times 10^{-18} (F = 4.9), C_6 = (3.2 \pm 0.7) \times 10^{-8} (F = 23). \) We note the drop of statistical significance of the nonlinear term with C4 below the threshold for both subsamples.

Switching to the UV luminosities, we generalise Eq. 4 by adding the term with the dependence on metallicity:

\[
SFR = C_2 m + C_3 m T^2 + C_4 m^2 + C_6 m ([O] - \langle [O] \rangle).
\]

Derived coefficients, their errors and statistical significances for FUV and NUV subsamples are shown in Table 4. All coefficients \( C_6 \) are negative and have the statistical significance more than 99.5%. Coefficients \( C_4 \) are statistically insignificant for all FUV and NUV subsamples, similar to that for Hα subsamples.

### Table 3

| Sample | \( T < 3.5 \) Myr | \( T > 4 \) Myr |
|--------|------------------|------------------|
|        | \( N \) | \( \text{SFR/m} \times 10^8 \) | \( \sigma \times 10^8 \) | \( N \) | \( \text{SFR/m} \times 10^8 \) | \( \sigma \times 10^8 \) | \( t \) |
| 1. Hα, “regular” | 137 | 20.9 | 6.9 | 100 | 8.8 | 3.3 | 17.8 |
| 2. Hα, “irregular” | 249 | 20.9 | 8.1 | 215 | 7.9 | 3.0 | 23.5 |
| 3. FUV, “regular” | 104 | 12.4 | 8.7 | 79 | 7.5 | 5.9 | 4.6 |
| 4. FUV, “irregular” | 198 | 13.8 | 11.8 | 177 | 5.4 | 2.5 | 9.7 |
| 5. NUV, “regular” | 114 | 15.6 | 11.1 | 88 | 9.7 | 7.5 | 4.5 |
| 6. NUV, “irregular” | 207 | 19.5 | 18.6 | 181 | 8.4 | 4.9 | 8.2 |
Summarising, we find that a nonlinear term $m^2$ in the regression relations (Eqs. 7 and 8) is statistically insignificant for all six subsamples. Speaking more precisely, we conclude that the statistical analysis gives us no reason to justify the existence of such a term. Would it be statistically significant it makes the ratio $L/m$ be depending on the young stellar population masses. This could be treated as an impact of the environment or as a result of some kind of an interaction of several regions of star formation. However, it is difficult to analyse these effects statistically because of the correlation between $m$ and $T$, which would lead to ambiguous conclusions.

We discard nonlinear term with $m^2$ adopting $C_4 = 0$ in Eq. 9 and obtain a regression relation in the form

$$SFR = C_5 mf(T) + C_6 m\langle [O] - \langle [O] \rangle \rangle. \quad (9)$$

We apply this relation for the Hα radiation. For the subsamples No.1 and 2 we use the function $f(T)$ from Eq. 5 with $T_0 = 3.2$ Myr and $p = 0.75$ Myr$^{-1}$. The values, errors and the statistical significances of the coefficients obtained by the LSM are shown in Table 4 (case (a)). Using these coefficients we calculate $SFR_{regr}(\text{Hα})$ and $L_{regr}(\text{Hα}) = SFR_{regr}(\text{Hα})/k$ for every galaxy from these subsamples, where $k = 7.9 \times 10^{-42}$. The comparison of the calculated values with the observed ones is plotted in Figure 3. It follows from the Figure that Eq. 9 provides a good approximation of the observational Hα data in the entire range of $SFR(\text{Hα}) = 0.8 - 77 \, M_\odot$ yr$^{-1}$.

For the FUV and NUV subsamples we use Eq. 8 with $C_4 = 0$. We can rewrite it in the form of Eq. 9 introducing

$$f(T) = 1 - \eta T^2, \quad C_5 = C_2, \quad \eta = -\frac{C_3}{C_2}. \quad (10)$$

From the two last rows of Table 4 (case (b)) we derive $\eta = (21.6 \pm 0.9) \times 10^{-3}$ Myr$^{-2}$ for the FUV band and $\eta = (18.5 \pm 0.9) \times 10^{-3}$ Myr$^{-2}$ for the NUV band. Certainly, the relation Eq. 10 cannot be used if the starburst age $T$ is greater than 7 Myr because $f(T)$ becomes negative. Note that the errors of $\eta$ were estimated taking into account not only the errors of $C_2$ and $C_3$ in Table 4 but their covariation too by using all elements of the correlation matrix including the nondiagonal ones.

Consider the final fine tuning of the parameters in the Eq. 9. Using LSM we obtain the optimal values of $T_0$ and $p$ in Eq. 4. For the Hα “regular” subsample we derive $\sigma = 3.3, \quad T_0 = 3.3$ Myr, $p = 0.69$, while for the Hα “irregular” subsample the derived values are $\sigma = 3.6, \quad T_0 = 3.3$ Myr, $p = 0.68$. Could Eq. 9 be used for the UV continuum radiation with $f(T)$ in the form of Eq. 6 similar to the Hα radiation? Such attempt turns out to be successful. For the subsamples No.7 and 8 we obtain the optimal values $T_0 = 2.9$ Myr and $T_0 = 3.1$ Myr, respectively. They are smaller than 3.2 Myr, probably, due to the larger data scatter in comparison with the Hα subsamples. With these optimal values of $T_0$ and $p$, the RMS standard deviations for the UV bands are slightly decreased as compared to the case when $f(T)$ is used in the form of Eq. 10. The minimum of the sum of square residuals $\sum (SFR_i - SFR)^2$, corresponding to the best value of
and UV luminosities and SFRs in luminous compact galaxies

Table 4

| Subsample       | N  | σ  | $C_2 \times 10^p(F)$ | $C_3 \times 10^{22}(F)$ | $C_4 \times 10^{18}(F)$ | $C_6 \times 10^8(F)$ | $\langle [O] \rangle$ |
|-----------------|----|----|----------------------|------------------------|------------------------|----------------------|---------------------|
| a) Regressions with $C_4 \neq 0$ |
| 3.FUV,regular   | 213| 4.7| 13.6±0.9(231)        | -27.9±3.1(46)          | 30.9±10.5(8.6)         | -7.0±1.7(16)         | 8.05                |
| 4.FUV,irregular | 418| 4.4| 10.2±0.5(375)        | -20.7±2.7(101)         | -3.4±3.5(1.0)          | -3.9±1.0(16)         | 8.13                |
| 5.NUV,regular   | 233| 5.5| 16.0±1.0(246)        | -30.2±4.7(-42)         | 23.8±12.1(3.9)         | -5.8±1.9(9.1)        | 8.05                |
| 6.NUV,irregular | 435| 7.3| 17.8±0.9(405)        | -39.1±4.3(83)          | 12.9±5.6(3.3)          | -12.0±1.6(57)        | 8.13                |
| b) Regressions with $C_4 = 0$ |
| 3.FUV,regular   | 213| 4.7| 13.6±0.9(231)        | -26.7±3.8(50)          | 0                      | -4.9±1.6(9.2)        | 8.05                |
| 4.FUV,irregular | 418| 4.4| 10.2±0.5(378)        | -22.3±2.2(101)         | 0                      | -3.8±0.9(16)         | 8.13                |
| 5.NUV,regular   | 233| 5.5| 16.1±1.0(248)        | -26.2±4.2(38)          | 0                      | -4.2±1.7(5.7)        | 8.05                |
| 6.NUV,irregular | 435| 7.3| 17.3±0.9(403)        | -33.3±3.6(88)         | 0                      | -12.2±1.6(59)        | 8.13                |
| 7.FUV,all       | 631| 4.8| 11.5±0.5(575)        | -25.2±2.0(157)        | 0                      | -4.8±0.9(31)         | 8.10                |
| 8.NUV,all       | 668| 6.8| 17.1±0.7(647)        | -31.6±2.8(130)        | 0                      | -9.7±1.2(65)         | 8.10                |

Table 5

| Subsample       | N  | σ  | $p$, Myr$^{-1}$ | $C_5 \times 10^7(F)$ | $C_6 \times 10^8(F)$ | $\langle [O] \rangle$ |
|-----------------|----|----|-----------------|----------------------|----------------------|---------------------|
| a) Regressions with $p = 0.75$ Myr$^{-1}$ |
| 1.H$\alpha$, regular | 276| 3.4| 0.75            | 2.10±0.04(2752)      | -4.8±1.0(21)         | 8.05                |
| 2.H$\alpha$, irregular | 519| 3.8| 0.75            | 1.98±0.02(7156)      | -3.4±0.7(27)         | 8.13                |
| b) Regressions with the optimal $p$ |
| 1.H$\alpha$, regular | 276| 3.3| 0.66            | 1.95±0.04(2913)      | -4.6±1.0(21)         | 8.05                |
| 2.H$\alpha$, irregular | 519| 3.6| 0.65            | 1.82±0.02(7849)      | -3.2±0.6(26)         | 8.13                |
| 9.H$\alpha$, all   | 795| 3.5| 0.65            | 1.85±0.02(10851)     | -3.6±0.5(46)         | 8.10                |
| 7.FUV, all         | 631| 4.7| 0.42            | 1.11±0.02(2771)      | -5.1±0.8(39)         | 8.10                |
| 8.NUV, all         | 668| 6.7| 0.32            | 1.60±0.03(3925)      | -10.1±1.1(79)        | 8.10                |
| c) Regressions with the optimal $p$ and alternative correction for extinction |
| 7.FUV, all         | 631| 4.7| 0.43            | 1.12±0.02(2799)      | -5.2±0.8(41)         | 8.10                |
| 8.NUV, all         | 668| 6.7| 0.33            | 1.63±0.03(3981)      | -10.3±1.1(83)        | 8.10                |

$T_0$, is rather shallow. Therefore, we can adopt a single value $T_0 = 3.2$ Myr for all subsamples.

In Table 4 (case (b)) we show the final values of the parameters for the subsamples No. 1, 2, 7, 8 and 9 in the form according to Eqs. 9 and 5.

One can see that the approximation Eq. 5 is much better than Eq. 10 for the FUV band and is slightly better for the NUV band. Moreover, the use of Eq. 5 for $f(T)$ in Eq. 3 is more preferable not only because of the decrease of the RMS standard deviation $\sigma$, but also by the same dependence on $T$ as that in the case of H$\alpha$ radiation. Starting from $T_0$, the fading half-times of the H$\alpha$, FUV and NUV emission are 1.1 Myr, 1.6 Myr and 2.1 Myr, respectively.

It is noted in Sect. 4 that for the reddening correction of galaxy fluxes we use $E(B-V)_{\text{SDSS}}$ derived from the hydrogen Balmer decrement. Alternatively, we also consider reddening corrections, adopting $E(B-V)_{\text{SDSS}}$ if $E(B-V)_{\text{SDSS}} > E(B-V)_{\text{NED}}$ (for ~90% of the sample) and $E(B-V)_{\text{NED}}$ if $E(B-V)_{\text{SDSS}} < E(B-V)_{\text{NED}}$ (~10% of the sample). The coefficients in this case are shown in Table 5 (case (c)). The comparison of case (b) and case (c) coefficients shows that differences are very small, indicating that both approaches can equally be used.

5 Star formation rates

We already noted in Section 4 that there are different indicators of star formation in a wide range of wavelengths from UV to radio and different calibrations to quantify it. As it is mentioned in numerous papers, each SFR indicator possesses its own strengths and disadvantages. Recently, the hybrid SFR indices were proposed, which are based on the combination of the ultraviolet and infrared tracers, the H$\alpha$ and the infrared or radio continuum tracers, the [O II] $\lambda3727$ \AA forbidden-line doublet and the infrared or radio continuum tracers. Studies of star formation rates for differ-
ent samples of galaxies with different level of star formation activity and with different SF tracers were carried out in many papers (see, e.g. Boquien et al. 2009; Calzetti et al. 2010; Gilbank et al. 2010; Hopkins et al. 2002; Iglesias-Paramo et al. 2006; Izotova & Parnovsky 2006; Kennicutt 1998; Kennicutt et al. 2009; Kewley et al. 2009; Lee et al. 2009; Li et al. 2010; Moustakas et al. 2006; Overzier et al. 2009; Sargsyan & Weedman 2009; Schmitt et al. 2006).

In the present paper, the galaxy luminosities in the Hα emission line and in the UV non-ionising continuum are used to obtain SFRs (Eq. 1). The Hα emission in the star-forming galaxies is produced by the gas ionised by the most massive short-lived hot O-stars with masses \( \gtrsim 17 M_\odot \) and traces the star formation over the period of a few Myr, corresponding to the lifetime of these stars. The non-ionising UV emission is produced by stars in a wider range of masses and therefore can in principle be used as a SFR tracer on a time scale of up to 100 Myr. However, in the case of strongly star-forming LCGs, similar trends in Figs. 2 and 3 imply that Hα, FUV and NUV emission in LCGs are produced by the same young stellar populations. This conclusion is supported by the fact that instantaneous burst with the age of 6 Myr emits \( \sim 4 \) times and \( \sim 3 \) times less radiation in the FUV and NUV ranges, respectively, as compared to that in the burst with the age of 3 Myr [Leitherer et al. 1999]. Similar difference is seen in Fig. 5. Calculating SFRs from Eq. 1 we actually use the galaxy luminosities observed at a certain current moment. However, in star-bursting galaxies, the observed Hα and UV-luminosities depend on the burst age and may vary on a time scale of several Myr. This effect is most pronounced for the Hα luminosity: it is constant over first \( \sim 3 \) Myr of a starburst and then quickly declines with time. To take into account the temporal luminosity evolution we introduce the initial value of the Hα luminosity \( L_0(\text{H} \alpha) \equiv L(\text{H} \alpha)(T = 0) \) after the onset of star formation and calculate the value of \( \text{SFR}_0(\text{H} \alpha) = k \times L_0(\text{H} \alpha) \).

Similarly, we also introduce the initial luminosities \( L_0(\text{FUV}) \) and \( L_0(\text{NUV}) \) in the FUV and NUV ranges and the corresponding values \( \text{SFR}_0(\text{FUV}) \) and \( \text{SFR}_0(\text{NUV}) \) according to Eq. 1. Hereafter we consider the temporal evolution in UV ranges in the form of Eq. 5. To distinguish the functions \( f(T) \) for the Hα line and the FUV and NUV ranges we will use the corresponding subscripts. These functions differ only in the terms of the coefficient \( p \) values, which are presented in the Table 5 case (b). As an illustrative example, we will demonstrate now the certain advantage of using \( \text{SFR}_0(\text{H} \alpha) \) in comparison with \( \text{SFR}(\text{H} \alpha) \).

We have an ample sample of the galaxies with known Hα and FUV luminosities. First, we derive SFRs from the observed luminosities. We show in Figure 5 the relation between \( \text{SFR}(\text{FUV}) \) and \( \text{SFR}(\text{H} \alpha) \) (or equivalently \( L(\text{FUV}) \) and \( L(\text{H} \alpha) \)). It is seen that both \( \text{SFR}(\text{H} \alpha) \)
and SFR(FUV) are of the same orders. The values of the LSM slopes in the dependences log \( L(FUV) \) on log \( L(H\alpha) \) for subsamples No. 3 and 4 are \( 1.07 \pm 0.05 \) and \( 1.04 \pm 0.04 \) (see dashed lines in Figure 5). However, the values of the slopes in the inverse dependences log \( L(H\alpha) \) on log \( L(FUV) \) are much smaller than unity, \( 0.66 \pm 0.03 \) and \( 0.72 \pm 0.03 \) for subsamples No. 3 and 4, respectively. These values would correspond to the lines with the slopes 1/0.66 = 1.51 and 1/0.72 = 1.40 in Figure 5. The differences in the slopes of the direct and inverse dependences are likely due to the Malmquist bias caused by our selection of only galaxies with high \( L(H\beta) \geq 3 \times 10^{40} \) erg s\(^{-1}\).

We reduce \( Ls \) and SFRs to a zero age of a starburst according to

\[
L_0 = L/f(T), \quad \text{SFR}_0 = \text{SFR}/f(T)
\]

with \( f(T) \) for \( H\alpha \) emission line and \( f_{FUV}(T) \) for FUV radiation. Adopting the values of \( p \) from Table 5 case b), we obtain the distribution of galaxies shown in Figure 6. The LSM gives the slopes 1.04 ± 0.04 and 0.95±0.03 for “regular” and “irregular” galaxies respectively, implying that the initial galaxy FUV luminosity \( L_0(FUV) \) is proportional to the initial \( H\alpha \) luminosity \( L_0(H\alpha) \). Slopes of the inverse linear dependences log SFR\(_0(H\alpha)\) on log SFR\(_0(FUV)\) for the same subsamples are \( 0.76 \pm 0.03 \) and \( 0.85 \pm 0.03 \). These values correspond to the lines with the slopes 1/0.76 = 1.31 and 1/0.85 = 1.18 in Figure 6. Thus, though Malmquist bias is also present for the data reduced to the zero starburst age, its effect is much smaller because of smaller differences between the slopes of the direct log SFR\(_0(FUV)\) - log SFR\(_0(H\alpha)\) and inverse log SFR\(_0(H\alpha)\) - log SFR\(_0(FUV)\) dependences. We also note that the data point scatter in Figure 6 is slightly smaller than that in Figure 5.

However, there is a downward shift of the data points relative to the line of equal SFRs in Figure 6 indicating that SFRs obtained from different indicators are proportional, but not equal.

Izotov et al. (2011) derived a single value of reddening \( E(B - V) \) for both the gaseous and stellar emission assuming uniform distribution of dust. However, dust in galaxies is distributed non-uniformly. E.g. Calzetti et al. (1994) and Charlot & Fall (2000) suggested that young massive stars responsible for the \( H\alpha \) emission are located in more dusty regions as compared to the stars which produce non-ionising UV radiation, including FUV and NUV ranges. In particular, Calzetti et al. (1994) assumed that non-ionising UV radiation is produced by older stars which were formed in regions different from those where most massive young stars are present.

Could the non-uniform distribution of dust explain the downward shift in Fig. 6? Apparently, not. Assuming that \( E(B - V) \) for FUV and NUV ranges is smaller we obtain lower FUV and NUV luminosities. Therefore, the downward shift would be larger. Furthermore, as it was already noted above, similar trends in Figs. 2 and 6 imply that \( H\alpha \), FUV and NUV emission in LCGs are produced by the same young stellar populations, contrary to assumption by Calzetti et al. (1994).

In order to equalise the values of SFR\(_0(H\alpha)\) and SFR\(_0(FUV)\) the coefficients \( k \) in Eq. (11) should be changed from their nominal values. We find that the mean ratios of SFR\(_0(H\alpha)/SFR_0(FUV)\) and SFR\(_0(H\alpha)/SFR_0(NUV)\) are equal to 1.9 and 1.5, respectively. More precisely, we find that 10\[\log(SFR_0(NUV)/SFR_0(H\alpha))\] = 0.53, 10\[\log(SFR_0(FUV)/SFR_0(H\alpha))\] = 0.69.

Using these average ratios we obtain statistical relations

\[
L_0(FUV) = 3.0 \times 10^{-14} \times L_0(H\alpha), \quad L_0(NUV) = 3.9 \times 10^{-14} \times L_0(H\alpha),
\]

(12)

\[
L_0(NUV) = 1.3 \times L_0(FUV).
\]

We adopt the factor \( k^* = 1.4 \times 10^{-28} \times \gamma \) in Eq. (11) for the NUV range and derive the values of modified factors \( k^* = 5.3 \times 10^{-22} \times \gamma \) for the \( H\alpha \) emission line and \( k^* = 1.8 \times 10^{-28} \times \gamma \) for the FUV range. These values
correspond to the rough equality of the SFR\(_0\) obtained from the initial H\(_\alpha\), FUV and NUV luminosities. The multiplier \(\gamma\) can be used for overall tuning of the set of factors. It is equal to \(\sim 1\), if the modified coefficient \(k^*(\text{NUV})\) is set to its nominal value \(k(\text{NUV})\) by Kennicutt (1998). On the other hand, if \(k^*(\text{H}\alpha)\) is set to its nominal value \(k(\text{H}\alpha)\) by Kennicutt (1998), then \(\gamma \sim 1.5\). Thus, we obtain estimations of SFR\(_0\)

\[
\text{SFR}_0 = 5.4 \times 10^{-42} \times \gamma \times L(\text{H} \alpha)/f_{\text{H} \alpha}(T) = 1.8 \times 10^{-28} \times \gamma \times L(\text{FUV})/f_{\text{FUV}}(T) = 1.4 \times 10^{-28} \times \gamma \times L(\text{NUV})/f_{\text{NUV}}(T),
\]

where \(L(\text{H} \alpha)\), \(L(\text{UV})\) and SFR are measured in erg s\(^{-1}\), erg s\(^{-1}\) Hz\(^{-1}\) and \(M_\odot\) yr\(^{-1}\), respectively. The relations in Eq. 13 give the approximately equal SFR\(_0(\text{H}\alpha)\), SFR\(_0(\text{FUV})\) and SFR\(_0(\text{NUV})\) for LCGs from our sample. If the alternative correction for extinction is used, we obtain very similar results. Only one coefficient changes and the first row in Eq. 13 get the form SFR\(_0 = 5.3 \times 10^{-42} \times \gamma \times L(\text{H} \alpha)/f_{\text{H} \alpha}(T)\).

What value of the parameter \(\gamma\) is preferable? We can measure the flux from galaxies in some wavelength ranges but we cannot directly measure their SFRs. These values can be estimated using different indicators of star formation. The values of the coefficients \(k\) in Eq. 1 for different wavelength ranges are obtained by modeling and therefore dependant from the parameters and assumptions in these models. Thus they can vary in some intervals. We use the certain values of \(k\) for the H\(_\alpha\) line and the UV range. The values SFR\(_0(\text{H}\alpha)\) and SFR\(_0(\text{FUV})\) are in general proportional, but not equal, as they must be. Thus we have to use some agreed set of the coefficients \(k\) for different ranges which matches various estimations of SFR\(_0\). We obtain the agreement condition for our sample in Eq. 12. There is interval of the parameter \(\gamma\) in which all coefficients \(k\) agree with values obtained from modeling. The increase of the quality of modeling will lead to fine-tuning of the value of \(\gamma\). Unfortunately if we use the values of the coefficients in Eq. 1 for different wavelength ranges we get some discrepancy in SFRs obtained. This means that the models used to obtain these values have to be improved. In particular it would be useful to search out the ratio of initial values of the luminosities in different wavelength ranges to SFR after the onset of star formation.

Lee et al. (2009) studied the consistency between the SFRs derived from the FUV continuum and H\(_\alpha\) emission for a sample of the dwarf star-forming galaxies. Particularly, authors discuss the dependence of the number ratio of ionising to non-ionising photons in the radiation of dwarf galaxies on its metallicity. We investigated the dependence of both \(L(\text{H} \alpha)/L(\text{FUV})\) and \(L_0(\text{H} \alpha)/L_0(\text{FUV})\) on \([\text{O}]\) and do not find any statistically significant trend. All values of Fisher coefficients do not exceed \(F = 3.5\). However, we note that the rather small range of \([\text{O}]\) for the galaxies from our sample makes it difficult to study this dependence.

Using Eq. 1 we derive SFRs and obtain the distributions of SFR\(_0(\text{H}\alpha)\), SFR\(_0(\text{FUV})\), SFR\(_0(\text{NUV})\) as well as SFR\(_0(\text{H}\alpha)\), SFR\(_0(\text{FUV})\) and SFR\(_0(\text{NUV})\). SFRs derived from the luminosities in the H\(_\alpha\) emission line, FUV and NUV continuum vary in the wide ranges \(0.8 \div 77 M_\odot\) yr\(^{-1}\), \(0.18 \div 86 M_\odot\) yr\(^{-1}\) and \(0.24 \div 113 M_\odot\) yr\(^{-1}\), respectively. The corresponding median values of SFRs are \(6.7 M_\odot\) yr\(^{-1}\), \(3.8 M_\odot\) yr\(^{-1}\) and \(5.2 M_\odot\) yr\(^{-1}\).

Star formation rates SFRs derived from the H\(_\alpha\), FUV and NUV luminosities are in better mutual agreement if Eq. 12 is used instead of Eq. 1. We derive the median values of \(5.8 \times \gamma \times M_\odot\) yr\(^{-1}\) for SFR\(_0(\text{H}\alpha)\), \(6.6 \times \gamma \times M_\odot\) yr\(^{-1}\) for SFR\(_0(\text{FUV})\) and \(6.5 \times \gamma \times M_\odot\) yr\(^{-1}\) for SFR\(_0(\text{NUV})\).

We already mentioned in Section 4 that in general Eq. 1 for SFR can be applied for the continuous star formation during certain time interval \(\Delta t\). Formally, for strongly star-bursting galaxies, we may estimate \(\Delta t\) as well, assuming the continuous star formation with the constant SFR and adopting nominal values for the coefficient \(k\). Then, it is expressed as \(\Delta t = 1/C_5\) with \(C_5\) from Table 5 and attains the values in the range \(5.1 \div 8.9\) Myr for different samples of case (b). The histogram for the H\(_\alpha\) emission line luminosity \(L(\text{H}\alpha)\) is shown in Figure 7. The standard way to study the luminosity function is its approximation by the Schechter function (Schechter 1976) in the form

\[
\psi(L)\,dL = \text{const}(L/L^*)^\alpha \exp(-L/L^*)\,d(L/L^*)
\]

where \(\psi\) is the number of galaxies per unit volume in the luminosity interval from \(L\) to \(L + dL\). Assuming that the volume \(V\) of the galaxies with luminosity \(L\) entering the sample \(V \propto L^{3/2}\) and using the maximum likelihood method we obtain the values \(\alpha = -1.04\) and \(L^* = 8.5 \times 10^{41}\) erg s\(^{-1}\). This value of \(L^*\) corresponds to SFR\(_0\) \(= 6.7 M_\odot\) yr\(^{-1}\) according to Eq. 1. The value \(\alpha = -1.04\) is in agreement with the value obtained from 147,986 galaxy redshifts and fluxes from the SDSS (Blanton et al. 2003).
The distribution of galaxies calculated with the Schechter function in a larger extent compared to the distribution of $L(H\alpha)$ because of the larger luminosities. The distributions of the FUV and NUV luminosities are similar to that in Figure 7 after the luminosity scaling in accordance with the difference of the median values.

### 6 Summary

We analyse the properties of $H\alpha$ and UV radiation for the sample of about 800 luminous compact galaxies (LCGs) selected by Izotov et al. (2011) from the Data Release 7 (DR7) of the Sloan Digital Sky Survey (SDSS). These low-metallicity galaxies are characterised by an active star formation with the star formation rate SFR($H\alpha$) in the range $\sim 1 - 80 M_\odot$ yr$^{-1}$ and can be considered as local counterparts of the high-redshift ($z > 2$) star-forming Lyman-break galaxies (LBGs) and Ly-$\alpha$ emission-line galaxies (LAEs). We use the optical SDSS spectroscopic data for LCGs to derive the luminosity in the $H\alpha$ emission line and SFR($H\alpha$). Galaxy Evolution Explorer (GALEX) UV fluxes are used for obtaining luminosities and SFRs in the far-UV (FUV, $\lambda_{\text{eff}} = 1528$ Å) and in the near-UV (NUV, $\lambda_{\text{eff}} = 2271$ Å) ranges. These data are supplemented by other global LCG characteristics derived by Izotov et al. (2011) from their SDSS spectra: chemical element abundances of the interstellar medium, masses $m$ and ages $T$ of young starbursts. Our main results are as follows:

1. We study the extinction in a sample of LCGs. It is found that LCGs are rather unobscured galaxies with a mean reddening about of $E(B-V) = 0.136$. The mean internal reddening in the sample is 0.106. For subsamples of "regular" galaxies with round shape and "irregular" ones having shape with some sign of disturbed morphology we obtain internal reddening of 0.081 and 0.120. The difference of internal reddening for subsamples is statistically significant value.

2. We find that the ratio $L(H\alpha)/m$ in starbursts with ages $T < 3.2$ Myr is constant implying that $H\alpha$ luminosity in young starbursts is proportional to the mass of the young stellar population. At later starburst ages $T \geq 3.2$ Myr, the ratio $L(H\alpha)/m$ is declined exponentially with $T$. This temporal dependence of the $L(H\alpha)/m$ ratio is in general agreement with that from the population synthesis models by Scherer & Vacca (1998) which predict the decrease of $L(H\alpha)$ after $\sim 3$ Myr, the lifetime of the most massive stars.

The dependences of the luminosities per unit mass of the young stellar population $L(H\alpha)/m$, $L(\text{FUV})/m$ and $L(\text{NUV})/m$ on $T$ (Eqs. 10) are similar implying that $H\alpha$, FUV and NUV radiation is produced by the same young populations. However, the dependences of $L(\text{FUV})/m$ and $L(\text{NUV})/m$ on $T$ are weaker as compared to $L(H\alpha)/m$. Starting from $T_0 \sim 3.2$ Myr, the half-times of the $H\alpha$, FUV and NUV luminosities decline are 1.1 Myr, 1.6 Myr and 2.1 Myr, respectively. The ratios $L(H\alpha)/L(\text{FUV})$ and $L(H\alpha)/L(\text{NUV})$ also start to decrease after $\sim 3.2$ Myr. Thus, these ratios can be used for estimation of the starburst age $T$.

With this value of $T$ we can estimate $m$ from $L(H\alpha)$ in young starbursts without invoking modelling of spectral energy distribution (SED). For that we introduce a function $f_{H\alpha}(T)$ which takes into account the variation of $L(H\alpha)/m$ with $T$. Then $m \sim L(H\alpha)/f_{H\alpha}(T)$.

3. The main impact of galaxy metallicity on its luminosity is the indirect one through the variation of
the mass of the young stellar population $m$. Dividing the sample of galaxies into subsamples with high and low metallicities, we obtain that the mean luminosity will be greater for the subsample with high metallicity due to the considerable increase of the mean value of $m$. On the other hand, the direct impact of metallicity has the opposite sign. The ratio $L/m$ slightly decreases with increasing of the galaxy metallicity if the starburst age is constant. Thus, the galaxy luminosity decreases with increasing metallicity at fixed values of $m$ and the starburst age $T$. This direct impact is weaker than the indirect one, but it is statistically significant.

4. Luminosities in H$\alpha$ and UV decrease rapidly after the starburst age of $\sim 3.2$ Myr. We take into account this temporal evolution and introduce time-independent characteristics of the star formation activity, namely the initial luminosities $L_0$ at the starburst age $T = 0$. The initial luminosities in the H$\alpha$ emission line, FUV and NUV ranges can be obtained from the current luminosities and the starburst age $T$ from Eq. [11]. We find that $L_0$(FUV) and $L_0$(NUV) are proportional to $L_0$(H$\alpha$) over a large range of luminosities. We can obtain the approximative equality of the values $SFR_0$ derived from the initial H$\alpha$, FUV and NUV luminosities by tuning the factor $k$ in Eq [1]. The set of factors $k$ for H$\alpha$ emission line and FUV and NUV ranges providing such equality for the sample of LCGs is used in Eq. [13].

5. We find that SFRs derived from the extinction-corrected H$\alpha$, FUV and NUV luminosities vary in the wide ranges of $0.8 \pm 0.77 \ M_\odot \ yr^{-1}$, $0.18 \pm 0.86 \ M_\odot \ yr^{-1}$ and $0.24 \pm 1.13 \ M_\odot \ yr^{-1}$, respectively. The corresponding median values of SFRs are $6.7 \ M_\odot \ yr^{-1}$, $3.8 \ M_\odot \ yr^{-1}$ and $5.2 \ M_\odot \ yr^{-1}$. The median values of initial SFRs are $SFR_0$(H$\alpha$)$=8.7 \ M_\odot \ yr^{-1}$, $SFR_0$(FUV)$=5.1 \ M_\odot \ yr^{-1}$ and $SFR_0$(NUV)$=6.5 \ M_\odot \ yr^{-1}$. In all cases the nominal coefficients $k$(H$\alpha$), $k$(FUV) and $k$(NUV) by Kennicutt ([1998]) are adopted. The corresponding equalised median SFR$0$ values in accordance with Eq. [13] are equal to $5.8 \times \gamma \times M_\odot \ yr^{-1}$ for $SFR_0$(H$\alpha$), $6.6 \times \gamma \times M_\odot \ yr^{-1}$ for $SFR_0$(FUV), and $6.5 \times \gamma \times M_\odot \ yr^{-1}$ for $SFR_0$(NUV).

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