A Comparison of SFR Calibrators for Star-Forming Galaxies from $z = 0$ to $z = 0.9$

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Based on the VIMOS Public Extragalactic Redshift Survey (VIPERS, $z > 0.5$) and on the *GALEX*-SDSS-WISE Legacy Catalog (GSWLC, $z < 0.3$), we constrained a set of Star Formation Rate (SFR) calibrators able to work from $z = 0$ to $z = 0.9$. Such calibrations are crucial to study the formation and evolution of galaxies over cosmic time. We used as estimators photometric bands from ultraviolet (UV) to mid-infrared (mid-IR) and the spectral lines Hβ, [O II]λ3727 and [O III]λ5007. Because the Hα spectral line is shifted out of the optical window above $z \sim 0.5$, we assume a reference SFR obtained from the spectral energy distribution reconstructed with CIGALE.

1 Introduction

The formation and evolution of galaxies is a complex process guided by the build-up of stellar mass (M_*) through the formation of stars. The measurement of SFR over a large range of redshifts is crucial to have a broad and accurate understanding of the Universe. Because different surveys are characterized by different sets of observed wavelengths and/or spectroscopic features, it is necessary to be able to estimate the SFR in a consistent way from different bands.

For instance, the Hβ line can be used as an SFR tracer if we assume that it can be related to Hα, however the former suffers from higher dust attenuation. Another spectral line commonly used is the [O II]λ3727 line as its strength is generally higher compared to Hβ. However, this line is less related to the emission of photons from high-mass stars, suffers from high attenuation and can strongly depend on the ionization parameter and metallicity. The [O III]λ5007 gives poor estimation due do its strong dependence on metallicity and ionization parameter. Nonetheless, proper SFR calibration will become necessary for future observations with the James Webb Space Telescope (JWST). The UV continuum is a tracer of high-mass stars, sensitive to short timescales (∼100 Myr) but suffers from high dust attenuation and its emission shows a dependence on metallicity. The u-band is less affected by dust attenuation but can be contaminated by old stellar population emission, which becomes more and more important as the redshift decreases. Contrary to the

above-mentioned bands, u-band measurements can be easily obtained from ground-based telescopes, making it a potentially powerful SFR tracer. At 8 μm, the flux is dominated by the emission of polycyclic aromatic hydrocarbons (PAHs) which are found around H II regions, roughly tracing the SFR. The flux at $\sim$20 μm is often used as an SFR tracer since it provides a robust measurement of the total infrared luminosity ($L_{\rm TIR}$, 8–1000 μm).

Beyond $z \sim 0.5$, the Hα line widely-used as an SFR tracer is redshifted out of the optical window. In order to calibrate the continuum bands and spectral lines, we reconstructed the spectral energy distribution (SED) of the galaxies with the Code Investigating GALaxy Emission (CIGALE, Boquien et al. 2019). Such reconstruction allowed us to extract fundamental properties of the galaxies such as a reference SFR, to which SFR estimations from the literature will be compared.

2 Methodology

From the VIPERS Public Data Release-2 catalog, we selected star-forming galaxies from the Baldwin, Phillips & Terlevich (BPT) diagram with a well-defined spectroscopic redshift and good line detection, for a total of 3457 galaxies. The CFHTLS data (*ugriz* bands) were cross-matched with *GALEX*, WIRCam-K_s, VIDEO-K_s, WISE, *Spitzer* and *Herschel* data.

We reconstructed the SED of VIPERS galaxies using CIGALE, which employs a Bayesian approach to estimate galaxy properties. We used a delayed Star-Formation History followed by a recent burst, the Bruzual & Charlot (2003) stellar models with nebular emission, Charlot & Fall (2000) dust attenuation and the dust emission templates of Draine et al. (2014). As reported by Brown et al. (2014), WISE-4 fluxes can be overestimated and were considered as upper limits. The mock analysis showed that the physical properties of our sample were derived with a good accuracy. In addition, the flux of the Hβ emission line from CIGALE is in agreement with observations, indicating that the applied stellar absorption correction yields proper results.

From the GSWLC catalog, we selected star-forming galaxies from the BPT diagram with a SED characterized by $\chi^2_{\rm red} < 5$, excellent photometric coverage and line measurements from the MPA-JHU catalog. After applying a cut to match the VIPERS M_* range, we ended up with a sample of 91,533 star-forming galaxies.

3 Results and conclusions

The UV emission of galaxies represents an excellent tracer of star formation, but the dust attenuation is particularly significant at such wavelengths and the method used to correct for it has a strong impact on the derived SFR. From the SED fitting, we derived a new calibration between the attenuation in the UV and the UV slope. Associated with the calibrations of Salim et al. (2007), we were able to accurately recover the SFR from the FUV and NUV bands.

The u-band can also be used as an SFR tracer but can be strongly affected by the old stellar population ($\geq$ 100 Myr). We derived this contamination by the old stellar population to the total stellar luminosity ratio and found an average value of 36%. Nonetheless, the non-linear calibration of Hopkins et al. (2003) gives a good estimation of the SFR for VIPERS and GSWLC without having to perform

any decontamination, probably due to the similar contamination between the two samples. Such decontamination is difficult to perform accurately but should be accounted for to derive a universal calibration based on the young stellar population u-band emission.

Using different calibrations at 8 μm, we observed an underestimation of the SFR for each of them. This discrepancy could come from the difference between VIPERS and galaxies used to calibrate the SFR and from the destruction of Polycyclic Aromatic Hydrocarbons. The 24 μm emission is an excellent SFR tracer and calibrations assuming a proportionality with $L_{24\mu\mathrm{m}}$ work relatively well. However, a better agreement is found when non-linear relations calibrated on entire galaxies are used for the VIPERS and GSWLC samples. On the other hand, the WISE-4 band above $z \sim 0.5$ is found to significantly overestimate L_{TIR} and the SFR for VIPERS galaxies.

A popular method to obtain the SFR without relying on attenuation laws is to use a direct tracer of young high-mass stars and an indirect tracer representing the re-emission by dust in the infrared. Since the old stellar population also heats the dust, we estimated this contamination for VIPERS galaxies from the absorbed luminosity of the young and old stellar population relative to L_{dust} and the relation established by Nersesian et al. (2019) for GSWLC galaxies. We found an average contamination of 11% and 45% for VIPERS and GSWLC, respectively. Using these values in the calibration of Clark et al. (2015), we obtained a good agreement with the CIGALE SFR.

Based on metallicity estimation from the R_{23} parameter and the Zaritsky et al. (1994) calibration, we estimated the SFR from [O II] for galaxies lying on the high-metallicity branch. For VIPERS, the metallicity correction slightly degrades the SFR estimation and a simple correction based on the [O II]/Hα ratio gives better results. We estimated the metallicity using other calibrations but none of them was found to improve significantly the estimation of the SFR. The [O III]λ5007 line is not widely used as an SFR indicator, as only a rough estimation of the SFR can be obtained. [O III] depends more strongly on the [O III]/Hα ratio, hence a metallicity correction cannot be avoided in this case. After such a correction, the scatter between the SFR from CIGALE and Kennicutt (1998) is reduced to 0.26 and 0.2 dex for VIPERS and GSWLC, respectively, compared to 0.3 dex when no correction is applied.

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