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ON THE IMPORTANCE OF USING APPROPRIATE SPECTRAL MODELS TO DERIVE PHYSICAL PROPERTIES OF GALAXIES†

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ABSTRACT

Interpreting ultraviolet-to-infrared (UV-to-IR) observations of galaxies in terms of constraints on physical parameters – such as stellar mass (M_*) and star formation rate (SFR) – requires spectral synthesis modelling. We investigate how increasing the level of sophistication of the standard simplifying assumptions of such models can improve estimates of galaxy physical parameters. To achieve this, we compile a sample of 1048 galaxies at redshifts $0.7 < z < 2.8$ with accurate photometry at rest-frame UV to near-IR wavelengths from the 3D-HST Survey. We compare the spectral energy distributions of these galaxies with those from different model spectral libraries to derive estimates of the physical parameters. We find that spectral libraries including sophisticated descriptions of galaxy star formation histories (SFHs) and prescriptions for attenuation by dust and nebular emission provide a much better representation of the observations than 'classical' spectral libraries, in which galaxy SFHs are assumed to be exponentially declining functions of time, associated with a simple prescription for dust attenuation free of nebular emission. As a result, for the galaxies in our sample, M_* derived using classical spectral libraries tends to be systematically overestimated and SFRs systematically underestimated relative to the values derived adopting a more realistic spectral library. We conclude that the sophisticated approach considered here is required to reliably interpret fundamental diagnostics of galaxy evolution.

Key words: galaxies: general – galaxies: fundamental parameters – galaxies: stellar content – galaxies: statistics

1. INTRODUCTION

A main caveat in current statistical studies of galaxies at $z \sim 1$ is that the way in which the physical properties of galaxies, such as stellar mass (M_*) and star formation rate (SFR), are generally derived from multi-wavelength datasets does not reflect recent advances in the sophisticated modelling of galaxy spectral energy distributions (SEDs). For example, spectral analyses often rely on oversimplified modelling of the stellar spectral continuum using simple star formation histories (SFHs), such as exponentially declining τ-models. Some studies have shown that more sophisticated SFH parametrizations provide better agreement with the data (e.g. Pacifici et al. 2013; Behroozi et al. 2013). The inclusion of nebular emission is also important to interpret observed SEDs of galaxies. Elaborate prescriptions have been proposed, based on combinations of stellar population synthesis and photoionization codes. In this paper, we investigate, in a systematic way, how different SED modelling approaches affect the constraints derived for the physical parameters of high-redshift galaxies.

2. DATA

We use version 4.1 of the 3D-HST Survey photometric catalogue for the GOODS-South field covering an area of 171 arcmin^2 (Skelton et al. , 2014). We compile a sample of 1048 galaxies at redshifts $0.7 < z < 2.8$ ($H < 23$) with accurate photometry at rest-frame UV to near-IR wavelengths (U, ACS-F435W, ACS-F606W, ACS-F775W, ACS-F850lp, WFC3-F125W, WFC3-F140W, WFC3-F160W and IRAC 3.6μm).

3. MODELLING APPROACH

We consider three modelling approaches relying on different assumptions: the explored (prior) ranges of star formation and chemical enrichment histories; attenuation by dust; and nebular emission. We build:

†The work presented here is an extract from a paper submitted to the Monthly Notices of the Royal Astronomical Society.

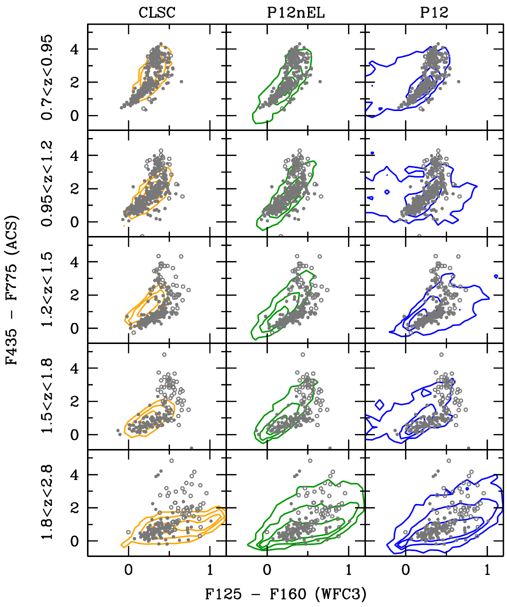

Figure 1. Optical-NIR colour-colour diagrams comparing the 3D-HST sample (grey symbols; open circles mark objects for which error bars are larger than 0.2 mag) with the three model libraries as labeled on top (contours; the three lines mark 50, 16 and 2 per cent of the maximum density).

- A classical spectral library (CLSC) adopting exponentially declining SFHs, fixed stellar metallicities, a two-component dust model with fixed parameters, and no nebular emission;
- A sophisticated spectral library (P12nEL) adopting star formation and chemical enrichment histories from cosmological simulations, a two-component dust model with variable parameters, and no nebular emission;
- The same P12nEL spectral library, but also including the nebular component (P12, Pacifici et al. 2012).

In Figure 1, we compare the observer-frame colours of the galaxies in the sample (grey symbols) with the predictions of the three model spectral libraries (coloured contours). This figure shows that the CLSC spectral library leaves a few observed galaxies with no model counterparts. Thus, SED fits for these galaxies will be biased towards models that lie at the edge of the spectral library. The P12nEL spectral library can cover the bulk of the observations reasonably well, showing the importance of accounting for more realistic ranges of SFHs and dust properties than included in the CLSC spectral library. A few observed galaxies fall outside the contours of the P12nEL model spectral library, presumably because of the contamination of the WFC3-F160W flux by strong Hα emission. The P12 spectral library allows us to cover the entire observed colour-colour space reasonably well.

4. CONSTRAINTS ON PHYSICAL PARAMETERS

We compare the constraints on M_* and SFR derived for all 1048 galaxies in the sample using the CLSC and P12nEL model spectral libraries to those obtained using the more sophisticated P12 library. We summarise the results in Table 1. The use of simple exponentially declining SFHs (CLSC spectral library) can cause strong biases in both the M_* (~ 0.1 dex) and the SFR (~ -0.6 dex). Not including the emission lines in the broad-band fluxes (P12nEL) does not strongly affect the estimates of M_*, but can induce an overestimation of the SFR (~ 0.1 dex).

Table 1

16, 50 and 84 percentiles of the distributions of the differences between best estimates of M_* and SFR when comparing constraints with different libraries.

	CLSC − P12		
	16th	50th	84th
$\log(M_*/M_\odot)$	0.27	0.08	-0.03
$\log[\psi/(M_\odot \mathrm{yr}^{-1})]$	-0.14	-0.63	-2.23
	P12nEL − P12		
	16th	50th	84th
$\log(M_*/M_\odot)$	0.06	0.00	-0.13
$\log[\psi/(M_\odot \mathrm{yr}^{-1})]$	0.62	0.12	-0.15

5. CONCLUSIONS

The results obtained in this paper reveal the importance of choosing appropriate spectral models to interpret deep galaxy observations. In particular, the biases introduced by the use of classical spectral libraries to derive estimates of M_* and SFR can significantly affect the interpretation of standard diagnostic diagrams of galaxy evolution, such as the galaxy stellar-mass function and the main sequence of star-forming galaxies. In this context, the spectral library developed by Pacifici et al. (2012) offers the possibility of interpreting these and other fundamental diagnostics on the basis of more realistic, and at the same time more versatile models. This is all the more valuable in that the approach can be straightforwardly tailored to the analysis of any combination of photometric and spectroscopic observations of galaxies at any redshift.

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