On the Simultaneous Modelling of Dust and Stellar Populations for Interpretation of Galaxy Properties

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Introduction

- Information on the physical properties of galaxies is encoded within its spectral energy distribution (SED).
- Extracting information from SEDs requires comparison with models, made up of a synthetic stellar population and, when infrared data is used, dust reemission models.
- Dust reprocesses ultraviolet and optical emission from stars, reemitting in infrared (Fig. 1). Dust attenuates shorter-wavelength radiation more.
- Dust models require prescriptions for an interstellar medium (ISM) and a birth cloud component, with the later a denser region of dust found close to newly born stars that is exposed to increased levels of stellar radiation, causing increased attenuation.
- A recent inclusion to stellar population synthesis models is the evolution of multiple interacting stellar (binary) systems, which alters the amount of energy available for reprocessing by dust.
- We investigate the impact of stellar population choice on derived dust parameters, and vice versa.

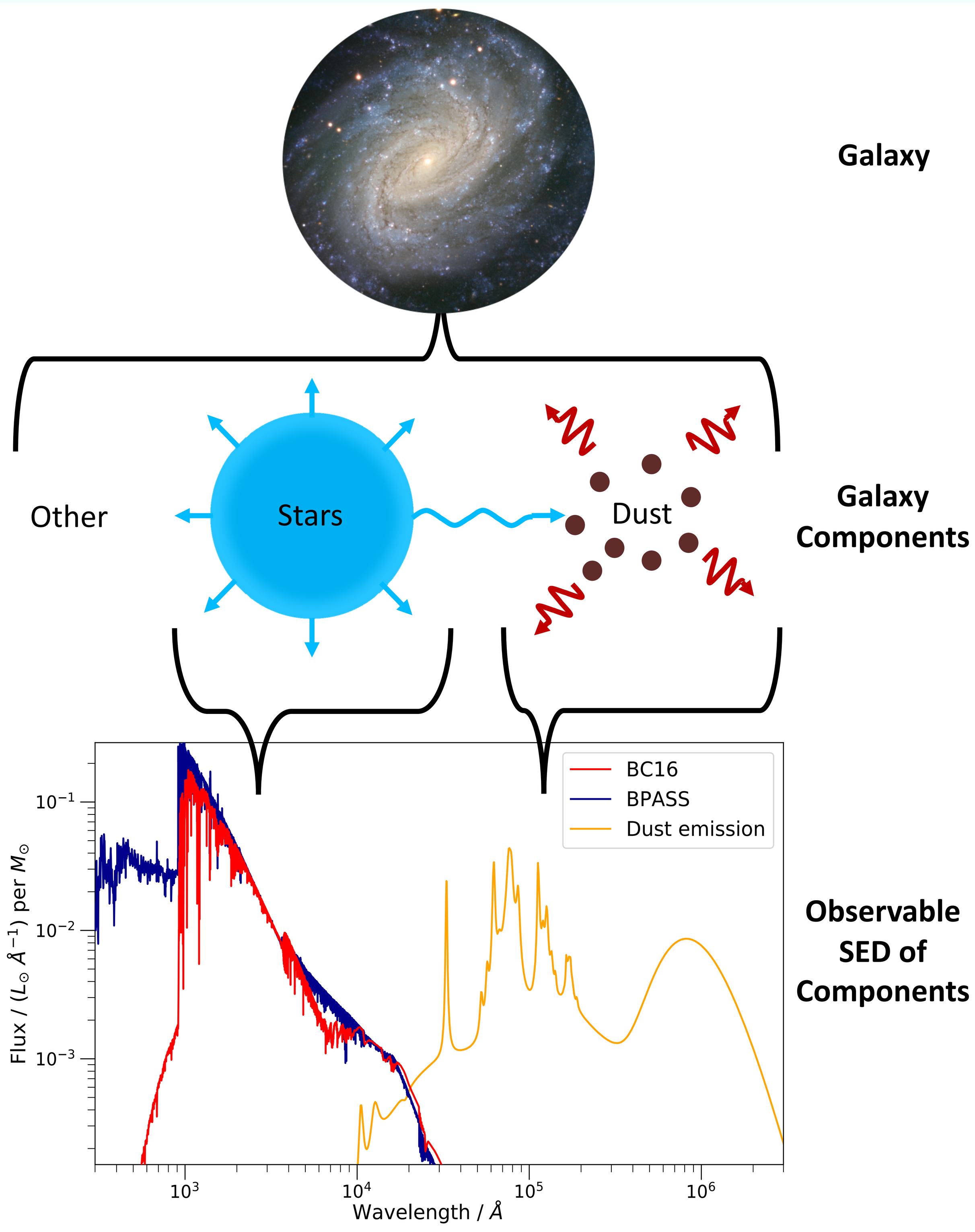

Figure 1. Select components within galaxies with their emission spectrum shown at the bottom. The middle panel shows the dust and stellar components which make up galaxies. Blue arrows are stellar radiation which are absorbed and reemitted by dust, with its radiation shown as red arrows. The plot shows emission from a 10 Myr old stellar population for two stellar templates of BC16 (red) and BPASS (blue) and from a template dust spectrum (orange).

Models

We test combinations of stellar and dust reemission models, a selection of which are listed with their key underlying physics in Tables 1 and 2. Full details are in Jones et al. (2022).

Bruzual & Charlot (2003, updated to the 2016 version BC16)	Binary Population And Spectral Synthesis (BPASS, Eldridge et al. 2017)
Single star evolution tracks	Single and binary evolution tracks
Most UV emission emitted by 5 Myr	Most UV emission emitted by 10 Myr

Table 1. The stellar population synthesis models and their key input physics.

Draine & Li (2007, DL07)	Draine et al. (2021, D20)
One model for all components, with a parameter to describe fraction of dust heated by more intense radiation, U, simulating a birth cloud-like component	Separate models for a birth cloud and ISM component
Three parameters of PAH molecule fraction, minimum starlight intensity, U_{min}, and fraction of stars heated by intensity $U > U_{min}$	Four parameters of two starlight heating intensities (one each for birth cloud and ISM dust), and PAH molecule size and ionization

Table 2. The dust reemission models and their key input physics.

Algorithm

- Models were validated using BAGPIPES (Carnall et al. 2018), a Bayesian fitting code to model ultraviolet (UV) to microwave emission from galaxies.
- Observational sample is taken from COSMOS2015 (Laigle et al. 2016), selecting galaxies with good spectral coverage in the local Universe (z < 0.5).
- Galaxies were stacked via mass and redshift binning to get a 'typical' galaxy SED for each group.
- Models were formed of an old stellar population of fitted age > 0.1 Gyr and a young one of fixed age 5 Myr, using a simple star formation history (SFH) and assuming Solar metallicity stellar models (Z = 0.02).

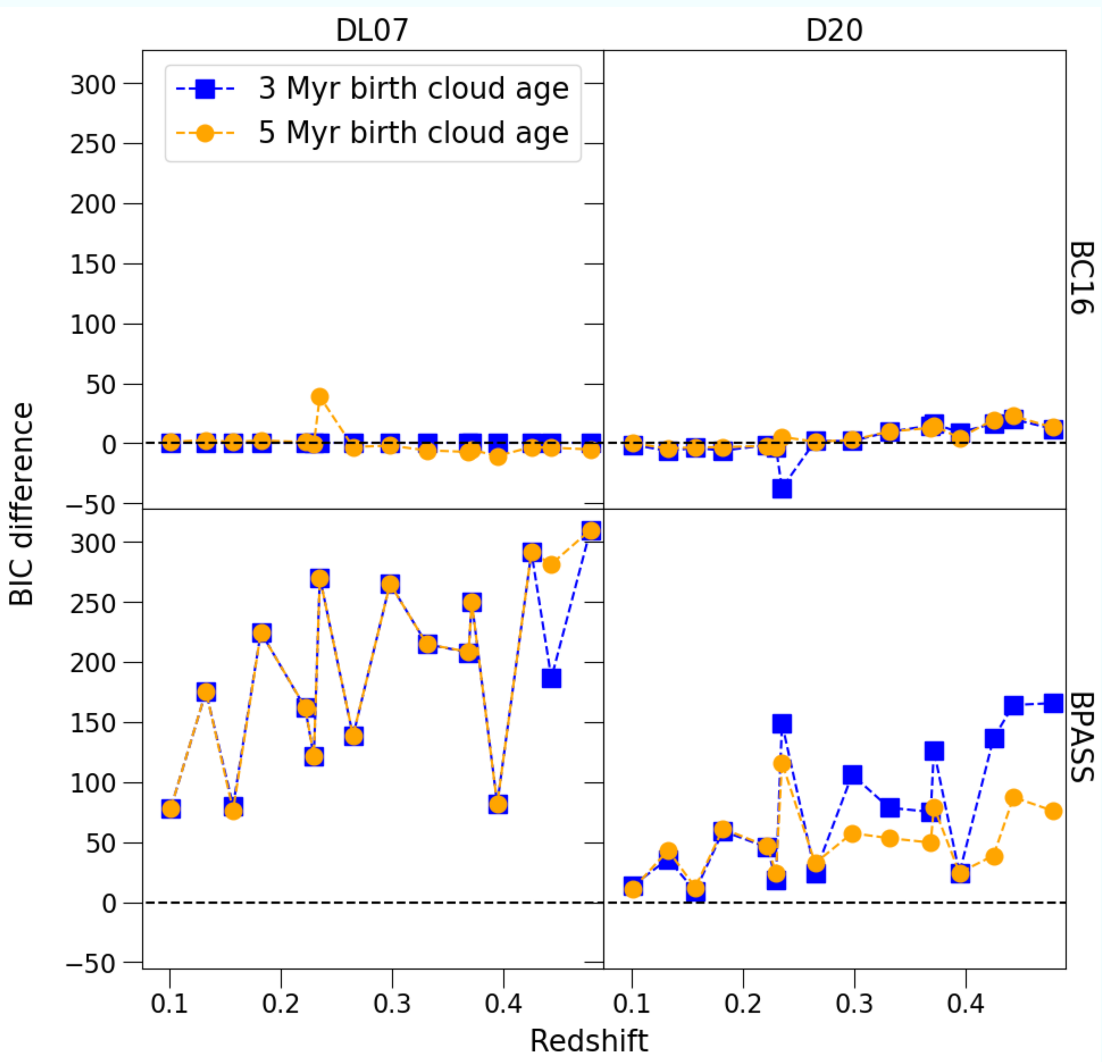

Figure 2. BIC values calculated as difference to BC16 and DL07 with a 3 Myr birth cloud combination. Top and bottom rows show BC16 and BPASS models combined with DL07 and D20 models in the left and right columns. Blue squares and orange circles are for 3 and 5 Myr birth cloud ages. Lower BIC differences indicate the preferred model.

Optimising the star-dust relationship

Fig. 2 shows Bayesian Information Criterion (BIC) values, where lower values identify better fits to observations. BC16 stellar models have similar performance for both dust models while BPASS fits poorer with the DL07 dust model, since this model does not consider an independent birth cloud component.

The BPASS and D20 model combination in Fig. 2 shows an improvement in performance when using a longer birth cloud. A larger range of birth cloud ages is plotted in Fig. 3. This shows the importance of a birth cloud component to get accurate fits. After 5 Myr, most young stellar emission has been attenuated.

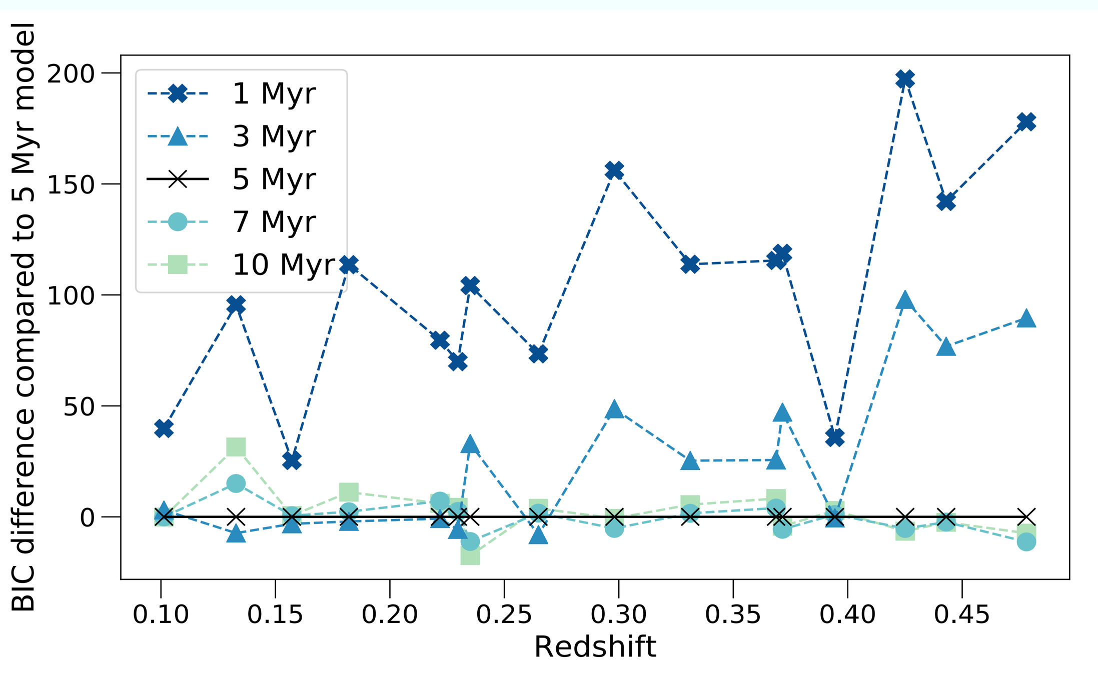

Figure 3. BIC values for BPASS and D20 model combination using a range of birth cloud dispersal ages from 1 to 10 Myr, shown as the difference to the 5 Myr model. Dashed lines are for clarity to indicate trends.

Uncertainty in derived stellar parameters

Variation in the stellar parameter space is shown in Fig. 4.

- BAGPIPES derived ages differ significantly to COSMOS2015 values due to a simpler parametric SFH used in this analysis.
- Mass of galaxies is consistent between fits, but BPASS typically has lower estimates by 0.15 dex than BC16 models due to a lower optical continuum mass-to-light ratio.
- BPASS requires less extinction than BC16, by E(B-V) = 0.064± 0.022, due to a harder ionizing spectrum. Birth cloud models using 5 Myr are lower than the 3 Myr models by E(B-V) = 0.03 as they naturally have increased attenuation.
- Star formation rates (SFR) found using BPASS are lower than BC16 with average offset of 0.31±0.17 dex. This could help reconcile a discrepancy between the local cosmic star formation rate density and stellar mass density at a given redshift.

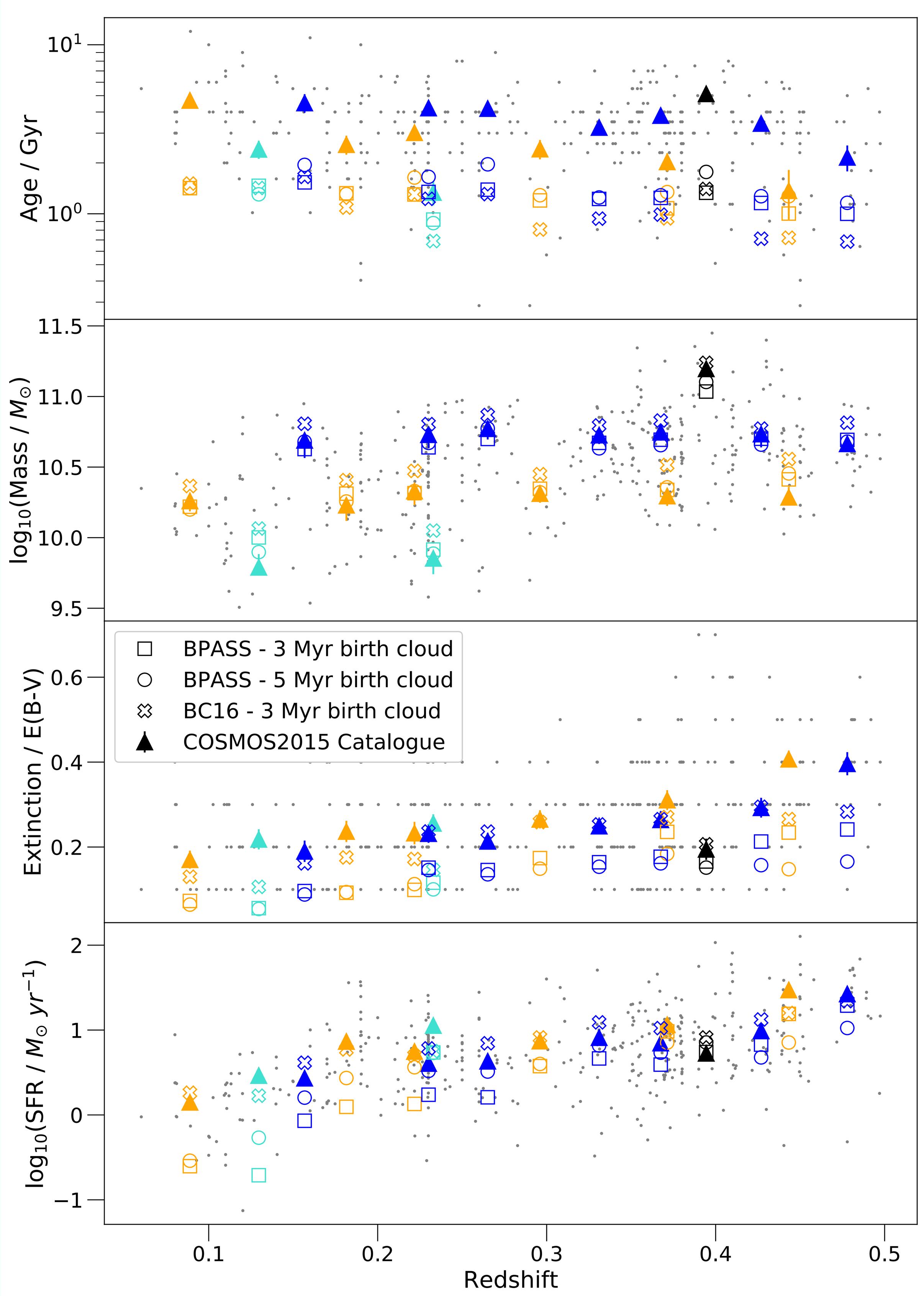

Figure 4. Derived stellar parameters from BAGPIPES. COSMOS2015 derived values are included for individual galaxies as grey dots, and the average value for each sample as filled triangles. Open symbols are BAGPIPES values using D20 dust model with BPASS stellar models represented by squares and circles for 3 and 5 Myr birth cloud ages, while the cross is BC16 for a 3 Myr birth cloud. Colours represent different mass bins, where $\log(M/M_\odot)$ = 9.5-10.0, 10.0-10.5, 10.5-11.0 and 11.0-11.5 bins are in light blue, orange, dark blue and black. Errors are included only on the COSMOS2015 values for clarity.

Conclusions

We have shown that dust emission models need to consider the stellar population synthesis models, and vice versa. We also showed that the derived stellar parameter space is variable on both stellar model, i.e. inclusion of binaries, and dust prescription, i.e. birth cloud age. For further analysis and full results, see Jones et al. (2022, available on request).

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