Quantifying the impact of AGN and nebular emission on stellar population properties with REBETIKO

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Introduction

Star formation and chemical evolution histories of galaxies can be reconstructed from their spectral energy distribution (SED) using spectral population synthesis (SPS). However, the impact of non-stellar light sources on the estimation of the stellar component properties of galaxies is largely unknown with state-of-the-art SPS codes, given that most of these assume that the optical continuum of galaxies is mainly due to stellar emission (e.g. Cappellari & Emsellem 2004; Cid Fernandes et al. 2005; Ocvirk et al. 2006a,b; Koleva et al. 2009). The goal of this project is to quantify the impact of active galactic nucleus (AGN) and nebular emission on the determination of stellar properties of galaxies, such as mass, mean age and mean metallicity, on the basis of a combined application of evolutionary and population synthesis models.

Methodology

Reckoning galaxy Emission By means of Evolutionary Tasks with Input Key Observables (REBETIKO) is an evolutionary code we developed to compute the time and chemical evolution of SEDs of galaxies. The code accounts for the main optical luminosity contributions to the SED of a galaxy, such as a composite stellar population (CSP) and nebular emission (continuum and most prominent optical emission lines assuming Case B recombination) for different commonly used star formation rate (SFR) functions (see Figure 1), in addition to an AGN power-law component.

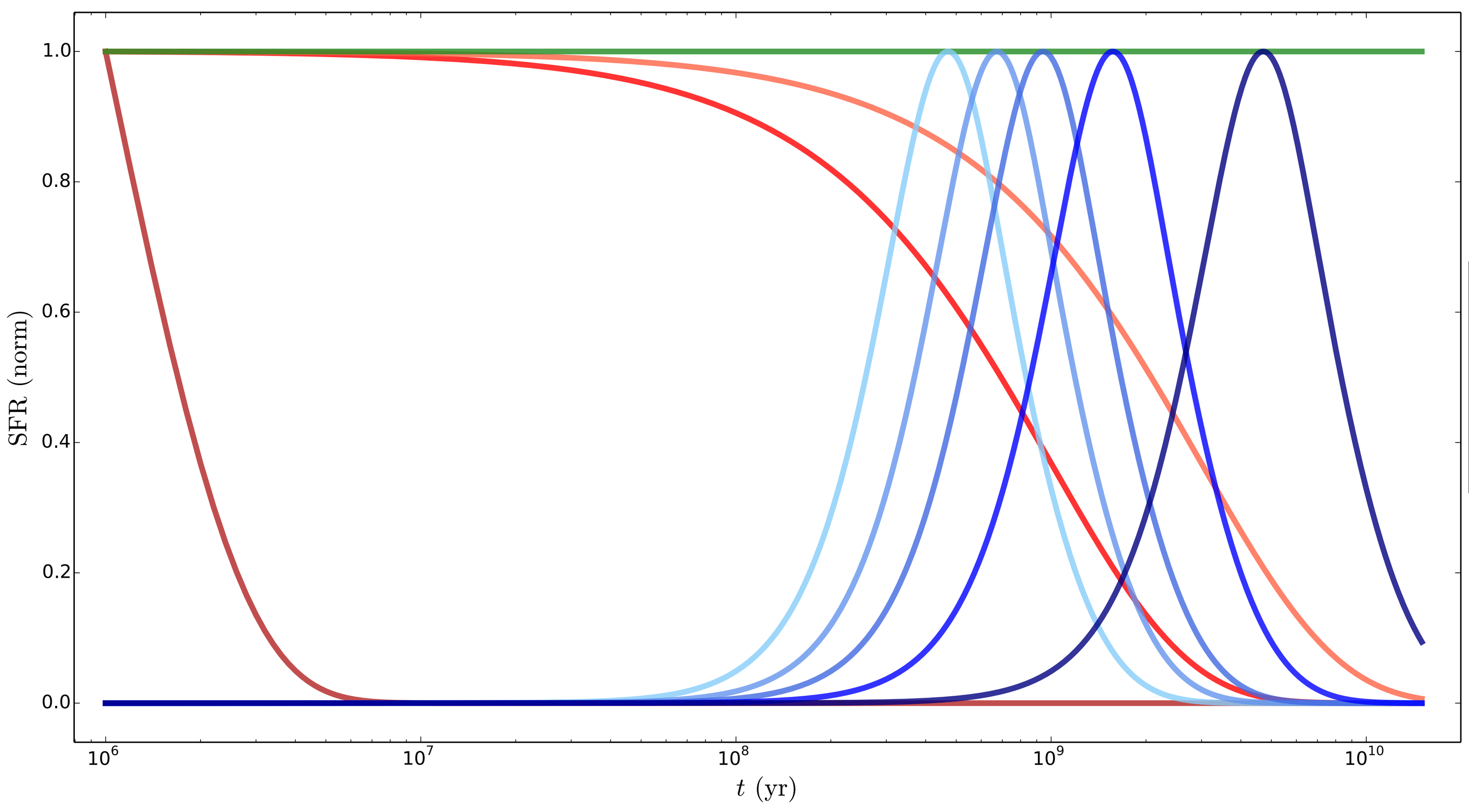

Figure 1 – Star formation histories (SFHs) for various commonly adopted normalized SFRs: exponentially declining SFRs (*red lines*) with an e-folding time scale of 0.01 Gyr (TAU1), 1 Gyr (TAU2) and 3 Gyr (TAU3); continuous SFR (*green line* labeled as CONT) and delayed SFRs (*blue lines*) with t_{down} of 0.1 (DEL1), 0.3 (DEL2), 0.5 (DEL3), 0.7 (DEL4) and 1 (DEL5).

The results presented here are based on SEDs for an instantaneous burst SFR at 716 ages between 1 Myr and 15 Gyr. The SEDs computed with REBETIKO use Bruzual & Charlot (2003) simple stellar population (SSP) models with solar metallicity (see Figure 2 for purely-stellar SEDs) and include nebular emission computed with CLOUDY (Ferland et al. 1998) for Case B recombination and a neutral hydrogen density n_H of 100 cm^{-3}. Moreover, the AGN emission is assumed to be well represented by a power-law defined as $F_\nu \propto \nu^{-\alpha}$ (e.g. Oke, Neugebauer & Becklin 1970; O'Connell 1976; Koski 1978) for α = 0.5, 1, 1.5 and 2 (e.g. Stasińska 1984a,b; Veilleux & Osterbrock 1987) and varying flux fractional contribution at λ_0 = 4020 Å of x_{AGN} = 0.2, 0.4, 0.6 and 0.8.

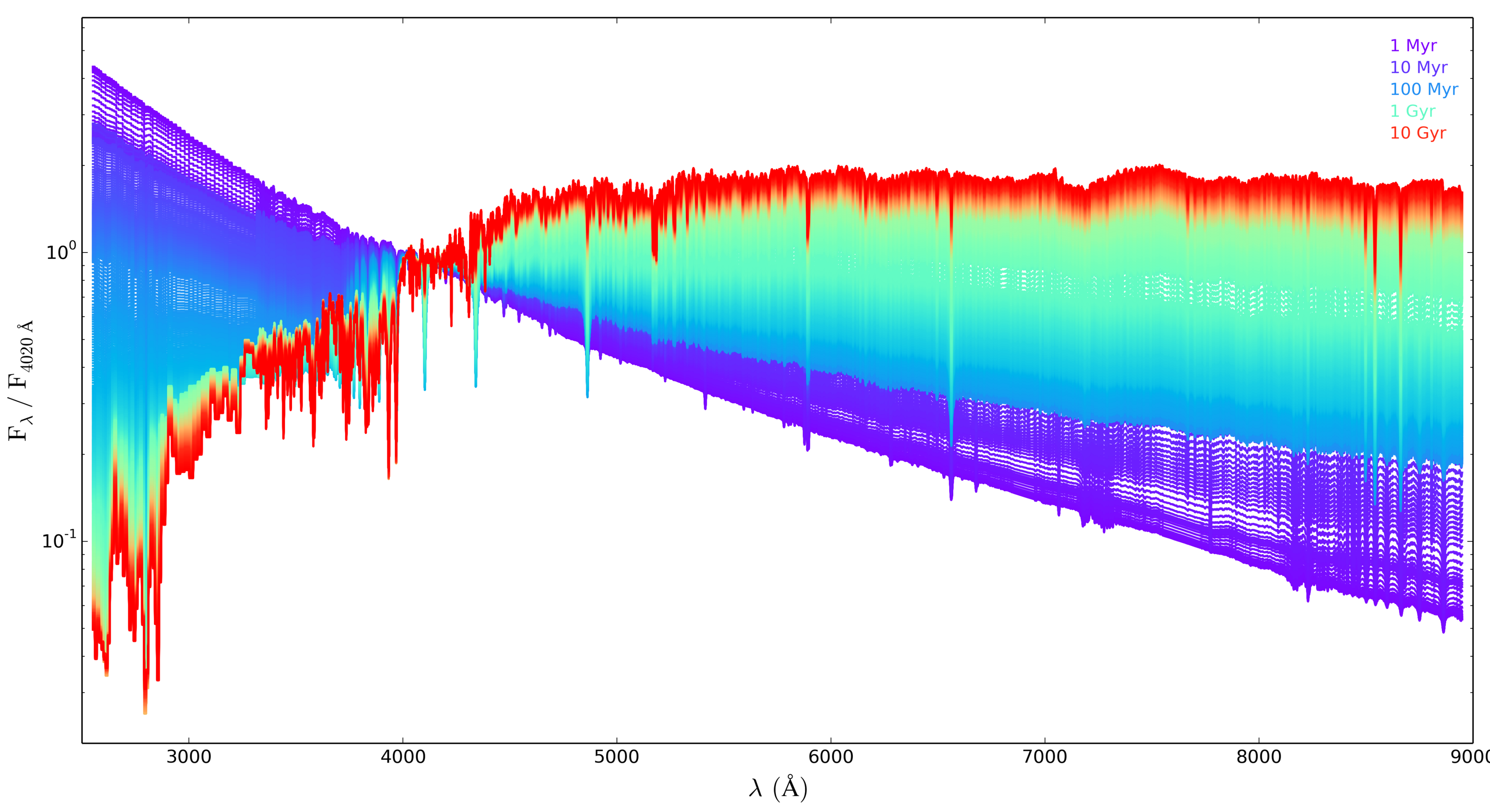

Figure 2 – Purely-stellar spectra created with REBETIKO normalised at λ_0 = 4020 Å for an instantaneous burst of star formation with fixed solar stellar metallicity. Different line colours correspond to different evolutionary stages, with *purple*, *violet*, *blue*, *green* and *red* depicting the computed SED for an age of 1 Myr, 10 Myr, 100 Myr, 1 Gyr and 10 Gyr, respectively.

Results

The synthetic SEDs from REBETIKO were subsequently modeled with STARLIGHT (Cid Fernandes et al. 2005) which can be regarded as representative of the currently available state-of-the-art (i.e. purely-stellar) SPS codes. Figure 3 displays an example of such an application. STARLIGHT fits were computed in the spectral range between 3400 and 8900 Å using a library of SSPs from Bruzual & Charlot (2003) with 25 ages between 1 Myr and 15 Gyr and 4 metallicities (Z = 0.2, 0.4, 1 and 2.5 Z$_\odot$).

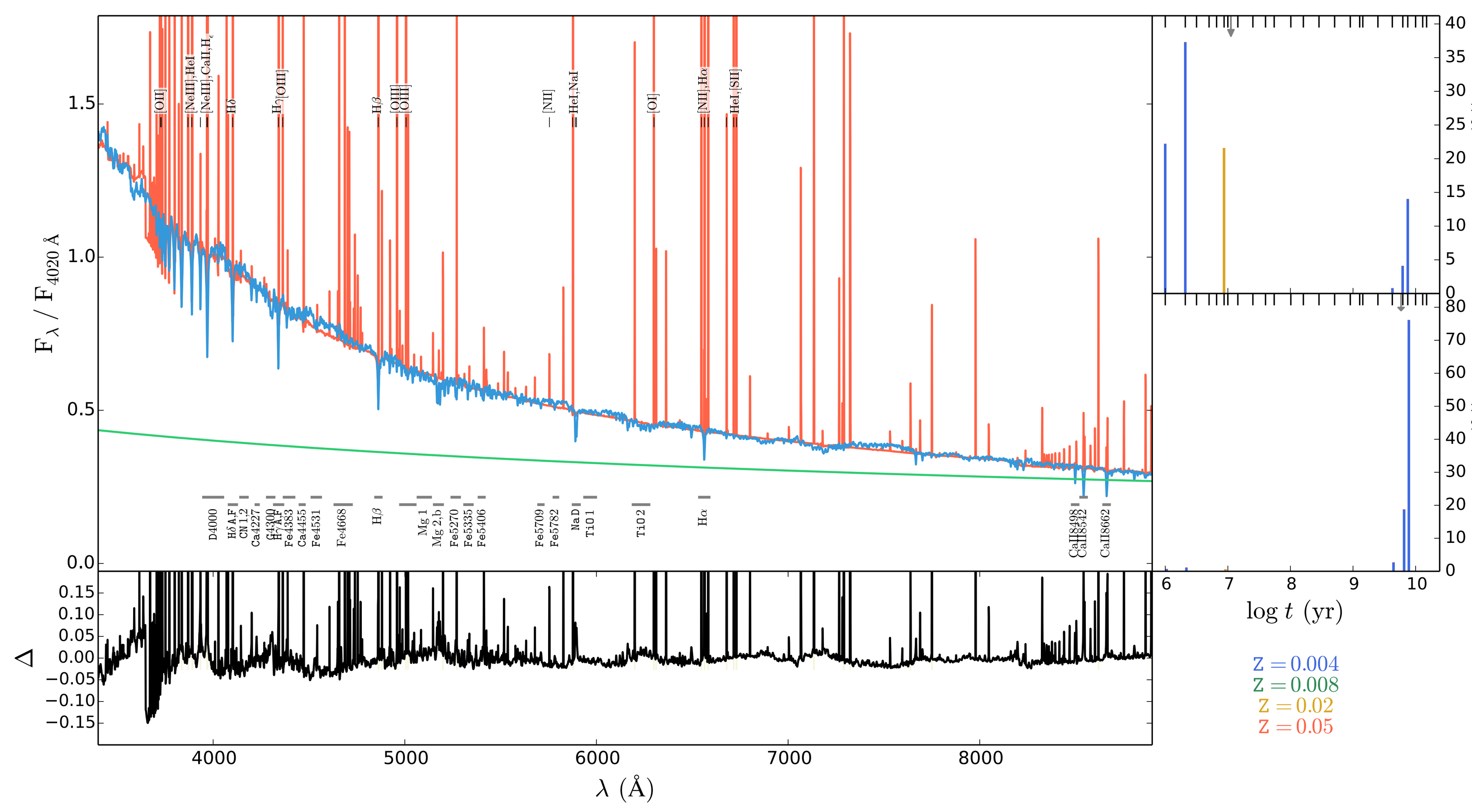

Figure 3 – STARLIGHT fit to an AGN-host spectrum computed with REBETIKO for a solar metallicity CSP with 5 Myr and an AGN power-law component with α = 1.5 and x_{AGN} = 0.4. Nebular emission was computed with CLOUDY assuming Case B recombination and n_H = 100 cm^{-3}. Top left panel: *Red* and *blue lines* correspond to input and fitted spectra, respectively. *Green line* illustrates the underlying AGN component in the input spectrum. Bottom left panel: *Black line* illustrates the residual spectrum after subtraction of the best-fit model to the input spectrum. Top right panel: SFH histogram in light fractions. Bottom right panel: SFH histogram in mass fractions.

Figure 4 shows that the stellar mass $M_\star$ inferred from STARLIGHT fits can be overestimated by up to 3 orders of magnitude by adding just AGN emission, with a trend of increasing $M_\star$ with increasing α and x_{AGN} (*blue*, *green*, *yellow* and *red lines* in top row). Addition of nebular emission to stellar SEDs results in an overestimation of $M_\star$ by up to 2 orders of magnitude, depending on the relative contribution of young and blue SSPs (*black line* in bottom row). The AGN is the main source of bias in the case where both nebular and AGN emission are added to the stellar SED (*blue*, *green*, *yellow* and *red lines* in bottom row).

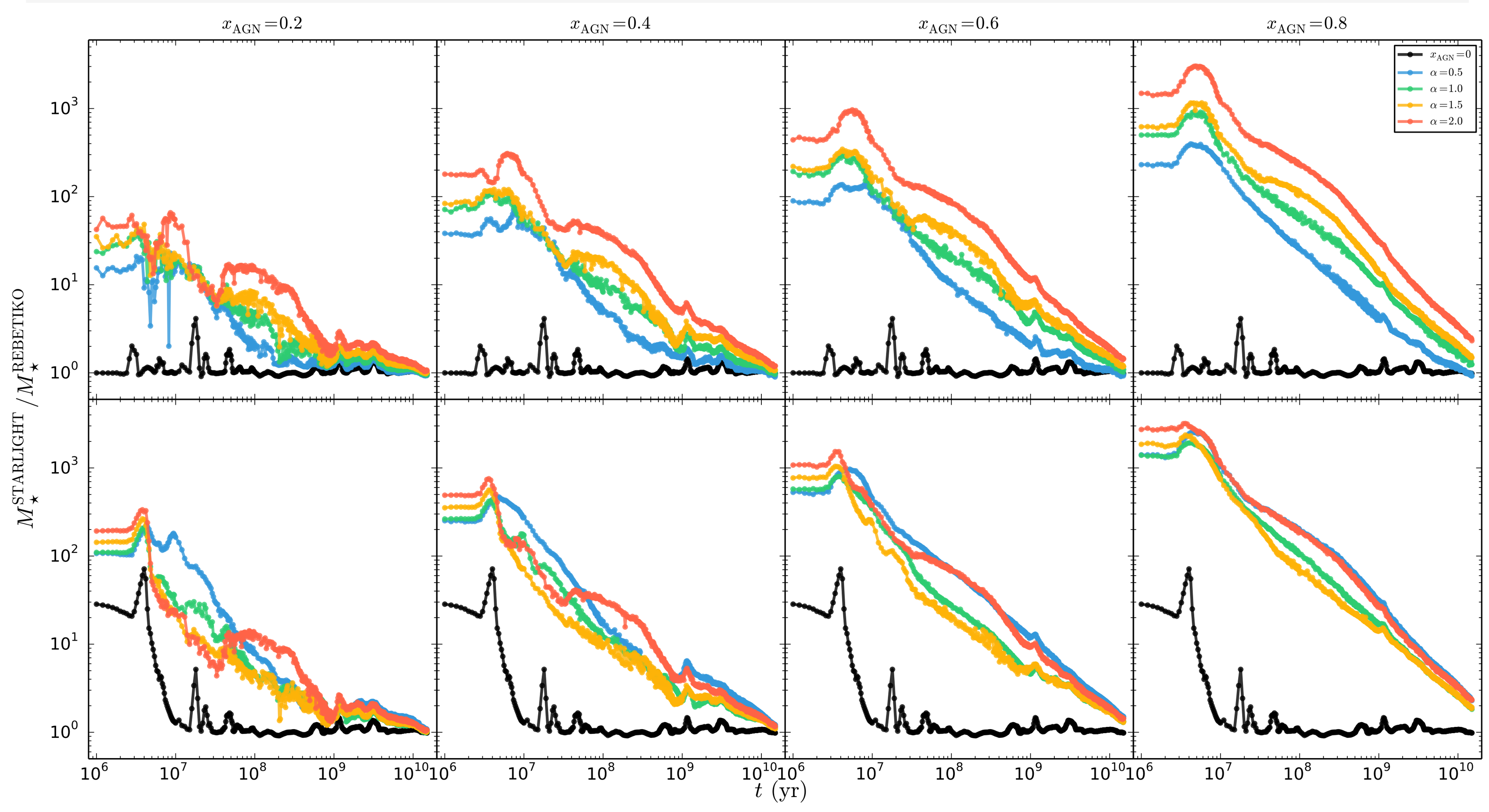

Figure 4 – Total stellar mass $M_\star$ ratio between STARLIGHT and REBETIKO values as a function of model age t for an instantaneous burst SFR. Top and bottom rows correspond to input models without and with nebular emission, respectively. Panels from left to right correspond to AGN flux fractional contributions of x_{AGN} = 0.2, 0.4, 0.6 and 0.8, respectively. *Black*, *blue*, *green*, *yellow* and *red lines* represent purely-stellar and stellar with AGN models with α = 0.5, 1.0, 1.5 and 2.0, respectively.

Our study also reveals that the light-weighted mean stellar age from STARLIGHT models can be over- or underestimated by up to ~2 dex for young (< 10 Myr) and old ages (> 1 Gyr), respectively. Moreover the mass-weighted mean stellar age is systemically overestimated with decreasing age reaching up to ~4 dex when < 10 Myr. These biases become more severe with both increasing α and x_{AGN}. Conversely, both the light- and mass-weighted mean stellar metallicity is overestimated up to ~0.4 dex with increasing α and underestimated by up to ~0.8 dex with increasing x_{AGN}.

Conclusion

The results presented here imply that determinations of the galaxy mass assembly history through state-of-the-art SPS codes can be severely biased in the presence of AGN and/or nebular emission. Such biases should hence be taken into consideration when interpreting spectral synthesis models for galaxies exhibiting strong AGN and/or starburst activity.

Acknowledgements

LSMC acknowledges support by Fundação para a Ciência e a Tecnologia (FCT) (Ref. UID/FIS/04434/2013) through national funds and by FEDER funding through the program Programa Operacional de Factores de Competitividade (COMPETE) 2020 (Ref. POCI-01-0145-FEDER-007672). JMG acknowledges support by FCT through the Fellowship SFRH/BPD/66958/2009 and POPH/FSE (EC) by FEDER funding through the program COMPETE. PP is supported by FCT through the Investigador FCT Contract No. IF/01220/2013 and POPH/FSE (EC) by FEDER funding through the program COMPETE. LSMC, JMG & PP acknowledge support by FCT under project FCOMP-01-0124-FEDER-029170 (Ref. FCT PTDC/FIS-AST/3214/2012), funded by FCT-MEC (PIDDAC) and FEDER (COMPETE). LSMC & JMG also acknowledge the exchange programme 'Study of Emission-Line Galaxies with Integral-Field Spectroscopy' (SELGIFS, FP7-PEOPLE-2013-IRSES-612701), funded by the EU through the IRSES scheme.

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