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Investigating multiple stellar populations in young LMC stellar clusters by means of integrated spectra

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Abstract. A puzzling issue recently observed in the integrated spectra of young LMC clusters is a partial mismatch between the observed integrated spectra and the theoretical spectral models. Different scenarios were suggested as possible solutions for the mismatch, one of them being the Multiple Stellar Population (MSP) scenario. In order to test this scenario, we introduce an automated program that determines and plots the mass fraction for combinations of SSPs that can improve the fit and minimize the mismatch. We call our program **A**nalyzer of integrated **S**pectra for **A**ge **D**etermination to test the **m**ultiple **s**tellar **p**opulation scenario (ASAD$_{msp}$). The program can test other possible solutions for minimizing the mismatch. We use our program to investigate four new young stellar clusters and confirm that the Multiple Stellar Population solution does not improve the match.

1. Introduction

Traditionally, star clusters are described by simple stellar population (SSP) models; however, in the recent years the new discoveries that resulted from analyzing deep CMDs, challenged our understanding of the clusters due to the observed extended main sequence turn off (eMSTO), raising the question of whether these clusters consist of multiple stellar populations as one of the scenarios of interpreting the eMSTO. In the LMC, the subject of MSP has been studied excessively using CMDs for a large number of young clusters (Milone et al. 2013, 2015, 2016, 2017; Correnti et al. 2015, 2017; Bastian & Silva-Villa 2013; Bastian et al. 2016; Niederhofer et al. 2015a,b). Only few studies (Cabrera-Ziri et al. 2014; Asa'd et al. 2017) have explored the topic by means of integrated spectra despite the reported systematic mismatch between the observed spectra and the different stellar libraries models which might be due to the MSP. In Asa'd et al. (2017) we analyzed three young clusters and investigated different solutions in an attempt to better understand the origin of the mismatch. In this work, we provide the community with a user-friendly program that can easily test the different scenarios for a given integrated spectrum of a star cluster, and use it to analyze four more young clusters in the LMC. Section 2 introduces our new automated program, section 3 discussed the sample we will use in this work and section 4 summarizes our results.

2. Our Program

ASAD$_{msp}$ (**A**nalyzer of integrated **S**pectra for **A**ge **D**etermination to test the **m**ultiple **s**tellar **p**opulation Scenario (ASAD$_{msp}$)) is an updated version of (ASAD) and (ASAD$_2$) introduced in Asa'd (2014) and Asa'd et al. (2016) respectively, where the age and reddening of the cluster was easily determined from its integrated spectrum by performing a χ^2 minimization test with spectral libraries using SSPs. ASAD$_{msp}$ can be used to obtain the best SSP age as in previous versions, in addition to the new feature of exploring the mass fraction for a combination of more than one SSP age, that can improve the match between the observed integrated spectra and the models.

ASAD$_{msp}$ uses the provided SSP models and creates spectral combinations according to:

$$f_x * SSP(\log t = x) + (1 - f_x) * SSP(\log t) \quad (1)$$

where f_x refers to the mass fraction contribution of an SSP with $\log t = x$ which is chosen by the user and $\log t$ is the age of the best match obtained from 1 SSP. Both ages are kept fixed and only the value of f_x is varied, running from 0 to 1 in steps of 0.01. Note that a change of 0.01 in mass fraction might be relevant for these fits as it reflects a larger luminosity fraction, depending on the age difference between the two SSPs.

In Asa'd et al. (2017) we showed that the mass fraction with most significant contribution is $SSP(\log t = 7)$, which is the age at which the RSG contribution peaks.

In ASAD$_{msp}$ $SSP(\log t = x)$ can be replaced by any other solution to be tested for improving the fit. For example in Asa'd et al. (2017) in equation 2 we replaced $SSP(\log t = x)$ with the spectrum of a RSG to examine if the mismatch is caused by the fact that the model doesn't provide the correct contribution of the RSG phase.

ASAD$_{msp}$ plots the spectra of the best match for the 1SSP as well as the result obtained from equation 1 with the residuals by subtracting the model spectrum form the observation spectrum bin by bin.

ASAD$_{msp}$ also gives the user to option of performing reddening correction for the observed spectra. It creates plots showing the inverse of the χ^2 values obtained over a 2D surface plot of the full age and reddening range explored by the algorithm as explained in Asa'd (2014).

3. Using ASAD$_{msp}$ to analyze a new sample

In Asa'd et al. (2017), we investigated the possible reasons for the mismatch between the observed spectra and the theoretical spectral models for three young clusters. In this work we use ASAD$_{msp}$ to expand our investigated sample by analyzing four more young clusters (NGC1847, NGC1870, NGC1983 and NGC2102) obtained by integral field spectroscopy observations obtained with the Wide Field Spectrograph (WiFeS) (Dopita et al. 2007, 2010) on the ANU 2.3m telescope at Siding Spring Observatory in Australia in November 2010.

Our observed spectra were affected by the poor weather conditions on the observing night, hence the results of this study are rough estimates to be improved with future better observations. The data were reduced using the PyWiFeS (Childress et al. 2014) pipeline using standard procedures. These include bias and overscan subtraction, cosmic ray correction using LA Cosmic (van Dokkum 2001), spectral and spatial flatfielding, wavelength rectification, spectrophotometric flux calibration, and correction of telluric absorption. The PyWiFeS wavelength solution is derived using an optical model of the spectrograph, and for the $R = 7000$ resolution gratings employed in this work this model achieves a global wavelength

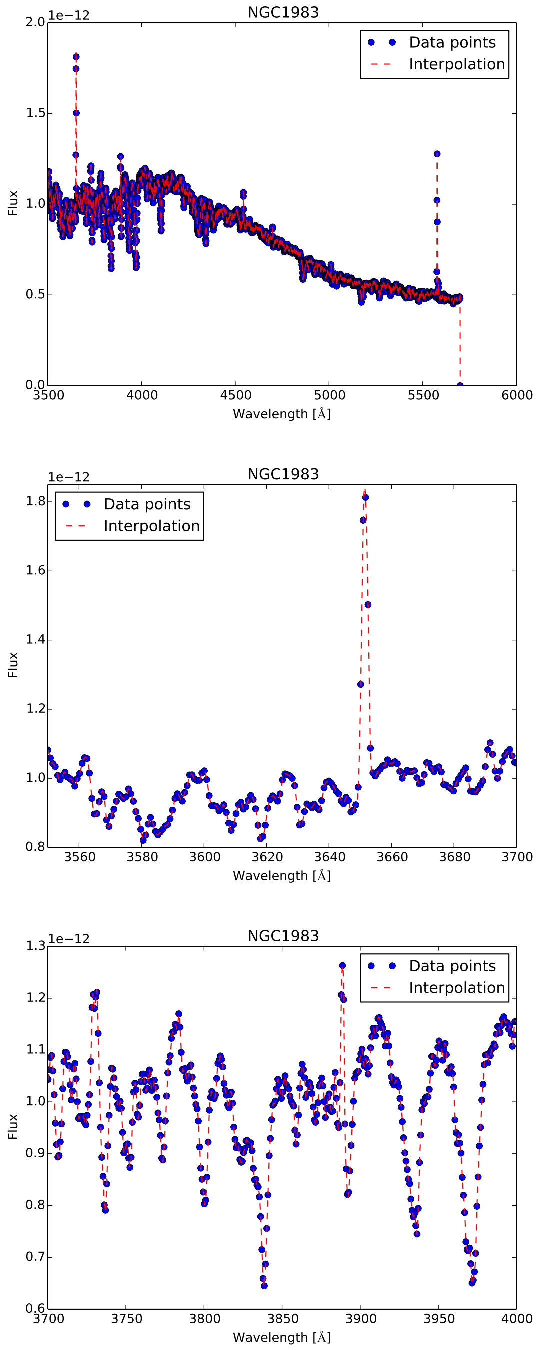

Fig. 1. Spectrum for the cluster NGC 1983, shown over the full wavelength range, the range 3550 – 3700Å, and the range 3700 – 4000Å. The interpolation is reasonable in the regions between data points.

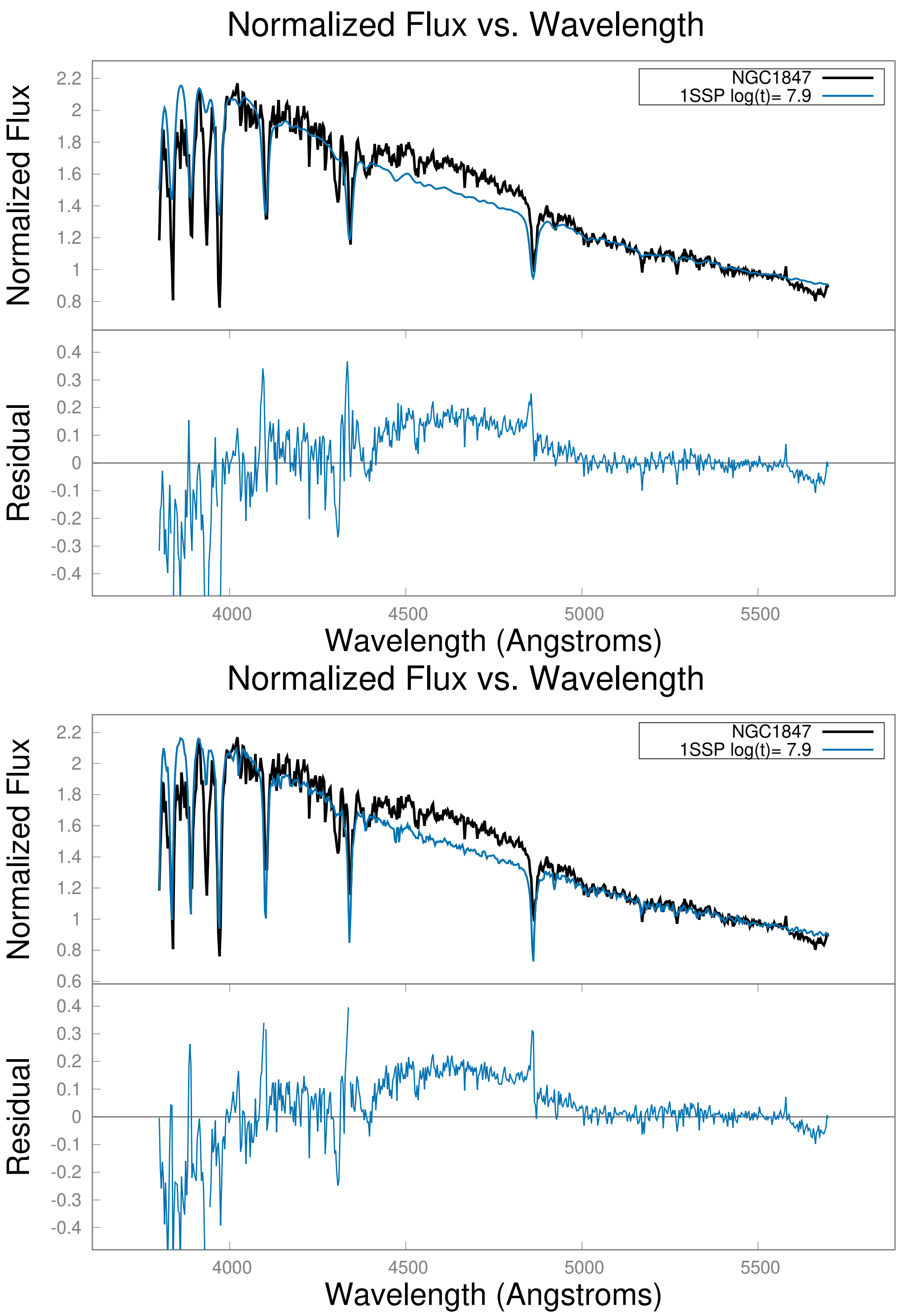

Fig. 2. The best match SSP solution for NGC1847, for model resolution 14Å (upper panel) and model resolution 3.6Å.

Table 1. Results using the Kroupa Universal IMF (Kroupa 2001) for several scenarios

Name	Age[1]	E(B-V)[1]	Age[2]	Age[3]	f_7^4
NGC 1847	7.9	0.00	7.9	7.9	0.00
NGC 1870	8.0	0.08	8.0	8.0	0.00
NGC 1983	6.9	0.12	6.9	6.9	0.00
NGC 1994	7.2	0.00	7.2	7.2	0.00
NGC 2012	7.2	0.00	7.2	7.2	0.00

[1] Age (log(age/yr)) and E(B-V) using 1SSP with reddening correction.
[2] Age (log(age/yr)) using 1SSP neglecting reddening correction.
[3] Age (log(age/yr)) using 2 SSPs according to equation 1.
[4] Fraction of the contribution of the 10 Myr SSP according to equation 1.

solution across the entire CCD whose dispersion is 0.05Å ($\sim 3\ \mathrm{km\,s^{-1}}$).

The reduced datasets were divided into 3-D data cubes, which gave the flux as a function of the spatial coordinates x, y and the wavelength for each object. To flatten the data and obtain the total flux as a function of only wavelength for each object, we sum over the spatial coordinates. We then re-sample the data at even wavelength intervals to obtain the data points used in the final analysis. This is done by performing a simple cubic spline interpolation on each dataset, which approximates the data curve with a piecewise 3rd-degree polynomial (with continuous first and second derivatives) that passes through each data point. To check that the interpolation is reasonable, we plot the data together with the interpolation, especially concentrating on regions where the data is rapidly varying. An example of this, for the cluster NGC 1983, is shown in Fig. 1.

4. Results

Our analysis in Asa'd et al. (2017) was using the wavelength range 3800A - 3626A, however for our current sample the available range is only 3800A - 5699A, so we start by redoing our analysis of the previously studied clusters with the new wavelength range and confirm that the same results are obtained.

The clusters studied in this work are NGC1847, NGC1870, NGC1983, NGC1994 and NGC2102. NGC1994 is common between this work and Asa'd et al. (2017). Fig. 2 shows the mismatch between the best 1SSP solution and the model for NGC1847 using model resolution 14Å (upper panel) and 3.6Å (lower panel).

We use ASAD$_{msp}$ to investigate if the MSP scenario can improve the match. This is done by adding a mass fraction contribution of an SSP with $\log t = 7.0$ to the best SSP determined above. We use equation 1 with $x = 7$.

Table 1 presents the results using the Kroupa Universal IMF for several scenarios using model resolution 14Å: Columns 2 and 3 list the age and E(B-V) using 1SSP with reddening correction, column 4 lists the age using 1SSP neglecting reddening correction. Column 5 lists the age using two SSPs, the first is the one in column 4 and the other is the fixed age of 10 Myr with a contributed fraction according to equation 1 given in column 6. The age obtained in the three scenarios is the same. The same results are obtained with model resolution 3.6Å except NGC2012 which predicts a log (age/year) of 7.1.

We conclude that the Multiple Stellar Population scenario is rejected for this sample. This is consistent with recent CMD studies that show no evidence of MSP in young clusters.

Our observations were affected by bad weather conditions so a more accurate analyses of this sample is needed to confirm these results.

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