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Measuring age, metallicity and abundance ratios from absorption line indices

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Abstract. In this work the ability of the line strength indices to assess the metallicity, age and abundance ratios $[\alpha/Fe]$ of EGs have been investigated. The analysis has been made adopting the line strength indices of the Lick System based on the new stellar models by Salasnich et al. (2000) both for solar end α-enhanced partitions of chemical elements. Using these models and the calibration by Tripicco & Bell (1995), the integrated indices of Single Stellar Populations (SSPs) of different age, metallicity and degree of enhancement in the α-elements have been calculated. Finally, with the aid of the *Minimum-Distance Method* proposed by Trager et al. (2000), it has been derived the age, metallicity and enhancement degree for the galaxies of the González (1993) sample. An analysis of all possible source of disagreement from previous results has been performed.

Key words. Galaxies: elliptical – Galaxies: metallicities – Galaxies: ages

1. Introduction

The integrated line strength indices of single stellar populations (SSP) and/or large assemblies of stars, are known to depend on the metallicity, age, and the degree of enhancement in α-elements of their stellar content. The indices of individual stars are calculated with the aid of the "*Fitting Functions*" (Worthey 1994) which correlate the intensity of an index to T_{eff}, $Log(g)$ and $[Fe/H]$ of the star. Worthey (1994) analyzed the sensitivity of each index to the age and metallicity of SSPs, and found that some indices seems to be more sensitive to the age, whereas others are more sensitive to the metallicity. Therefore, those indices seem to have the potential of partially resolving the *Age-Metallicity Degeneracy*. Over the years, an extensive use of the two indices diagnostics has been made to infer the age and the metallicity of early type galaxies (Trager et al. 2000, Tantalo & Chiosi 2003 and references therein) neglecting the dependence on the degree of enhancement in α-elements. Only recently, the effect of this starts being considered.

2. The enhancement factor and the TB95 calibration

In presence of enhancement in α-elements one has to modify the relationship between the total metallicity Z and the iron content $[Fe/H]$ by suitably defining the enhancement factor (Γ) (see Tantalo & Chiosi 2003 for all details).

Splitting the metallicity Z in the sum of two contributions: (i) from all heavy elements but Fe and (ii) from the iron, one may define the so-called "*enhancement degree*" Γ in the following way:

$$[Fe/H] = [Z/H] - \Gamma.$$

Assuming a certain degree of enhancement Γ and a total metallicity Z, the abundances of all elements but $[Fe/H]$ can be arbitrarily varied provided their sum is equal to Γ. The results will of course depend on the exact way this partition is made.

The indices of the SSPs are first obtained using the Worthey "*fitting functions*" (FFs) at zero enhancement and then re-scaled to the particular set of abundances. To this aim we adopt the method developed by TFWG00 which stems from the study of Tripicco & Bell (1995, TB95) who first introduced the concept of *response function*. The correction for any specific index is given by:

$$\delta I = \frac{\Delta I}{I_0} = \left\{ \prod_i [1 + R_{0.3}(X_i)]^{\left(\frac{[X_i/H]}{0.3}\right)} \right\} - 1$$

where $R_{0.3}(X_i)$ is the response function for element i at $[X_i/H] = +0.3$dex. This is given by $(\delta R_i \star \sigma_0)$ where δR_i is the value for each element in unit of standard errors σ_0 as tabulated in TB95.

Applying the TB95 correction using the Salasnich et al. (2000, there in after SGWC00) mixture new set of SSPs indices have been obtained.

3. Results from the Minimum-distance method

The above new grid of indices has been applied to the González (1993, G93) catalog of EGs using the minimum-distance method described by TFWG00. The top panels of left part of Fig. 1 compares the results obtained here (shaded histograms) with those derived by TFWG00 for their C^0O^+-model (heavy line histograms). Even considering the uncertainty due to the observational "errors", there are important differences between the two work. The major difficulty of the above results is with the age, because too many galaxies have the formal age of 20 Gyr, which on one hand is unacceptably too old on the other hand is the maximum value of the age grid.

There are several, possible causes for the above large difference: (i) stellar models and SSPs in use; (ii) pattern of abundances in the enhanced mixtures, and (iii) details on the construction of the indices grids and their extensions to regions of the parameter space not covered by the original models. In the following the above topics will be discuss separately with the aid of suitable experiments.

3.1. The stellar models-isochrones-SSPs

The analysis by TFWG00 is based on the SSPs calculated by Worthey (1994) which are obtained by patching together stellar models and these may not be fully self-consistent in all details. In contrast, the SSPs of SGWC00 stem from accurate evolutionary stellar models and isochrones, homogeneous in their input physics and extending up to the latest visible phases.

Since not all SSPs in literature contain all evolutionary phases predicted by stellar evolution theory (in some extreme cases they do not extend beyond the TO or the T-RGB) it is worth looking at the uncertainty introduced in the calculation of indices by neglecting late evolutionary phases. To this aim a new set of *fictitious* SSPs indices based on TP96[1] isochrones have been calculated, whose last evolutionary phase is the TO, the T-RGB, the end of core HeB, the end of the TP-AGB, and the P-AGB. Chief conclusion by analysing the behavior of the indices at including differ-

[1] the SSPs adopted in this work were actually calculated from the Padova library of stellar models with solar partition of elements and old opacities (Bertelli et al. 1994) and the classical recipe for mass-loss during the red giant branch (RGB) whereas the mass-loss rate along the AGB phase follows the formulation by Vassiliadis & Wood (1993). These have been described for the first time in the data base for galaxy evolution models by Leitherer et al. (1996). In the following we will refer to these SSPs as the Tantalo's version of the Padova SSPs, shortly indicated as TP96.

ent phases, is that detailed and accurate calculations of SSPs throughout all evolutionary phases are the main prerequisite to obtain reliable indices (see Tantalo & Chiosi 2003 for a more detailed analysis).

3.2. The abundance patterns

Case A: The SGWC00 mixture.
Beside the new set of indices using the stellar models by SGWC00 with Γ=0. and Γ=0.3557, further set based on another choice for an α-enhanced composition (Γ=0.50dex) has been calculated for the purposes of this study[2] (see Tantalo & Chiosi 2003 for details). This allows to combine the effect of enhancement both on the stellar models/isochrones and the indices in a self consistent way.
Case B: C^0O^+ model by TFWG00.
To compare new results with those of TFWG00, an *ad-hoc* sets of indices for solar-scaled isochrones correct with the pattern of enhanced abundances as in the model C^0O^+ by TFWG00 have been derived. To this aim has been adopted the isochrones by TP96. This allows to test the effect of a simple enhancement scheme on standard stellar models/isochrones
Case C: TP96 isochrones and the SGWC00-mixture.
Finally, SSPs indices using the old isochrones by TP96, and the mixture of chemical abundances as in SGWC00, namely solar, Γ=0.3557dex and Γ=0.50dex have been calculated. This allows to test the effect of a complex enhancement scheme on standard stellar models/isochrones.
The results of applying the *Minimum-Distance Method* to the above three cases are shown in left panel of Fig. 1.
Uncomfortably, each case in the left panel yields different results due to the different assumption for the input SSPs and pattern of abundances. Comparing Case **B** to Case **C** the effect of different patterns of chemical abundances in the α-enhanced mix is revealed, whereas comparing Case **A** to Case **C**, the effect of different stellar models/isochrones is highlighted.

The conclusion is that the solution is highly model dependent (i.e. depend by the stellar models, the companion isochrones and SSPs, the chemical composition and in particular the abundance ratios assumed in the mix, the FFs and the Response Functions in usage, together with some technical details such as the way the theoretical grids are assembled). At this stage it is hard to decide which result has to be preferred.

3.3. Extrapolating grids of indices

Another important point is the way grids of stellar models/SSPs/indices are extrapolated from existing tabulations.

To illustrate the point one have to look to the extension made by TFWG00 of the Worthey (1994) grid of SSPs. The maximum age of the SSPs is 17 Gyr and three values of metallicity are considered, i.e. Z=0.007, 0.02, 0.05. For ages older than about 5 Gyr the behavior of the various indices under examination is very smooth, almost linear in the two parameters. Basing on this, the linear extrapolation of the indices to older ages, higher metallicities, and higher values of Γ seems to be reasonable. Indeed the grids have been extrapolated by TFWG00 to ages up to 30 Gyr and metallicities up to Z=0.07.

Has been demonstrated that stellar models, SSPs, and indices in turn are very sensitive to age and metallicity, and that past the T-RGB some unexpected evolutionary phases may appear largely affecting the regular trend of the indices in previous stages, at younger ages and/or lower metallicity. The effect is clear looking at the right panel of Fig. 1 comparing results obtained using the Case **B** for complete SSPs with the TP96 SSPs truncated at Tip-RGB phase.

Therefore the use of incomplete grids of stellar models and the straight extrapolation of stellar models/indices to much older ages and/or much higher metallicities might not be a safe procedure to adopt.

[2] This is necessary since to be applied the *Minimum-Distance Method* requires large grids of SSPs with fine spacing in age metallicity and Γ

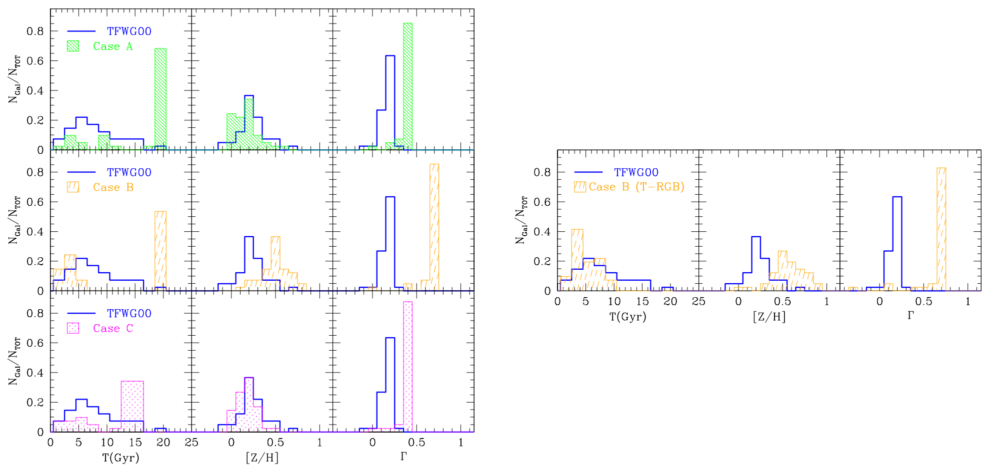

Fig. 1. Distribution histograms of the age T (in Gyr), metallicity ($[Z/H]$), and enhancement factor Γ obtained applying the *Minimum-Distance Method* with the index-triplet H_β, Mg_b, $\langle Fe \rangle$ to the G93 sample. **Left panel** shown the results for the Cases **A**, **B** and **C**, as indicated. **Right panel**: the same for Case **B** but adopting the SSPs of TP96 limited to the T-RGB. All the distribution are compared with the TFWG00 solution (thick lines).

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