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Age and metallicity effects in single stellar populations: application to M 31 clusters

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Abstract. We have recently calculated (Borges et al. 1995) integrated metallicity indices for single stellar populations (SSP). Effects of age, metallicity and abundances were taken into account. In particular, the explicit dependence of the indices Mg_2 and NaD respectively on the ratios [Mg/Fe] and [Na/Fe] was included in the calibration. We report in this work an application of those models to a sample of 12 globular clusters in M 31. A fitting procedure was used to obtain age, metallicity and the [Mg/Fe] ratio for each object, which best reproduce the data. The mean age of the sample is 15±2.8 Gyr and the mean [Mg/Fe] ratio is 0.35±0.10. These values and the derived metallicity spread are comparable to those found in galactic counterparts.

Key words: galaxies: M 31 – galaxies: abundances – galaxies: star clusters – globular clusters: general

1. Introduction

The study of distant stellar systems is a rather complex problem, since from an observational point of view, we can only have access to their integrated spectra. Therefore, all physical information as for instance the chemical composition, comes from absorption features due to stars of different populations. However the interpretation of line strengths is difficult since effects of spread in age and metallicity are strongly coupled.

A first and necessary step to approach this problem concerns the calibration of metallicity indicators for single stellar populations (SSP). The synthesis of metallicity indices (for a definition of the usual indices see, for instance, Faber et al. 1985) requires the knowledge of the light contribution from different evolutionary stages at a given age, and the variation of the indices themselves as a function of stellar parameters like effective temperature, gravity and metallicity. The light contribution can be obtained from theoretical isochrones and the variation of the metallicity indices can be derived empirically (Worthey 1994; Idiart & Freitas Pacheco 1995).

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However empirical relations between those indices and metallicity are plagued by the fact that they reflect the chemical history of our Galaxy. Low metallicity stars used as calibrators are, in general, halo objects whereas stars with solar metallicity and slightly above belong to the disk. These distinct populations have a different abundance ratio pattern, which reflect the relative contribution of type II and Ia supernovae to the galactic chemical enrichment. Recently, Borges et al. (1995) presented new empirical formulae in which the explicit dependence on the ratios [Mg/Fe] and [Na/Fe] was also taken into account for the indices Mg_2 and NaD respectively, besides the usual atmospheric stellar parameters as temperature, gravity and metallicity. These new formulae opened the possibility of modeling synthetic spectral features with a chemical history not linked to that of our own Galaxy.

Since the equations derived by Borges et al. (1995) give quite good results when applied to galactic globulars, a further step is reported in the present work. Here, such a calibration is applied to a sample of globular clusters in M 31, which have measured integral properties (Burstein et al. 1984). For the first time age, metallicity and relative abundance ratios for SSP objects are derived in a consistent way from their integrated spectra. As we shall see, the resulting average values are comparable to galactic counterparts.

2. The method and results

Borges et al. (1995) computed a grid of SSP models from which integrated metallicity indices as Mg_2, $< Fe >$, NaD, $H\beta$ and the color (B-V) were derived as functions of age, metallicity **and relative abundances**. Since these results are given in form of tables or interpolation formulae in that reference, we just recall here some basic assumptions of those models.

The mass spectrum was assumed to be a power law with an exponent equal to 2.35 (Salpeter's law). The evolutionary tracks used in the calculations are those of VandenBerg et al. (1983) for masses lower than 0.6 $M_\odot$, and those by Bressan et al. (1993), Fagotto et al. (1994a,b,c) for higher values. Bolometric and color transformations to an observational CMD are from VandenBerg (1992). The empirical relations between indices

Table 1. Properties of M31 Clusters⋆

Object	Age (Gyr)	[Fe/H]	[Mg/Fe]	(B-V)	$< Fe >$	Mg_2
K 001	14.0±2.4	-0.90±0.16	0.50±0.07	0.80	1.61	0.124
-	-	-	-	0.78	1.61	0.148
K 064	15.0±2.8	-1.80±0.20	0.20±0.10	0.64	0.81	0.047
-	-	-	-	0.61	0.84	0.042
K 078	16.0±3.0	-0.85±0.15	0.50±0.10	0.82	1.71	0.141
-	-	-	-	0.83	1.79	0.160
K119	14.6±1.5	-1.11±0.20	0.10±0.08	0.76	1.37	0.072
-	-	-	-	0.75	1.47	0.069
K213	15.0±3.3	-0.73±0.13	0.35±0.10	0.84	1.86	0.134
-	-	-	-	0.82	1.86	0.133
K217	17.0±5.0	-0.35±0.10	0.35±0.08	0.92	2.48	0.215
-	-	-	-	0.95	2.50	0.227
K222	16.0±4.5	-0.45±0.10	0.35±0.08	0.91	2.46	0.208
-	-	-	-	0.90	2.43	0.201
K230	14.0±1.0	-1.20±0.22	0.50±0.11	0.74	1.27	0.093
-	-	-	-	0.74	1.19	0.105
K244	15.0±2.8	-0.10±0.18	0.20±0.13	0.95	2.89	0.227
-	-	-	-	0.91	3.09	0.223
K272	14.0±2.3	-0.90±0.16	0.50±0.10	0.80	1.61	0.124
-	-	-	-	0.76	1.83	0.124
K280	14.0±2.8	-0.40±0.20	0.35±0.10	0.89	2.34	0.184
-	-	-	-	0.84	2.32	0.184
K302	17.0±2.9	-1.80±0.20	0.35±0.10	0.66	0.85	0.058
-	-	-	-	0.67	0.80	0.057

⋆ The second entry in the last three columns corresponds to the observed values

and stellar parameters are from Idiart & Freitas Pacheco (1995a) for the indices $< Fe >$ and $H\beta$, and from Borges et al. (1995) for Mg_2 and NaD. Other details may be found in the original paper by Borges et al. (1995).

In our analysis, the indices $H\beta$ and NaD were discarded. The reasons were already discussed by Idiart & Freitas Pacheco (1995a). The index $H\beta$ depends on the morphology of the horizontal branch (HB) and, in particular, on the existence of "blue tails" (Freitas Pacheco & Barbuy 1995), which may be associated to dynamical effects (Djorgovski et al. 1991; Fusi-Pecci et al. 1993).

The integrated indices (B-V), $< Fe >$ depend on age and metallicity; the index Mg_2, besides those two parameters, depends also on the ratio [Mg/Fe], a key point in our calculations. In fact, the color (B-V) depends on the total metal amount responsible for blanketing effects. The scaling relation by Chieffi et al. (1991) relating Z with the iron content and the relative α-elements abundance (here assumed to be represented by the magnesium abundance) was adopted for such a conversion, in spite of some recent criticism on its validity for intermediate and high metallicity values (Weiss et al. 1995).

We selected a sample of 12 globular clusters in M 31 for which integrated properties like the (B-V) color and metallicity indices are known (Burstein et al. 1984). Then, a numerical code searches the best values of age, metallicity and [Mg/Fe] ratio, which give the best fit between the set of observed parameters like (B-V), Mg_2, $< Fe >$ and model predictions.

The results of our calculations are shown in Table 1. For each object the resulting age, metallicity and abundance ratio are given, as well as predicted indices and observed ones (second entry in each column).

3. Discussion

The first question to be analyzed refers to the accuracy of our results. If only a color-age-metallicity is employed, errors of 0.05 mag in the integrated color may lead to errors in age of about 40% in the relevant metallicity interval, as shown by Borges et al. (1995). Such an uncertainty may considerably be reduced if further observational constraints are included in the analysis. In our case, this corresponds to the relations $< Fe >$-age-metallicity and Mg_2-age-metallicity-[Mg/Fe] ratio.

In order to estimate the errors associated with the derived quantities, the following procedure was adopted: Eq. (8), (9) and (11) of Borges et al. (1995) were linearized with respect to metallicity ([Fe/H]), fractional age and ratio [Mg/Fe]. Then, for each object, the error matrix was calculated assuming uncertainties of 0.05 mag for the color (B-V), 0.25**Å** and 0.02 mag respectively for the indices $< Fe >$ and Mg_2. The resulting error estimates are given for each object in Table 1. This analysis shows that the typical error in cluster ages is about 2.8 Gyr. Metallicities can be considered accurate to within 0.20 dex in our scale, while the uncertainty in the [Mg/Fe] ratio is of about 20%. A further verification on the error analysis was performed, applying our procedure to the seven galactic globular clusters considered by Borges et al. (1995), which have an independent age determination from their CMD's, and metallicity derived from spectroscopic analysis of individual members. The integrated indices are also from Burstein et al. (1984). Differences between our method and other determinations amount to about 2.3 Gyr (rmsd) in age and about 0.30 dex (rmsd) in metallicity. These values are quite consistent with the estimated errors, reinforcing their significance. We compared also the present metallicities with those derived from the colors (V-K) and (J-K), calibrated by Brodie & Huchra (1990). The results are consistent within the expected uncertainties, although it seems that the infrared colors give, on the average, values systematically lower by 0.14 dex.

The mean age of the 12 clusters listed in Table 1 is 15 ± 2.8 Gyr, comparable to ages found for galactic globulars. Moreover, the derived mean [Mg/Fe] ratio is 0.35±0.13, also in agreement with values observed in metal poor stars (Borges et al. 1995). These results are consistent with a chemical enrichment where type II supernovae played a major role. It should be emphasized that most of our sample objects are in the metallicity interval $-1.80 < [Fe/H] < -0.10$. This is comparable to the range where most of the galactic globular clusters are observed. Reed et al (1994) also reached a similar conclusion. Based on a larger sample, they derived metallicities using integrated colors, and found that globulars in M 31 have a metallicity distribution comparable to Milky Way objects. However, it seems that M 31 has relatively more globulars at the high metallicity end than the Galaxy. These findings are also in agreement with recent CMD's obtained with the HST (Rich et al. 1996; Ajhar et al. 1996), since the metallicities derived for some clusters by calibrating the position of the red giant branch, are quite compatible with the range found in the present study.

On the other hand, if the metallicity distribution of field stars and globular clusters in the galactic halo are similar (although no cluster with [Fe/H] $<$ -2.5 has been found yet), there is an increasing evidence that the situation may be different in M 31. The CMD's analysis of field stars in the halo of M 31 (Durrel et al. 1994) indicates a high mean metallicity ([Fe/H] $\approx$ -0.60) and a " red " morphology for the horizontal branch, suggesting some differences in the evolutionary scenario for the haloes of both galaxies.

However, other differences claimed in the past (Burstein et al. 1984), in the sense that some M 31 globulars could be younger than those in our galaxy are not supported by the present results. A stronger $H\beta$ feature is not necessarily an indication of a younger population, since the morphology of HB stars is an important parameter to be considered besides age, as Freitas Pacheco & Barbuy (1995) have shown. Moreover differences in the CN strength between some clusters of both populations are not also a strong argument to support age variations. Similar differences are equally observed between halo field and globular cluster stars in our galaxy (Langer et al. 1992), weakening such an argument.

It is worth mentioning that our method shows that age, metallicity and abundance ratios can be disentangled if the right indices are chosen, and if effects of the chemical history of our galaxy are suppressed. This implies the inclusion of all relevant stellar parameters, in particular abundance ratios, to calibrate the usual metallicity indicators.

We strongly emphasize that the reported procedure is suitable to be applied to SSP only. Stellar systems like elliptical galaxies and spiral bulges, in which a spread in age and metallicity are present, require a more complex modeling . Population mix models using the same calibration formulae were developed by Idiart et al. (1996) and applied to the galactic bulge. They have estimated the average metallicity and the average [Mg/Fe] ratio in the Baade's window , using integrated indices. Their results are in quite good agreement with K giants data, giving further support to our methodology.

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