Boletim da Sociedade Astronômica Brasileira, **30**, no. 1, 109-110

Calibration of $(B - V)_o$ with MILES stars

A. Milone[1], P. Sánchez-Blázquez[2], A. Vazdekis[3], C. Allende-Prieto[4], and A. Sansom[5]

[1] Instituto Nacional de Pesquisas Espaciais, Brazil, e-mail: andre.milone@inpe.br
[2] Universidad Autónoma de Madrid, Spain, e-mail: psanchezblazquez@gmail.com
[3] Instituto de Astrofísica de Canarias, Spain, e-mail: vazdekis@iac.es
[4] Universidad de La Laguna, Spain, e-mail: callende@iac.es
[5] University of Central, Lancashire, UK, e-mail: AESansom@uclan.ac.uk

Abstract. $(B - V)$ is one of the integrated properties of a stellar system that can help determining its light-weighted average age and metallicity. We have derived a set of empirical calibrations of the intrinsic colour $(B - V)_o$ as a function of T_{eff}, [Fe/H] and [α/Fe]. The photospheric parameters of MILES (Mid-resolution Isaac Newton Telescope Library of Empirical Spectra) stars have been homogeneously redetermined (approach to be shown in another work). The calibrations have been independently obtained for distinct spectral types (O-B, A, F-G-K and M), which have been split into up to five ranges in [Fe/H]. For M type only, the stars are divided in dwarfs and giants. $(B - V)_o$ has been directly measured by using the MILES fully calibrated stellar spectra with a typical error of 0.025 mag. In the current work, we just present the $(B - V)_o$ calibrations for F-G-K types, whose error in $(B - V)_o$ varies from 0.014 up to 0.022 mag. The next main goal is to self-consistently compute $(B - V)_o$ for semi-empirical simple stellar population models based on MILES.

Resumo. $(B - V)$ é uma das propriedades integradas de um sistema estelar que pode nos ajudar a determinar sua idade e metalicidade ponderadas em fluxo. Nós obtivemos um conjunto de calibrações empíricas para a cor intrínseca $(B - V)_o$ em função de T_{eff}, [Fe/H] and [α/Fe]. Os parâmetros fotosféricos das estrelas de MILES (Mid-resolution Isaac Newton Telescope Library of Empirical Spectra) foram redeterminados de modo homogêneo (metodologia a ser apresentada noutro trabalho). As calibrações foram derivadas de modo independente para tipos espectrais distintos (O-B, A, F-G-K and M), os quais foram divididos em até cinco intervalos de [Fe/H]. As estrelas foram separadas em anãs e gigantes para apenas o tipo M. $(B - V)_o$ foi medida com um erro típico de 0,025 mag diretamente nos espectros estelares MILES, os quais são inteiramente calibrados. No presente trabalho, nós somente apresentamos as calibrações de $(B - V)_o$ para os tipos F-G-K, cujo erro em $(B - V)_o$ varia desde 0,014 a 0,022 mag. O objetivo principal seguinte será calcular $(B - V)_o$ de modo autoconsistente para modelos semiempíricos de populações estelares simples com uso de MILES.

Keywords. catalogs – stars: fundamental parameters – stars: abundances

1. Introduction

The age and chemical abundances of a hypothetical simple stellar population (SSP) are imprinted in its integrated spectrum and photometric colours. Even in the case of more complex stellar systems such as a galaxy, those properties, or even their luminosity-weighted averages, can be extracted through a stellar population synthesis method. In fact, $(B - V)_o$ increases with mean age as well as with mean metallicity of the stellar component. here is also a dependence of this colour on the timescale of star formation history, because it is closely related to the mean age.

The $(B - V)_o$ integrated colour of semi-empirical SSP models can be computed from $(B - V)_o$ of all stellar evolutive stages defined over the isochrone of a given age and chemical composition ([M/H], [Fe/H], [α/Fe]). $(B - V)_o$ of each stage can be expressed as a function of the photospheric parameters T_{eff}, [Fe/H] and [α/Fe] through empirical calibrations. The precision of SSP model colour is, in fact, dominated by the calibration error acquired for the brightest stages in B and V bands. This self-consistent procedure aims to minimize the errors in the derivation of $(B-V)_o$ for a large variety of semi-empirical SSP models. This modelling of $(B - V)_o$ for SSPs will be useful to help deriving age, star formation history and metallicity of galaxies, when included in a full evolutionary stellar population synthesis.

2. Multi-parametric calibration of $(B - V)_o$

$(B - V)_o$ of MILES stars have been directly measured on the MILES spectra by applying the Johnson & Morgan (1953) filter transmissions (the Revised Yerkes Atlas System of Spectral Classification, MK) and a spectrophotometric calibration to Vega such that B=V=0.03 mag (Castelli & Kurucz 1994). The average systematic error of $(B - V)_o$ is about 0.025 mag when compared with different samples with stars in common (Sánchez-Blázquez et al. 2006).

Also taking into account $[M/H]$ of BaSTI scaled-solar and α-enhanced isochrones (Pietrinferni et al. 2004, 2006), we have divided the MILES stars into T_{eff} and [Fe/H] intervals.

T_{eff} ranges nearly resemble spectral types: $11000 \leq T_{eff} < 3600$ K (O-B types), $7000 \leq T_{eff} < 11000$ K (A type), $4750 \leq T_{eff} < 7000$ K (F-G-K types), and $3000 \leq T_{eff} < 4750$ K (M type). Only M type is split in dwarfs ($\log g \geq 3.0$) and giants ($\log g < 3.0$). Only F-G-K types have five [Fe/H] ranges: $[Fe/H] < -1.0$ (metal poor), $-1.0 \leq [Fe/H] < -0.2$ (intermediate metal poor), $-0.2 \leq [Fe/H] < +0.2$ (solar metallicity), $+0.2 \leq [Fe/H] < +0.6$ (intermediate metal rich), and $[Fe/H] \geq +0.6$ (metal rich). O-B stars are not split in [Fe/H], A stars and M giants have both two [Fe/H] ranges ($[Fe/H] < -0.2$ and $[Fe/H] \leq -0.2$), and M dwarfs with different [Fe/H] are dealt together.

T_{eff}, [Fe/H], $\log g$, V_{micro} and [α/Fe] have been homogeneously determined through a full spectrum analysis of the MILES spectra ($\lambda\lambda$3544.1–7406.9 Å), whose details will be described in an specific paper. We have just adopted the original MILES library (Sánchez-Blázquez et al. 2006).

$$(B-V)_o = a + b.\theta_{\rm eff} + c.\theta_{\rm eff}^2 + d.[{\rm Fe/H}] + e.[{\rm Fe/H}]^2 + f.[\alpha/{\rm Fe}] + d.[\alpha/{\rm Fe}]^2. \quad (1)$$

We have applied polynomial fits to calibrate $(B-V)_o$ as a function of $T_{\rm eff}$, [Fe/H] and [α/Fe], nearly similar to Alonso, Arribas & Martinez-Roger (1996). Eq. 1 shows the adopted multi-parametric 2nd order polynomial function, where $\theta_{\rm eff}$ = 5040 K/$T_{\rm eff}$ (K). In order to derive the final dependence of $(B-V)_o$ with the terms of Eq. 1, we have added each term one by one based on the analysis of fit residuals as a function of each additional parameter. The base polynomial fit is $a + b.\theta_{\rm eff} + c.\theta_{\rm eff}^2$, and the inclusion of other terms was done following the sequence: [Fe/H], [Fe/H]^2, [α/Fe] and [α/Fe]^2. Each term is only included if the fit is improved based on the resulting *rms* and χ^2 and the error of the correspondent fitting parameter is smaller than its value. Alonso et al. (1996) derived for a sample of F-G-K dwarfs a *rms* of 0.039 mag through a similar multi-parametric fit by including the cross term $\theta_{\rm eff}$.[Fe/H], but without adding any dependence on [α/Fe] and without splitting the stars in ranges of [Fe/H].

We will also consider an additional sample of 205 stars, whose spectra were collected with the 2.5 m Isaac Newton Telescope (Observatorio del Roque de Los Muchachos, La Palma, Spain) in 2011, employing the same instrumental setup as MILES.

3. Results for F-G-K types

The best multi-parametric polynomial fits for F, G and K types ($4750 \leq T_{\rm eff} < 7000$ K) and their five metallicity ranges have been derived (see Fig. 1). We have reached good agreement of our $(B-V)_o$ calibration for a sample of MILES F-G-K dwarfs against that calibration by Alonso et al. (1996), considering their same multi-parametric function with six terms and stellar parameters ranges. The derived fit rms are: 0.021 mag for the metal poor stars ($\chi^2 = 0.9815$), 0.015 mag for the intermediate metal poor stars ($\chi^2 = 0.9928$), 0.014 mag for the solar metallicity stars ($\chi^2 = 0.9943$), 0.019 mag for the intermediate metal rich stars ($\chi^2 = 0.9856$), and 0.022 mag for the metal rich stars ($\chi^2 = 0.9807$).

We have found a dependence of $(B-V)_o$ on [α/Fe] for intermediate metal poor, solar metallicity and intermediate metal rich stars. For instance, the resulting calibration *rms* for the solar metallicity stars, having just included a single linear term of [Fe/H], decreases from 0.017 mag down to 0.014 mag after adding both terms [α/Fe] and [α/Fe]^2. The relative errors of [α/Fe] fitting terms parameters are, respectively, about 12.5% and 20% in this case.

4. Summary

Our calibrations of $(B-V)_o$ for F-G-K types are quite reliable and provide an acceptable precision to compute this colour for a wide set of SSP models. We will present in a further work the $(B-V)_o$ calibrations for other spectral types as well as the whole set of $T_{\rm eff}$ calibrations as a function of $(B-V)_o$, [Fe/H] and [α/Fe] (already derived for F-G-K types only).

Acknowledgements. A. Milone thanks the Brazilian foundation CNPq/MCTIC (grant number 309562/2015-5). A. Vazdekis thanks the Spanish Ministry of Economy and Competitiveness (MINECO grant process AYA2016-77237-C3-1-P).

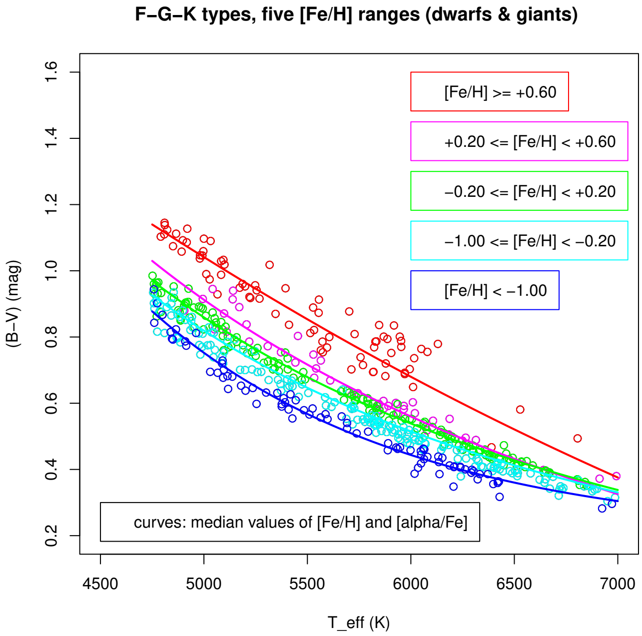

Figure 1. $(B-V)_o$ as a function of $T_{\rm eff}$ for F-G-K types over five [Fe/H] ranges. The colourful curves represent polynomial fits assuming median values of [Fe/H] and [α/Fe] of each subsample.

References

Alonso, A., Arribas, S., & Martinez-Roger, C. 1996, A&A, 313, 873

Castelli, F., & Kurucz, R. L. 1994, A&A, 281, 817

Johnson, H. L., & Morgan, W. W. 1953, ApJ, 117, 313

Pietrinferni, A., Cassisi, S., Salaris, M., & Castelli, F. 2004, ApJ, 612, 168

Pietrinferni, A., Cassisi, S., Salaris, M., & Castelli, F. 2006, ApJ, 642, 797

Sánchez-Blázquez, P., Peletier, R. F., Jimenez-Vicente, J., Cardiel, N., Cenarro, A. J., Falcón-Barroso, J., Gorgas, J., Selam, S., & Vazdekis, A. 2006, MNRAS, 371, 703