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Conference Report

Interstellar Reddening Effect on the Age Dating of Population II Stars

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Abstract: The age measurement of the stellar halo component of the Galaxy is based mainly on the comparison of the main sequence turn-off luminosity of the globular cluster (GC) stars with theoretical isochrones. The standard procedure includes a vertical shift, in order to account for the distance and extinction to the cluster, and a horizontal one, to compensate the reddening. However, the photometry is typically performed with broad-band filters where the shape of the stellar spectra introduces a shift of the effective wavelength response of the system, dependent on the effective temperature (or color index) of the star. The result is an increasing distortion—actually a rotation and a progressive compression with the temperature—of the color-magnitude diagrams relatively to the standard unreddened isochrones, with increasing reddening. This effect is usually negligible for reddening $E(B-V)$ on the order of or smaller than 0.15, but it can be quite relevant at larger extinction values. While the ratio of the absorption to the reddening is widely discussed in the literature, the importance of the latter effect is often overlooked. In this contribution, we present isochron simulations and discuss the expected effects on age dating of high-reddening globular clusters.

Keywords: interstellar matter; stellar evolution; galactic halo

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1. Introduction

Interstellar reddening causes a reduction of the flux received from the stars following the well-known Whitford law [1,2]. The relations between the absorption in different bands and the color excess are discussed widely in the literature and are well established (e.g., [3,4]). However, in practical cases of wide-band photometry, the interstellar extinction convolution with the spectra of stars having different T_{eff} also causes a shift in the effective wavelength of the bands, whose effects are not much considered in the literature.

The variation of the $R_V = A_V/E(B-V)$ ratio as a function of the intrinsic $(B-V)$ color was calculated by [5]. More recently, [6] published detailed results on the selective extinctions for stars with temperatures in the range $3500 \leq T_{eff}(K) \leq 40,000$, metallicities equal to $[Fe/H] = -2.0, -1.0$, and $+0.5$, and luminosity classes I, III, and V, based on Kurucz synthetic spectra and Scheffer interstellar extinction. They found that R_V changes by about 15% over the full temperature range. One of the main results of the paper is an increase of the R_V ratio for the spectral type of the stars most used in the extinction determination for globular clusters (GCs), and a consequent shortening of the distance scale in the Galaxy, but the result is biased by a relatively high choice of the normalization of R_V to a value of 3.346 at 17,000 K.

The large variation of R_V with spectral type has been confirmed by [7], which used the [8] library of spectra and a normalization $R_V = 3.07$ for Vega ($(B-V) = 0$)—considerably lower than Grebel and Roberts' assumption. The range of his results is roughly consistent with the original Schmidt–Kaler findings, with an increase of R_V up to 3.6 for the coolest stars.

Recent examples of extinction temperature-dependent corrections implemented in theoretical isochrones are from [9,10]. Although the basis of the stellar temperature dependence is well established, none of these papers clearly addressed the issue of the systematic effects of the reddening on GC ages derived from isochrone fitting in color-magnitude diagrams (CMDs).

In this contribution, we show how even a relatively moderate extinction $A_V = 1$ can produce a significant bias when the age is derived from main sequence (MS) turn off (TO) fitting using isochrones not corrected for temperature-dependent extinction. Our simulations include the Johnson BVI and ACS@HST F606W/F775W/F814W photometric bands.

2. Methodological Approach

Numerical simulations were perfomed with the BaSTI evolutionary models ([11,12], available at the following URL: http://www.oa-teramo.inaf.it/BASTI). We selected isochrones with age in the range 12.0–13.0 Gyr, for an $\alpha-$enhanced mixture $[\alpha/Fe] = +0.40$, metallicity Z = 0.004, and initial helium abundance Y = 0.256, corresponding to $[Fe/H] = -1.0$.

A temperature-dependent extinction with $A_V = 1$ and $A_V = 2$ has been applied to the isochrones (hereinafter *simulated isochrones*). To account for this effect, we used the web interface at http://stev.oapd.inaf.it/cgi-bin/cmd, which implements the results by [9] to determine the extinctions in the selected Johnson–Cousins (UBVI) and ACS@HST F606W, F775W, F814W photometric filters, covering the full range of effective temperature of our isochrones, for our selected A_V values. These extinctions are calculated assuming the extinction law by [3] with a reference $R_V = 3.1$. Finally, the simulated isochrones have been shifted and matched to the unreddened ones at two points: one on the MS at $M_V = 5.5$, and another one on the rising sub-giant branch (SGB).

Figure 1 shows the results in the $(V, B-V)$ CMD. The MS turn-off of the 12.0 Gyr reddened isochrone matches very well with that of the 12.5 Gyr one, if not corrected for temperature-dependent effects. This means that unreddened isochrones matched to the simulated one give an age older by about 0.5 Gyr at $A_V = 1$. With an extinction $A_V = 2$, the distortion of the shape of the simulated isochrone with respect to the unreddened ones causes a 12.0 Gyr reddened isochrone to overlap almost perfectly with the 13 Gyr unreddened one. In both cases, the derived older age is a consequence of the shorter color range spanned by the SGB. This is a consequence of the compression in color of the reddened isochrone, due to the relatively higher reddening of the hotter stars compared to the cooler ones. The effect of a lower MS TO luminosity—due to the higher extinction in the blue—is also present but less important.

As shown in Figure 2, this effect is reduced by about a factor of two in the $(V, V-I)$ CMD, due to the longer wavelengths of V/I bands compared to B/V, and the consequent smaller shift of the effective wavelengths with temperature. The conclusion is that a bias of ≈0.5–0.7 Gyr on the age estimate is produced only for an absorption $A_V = 2.0$ or larger.

The case of the ACS@HST photometric bands is shown in Figures 3 and 4. For the F775W/F606W CMD, the effect of the age bias is already very strong—about 1.5 Gyr—at $A_V = 1$, so we have not investigated the case $A_V = 2$. This effect is reduced in the F606W/F814W CMD. The higher sensitivity of extinction in the ACS@HST bands with stellar effective temperature of the ACS@HST is due to the wider wavelength range of the ACS filters compared to the Johnson counterparts. Whilst B and V have a typical FWHM around 100 nm, the ACS filters have a width ranging from 150 (F775W) to 250 nm (F606W and F804W).

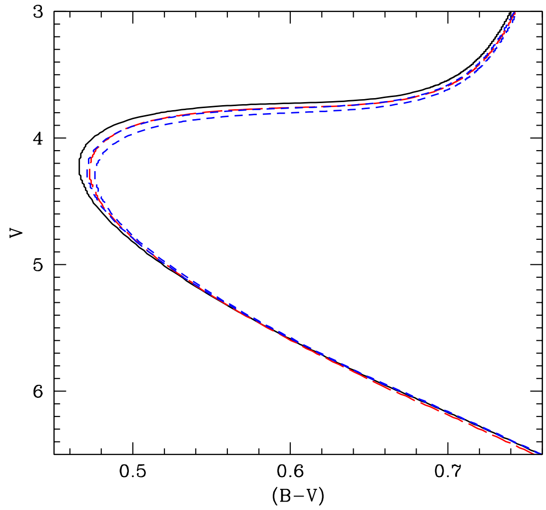

Figure 1. $(V, B - V)$ color-magnitude diagram (CMD) of a t = 12.0 Gyr simulated isochrones for $A_V = 1$ (red dashed line), compared to a set of unreddened isochrones with t = 12.0 (solid black line), 12.5, and 13.0 Gyr (dashed blue lines) according to the procedure discussed in the text.

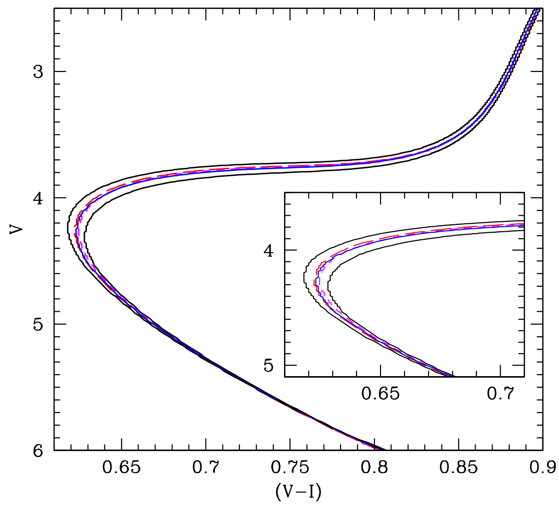

Figure 2. As Figure 1 but for the $(V, V - I)$ CMD, for two assumptions about A_V.

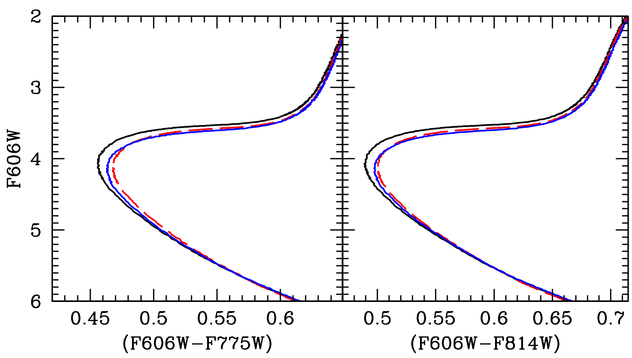

Figure 3. Left panel: as Figure 1, but for the $(F606W, F606W - F775W)$ ACS@HST CMD. **Right panel**: as left panel, but in the $(F606W, F606W - F814W)$ CMD.

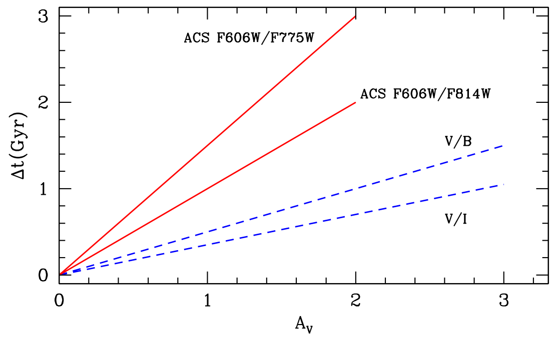

Figure 4. Bias on ages derived using isochrones accounting for T_{eff}-dependent extinction, compared to the case of neglecting this effect, for various A_V values and band combinations.

3. Final Remarks

In an age of Galactic GC surveys based on isochrone fitting without correction for T_{eff}-dependent extinction, systematic age trends can be introduced, because reddening is a function of Galactic latitude. Given the relation between galactocentric distance and galactic extinction, neglecting T_{eff}-dependent extinction can bias estimated ages depending on the GC position in the Galaxy. The effect is generally very small at large galactocentric distances, but in the inner halo/bulge, at galactocentric distances shorter than 5 Kpc, most of the GCs have visual extinctions larger than $A_V = 1.0$. In these cases, neglecting T_{eff}-dependent extinction causes a bias towards ages older by more than 0.5 Gyr when using the Johnson B/V bands, this figure increasing by a factor of two in optical ACS bands. In a forthcoming paper, we plan to investigate the impact of using appropriate T_{eff}-dependent extinction corrections on GC age dating, based on the use of the standard horizontal and vertical methods (see [13] and references therein).

Author Contributions: All authors have equally contributed to the analysis of the data and the writing of the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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