IMPACT OF THE LOW SOLAR ABUNDANCE ON THE AGES OF GLOBULAR CLUSTERS

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ABSTRACT

We present the result of our investigation on the impact of the low Solar abundance of Asplund and collaborators (2004) on the derived ages for the oldest star clusters based on isochrone fittings. We have constructed new stellar models and corresponding isochrones using this new solar mixture with a proper Solar calibration. We have found that the use of the Asplund et al. (2004) metallicity causes the typical ages for old globular clusters in the Milky Way to be increased roughly by 10%. Although this may appear small, it has a significant impact on the interpretation for the formation epoch of Milky Way globular clusters. The Asplund et al. (2004) abundance may not necessarily threaten the current concordance cosmology but would suggest that Milky Way globular clusters formed before the reionization epoch and before the main galaxy body starts to build up. This is in contrast to the current understanding on the galaxy formation.

Key words : stars: evolution — globular clusters: general — galaxies: formation — cosmology: miscellaneous

1. INTRODUCTION

The Solar mixture of Asplund et al. (2004) suggests a surprisingly-low metallicity for the Solar atmosphere, $Z/X = 0.0165$, compared to the previous estimates (e.g., $Z/X = 0.0231$; Grevesse & Sauval 1998). Their mixture has been challenged by a few studies since then (e.g., Basu & Antia 2004; Landi et al. 2007; Centeno & Socas-Navarro 2008). Although they recently have revised their mixture whose $Z/X = 0.0181$ (Asplund et al. 2009), it is still uncomfortably lower than the values regarded in general. It obviously would have profound impact on many subfields of astronomy if the abundance is found to be true.

In this paper, we present the result of our investigation on its impact on the age derivation for globular clusters based on isochrone fittings. We have adopted Asplund et al. (2004) mixture which is more extreme. Old globular clusters in the Milky Way galaxy are often considered the oldest stellar objects in the universe and thus place an important constraint to our cosmological paradigm.

Stellar isochrones are the most powerful and thus widely-used tools for deriving the ages of globular clusters. This is possible mainly because globular clusters are considered "simple" stellar populations that are composed of stars of effectively the same age and chemical composition. The validity of the "simple" population assumption is challenged by a number of recent studies that found multiple stellar populations in some

globular clusters (e.g., Bedin et al. 2005; Norris 2004; Piotto et al. 2005), yet globular clusters are still the simplest populations we know of.

Numerous improvements in microphysics, such as opacities and equations of states, have polished stellar models steadily, and we now boast knowing the ages of globular clusters and thus the lower limit on the age of the universe with unprecedented accuracy (e.g., for globular cluster ages Marin-Franch et al. (2009, 2010); for stellar ages Soderblom (2010)). Together with the recent advances in the cosmological understanding, notably from cosmic microwave background radiation and dark matter/energy studies, this has finally led us to achieve a concordance model in the big bang paradigm. The basic teachings of the concordance model include the age of the universe, roughly 13.7 Gyr (Komatsu et al. 2010), the existence of reionization at roughly 1 billion years after the big bang (Becker et al. 2001; Dunkley et al. 2009; Komatsu et al. 2010), and the formation of galaxies after reionization. First stars, deemed responsible for reionization, were the only astronomical objects that are considered to have been formed before reionization, and their traces are found only in the metal abundance in population II stars. In conclusion, no stellar objects are expected in the concordance cosmology to have ages greater than 13 billion years. In this paper we show how the recent Solar mixture affects the derived ages of globular clusters and such a concordance prediction.
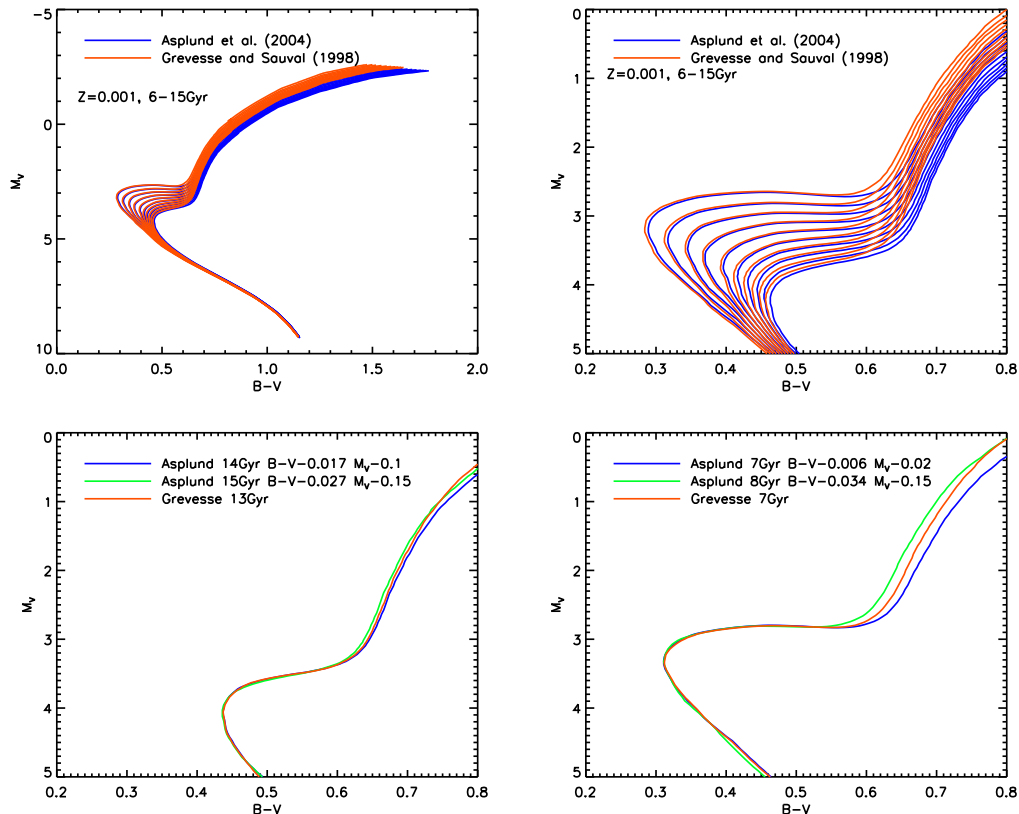

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Fig. 1.— The isochrones based on the previous Grevesse and Sauval (1998) mixture and the recent Asplund et al. (2004) mixture. (top left) Isochrones for $X = 0.767$, $Z = 0.001$, $[\alpha/Fe] = 0.3$, and ages = 6 through 15 Gyr with 1Gyr spacing. (top right) Zoom-in figure of the top left panel. (bottom left) The 14Gyr isochrone based on the Asplund et al. (2004) mixture closely reproduces the 13Gyr isochrone based on the Grevesse & Sauval mixture. (bottom right) The 8Gyr isochrone based on the Asplund et al. (2004) mixture closely reproduces the 7Gyr isochrone based on the Grevesse & Sauval mixture.

2.   STELLAR MODEL CONSTRUCTION

We have used the Yale stellar evolution code, $YREC$, to construct stellar models. For the reference model, we have adopted the Grevesse & Sauval (1998) mixture for the Sun. For our comparison model, we use the recent Asplund et al. (2004) mixture. Other microphysics prescriptions were kept the same. The input physics details can be found in Yi et al. (2001) and Kim et al. (2002). In order to construct the isochrones for the age range 6 – 15 Gyr that extend to the tip of the RGB, we have constructed stellar models of mass $0.4 - 1.2 \, M_\odot$ with $0.05 \, M_\odot$ spacings.

Our stellar models, regardless of the choice of the Solar mixture, have been calibrated against the sun, following the standard practise as described in Yi et al. (2001). The mixing length parameters of $l/H_p = 1.811$ and 1.742 have been found to match the Solar properties for the Grevesse & Sauval (1998) and Asplund et al. (2004) mixtures, respectively. A lower value of metallicity causes lower opacities in the Solar atmosphere which make it easier for photons to escape the

Sun. This causes a reduction in the stellar radius. A smaller value of mixing length parameter counteracts this effect.

3.   IMPACT ON THE AGE ESTIMATES

Isochrones are used for age derivations mainly in two approaches. One is to use the width between the main-sequence turn off and the bottom of the red giant branch, a.k.a. the $\Delta(B - V)$ method. The other is to use the height of the horizontal branch measured from the main-sequence turn off. Reviews are available on these techniques (e.g., VandenBerg et al. 1996; Sarajedini et al. 1997).

3.1 $\Delta(B - V)$ Method

Fig. 1 shows the result of our comparison for a typical metal-poor populations ($Z = 0.001$) using the $\Delta(B - V)$ method. The top panels show the isochrones for the two Solar mixtures. A cursory inspection might suggest little impact. But the lower panels suggest otherwise. The lower panels compare the two sets of
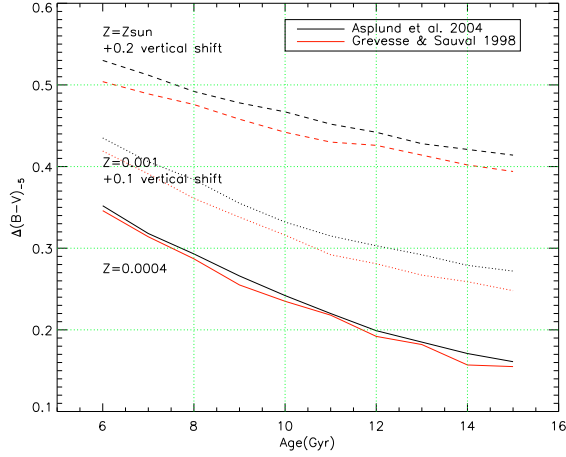
Fig. 2.— The $\Delta(B-V)$ as a function of age for three different metallicities and two different mixtures. For visual clarity, vertical shifts were applied to the two more metal-rich models. For given values of $\Delta(B-V)$ the use of Asplund et al. (2004) mixture suggests systematically larger ages.

isochrones at two different ages, 13Gyr (left) and 7Gyr (right). The width between the main-sequence turn off and the bottom of the sub giant branch (hereafter, $\Delta(B-V)$) has become larger as we switched the mixture from Grevesse & Sauval (1998) to Asplund et al. (2004). The use of Asplund et al. (2004) mixture suggests a larger age by 7–8 percent for this age range and metallicity. Similar exercises for other metallicities yield different amounts of age increase. Isochrone ages increase roughly by 5–8, 7–8, and 14–15 percent as we change the metallicity from $Z = 0.0001$, through 0.001 and to the Solar metallicity. That is, the impact of the mixture on age estimates is greater for higher metallicities, as expected.

The evolution of $\Delta(B-V)$ with time and the impact of the change of the Solar mixture are more clearly illustrated in Fig. 2. We measure $\Delta(B-V)$ as a horizontal distance in the color-magnitude diagram between the main-sequence turn off (the bluest point) and the base of the subgiant branch. We made an arbitrary decision for the location of the base of the subgiant branch, that is, the place where the slope of $\delta M_V/\delta(B-V) = -5$. The change of this criterion does not make a significant impact on the result.

Fig. 3 shows the isochrone fits to the observed data for the globular cluster M68. The data are from Walker (1994; private comm.). The estimates of [Fe/H] and reddening are from Harris (1996), and [α/Fe]=0.3 has been adopted following the halo observations. It shows that one can achieve the same quality isochrone fits regardless of the choice of the mixture.
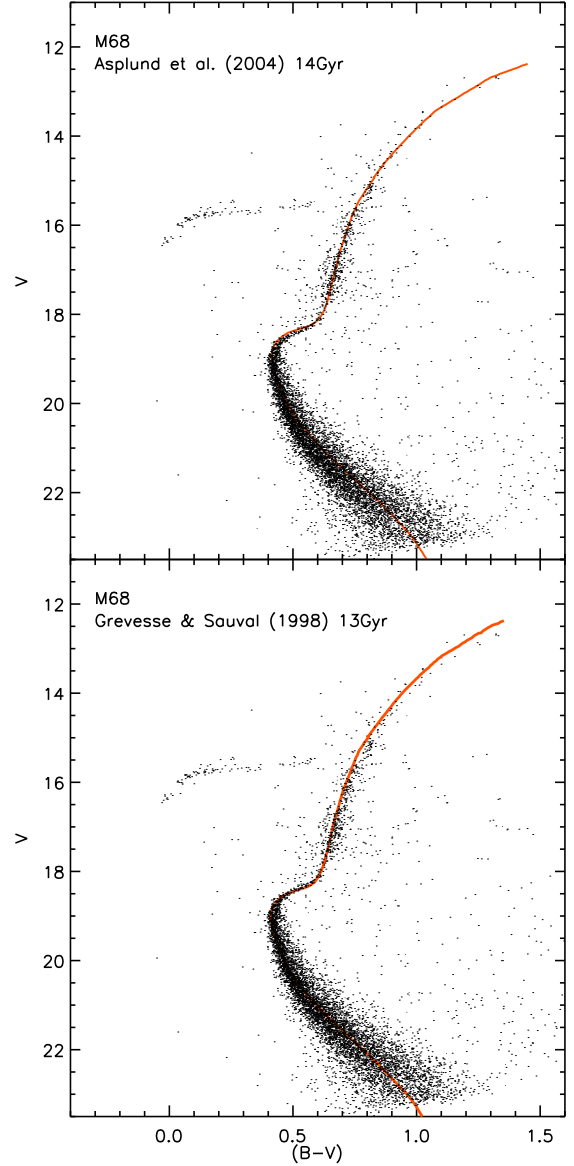

Fig. 3.— Sample isochrone fits to the data of M68 using the Asplund et al. (2004) mixture (top) or the Grevesse & Sauval (1998) mixture (bottom). Cluster properties were kept the same: [Fe/H] $= -2.10$, $E(B-V) = 0.02$, $(m-M)_V = 15.17$.

3.2 $\Delta M_V(\mathrm{ZAHB}-\mathrm{TO})$ Method

We do not have the horizontal branch stellar models yet for the recent mixture. So in this work we compare just the main-sequence brightness when the two different mixtures are used. Fig. 4 shows the main-sequence turn-off luminosity for the age range of 6 – 15Gyr. For sub-solar metallicities, the brightness difference is negligible. The difference becomes notable for the solar metallicity, obviously because the two mix-
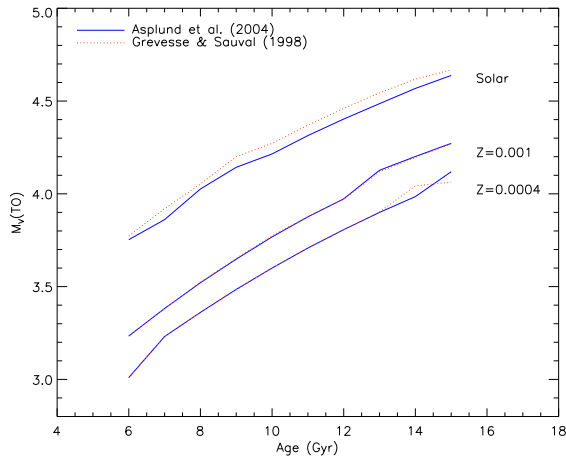
Fig. 4.— The magnitude difference at the main-sequence turn off with respect to age, based on the two different mixtures.

tures assume different metallicities for the Sun. For the typical metallicity range for metal-poor globular clusters, that is, $Z = 0.0001 - 0.001$, the choice of the Solar mixture does not appear to affect much the main-sequence brightness and thus $\Delta M_V(\mathrm{ZAHB-TO})$-based isochrone ages. Degl'Innocenti et al. (2006) have explored this effect and concluded that the maximum variation in the age estimates is of the order of 10% but only in young star clusters. Our investigation on this vertical method is incomplete and a more thorough analysis would require horizontal-branch stellar models in addition.

4. DISCUSSION

The arguably more robust age derivation method, the $\Delta(B-V)$ method, is somewhat sensitive to the choice of Solar mixture. The ages of old metal-poor globular clusters would be roughly 5–10% larger if the recent Asplund et al. (2004) mixture is adopted. The magnitude of the sensitivity may appear small but significant from the perspective of galaxy formation. The typical age of old metal-poor globular clusters would become substantially larger than 13Gyr, which is very close to the current estimate for the age of the universe based on the concordance model. This may have an important implication to the current understanding on the formation of the first and second generations of stars. If many of the Milky Way globular clusters indeed formed at the epoch so close to the age of the universe, it could mean that they formed even before the reionization. This would be logically implausible considering that these clusters already have non-zero metallicities and would not have had enough time to be chemically enriched. In this respect, the recent Asplund et al. (2004) mixture appears incompatible with the concordance picture of cosmology and galaxy for-

mation.

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