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The chemical composition of AGB stars in globular clusters

A. Mucciarelli

Dipartimento di Fisica & Astronomia, Università degli Studi di Bologna, Viale Berti Pichat, 6/2 - 40127 Bologna, Italy, e-mail: alessio.mucciarelli2@unibo.it

Abstract. We discuss the iron abundance of asymptotic giant branch (AGB) and red giant branch (RGB) stars in four Galactic globular clusters, namely 47 Tucanae, M62, NGC 3201 and M22, based on high-resolution spectra. In the majority of the AGB stars, [FeI/H] abundances are significantly lower than [FeII/H], the latter being, instead, in agreement with those measured for RGB stars (where abundances from Fe I and Fe II lines match well each other). This behavior is qualitatively similar to that expected in the case of non-local thermodynamical equilibrium driven by over-ionization. This effect has a significant impact also on the determination of the metallicity in globular clusters suspected to have an intrinsic iron spread, like NGC 3201 and M22. When their stars are analysed by adopting photometric gravities and Fe II lines, these two clusters turn out to be mono-metallic.

Key words. Stars: abundances – Stars: atmospheres – Stars: Population II – Galaxy: globular clusters

1. Introduction

The asymptotic giant branch (AGB) stage is the last evolutionary phase characterized by thermonuclear burning for low- and intermediate-mass stars (M<8$M_{\odot}$). AGB stars are known to dominate the integrated light of intermediate-age stellar systems (see e.g. Renzini & Buzzoni 1986; Cioni & Habing 2003; Maraston 2005; Mucciarelli et al. 2006) and to play a crucial role in the chemical enrichment processes of cosmic structures. They are the main sites where elements heavier than the Fe-peak are formed, through slow neutron captures (Busso, Gallino & Wasserburg 1999). Also, their interiors can reach temperatures high enough to activate the proton-capture reaction chains, like the NeNa and the MgAl chains. Thus, intermediate-mass AGB stars are also considered to be responsible for the chemical anomalies detected in all the old globular clusters (GCs) in the Milky Way (Carretta et al. 2009) and in the Large Magellanic Cloud (Mucciarelli et al. 2009).

Despite their luminosity, the AGB stars are still not well studied from the chemical point of view. Only a few works have investigated the chemical composition of AGB stars in GCs (see e.g. Ivans et al. 2001; Worley et al. 2009; Campbell et al. 2013). Here we present the results concerning the determination of [Fe/H] in AGB stars of four Galactic GCs, namely 47 Tucanae, M62, NGC 3201 and M22, by using high-quality, high-resolution spectra collected with UVES@VLT, FLAMES-UVES@VLT and FEROS@MPG/ESO-2.2m.

2. 47 Tucanae

Lapenna et al. (2014) analysed a sample of 24 AGB stars members of the GC 47 Tucanae, by using high-resolution spectra collected with the FEROS spectrograph at the MPG/ESO-2.2m telescope (see the position of the targets on the color-magnitude diagram in Fig. 1). A sample of 11 red giant branch (RGB) cluster stars observed with FLAMES-UVES@VLT has been analysed as reference. Effective temperatures and surface gravities have been obtained from the photometry.

For the AGB stars we derived average iron abundances [FeI/H]=–0.94±0.01 dex and [FeII/H]=–0.83±0.01 dex (see right panel of Fig. 1). On the other hand, for the RGB stars we obtained [FeI/H]=–0.83±0.01 dex and [FeII/H]=–0.84±0.01 dex.

While the iron abundance estimated from single-ionized lines in AGB stars well matches that obtained for RGB stars, the value measured from neutral lines is systematically lower. We carefully checked all the steps of our chemical analysis procedure and the adopted atmospheric parameters, finding no ways to alleviate this discrepancy. In particular, the surface gravity can have a significant impact on the difference between [FeI/H] and [FeII/H], because it affects mainly the ionized lines, with a null impact on the neutral lines. We compared the photometric gravities with those derived by using the *ionization balance* (by imposing the same abundances from Fe I and Fe II lines). The spectroscopic gravities are on average lower than the photometric ones by 0.25 dex, with a maximum difference of ~0.5 dex. This set of gravities leads to [FeI/H] and [FeII/H] abundances systematically lower than the abundances measured in RGB stars. Also, these gravities would require that stars reach the AGB phase with an average of ~ $0.4M_{\odot}$. This value is lower than that expected by considering a main sequence turnoff mass of $0.9M_{\odot}$ and a ~ $0.25M_{\odot}$ mass loss during the RGB phase (Origlia et al. 2014).

The metallicity of the AGB stars well matches with that measured in RGB stars only when photometric gravities and Fe II lines are used. A possible working hypothesis to explain the different behavior of [FeI/H] and [FeII/H] in the AGB stars is that these stars could be affected by non-local thermodynamical equilibrium (NLTE) driven by overionization. These effects are known to affect mainly the less abundant species, like Fe I, and to leave unaltered the dominant species, like Fe II (see e.g. Thevenin & Idiart 1999; Asplund 2005; Mashonkina et al. 2011; Lind, Bergemann & Asplund 2012; Bergemann & Nordlander 2014). The difference between [FeI/H] and [FeII/H] observed in AGB stars is qualitatively compatible with the occurrence of NLTE effects but this finding challenges the available NLTE calculations (Lind, Bergemann & Asplund 2012) that predict similar corrections for AGB and RGB stars like those measured in 47 Tucanae.

3. M62

A similar result has been recently found for the GC M62. Lapenna et al. (2015) analysed high-resolution FLAMES-UVES spectra for 6 AGB stars and 13 RGB stars. The abundances from Fe I lines in AGB stars are significantly underestimated with respect to those obtained from Fe II lines. The latter agree well with those derived in RGB stars, both from neutral and single ionized lines. A similar finding is found when the titanium lines are analysed, being titanium the only other chemical species presenting a large number of neutral and single ionized lines.

4. NGC 3201

The results obtained for the AGB stars in 47 Tucanae and M62 have a significant impact on the approach traditionally adopted for the chemical analysis in giant stars. In particular: (i) the Fe I lines should be not used to determine the iron abundance of AGB stars. The [FeI/H] abundance ratio is systematically lower than that obtained from Fe II lines both with photometric and spectroscopic gravities. The most reliable route to derive the iron abundance in AGB stars is to use the Fe II lines, that are essentially unaffected by NLTE effects and provide the same abundances for both RGB

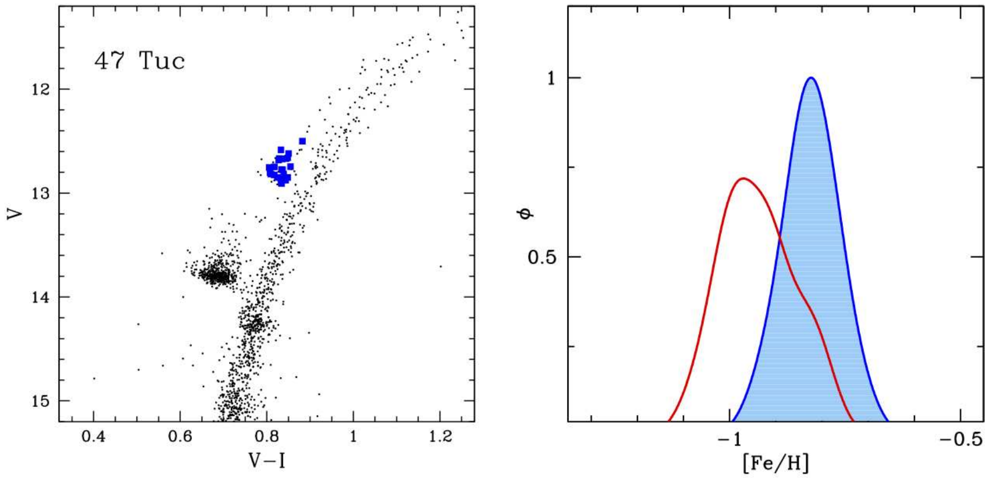

Fig. 1. *Left panel:* The color-magnitude diagram of 47 Tucanae with marked, as blue squares, the AGB stars analysed by Lapenna et al. (2014). *Right panel:* The generalized histograms of [FeI/H] (red histogram) and [FeII/H] (blue histogram) abundances for the AGB stars in 47 Tucanaes, as obtained by adopting photometric gravities.

and AGB stars. (ii) AGB stars must be analysed by using the photometric gravities and not adopting gravities derived through the *ionization balance* (at variance with the case of RGB stars where this approach is still valid).

If the Fe I lines are used to derive the iron abundance in a sample including both AGB and RGB stars, this approach could lead to a spurious detection of large iron spreads, because [FeI/H] in AGB stars will be systematically lower than those measured in RGB stars of the same GC.

Following these considerations, Mucciarelli et al. (2015a) discussed the case of the GC NGC 3201. Simmerer et al. (2013) analysed FLAMES-UVES spectra for giant stars of this cluster, finding a metallicity distribution as large as 0.4 dex, not explainable within the uncertainties. This iron spread, qualitatively similar to that observed in the candidate anomalous cluster M22 (Marino et al. 2009) would make NGC 3201 the least massive cluster with evidence of supernovae ejecta retention. The analysis performed by Simmerer et al. (2013) is based on spectroscopic gravities, thus we re-analysed the spectra with two different approaches. First, we performed a fully spectroscopic analysis, as done by Simmerer et al. (2013), deriving the surface gravities by imposing the *ionization balance*. We derived [FeI/H]=–1.46±0.02 dex and [FeII/H]=–1.48±0.02 dex (red and blue histograms, respectively, in the left panel of Fig. 2). This result matches well that obtained by Simmerer et al. (2013) and suggests a clear star-to-star scatter in the iron content. On the other hand, when the surface gravities are derived photometrically, the [FeI/H] and [FeII/H] distributions are quite different. The iron distribution obtained from Fe I lines (red histogram in the right panel of Fig. 2) resembles that obtained with the spectroscopic parameters, while the distribution obtained from Fe II lines has a narrow gaussian-shape (fully compatible within the uncertainties), pointing to a quite homogeneous iron content.

The inspection of the position of these targets on the color-magnitude diagram reveals that the stars with the lower [FeI/H] abundance (and labelled as metal-poor by Simmerer et al. 2013) are AGB stars and their inclusion in the sample, coupled with the use of spectroscopic gravities, leads to a spuriously broad iron distribution.

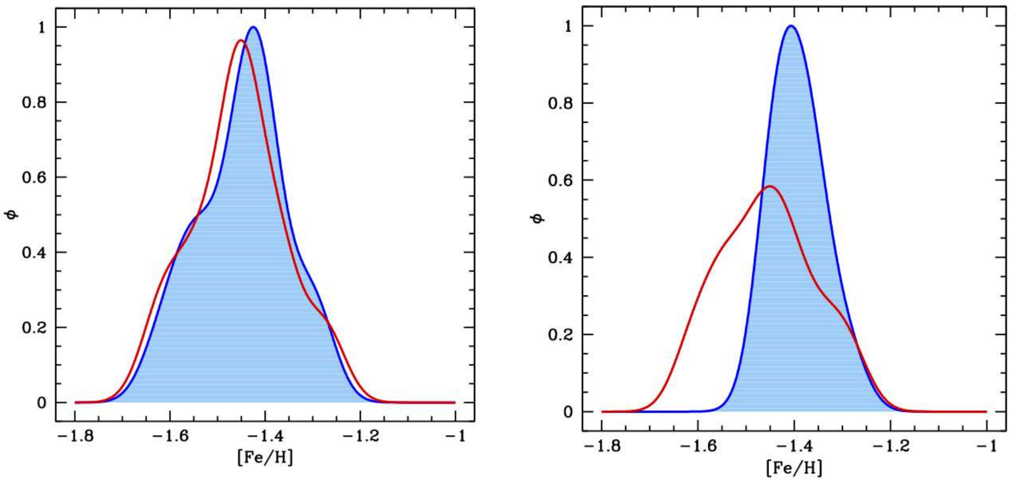

Fig. 2. Generalized histograms for [FeI/H] (red histograms) and [FeII/H] (blue histograms) for the stars of NGC 3201 analysed with spectroscopic (left panel) and photometric (right panel) gravities.

5. M22

As demonstrated by the case of NGC 3201, the analysis of GCs suspected to have an intrinsic Fe spread deserves a particular care, in particular to avoid possible spurious effects. We have re-analysed the case of M22, a metal-poor globular cluster suspected to have an intrinsic Fe spread since forty years, because of the broad colour distribution of its RGB in the color-magnitude diagram. Recently, Marino et al.(2009) and Marino et al.(2011) analysed high-resolution spectra for giant stars members of M22 finding the presence of two groups of stars, distinct in their chemical composition. In particular, the group enriched in [Fe/H] is also enriched in the C+N+O and s-process elements abundances. Mucciarelli et al. (2015b) re-analysed the sample of 17 giant stars already discussed by Marino et al.(2009). As done in the case of NGC 3201, this sample has been analysed adopting two different approaches to derive the surface gravities, by imposing the *ionization balance* and by using the photometry. Also for M22, a clear difference is found between the results obtained with these two approaches. When spectroscopic gravities are used, the distributions of [FeI/H] and [FeII/H] are very similar each other and broad, pointing out an intrinsic iron scatter. On the other hand, the use of photometric gravities leads to [FeI/H] and [FeII/H] distributions different each other (similar to the case of NGC 3201): Fe II lines provide a narrow metallicity distribution, fully compatible within the uncertainties and demonstrating that M22 is a mono-metallic cluster.

Five targets are likely AGB stars. Four of them show large differences between [FeI/H] and [FeII/H], confirming the findings obtained in the other clusters. However, the situation in M22 is more complex, because a large difference between [FeI/H] and [FeII/H] is found also in most of the RGB stars and not only in AGB stars.

6. Conclusions

The results obtained for four Galactic globular clusters show that in AGB stars the abundances from Fe I lines are systematically lower than those from Fe II lines, while the two abundance agree each other in RGB stars. A possible explanation is that AGB stars are affected by NLTE effects. The best approach to analyse AGB stars is to use Fe II lines coupled with photometric gravities. Also, any claim of intrinsic iron spread in GCs should be always confirmed by using the same approach.

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