Mem. S.A.It. Vol. 87, 650

Memorie della

Unexpected results from AGB star spectroscopy

E. Lapenna,[1,2] on behalf of the Cosmic-Lab team

[1] Dipartimento di Fisica e Astronomia, Università di Bologna, Viale Berti Pichat 6/2, I–40127 Bologna, Italy, e-mail: emilio.lapenna2@unibo.it
[2] INAF - Osservatorio Astronomico di Bologna, Via Ranzani 1 - 40127 Bologna, Italy

Abstract. We derived chemical abundances for C, N, O, Na and Al in 20 asymptotic giant branch (AGB) stars in the globular cluster NGC 6752. All these elements show intrinsic star-to-star variations and statistically significant correlations or anticorrelations analogous to those commonly observed in red giant stars of globular clusters hosting multiple populations. This demonstrates that, at odds with previous findings, both first and second generation stars populate the AGB of NGC 6752. The comparison with the Na abundances of red giant branch stars in the same cluster reveals that second generation stars (with mild Na and He enrichment) do reach the AGB phase.

Key words. globular clusters: individual (NGC 6752) – stars: abundances – stars: AGB and post-AGB — techniques: spectroscopic

1. Introduction

The vast majority of Galactic globular clusters (GCs) host multiple stellar populations (MPs) characterized by different light elements abundance ratios. The typical chemical elements showing peculiar patterns are C, N, O, Na, Mg and Al. The patterns are not random, but anticorrelated variations of the pairs C-N and O-Na are commonly observed. These are generally considered to arise from two stellar populations, the second one being formed from the ejecta of hot hydrogen burning processes occurred in a previous generation of more massive stars, as asymptotic giant branch (AGB) stars (Ventura & D'Antona 2005), fast-rotating massive stars (Decressin et al. 2007), interacting massive binary stars (De Mink et al. 2009), and/or super-massive stars (Denissenkov & Hartwick 2014). Objects with standard composition are commonly denoted as first generation (FG) stars, and those with modified chemistry as second generation (SG) stars. In a few GCs the SG/FG star number ratio measured along the red giant branch (RGB) is observed to differ from that measured along the AGB, with a substantial deficiency of SG stars within the AGB population, compared to the RGB (Norris et al. 1981; Gratton et al. 2010a; Campbell et al. 2012, 2013; Johnson et al. 2015; Lapenna et al. 2015; MacLean et al. 2016). *In principle, this can be explained by taking into account that SG stars are expected to have lower masses along the HB with respect to FG stars, and stars with evolving masses below* $0.55 M_{\odot}$ *are indeed expected to fail reaching the AGB phase (the so-called "AGB-manqué" stars).* Within the family of Galactic GCs that show extreme blue HB morphology and a complete lack of SG stars along the AGB, we find the metal-intermediate GC NGC 6752 (Campbell et al. 2013, hereafter

C13). These authors measured the Na abundance of 20 AGB stars in NGC 6752 and, from the derived [Na/Fe] distribution, they concluded that all objects belong to the FG population. In their interpretation, the SG stars fail to reach the AGB phase because their HB progenitors were all located at effective temperatures ($T_{\rm eff}$) hotter than the Grundahl Jump (at ∼11 500 K) and experienced a very strong mass loss (a factor of 20 larger than that suffered along the RGB). This quite unexpected result has been debated by several other studies, suggesting alternative explanations. For instance, Charbonnel et al. (2013) argued that the lack of SG AGB stars can be explained within the fast-rotating massive stars scenario by assuming very high He abundances (up to Y ∼0.7) for the SG objects, and Cassisi et al. (2014) were able to reproduce the star distribution along the HB of NGC 6752 by assuming the canonical initial He-abundance distribution and without invoking any extreme HB mass loss.

2. Observations and chemical analysis

The 20 AGB stars previously studied by C13 have been re-observed (program 095.D-0320(A), PI: Mucciarelli) with the UVES spectrograph mounted at the ESO Very Large Telescope. We used the Dichroic1 mode, adopting the gratings 390 Blue Arm CD#2 and 580 Red Arm CD#3, with the 1″ slit (R = 40000). The obtained spectra have signal-to-noise ratios larger than 100.

The chemical analysis has been performed following the same procedure described in Lapenna et al. (2015). The stellar atmospheric parameters have been derived as follows:

(1) $T_{\rm eff}$ have been derived spectroscopically by requiring no trend between iron abundances and excitation potentials;
(2) surface gravities ($\log g$) have been obtained through the Stefan-Boltzmann relation;
(3) microturbulent velocities (v_t) have been obtained by requiring no trend between iron abundances and line strengths.

The abundances of Fe, Na, Mg, and Al have been derived using the classical method of the equivalent widths, while the abundances of C, N and O have been derive through the spectral synthesis technique. The abundances of Na have been corrected for NLTE effects according to Gratton et al. (1999) and consistently with the analysis of C13.

3. Results

3.1. Iron abundances

For the 20 AGB stars we obtain average [FeI/H] = −1.80 ± 0.01 dex (σ = 0.05 dex) and [FeII/H] = −1.58 ± 0.01 dex (σ = 0.02 dex). The average [FeII/H] abundance is consistent with the values measured in RGB stars by Yong et al. (2003), Gratton et al. (2005) and Carretta et al. (2007, 2009b), while [FeI/H] is 0.22 dex lower than the metallicity inferred from FeII lines. Such a discrepancy between [FeI/H] and [FeII/H] among AGB stars is too large to be explained within internal uncertainties and has been already observed in other GCs (Ivans et al. 2001; Lapenna et al. 2014, 2015; Mucciarelli et al. 2015a,b). The same [FeI/H]-[FeII/H] discrepancy remains also if we adopt the atmospheric parameters quoted in C13.[1] With their atmospheric parameters we obtain [FeI/H]=−1.77 ± 0.01 dex (σ = 0.05 dex) and [FeII/H]=−1.50 ± 0.01 dex (σ = 0.02 dex). Even if a complete explanation of this effect is still lacking, this iron discrepancy seems to be a general feature of AGB stars in GCs.

3.2. Light elements

In Figure 1 we present several combinations of the abundances of light-elements derived for the 20 AGB stars. In each panel, the abundances appear to be mutually correlated: in fact we can appreciate clear C-N and O-Na anticorrelations, and N-Na and Na-Al correlations, both if we consider the abundance ratios referred to Fe, and if we normalize to H.

[1] Note that C13 do not measure directly the Fe abundance, but, for all the targets, they assume the average [Fe/H] of RGB stars derived by Carretta et al. (2007).

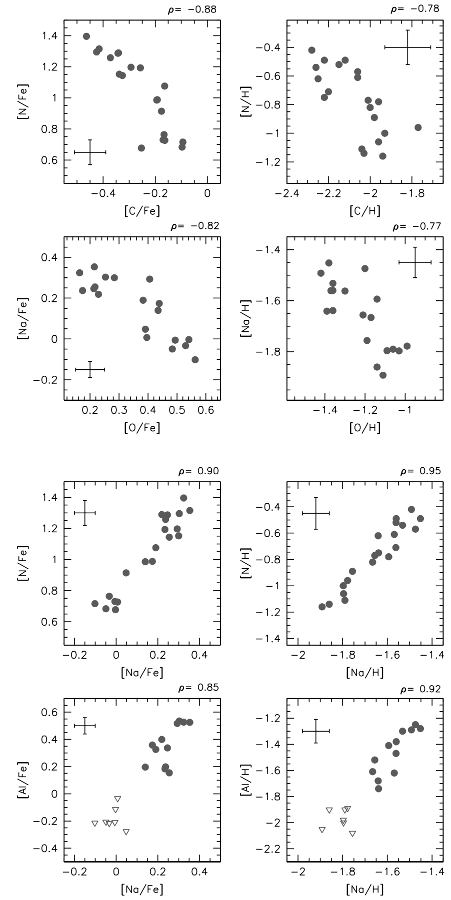

Fig. 1. Light-element abundances measured for the investigated AGB stars. All abundance ratios are shown normalized both to iron and to hydrogen. The typical errorbars of the measured abundances and the Spearman rank coefficients of every correlation are marked in each panel. In the bottom panels the empty triangles mark the stars for which only upper limits to [Al/Fe] have been derived.

In all cases, the statistical significance, as measured by the Spearman rank coefficients $|\rho|$, is very high (values of $|\rho|$ larger than 0.74 corresponds to non-correlation probabilities lower than $\sim 10^{-4}$).

The existence of such well-defined correlations, by itself, clearly indicates that the AGB stars of NGC 6752 do not share the same chemical composition. This suggests the presence of multiple sub-populations along the AGB. By definition, in fact, a sample composed exclusively of FG stars (as suggested by C13) would display homogeneous abundances and produce no correlations. Indeed, the detected correlations are perfectly in agreement with those commonly ascribed to FG and SG sub-populations in GCs (see, e.g., Carretta et al. 2009a,b).

4. Conclusions

Figure 2 shows the AGB population (solid circles) of NGC 6752 in the "standard" [Na/Fe]−[O/Fe] plane. For reference, we also plot the results obtained for the RGB population of NGC 6752 (empty squares, from Yong et al. 2003) and several RGB samples in 19 GCs (gray dots, from Carretta et al. 2009a). The AGB population of NGC 6752 clearly outlines and follows the anti-correlation stream defined by the RGB samples, thus confirming the existence of SG stars along the AGB of NGC 6752. To better characterize the cluster sub-populations, in Figure 2 we also plot three ellipses corresponding to the values of [Na/Fe] and [O/Fe] that Milone et al. (2013), on the basis of their photometric study and the chemical abundances measured by Yong et al. (2003), associate to the FG, SG and extreme SG subsamples in NGC 6752 (see Figure 15 in Milone et al. 2013). Notably, the abundances here determined for the AGB population nicely match the FG and SG loci, thus demonstrating that, at odds with the claim of C13, also SG stars do experience the AGB phase in NGC 6752.

Therefore, the observed fraction of failed AGB stars in NGC 6752 can be easily explained within the standard stellar evolution framework, with no need of invoking exceptional mass loss for HB stars hotter than the Grundahl jump (C13), or extremely high initial He abundances (inconsistent with the photometric constraints from the main sequence) for the SG population (Charbonnel et al. 2013).

The full discussion of the results presented here can be found in Lapenna et al. (2016).

Acknowledgements. EL acknowledges the financial support from PRIN-INAF 2014.

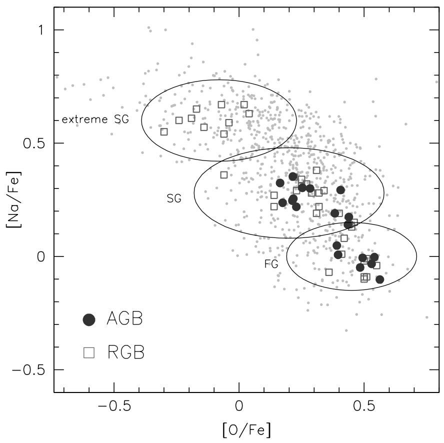

Fig. 2. Behavior of [Na/Fe] as a function of [O/Fe] for the AGB stars (filled circles, this work) and RGB stars (open squares Yong et al. 2003) of NGC 6752. The results obtained for RGB stars in other GCs (Carretta et al. 2009a), rescaled to the solar values adopted in this work, are shown as gray dots for reference. The regions corresponding to the three populations (FG, SG and extreme SG) identified by Milone et al. (2013, see their Figure 15) are encircled and labelled.

References

Campbell, S. W., Yong, D., Wylie-de Boer, et al. 2012, ASP Conf. Ser., 458, 205
Campbell, S. W., D'Orazi, V., Yong, D., et al. 2013, Nature, 498, 198
Carretta, E., et al. 2007, A&A, 464, 92
Carretta, E., Bragaglia, A., Gratton, R. G., et al. 2009, A&A, 505, 117
Carretta, E., et al. 2009, A&A, 505, 139
Cassisi, S., & Salaris, M. 2013, Old Stellar Populations: How to Study the Fossil Record of Galaxy Formation (Wiley-VCH, Weinheim, Germany)
Cassisi, S., et al. 2014, A&A, 571, A81
Charbonnel, C., et al. 2013, A&A, 557, L17
Decressin, T., et al. 2007, A&A, 464, 1029
De Mink, S. E., et al. 2009, A&A, 507, L1
Denissonkov, P. A., & Hartwick, F. D. A. 2014, MNRAS, 437, 21
Johnson, C. I., McDonald, I., Pilachowski, C. A., et al. 2015, AJ, 149, 71
Ivans, I. I., Kraft, R. P., Sneden, C., et al. 2001, AJ, 122, 1438
Lapenna, E., Mucciarelli, A., Lanzoni, B., et al. 2014, ApJ, 797, 124
Lapenna, E., Mucciarelli, A., Ferraro, F. R., et al. 2015, ApJ, 813, 97
Lapenna, E., Lardo, C., Mucciarelli, A., et al. 2016, ApJ, 826, L1
Gratton, R. G., et al. 1999, A&A, 350, 955
Gratton, R. G., Bragaglia, A., Carretta, E., et al. 2005, A&A, 440, 901
Gratton, R. G., et al. 2010, A&A, 522, 77
MacLean, B. T., et al. 2016, arXiv:1604.05040
Milone, A. P., et al. 2013, ApJ, 767, 120
Mucciarelli, A., et al. 2015, ApJ, 801, 69
Mucciarelli, A., Lapenna, E., Massari, D., et al. 2015, ApJ, 809, 128
Norris, J., et al. 1981, ApJ, 244, 205
Ventura, P., & D'Antona, F. 2005, ApJ, 635, L149
Yong, D., et al. 2003, A&A, 402, 985