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Spurious and real iron spreads in globular clusters

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Abstract. I present a critical review of the metallicity distribution of some globular clusters suspected to have an intrinsic iron spread (NGC 3201, M22, NGC 5286 and M2). When the gravities are derived spectroscopically, both Fe I and Fe II lines provide hints of iron spreads. On the other hand, when photometric gravities are adopted, Fe II lines provide a narrow metallicity distribution, pointing out that these clusters are mono-metallic. Different cases where the iron spreads can be spurious are discussed.

Key words. Stars: abundances – Stars: AGB and post-AGB – Stars: Population II – globular clusters: individual (NGC 3201, M22, NGC 5286, M2)

1. Intruduction

Globular clusters (GCs) are characterized by a general homogeneity in their content of Fe and Fe-peak elements, as measured by high-resolution spectroscopy (see e.g. Carretta et al. 2009). This homogeneity in the Fe content is considered as the typical feature to distinguish GCs from more complex stellar systems (Willman & Strader 2012), suggesting that in the past GCs were not massive enough to retain the ejecta of supernovae (SNe). However, some exceptions have been discovered, suggesting that those stellar systems were able to retain the SN ejecta. The two undeniable cases are ω Centauri (Johnson & Pilachowski 2010; Sollima et al. 2005; Pancino et al. 2011; Marino et al. 2011a) and Terzan 5 (Ferraro et al. 2009, 2016; Origlia et al. 2011, 2013; Massari et al. 2014), both showing metallicity distributions wider than 1 dex. Significant iron spreads (but smaller than those measured in ω Centauri and Terzan 5) have been detected from high-resolution spectra in other GCs, i.e. M54 (Carretta et al. 2010), M22 (Marino et al. 2009, 2011b), M2 (Yong et al. 2014), NGC 3201 (Simmerer et al. 2013) and NGC 5286 (Marino et al. 2015). A proposed scenario for these *anomalous* clusters is that they are the nuclei of dwarf galaxies tidally disrupted through the interactions with the Milky Way, with a significant impact on the missing satellites problem (Marino et al. 2015).

2. The lesson from AGB stars

Several studies based on high-resolution spectroscopy (Ivans et al. 2001; Lapenna et al. 2014, 2015, 2016) revealed that in GC asymptotic giant branch (AGB) stars, Fe I lines provide systematically lower abundances (by ~0.2 dex) with respect to red giant branch (RGB) stars of the same cluster. Instead, the use of Fe II lines, combined with photometric gravities, provides abundances that well match those observed in RGB stars. Even if the origin of this *FeI-FeII discrepancy* is still unknown and only working hypotheses (as non-local thermodynamical equilibrium – NLTE – effects; see Ivans et al. 2001) have been proposed, this finding has a significant impact on the approach traditionally adopted for the chemical analysis of giant stars. The first lesson learned from these results is that Fe I lines should not be used to determine the iron abundance of AGB stars. In fact, their [FeI/H] abundance ratio is systematically lower than that obtained from Fe II lines, both with photometric and with spectroscopic gravities. As a consequence, if Fe I lines are used to derive the iron abundance in a sample including both AGB and RGB stars, spurious detections of large iron spreads can be obtained, because [FeI/H] in AGB stars will be systematically lower than that measured in RGB stars of the same GC. The second lesson is that AGB stars must be analysed by using Fe II lines and 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).

Starting from these results, we re-analysed some GCs that, based on studies where spectroscopic gravities only were adopted, have been proposed to have an intrinsic iron spread. In the new analysis we used Fe II lines and photometric gravities. If a GC has a real intrinsic iron spread, this should be detected both using photometric and spectroscopic gravities, and both using neutral and ionized lines. A difference in the metallicity distributions inferred from Fe I and Fe II lines separately, instead, can indicate the presence of additional effects (i.e. NLTE).

3. NGC 3201

Simmerer et al. (2013) analysed FLAMES-UVES spectra for giant stars of the GC NGC 3201, finding a metallicity distribution as large as 0.4 dex. 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 SN ejecta retention. The analysis performed by Simmerer et al. (2013) is based on spectroscopic gravities. Mucciarelli et al. (2015a) found that, 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 resembles that obtained with the spectroscopic parameters, while the distribution obtained from Fe II lines has a narrow Gaussian-shape (fully compatible with the uncertainties), pointing out a 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, led to a spuriously broad iron distribution.

4. M22 and NGC 5286

M22 is 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. (2011b) analysed high-resolution spectra of giant stars members of M22, finding two groups of objects with distinct 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 and broad, pointing to an intrinsic iron scatter (see left panel of Fig. 1). On the other hand, the use of photometric gravities leads to different [FeI/H] and [FeII/H] distributions (similar to the case of NGC 3201): Fe II lines provide a narrow metallicity distribution, fully compatible with the uncertainties and demonstrat-

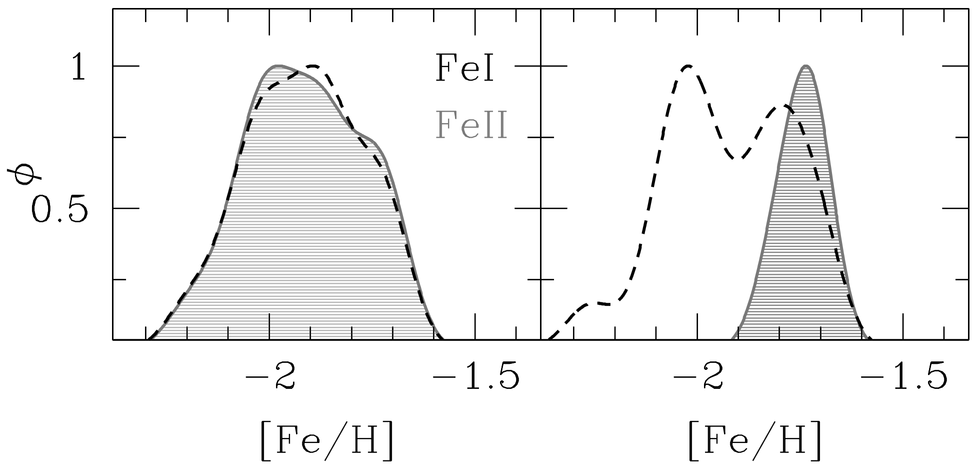

Fig. 1. Generalized histograms for [FeI/H] (dashed) and [FeII/H] (solid grey) abundances obtained from the analysis performed with spectroscopic gravities (left panel) and with photometric gravities (right panel).

ing that M22 is a mono-metallic cluster (right panel of Fig. 1).

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.

The same result has been found for the stars of NGC 5286, a GC that shows iron and s-process abundance spreads similar to those observed in M22 (Marino et al. 2015). Also for this cluster, the metallicity distribution derived from Fe II lines and photometric gravities is narrow and points out a lack of iron spread.

5. M2

M2 has been proposed to posses three distinct stellar populations with [Fe/H]= -1.7, -1.5 and -1.0 dex (Yong et al. 2014). The first two stellar groups show difference in the s-process abundances, similar to the case of M22, while the third, metal-richest, component does no show any s-process enrichment.

Lardo, Mucciarelli & Bastian (2016) re-analysed the same dataset already discussed by Yong et al. (2014), finding that the metallicity distribution of M2 obtained from Fe II lines and using photometric gravities shows the presence of only two stellar groups with metallicity [Fe/H]~ -1.5 and -1.1 dex, which are internally homogeneous in iron. Hence, the large majority of stars in M2 ($\sim$99% according to Milone et al. 2015) does not show any metallicity spread, the objects with [FeII/H]~ -1.1 dex representing only a very small fraction ($\sim$ 1%) of the cluster population.

6. Conclusions

The re-analysis of some anomalous GCs by using FeII lines and photometric gravities revealed that NGC 3201, M22 and NGC 5286 are mono-metallic, while the metallicity distribution of M2 is unimodal with a presence of a minor ($\sim$1% of the cluster population) metal-poor component. The use of Fe II lines and photometric gravities provides a simple but solid method to check for the existence of iron spreads.

Why we trust the abundances from Fe II lines (and photometric gravities), instead of those obtained from Fe I lines? It is worth noticing that Fe II lines are most trustworthy than Fe I lines because Fe II is a dominant species in the atmospheres of late-type stars and these lines are unaffected by NLTE. A simple but sound method to check the spectroscopic gravities is to derive the stellar masses that these gravities would imply. In "normal" GCs the spectroscopic gravities lead to reliable stellar masses, with a small star-to-star dispersion: for instance, the mass distribution obtained for giant stars in NGC 6752 has a mean value of $0.75M_{\odot}$ and $\sigma = 0.05M_{\odot}$ (see Mucciarelli et al. 2015b). On the other hand, the spectroscopic gravities obtained for the "anomalous" clusters discusses here lead to very low (and unreliable) masses for giant stars, down to $\sim 0.2M_{\odot}$, with a large star-to-star scatter ($\sim 0.2M_{\odot}$).

In conclusion, we recognize two cases where the claimed iron spreads could be spurious: (1) normal GCs (with no star-to-star variations in s-process and C+N+O abundances) if some AGB stars are included in the sample and analysed by using spectroscopic gravities (the case of NGC 3201); (2) anomalous GCs (with variations in s-process and C+N+O abundances), where both AGB and RGB stars can be affected by the *FeI-FeII discrepancy* (the cases of M22, M2 and NGC 5286).

Before to speculate about the origin of these clusters as possible remnants of nuclear galaxies, the origin of the *FeI-FeII discrepancy* should be firmly understood.

References

Carretta, E., et al. 2009, A&A, 508, 695
Carretta, E., et al. 2010, ApJ, 714, L7
Ferraro, F. R., Dalessandro, E., Mucciarelli, A., et al. 2009, Nature, 462, 483
Ferraro, F. R., Massari, D., Dalessandro, E., et al. 2016, ApJ, 828, 75
Johnson, C. I., & Pilachowski, C. A. 2010, ApJ, 722, 1373
Ivans, I. I., Kraft, R. P., Sneden, C., et al. 2001, AJ, 122, 1438
Lapenna, E., et al. 2014, ApJ, 797, 124
Lapenna, E., et al. 2015, ApJ, 813, 97
Lapenna, E., Lardo, C., Mucciarelli, A., et al. 2016, ApJ, 826, L1
Lardo, C., Mucciarelli, A., & Bastian, N. 2016, MNRAS, 457, 51
Marino, A. F., et al. 2009, A&A, 505, 1099
Marino, A. F., et al., 2011, ApJ, 731, 64
Marino, A. F., et al. 2011, A&A, 532, 8
Marino, A. F., et al. 2015, MNRAS, 450, 815
Massari, D., et al. 2014, ApJ, 795, 22
Milone, A. P., et al. 2015, MNRAS, 447, 927
Mucciarelli, A., et al. 2015, ApJ, 801, 69
Mucciarelli, A., et al. 2015, ApJ, 809, 128
Pancino, E., et al. 2011, A&A, 527, 18
Origlia, L. et al. 2011, ApJ, 726L, 20
Origlia, L., et al. 2013, ApJ, 779, L5
Simmerer, J., et al. 2013, ApJ, 764, L7
Sollima, A., Pancino, E., Ferraro, F. R., et al. 2005, ApJ, 634, 332
Willman, B. & Strader, J. 2012, AJ, 144, 76
Yong, D., et al. 2014, MNRAS, 441, 3396