Star Clusters: From the Milky Way to the Early Universe
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Globular clusters and their link with stellar populations in the Milky Way

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Abstract. Observations of stellar chemical compositions enable us to identify connections between globular clusters and stellar populations in the Milky Way. In particular, chemical abundance ratios provide detailed insight into the chemical enrichment histories of star clusters and the field populations. For some elements, there are striking differences between field and cluster stars which reflect different nucleosynthetic processes and/or chemical evolution. The goal of this talk was to provide an overview of similarities and differences in chemical compositions between globular clusters and the Milky Way as well as highlighting a few areas for further examination.

Keywords. (Galaxy:) globular clusters: general, stars: abundances

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1. Metallicity

Iron is the canonical measure of stellar metallicity because its relative abundance is high and there are many absorption lines in the visible spectrum of FGK-type stars. It is well known that the iron distribution function for the Milky Way globular clusters exhibits two peaks; one near [Fe/H] = −1.5 and the other near [Fe/H] = −0.5, e.g., Harris (1996); Forbes & Bridges (2010). (See Figure 1.)

For the metal-poor globular cluster population, the peak in the metallicity distribution is similar to that of the Milky Way halo (An *et al.* (2013)). For the metal-rich globular cluster population, the peak in the metallicity distribution is similar to the thick disk (Lee *et al.* (2011)) and the bulge of the Milky Way (Ness *et al.* (2013)).

While others have examined the following issue in considerably more detail (Kruijssen (2019)), one can ask 'Where aren't there more metal-poor globular clusters?' Assuming that the metal-poor globular cluster population can be represented by a Gaussian distribution with a peak near [Fe/H] = −1.5 and a width of 0.4 dex, i.e., drawn from a similar distribution as the Milky Way halo, then the probability of an object having [Fe/H] < −2.5 is less than 1%. Given that there are roughly 150 globular clusters in the Milky Way, it is not too surprising that there are no globular clusters substantially more metal-poor than [Fe/H] = −2.5.

When using [Fe/H] as a proxy for the overall metallicity, the two groups of globular clusters have plausible analogues among the stellar populations of the Milky Way.

2. Light elements ($Z < 14$)

Globular clusters are known to exhibit star-to-star abundance variations and correlations among the light elements, $Z < 14$. The abundances of C and O are low when N is high, O and Na are anticorrelated as are Mg and Al (Kraft (1994); Gratton *et al.* (2012)). That is, in a given globular cluster there are stars with chemical abundances

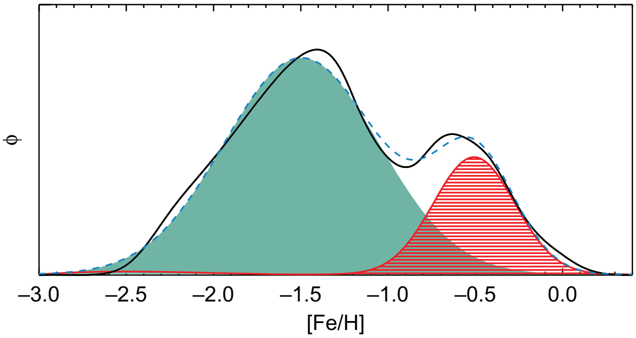

Figure 1. Metallicity distribution function for the Milky Way globular clusters (solid black line) using data from Harris (1996). Two Gaussians (green and red) are generated to fit the distribution and their sum is shown as the dashed blue line.

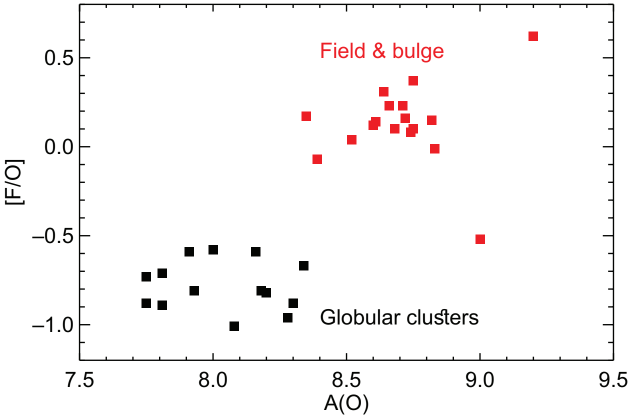

Figure 2. [F/O] versus A(O) for globular clusters (black) and field and bulge stars (red). Data are taken from Smith *et al.* (2005) and Yong *et al.* (2008). While there is only a marginal overlap in oxygen abundance, there appears to be a factor of 10 difference in [F/O] between the globular clusters and field stars.

that appear similar to the Milky Way field (i.e., high O and low Na) as well as stars with high Na and low O. The former are referred to as “primordial” or first generation stars while the latter are called “polluted” or second generation stars. The origin of these light element abundances continues to be debated (D’Antona *et al.* (2016); Charbonnel *et al.* (2014)) and was the focus of other talks at this conference (see talk and contribution from F. D’Antona).

Recently, a relatively small number of stars in the Milky Way field halo and bulge have been found with chemical abundance patterns that resemble the second generation stars (i.e., high Na and low O). It has been suggested that these objects were born in a globular cluster but have since been ejected (Lind *et al.* (2015); Schiavon *et al.* (2017); Lee *et al.* (2019)).

There are two aspects of the light element abundances that deserve further attention. First, the abundance of fluorine ($Z = 9$) appears to follow oxygen (Smith *et al.* (2005)). The ratio of fluorine to oxygen, however, appears constant within a given cluster. Figure 2 indicates that the [F/O] abundance ratio is a factor of 10 higher in field halo stars when compared to globular clusters. This appears to be true for both the first and second generation globular stars. The samples barely overlap, so there is a clear need to examine

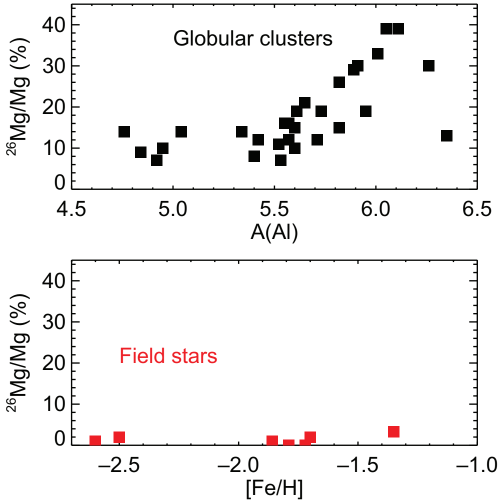

Figure 3. (Upper) ^{26}Mg/Mg (%) versus A(Al) for globular cluster stars (data from Da Costa *et al.* (2013)). (Lower) ^{26}Mg/Mg (%) versus [Fe/H] for Milky Way halo stars (data from Meléndez & Cohen (2007)). The range of the y-axis is the same in both panels and the field stars have much lower fractions of ^{26}Mg when compared to globular clusters.

this issue more closely as it may indicate differences between field halo stars and first generation globular cluster stars.

Second, the isotopic ratios of magnesium have been measured in a small number of globular clusters. The ratio ^{26}Mg/Mg increases with increasing aluminium abundance, e.g., see Figure 3 in which the globular cluster data are from Da Costa *et al.* (2013) and the field star data are from Meléndez & Cohen (2007)). For the first generation globular cluster stars, the typical value is $^{26}\mathrm{Mg/Mg} = 0.10$. For field halo stars, however, the typical value is $^{26}\mathrm{Mg/Mg} = 0.02$. While the samples are small, and the comparison is often between field halo dwarf stars and globular cluster giant stars, there are tantalising hints of a significant difference in the isotopic ratios of magnesium between field and cluster stars (both first and second generation).

Another issue worth examining in more detail is the chemical substructure among halo stars. Nissen & Schuster (2010) found evidence for two populations of halo stars with distinct [α/Fe] vs. [Fe/H], [Ni/Fe] vs. [Na/Fe] and neutron-capture element ratios. Can the globular clusters also be separated into two (or more) populations using similar abundance ratios? (See talk and contribution from A. Recio-Blanco.)

3. Heavy elements ($Z \geqslant 20$)

The "globular cluster" omega Centauri has long been known to host stars with a large range in heavy element abundance (Norris & Da Costa (1995); Johnson & Pilachowski (2010)). It is widely accepted that omega Centauri is the nucleus of an accreted dwarf galaxy (Bekki & Freeman (2003)).

Concerning the heavy element abundances in this object and the comparison with the Milky Way, two points are worth noting. First, omega Centauri exhibits a striking increase in the slow neutron-capture process element abundances with increasing metallicity. Second, the abundance of copper exhibits a constant [Cu/Fe] ratio with increasing metallicity in contrast to the Milky Way halo where [Cu/Fe] rises with increasing metallicity (Cunha *et al.* (2002)).

In addition to omega Centauri, today there are nearly 15 globular clusters which also exhibit star-to-star abundance variations in neutron-capture element abundances and/or metallicity (Marino *et al.* (2018)). These objects have been called “anomalous” globular clusters. For the students and younger researchers, it is worth noting that as recently as 2007, only M22 was suspected of hosting heavy element abundance variations (Lehnert *et al.* (1991)) and M15 was known to host a range in neutron-capture element abundances (Sneden *et al.* (1997)). Enormous progress has taken place over a relatively short period of time!

While it may be tempting to speculate that all globular clusters with large metallicity spreads may be the nuclei of disrupted dwarf galaxies, the metallicity distribution functions of surviving dwarf galaxies are distinct from those of the anomalous globular clusters. In particular, the metallicity distribution functions of surviving dwarf galaxies tend to rise slowly then fall abruptly as the metallicity increases. On the other hand, the anomalous globular cluster metallicity distribution functions tend to rise rapidly then fall slowly as the metallicity increases (see Norris *et al.* (2010)).

Indeed, as noted by Da Costa (2016), in the context of the dwarf galaxy origin for omega Centauri, the disrupted dwarf galaxy stars of the original host are now likely to reside in the Milky Way halo which has a stellar mass of 10^9 $M_\odot$. If too many more globular clusters with metallicity spreads are found, then the disrupted dwarf galaxy stars could potentially overpopulate the Milky Way halo.

Finally, among field halo stars, a large fraction exhibit large enhancement in carbon abundance relative to iron, $[C/Fe] > 0.7$. These carbon enhanced metal-poor stars (CEMP) represent about 20% of field stars at $[Fe/H] = -2.0$ (Placco *et al.* (2014)), and the CEMP fraction rises with decreasing metallicity. For some of these CEMP stars, they also exhibit enhancements in the neutron-capture element abundances. Where are the CEMP stars in the metal-poor globular clusters? While a handful are known, the metal-poor globular clusters do not appear to have CEMP stars at the 20% level.

4. Summary

The goal of this review talk was to highlight similarities and differences in chemical abundance ratios between globular clusters and the stellar populations of the Milky Way. The main points of this talk and/or open questions can be summarised as follows:

(*a*) The two metallicity groups of globular clusters have plausible analogues among the Milky Way stellar populations.

(*b*) The first generation globular clusters stars may *not* be chemically identical to Milky Way stars of similar metallicity.

(*c*) What is the degree and extent of chemical substructure among the globular clusters?

(*d*) Anomalous globular clusters exhibit chemcal abundance differences with respect to the surviving dwarf satellites of the Milky Way.

(*e*) If significantly more anomalous globular clusters with spreads in [Fe/H] are found, then the connection between such clusters and their putative dwarf galaxy hosts may require re-consideration.

(*f*) Where are the CEMP stars in globular clusters?

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References

An, D., Beers, T. C., Johnson, J. A., *et al.* 2013, *ApJ*, 763, 65
Bekki, K. & Freeman, K. C. 2003, *MNRAS*, 346, L11

Charbonnel, C., Chantereau, W., Krause, M., Primas, F., & Wang, Y. 2014, *A&A*, 569, L6
Cunha, K., Smith, V. V., Suntzeff, N. B., *et al.* 2002, *AJ*, 124, 379
Da Costa, G. S., Norris, J. E., & Yong, D. 2013, *ApJ*, 769, 8
Da Costa, G. S. 2016, The General Assembly of Galaxy Halos: Structure, Origin and Evolution, 317, 110
D'Antona, F., Vesperini, E., D'Ercole, A., *et al.* 2016, *MNRAS*, 458, 2122
Forbes, D. A. & Bridges, T. 2010, *MNRAS*, 404, 1203
Gratton, R. G., Carretta, E., & Bragaglia, A. 2012, *A&ARvr*, 20, 50
Harris, W. E. 1996, *AJ*, 112, 1487
Johnson, C. I. & Pilachowski, C. A. 2010, *ApJ*, 722, 1373
Kraft, R. P. 1994, *PASP*, 106, 553
Kruijssen, J. M. D. 2019, *MNRAS*, 486, L20
Lee, Y. S., Beers, T. C., An, D., *et al.* 2011, *ApJ*, 738, 187
Lee, Y.-W., Kim, J. J., Johnson, C. I., *et al.* 2019, *ApJ*, 878, L2
Lehnert, M. D., Bell, R. A., & Cohen, J. G. 1991, *ApJ*, 367, 514
Lind, K., Koposov, S. E., Battistini, C., *et al.* 2015, *A&A*, 575, L12
Marino, A. F., Yong, D., Milone, A. P., *et al.* 2018, *ApJ*, 859, 81
Meléndez, J. & Cohen, J. G. 2007, *ApJ*, 659, L25
Ness, M., Freeman, K., Athanassoula, E., *et al.* 2013, *MNRAS*, 430, 836
Nissen, P. E. & Schuster, W. J. 2010, *A&A*, 511, L10
Norris, J. E. & Da Costa, G. S. 1995, *ApJ*, 447, 680
Norris, J. E., Wyse, R. F. G., Gilmore, G., *et al.* 2010, *ApJ*, 723, 1632
Placco, V. M., Frebel, A., Beers, T. C., & Stancliffe, R. J. 2014, *ApJ*, 797, 21
Schiavon, R. P., Zamora, O., Carrera, R., *et al.* 2017, *MNRAS*, 465, 501
Smith, V. V., Cunha, K., Ivans, I. I., *et al.* 2005, *ApJ*, 633, 392
Sneden, C., Kraft, R. P., Shetrone, M. D., *et al.* 1997, *AJ*, 114, 1964
Yong, D., Meléndez, J., Cunha, K., *et al.* 2008, *ApJ*, 689, 1020