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Contributions from the s- and r- process: examining giant stars in M15

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Abstract. Ba abundances have been derived for 63 giant stars in the metal-poor globular cluster, M15. Abundances for Ca, La, and Eu have also been derived where possible to investigate the contributions from Supernova and AGB stars in the pollution history of this cluster. The stellar parameters and abundances for Fe, Na and O were taken from Carretta et al. 2009 but microturbulence values were calculated based on a relation between microturbulence and surface gravity that was derived here.
A bimodal distribution in Ba and Eu was detected within this sample, which is complete along the red giant branch, with mean values of <[Ba/H]>=–2.00±0.16 and <[Eu/H]>=–1.65±0.13 for the high Ba-Eu mode, and <[Ba/H]>=–2.41±0.16 and <[Eu/H]>=–1.80±0.08 for the low Ba-Eu mode. The results imply that both modes have a pollution history dominated by the r-process, hence a single burst of Supernova Type II, but there may be evidence to suggest some further small contribution from the s-process.

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

1. Introduction

Previous studies of the globular cluster M15 have consistently shown a spread in Ba and Eu abundances with no corresponding spread in Fe. The key papers and corresponding abundances are listed in Table 1. M15 is a metal-poor globular cluster, shown mostly recently in the large sample study of Carretta et al. (2009) to have a metallicity of [Fe/H] = –2.341 dex. Other large studies looking at heavy element abundances have observed a bimodal distribution in Ba (Sneden et al., 1997, 2000a,b).

The location of these stellar samples in the CMD of M15 and the corresponding HR diagram is shown in Figure 1. There are 9 stars which have overlaps between studies.

2. M15 observations

The targets in this study were selected from the C09 sample, which is complete along the red giant branch (RGB). In this study 63 of the 84 C09 targets were re-observed using the HR14A setup of GIRAFFE on the VLT. This wave-

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Table 1. Key studies of M15 stars listing size of sample (N_{star}) and the corresponding sample mean Fe, Ba, La and Eu abundances.

Study	N_{star}	<[Fe/H]> $\pm\sigma$	<[Ba/H]> $\pm\sigma$	<[La/H]> $\pm\sigma$	<[Eu/H]> $\pm\sigma$
Worley et al. (2013) **W13**	63	-	–2.20±0.26	–2.05±0.15	–1.72±0.15
Sobeck et al. (2011) **Sk11***	3	–2.55±0.02	–2.10±0.12	–2.07±0.23	–1.72±0.29
D'Orazi et al. (2010) **DO10**	57	-	–2.152±0.412	-	-
Carretta et al. (2009) **C09**	84	–2.341±0.007	-	-	-
Otsuki et al. (2006) **O06**	7	–2.40±0.05	–2.56±0.18	–2.46±0.25	–1.85±0.24
Sneden et al. (2000a) **S00a**	3	–2.28±0.05	–2.28±0.19	-	–1.41±0.31
Sneden et al. (2000b) **S00b**	31	–2.37±0.05	–2.25±0.21	-	-
Sneden et al. (1997) **S97**	18	–2.40±0.04	–2.30±0.21	-	–1.91±0.21

* RGB stars only

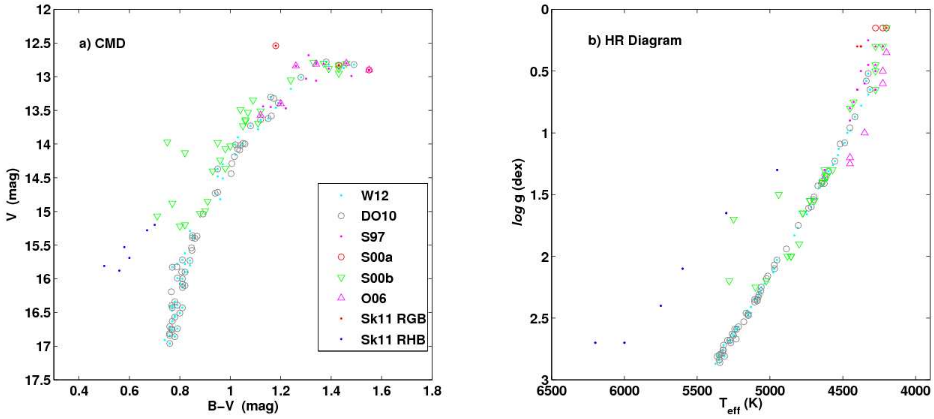

Fig. 1. a) CMD of key samples of M15 stars. b) Corresponding HR diagram of the key M15 samples.

length range included the key heavy elements lines of Ba at 6496.8980 Å, La at 6390.4770 Å and Eu at 6437.6400 Å & 6645.1270 Å.

The C09 have also been analysed for their Ba abundances in DO10, where 57 of the C09 targets were analysed. Of these 38 are in common with W13. The equivalent widths of the Ba line at 6141 Å from DO10 were re-analysed in W13 (D'Orazi, private communication).

For the analysis of the W13 stars, and the re-analysis of the DO10 stars ($DO10_{W13}$), the effective temperature and surface gravity for each star were taken from C09 and the microturbulence was taken from a microturbulence-surface gravity relation that was derived in W13.

3. Heavy & light abundances in M15

Figure 2a and b show the histograms for the W13 and $DO10_{W13}$ Ba abundances respectively. A bimodal distribution is clear in the W13 sample with the peak in the low Ba mode lying at <[Ba/H]>=–2.41±0.16 and the peak in the high Ba mode lying at <[Ba/H]>=–2.00±0.16.

A bimodal distribution is not obvious in the DO10 sample, however the rectangular shape

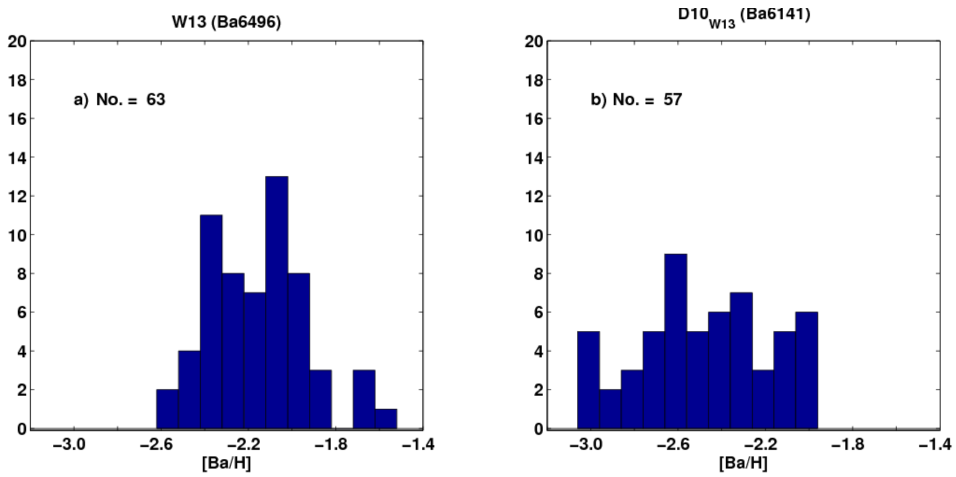

Fig. 2. a) Histogram of Ba for W13 sample. b) Histogram of Ba for DO10$_{W13}$ sample.

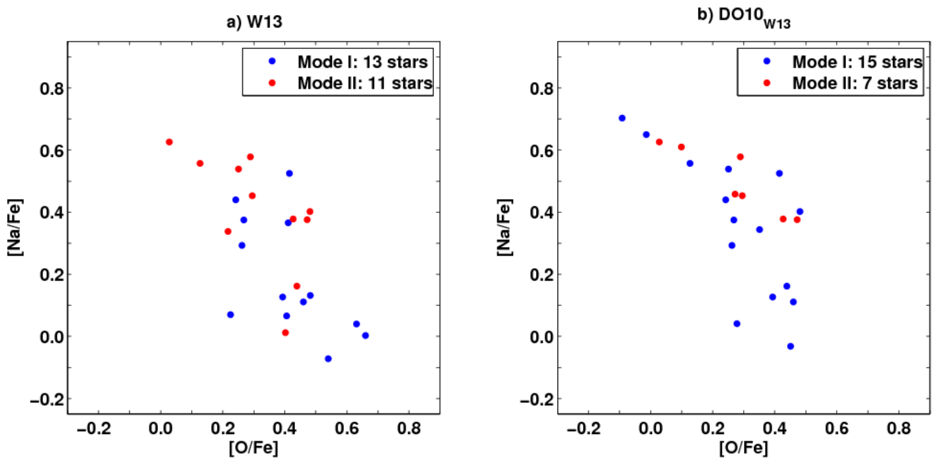

Fig. 3. a) [Na/Fe] against [O/Fe] for W13 decomposed into the two Ba modes: Mode I low Ba (Blue), Mode II high Ba (Red). b) As for a) but for the DO10$_{W13}$ sample.

of the histogram argues against a simple single mode gaussion distribution.

The bimodal distribution for W13 is reflected in the Eu abundances with mean values of <[Eu/H]>=–1.80±0.08 for the low Ba mode and <[Eu/H]>=–1.65±0.13 for the high Ba mode. The [Ba/Fe] and [Eu/Fe] values for both modes, despite the spread in values, are sufficiently low to be indicative of pollution of the star-forming material by r-process only sources (Supernova Type II).

Figure 3a and b show the Na and O abundances that were determined in C09 for the stars in W13 and DO10 decomposed into the two Ba modes, as defined by the W13 bimodal distribution. For W13 both modes show a continuum of Na anti-correlated with O which is indicative of two stellar populations whereby the the second population was formed from material contaminated by the Na-O nucleosynthetic processing that took place in the first population (Carretta et al., 2010).

Only Mode I shows such a distinct continuum for the $DO10_{W13}$ sample and, in light of the lack of a bimodal distribution in this sample, taken as a whole there is an Na-O anticorrelation present.

4. Conclusions

The combination of two Ba modes, and Na-O anti-correlations within each of these modes for the W13 sample could be evidence for up to four populations of star within M15: The two Ba stellar populations which are each composed of a primordial 'low-Na:solar-O' generation and a 2nd 'enriched-Na:subsolar-O' generation.

This is a much more complex scenario then has previously been considered for M15. Other likely scenarios may be a continuum of Ba-Eu abundances with a corresponding Na-O anticorrelation indicating only two stellar populations based on a single Na-O anticorrelation.

The heavy element analysis strongly supports an r-process dominated origin of Ba and Eu. However, the abundances are not completely described by r-process only yields hence there may be some further contribution by another process.

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