Super-massive stars as a source of abundance anomalies of proton-capture elements in globular clusters

We propose that the abundance anomalies of proton-capture elements in globular clusters (GCs), such as the C-N, Na-O, Mg-Al and Na-F anti-correlations, were produced by super-massive stars with $M \sim 10^4\ M_\odot$. Such stars could form in the runaway collisions of massive stars that sank to the cluster centre as a result of dynamical friction, or via the direct monolithic collapse of the low-metallicity gas cloud from which the cluster formed. To explain the observed abundance anomalies, we assume that the super-massive stars had lost significant parts of their initial masses when only a small mass fraction of hydrogen, $\Delta X \sim 0.15$, was transformed into helium. We speculate that the required mass loss might be caused by the super-Eddington radiation continuum-driven stellar wind or by the diffusive mode of the Jeans instability. The agreement between the observations and theory is very good (Fig.1), including the correlations of the Mg isotopic ratios with [Al/Fe] recently complemented by Da Costa et al. (2013). From the nucleosynthesis point of view, this result is not surprising because Denissenkov et al. (1998) demonstrated that the GC abundance anomalies could be the products of H burning at $T \approx 74\times10^6$ K, that had consumed only a few percent of initial hydrogen, mixed with the original gas. However, the main stellar source in which these conditions can be realized has remained unknown. We think that the stars with masses $\sim 10^4\ M_\odot$ could be such a source because our models do have the required central temperatures $74\times10^6\ \mathrm{K} \le T_c \le 78\times10^6$ K. Besides, the plausible mechanism of their formation via the runaway star merger in young dense star clusters that are similar to young GCs (Portegies Zwart et al. 2004) as well as the possible presence of intermediate-mass black holes with masses up to $4.7\times10^4 M_\odot$ in the present-day GCs (Luetzgendorf et al. 2013) support our hypothesis.

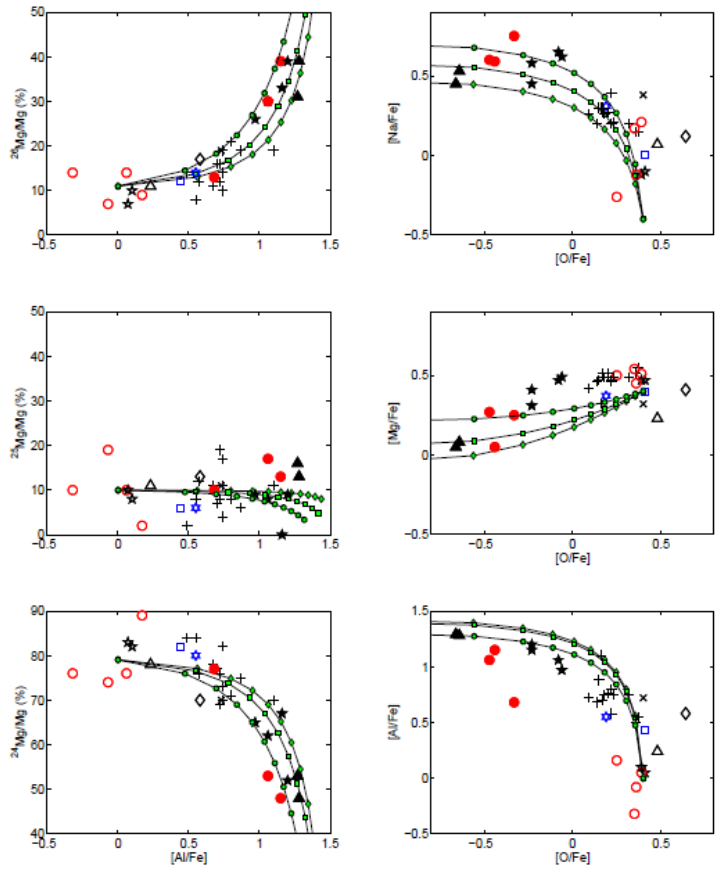

Figure 1: The correlations and anti-correlations between the proton-capture isotopes for stars in the globular clusters ω Cen, M13, M71, and M4 taken from the work of Da Costa et al. (2013) (we used their original symbols; for data sources, see the caption to Fig. 4 in the cited paper) are compared with our model abundances (green symbols connected by curves) obtained from mixtures of the GC original gas and matter lost by the $2\times10^4 M_\odot$ (circles), $3\times10^4 M_\odot$ (squares), and $4\times10^4 M_\odot$ (diamonds) stars. The fraction of the original gas in the mixture decreases from 1 to 0 with the step 0.1, starting from the following assumed initial abundances: [Na/Fe]=-0.4, [O/Fe]=0.4, [Al/Fe]=0, and solar Mg isotopic ratios.

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Published in 2014, MNRAS, 437, L21