Mem. S.A.It. Vol. 84, 208
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# Carbon abundances from SDSS globular clusters: exploring the origin in the large spread in [C/Fe]

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**Abstract.** Globular clusters were once thought to be chemically homogeneous systems with a single stellar population. However, recent results suggest the presence of more than one stellar population among most all globular clusters. These stars have a different abundance pattern compared to halo stars of similar metallicities. To understand globular cluster formation in the context of hierarchical Galaxy formation models, it is necessary to understand the origin of their abundance patterns. We have used the SDSS spectra from Data Release 8 to estimate the carbon abundances for member stars in 5 globular clusters. We find large spreads in the carbon abundances throughout the CMDs of the clusters, indicating multiple populations with different carbon abundances.

**Key words.** globular clusters: general — globular clusters: individual(M2, M3, M13, M15, M92

## 1. Introduction

Globular clusters (GCs) do NOT exhibit single stellar populations. Evidence for this includes split sequences in color magnitude diagrams and chemical variations among member stars of similar luminosity and evolutionary class.

Chemical variations occur mostly in the lighter, proton-capture process elements in GCs, and exhibit trends involving enrichment of N, Na, and Mg, and depletions of C, O, and Al. These trends are not just from hydrogen burning - main sequence stars show these trends but are not hot enough to exhibit this process. Therefore, the current generation of cluster stars that exhibit signatures of hydrogen burning products must have formed from material polluted by first generation stars, or a primordial population.

How many stellar populations are likely to exist in GCs? For normal GCs, variation is only seen among light elements and most likely only two generations are needed to explain their formation. However, for anomalous GCs, variation is seen among heavier, neutron capture elements like Ba and Sr as well, and several generations may be involved in their formation. Hence, looking at which chemical abundance variations are found among GCs can help us determine the number of stellar populations contained within them.

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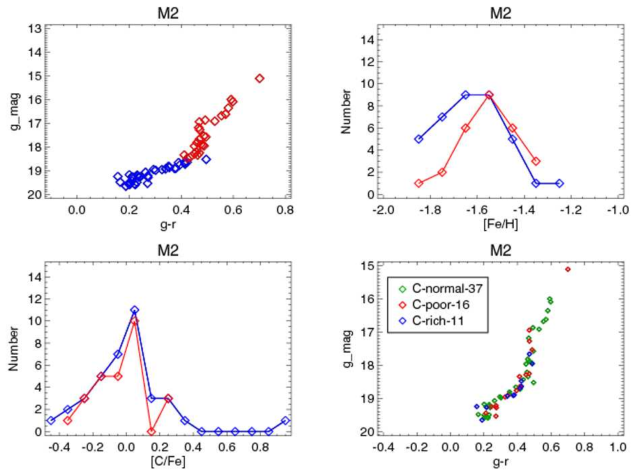


**Fig. 1.** Cluster plots for M2. Upper left panel: CMD with blue, red, and black diamonds corresponding to MS, RG, and HB stars, respectively. Upper right panel: photometric metallicity distributions for MS stars (blue) and RGs (red) as given by Smolinski et al. (2011). Lower left panel: distributions of [C/Fe] for MS stars (blue) and RGs (red) as measured in this work. Lower right panel: CMD with green, red, and blue dots corresponding to carbon-normal, carbon-poor, and carbon-rich stars, respectively.

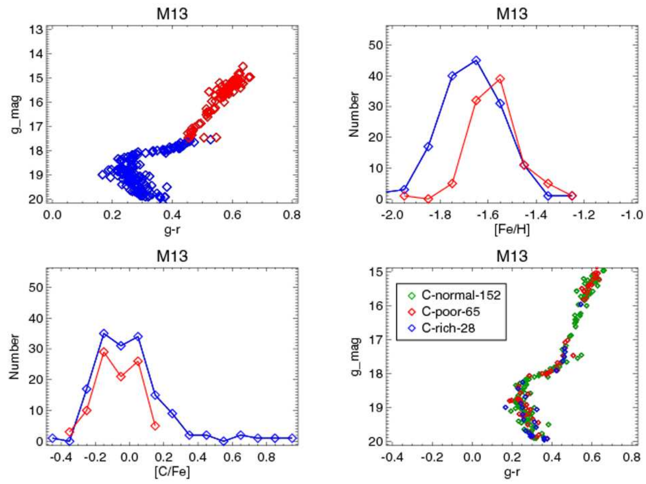


**Fig. 2.** Cluster plots for M13 (same format as Figure 1)

## 2. C abundance measurements

We start by measuring C abundances in member stars of a sample of 5 GCs preciously studied by Smolinski et al. (2011). Spectroscopic properties for these GCs can be found in Table 1. These properties are drawn from the literature (Harris 1996; McLaughlin & van der

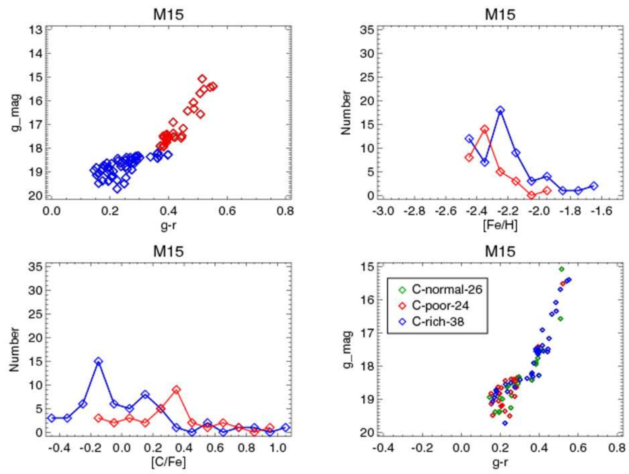


**Fig. 3.** Cluster plots for M15 (same format as Figure 1)

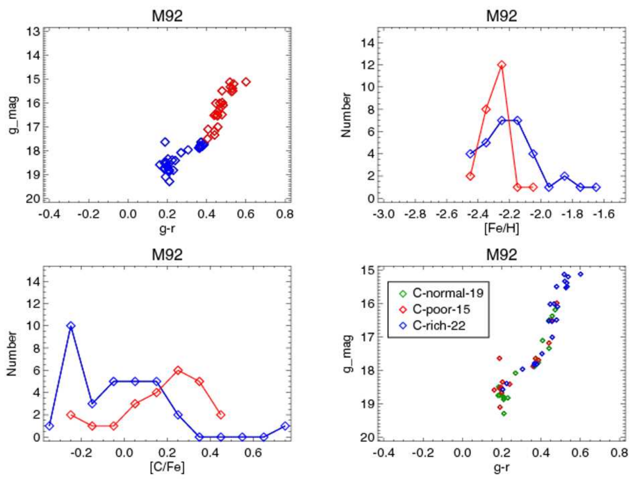


**Fig. 4.** Cluster plots for M92 (same format as Figure 1)

Marel 2005; Mandushev, Staneva & Spasova 1991). Spectroscopy was obtained from DR8 of SDSS (Aihara, Prieto, & An et al. 2011).

The stellar parameters effective temperature ($T_{\rm eff}$) surface gravity (log g) and metallicity ([Fe/H]) were computed from the SEGUE Stellar Parameter Pipeline (SSPP; Lee et al. 2008a,b). These were used with the NEWODF models of Castelli & Kurucz (2003) to create a grid of synthetic spectra, which were generated from the TURBOSPECTRUM synthesis code (Alvarez & Plez 1998). Then, to measure

**Table 1.** Globular Cluster Spectroscopic and Physical Properties

| Cluster | [Fe/H] | log[M/$M_\odot$] (dex) | $R_{gc}$ (kpc) |
|---|---|---|---|
| M2 | -1.65 | 5.84 | 10.4 |
| M3 | -1.50 | 5.58 | 12.0 |
| M13 | -1.53 | 5.57 | 8.4 |
| M15 | -2.37 | 5.84 | 10.4 |
| M92 | -2.31 | 5.43 | 9.6 |

C abundances, observed spectra were matched near the CH G band at 4300 with this broad grid of synthetic spectra.

We analyze the distributions of [C/Fe] abundances in main-sequence (MS) and red-giant (RG) stars separately, as well as distributions of [Fe/H] as given in Smolinski et al. (2011). Figures 1 show cluster plots for the globular clusters M2, M13, M15, and M92, respectively. The upper left panel shows the CMD for the given cluster. Blue, red, and black diamonds correspond to MS, RG, and horizontal branch (HB) stars, respectively. The upper right panel displays the photometric metallicity distributions for MS stars (blue) and RGs (red) as given by Smolinski et al. (2011). The lower left panel shows the distributions of [C/Fe] for MS stars (blue) and RGs (red) as measured in this work. Finally, the lower right panel shows the CMD, with green, red, and blue dots corresponding to carbon-normal, carbon-poor, and carbon-rich stars, respectively. Carbon-normal stars are defined as stars with 0.15 > [C/Fe] > -0.15; carbon-poor stars are below this bound and carbon-rich stars are above.

## 3. Conclusions

The wide spread in carbon abundances within all sample globular clusters serves as strong evidence for a carbon-rich, a carbon-normal, and a carbon-poor population. Both MS stars and RGs, taken as individual groups, show varying star-to-star carbon abundances, confirming that this is not merely an evolutionary effect. MS stars and RGs in M2 and M13 (higher overall metallicity) have roughly the same numbers of stars that are carbon rich, carbon-normal, and carbon poor. However, in M15 and M92 (overall lower metallicity), the carbon poor stars are found primarily in the MS, while carbon rich stars are found primarily in the RGB. Furthermore, for each cluster, the distributions of carbon normal, carbon rich, and carbon poor stars are spread over the CMDs. The latter two observations are opposite of what standard stellar evolutionary theory predicts, which is for RGs to have lower abundances of carbon than MS due to CN processing that occurs in RGs, which are hotter, but not in MS stars, which are cooler. Further research is necessary to discern the cause of the latter results. We plan to measure Ba and Sr abundances within our GCs. Observing abundance variations among these neutron-capture elements would strengthen our claim that more than two stellar populations exist within them.

*Acknowledgements.* We thank the International Research Experience for US Graduate Students (IRES) Program for providing the funding the first author's travel to the Indian Institute of Astrophysics in Bangalore to complete this work. This work was funded by the National Science Foundation's Office of International Science and Engineering, Grant Number 0854436: International Research Experience for Students, and managed by the National Solar Observatory's Global Oscillation Network Group in coordination with the Indian Institute of Astrophysics.

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