A Study of the Multiple Populations in M10

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Globular clusters in the Milky Way are not simple stellar populations, but rather contain the products of multiple epochs of star formation. The discovery of multiple stellar populations in globular clusters, as revealed by both photometric and spectroscopic studies, has raised fundamental questions concerning all aspects of their formation and dynamical evolution. Accurately measuring the properties of Milky Way globular clusters is necessary to address these questions. We present analysis of the CN and CH molecular band strengths derived for ~140 red giant stars in M10. Our sample comes from two observation runs conducted in Aug. 2014 and Jun. 2016 using Hydra on the WIYN 3.5m telescope. CN and CH band strengths are used to sort the stars into a nitrogen normal and enhanced population based on the CN band strength as a function of magnitude. Once the stars are sorted into first and second generation (CN normal and enhanced, respectively), we compare this analysis with other ways of determining multiple stellar populations such as with the light elements Na and O (Carretta et al. 2009a,b) and photometric indicators, particularly the UV photometry from the Hubble Space Telescope (Piotto et al. 2015). We then use the band measurements to derive carbon and nitrogen abundances by comparing observed band strengths to synthetic spectra produced by the Synthetic Spectrum Generator (SSG) (Bell et al. 1994, and references therein), which makes use of MARCS model atmospheres (Gustafsson et al. 1975). The large sample size also allows us to study characteristics like radial distribution, and evolutionary effects such as the depletion of carbon (and subsequent nitrogen enrichment) likely due to thermohaline mixing (Eggleton et al. 2008), which occurs after a low mass star climbs the red giant branch past the luminosity function (LF) bump.

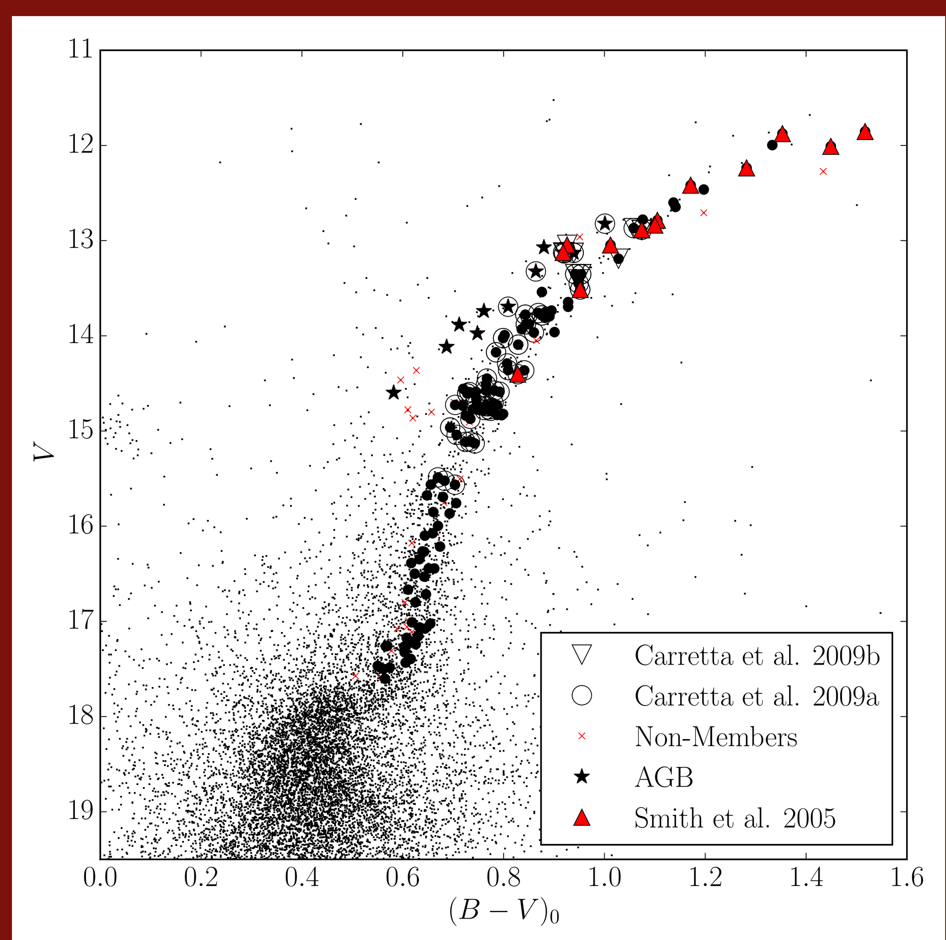

Figure 1. V vs. B-V photometry from Pollard et al. (2005). All observed stars are shown with those determined non-members based on their radial velocities indicated as red x's. Stars are also marked based on whether or not they were measured as part of previous studies such as Carretta et al. (2009a,b), for Na and O abundances and Smith et al. (2005) for C and N abundances. AGB stars were determined based on their location on the CMD and are indicated as such.

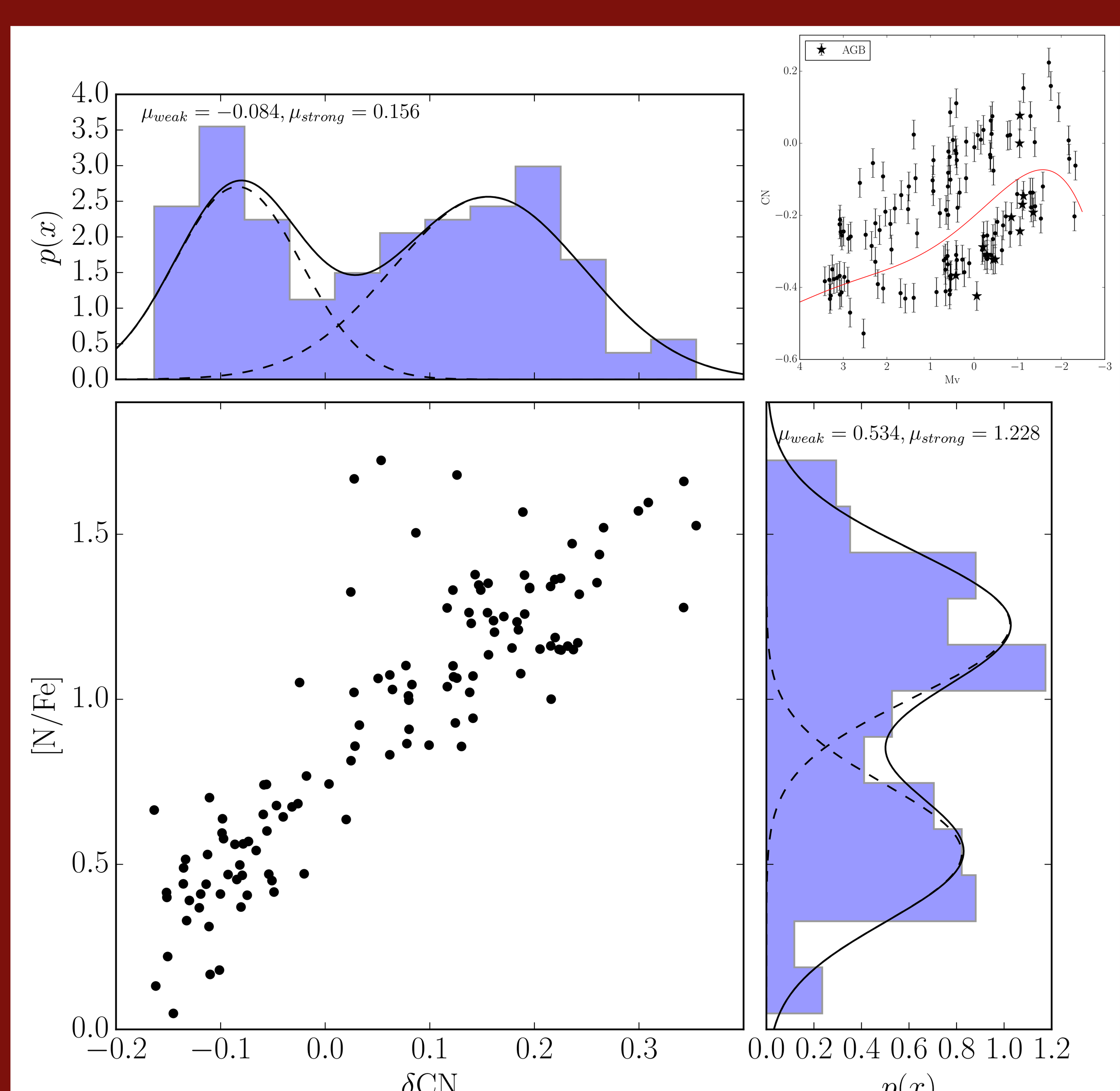

Figure 2. [N/Fe] vs. δCN for the RGB stars in the sample. CN bands were calculated based on the CN feature at 3883 Å by numerically integrating a feature bandpass and comparing it to a nearby continuum bandpass. The behavior of the CN band with T_{eff} and logg was modeled to create a fiducial band strength with M_v (the red line in the inset plot of CN vs. M_v), and δCN formed as the difference between the measured CN band and this fiducial. δCN correlates, as expected, with [N/Fe], and both show the clear presence of two distinct populations.

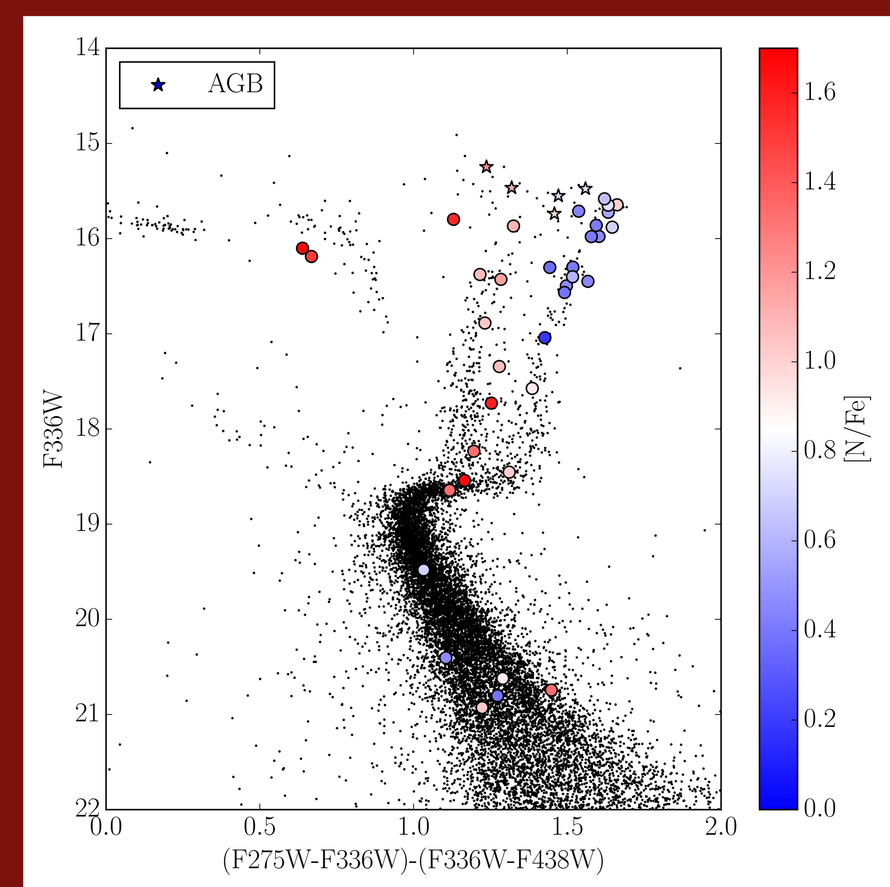

Figure 3. A pseudo-color magnitude diagram as used by Piotto et al. (2015), e.g. to determine multiple populations photometrically is shown with stars color-coded based on [N/Fe]. The pseudo-color enhances the separation between the red-giant branches of the populations in the cluster. Stars in different populations with different light element abundances such as C, N, and O, alter the OH, NH, CN, and CH bands that appear in the regions of the HST filters used. As expected, stars rich in nitrogen appear on the "bluer" branch and stars weak in nitrogen appear on the "redder" branch. AGB stars are indicated as triangles as in Fig. 1.

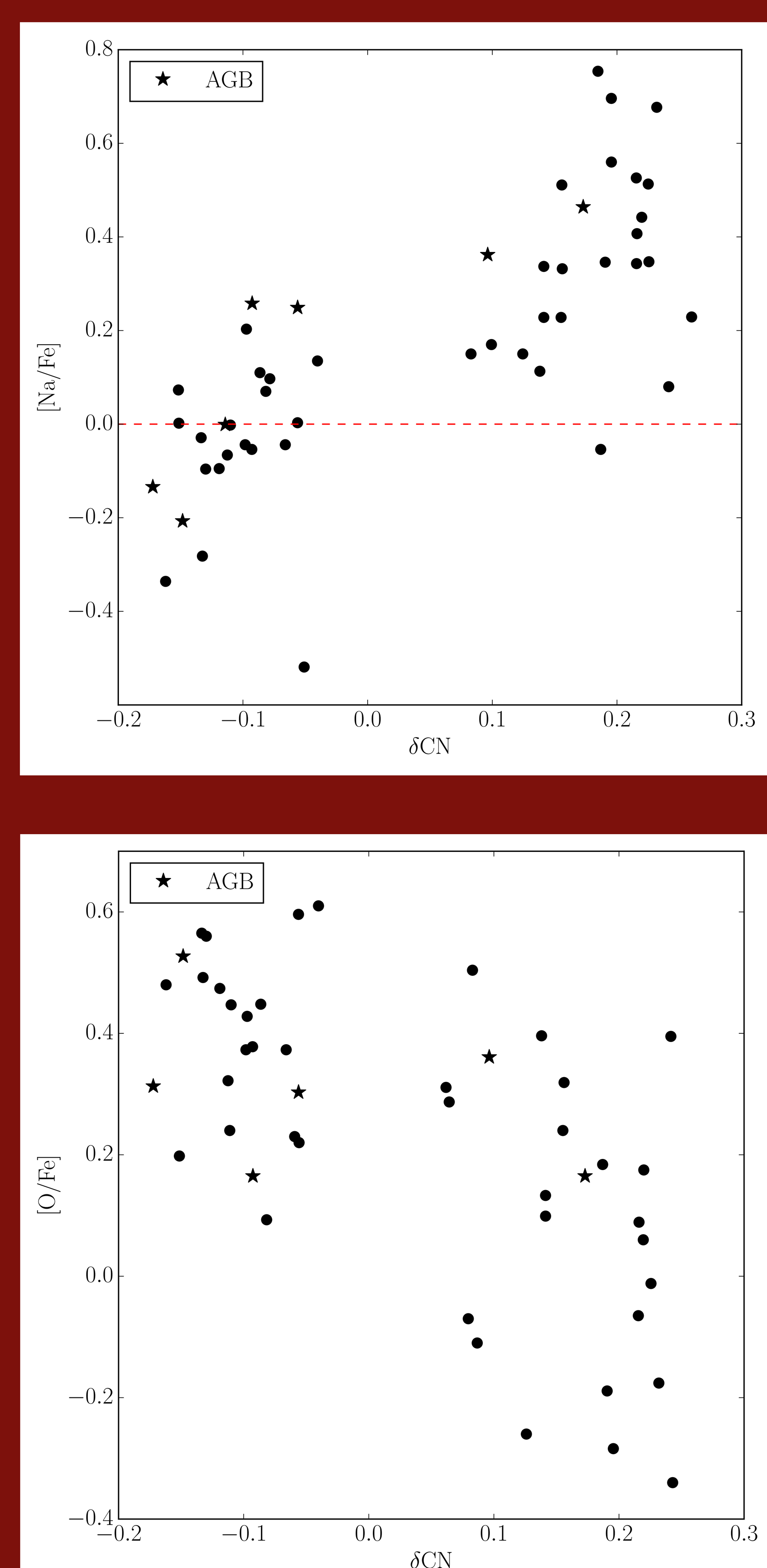

Figure 4. [Na/Fe] and [O/Fe] vs δCN (top and bottom, respectively). Na and O measurements come from Carretta et al. (2009a,b). The red dashed line in the top plot indicates the separation between populations in [Na/Fe] as defined by Carretta et al. (2009a,b). Because of the way the δCN bands were calculated (see Fig. 2), zero is the division between the CN normal and enhanced populations. Stars with enhanced CN also have enhanced Na as expected (except for one star who is in agreement within uncertainty for [Na/Fe]). An anti-correlation with O abundance is also seen; however, there is a larger range of O abundances for the CN enhanced population. No stars are seen with enhanced CN and normal Na as observed in 47 Tuc by Smith (2015).

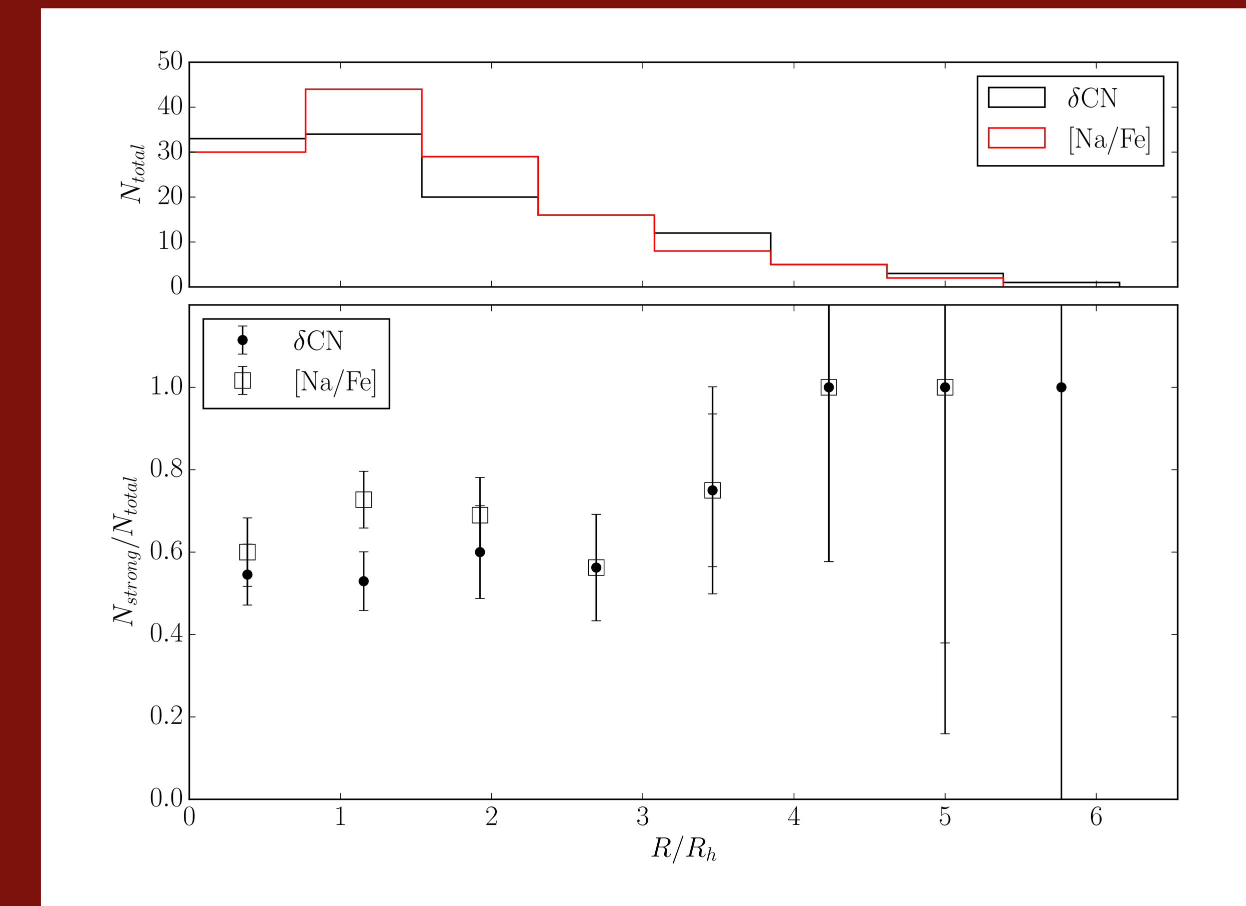

Figure 5. The radial distribution of the ratio of the number of CN or Na enhanced, second generation stars to the total number of stars from the cluster center. The populations are roughly equal with a slight enhancement in the second generation (60% of stars in the total sample). Both populations appear to have similar radial distributions, not showing the central concentration of second generation stars seen in many clusters, likely due to M10's relatively short relaxation time.

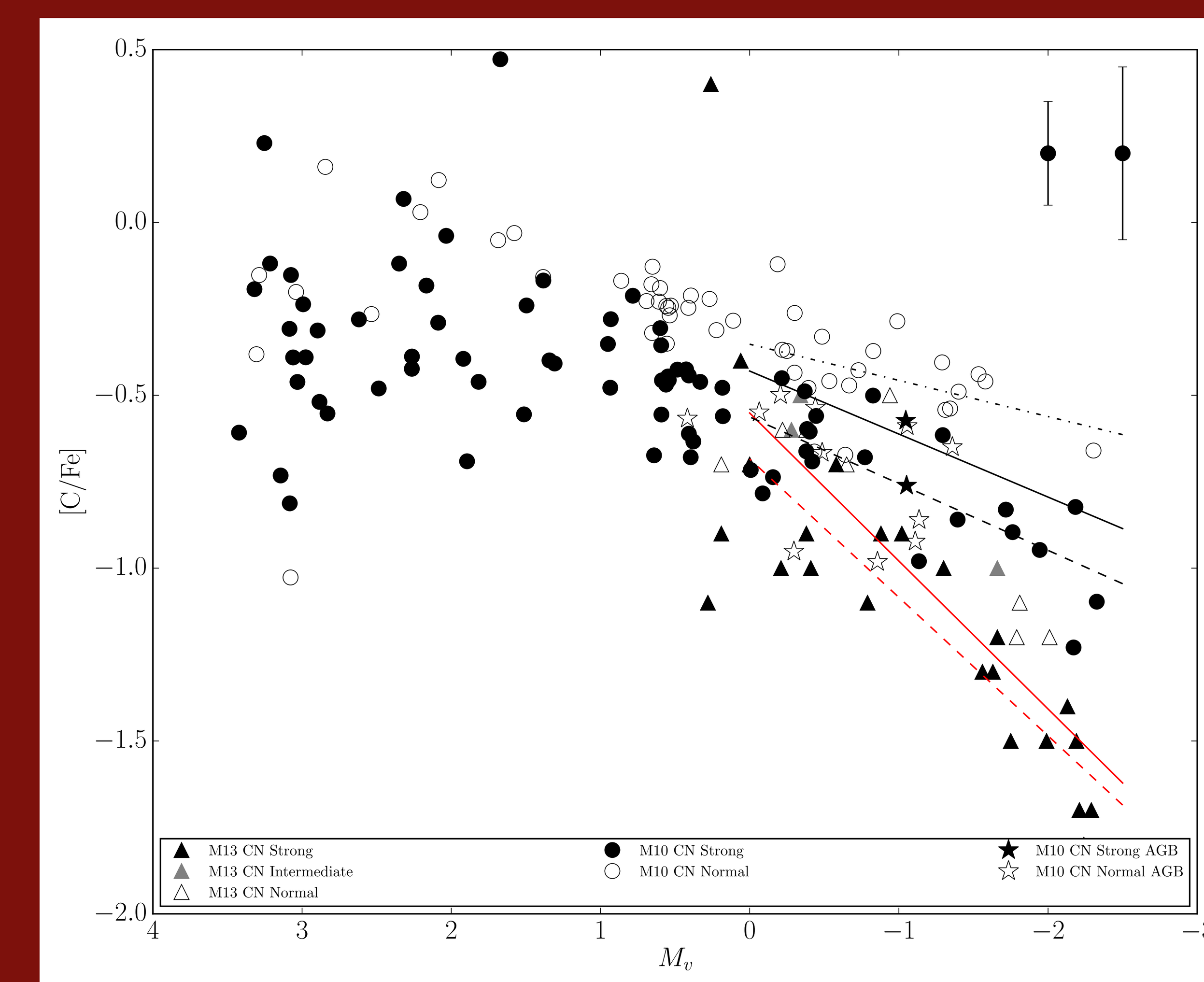

Figure 6. [C/Fe] vs. Mv for M10 and M13 (circles and triangles, respectively). Abundances for M13 come from Smith et al. (2006). For both clusters, CN enhanced stars are shown as closed points with CN normal stars as open. The solid lines indicate linear fits to each cluster including points from both populations, dashed lines indicate fits to the CN enhanced population, and dot-dashed lines indicate fits to the CN normal population with red being M13 fits and black being M10 fits. The CN normal stars are not fit for M13 due to a lack of points available. Representative error bars for bright (Mv < 1.0) and faint (Mv > 1.0) stars are shown in the top right corner. Stars indicate AGB stars in M10 as in Fig. 1. While M13 and M10 have similar metallicities, M13 clearly shows stronger C depletion after the LF bump than M10.

Conclusions

- M10 clearly shows two populations in both the CN band and [N/Fe] distributions that continue to the base of the red giant branch. Gaussian mixture modeling shows that while the CN enhanced population has a larger range in δCN compared to the CN normal, the two populations have similar dispersions in [N/Fe] comparable to observational errors.
- When compared to other methods of identifying multiple populations, we find that the CN band analysis identifies the same stars belonging to each population as other methods as well as finding similar characteristics such as radial distribution.
- Studying the distributions of each population reveals that the two populations in M10 are distributed similarly across the cluster, which can be explained by M10's relatively short relaxation time.
- The evolution of [C/Fe] as a function of Mv has been studied for each population to determine a rate of change above the LF bump. We find that in M10 the second generation depletes its carbon slightly more rapidly than the first generation. When comparing to M13 (a cluster of similar metallicity), we see that it depletes carbon much faster than M10. Because these clusters are of similar metallicity, this result is likely caused by another factor such as He abundance.

References and Acknowledgements

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We would like to thank Roger A. Bell for making the SSG program available to us.