

The Chemical Inhomogeneity of Faint M13 Stars: C and N Abundances ¹

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ABSTRACT

Building upon earlier observations which demonstrate substantial star-to-star differences in the carbon abundances of M13 subgiants, we present new Keck LRIS spectra reaching more than 1.5 mag below the M13 main-sequence turn-off (to $V \approx 20$). Our analysis reveals a distribution of C abundances similar to that found among the subgiants, implying little change in the compositions of the M13 stars at least through the main-sequence turn-off. We presume these differences to be the result of some process operating early in the cluster history.

Additional spectra of previously studied bright M13 giants have been obtained with the Hale 5-m. A comparison of C abundances derived using the present methods and those from the literature yield a mean difference of 0.03 ± 0.14 dex for four stars in common with Smith et al. (1996) and 0.14 ± 0.07 dex for stars also observed by Suntzeff (1981) (if one extreme case is removed). We conclude that the lower surface C abundances of these luminous giants as compared to the subgiants and main-sequence stars are likely the result of mixing rather than a difference in our abundance scales.

NH band strengths have also been measured for a handful of the most luminous M13 turn-off stars. While molecular band formation in such stars is weak, significant star-to-star NH band strength differences are present. Moreover, for the stars with both C and N measurements, differences between stars in these two elements appear to be anticorrelated.

Finally, the most recent C and N abundances for main-sequence, main-sequence turn-off, and subgiant stars in 47 Tuc, M71, M5, and the present M13 data are compared.

Subject headings: globular clusters: general — globular clusters: individual (M13) — stars: evolution – stars:abundances

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1. INTRODUCTION

It has been known since the early 1970’s that the otherwise indistinguishable members of any given Galactic globular cluster (GC) exhibit significant star-to-star variations in surface abundances of certain light elements (most notably C and N, as well as O, and often Na, Al, and Mg)⁵. However, while the abundance patterns commonly observed point to an origin in proton capture nucleosynthesis (Denisenkov & Denisenkova 1990; Langer & Hoffman 1995; Cavallo, Sweigart, & Bell 1996), identification of the specific reaction site(s) and a full theoretical description of the abundance modifying process(es) remain uncertain. As has been pointed out in numerous reviews (see Smith 1987; Kraft 1994; Da Costa 1998) two possibilities exist:

First, the present day cluster stars may have modified their own surface compositions through some mixing process not included in standard models (i.e., an “in situ” scenario). By far the most promising candidate site in this regard is the region above the H-burning shell after first dredge-up in evolving cluster giants, where conditions for partial CN and possibly ON-cycle reactions exist (see Sweigart & Mengel 1979, for one of the earliest treatments). Subsequent circulation of this material into the stellar envelope via meridional currents or turbulent diffusion (for example Denissenkov & Vandenberg 2003) will result in decreasing C abundances and increasing N with evolutionary state as has been observed along the red giant branches (RGB) of several metal-poor clusters (see Carbon et al. 1982; Trefzger et al. 1983; Briley et al. 1990, for classic examples). Moreover, the operation of such a mechanism can at least qualitatively explain the O and Mg versus Na and Al anticorrelations found among the most luminous red giants in several clusters (e.g. Kraft et al. 1998, and references therein).

Common to all models of this process is the prohibition of “extra mixing” by the molecular weight gradient left behind by the inward excursion of the convective envelope during first dredge-up. Only after the molecular weight discontinuity has been destroyed by the outward moving H-burning shell, an event marked by the RGB luminosity function (LF) bump, is mixing expected to take place (Sweigart & Mengel 1979; Charbonnel, Brown, & Wallerstein 1998, and others). This theoretical prediction appears to be borne out by observations of decreased Li abundances following the LF bump in NGC 6752 (Grundahl et al. 2002) and similar drops in $^{12}\text{C}/^{13}\text{C}$ seen by Shetrone (2003) in NGC 6528 and M4.

However, this cannot be the entire picture. As early as 1978, it was noted by Hesser (1978) that the subgiant branch (SGB) and likely the main-sequence (MS) stars of 47 Tuc also possessed star-to-star differences in CH and CN band strengths. This has been most recently followed in 47 Tuc to ≈ 2.5 mag below the MS turn-off (MSTO) by Harbeck et al. (2003). An analysis of their observed CN and CH band strengths yields factors of 10 variations in N anticorrelated with factors of 3 differences in C (Briley et al. 2004), matching those found among the more evolved members. Such CN and CH (N and C) variations have also been shown to exist among the MS,

⁵Note we are excluding ω Cen and M22, both of which appear to have experienced some degree of self-enrichment.

MSTO, or SGB stars of NGC 6752, M71, and M5 (Suntzeff & Smith 1991; Cohen 1999a; Cohen, Briley & Stetson 2002) Moreover, star-to-star variations in Na, Al, O, and Mg, similar to those found among the luminous cluster stars, have been identified among the SGB and MSTO stars of 47 Tuc (Briley et al. 1996), NGC 6752 (Gratton et al. 2001), M71 (Ramírez & Cohen 2002), and M5 (Ramírez & Cohen 2003). Although the various correlations and anticorrelations among these elements suggest the presence of material exposed to proton-capture reactions, such stars lie well below the LF bump and, particularly in the case of the MS stars, no mechanism is known for circulating significant quantities of CN(O) nucleosynthesized material to their surfaces.

Thus the second possible origin of the GC abundance variations - they have been set in place before RGB ascent and are due to the operation of some mechanism early in the cluster history (sometimes referred to as a “primordial” scenario). A number of possibilities exist as are discussed extensively by Cannon et al. (1998), including: that the proto-cluster gas was inhomogeneous in these elements (a true primordial origin), that there was an extended period of star formation of sufficient duration to allow some low-mass stars to form with material ejected from more massive already-evolved cluster asymptotic giant branch (AGB) stars, or that the present day cluster stars have accreted AGB ejecta onto their surfaces after their formation. The appeal of AGB stars as sites of the proton capture nucleosynthesis lies in their ability to modify the cluster gas in light elements (including C, N, O, Al, Na, and Mg - see Ventura et al. 2001) while not altering the abundances of heavy elements.

As the reader has likely noted, observational evidence exists for both mixing and early contamination scenarios, which has led many investigators to conclude that the compositions of the cluster stars we observe today are not the result of one or the other scenario exclusively, but rather both. Unfortunately, this leads to difficulties in disentangling the contributions of each process among the more luminous cluster stars - a problem that can only be reconciled by exploring the compositions of a cluster’s stars to the MSTO and below. Clearly, abundance trends found among a cluster’s MS stars reflect the original makeup of the bright giants, while deviations from this “baseline” composition are likely the result of mixing. This was recently demonstrated in the case of M13 by Briley et al. (2002) (hereafter BCS02) - that a large spread in C abundances exists among the SGB stars of M13, which presumably reflects star-to-star variations in C abundances set early in the cluster history. However, the SGB C abundances also appear larger than those found by other investigators among the more luminous M13 stars, implying the operation of a mixing mechanism on the RGB which has reduced surface C abundances.

In the present paper, we return to M13 and extend our sample more than two magnitudes fainter to include MS stars. In addition, we have also obtained spectra of M13 bright giants observed in earlier studies to verify our abundance scale. Our results confirm those of BCS02 - that a primordial spread in the distribution of light elements exists in M13 which has further been modified during RGB ascent. Measurements of the 3360Å NH bands also were obtained for a handful of the more luminous stars in our sample. N abundances calculated from these bands suggest a C versus N anticorrelation at the level of the MSTO.

2. OBSERVATIONS

2.1. THE FAINT STAR SAMPLE

The initial sample of stars in M13 was aimed to produce subgiants at the base of the RGB. It consisted of those stars from the photometric database (described by Stetson, Hesser, & Smecker-Hane 1998; Stetson 2000) located more than 150 arcsec from the center of M13 (to avoid crowding) with $16.9 < V < 17.35$ and with $0.86 < (V - I) < 0.96$ mag. A slitmask with 0.7 arcsec wide slitlets, narrower than normal to enhance the spectral resolution and minimize contributions from adjacent stars in these crowded fields, was designed using JGC’s software from this sample and used in May 2001 with LRIS (Oke et al. 1995) at Keck. For this slitmask, as for all those used for the M13 stars, the red side of LRIS was set to include the NaD lines and $H\alpha$. We used the highest possible dispersion, $0.64 \text{ \AA}/\text{pixel}$ ($29 \text{ km s}^{-1}/\text{pixel}$) or $1.9 \text{ \AA}/\text{spectral resolution element}$ there, to facilitate radial velocity confirmation of cluster membership. Given that the radial velocity of M13 is -246 km s^{-1} , distinguishing field stars from cluster members is then straightforward.

The blue side of LRIS (McCarthy et al. 1998) was used with the 600 line/mm grism blazed at 5000 \AA . The detector for LRIS-B at that time was a 2048×2048 CCD not optimized for UV response. The spectra covered the range from ~ 3400 to 5000 \AA , thus including the strongest CN band at 3885 \AA and the G band of CH at 4300 \AA , with a resolution of $\sim 4 \text{ \AA}$ ($1.0 \text{ \AA}/\text{pixel}$). Two additional slitmasks were defined from this sample and used in May 2002 during less than ideal weather conditions for 6 exposures of 4800 sec each. The spectra were dithered by moving the stars along the length of the slitlets by 2 arcsec between exposures. These spectra are part of those presented in BCS02.

Because of the crowded fields, in addition to the intended stars some slitlets contained additional stars bright enough to provide suitable spectra, and these were utilized as well. As might be expected from the luminosity function, most of the secondary sample consists of stars at or just below the main-sequence turnoff. Hence subtraction of sequential exposures was not possible, and they were reduced individually using Figaro (Shortridge 1988) scripts, then the 1D spectra for each object were summed.

Based on the serendipitous main sequence stars found in the 2002 observations (see the plots in BCS02), we decided to try to reach main sequence stars well below the turnoff in M13, sufficiently faint to be cool enough to have detectable CH bands. The criteria used to define the sample from the photometric database were $19.3 < I < 19.7$, $V-I$ within 0.06 mag of the main sequence of M13, taken as $1.26 + 0.28(I - 19.4)$, and located more than 200 arcsec from the center of M13. A single slitmask with 0.8 arcsec wide slitlets was designed and used at Keck with LRIS June 26, 2003. The blue spectra cover the full range from the atmospheric cutoff to 5000 \AA , with $1.0 \text{ \AA}/\text{pixel}$ and a spectral resolution of $\sim 4 \text{ \AA}$. Four exposures totalling 4200 sec were obtained. The new very high quantum efficiency detector for LRIS-B consisting of two $2k \times 4k$ Marconi CCDs, with 15μ pixels and a readout noise of $4.0 e^-$, was completed and installed into LRIS in June 2002, and so

was available for these observations. The high UV throughput of LRIS-B with this new sensitive detector for the first time enabled us to reach the NH bands in the brighter of these stars with some precision. The locations of the faint program stars on the M13 color-magnitude diagram (CMD) are shown in Figure 1.

2.2. THE BRIGHT STAR SAMPLE

There are published surveys (Suntzeff 1981; Smith et al. 1996) in which CH indices have been used to determine $[C/Fe]$ values for large samples of the highest luminosity giants in M13. However, our Keck/LRIS sample of low luminosity stars in M13 has no overlap with these earlier works. To ensure that the merger of our data for faint stars in M13 with these published datasets for CH band strengths in M13 giants is valid, we need to verify the consistency of the different measurements of the CH indices and resulting abundances. To demonstrate this, we obtained new blue spectra of a small sample of bright giants with published CH band strengths from earlier studies, and remeasured their CH indices with the same procedures used for the lower luminosity M13 stars of our main sample (as described below). These spectra were taken in April and May, 2003 at the Hale Telescope on Palomar Mountain during observing runs intended primarily for other projects. The blue channel of the Double Spectrograph (Oke & Gunn 1982) was used with a 1200 line/mm grating and a Loral 512x2788 15μ pixel CCD, giving $0.55 \text{ \AA}/\text{pixel}$ with a spectral resolution of 1.9 \AA for a 1 arcsec slit.

3. ANALYSIS

3.1. THE FAINT STAR SAMPLE

Our analysis essentially repeats that of BCS02 and is fully described in Briley & Cohen (2001) (hereafter BC01) and the reader is referred to these works for details. To summarize: strengths of the 4350\AA CH (G) bands of our program stars were measured via the I(CH) index of Cohen (1999b,a) - an index which compares the flux removed by the G-band to the adjacent continuum on both sides. The resulting indices, calculated using bandpasses corrected for the radial velocity of M13, are plotted for the sample of faint stars as a function of I magnitude in Figure 2. The decrease in CH band strengths near $I \approx 18$ is due to the higher temperatures of the MSTO stars (as pointed out by BC01). However, among the fainter MS stars in the sample (near $I \approx 19.5$), the surface temperatures have dropped by roughly 300K and again a large and significant scatter in CH band strengths is apparent. The one sigma error bars plotted for the present sample have been determined entirely from Poisson statistics in the molecular-band and continuum spectral windows.

In a similar manner, the strength of absorption by the 3350\AA NH band was measured in spectra of the more luminous members of the Keck MS/MSTO sample using the double sided logarithmic

s_{NH} index as defined in Briley & Smith (1993). The resulting indices (and one sigma Poisson error bars) are also plotted in Figure 2. This marks the first time NH bands have been observed among such faint stars in a globular cluster. Spectra of two MSTO stars exhibiting differing NH band strengths, and two MS stars with differing CH band strengths are shown in Figure 3.

In order to relate the observed indices to the underlying [C/Fe], we employ a series of synthetic spectra based on MARCS (Gustafsson et al. 1975) model atmospheres. Our models are those used in BC01 and BCS02 and based on the 16 Gyr $[Fe/H] = -1.48$ O-enhanced isochrone grid of Bergbusch & Vandenberg (2001). The locations of the model points on the M13 I, V–I CMD are shown in Figure 1 assuming $(m - M)_V = 14.43$ and a reddening of $E(B-V) = 0.02$ as in BC01 and BCS02.

From each model and a given set of C/N/O abundances, synthetic spectra were computed using the SSG program (Bell, Paltoglou, & Tripicco 1994, and references therein) and the line list of Tripicco & Bell (1995) at a step size of 0.02\AA (see BC01 for further details) assuming the average heavy element compositions of Kraft et al. (1993, 1997). The result was then convolved with a Gaussian kernel to match the resolution of the observed spectra and I(CH) and s_{NH} indices were measured. The model indices for I(CH) are illustrated in Figure 2 for four C abundances (as in BCS02): $[C/Fe] = -0.85$ and $[C/Fe] = -1.1$, which roughly match the observed compositions of M13’s CN-weak and strong bright giants respectively (see Smith et al. 1996), and $[C/Fe] = 0.0$ and $[C/Fe] = -0.5$. Also plotted in Figure 2 are s_{NH} indices for a variety of [N/Fe] values. Note that among these relatively warm MS/MSTO stars, there is little sensitivity in the CH (NH) band strengths to changes in N, O (C, O) abundances (as opposed to the cool giants where molecular equilibrium must be considered, particularly with regard to O). As a check of this, Table 1 shows the sensitivity of I(CH) and s_{NH} to such changes in a cool MS model ($T_{eff}=5601$, $\log g=4.66$, corresponding to an M13 MS star with $I=19.60$).

Following BCS02, we have applied the method of Briley et al. (1990) to convert the observed indices to corresponding C and N abundances: the model isoabundance curves were interpolated to the M_I of each program star, and the observed index converted into the corresponding abundance based on the synthetic index at that M_I . Resulting C and N abundances are plotted in Figures 4 and 5. Note that the large error bars which accompany the stars of Figure 4 near $I=19$ and the stars of low [C/Fe] (≈ -1) are due to the overall weakness of the CH bands — small errors in I(CH) therefore result in large changes in [C/Fe]. Likewise, a similar situation exists among the MSTO stars with measured NH band strengths.

3.2. THE BRIGHT STAR SAMPLE

As with the faint stars, the I(CH) index was measured from the spectra of the six bright M13 giants. For each star this value was compared to synthetic indices generated from model atmospheres whose stellar parameters were taken from the high resolution analyses of Kraft et al.

(1993, 1997), and Pilachowski et al. (1996), including their heavy element and [O/Fe] abundances. Where available, [N/Fe] values from Smith et al. (1996) were also used. For two stars (K188 and III-7), N abundances were not available from the literature, and a value of +1.0 was assumed. For star III-7, an [O/Fe] of 0.0 was used. The model parameters and the resulting [C/Fe] abundance which matched the observed I(CH) indices are listed in Table 2 along with the C abundances from Smith et al. (1996) and Suntzeff (1981).

For the four bright giants in common with Smith et al. (1996), we find an average offset of $0.03(\pm 0.14)$ dex in [C/Fe] (present – Smith). We therefore consider our C abundances to be essentially on the same scale, as might be expected considering the similar analysis tools used. The difference between our results and those of Suntzeff (1981) are somewhat larger: $0.25(\pm 0.23)$. However, almost half of this offset is driven by the result for II-76. Excluding this star reduces the average difference to $0.14(\pm 0.07)$. Note that II-76 has both a high [O/Fe] and a lower [N/Fe] abundance as might be expected from a star with a lesser amount of CN(O)-cycle material in its atmosphere (it also has the second lowest Na abundance of the large sample of Pilachowski et al. 1996). The source of this discrepancy is likely the cooler model used for II-76 by Suntzeff ($T_{eff} = 4220\text{K}$ versus the 4350K used here), as well as the lower O abundance ([O/Fe] = 0.0) and higher microturbulent velocity (2.5 km s^{-1}). Repeating our analysis with the values used by Suntzeff reduces our resulting [C/Fe] by 0.32 dex to -0.96 . The luminous stars of Suntzeff plotted in Figure 4 have therefore been shifted by 0.14 in [C/Fe] to place them on our abundance scale.

Given the use of the same modeling codes, line lists, and CH indices throughout our analysis, we presume the resulting C abundances from both the faint and bright star samples, as well as those of Smith et al. (1996) and Suntzeff (1981) (with the appropriate shift), to be on the same abundance scale. Any systematic differences due to different telescope/spectrograph systems will be minimized by the use of the I(CH) index which uses continuum bands both blueward and redward of the CH feature to remove slope differences due to variations in instrumental response.

4. RESULTS

There are several points to be made about the present results, which are given in tabular form in Tables 3 and 4 of Appendix A. First, as can be seen in Figure 2, significant differences in [C/Fe] exist among stars at least 1.5 mag fainter than the MSTO in M13. This corresponds to a mass of approximately $0.66 M_{\odot}$ using the isochrone of Figure 1. Among these old MS stars, CN(O)-cycle reactions are entirely confined to the central core (see for example Figures 4 and 5 of Richard et al. 2002) and as has been pointed out by numerous investigators, MS stars such as these are not thought to possess a mechanism that connects their surface with regions of energy generation (namely the core). Indeed, should such mixing take place, the subsequent paths of the stars in the CMD would be radically altered by the infusion of fresh H into the core (e.g. VandenBerg & Smith 1988). One must conclude the source of the observed differences in [C/Fe] is likely not the stars themselves. Moreover, the values of [C/Fe] among the MS stars are consistent with those found

by BCS02 among the M13 SGB stars (see Figure 4) and imply little change in composition has occurred from the MS to at least the base of the SGB.

Figure 4 also includes the $[C/Fe]$ values of Smith et al. (1996) and Suntzeff (1981) (shifted upwards by 0.14 dex). As discussed in BCS02, there appears to be a marked decline in $[C/Fe]$ towards higher luminosities among the M13 giants. Clearly an evolutionary change such as this can be best interpreted as the result of a mixing process bringing up C-depleted material from a region in which at least CN-cycle reactions are operating (see BCS02 for a more detailed discussion). Also shown in Figure 4 is the location of the LF bump in M13 (from Paltrinieri, Ferraro, Carretta, & Fusi Pecci 1998) — the event which marks the destruction of the molecular weight gradient thought to inhibit deep mixing. Unfortunately, the luminosity at which the onset of C depletion begins is uncertain due to the gap in the available data (from $15 < V < 17$). However, since an extrapolation of the trend in giant-branch $[C/Fe]$ abundance faintward intersects the magnitude of the LF bump at the average abundance of the fainter stars, it is reasonable to infer that the abundance decline begins near that event; neither a significant decrease nor a significant increase in carbon abundance with a subsequent recovery to the original value hidden within the gap in our data is reasonably to be expected.

The $[N/Fe]$ values determined from the NH band strengths of the MSTO stars are plotted in Figure 5. Although the error bars are admittedly larger than one would like owing to the weaknesses of the CH and NH bands among the warmer MSTO stars, a general anticorrelation between $[C/Fe]$ and $[N/Fe]$ is suggested. Note that these abundances do not suffer from the inherent tendency towards C/N anticorrelations of analyses based on CH and CN band strengths. Of course an overall C/N anticorrelation is known to be present among the evolved M13 stars and the values for the bright RGB stars of Smith et al. (1996) are also shown in Figure 5. Immediately apparent is the shift of the RGB stars towards lower $[C/Fe]$, as is expected from Figure 4. If C-poor/N-rich material is indeed being circulated into the stellar envelopes during RGB ascent, the lack of near solar $[N/Fe]$ RGB stars is also explained (although the error bars on the two lower $[N/Fe]$ MSTO stars severely limit the weight which can be placed on this statement). That higher N abundances do not appear to be found among the RGB stars under these circumstances is perhaps not a surprise if these stars are already leaving the MSTO with large $[N/Fe]$ overabundances: an M13 MSTO star with $[C/Fe] = -0.4$ and $[N/Fe] = 1.0$ which undergoes a mixing episode reducing $[C/Fe]$ to -1.2 will experience a rise in $[N/Fe]$ of only 0.05 dex — in essence, the N abundances are already so large, the addition of freshly minted N via the CN-cycle results in only a small fractional change in $[N/Fe]$. Thus, while the error bars in Figure 5 are large, we can at least claim it is not inconsistent with the assertion that we are seeing substantial star-to-star variations in C (and N) set early in the cluster history, which are further being modified by mixing during RGB ascent. The possibility of also mixing ON-cycle material to the surface is more difficult to assess because of the large N variations among the MSTO stars. In the example above, an additional reduction in $[O/Fe]$ from $+0.45$ to -0.35 would increase $[N/Fe]$ by 0.46 dex — and among the bright giants, even larger O depletions (as much as $[O/Fe] = -0.7$ to -0.8) have been noted. Starting with an even larger N

overabundance of +1.4 reduces the change in $[N/Fe]$ to +0.25. However, at least from the small sample of Figure 5, it appears that none of the bright RGB stars possess larger N abundances than their MSTO counterparts, which in turn suggests the envelopes of at least the initially N-rich stars may not be cycled through a region of ON-cycle reactions while on the RGB. Clearly knowledge of the O abundances of the M13 MSTO stars would help settle this question.

A similar result was noted in the more metal-poor clusters M92 and M15 by Carbon et al. (1982) and Trefzger et al. (1983) (respectively) — that substantial N overabundances are present from the SGB to AGB that are not necessarily correlated with C abundances. Indeed, an analogous situation can be seen in the present results and those of Cohen et al. (2002) for M5 (see Figures 5 and 6): the “higher” $[C/Fe]$ MSTO stars (at ≈ -0.4) span almost a dex in $[N/Fe]$. It is clear that if we are to ascribe the same mechanism to the origin of the SGB/MSTO inhomogeneities in these clusters, it must be operating at the MSTO or earlier.

5. DISCUSSION

That significant and correlated star-to-star differences in C and N, as well as O, Na, Al, and Mg have been found among the SGB, MSTO, and MS stars of several clusters (see references above), implies the operation of some process external to the present stars, presumably having taken place early in the cluster history. The discussion of Cannon et al. (1998) includes a comprehensive look at various possibilities. It is worth while however, to revisit a few of the more critical constraints on any theory of the origin of the abundance variations.

First, whatever mechanism has altered the light-element compositions of the cluster stars has left the heavy elements essentially untouched, at least to the limits of our ability to determine them — the analysis of M5 by Ramírez & Cohen (2003) is an excellent example. This alone would seem to exclude the possibility of the light-element variations arising from the merger of two distinct proto-cluster clouds (as has been pointed out by numerous authors).

Second, these abundance variations appear to be almost ubiquitous among the population of Galactic globular clusters. To highlight this, we have plotted in Figure 6 the $[C/Fe]$ and $[N/Fe]$ values for the present sample of M13 MSTO stars, the 47 Tuc MS stars of Briley et al. (2004), the M5 SGB stars of Cohen et al. (2002), and the MSTO stars of M71 from BC01. Note that BC01 did not directly extract C and N abundances from their observed indices — we have converted them here following the procedure outlined in Cohen et al. (2002) and using the indices and models presented in BC01; the values are given in Appendix A, Table 5.

Third, the elements which are observed to vary are associated with proton capture nucleosynthesis under conditions of CN and ON-cycling. The source/site must process these CNO-group elements and return this material to the cluster to be incorporated into the present population of low mass stars either before, during, or after their formation.

A popular model which fits these constraints is the incorporation of ejecta from intermediate mass ($3-6M_{\odot}$) AGB stars undergoing hot bottom burning and third dredge-up (see Ventura et al. 2001), although difficulties such as the establishment of an O-Na anti-correlation remain (see for example Denissenkov & Herwig 2003). However, as is discussed in Briley, Smith, & Claver (2001) and BCS02, the quantities of material required to produce the observed star-to-star differences among the low luminosity stars (most notably extreme C depletions), which are clearly not diluted as the convective envelopes deepen during RGB ascent, rules out any sort of simple accretion model. Indeed, for the present M13 stars, roughly 70% of a C-poor MS star’s total mass must be captured ejecta if the accreted matter is completely free of C (see BCS02). It is of course unclear how such an enormous amount of material can be returned to the cluster without appealing to a shallow initial mass function (see Briley et al. 2001), nor how the present stars can sweep up the necessary mass of ejecta (although a novel look at accretion by Thoul et al. 2002, suggests significant quantities of AGB ejecta could be captured by stars in clusters with high central concentrations, it should be noted that M13 is definitely *not* a cluster with a high central concentration). We note in Figure 6 that the depletions in C do appear smaller in the more metal-rich clusters M71 and 47 Tuc in accord with the prediction the of AGB ejecta models of Ventura et al. (2001). Yet at the same time, if one presumes the highest [C/Fe] SGB/MSTO stars in M13 and M5 to represent the original (accretion free) C abundance of the cluster stars, they are still some 0.4 dex more C-poor than their 47 Tuc/M71 counterparts, implying either truly primordial (i.e., pre-accretion) differences in at least C or that nearly all the present stars in M13 and M5 have undergone at least some accretion of C-poor material. However, the spread in [N/Fe] is essentially identical among all four clusters. Clearly, knowledge of the patterns of [O/Fe] and [Na/Fe] among the present stars would help constrain the AGB ejecta theories.

An interesting counterpoint to this model is the scenario suggested by Carbon et al. (1982) and Trefzger et al. (1983) to explain similar results among M92 and M15 SGB stars — that the stars of these clusters were inhomogeneously “polluted” by an injection of raw C from intermediate mass AGB stars which is subsequently converted into N in the present stars before SGB evolution thereby explaining both the C deficiencies and large N enhancements as well as star-to-star differences in (C+N). This has the additional advantage of requiring considerably more modest composition modifications (a factor of 4 or so in C from star to star), which in turn lowers the mass of captured ejecta required. However, to explain the large C depletions already in place by the MSTO, significant processing of the envelope through a region of CN-cycling must have taken place while the stars occupied the MS. One then returns to the difficulty of mixing in such stars discussed above.

Another site of the proton-capture reactions has recently been suggested by Li & Burstein (2003), who note that the high mass ($250-300 M_{\odot}$) zero metallicity models of Fryer, Woosley, & Heger (2001) tend to mix He and He-burning products into their H-burning shells during the later stages of He-burning. This fresh C, N, O is partially processed into N while at the same time, the stars expand into red supergiants. If mass loss also occurs at this point, the cluster could be seeded

with freshly produced C/O-poor, N-rich material. Such a scenario is presented within the context of the cluster formation history of Cayrel (1986) — that the GCs formed from primordial material (zero-metal) that was subsequently enriched by the supernovae of massive stars before low mass stars could form. However, the problem remains that the production/seeding and mixing of the heavy-elements must be decoupled from that of the light-elements in order to explain the remarkable homogeneity of Fe, Ti, Ca, etc. within the GCs. In the context of GC formation in a well mixed supershell (e.g. Brown, Burkert, & Truran 1991) this is difficult to explain if the CNO-modified material is ejected prior to the driving supernovae and subsequent supershell expansion/mixing.

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A. TABLES OF OBSERVED INDICES AND RESULTING ABUNDANCES

Table 3. Current Program Stars: Photometry, Indices, and Abundances

Star	V	I	V–I	I(CH)	s_{NH}	[C/Fe]	[N/Fe]
41211_2349	17.30	17.10	0.20	-0.010	-0.024	-	-
41217_2535	17.63	16.88	0.75	0.104	0.228	-0.49	1.09
41132_2535	18.20	17.61	0.59	0.013	0.060	-	1.37
41185_2646	18.52	17.98	0.54	0.008	0.031	-	1.24
41165_2813	18.64	18.10	0.54	0.034	-0.026	-0.25	-0.14
41204_2622	18.89	18.34	0.55	0.034	0.004	-0.39	0.81
41302_2212	18.90	18.32	0.58	0.057	-	0.30	-
41228_2301	19.05	18.53	0.52	0.022	0.054	-	1.20
41211_2513	19.06	18.49	0.57	0.032	-0.022	-0.50	0.02
41157_2535	19.07	18.49	0.58	0.028	0.069	-0.77	1.32
41170_2333	19.07	18.50	0.57	0.024	0.094	-	1.46
41191_2527	19.38	18.77	0.61	0.030	-	-0.91	-
41274_2133	19.41	18.73	0.68	0.000	-	-	-
41265_2254	19.55	18.94	0.61	0.061	-	-0.12	-
41197_2648	19.58	18.97	0.61	0.038	0.175	-0.66	1.47
41171_2802	19.92	19.33	0.59	0.043	-	-0.93	-
41173_2418	19.97	19.30	0.67	0.097	-	-0.16	-
41188_2516	19.98	19.31	0.67	0.089	-	-0.24	-
41107_2643	20.00	19.33	0.67	0.071	-	-0.44	-
41334_2223	20.00	19.35	0.65	0.070	-	-0.47	-
41243_2227	20.01	19.39	0.62	0.043	-	-1.02	-
41122_2707	20.03	19.36	0.67	0.100	-	-0.21	-
41227_2356	20.04	19.30	0.74	0.102	-	-0.12	-
41120_2625	20.05	19.36	0.69	0.032	-	-1.47	-
41264_2258	20.05	19.31	0.74	0.070	-	-0.43	-
41296_2221	20.05	19.40	0.65	0.113	-	-0.15	-
41135_2723	20.06	19.38	0.68	0.101	-	-0.22	-
41277_2355	20.11	19.35	0.76	0.049	-	-0.78	-
41198_2646	20.13	19.42	0.71	0.075	-	-0.49	-
41219_2530	20.15	19.48	0.67	0.037	-	-1.41	-
41167_2650	20.19	19.50	0.69	0.115	-	-0.25	-
41276_2132	20.21	19.60	0.61	0.077	-	-0.60	-
41202_2321	20.23	19.55	0.68	0.056	-	-0.87	-

Table 3—Continued

Star	V	I	V–I	I(CH)	s_{NH}	[C/Fe]	[N/Fe]
41210_2353	20.23	19.56	0.67	0.127	-	-0.23	-
41130_2540	20.24	19.54	0.70	0.077	-	-0.56	-
41340_2151	20.24	19.55	0.69	0.104	-	-0.38	-
41130_2641	20.25	19.54	0.71	0.130	-	-0.19	-
41131_2639	20.26	19.50	0.76	0.086	-	-0.47	-
41207_2619	20.26	19.56	0.70	0.113	-	-0.33	-
41243_2229	20.27	19.56	0.71	0.096	-	-0.45	-
41279_2407	20.27	19.60	0.67	0.095	-	-0.49	-
41191_2530	20.28	19.54	0.74	0.113	-	-0.31	-
41208_2557	20.31	19.60	0.71	0.087	-	-0.53	-
41255_2229	20.32	19.55	0.77	0.103	-	-0.39	-
41278_2232	20.32	19.64	0.68	0.097	-	-0.50	-
41301_2213	20.32	19.65	0.67	0.125	-	-0.35	-
41315_2143	20.33	19.62	0.71	0.135	-	-0.25	-
41270_2213	20.35	19.60	0.75	0.105	-	-0.43	-
41166_2612	20.38	19.65	0.73	0.141	-	-0.24	-
41183_2653	20.40	19.66	0.74	0.118	-	-0.41	-
41255_2307	20.46	19.66	0.80	0.053	-	-1.15	-

Table 4. M5 Subgiants from BCS02: Program Stars, Photometry, Indices, and Abundances

Star	V	I	V–I	I(CH)	[C/Fe]
41230_2604	16.83	16.00	0.83	0.166	-0.34
41244_2423	16.88	16.05	0.83	0.182	-0.25
41224_2734	16.92	16.11	0.81	0.154	-0.40
41299_2630	16.95	16.12	0.83	0.212	-0.07
41213_2642	16.99	16.20	0.79	0.098	-0.72
41259_2821	17.03	16.23	0.80	0.182	-0.22
41210_2830	17.07	16.30	0.77	0.168	-0.29
41320_2941	17.07	16.31	0.76	0.118	-0.56
41207_2719	17.09	16.31	0.78	0.136	-0.47
41296_2957	17.11	16.34	0.77	0.201	-0.10
41249_2549	17.30	16.46	0.84	0.104	-0.63
41210_2834	17.05	16.48	0.57	0.128	-0.48
41301_2440	17.32	16.49	0.83	0.208	-0.03
41188_2619	17.34	16.57	0.77	0.081	-0.84
41260_3026	17.35	16.60	0.75	0.112	-0.55
41212_2744	17.39	16.60	0.79	0.165	-0.24
41256_2801	17.43	16.66	0.77	0.082	-0.79
41260_2850	17.43	16.69	0.74	0.127	-0.43
41340_2401	17.54	16.72	0.82	0.072	-0.92
41252_2524	17.53	16.73	0.80	0.149	-0.28
41282_2908	17.49	16.76	0.73	0.094	-0.62
41284_2922	17.54	16.81	0.73	0.113	-0.47
41217_2534	17.63	16.88	0.75	0.106	-0.47
41260_2459	17.69	16.88	0.81	0.116	-0.40
41256_3005	17.67	16.94	0.73	0.023	- ^a
41249_2548	18.09	17.03	1.06	-0.032	- ^a
42103_2722	-	17.03	-	0.091	- ^a
41253_2521	17.79	17.07	0.72	0.068	- ^a
42104_2748	-	17.15	-	0.067	- ^a
42108_2808	-	17.18	-	0.039	- ^a
42071_2457	-	17.20	-	0.051	- ^a
42055_2321	-	17.23	-	0.053	- ^a
42097_2610	-	17.24	-	0.042	- ^a

Table 4—Continued

Star	V	I	V–I	I(CH)	[C/Fe]
42088_2635	-	17.33	-	0.046	_a
42077_2623	-	17.40	-	0.033	_a
41112_2621	18.05	17.44	0.61	0.012	_a
41284_2930	18.02	17.47	0.55	0.031	_a
42062_2223	-	17.51	-	0.030	_a
42095_2656	-	17.52	-	0.101	_a
42104_2854	-	17.55	-	0.009	_a
42068_2553	-	17.60	-	0.017	_a
42040_2211	-	17.63	-	0.048	_a
42073_2606	-	17.68	-	0.016	_a
42028_2442	-	17.71	-	0.006	_a
42033_2200	-	17.72	-	0.015	_a
42072_2737	18.32	17.74	0.58	0.035	_a
42071_2508	-	17.74	-	0.010	_a
42068_2541	-	17.76	-	0.011	_a
42129_2833	-	17.78	-	0.039	_a
42096_2708	-	17.79	-	0.047	_a
42071_2515	-	17.92	-	-0.002	_a
41281_2911	18.15	17.96	0.19	0.001	_a
42051_2422	-	17.96	-	0.018	_a
42062_2405	-	17.96	-	0.044	_a
42064_2355	-	17.96	-	0.044	_a
42078_2253	-	17.99	-	0.014	_a
41213_2651	18.54	18.00	0.54	0.020	_a
42060_2650	-	18.04	-	0.013	_a
42034_2250	-	18.04	-	0.043	_a
42065_2305	-	18.05	-	0.029	_a
42029_2445	-	18.07	-	0.013	_a
42050_2430	-	18.10	-	0.028	_a
42058_2452	-	18.17	-	-0.002	_a
41099_2615	18.75	18.19	0.56	-0.006	_a
42064_2349	-	18.21	-	-0.009	_a
41341_2405	18.83	18.22	0.61	0.004	_a

Table 4—Continued

Star	V	I	V–I	I(CH)	[C/Fe]
42035_2345	-	18.24	-	0.012	_a
42099_2820	-	18.36	-	0.035	_a
41136_2455	19.01	18.42	0.59	0.028	_a
41081_2630	19.05	18.46	0.59	0.039	_a
41157_2535	19.07	18.49	0.58	0.024	_a
41228_2301	19.05	18.53	0.52	0.020	_a
41121_2548	19.12	18.54	0.58	0.009	_a
41102_2643	19.14	18.54	0.60	0.008	_a
41096_2617	19.14	18.56	0.58	0.130	_a
41173_2525	19.15	18.56	0.59	0.040	_a
41150_2415	19.16	18.56	0.60	0.021	_a
41172_2423	19.17	18.58	0.59	0.046	_a
41216_2412	19.18	18.61	0.57	0.034	_a
41116_2614	19.21	18.62	0.59	0.023	_a
41280_2145	19.21	18.62	0.59	0.034	_a
41139_2533	19.21	18.62	0.59	0.041	_a
41317_2148	19.21	18.66	0.55	0.038	_a
41256_2223	19.22	18.66	0.56	0.040	_a
41204_2446	19.27	18.66	0.61	0.054	_a
41279_2334	19.27	18.67	0.60	0.044	_a
41200_2315	19.28	18.68	0.60	0.060	_a
41263_2211	19.28	18.69	0.59	0.021	_a
41236_2215	19.37	18.77	0.60	0.019	_a
41255_2324	19.39	18.79	0.60	0.023	_a
41174_2358	19.39	18.79	0.60	0.030	_a
41134_2417	19.41	18.80	0.61	0.017	_a
41231_2331	19.42	18.81	0.61	0.048	_a
41094_2540	19.43	18.82	0.61	0.050	_a
41136_2550	19.45	18.85	0.60	-0.005	_a
41310_2206	19.65	18.88	-	0.030	_a
41290_2218	19.49	18.89	0.60	0.016	_a
41219_2401	19.50	18.96	0.54	0.010	_a
41161_2532	19.80	19.18	0.62	0.029	_a

Table 4—Continued

Star	V	I	V-I	I(CH)	[C/Fe]
41175_2421	19.93	19.25	0.68	0.085	- ^a
41286_2327	20.13	19.40	0.73	0.090	- ^a
41140_2549	20.23	19.52	0.71	0.093	- ^a
41266_2209	20.43	19.71	0.72	0.093	- ^a

^aValues of [C/Fe] were not determined for stars near the MSTO due to the weakness of the CH-bands.

Table 5. M71 Subgiants from BC01: Program Stars, Photometry, Indices, and Abundances

Star	R	B–R	I(CH)	S(3839)	[C/Fe]	[N/Fe]
C51228_3737	17.00	1.38	0.138	0.131	-0.17	0.32
C51265_3739	17.01	1.31	0.122	0.141	-0.25	0.49
C51314_3755	17.01	1.34	0.096	0.340	-0.39	1.41
C51385_4166	17.01	1.40	0.092	0.378	-0.40	1.54
C51312_3634	17.03	1.35	0.156	0.388	0.04	1.19
C51418_4158	17.03	1.36	0.091	0.347	-0.39	1.48
C51419_3870	17.03	1.38	0.112	0.333	-0.24	1.29
C51291_3655	17.05	1.33	0.125	0.296	-0.13	1.11
C51417_3943	17.05	1.41	0.146	0.124	-0.03	0.25
C51396_4020	17.11	1.33	0.140	0.327	0.04	1.15
C51285_3749	17.12	1.29	0.120	0.142	-0.10	0.55
C51260_4161	17.13	1.40	0.096	0.351	-0.20	1.49
C51266_3848	17.13	1.36	0.090	0.280	-0.28	1.34
C51254_3957	17.14	1.42	0.143	0.143	0.06	0.43
C51413_4033	17.14	1.27	0.092	0.236	-0.27	1.18
C51352_4055	17.15	1.31	0.127	0.115	-0.02	0.30
C51424_3823	17.15	1.31	0.086	0.279	-0.29	1.38
C51400_3529	17.16	1.31	0.118	0.105	-0.08	0.26
C51250_3763	17.17	1.39	0.136	0.107	0.05	0.18
C51373_3631	17.17	1.31	0.128	0.102	-0.01	0.17
C51368_4074	17.18	1.31	0.077	0.253	-0.37	1.39
C51306_3738	17.19	1.32	0.124	0.113	-0.01	0.31
C51277_3950	17.20	1.34	0.094	0.255	-0.20	1.25
C51270_3931	17.21	1.40	0.082	0.285	-0.27	1.43
C51386_3659	17.21	1.28	0.123	0.103	-0.01	0.21
C51416_3834	17.22	1.31	0.118	0.124	-0.03	0.45
C51266_4149	17.24	1.34	0.092	0.273	-0.18	1.32
C51346_4124	17.24	1.39	0.133	0.340	0.10	1.26
C51267_4025	17.25	1.35	0.127	0.121	0.04	0.38
C51378_3975	17.25	1.34	0.124	0.106	0.02	0.25
C51404_3918	17.25	1.35	0.111	0.109	-0.07	0.35
C51308_3765	17.26	1.27	0.099	0.283	-0.12	1.31
C51316_3960	17.26	1.29	0.071	0.276	-0.37	1.53

Table 5—Continued

Star	R	B–R	I(CH)	S(3839)	[C/Fe]	[N/Fe]
C51377_3737	17.26	1.25	0.105	0.122	-0.10	0.51
C51430_3648	17.29	1.34	0.083	0.234	-0.25	1.27
C51385_3962	17.30	1.24	0.107	0.113	-	-
C51290_3644	17.33	1.36	0.113	0.109	-0.03	0.36
C51224_4027	17.35	1.31	0.098	0.161	-0.12	0.84
C51279_3957	17.35	1.36	0.120	0.139	0.02	0.57
C51287_4050	17.35	1.38	0.116	0.135	0.00	0.55
C51261_4172	17.36	1.32	0.121	0.108	0.03	0.30
C51281_3638	17.37	1.28	0.111	0.113	-0.04	0.41
C51331_4042	17.38	1.28	0.076	0.229	-0.30	1.34
C51252_4126	17.39	1.39	0.098	0.134	-0.12	0.68
C51279_3842	17.39	1.28	0.124	0.082	0.05	-0.14
C51310_3849	17.39	1.29	0.109	0.140	-0.04	0.64
C51334_3732	17.40	1.29	0.115	0.112	0.00	0.37
C51262_3874	17.42	1.33	0.114	0.103	-0.01	0.29
C51377_3766	17.42	1.29	0.080	0.231	-0.25	1.31
C51243_4217	17.43	1.35	0.072	0.211	-0.34	1.31
C51412_4143	17.43	1.27	0.089	0.170	-	-
C51287_3658	17.44	1.30	0.114	0.099	-0.01	0.23
C51315_4161	17.44	1.30	0.134	0.458	0.22	1.60
C51324_3542	17.45	1.38	0.068	0.236	-0.38	1.45
C51405_3749	17.45	1.24	0.072	0.234	-0.31	1.39
C51252_3923	17.46	1.29	0.081	0.253	-0.23	1.38
C51235_3931	17.47	1.34	0.106	0.106	-0.06	0.37
C51244_3757	17.47	1.35	0.116	0.126	0.01	0.50
C51296_3969	17.48	1.25	0.113	0.086	-0.02	0.02
C51279_4119	17.49	1.36	0.123	0.105	0.06	0.25
C51289_3768	17.49	1.23	0.139	0.261	0.18	1.01
C51416_4137	17.51	1.39	0.061	0.207	-0.48	1.44
C51229_3628	17.52	1.28	0.082	0.240	-0.23	1.33
C51391_3723	17.52	1.26	0.132	0.163	0.12	0.65
C51393_4120	17.52	1.27	0.115	0.135	0.00	0.58
C51288_4040	17.53	1.30	0.130	0.140	0.11	0.52

Table 5—Continued

Star	R	B–R	I(CH)	S(3839)	[C/Fe]	[N/Fe]
C51292_3964	17.54	1.42	0.107	0.117	-0.05	0.48
C51398_3758	17.54	1.24	0.078	0.226	-0.27	1.31
C51336_3569	17.55	1.23	0.107	0.110	-0.06	0.41
C51338_3624	17.55	1.28	0.107	0.137	-0.05	0.64
C51402_3627	17.55	1.30	0.118	0.101	0.02	0.23
C51409_4045	17.56	1.28	0.108	0.105	-0.05	0.35
C51275_3873	17.57	1.32	0.073	0.227	-0.33	1.37
C51299_4161	17.57	1.28	0.118	0.084	0.02	-0.05
C51307_3821	17.59	1.28	0.082	0.232	-0.24	1.30
C51419_3843	17.59	1.29	0.074	0.239	-0.32	1.41

B. UPDATE ON ANOMALOUS STARS PREVIOUSLY OBSERVED IN M5

In Cohen et al. (2002), we studied the CH bands in a large sample of stars in M5. Even taking into account the substantial star-to-star variation seen among the CH band strengths of the stars in our sample, we denoted six of these stars as anomalous. Since that time, we have checked the data for these stars yet again. We have found that two of the six stars were misidentified. C18206_0533 with $V=18.42$ is actually C18188_0733, with $BVI = 17.71, 17.03, 16.17$. With this correction, as compared to the bulk of our M5 sample (see Figures 8 and 9 of Cohen et al. 2002) the star has normal CH for its T_{eff} , although its uvCN is still anomalously strong, but not as much as previously. Also, star C18211_0559 ($V=18.06$) is actually C18191_0559, with $BVI = 18.27, 17.57, 16.74$. Its CN is now reasonable for its corrected V mag, but its CH index is still unexpectedly strong.

In our earlier paper, we presented low accuracy radial velocities from the LRIS spectra at $H\alpha$ which suggested that 4 of the 6 stars classified as anomalous are radial velocity members of M5. Such data was not available for one star, while the radial velocity of C18211_0559 (now identified as C18191_0559) was 25 km/sec higher than that of the cluster.

To verify the membership of C18191_0559 in M5, we obtained low SNR spectra with HIRES (Vogt et al. 1994) for it and for a second star from the LRIS sample. A single 1200 sec exposure for each was made on May 1, 2002, a night with considerable clouds. The HIRES slit for one of these two also included a second M5 star. The heliocentric radial velocities for these three stars derived from the NaD lines are presented in Table 6. The radial velocity for M5 found by Ramírez & Cohen (2002) from an extensive high dispersion analysis of stars over a wide range in luminosity is +55.0 km/sec, so we conclude all three of these stars are members.

Table 6. Precision Radial Velocities for Three M5 Stars

Star	V mag	Radial Velocity km s ⁻¹	Comment
C18225_0537	17.07	+58.2	Anomalous star in Cohen et al.
C18191_0554	17.12	+63.1	in LRIS sample, but not anomalous
C18191_0558	17.57	+58.5	Anomalous in Cohen et al. as C18211_0559

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Fig. 1.— The I, V–I color-magnitude diagram of M13 is plotted using the database of Stetson with the locations of our program stars and those of BCS02 indicated. Also shown are the positions of the model points used in the present analysis.

Fig. 2.— G-band indices ($I(\text{CH})$) are plotted as a function of I for the program stars as well as those of BCS02 (lower panel). Measured values of s_{NH} are shown in the upper panel. Error bars are one sigma levels determined from Poisson statistics. Also plotted are model indices for a variety of $[\text{C}/\text{Fe}]$ and $[\text{N}/\text{Fe}]$ values as discussed in the text.

Fig. 3.— Sample spectra of the NH region of two similar M13 MSTO stars (left) and the G-band (CH) region of two MS stars. In both, significant differences are apparent.

Fig. 4.— Derived C abundances for the present M13 MS and RGB stars as well as the SGB stars of BCS02. Also plotted are the $[\text{C}/\text{Fe}]$ values from Smith et al. (1996) and Suntzeff (1981) (the later having been shifted upwards by 0.14 dex as discussed in the text, the size of this shift is indicated by the lines attached to the symbols). The dashed line indicates the location of the LF bump from Paltrinieri, Ferraro, Carretta, & Fusi Pecci (1998) - the point before which mixing is believed to be inhibited. There is a clear and significant scatter in C abundances among both the present MS sample and the SGB stars of BCS02. $[\text{C}/\text{Fe}]$ appears to decrease with V among the most luminous giants as would be expected from mixing, but the onset is uncertain.

Fig. 5.— Values of $[\text{N}/\text{Fe}]$ are plotted versus $[\text{C}/\text{Fe}]$ for the M13 MSTO stars where (despite the large error bars) an anticorrelation is suggested. Also shown are the abundances from luminous giants from Smith et al. (1996) which, as expected from Figure 4, appear more deficient in $[\text{C}/\text{Fe}]$. That the presumably mixed RGB stars do not show greater N abundances than their MSTO counterparts appears to be the result of the large initial N abundances as discussed in the text.

Fig. 6.— The $[\text{N}/\text{Fe}]$ versus $[\text{C}/\text{Fe}]$ values are plotted for MS, MSTO, and SGB stars in four different clusters. The present MSTO abundances appear consistent with the SGB stars of M5 (Cohen et al. 2002), a cluster of roughly similar metallicity ($[\text{Fe}/\text{H}] = -1.26$ versus -1.51), as opposed to those of the higher metallicity 47 Tuc and M71 stars ($[\text{Fe}/\text{H}] = -0.7$).

Table 1. Indices for Deviations from Assumed Composition for $T_{eff}=5601\text{K}$, $\log g=4.66$ Model

[C/Fe]	[N/Fe]	[O/Fe]	I(CH)	s_{NH}
-0.50	0.0	+0.40	0.075	0.044
-0.50	1.0	+0.40	0.074	0.232
-0.50	0.0	0.00	0.079	0.048
-1.00	0.0	+0.40	0.042	0.044

Table 2. Indices, Model Atmosphere Parameters, and Resulting [C/Fe] Abundances for M13 Bright Giants

Star	I(CH)	T_{eff} (K)	$\log g$	v_t km s^{-1}	V mag	[O/Fe]	[N/Fe]	[C/Fe] Present	[C/Fe] Smith et al. (1996)	S
IV-25/L-954	0.166	4000	0.15	2.25	12.09	-0.90	+1.22	-1.31	-1.36	
II-67/L-70	0.165	3950	0.20	2.10	12.12	-0.79	+1.33	-1.32	-1.34	
II-76/L-96	0.200	4350	1.15	1.85	12.52	+0.46	+0.59	-0.62	-0.82	
III-18/L-77	0.156	4350	1.15	1.85	12.77	-0.18	+1.10	-1.11	-0.97	
K188/A1	0.238	4550	1.50	1.80	13.39	+0.45	+1.00	-0.32	-	
III-7/L-114	0.173	4600	1.65	2.00	13.45	0.00	+1.00	-0.83	-	

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