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Are there radical cyanogen abundance differences between galactic globular cluster RGB and AGB stars?

Possibly a Vital Clue to the Globular Cluster Abundance Anomaly Problem

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Abstract.
On reading an old paper about galactic globular cluster abundance observations (of NGC 6752) we came across an intriguing result. Norris et al. (1981) found that there was a distinct lack of cyanogen-strong (CN-strong) stars in their sample of AGB stars, as compared to their sample of RGB stars (which had roughly equal numbers of CN-normal and CN-strong stars). Further reading revealed that similar features have been discovered in the AGB populations of other clusters. Recently, Sneden et al. (2000) followed up on this possibility (and considered other proton-capture products) by compiling the existing data at the time and came to a similar conclusion for two more clusters. Unfortunately all of these studies suffer from low AGB star counts so the conclusions are not necessarily robust — larger, statistically significant, sample sizes are needed.
In this conference paper, presented at the Eighth Torino Workshop on Nucleosynthesis in AGB Stars (Universidad de Granada, Spain, 2006), we outline the results of a literature search for relevant CN observations and describe our observing proposal to test the suggestion that there are substantial abundance differences between the AGB and RGB in galactic globular clusters. The literature search revealed that the AGB star counts for all studies (which are not, in general, studies about AGB stars in particular) are low, usually being $\leq$ 10. The search also revealed that the picture may not be consistent between clusters. Although most clusters appear to have CN-weak AGBs, at least two seem to have CN-strong AGBs (M5 & 47 Tuc). To further complicate the picture, clusters often appear to have a combination of both CN-strong and CN-weak stars on their AGBs – although one population tends to dominate. Again, all these assertions are however based on small sample sizes. We aim to increase the sample sizes by *an order of magnitude* using existing high quality photometry in which the AGB and RGB can be reliably separated. For the observations we will use a wide-field, low- to mid-resolution multi-object spectroscope to obtain data not only on the AGB but also on the horizontal branches and first giant branches of a sample of clusters. With the new information we hope to ascertain whether significant abundance differences really exist.

Key words. AGB stars – Globular cluster – Abundances – Cyanogen

1. Introduction

We are attempting to perform a conclusive test of the suggestion put forward by Norris et al. (1981), which has been touched upon by many authors since and recently explored by Sneden et al. (2000), that there are differences in cyanogen abundance distributions between the first and second giant branches in galactic globular clusters.

Although galactic globular clusters (GCs) are chemically homogeneous with respect to Fe and most other heavy elements (see eg. Kraft et al. 1992), it has long been known that they show inhomogeneities in many lighter elements (eg. C, N, O, Mg, Al). These inhomogeneities are considered anomalous because they are not seen in halo field stars of similar metallicity (see eg. Gratton et al. 2000).

One of the first inhomogeneities discovered was that of the molecule Cyanogen (CN, often used as a proxy for nitrogen). A picture of 'CN-bimodality' emerged in the early 1980s whereby there appears to be two distinct chemical populations of stars in most, if not all, GCs. One population is known as 'CN-strong', the other 'CN-weak' (the CN-weak population might be more informatively called 'CN-normal' – as these stars show CN abundances similar to the Halo field stars). Originally, observations of CN were mainly made in stars on the giant branches but more recently there have been observations on the main sequence (MS) and sub-giant branch (SGB) of some clusters (eg. Cannon et al. 1998). These observations show that there is little difference in the bimodal CN pattern on the MS and SGB as compared with the giants — indicating a primordial origin for the differing populations. Figure 6 in Cannon et al. (1998) exemplifies this situation.

Due to the paucity of asymptotic giant branch (AGB) stars in GCs (a result of their short lifetimes) there have been very few systematic observational studies of the CN anomaly on the AGB in globular clusters (Mallia 1978, is one that the Authors are aware of). What little that has been done has been an aside in more general papers (eg. Norris et al. 1981, Briley et al. 1993, Ivans et al. 1999). However these studies have hinted at a tantalising characteristic: most (observed) GCs show a lack of CN-strong stars on the AGB. If this is true then it is in stark contrast to the red giant branch (RGB) and earlier phases of evolution, where the ratio of CN-Strong to CN-Weak stars is roughly unity in many clusters.

This *possible* discrepancy was noted by Norris et al. (1981) in their paper about abundances in giant stars in NGC 6752. They state that "The behaviour of the CN bands in the AGB stars is... quite difficult to understand... not one of the stars studied here has enhanced CN... yet on the [first] giant branch there are more CN strong stars than CN weak ones." (also see Figure 3 in that paper). More recently Sneden et al. (2000) presented a conference paper on this exact topic. Compiling the contemporaneous preexisting data in the literature they discussed the relative amounts of CN in AGB and RGB stars in the GCs NGC 6752 (data from Norris et al. 1981, M13 data from Suntzeff 1981, and M4 data from Norris et al. 1981 and Suntzeff & Smith 1991). They also discuss Na abundance variations in M13 (data from Pilachowski et al. 1996a and Pilachowski et al. 1996b). Their conclusion for the CN variations was that the clusters in question all showed significantly less CN on the AGB as compared to the RGB. However the data compiled only contained about 10 AGB stars per cluster. In their closing remarks they suggest observations with larger sample sizes are needed — which may be done using wide-field multi-object spectroscopes. This is exactly the conclusion the present authors also came to, inspiring this seminar/conference paper at the Eighth Torino Workshop on Nucleosynthesis AGB Stars held at the Universidad de Granada, Spain, in 2006.

2. Literature Search Results and the Observing Proposal

We conducted a literature search (which may not be complete) to ascertain what work had already been done in terms on CN on the AGB in galactic globular clusters. The results are displayed in Table 1. The main result from this search was that the available number of AGB star observations are not statistically significant enough to come to any real conclusion about the nature of the CN abundance distributions. This has mainly been due to technological constraints. However, the data that does exist shows that there appears to be a strong trend towards CN-weak asymptotic giant branches. The picture is not so simple though, as two clusters in Table 1 actually have CN-strong AGBs. In addition to this, most clusters have some stars of the opposite class on their AGBs – the classifications given in Table 1 (usually) refer to strong majorities in each cluster, rather than totally homogeneous populations.

A vital part in being able to observe significant numbers of AGB stars is having photometry good enough to separate the AGB from the RGB. Photometric observations have now reached such high accuracy that it is becoming feasible to separate the AGB and RGB populations reliably. In addition to this, widefield multi-object spectroscopes are now available. During our literature search we came across some very high-quality photometric studies. For example, the study of M5 done by Sandquist & Bolte (2004). Their set of observations is complete out to 8-10 arc min. They also tabulate all their stars according to evolutionary status – and find 105 AGB stars! This represents a sample size increase of *one order of magnitude*. Further to this we found colour magnitude diagrams for two more GC candidates that have the required accuracy (and high AGB star counts). Thus our current study involves three GCs, one of which appears to have a majority of CN-strong stars on its AGB (M5) which makes it an important outlier that may cause problems for some explanations of the (possible) phenomenon.

Fortuitously, observations of CN bands require only low- to mid-resolution spectroscopes. This combines well with the fact that a large sample is required, which is easily achievable with multi-object spectroscopes which also tend to have lower resolutions. Our proposal also includes some (red) HB stars, as this may let us know which stars reach the HB only, and which stars proceed to the second giant branch. RGB stars will be used as control stars as they are very well studied already – and have similar temperatures and luminosities to the AGB stars. Depending on the quality of the final data we will also attempt to derive abundances for aluminium and CH (a proxy for carbon).

3. Discussion

Assuming for the purpose of discussion that the lack of CN-normal AGB stars is real, then this is actually the opposite to what we would expect based on observations at the tip of the RGB. These stars, which are the precursors to the AGB stars (via the HB), actually tend to become *more* N-dominated due to 'extra mixing' (the results of extra mixing are routinely observed in Halo field RGB stars as well GC RGB stars – see eg. Shetrone 2003). Thus we would predict an *increase* in the number of CN-strong AGB stars over the RGB mean – rather than a decrease.

Norris et al. (1981) proposed two possible explanations to explain the (apparent) lack of CN-strong stars on the AGB:

1. The two populations in NGC 6752 have different He abundances (they suggest $\triangle Y \sim 0.05$). This may have come about through a merger of two proto-cluster clouds with differing chemical histories or through successive generations of stars (ie. self-pollution). The He-rich material would also be N-rich. The He-rich stars would then evolve to populate the blue end of the HB – and not ascend the AGB – leaving only CN-normal stars to evolve to the AGB.
2. Mixing in about half of the RGB stars pollutes their surfaces (increasing N) and also increases mass-loss rates, again leading to two separate mass groups on the HB. As before, the CN-strong, low mass group does not ascend the AGB.

A constraint on the first explanation (for NGC 6752) is that about *half the mass of the cluster* must be polluted, as the number of CN-strong and CN-normal stars is roughly equal. As Norris et al. state, this is not a serious problem for the merger scenario, as the merging clouds/proto-clusters may very well have had

Table 1. Results of the literature search for CN abundances in GC AGB stars. Note that 'weak' or 'strong' means that there is a very significant majority of that class of star in each case.

Cluster	No. AGB Stars	AGB CN Classification	Reference
M3	8	weak	Suntzeff (1981)
M4	11	weak	Ivans et al. (1999)
M5	8	strong	Smith & Norris (1993)
M13	12	weak	Suntzeff (1981)
M15	2	weak	Lee (2000)
M55	10	weak	Briley et al. (1993)
NGC 6752	12	weak	Smith & Norris (1993)
47 Tuc	14	strong	Mallia (1978)

similar masses. However, due to the constancy of Fe group elements, the chemical histories of the two clouds/proto-clusters would have to have been identical with respect to these heavy elements. This is more difficult to explain since we require a differing chemical histories for the light elements.

The self-pollution scenario, whereby a second generation of stars pollutes the cluster at an early epoch, also needs to satisfy these two constraints. Fenner et al. (2004) have explored this scenario. To maintain the heavy element abundances whilst increasing N (and other elements) they assume that the cluster does not retain the ejecta from the second generation supernovae but does retain the material from the less energetic winds from intermediate mass AGB stars. Qualitatively AGB stars have a perfect site for the hydrogen burning needed to produce many of the abundance anomalies in GCs – the bottom of the convective envelope (so-called 'hot-bottom burning'). However, the theoretical study of Fenner et al. (2004) suggests that there are actually serious problems for the scenario as the AGB stars not only produce the N needed but also produce primary carbon (which is dredged up to the surface). This also alters the sum of C+N+O significantly which is observed to be (roughly) constant in GCs. Constraints from other hydrogen burning products also cause this model to fail.

In light of recent observations on the MS and SGBs of some clusters, the second explanation by Norris et al. may require some clarification. As N appears to have a preformation source (as evidenced my MS observations), the extra mixing is not required (although it does still exist). However, the general suggestion that the differing compositions may affect mass-loss rates and lead to different mass populations on the HB may be a valid one.

An important point visible in Table1 is that it appears that there may be variation between the clusters themselves – some asymptotic giant branches seem to be CN-strong as opposed to the majority which appear to be CN-normal. In addition, the fact that most clusters have a *mix* of CN-strong and CN-normal AGB stars (although usually strongly dominated by one population), rather than a homogeneous set, suggests that there may be a continuum of CN-strong to CN-normal ratios. Theories such as those of Norris et al. (1981) will have to account for these points also if the conclusions from observations to date are proven correct. Of course, the low sample sizes may be artificially complicating the issue.

If there really are substantial abundance differences between the RGB and AGB then this may also reveal other clues to the GC abundance anomaly problems (ie. those of the heavier p-capture products - see Sneden et al. (2000) for a discussion), and the second parameter problem.

Our study seeks to clarify the understanding of abundance differences between the various stages of evolution by very significantly increasing the amount of information available about the asymptotic branch.

Finally we note that the AGB stars in question are generally *early* AGB stars – they are not thermally pulsing. However, this should have no impact on the testing for abundance differences as they are not expected to reduce their surface abundance of nitrogen. Indeed, third dredge-up on top of preformation pollution and deep mixing would make the issue even more complex.

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