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AGB Stars in Galactic Globular Clusters: Are They Really Chemically Distinct from Their Fellow RGB and HB Stars?

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Abstract. The handful of available observations of asymptotic giant branch (AGB) stars in Galactic globular clusters (GCs) suggest that the globular cluster AGB populations are dominated by cyanogen-weak (CN-weak) stars. This contrasts strongly with the distributions on the red giant branch (RGB) and other populations, which often show a 50:50 bimodality in CN band strength. If this is true then it presents a serious problem for low metallicity stellar evolution theory, since such a surface abundance change going from the RGB to AGB is not predicted by stellar models. However this is only a tentative conclusion, since it is based on very small AGB sample sizes. To test whether this problem really exists we have carried out an observational campaign targeting AGB stars in globular clusters. We have obtained medium resolution spectra for about 250 AGB stars across 9 Galactic globular clusters (NGC 1851, NGC 288, NGC 362, NGC 6752, M2, M4, M5, M10, and 47 Tuc) using the multi-object spectrograph on the Anglo-Australian Telescope (2df/AAOmega). In this contribution we present some preliminary findings of the study, in particular for the second-parameter pair NGC 288 and NGC 362.

1. Introduction

A picture of cyanogen (CN) bimodality in Galactic globular clusters (GCs) emerged in the early 1980s whereby there appear 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', based on the observed strength of the cyanogen molecular bands. The bimodality is present in the red giant branch (RGB), main sequence, and subgiant branch populations of GCs, suggesting that the phenomenon has a primordial origin. However, due to the paucity of asymptotic giant branch (AGB) stars in GCs (a result of their short lifetimes) and the difficulty in identifying them, there have been very few observational studies of the CN anomaly on the AGB. What little has been done has usually been an aside in more general papers (e.g. Norris et al. 1981, Briley et al. 1993, Ivans et al. 1999).

Motivated by the observations of NGC 6752 by Norris et al. (1981) in which they found that *none* of the AGB stars in their sample were CN-strong, we conducted a literature search to ascertain whether this was true of other GCs (Campbell, Lattanzio, & Elliott 2006). 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 ≤ 10 (see Table 1 of Campbell et al. 2006). However, these studies have hinted at a tantalising characteristic: most (observed) GCs appear to show a lack of CN-strong stars on the AGB. If this is true then it is in stark contrast to the RGB and earlier phases of evolution, where the ratio of CN-strong to CN-weak stars is roughly unity in many clusters. The search also revealed that the picture may not be consistent between clusters. Although most clusters appear to have CN-weak AGB stars, at least two seem to have CN-strong AGB stars (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. Again, all these assertions are based on small sample sizes.

We note that the CN band strength differences between the AGB and RGB is thought to reflect strong variations in N abundance, rather than the small temperature and log g differences between the stars (see e.g. Norris et al. 1981).

Here we present some preliminary results of an observational campaign that increases the GC AGB sample sizes substantially. With this new information we hope to confirm or disprove the existence of these abundance differences.

2. The AGB Samples – Photometry and Astrometry

A vital ingredient in being able to find significant numbers of AGB stars in globular clusters 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. During our literature search (Campbell et al. 2006) we came across some very high-quality photometric studies, such as the study of M5 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 10-fold increase in sample size. For the current study we have used the Sandquist & Bolte (2004) sample for M5, plus a number of other CMDs, mostly from Grundahl et al. (1999). The Grundahl CMDs are in the Strömgren *uvby* system (Strömgren 1966). In Figure 1 of Campbell et al. (2010) we show an example of our CMD selection of AGB stars, for NGC 6752.

Using a multi-object spectroscope placed a further constraint on the AGB samples. Very accurate astrometry was needed. This reduced some of the sample sizes. Also, due to crowding on the 2dF field plate, a few more stars were lost from each sample. In all, our AGB sample was reduced from ~ 500 stars to ~ 400 stars, across 10 GCs: NGC 1851, NGC 288, NGC 362, NGC 6752, M2, M4, M5, M10, 47 Tuc, and ω Cen. In our GC sample we have included the outlier M5, which appears to have a majority of CN-strong stars on its AGB, a fact that may cause problems for some explanations of the (possible) phenomenon. We also include 47 Tuc, which shows a mix of CN-weak and CN-strong stars (Mallia 1978). In addition to the AGB samples we have selections of RGB stars and red horizontal-branch (HB) stars. The RGB stars serve as checks, since these populations are usually well studied in terms of CN, and they have luminosities and temperatures similar to the AGB stars. The HB stars may provide information on when the ratio of CN-strong to CN-weak stars changes, if indeed the CN-weak AGB phenomenon is real. In all we now have a database of ~ 800 stars at various stages of evolution in 10 GCs with accurate photometry and astrometry.

3. Method and Preliminary Results

The observing run consisted of 5 nights on the Anglo-Australian Telescope (AAT). We used the multi-object spectroscope, AAOmega/2dF. On the blue arm we used the 1700B grating with spectral coverage from 3755 to 4437 Å, which includes the violet CN bands and the CH bands. On the red arm we used the 2000R grating. The resolution of the spectra is ~ 1.2 Å. Near the CN bands the S/N ratio is $\gtrsim 20$, rising to $\gtrsim 50$ at the CH bands.

Data reduction and analysis is still ongoing. We are using the 2dFdr software provided by the AAO for initial reductions, then IRAF for analysis. Although the spectral resolution is only moderate, it is sufficient to check for cluster non-members (or binaries) using radial velocities. For this we used the IRAF command *fxcor*. So far we have found only 1 or 2 stars per cluster that show strongly deviant velocities, which suggests there is not much noise in our sample from non-members.

To quantify the CN band strengths in each star we use the S(3839) CN index of Norris et al. (1981) which compares a region depressed by the CN bands with a neighboring pseudo-continuum:

$$S(3839) = -2.5 \log \frac{\int_{3846}^{3883} I_\lambda \, d\lambda}{\int_{3883}^{3916} I_\lambda \, d\lambda} \tag{1}$$

IRAF was used to measure the integrated fluxes. We discarded data with low counts, effectively putting a lower limit on the S/N of ~ 20 at the CN bands. In Figure 2 of Campbell et al. (2010) we show some results for NGC 6752. This is the cluster investigated by Norris et al. (1981) that inspired the current study. They reported that all 12 of their AGB stars are CN-weak, as opposed to the RGB sample which shows bimodality. Our data shows the same – a clear bimodality in the RGB sample, whilst *all* the AGB stars (24 stars) are CN-weak!

In Figure 1 we show our preliminary results for NGC 288 and NGC 362. These two GCs are a second-parameter pair, since their metallicities are the same ([Fe/H] ~ −1.2) but their HB morphologies are very different. NGC 288 has an extended blue HB, with no real red HB (similar to NGC 6752) whilst NGC 362 is the opposite, having a mainly red HB with no blue extension. In Figure 1 it can be seen that NGC 288 presents a very similar picture to NGC 6752 – a clear-cut bimodality on the RGB and a 100% CN-weak dominated AGB. NGC 362 (right hand panel of Fig. 1) also shows CN bimodality on the RGB (albeit not quite as clearly as NGC 288), but its AGB does contain a few CN-strong stars. The majority of the AGB stars are, however, CN-weak. Looking at the CN-strong to CN-weak ratios of stars we find that in NGC 288 the ratio has changed from 50:50 on the RGB to 0:100 on the AGB. In NGC 362 the AGB ratio is more difficult to measure but we estimate it has changed from 60:40 on the RGB to ~ 40:60 on the AGB. Thus in both clusters there is a relative paucity of CN-strong stars on the AGB.

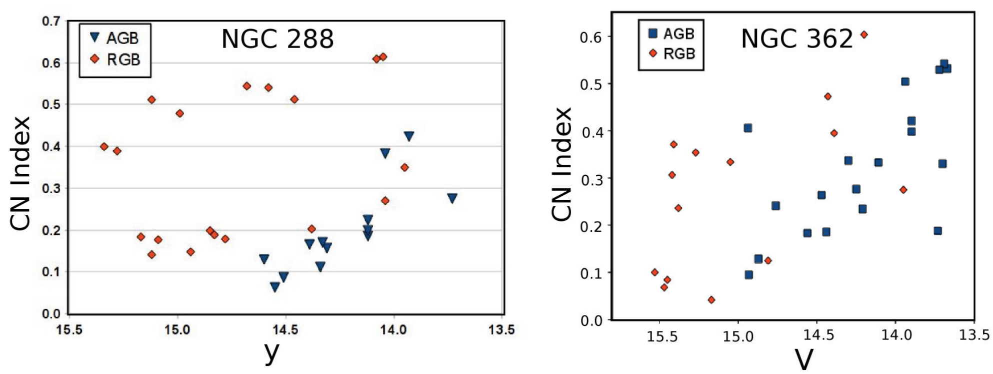

Figure 1. *Left panel:* Preliminary results for NGC 288, showing the S3839 CN index versus *y* magnitude. Diamonds (red) are RGB stars, filled triangles (blue) are AGB stars. A very clear CN bimodality can be seen on the RGB, whilst the AGB is 100% CN-weak. The trend with magnitude is due to stellar temperature effects. *Right panel*: Results for NGC 362 showing the S3839 CN index versus *V* magnitude. Diamonds (red) are RGB stars, filled squares (blue) are AGB stars. On the RGB a CN bimodality can be seen. The AGB is less well defined but the majority of stars appear to be CN-weak.

4. Discussion

Preliminary results of the current study strongly support the unexpected phenomenon in which CN-strong stars seem to 'disappear' between the RGB and AGB, leaving the asymptotic giant branches of globular clusters dominated by CN-weak stars.

There is the possibility that the measurements of CN in AGB stars are biased in some way, either by gravity or temperature differences as compared to the RGB stars. However, as discussed by Norris et al. (1981), the fact that we see stars at the same temperature on the RGB with varying CN band strengths indicates that this is not affecting the results. The higher luminosity of the AGB stars at the same temperature would tend to increase the CN band strength, so that gravity acts in the wrong direction to account for the observed effect. Furthermore, in some of our observations we see CN-strong AGB stars as well as CN-weak AGB stars in the same cluster, which again indicates that the AGB measurements are not affected by their slightly different properties. We do however plan to perform spectral synthesis calculations to double-check. An advantage of the current study is that our spectral data set is homogeneous, since all the spectra were taken on the same instrument.

If we accept the above arguments and that the paucity (or total lack) of CN-strong stars on the AGB is real, then we need to look at evolutionary effects. There is however no known reason why the surface abundance of CN (which is a proxy for N) should decrease when a star evolves from the RGB to the AGB, at least in standard stellar evolution theory. Moreover, due to the well-known 'deep mixing' effect that increases the N abundance (at the expense of C) in stars as they ascend the RGB (e.g. Shetrone 2003), this is actually the opposite to what we would expect on the AGB – we would predict, if anything, *more* CN-strong stars on the AGB!

Another important feature of the data is that there appears to be a variation in the number of CN-strong stars that 'disappear' – some GCs show a total lack of CN-strong stars on their AGBs, whilst some show a mix of CN-strong and CN-weak stars, although they are still dominated by CN-weak stars. The second-parameter pair of GCs presented here may help to understand this. NGC 288 and NGC 6752 (Campbell et al. 2010) show very similar CN behaviour and also have similar horizontal branch morphologies (both have blue HBs). This suggests that the AGB CN 'anomaly' is related to the second parameter problem of globular clusters. However, to complicate matters, NGC 362 shows similar AGB CN behaviour to M5 (Campbell et al. 2010) despite the fact that they have different HB morphologies (the NGC 362 HB is red, the M5 HB is red + blue). It may be that all the GCs with red HBs (e.g. NGC 362 and 47 Tuc) behave like GCs with 'intermediate' HB morphologies (e.g. M5 and NGC 1851). Results from our other clusters will confirm or deny this.

Finally, the inferred abundance differences between the GC RGBs and AGBs reported here may reveal other clues to the GC abundance anomaly problems (i.e. those of the heavier p-capture products; see Sneden et al. 2000 for a discussion), and even the GC formation problem (since the abundances anomalies appear to be primordial). To investigate this we are currently pursuing higher-resolution observations to obtain abundances of O, Na, Mg and Al for our extensive GC AGB sample. This will give definitive information with regard to whether the abundance differences between the RGB and AGB are real or not, and whether any of these elements are linked to the AGB CN anomaly.

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Discussion

Melbourne: Can you do this CN work on HB?

Campbell: Yes, I have some results from 47 Tuc that show a clear bimodality in CN. However, one is limited to the red HB since we lose the CN bands in the hotter/bluer HB stars.

Neyskens: Did you try to derive stellar parameters of your stars like the effective temperature, gravity, C/O ratio, ..., because if you combine this information with chemical equilibrium calculations, you can find a clue for the CN band-behavior.

Campbell: Not yet, but we plan to do some spectral synthesis to check whether there is something other than the N abundance doing this. However, this has been checked in early studies.

Feast: What are the typical errors on a CN measurement?

Campbell: I haven't calculated the error bars for my data yet but I would estimate about ± 0.1 or less.

Maraston: This is more a comment. CN anomalies are also detected in the integrated spectroscopy of Galactic globular clusters, by comparing with evolutionary population synthesis models with different C, N abundance ratios. It would be interesting to correlate the CN integrated index with the horizontal branch morphology to be used for external galaxies.

Wing: Does the G-band of CH show a bimodal distribution similar to CN, and if so, are they correlated?

Campbell: I haven't looked at the G-band in my data yet, but it has been shown before that CN and CH are inversely correlated.