Horizontal Branch Morphology and the Second Parameter Problem

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1 Introduction

For the study of stellar evolution, Globular Clusters (GCs) are very instructive, plotted in an HR diagram or a color magnitude diagram (CMD). Such diagrams display a noticable feature: a horizontal branch indicating Population II stars burning He in the core. The location in color on the HB depends on various parameters (mass loss in the RGB, ratio of core mass to envelope mass, age, initial He abundances). More massive stars ($\sim M_\odot$) form a He core burning "clump" or "red clump" seen in younger (few Gyr old) populations. The older populations with masses of ca. 0.5 $M_\odot$ are located at the blue end of the HB.

While theory and observations agree that the HB morphology becomes, on average, redder with increasing metallicity, there are many examples of GCs having very similar metallicities but markedly different HB morphologies. This indicates that another (*second*) parameter must be affecting the evolution of the HB in these clusters. In this concise summery we will discuss the morphology of the HB and mention a few second parameter candidates. We begin by outlining the canonical model.

2 Characteristics of the Zero Age Horizontal Branch (ZAHB)

- For any metallicity, [Fe/H], fixed He abundance and core mass ZAHB models are bluer with decreasing total mass (M_{tot}).
- For fixed He abundances, core mass (M_c), M_{tot} the ZAHB is bluer with decreasing [Fe/H].
- For fixed [Fe/H], assuming no or identical mass loss during the previous RGB phase stars evolving from the RGB toward ZAHB have smaller initial mass with increasing cluster age, i.e. they are bluer with increasing cluster age.
  This explains, why age is an obvious 2^{nd} parameter candidate
- For fixed age, [Fe/H], M_{tot}, M_c the ZAHB is uniquely identified

This delivers a general understanding of the observed HB morphologies, but failes to yield a detailed description of each individual case, due to a lack of observational data, constraints and even a general hint on mass loss and on its dependence on stars intrinsic parameters (esp. to metallicity).

3 Importantance of HB stars in GCs

The most easily observable features of the Galactic halo are globular clusters. Those consist of some of the oldest stars in the Galaxy and therefore contain information on metallicity, density and chemical abundance in the early stages of the formation of the Galaxy.

Since they are bright, and their luminosity is not very dependent on colour, they could give direct information about their distance, if the HB morphology is understood. Thus, HB stars play an important part in defining the absolute distance scale in the universe as well as their spatial distribution in the Galaxy.

4 Suggestions for the second parameter

4.1 Cluster age as a second parameter

It has been shown by various methods that the age of clusters in the galaxy varies by about 2-4 Gyr cf. [Sarajedini et al. '97]. Consider the two GCs NGC 362 and NGC 288. Their metallicities are similiar, ([Fe/H] ≈ -1.3) but their HB have nothing in common. HB stars in NGC 362 form a clump in the red, whereas in NGC 288 all the HB stars are blue.

By making a precise CMD for these clusters, shifting the stars by the relative reddening and distance moduli, Bolte (1989) showed that the MSTO for NGC 362 is brighter than for NGC 288. From this he concluded that NGC 362 is younger, by an age difference of ≈ 3 Gyr. This has been interpreted as proof that the cluster age is the 2^{nd} parameter controlling the color of HB stars.

Other investigators have both supported and challenged these results. By using other distance moduli, which they found using the magnitude of the first ascent red giant branch tip, VandenBerg and Durren (1990) come to the conclusion that there is no distinguishable difference between the ages of NGC 362 and NGC 288. According to [Sarajedini et al. '97] this method of acquiring distance modulus is incorrect and that their chosen representative stars were several orders of magnitude to faint.

In a recent review on the issue, Stetson, VandenBerg and Bolte (1996) analyse the whole question again, using the NGC 1851 as a "brigde" between NCG 288 and NGC 362. The measured the shift needed to make the almost horizontal part of the sub giant branch coinside on a CMD. They then shifted the HB by the same offset, and found very good alignment, which would not be expected if there were any age differences between the clusters.

Again, [Sarajedini et al. '97], find the opposite when examing the data. They state that the difference in results is due to an error in another "2^{nd} parameter pair" is M3 and M13. Their morphologies are more similar than the NGC 288, NGC 362 pair, so if an age difference between them is measured, it would be expected to be less than the difference between NGC 288 and NGC 362. If such an age difference is measured it would support cluster age as a second parameter. In fact an upper limit on the age difference has been established at ~ 3 Gyr, but since it doesn't exclude that M3 and M13 are the same age, it is not very useful information.

4.2 Deep Mixing and Radiative Levitation

Most of the stars along the blue HB show significantly lower gravities than is expected from canonical stellar evolution theory. [Moehler et al. '99] show that He mixing and the radiative levitation scenarios can explain the dicrepancies from the canonical models for HB stars between 11 500 & 20 000 K.

If deep mixing currents extend into the H burning in the RGB, He can be mixed into the stellar envelope. This would increase the luminosity (and mass loss) along the RGB and thus create less massive (i.e. bluer) HB stars with He enriched H envelopes. The He enrichment increases the H burning rate, leading to higher luminosities and lower gravities compared with the canonical HB stars of same temperature. Stars hotter than 20 000 K are not affected by mixing processes because they have inert H shells.

Radiative levitation of Fe or other heavy elements can explain an observed "jump" in the u vs. $u - y$ color diagram in 15 GCs. This was confirmed by spectroscopical analysis of M13 showing high Fe abundances. This leads to changes in the model atmospheres, and less discrepancy over the temperature range 11 500 to 20 000 K.

[Cavallo et al. '98] found another indication of He mixing: Al enhancement in two GCs M3 and M13. A He mixed RGB star would evolve onto the HB at a bluer color and brighter luminosity than an unmixed star. Because of Al is produced in large quantities inside the H burning shell only in the presence of He, Al makes a good tracer of He. Thus a relationship should exist between the ratio of Al-rich to Al-normal stars on the RGB and the ratio of blue to red HB stars.

4.3 Cluster Densities

[Buonanno et al. '97] performed an extensive statistical analysis of 63 clusters in comparison with other datas. Their result is that a net length of the HB and the presence and extent vertical blue tail in particular are correlelated with the cluster density and concentration: more concentrated or denser clusters having bluer and longer HB morphologies, this effect is especially strong for intermediate metallicity clusters, (which should be the most sensitive group, according to a simple theoretical arguments). Thus the cluster environment can effect the stellar evolution.

This can be interpreted in term of an enhanced mass removal from the HB progenitors in the RGB phase, possibly due to an increase in interaction between stars in denser cluster environment.

While the location of the HB distribution peak in color presumable reflects the effects due to basic "average" parameters (metallicity, age, mean mass loss, etc.) common to all cluster members, the spread arround it yields a direct measure of the spread in total mann loss and/or core mass.

4.4 High He & Rotation Scenarios

[Schweigart et al. '98] showed by simulation that the slight upwards slope in a CMD with decreasing B-V can be explained by high He abundances & rotation scenarios.

RHB stars evolve alomg blue loops during most of their HB lifetimes. Normally these loops cover a small range range in B-V. For largerHe abundances these blue loops can become considerably longer, deviating more from the ZAHB. At least qualitatively one would expect the HB for a sufficient high He abundances to slope upward with decreasing B-V.

It is known that rotation during the RGB phase can delay the "He flash". This leads to two consequences for subsequent HB evolution:

1) increase the He m_c, thus luminosity, 2) enhanced mass loss near the tip of the RGB, thus smaller HB envelope mass.

The net effect would be a shift in the HB locations towards higher eff. temperature and higher luminosity.

4.5 Influence of Planets on HB Morphology

[Soker, 1998] brought up a speculative argument for effect of planets at small orbital distances on the HB morphology.

First of all, in the absence of planets and other 2^{nd} parameter effects, The RGB stars will form the red HB.

In an earlier work Soker has estimated, based on statistical observations on planetary nebulae (PN) shapes that $\approx 50\%$ of all progenitors of PNs have substellar systems within ~ 5 AU. As the stars with such systems evolve up the red giant branch and expand, these planets deposit angular momentum and energy onto the star's surface. This is likely to enhance the mass loss on the RGB, which in turn causes the star to become bluer as it turns up on the HB.

Soker notes however that the presence of planets cannot be the only factor that influences the 2^{nd} parameter. Additionally he warns that the statistical analysis that gave the number of stars with planetary systems was done on field PNs and conclusions may be different for dense clusters. Soker offers three scenarios for a planet engulfed by an expanding RGB envelope: a) The planet evaporates in the envelope, b) the planet collides with the core. (can happen if $R \sim R_\odot$ and $M \sim 0.01 M_\odot$) and c) the planet survives the common envelope evolution.

He goes on to show that the three different fates of the engulfed planets can explain the division of blue HB stars into 3 subgroups as has been observed.

5 Conclusion and Outlook

5.1 Implications for the formation of the Milky Way

Two main scenarios have been offered on the formation of the Milky Way, depending on the time scale of the contraction of the Those are the ELS model which predicts that all clusters were created within a short time interval, and the SZ model which predicts a 2-4 Gyr age range between clusters.

If age is indeed the second parameter then that implies the clusters have a wide age range, contradicting the ELS model.

5.2 Observational Outlook

Conclusive identification of the 2^{nd} parameter must await an adequate theory for mass loss along the RGB. In order to understand all the fine structure of the HB morphologies we need more observational data to a higher precision (esp. better parallaxes). Also HIPPARCOS left many questions unanswered.

References

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