Analysis of the Globular Cluster M13

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I analyzed images of the globular cluster M13 with the U, B, and V filters. With these data I have constructed color magnitude diagrams from which I have compiled lists of stars in the Red Giant Branch, Horizontal Branch, Asymptotic Giant Branch, and also AGB manqué stars. Knowing the quantities of stars in each branch allows us to produce ratios with which we are able to compare the relative times that stars spend in these phases. The R_2 ratio measures the percentage of stars contained within the asymptotic giant branch with respect to the horizontal branch, while the AGB manqué star ratio measures the percentage of manqué stars with respect to the horizontal branch. With these lists I have produced an R_2 value of .1620 +/- .0239 and a manqué star ratio of .0237 +/- .0136. In addition, I have compared my CMDs and star lists with synthetic models, concluding that these models do not have a large enough dispersion of stellar masses, and they under predict the numbers of AGB and AGB manqué stars. More detailed comparisons of larger star samples with models should be undertaken.

Introduction

The color magnitude diagram can be used to identify the evolutionary stages of stars. Plotting magnitude vs. color, we are able to see evolutionary phases represented as branches on the CMD. Figure 1 shows the CMD of globular cluster M13, broken up into its Horizontal Branch (HB; plus symbol), Red Giant Branch (RGB; star symbol), Asymptotic Giant Branch (AGB; triangle symbol) and AGB manqué stars (circled HB stars). The main sequence is the largest group, below the RGB, and was not used in my research.

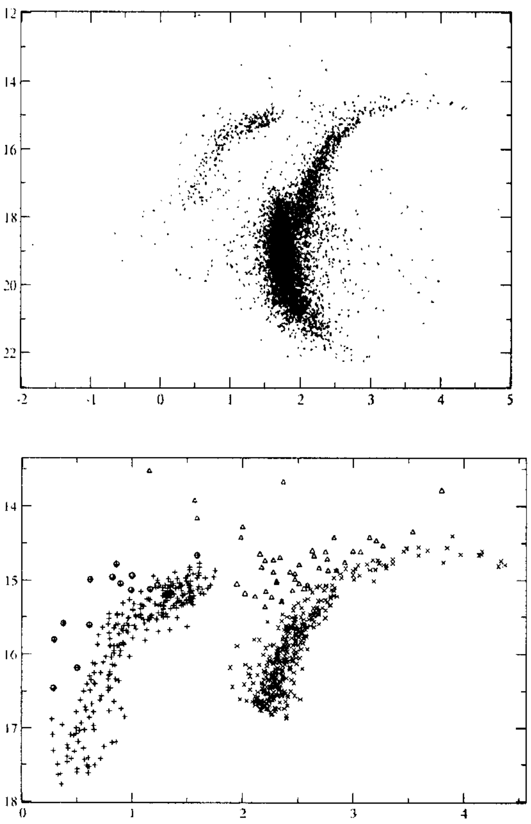

Fig. 1
U vs. U-V Color Magnitude Diagram (top) broken up into the HB, AGB, RGB, and AGB manqué (bottom)

A star on the main sequence evolves to the RGB when its hydrogen core is depleted and a hydrogen fusion shell forms around the growing dead helium core. When massive enough, the helium core is ignited in a massive helium flash, which quickly moves the star from the RGB to the HB phase. From there the star evolves to the AGB phase as its helium core is depleted and a helium shell joins the hydrogen shell surrounding the dead carbon core. Some stars, however, move into the AGB manqué phase before evolving into the AGB. Some stars, below a certain mass, do not even go to the AGB, but move up and to the left of the HB in the manqué phase, eventually falling into the white dwarf phase.

The ratios of stars in each branch of the CMD can be used to give a rough estimate of the relative amount of time stars spend in these phases of their lives. For example, the R_2 value is the number of AGB stars divided by the number of HB stars (# AGB/ # HB), and reveals the amount of time a star spends in the AGB phase with respect to the HB phase. By calculating these ratios and determining the approximate span of a stars' life that is spent in each phase, we are able to better understand stellar evolution after the main sequence.

Comparing models to observations allows us to determine how well we are able to predict natural phenomena, thereby showing us the accuracy of our understanding of these processes. If the models do not well predict the observations, in part or in whole, the models will thus reveal where more research emphasis in necessary. When the models match the observations well, it usually means that we have come to a good understanding of what we see.

Observations and Reduction

My data were taken by Dr. Eric Sandquist on the night of May 25, 2005 with the 40" reflector telescope at Mt. Laguna Observatory. They were taken with an air mass of roughly 1, and a full width, half maximum averaging between 2".8 and 3".2. From the raw data I combined the bias frames together and the flat field images together, and divided the new master bias by the master flat. This new image I subtracted from each of the raw images. I combined the reduced images of similar color, exposure time, and full width at half maximum. At this point I determined the point spread function (PSF) of the images, to best model the shape of the stars on the exposures. Knowing the PSF and being able to subtract it from the images, I was able to obtain more accurate counts of the stars in each image, including the ability to better resolve neighboring stars previously blended together. From here I averaged the photometric measurements together, first by exposure time and then by filter type, finally combining the data from the three filters into one master star list.

From this list, the stars within 180 pixels of the center of the cluster were removed, since the center of the cluster was very crowded and any photometry from it would thus be unreliable. I also identified known foreground stars using the Cudworth and Monet catalogue from 1979, identifying the candidate stars from that catalogue and removing them from my master star list. I identified the RR Lyrae stars in a similar manner, moving them to their own list. Since I do not have average magnitude values for the variable stars of M13, I had to identify them so they would not be accidentally identified incorrectly, which would negatively affect my results.

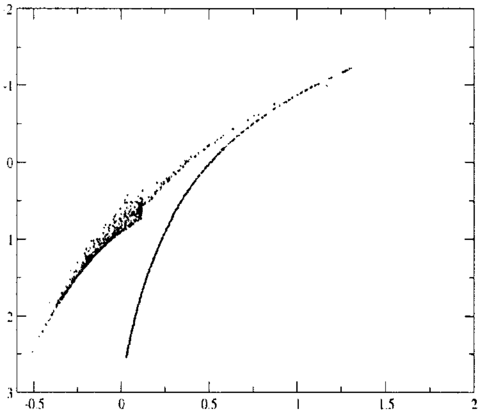

Fig. 2
Synthetic CMD, B vs. U-B

Analysis

Using the CMD of the globular cluster M13, I identified the stars within the AGB, RGB, and HB branches, also AGB manqué stars. The bins of each contain 46, 408, 276, and 15 stars, respectively. The manqué stars I identified by making a polynomial fit along the horizontal branch, listing the HB stars that were about 1.6 magnitudes above that line relative to most of the HB stars (Fig. 5). Classifying these stars by their appropriate branches shows the numbers of stars in each phase of the CMD, from which I was able to calculate my R_2 value and manqué star ratio with respect to the horizontal branch, .1620 +/- .0239 and .0237 +/- .0136, respectively.

My attention then turned to synthetic CMD models (Fig. 2), developed by Cassisi et al. (2004). The models differ in stellar mass and metallicity. Each one was comprised of 800 stars spread through the horizontal and asymptotic giant branches, with a spread in solar mass of .02. I first used the horizontal branches of the model to compare with my observations, since stars in the HB evolve into the AGB. In other words, in order for the AGB in the model to stand any chance of matching my observations, the distributions of stars on the HB have to match. The horizontal branches were aligned in color so

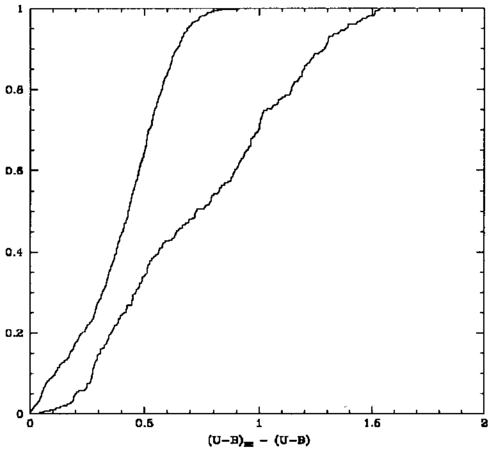

Fig. 3
Cumulative Distribution for .64 solar mass model (smooth line) and M13 (rough line)

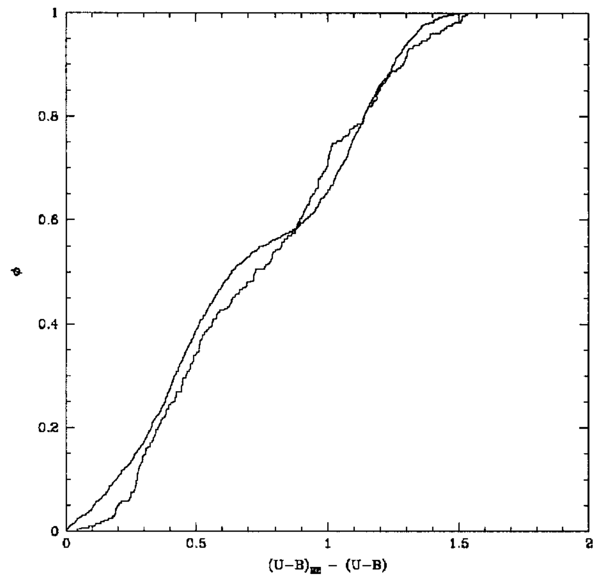

Fig. 4
Cumulative Distribution for summed model (smooth line) and M13 (rough line)

that the blue ends of the instability strip were in the same positions. The cumulative distributions (Figs. 3 and 4) are graphs of numbers of stars vs. color of the HB, with the blue end of the instability strip, where the variable stars are located, starting at 0, and moving toward bluer color to the right. Comparing the CMDs, histograms, and cumulative distributions of the model and observed HBs, the best match I found was with the .64 solar mass model. Though this is the best matching model, it can be seen best by the cumulative distribution (Fig. 3) that it does not compare well to my observations of the HB of M13. My next direction therefore was to determine what would model my observations well. From the horizontal branch comparison and cumulative distribution, it was evident that there were not enough blue stars in the model. I corrected for this by adding models of smaller masses together. From this process I was able to determine that a much better match comes from the sum of five .64 solar mass and four .54 solar mass synthetic models. It is evident from Figure 4 that this new model reflects much better the cumulative distribution of M13 than the previous model, though the Kolmogorov-Smirnov Test predicts only a 6% probability that the two distributions are related. Still, the HBs (Fig. 5) and histograms of this new model and the M13 data match much better than the previous model.

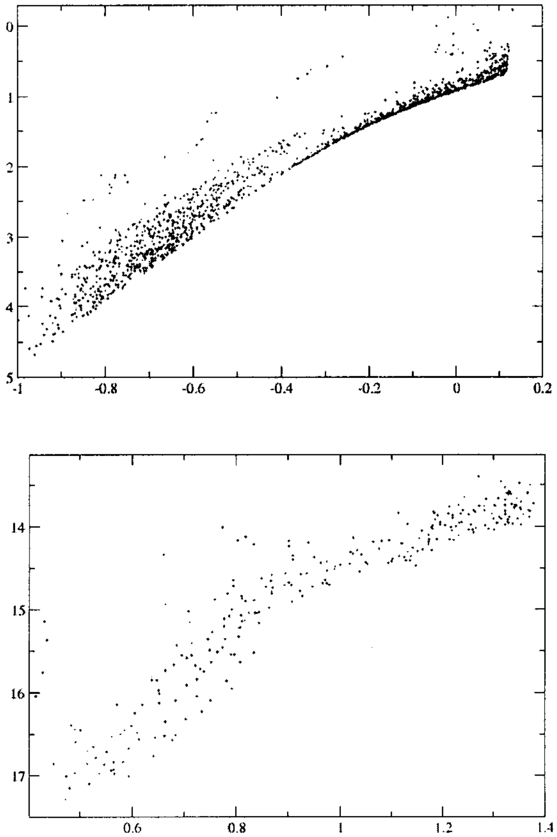

Fig. 5
B vs. U-B CMD of new model (top) and M13 (bottom)

I used this new model to derive an R_2 value and manqué star ratio, which I compared to the M13 data. These values I calculated to be .1019 +/- .00395 and .0528 +/- .00191, respectively. Remember that my values for the M13 data are an R_2 value of .1620 +/- .0239 and a manqué star ratio of .0237 +/- .0136 with the HB, larger values than that calculated for the model. These results will be discussed below.

Conclusions

I have compared my observations with synthetic color magnitude diagram models, and through comparing the horizontal branches, histograms, cumulative distributions, R_2 ratios, and AGB manqué ratios, I have shown that these models do not accurately reflect my observations of globular cluster M13. In each case the models had a stellar mass dispersion that was too small, most evidently seen by comparing the cumulative distributions between M13 and the .64 solar mass model and between M13 and the mixed model I built from five .64 solar mass models and four .54 solar mass models. Note that the second model matches my observations better than the strict .64 solar mass model, supporting this conclusion. Since this discrepancy exists for the modeled horizontal branch, it should be noted that the discrepancy may transfer to the asymptotic giant branch as well, since stars in the AGB phase evolved there from the HB phase. This effect can be seen in the comparison between my calculated R_2 values of the new model and my observations, and between the manqué star ratios of each. In both cases the values for the new model I produced were smaller than the observations, implying that the models are under-predicting the amount of AGB and AGB manqué stars produced in globular clusters.

The smaller AGB and AGB manqué values displayed in the models translate to inaccurate relative lifetimes predicted for stars in each phase. As discussed in the Introduction section, these ratios reflect the amount of time a star spends in these phases of its life. Smaller ratios, therefore, tell us that the models are predicting shorter AGB and shorter (or rarer) AGB manqué phases.

Future Work

In order to accurately compare my results with other published works, I must calibrate my data. This would align my values with the other values, allowing me to conduct an accurate comparative analysis.

In the future I plan to use data from the Hubble Space Telescope, which would provide valuable data allowing me to resolve the core of the M13 cluster. With this I could add those stars to my list, which I have had to previously remove because of unreliable photometry. With a larger list of stars my calculations would be more accurate, since more available stars reduce the errors in the ratios, which is evident in the errors I calculated for my observations and the models. The models have more stars, and thus lower errors.

Other areas in need of future research are U-band observations and, of course, more accurate modeling of globular cluster color magnitude diagrams. Little research has been conducted to date in the U-band, though in this color AGB Manqué stars are most easily identifiable. In this color the HB becomes more horizontal in the CMD versus other colors, allowing the manqué stars above it to be easily resolved. More U-band observations and calculations would provide better information on the AGB manqué phase, helping us to better understand the physical processes occurring. The models, as I have shown, to date do not perfectly reflect the observations, and I have given evidence that the first problem they have is too small of a mass dispersion within the horizontal branch. Rebuilding models with a more varied HB would better reflect observations of globular clusters. The next step is to uncover why these models are also predicting too few AGB and AGB manqué stars.

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